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Temporal and Spatial Assessment of Water Quality, Physical Habitat, and Benthic Communities in an Impaired Agricultural Stream in California's San Joaquin Valley

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The goal of this study was to characterize and discuss the relationships among water quality, physical habitat, and benthic community data collected annually over a three-year period (2000–2002) in an impaired agricultural stream (Orestimba Creek) in California's San Joaquin River watershed. Conductivity, pH, and turbidity were the most important water quality conditions influencing the various benthic metrics. Significantly higher flow conditions and lower dissolved oxygen values were reported in Orestimba Creek in 2001; increased turbidity conditions were reported in 2002. Channel alteration, riparian buffer, sediment deposition, and channel flow were the most important physical habitat metrics influencing the various benthic metrics. Higher total physical habitat scores were reported in 2001 when compared with 2002. The most dominant benthic taxa collected during all three years of sampling were oligochaetes and chironomids. Oligochaetes are found in stressful environments while chironomids can be either sensitive or tolerant to environmental stressors depending on the species. Populations of both daphnids and the exotic clam *Corbicula* were reported to increase over time. Both of these taxa are generally tolerant to most types of environmental degradation. The exception is that daphnids are highly sensitive to organophosphate insecticides. The % filterers increased over time, which suggests an increase in environmental disturbance. The % collectors decreased from 2000 to 2002, which suggests an improvement in environmental conditions. The presence of ~100 taxa in Orestimba Creek during each of the three years of sampling implies that benthic communities in this stream are fairly diverse, considering their ephemeral environment, but without

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a clear definition of benthic community expectations based on established reference conditions it is unknown if this water body is actually impaired.

Key Words: San Joaquin River watershed; Agricultural stream; Benthic communities; Physical habitat.

INTRODUCTION

Abundant water and long growing seasons are critical factors responsible for the highly productive agricultural economy in California's San Joaquin Valley. Approximately 10.2% of the total value of agricultural production in the United States originated from California in 1987—approximately half of this total valued at $6.82 billion came from the San Joaquin Valley.[1] Intense agricultural development in the San Joaquin Valley has modified many of the natural lotic systems in this area.[2] The changing landscape coupled with various other anthropogenic factors has created stressful conditions for resident aquatic biological communities. The following factors may have contributed to the decline of aquatic resources in California's Central Valley: water diversion, changes in basin hydrology, loss of habitat, introduction of exotic species, and contaminants (e.g., organophosphate insecticides).[3] Activities such as diking, dredging, filling of wetlands, and significant diversion of freshwater flows for irrigated agriculture and urban use have also altered fish habitat and resulted in adverse impacts on fish populations.[4]

Due to the various stressors reported in California's San Joaquin River Valley, it is imperative to understand how freshwater aquatic ecosystems are affected by these stresses and how they respond to management actions aimed at alleviating such insults. The use of benthic invertebrates for examining the effects of anthropogenic disturbance in freshwater streams has been endorsed throughout the country because these assemblages have tremendous diversity, longevity, and sensitivity, and provide critical roles in ecosystem function.[5] In recent years, assessments of benthic invertebrate assemblages and physical habitat (bioassessments) have been initiated in wadeable streams in California's Central Valley.[2,6–10] These efforts are valuable for determining the status of aquatic biological communities across large spatial scales and land use types (agricultural and urban). Information on the status of resident biological communities is particularly useful for determining impaired water bodies, developing total maximum daily loads (TMDLs), and measuring success of voluntary or regulatory actions. Bioassessments serve monitoring needs through three primary functions: (1) screening or initial assessment of conditions; (2) characterization of impairment and diagnosis; and (3) trend monitoring to evaluate improvements from mitigation practices or further degradation.

The primary goal of this study was to characterize water quality, physical habitat, and benthic communities over a three-year period at 10 sites in a representative agricultural stream (Orestimba Creek) in California's San Joaquin Valley. The relationship among these three types of data was discussed on both a spatial and temporal scale. Orestimba Creek has been listed as an impaired water body (303 d list) due to the presence of chlorpyrifos, diazinon, azinphos methyl, and DDE (www.swrcb.ca.gov); therefore, biological expectations are somewhat low.

MATERIALS AND METHODS

Site Selection

Ten sites in Orestimba Creek were sampled during late spring of 2000, 2001, and 2002 (Fig. 1). Orestimba Creek is an agricultural stream approximately 13 miles in length located on the west side of the San Joaquin River watershed in Stanislaus County. The upstream site in Orestimba Creek (ORE 10) is located above agricultural activity while the other nine sites are in areas dominated by agriculture. All sites were selected using a stratified random design with approximate equal spacing among sites.

Water Quality and Flow Measurements

The following water quality parameters in Table 1 were measured at each stream site using procedures described in Kazyak:[11] temperature, specific conductance, pH, dissolved oxygen, salinity, and turbidity. Flow (m/s) was measured using at all sites using a Swoffer flow meter (Table 2). Cross-sectional area (m^2) was also determined annually at each site during sampling (Table 1).

Physical Habitat Assessments

Physical habitat was evaluated at each site concurrently with benthic collections and water quality evaluations (Table 2). The physical habitat evaluation methods followed protocols described in Harrington[12] and Harrington and Born.[13] The physical habitat metrics used for this study are based on nationally standardized protocols described in Barbour et al.[14] A total of 10 continuous metrics scored on a 0–20 scale as well as noncontinuous metrics including percent canopy, % gradient, and substrate composition were evaluated as described previously.[7]

Benthic Macroinvertebrate Assessments

Benthic macroinvertebrates were collected in the late spring of 2000, 2001, and 2002 from three replicate samples at the 10 sample sites in Orestimba Creek. The sample site selections and sampling procedures were conducted

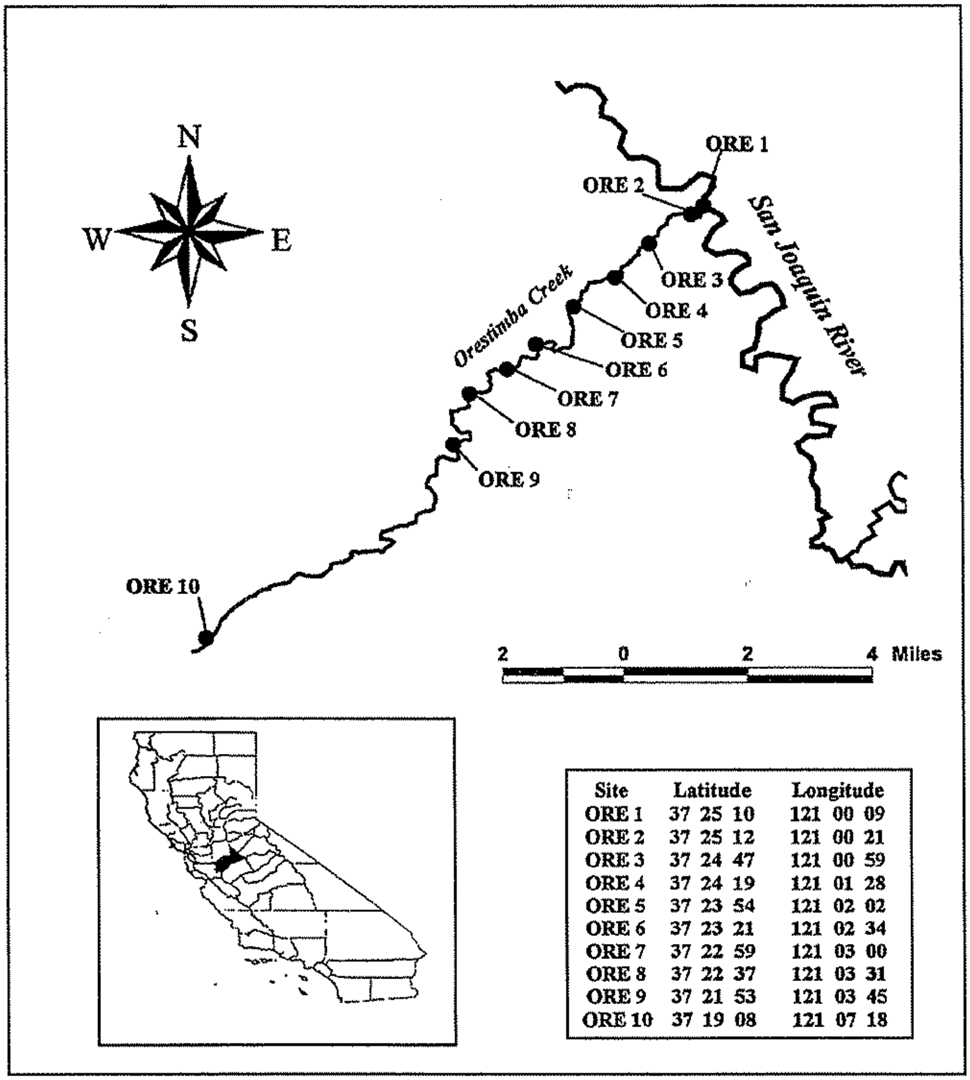

Figure 1: Orestimba Creek sample sites.

in accordance with methods described previously.[12,13] Sampling reaches were approximately equally spaced (except for the reach between ORE 9 and ORE 10) along the stream starting at the confluence with the San Joaquin River. Within each of these sample reaches, a riffle was located (if possible) for the collection of benthic macroinvertebrates. A tape measure was placed along the riffle and potential sampling transects were located at each meter interval of the tape. Using a random numbers table, three transects were randomly selected for sampling from among those available within the riffle. Benthic samples were then taken using a standard D-net with 0.5 mm mesh starting with the most

Table 1: Comparison of individual water quality measurements, flow, and cross-sectional area (m^2) for 10 sites sampled in Orestimba Creek in 2000, 2001, and 2002.

Site	Temperature (C)			Specific conductance (μmhos/L)			pH			Dissolved oxygen (mg/L)			Salinity (ppt)			Turbidity (NTU)			Flow (m/s)			Cross-sectional area (m^2)		
	00	01	02	00	01	02	00	01	02	00	01	02	00	01	02	00	01	02	00	01	02	00	01	02
ORE 1	21.5	18.8	18.1	754	648	663	8.01	7.96	7.80	6.7	8.4	7.6	—	0.4	0.4	115	142	376	0.61	2.55	0.12	4.29	5.50	3.77
ORE 2	22.5	20.3	19.9	744	662	605	8.23	8.12	8.01	8.2	5.0	7.8	—	0.4	0.3	158	126	207	0.58	2.29	0.60	1.44	3.86	1.21
ORE 3	23.0	20.3	21.1	739	675	653	8.18	7.86	8.12	7.5	4.9	8.1	—	0.4	0.3	156	142	153	0.23	1.20	0.30	1.18	4.58	1.23
ORE 4	21.4	21.4	21.0	683	334	640	8.01	8.17	8.09	7.8	4.2	8.3	—	0.2	0.3	107	104	226	0.37	1.44	0.18	0.69	2.73	0.29
ORE 5	22.0	22.8	18.8	654	636	656	8.10	8.08	8.06	8.1	4.3	7.6	—	0.3	0.4	107	110	201	0.32	0.37	0.21	0.53	0.76	0.76
ORE 6	22.9	24.7	18.7	644	584	696	8.25	7.80	8.21	8.9	4.0	8.1	—	0.3	0.4	131	128	178	0.22	1.16	0.21	0.73	1.82	0.49
ORE 7	29.5	19.5	20.1	620	663	711	8.48	8.04	8.14	8.9	4.2	8.4	—	0.4	0.4	153	136	166	0.10	0.95	0.29	0.49	2.35	0.72
ORE 8	22.9	21.6	22.6	840	695	763	8.21	7.87	8.08	8.2	3.3	7.9	—	0.4	0.4	80	92	150	0.17	1.67	0.17	0.50	2.55	0.36
ORE 9	27.7	30.3	23.1	857	1000	697	8.4	8.59	8.13	7.8	4.0	8.0	—	0.4	0.4	213	108	236	0.09	0.12	0.04	0.19	0.42	0.22
ORE 10	27.4	27.1	18.1	878	1044	825	8.37	8.37	8.25	13.0	4.8	3.2	—	0.5	0.1	0.51	0.82	0.88	0.02	0.01	0.00	0.23	0.05	0.42
Mean	22.1	22.7	20.2	741	694	691	8.2	8.1	8.1	8.5	4.7	7.5	0	0.4	0.3	122	109	189	0.27	1.18	0.21	1.03	2.46	0.95

Table 2: Comparison of individual physical habitat metrics (0–20 scale) and total scores for sites sampled in Orestimba Creek in 2000, 2001, and 2002.

	Epifaunal sunstrate			Embeddedness			Velocity depth/divers			Sediment deposition			Channel flow status			Channel alteration			Frequency bends/reffles		
Site	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**
ORE 1	6	13	9	4	6	0	7	13	6	4	6	1	16	17	14	18	16	14	5	15	4
ORE 2	10	14	10	13	11	13	10	16	9	5	10	14	15	20	16	18	15	15	17	12	11
ORE 3	14	15	11	14	16	15	10	18	10	15	16	10	19	20	14	15	15	8	18	15	7
ORE 4	15	12	8	14	16	14	17	19	10	16	15	16	15	20	10	15	14	14	10	11	v6
ORE 5	17	16	10	13	15	7	19	19	17	15	9	14	15	15	15	15	15	14	18	16	16
ORE 6	10	13	7	11	16	9	13	16	5	10	13	16	15	15	19	14	14	13	8	15	15
ORE 7	8	10	8	13	16	10	12	18	10	14	16	17	11	20	18	15	15	14	10	16	7
ORE 8	13	11	9	11	15	7	10	15	16	14	15	16	10	20	19	13	13	14	15	10	11
ORE 9	14	10	11	14	12	9	10	14	10	14	5	16	15	20	9	15	15	15	10	15	9
ORE 10	10	7	8	7	6	14	13	7	3	12	5	8	9	6	6	19	15	13	16	13	11

	Left bank stability			Right bank stability			Left bank veget. protect.			Right bank veget. protect.			Left bank ripar. zone			Right bank ripar. zone			Total score		
Site	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**
ORE 1	1	8	6	1	2	3	2	9	6	2	7	6	5	8	4	3	8	4	74	128	77
ORE 2	1	5	6	1	6	6	2	9	6	2	9	6	5	8	5	5	6	3	104	141	120
ORE 3	7	3	3	7	6	7	6	6	4	6	4	7	3	3	1	3	3	4	137	140	101
ORE 4	5	4	4	5	2	2	4	5	3	4	3	3	4	3	2	5	3	2	129	127	94
ORE 5	7	6	7	6	5	7	9	8	7	8	8	7	8	5	4	8	5	3	158	142	128
ORE 6	8	8	8	8	8	8	9	6	6	8	5	6	6	3	5	4	2	4	124	134	121
ORE 7	4	8	7	5	6	6	6	6	7	9	9	7	3	3	4	6	6	4	116	149	119
ORE 8	7	8	4	9	8	6	7	6	7	7	6	7	6	3	4	6	3	5	128	133	125
ORE 9	9	8	7	9	8	8	8	7	7	8	7	7	7	5	3	8	5	5	141	131	116
ORE 10	7	5	4	7	6	4	3	4	4	3	3	4	3	3	6	3	3	6	112	83	91

downstream portion of the riffle. A 1 × 2 foot section of the riffle immediately upstream of the net was disturbed to a depth of 4–6 inches to dislodge and collect the benthic macroinvertebrates. Large rocks and woody debris were scrubbed and leaves were examined to dislodge organisms clinging to these substrates. Within each of the randomly chosen transects, three replicate samples were collected to reflect the structure and complexity of the habitat within the transect. If habitat complexity was lacking, samples were taken near the side margins and thalweg of the transect and the procedures described above were followed. All samples were preserved with 95% ethanol.

Due to the physical nature of these agricultural stream sites, it was often difficult to locate a substantial number of riffles to sample. In various cases, there was only a single section of riffle available within a selected reach to sample, and in some instances there were no riffles present. In cases where riffles were lacking, alternative sampling methods for non-riffle areas were used as outlined in Harrington and Born.[13] This involved sampling the best available 1 × 2 foot sections of habitat throughout the reach using the same procedures described above. Nine 1 × 2 foot sections were randomly selected for sampling. Groups of three 1 × 2 foot sections were composited for each replicate for a total of three replicates per site.

Taxonomy of Benthic Macroinvertebrates

The goal of this study was to identify all benthic samples to the species level if possible. Species level identifications will be particularly useful when indices of biotic integrity (IBIs) are developed for wadeable streams in California's Central Valley. For taxa such as oligochaetes and chironomids, family and genus level, respectively, were often the lowest level of identification possible.

The benthic macroinvertebrate subsampling (resulting in a maximum of 300 individuals) and identifications were supervised by California's Department of Fish and Game (CDFG) in Rancho Cordova, California. The benthic macroinvertebrate samples were subsampled and sorted by personnel at the CDFG Laboratory located at Chico State University campus. Level 3 identifications (species level identifications) followed protocols outlined in Harrington and Born.[13] Slide preparations and mounting for species such as midges and oligochaetes followed protocols from the United States Geological Survey National Quality Control Laboratory described in Moulton et al.[15]

Statistical Analysis

Spearman's rank correlation analysis was used to determine: (1) the relationship between physical habitat metrics and benthic metrics, and (2) the relationship between water quality conditions and benthic metrics. The Wilcoxon signed rank test and the Friedman test were used to compare physical habitat and benthic metrics among years in Orestimba Creek. Cluster analysis, using the cluster procedure of SAS software systems,[16] was used to determine site grouping (spatial analysis) for both physical habitat and benthic metrics averaged over the three-year period.[16] Comparisons among sites using habitat and benthic metrics were conducted using Euclidean distance.[17]

RESULTS

Water Quality and Flow

A temporal comparison of water quality data for the 10 Orestimba Creek sites sampled annually in 2000, 2001, and 2002 in Table 1 showed the following: (1) temperature was lower at 6 of the sites in 2002; (2) specific conductance was lower for half of the sites in 2002; (3) pH was fairly consistent among all sites for the three years; (4) dissolved oxygen was substantially less at all sites in 2001 except ORE 1; (5) salinity was consistent among all sites for 2002 and 2001; and (6) turbidity was higher at 9 of the 10 sites in 2002. The mean site values for water quality parameters by year were consistent for most of the parameters except dissolved oxygen (lower in 2001) and turbidity (higher in 2002).

Flow was consistently higher at all sites in 2001 when compared with either 2000 or 2002 (Table 1). Mean flow for all sites was approximately four to five times greater in 2001. The mean flow for all sites for both 2000 and 2002 was similar. As expected based on the flow data, the cross-sectional stream area was greater at all sites (except ORE 10) in 2001 when compared with 2000 and 2002. The mean cross-sectional area for all sites was similar for 2000 and 2002.

Physical Habitat

The total physical habitat scores (maximum of 200) in Orestimba Creek for the three years ranged from 74 at ORE 1 in 2000 to 158 at ORE 5 in 2000 (Table 2). Total habitat scores by site were consistently lower for 6 of the 10 sites in 2002 when compared with 2000 or 2001.

Total physical habitat scores across the three years were variable for most of the sites except ORE 6 and ORE 8 (Table 2). Mean scores for all sites for channel flow, stream width, and stream depth were significantly higher ($p < 0.05$) between 2000 and 2001 (Table 3). The increase in channel flow, stream width, and stream depth between the two years implies that available aquatic habitat for benthic species increased between the two years as supported by the cross-sectional area data presented in Table 1. Although the mean total physical habitat score across all sites in Table 4 was similar between 2000 (122) and 2001 (131), the most significant changes in habitat by site occurred at both the downstream (ORE 1) and upstream (ORE 10) site (Table 2). A significant improvement occurred in physical habitat at ORE 1 between 2000 and

Table 3: Mean scores for each physical habitat metric, total score, and stream measurement for years 2000, 2001, and 2002 for Orestimba Creek. The *p*-value is based on Friedman's test and the pairwise comparisons are based on the Wilcoxon signed rank test.

Habitat metric	2000	2001	2002	Friedman *p*-value	2000 vs. 2001	2000 vs. 2002	2001 vs. 2002
EPI SUB	11.700	12.100	9.100	0.0583			
EMBEDDED	11.400	12.900	9.800	0.0720			
VEL DPTH	12.100	15.500	9.600	0.0033			*
SED DEP	11.900	11.000	12.800	0.3872			
CH FLOW	14.000	17.300	14.000	0.0405	*		
CHAN ALT	15.700	14.700	13.400	0.0102		*	
BENRIFF	12.700	13.800	9.700	0.0203			*
BANKSTAB	11.400	12.000	11.300	0.7674			
BANKVEG	11.300	12.700	11.700	0.5580			
RIPBUFF	10.100	8.800	7.800	0.0458			
TOTAL	122.300	130.800	109.200	0.0450			*
WIDTH	3.860	6.170	4.580	0.0202	*		*
DEPTH	0.220	0.479	0.200	0.0231	*		*
VELOC	0.445	0.514	0.351	0.0449			*
CANOPY	32.900	28.900	50.100	0.2359			*

2001 (an increase in total score from 74 to 128). Improved epifaunal substrate, velocity/depth/diversity, bank stability, and vegetative protection were critical metrics that improved over the one-year period. In contrast to the improved habitat at the downstream site, the total physical score at the most upstream site (ORE 10) declined from 2000 to 2001 (112 to 83). Qualitative observations by the field crew during the 2001 sampling noted the presence of wading cows in this stream site. We therefore speculate that the presence of cows (which were not observed in 2000) may have contributed to impaired physical habitat.

In contrast to the differences in various mean physical habitat metrics between 2000 and 2001, mean habitat metrics were similar in Orestimba Creek between 2000 and 2002 (Table 3). The exception was a significant decrease in channel alteration between 2000 and 2002.

The highest number of significant annual differences between mean site metrics in Orestimba Creek occurred between 2001 and 2002 (Table 3). The following habitat metrics were significantly higher in 2001: velocity/depth/diversity, bend/riffle frequency, width, depth, and velocity. The increase in stream width and depth suggests that the volume of available habitat was greater in 2001 when compared with 2002 as reported above. The increase in available habitat in 2001 also corresponds with a significantly higher total habitat score in 2001 when compared with 2002.

A comparison of noncontinuous annual mean habitat characteristics for stream sites in Table 4 shows that the following characteristics are consistent for the three years: % gradient, % gravel, % bolder, and % bedrock. The mean % canopy across all stream sites was higher in 2002 when compared with the

Table 4: Physical habitat characteristics for Orestimba Creek sites sampled in 2000, 2001, and 2002 that were not scored on a 0–20 scale.

	% Canopy			% Gradient			% Fines			% Gravel			% Cobble			% Boulder			% Bedrock		
Site	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**	**00**	**01**	**02**
ORE 1	10	23	44	1	1	1	85	75	100	15	25	0	0	0	0	0	0	0	0	0	0
ORE 2	61	23	47	1	1	1	40	60	30	60	40	70	0	0	0	0	0	0	0	0	0
ORE 3	29	32	81	1	1	1	30	15	25	70	45	55	0	20	5	0	2	15	0	0	0
ORE 4	60	49	61	1	1	1	45	40	20	45	50	70	10	10	10	0	0	0	0	0	0
ORE 5	68	66	91	1	1	1	15	20	40	75	60	40	10	20	20	0	0	0	0	0	0
ORE 6	8	6	0	1	1	1	40	20	40	60	50	60	0	30	0	0	0	0	0	0	0
ORE 7	77	52	44	1	1	1	35	10	25	60	70	50	5	20	25	0	0	0	0	0	0
ORE 8	0	0	0	1	1	1	47	10	40	48	70	40	5	20	20	0	0	0	0	0	0
ORE 9	10	33	67	1	1	1	50	30	30	45	60	55	5	10	15	0	0	0	0	0	0
ORE 10	0	5	66	1	1	1	45	40	40	50	40	35	5	20	25	0	0	0	0	0	0
Mean	33	29	50	1	1	1	43	32	39	53	51	48	4	15	12	0	0	0	0	0	0

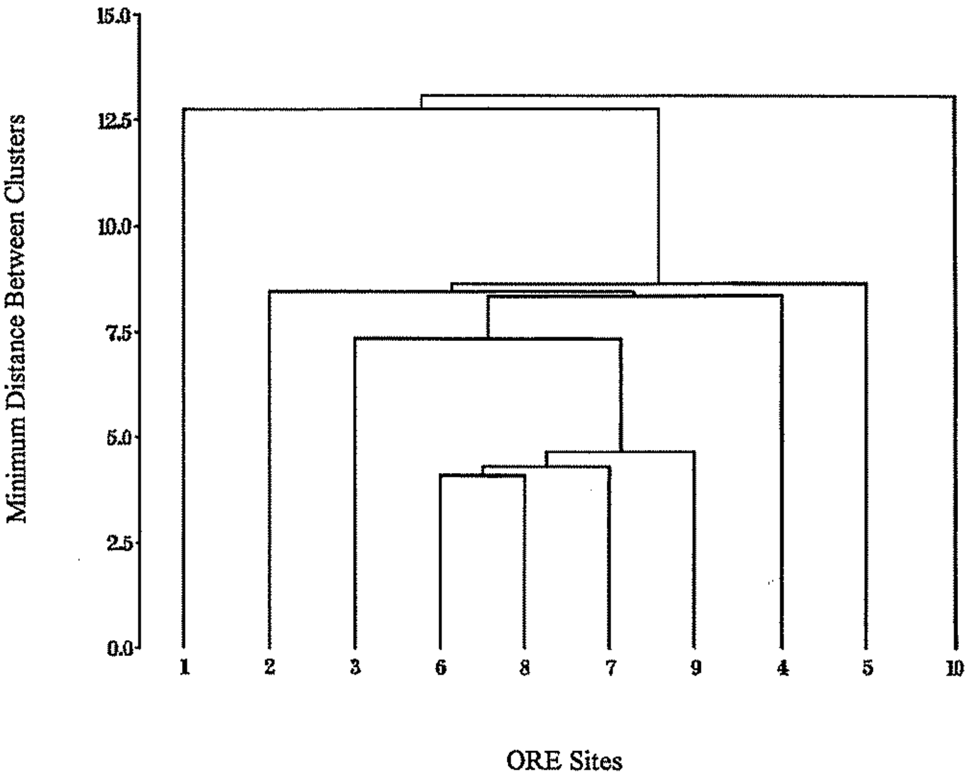

Figure 2: Cluster dendogram of Orestimba Creek sites based on Euclidean distance of average habitat scores for the three-year period of observation.

other two years (Table 3). The mean % fine sediment was somewhat lower in 2001 when compared with 2000 and 2002. In 2000, the % cobble was lower when compared with the other two years.

Spatial analysis of physical habitat metrics in Orestimba Creek over the three-year period showed a distinct grouping for ORE 6, ORE 8, ORE 7, and ORE 9 (Fig. 2). All the other sites were somewhat different from each other following a gradient of habitat heterogeneity. The dendogram in Figure 2 shows this chaining over a gradient. Physical habitat in sites ORE 1 (downstream site) and ORE 10 (upstream site) were most different from each other.

Benthic Communities

Approximately 5,400, 5,500, and 6,600 individual invertebrates were picked and identified from the 10 Orestimba Creek sites sampled in 2000, 2001, and 2002, respectively (Table 5). The total number of taxa collected by year were 98 taxa in 2000, 108 taxa in 2001, and 107 taxa in 2002. The following taxa

Table 5: Total taxon abundance (~75% cumulative %) for benthic macroinvertebrates collected in Orestimba Creek in 2000, 2001, and 2002. A detailed presentation of all taxa for 2000,[6] 2001,[7] and 2003[8] is available.

Year	Lowest taxa	Higher taxa	Total N	Total %	Cumulative %
2000	Naididae	Oligochaeta	1586	29.35	29.35
	Undetermined tubificidae	Oligochaeta	550	10.18	39.53
	Cricotopus bicinctus gp.	Chironomidae	474	8.77	48.30
	Cricotopus sp.	Chironomidae	358	6.62	54.92
	Prostoma	Enopla	213	3.94	58.86
	Undetermined oligochaeta	Oligochaeta	201	3.72	62.58
	Physa/physella	Gastropoda	183	3.39	65.97
	Gammarus lacustris	Amphipoda	152	2.81	68.78
	Megadrile	Oligochaeta	137	2.54	71.32
	Corbicula fluminea	Pelecypoda	122	2.26	73.58
	Nematoda	Nematoda	107	1.98	75.56
2001	Undetermined enchytraeidae	Oligochaeta	836	15.079	15.079
	Ophidonais serpentina	Oligochaeta	579	10.444	25.523
	Simulium sp.	Chironomidae	451	8.135	33.658
	Gammarus lacustris	Amphipoda	380	6.854	40.512
	Corbicula fluminea	Pelecypoda	337	6.079	46.591
	Cricotopus sp.	Chironomidae	304	5.483	52.074
	Cricotopus bicinctus gp.	Chironomidae	267	4.816	56.890
	Nais communis/variabilus	Oligochaeta	228	4.113	61.003
	Torrenticola sp.	Arachnida	215	3.878	64.881
	Dicrotendipes sp.	Chironomidae	198	3.571	68.452
	Prostoma sp.	Enopla	160	2.886	71.338
	Megadrile	Oligochaeta	157	2.832	74.170
	Undetermined tubificidae	Oligochaeta	121	2.183	76.352
2002	*Ophidonais serpentina*	Oligochaeta	685	10.417	10.417
	Simulium sp.	Chironomidae	661	10.052	20.468
	Orthocladius complex	Chironomidae	614	9.337	29.805
	Corbicula sp.	Pelecypoda	594	9.033	38.838
	Cricotopus sp.	Chironomidae	588	8.942	47.780
	Daphnidae	Cladocera	305	4.638	52.418
	Cricotopus bicinctus gp.	Chironomidae	294	4.471	56.889
	Physa/physella	Gastropoda	277	4.212	61.101
	Dugesia tigrina	Platyhelminthes	244	3.710	64.811
	Slavinia appendiculata	Oligochaeta	223	3.391	68.203
	Undetermined enchytraeidae	Oligochaeta	213	3.239	71.442
	Nais communis/variabilus	Oligochaeta	157	2.387	73.829
	Dicrotendipes sp.	Chironomidae	132	2.007	75.836

comprised slightly over 50% of the total number of individuals collected in 2000: naididae, undetermined tubificidae, *Cricotopus bicinctus*, and *Cricotopus* sp. In 2001, the taxa comprising slightly over 50% of the total number of individuals collected were: undetermined Enchytraeidae, *Ophidonais serpentina*, *Simulium* sp., *Gammarus lacustris*, *Corbicula fluminea*, and *Cricotopus* sp. The following taxa comprised over 50% of the total number of individuals collected in 2002: *Ophidonais serpentina*, *Simulium* sp., *Orthocladius complex*, *Corbicula* sp., *Cricotpus* sp., and *Daphnidae*. Oligochaetes and chironomids were the most dominant taxa collected during all three years of sampling.

A shift in dominant benthic taxa occurred from 2000 to 2002 for *Daphnidae* (water fleas) and the exotic clam *Corbicula fluminea*. For both 2000 and 2001, few if any daphnids were collected at the 10 Orestimba Creek sites. However, in 2002 daphnids were the sixth most dominant species in this stream comprising 4.6% of the total taxa abundance. The abundance of the exotic clam *Corbicula* also increased steadily in Orestimba Creek from 2000 to 2002. The annual percent of the total taxa represented by *Corbicula* was as follows: 2.3% in 2000, 6.1% in 2001, and 9% in 2002.

A temporal comparison of taxa richness for the 10 Orestimba Creek sites sampled over the three years showed highest richness for four sites in 2001 (Fig. 3). Lowest benthic macroinvertebrate richness was reported for the downstream sites in 2000 when compared with the other two years. The highest macroinvertebrate richness occurred for the two downstream sites (ORE 1 and ORE 2) in 2001 when compared with 2002 (Fig. 3). For all three years, taxa richness was always greater at the upstream site (ORE 10).

A temporal comparison of taxonomic abundance for the 10 Orestimba Creek sites sampled in 2000, 2001, and 2002 showed highest abundance for seven of the sites in 2002 (Fig. 4). There was no clear temporal pattern by site for

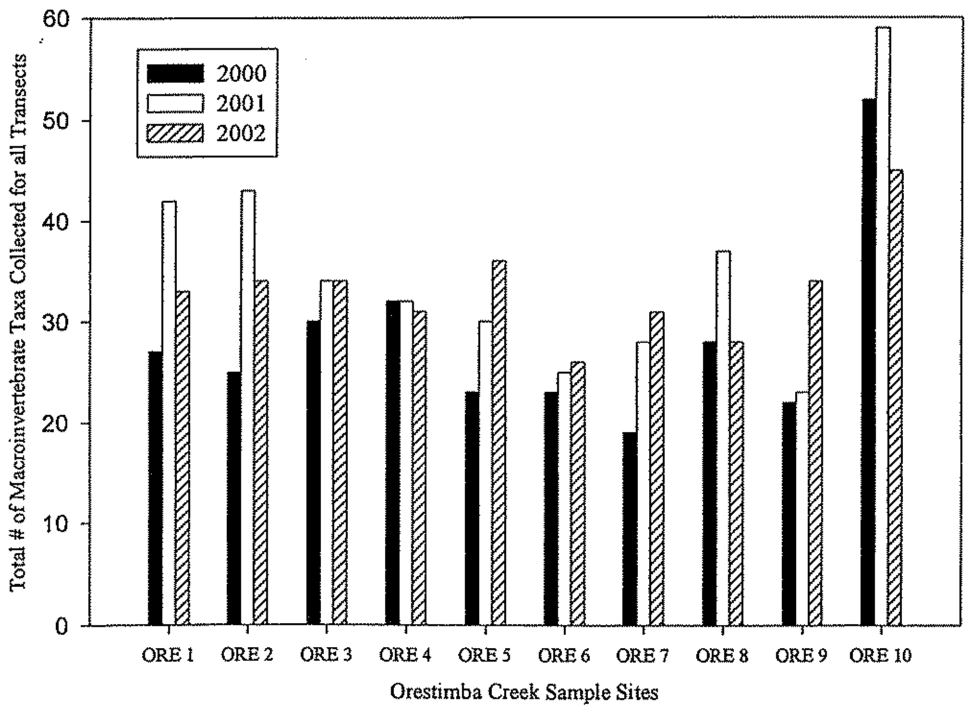

Figure 3: Macroinvertebrate richness of all transects (site totals) for the 10 Orestimba Creek sites sampled in 2000, 2001, and 2002.

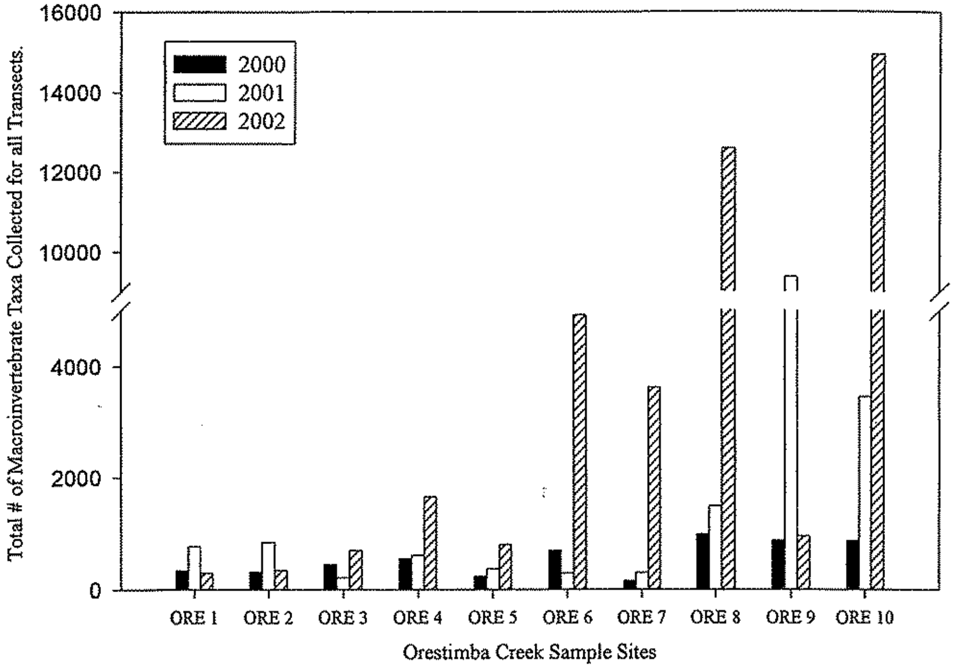

Figure 4: Macroinvertebrate abundance for all transects (site totals) for the 10 Orestimba Creek sites sampled in 2000, 2001, and 2002.

the lowest taxonomic abundance. The three upstream sites (ORE 8, ORE 9, and ORE 10) generally showed the greatest benthic abundance for the three-year period, while the three downstream sites generally showed the lowest abundance over the same time period.

Mean benthic metrics are summarized in Tables 6–8 for the 10 Orestimba Creek sites sampled in 2000, 2001, and 2002, respectively. Collectors—a feeding guild that dominates in stressed environments—were the dominant feeding group for the various benthic taxa collected in 2000 (Table 6). The lowest % collectors were reported at upstream site ORE 10. The following other metrics were also noteworthy at ORE 10 in 2000 when compared with the other 9 sites: taxa richness was highest, the % dominant taxa were lowest, EPT taxa (mayflies, stoneflies, and caddisflies generally associated with nonstressed environments) were more dominant, the % tolerant taxa were lowest, and abundance was highest.

Various benthic metrics summarized in Table 7 from the 2001 sampling were fairly consistent among sites. The mean % dominant taxa, mean % tolerant taxa, mean % collectors, and abundance were higher at ORE 9 when compared with the other sites. The most upstream site (ORE 10) also had a higher percent of Baetidae (tolerant mayflies). The % chironomidae were higher at one of the downstream sites (ORE 2) when compared with the other sites. As reported

Table 6: Mean benthic metrics (all three transects) for the 10 Orestimba Creek sites in 2000.

Metrics	ORE 1	ORE 2	ORE 3	ORE 4	ORE 5	ORE 6	ORE 7	ORE 8	ORE 9	ORE 10
Taxonomic richness	14	14	18	20	15	18	9	19	12	36
Cumulative taxa	27	25	25	25	23	23	19	28	22	52
% dominant taxa	56	52	48	49	35	35	65	34	52	16
Ephemeroptera taxa	0	0	0	0	0	0	0	0	0	6
Plecoptera taxa	0	0	0	0	0	0	0	0	0	0
Trichoptera taxa	0	0	1	0	1	1	0	1	0	1
EPT taxa	0	0	1	0	1	1	0	1	0	7
Cumulative EPT taxa	0	0	0	0	1	1	0	1	0	9
EPT index (%)	0	0	1	0	1	1	0	0	0	18
Sensitive EPT index (%)	0	0	0	0	0	0	0	0	0	4
Shannon diversity	1.4	1.6	1.8	2.0	2.0	2.0	1.1	2.0	1.5	2.9
Tolerance value	8.1	8.1	7.1	7.0	6.8	6.6	5.1	6.5	7.0	5.9
% Intolerant taxa (0–2)	0	0	0	0	0	0	0	0	0	3
% tolerant taxa (8–10)	87	82	63	65	57	37	24	40	57	15
% collectors	90	87	81	71	70	71	85	71	76	58
% filterers	2	5	9	12	16	2	7	3	0	16
% grazers	1	2	1	5	5	2	2	4	14	2
% predators	6	6	7	9	4	7	6	5	5	17
% shredders	2	1	2	4	5	18	1	17	5	7
Abundance (#/sample)	111	103	155	181	77	814	50	2048	578	6003

Table 7: Mean benthic metrics (all three transects) for the 10 Orestimba Creek sites in 2001.

Metrics	ORE 1	ORE 2	ORE 3	ORE 4	ORE 5	ORE 6	ORE 7	ORE 8	ORE 9	ORE 10
Taxonomic richness	22	29	16	23	19	16	18	28	17	35
Cumulative taxa	42	43	34	32	30	25	28	37	23	59
% dominant taxa	30	20	30	29	27	28	21	24	80	33
Ephemeroptera taxa	1	0	0	0	0	0	0	0	0	4
Plecoptera taxa	0	0	0	0	0	0	0	0	0	0
Trichoptera taxa	0	0	0	0	0	0	1	2	0	1
EPT taxa	1	0	0	0	0	1	1	2	0	5
Cumulative EPT taxa	3	0	1	0	0	2	2	3	0	8
EPT index (%)	15	0	0	0	0	1	1	1	0	24
Sensitive EPT index (%)	0	0	0	0	0	0	0	0	0	0
Shannon diversity	2.2	2.6	2.2	2.4	2.3	2.2	2.5	2.6	1.0	2.5
Tolerance value	6.3	6.5	7.3	6.9	6.6	7.0	6.4	6.4	9.4	5.4
% intolerant taxa (0–2)	0	0	0	0	0	0	0	0	0	2
% tolerant taxa (8–10)	56	47	63	58	47	56	41	44	91	25
% baetidae	1	0	0	0	0	0	0	0	0	22
% hydropsychidae	0	0	0	0	0	0	0	1	0	0
% chironimidae	20	44	9	9	10	8	26	28	7	22
Dipteran taxa	1	2	1	1	1	1	1	1	2	5
% dipteran	3	8	9	14	12	10	9	19	1	7
Non-insect taxa	11	11	10	14	12	11	11	15	10	12
% Non-insect taxa	57	48	69	66	79	81	63	52	91	41
% collectors	54	50	59	60	56	61	46	44	88	49
% filterers	6	9	10	16	31	27	26	34	4	2
% grazers	3	2	9	2	2	3	3	3	1	6
% predators	9	5	19	17	5	2	5	4	1	36
% shredders	7	21	3	3	3	5	13	8	4	2
Abundance (#/sample)	255	279	69	200	120	94	99	496	3119	1148

Table 8: Mean benthic metrics (all three transects) for the 10 Orestimba Creek sites in 2002.

Metrics	ORE 1	ORE 2	ORE 3	ORE 4	ORE 5	ORE 6	ORE 7	ORE 8	ORE 9	ORE 10
Taxonomic richness	21	19	16	21	25	20	26	18	23	29
Cumulative taxa	33	34	34	31	36	26	31	28	34	45
% dominant taxa	22	36	40	41	47	34	26	43	27	37
Ephemeroptera taxa	0	0	0	0	0	0	0	0	0	0
Plecoptera taxa	0	0	0	0	0	0	0	0	0	0
Trichoptera taxa	0	0	0	0	0	0	0	0	0	0
EPT taxa	0	0	0	1	1	0	2	1	0	3
Cumulative EPT taxa	0	0	0	1	2	1	3	2	0	4
EPT index (%)	0	0	0	0	1	0	4	2	0	6
Sensitive EPT index (%)	0	0	0	0	0	0	0	0	0	2
Shannon diversity	2.5	2.2	2.0	1.9	2.0	2.1	2.5	1.9	2.3	2.4
Tolerance value	8.3	6.5	7.1	6.2	6.0	5.9	5.2	6.3	7.8	7.9
% intolerant taxa (0–2)	0	0	0	0	0	0	0	0	0	0
% tolerant taxa (8–10)	64	11	28	5	5	20	10	23	63	78
% baetidae	0	0	0	0	0	0	0	0	0	0
% hydropsychidae	0	0	0	0	0	0	0	0	0	0
% chironimidae	69	39	37	28	13	58	44	30	9	15
% collectors	48	30	33	9	22	34	36	48	38	56
% filterers	18	44	33	75	72	24	17	10	10	4
% grazers	7	3	5	0	1	0	3	7	35	20
% predators	21	2	1	3	3	29	36	15	12	16
% shredders	7	21	27	13	3	12	7	20	5	4
Abundance (#/sample)	97	115	230	549	265	1637	1204	4197	315	4990

above for 2000, collectors were the dominant feeding group for the various benthic taxa collected in Orestimba Creek in 2001.

Various benthic metrics summarized in Table 8 for Orestimba Creek sites sampled in 2002 are as follows: (1) % dominant taxa were lower at ORE 1, ORE 7, and ORE 9; (2) EPT taxa were primarily found at ORE 10; (3) % tolerant taxa were highly variable among sites; and (5) % chironomidae were higher at downstream site ORE 1. The % collectors were higher at ORE 1, ORE 8, and ORE 10. The % shredders—taxa associated with nonstressed environments—were low (<27%) at all sites.

A statistical comparison of mean benthic metrics across all 10 Orestimba Creek sites for 2000, 2001, and 2002 showed significant ($p < 0.05$) changes for two trophic measures: percent collectors and percent filterers (Table 9). Collectors are macrobenthos that collect or gather fine particulate matter. Filterers are macrobenthos that filter fine particulate matter. Our analysis showed that

Table 9: Mean scores for each benthic metric by year for Orestimba Creek with *p*-values for among year means comparison and pairwise comparisons between years.

Benthic metric	2000	2001	2002	*p*-value+	2000 vs. 2001	2000 vs. 2002	2001 vs. 2002
Abundance (#/ sample)	1012.00	588.03	1456.92	0.2725			
Cumulative EPT taxa	—	1.90	1.30	0.4609			
Cumulative taxa	—	35.30	33.20	0.5234			
Dipteran taxa	—	1.53	—	—			
EPT index (%)	2.03	4.23	1.37	0.7855			
EPT taxa	0.93	1.00	0.93	0.9017			
Ephemeroptera taxa	0.60	0.57	0.40	0.5045			
Non-insect taxa	—	11.63	—	—			
Percent baetidae	—	2.33	0.23	0.5000			
Percent chironomidae	—	18.37	34.40	0.0578			
Percent collectors	75.83	56.57	35.43	0.0007	*	*	*
Percent diptera	—	9.07	—	—			
Percent dominant taxon	44.20	32.13	35.10	0.0450			
Percent filterers	7.07	16.43	30.90	0.0055	*	*	
Percent grazers	3.73	3.37	8.10	0.4516			
Percent hydropsychidae	—	0.13	0.53	0.2500			
Percent intolerant taxa	0.30	0.23	0.03	0.3679			
Percent non-insect taxa	—	64.60	—	—			
Percent predators	7.10	10.40	13.77	1.0000			
Percent shredders	6.07	6.73	11.77	0.2231			
Percent tolerant taxa	52.57	52.67	30.87	0.0608			
Plecoptera taxa	0.00	0.00	0.00				
Sensitive EPT index (%)	0.43	0.00	0.17	0.3679			
Shannon diversity	1.84	2.25	2.17	0.0608			
Taxonomic richness	17.33	22.37	21.90	0.2847			
Tolerance value	6.82	6.80	6.72	0.3872			
Trichoptera taxa	0.33	0.43	0.53	0.8777			

+Friedman test if three years, Wilcoxon signed rank test if two years.
*<0.05 by Wilcoxon signed rank test.

percent collectors were higher in 2000 than in 2001 and 2002 (Table 9). Percent collectors were also higher in 2001 than in 2002. The percent filterers were higher in 2001 than in 2000 and were also higher in 2002 than in 2000.

There were no other significant temporal differences among benthic metrics at the sites using a significance level of $p < 0.05$. However, using a cutpoint of $p < 0.07$ percent chironomidae taxa were higher in 2002 than 2001 and percent dominant taxa were higher in 2000 than 2001. Using the same cutpoint ($p <$ 0.07), percent tolerant taxa were lower in 2002 than 2000 or 2001. Shannon diversity index was lower in 2000 than in 2001 and 2002 ($p < 0.07$).

Spatial analysis of benthic community metrics from 2000 to 2002 showed the following site groupings: ORE 1, ORE 2, ORE 3, ORE 5; ORE 4 and ORE 7; ORE 6 and ORE 9; ORE 8; and ORE 10. (Fig. 5). ORE 6 and ORE 9 were also in the same group based on physical habitat metrics presented previously (Fig. 2). The grouping for ORE 1, ORE 2, and ORE 3 based on benthic community metrics corresponds with their location in the stream as these are the

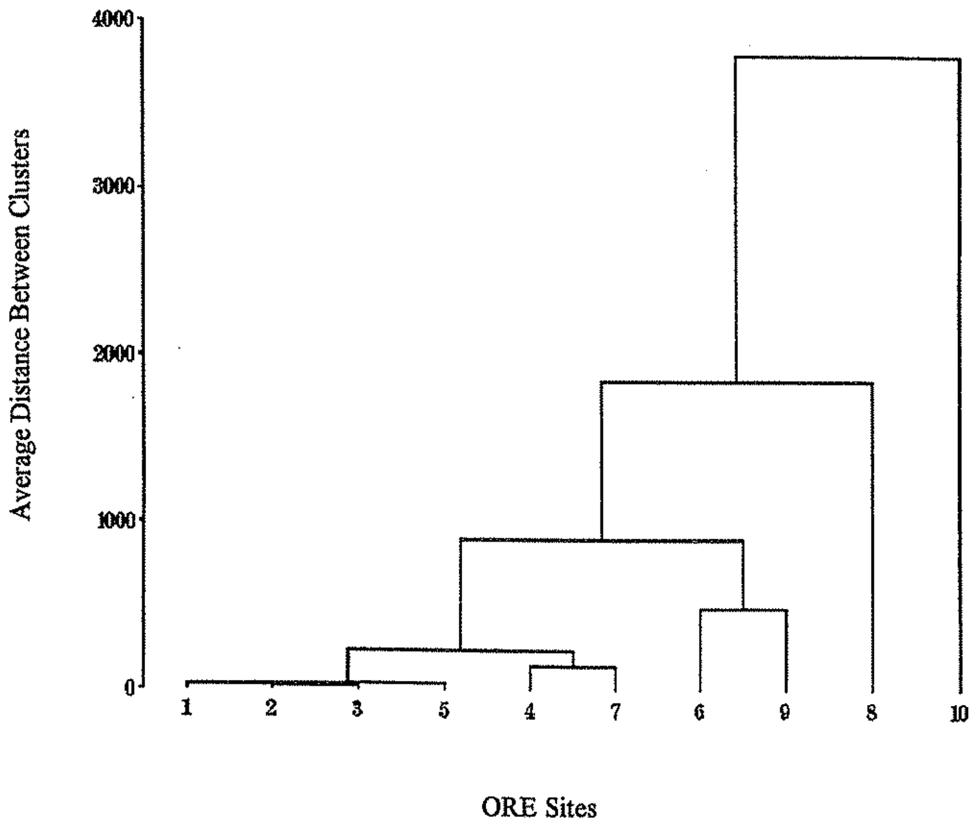

Figure 5: Cluster dendogram of Orestimba Creek sites based on Euclidean distance of average benthic metric scores for the three-year period using the 18 metrics collected in all years.

three most downstream sites. Benthic communities at ORE 10 were distinctly different from the three downstream sites and ORE 5.

Relationship of Physical Habitat and Benthic Communities

Spearman's rank correlation analysis showed that channel alteration, riparian buffer, sediment deposition, and channel flow were the most important physical habitat metrics influencing the various benthic metrics (Table 10). Channel alteration was negatively correlated with % shredders and positively correlated with % collectors. Riparian buffer was negatively correlated with % filterers and positively correlated with % collectors. Sediment deposition was negatively correlated with % collectors and tolerance values and positively correlated with % filterers. Channel flow was negatively correlated with % intolerant taxa and EPT index.

Relationship of Water Quality and Benthic Communities

Spearman's rank correlation analysis showed that conductivity, pH, and turbidity were the most important water quality conditions influencing the various benthic metrics (Table 11). Conductivity was negatively correlated with % filterers and positively correlated with abundance and % intolerant taxa. pH was negatively correlated with % filterers and positively correlated with abundance, % collectors, and % intolerant taxa. Turbidity was negatively correlated with EPT index, % collectors, and % intolerant taxa.

DISCUSSION

Water Quality and Flow

Mean annual water quality conditions for all sites combined were similar among years with the exception of lower dissolved oxygen values in 2001 and higher turbidity values in 2002. The consistently low dissolved oxygen values for all sites in 2001 (<5.0 mg/L except for ORE 1) were potentially stressful to aquatic life based on thresholds discussed by Lee and Jones-Lee.[18] However, the benthic community data collected at all Orestimba Creek sites in 2001 did not suggest any drastic changes in community composition that would suggest greater environmental stress in 2001 compared to the other two years when dissolved oxygen values were consistently greater than 5.0 mg/L. Dissolved oxygen was not reported to be one of the more significant water quality conditions influencing the various benthic metrics based on Spearman's correlation analysis (Table 11).

Turbidity is generally considered a surrogate measure for sediment loading. The U.S. EPA has listed sediment as the number one source of impairment nationwide on its list of impaired water bodies.[19] Turbidity was reported to be

Table 10: Spearman correlation coefficients (top) and *p*-values (bottom) for benthic metrics vs. habitat metrics based on three years of data from Orestimba Creek ($N=30$).

Benthic metric	BANK STAB	BANK VEG	CHAN ALT	BEN RIFF	EPI SUB	RIP BUFF	SED DEP	VEL DPTH	CH FLOW	EMBE DDED	TOTAL
Abundance	0.34403	−0.0226	−0.31014	−0.10983	−0.32014	0.11144	0.03305	−0.29807	−0.16115	−0.34714	−0.22707
(#/sample)	0.0627	0.9055	0.0953	0.5634	0.0846	0.5577	0.8624	0.1096	0.3949	0.0602	0.2275
EPT index %	0.12841	−0.0184	−0.0997	0.20051	−0.19964	−0.10571	0.10495	0.06177	−0.13015	−0.16606	−0.0315
	0.4989	0.9233	0.6002	0.2881	0.2902	0.5782	0.581	0.7457	0.493	0.3805	0.8687
EPT taxa	0.21197	−0.0634	−0.21024	0.24359	−0.25221	−0.15293	0.18284	−0.003	−0.12039	−0.16958	−0.0366
	0.2608	0.7391	0.2648	0.1946	0.1788	0.4198	0.3335	0.9891	0.5263	0.3703	0.8476
Ephemeroptera	0.03517	−0.35165	−0.12315	−0.0115	−0.37769	−0.2475	−0.0326	−0.31355	−0.28768	−0.15418	−0.32982
taxa	0.8536	0.0567	0.5168	0.9519	0.0396	0.1873	0.864	0.0915	0.1232	0.4159	0.0751
Percent	−0.0318	−0.009	0.44672	0.20265	0.23272	0.3675	−0.35595	0.10799	0.04718	0.07857	0.16854
collectors	0.8674	0.9639	0.0133	0.2828	0.2159	0.0457	0.0535	0.57	0.8045	0.6798	0.3733
Percent	−0.19557	−0.15963	0.11048	−0.0488	−0.15223	0.14527	−0.13424	−0.1918	−0.0979	−0.0112	−0.15652
dominant taxon	0.3003	0.3995	0.5611	0.7981	0.4219	0.4437	0.4794	0.3099	0.6069	0.9532	0.4088
Percent	0.0029	−0.0714	−0.3553	0.0079	0.05099	−0.49704	0.39593	0.25705	0.11427	0.30299	0.09867
filterers	0.9878	0.7076	0.054	0.9672	0.789	0.0052	0.0303	0.1703	0.5477	0.1036	0.6039
Percent	0.01213	0.11412	−0.0994	−0.18071	0.25962	0.16605	0.09102	−0.0111	−0.28137	0.04553	0.05098
grazers	0.9493	0.5482	0.6012	0.3393	0.1659	0.3805	0.6324	0.9538	0.132	0.8112	0.7891
Percent	−0.077	−0.40335	0.11857	0.133	−0.32333	−0.11994	−0.30006	−0.29721	−0.51837	−0.21919	−0.40056
intolerant taxa (0–2)	0.6858	0.0271	0.5326	0.4835	0.0814	0.5278	0.5062	0.1107	0.0033	0.2445	0.0283
Percent	−0.23744	−0.22314	0.047	−0.11688	−0.29526	−0.031	0.12624	−0.25421	−0.0996	−0.36616	−0.34681
predators	0.2064	0.2359	0.8052	0.5385	0.1132	0.8707	0.5062	0.1752	0.6004	0.0466	0.0604
Percent	0.31731	0.29222	−0.44971	−0.25871	−0.002	0.042	0.25567	−0.0639	0.11968	−0.034	0.05701
shredders	0.0875	0.1171	0.0127	0.1675	0.9906	0.8256	0.1727	0.7372	0.5287	0.8585	0.7648
Percent	−0.20877	−0.14254	0.325	0.03499	0.3065	0.29629	−0.35183	0.0064	0.12082	0.13761	0.09767
tolerant taxa (8–10)	0.2682	0.4524	0.0797	0.8544	0.0995	0.1119	0.0566	0.9732	0.5248	0.4683	0.6076
Plecoptera taxa	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1	1

(Continued on next page)

Table 10: Spearman correlation coefficients (top) and *p*-values (bottom) for benthic metrics vs. habitat metrics based on three years of data from Orestimba Creek ($N=30$). *(Continued)*

Benthic Metric	BANK STAB	BANK VEG	CHAN ALT	BEN RIFF	EPI SUB	RIP BUFF	SED DEP	VEL DPTH	CH FLOW	EMBE DDED	TOTAL
Sensitive EPT	−0.0775	−0.32054	0.05509	0.13059	−0.19074	0.0057	−0.18452	−0.19451	−0.40597	−0.0699	−0.2913
index (%)	0.6841	0.0842	0.7725	0.4916	0.3127	0.9761	0.329	0.303	0.026	0.7138	0.1183
Shannon	0.0678	0.0027	−0.10477	0.03278	0.04183	−0.14055	0.03434	0.06298	−0.0107	−0.0355	0.01093
diversity	0.7219	0.9887	0.5816	0.8635	0.8263	0.4588	0.857	0.7409	0.9551	0.8521	0.9543
Taxonomic	0.01794	−0.12608	−0.19349	−0.0463	−0.17098	−0.1755	0.05198	−0.0777	−0.11746	−0.27439	−0.20085
richness	0.925	0.5068	0.3056	0.808	0.3663	0.3536	0.785	0.6833	0.5365	0.1423	0.2872
Tolerance	−0.16904	−0.21191	0.08384	−0.0906	0.2778	0.0999	−0.35243	−0.0926	0.03533	0.21303	−0.0108
value	0.3719	0.2609	0.6596	0.634	0.1372	0.5994	0.0561	0.6265	0.8529	0.2584	0.9548
Trichoptera	0.31408	0.15092	−0.24025	0.27283	−0.0666	−0.0646	0.26882	0.18889	0.08546	−0.0786	0.18704
taxa	0.091	0.426	0.201	0.1446	0.7265	0.7344	0.1509	0.3175	0.6534	0.6797	0.3223

Table 11: Spearman correlation coefficients (top) and *p*-values (bottom) for benthic metrics vs. water quality conditions based on three years of data from Orestimba Creek ($N=30$).

Metric	Conductivity	DO (mg/L)	pH	Temperature (C)	Turbidity (NTU)
Abundance	0.584	0.1259	0.50913	0.10684	−0.23278
(#/sample)	0	0.5074	0.0041	0.5741	0.2158
EPT	0.222	0.06	−0.01999	−0.07899	−0.34773
index (%)	0.238	0.7509	0.9165	0.6782	0.0597
EPT	0.289	0.037	0.02532	−0.10625	−0.33432
taxa	0.121	0.8446	0.8943	0.5763	0.071
Ephemeroptera	0.184	0.055	0.08036	−0.10768	−0.26632
taxa	0.331	0.7742	0.6729	0.5711	0.1549
Percent	0.255	−0.04	0.35516	0.57569	−0.37202
collectors	0.175	0.8539	0.0541	0.0009	0.0429
Percent	0.169	0.1116	0.31874	0.26736	0.15691
dominant taxon	0.373	0.557	0.086	0.1532	0.4076
Percent	−0.56	−0.08	−0.53994	−0.43107	0.28424
filterers	0	0.6746	0.0021	0.0174	0.1279
Percent	0.227	−0.135	−0.1569	−0.02565	−0.06244
grazers	0.228	0.4766	0.4077	0.893	0.7431
Percent intolerant	0.47	−0.07	0.39945	0.12438	−0.52093
taxa (0–2)	0	0.7075	0.0288	0.5125	0.0032
Percent	0.318	0.1514	0.14133	−0.14972	−0.07629
predators	0.09	0.4244	0.4563	0.4297	0.6887
Percent	−0.13	0.2455	−0.16107	−0.29797	0.13127
shredders	0.481	0.1911	0.3952	0.1098	0.4893
Percent tolerant	0.245	−0.423	−0.05025	0.11013	−0.18014
taxa (8–10)	0.192	0.02	0.792	0.5623	0.3408
Plecoptera	0	0	0	0	0
taxa	1	1	1	1	1
Sensitive	0.341	0.015	0.30997	−0.02547	−0.41777
EPT index (%)	0.07	0.9375	0.0955	0.8937	0.0216
Shannon	0	−0.234	−0.24261	−0.34303	−0.29737
diversity	0.859	0.2139	0.1964	0.0635	0.1105
Taxonomic	0.125	−0.13	−0.03076	−0.34184	−0.24532
richness	0.51	0.4946	0.8718	0.0645	0.1913
Tolerance	0.151	−0.39	−0.10672	0.04442	0.03874
value	0.425	0.033	0.5746	0.8157	0.839
Trichoptera	0.248	−0.03	−0.06513	−0.0639	−0.29677
taxa	0.186	0.8754	0.7324	0.7373	0.1113

negatively correlated with both the EPT index and intolerant taxa in Orestimba Creek. Various other investigators have also documented the negative effects of sediment to benthic invertebrates.[20] Therefore, increased turbidity for most of the Orestimba Creek sites in 2002 would suggest increased stress for benthic communities. For example, an increase in % chironomidae—taxa associated with stressed conditions—would suggest degrading environmental conditions in 2002. A significant increase in % filterers—a trophic guild that dominates in stressed environments—also suggest that benthic communities were somewhat more stressed in 2002. The exotic clam species *Corbicula* (a filterer) was particularly dominant in 2002 comprising 9% of the taxa collected and ranking as the fifth most dominant species. Harrington and Born[13] have reported that most of the clam and mussel species remaining in California streams and rivers are relatively pollution tolerant and tend to be concentrated in warm waters with high nutrient loads. These authors have also reported that *Corbicula* has spread throughout streams and rivers in the United States displacing native species.

The spatial differences in turbidity were clear during all three years of sampling as the upstream site (ORE 10) had turbidity values more than 100 times lower than the other nine sites. ORE 10 is located above all agricultural activity so the low turbidity values at this site are not surprising because there is no suspended sediment coming from eroded soil in irrigated agricultural fields. Two critical benthic metrics that increase in nonstressed environments—species richness and EPT taxa—were consistently higher at ORE 10 when compared with the other nine sites. Therefore, the low turbidity at ORE 10 is likely a factor contributing to higher benthic community condition at this site during all three years of sampling.

The increased flow and cross-sectional area by site in 2001 does not appear to be related to any of the critical benthic metrics such as richness, abundance, and the various trophic measures. However, physical habitat metrics such as velocity/depth/diversity and bend/riffle frequency were higher in 2001 when compared with the other two years. Total physical habitat scores were also statistically higher in 2001 than 2002.

Physical Habitat

Critical stressors to aquatic life in California streams are water augmentation, sediment loading, and impaired physical habitat. Altered physical habitat structure is also considered one of the major stressors of aquatic systems throughout the United States.[21] Identifying degraded physical habitat in streams is critical for bioassessments as failure to do so can sometimes hinder investigations on the effects of toxic chemicals or other water quality related stressors. There is a small but still significant risk of reporting a water quality related impact when one does not exist (false positive) when habitat assessments are insufficient or absent.[22] Physical habitat evaluations are not intended to replace biological assessments but rather to add an additional line of evidence about the status of lotic systems when conducted in concert with biological assessments. Evaluation of physical habitat in agricultural streams in California's Central Valley is particularly important due to the intensive development and landscape modifications in these areas.

Temporal comparison of physical habitat metrics in Orestimba Creek showed differences (declining scores) for a greater number of metrics between 2001 and 2002. The general pattern, as supported by the final habitat score across all sites, is that physical habitat in Orestimba Creek has declined between 2001 and 2002. Benthic metrics that increased concurrently with declining physical habitat in Orestimba Creek in 2002 were % chironomidae and % filterers. Both of these metrics increase in response to environmental disturbance.[13] The increase in % filterers was influenced by the increase in abundance for the exotic clam *Corbicula* in 2002 as discussed above. These benthic data suggest a decline in community assemblages with a concurrent decline in physical habitat conditions. This finding is in agreement with other studies that have documented the importance of physical habitat for benthic communities.[10,22,23]

Historical comparisons of our Orestimba Creek physical habitat data with other streams in the San Joaquin watershed is problematic due to both limited available data and consistent methods of habitat assessment. The total physical habitat score for all sites combined in Orestimba Creek was significantly higher than another stream in the San Joaquin watershed (Salt Slough) based on physical habitat assessments conducted in 2001 and 2002.[7,8] Various metrics such as epifaunal substrate, sediment deposition, and embeddedness were significantly higher in Orestimba Creek when compared with Salt Slough in both 2001 and 2002. In contrast, total physical habitat scores in Orestimba Creek were similar to another nearby San Joaquin stream (Del Puerto Creek) sampled in 2001 and 2002.[7,8]

Griffith et al.[10] evaluated physical habitat in 95 wadeable streams in California's Central Valley in 1994 and 1995 using protocols described by Lazorchak, Klemm, and Peck.[24] However, exact comparisons with our physical habitat data are not possible due to different field methods. The general conclusion from Griffith et al.[10] was that physical habitat in most of these altered streams in the Central Valley is poor due to insufficient substrate heterogeneity and instream habitat. Our physical habitat data from three years of sampling in Orestimba Creek would generally support this finding.

Benthic Communities

Oligochaetes and chironomids were the most dominant taxa collected during all three years of sampling in Orestimba Creek. Oligochaetes are generally found in stressful environments while chironomids can be either sensitive or tolerant to environmental stressors depending on the species.[13,23] Temporal shifts in taxa were reported for both daphnids and the exotic clam *Corbicula* during the three years of sampling in Orestimba Creek. For both 2000 and 2001, few if any daphnids were collected at the 10 Orestimba Creek sites. However, in 2002 daphnids were the sixth most dominant species in this stream comprising 4.6% of the total taxa abundance. Harrington and Born[13] have reported that daphnids generally have a high tolerance value to most environmental stressors (except organophosphate insecticides as discussed below). Therefore, increased numbers of this tolerant taxa are generally associated with stressful conditions. The abundance of the clam *Corbicula* also increased in Orestimba

Creek from 2000 (2.2% of the total abundance) to 2002 (9% of the total abundance). Increased numbers of exotic (tolerant) species such as *Corbicula* are generally a sign of impairment.

Two trophic measures reported to significantly change over the three-year sampling period in Orestimba Creek were % collectors and % filterers. Both of these trophic measures increase in response to environmental disturbance.[13] The % collectors were reported to decrease over the three-year period, which suggests some improvement in environmental conditions. In contrast, % filterers were reported to increase significantly over the three-year period, which suggests an increase in environmental disturbance. The temporal pattern of increasing numbers of filterers in Orestimba Creek and associated increased environmental degradation would support the daphnia and *Corbicula* abundance data presented above that also suggests an increase in environmental degradation over time.

Due to limited historical benthic data in the San Joaquin River watershed, comparisons with our Orestimba Creek data were limited. In 1993, the US. Geological Survey collected benthic macroinvertebrates at one site in Orestimba Creek that was approximately halfway between our stations ORE 2 and ORE 3.[25] Dominant taxa reported by these investigators were mayflies, oligochaetes, and gastropods. The dominant taxa we reported in Orestimba Creek (particularly at ORE 2 and ORE 3) over the three-year period were oligochaetes and chironomids. Mayflies were not collected at ORE 2 or ORE 3 during our three years of sampling. Gastropods were collected in low numbers at ORE 2 and ORE 3 over the three-year period. Due to the seven-to nine-year time period between the two sampling events, it is difficult to explain possible factors contributing to the differences in dominant taxa.

Benthic data comprising 27 metrics from sampling Orestimba Creek in 2001 can be compared with benthic data collected in two other San Joaquin streams—Salt Slough and Del Puerto Creek—using the same sampling methods in the same year.[7] Taxonomic richness was similar among three streams in 2001. The % non-insect taxa and % diptera were significantly higher in Orestimba Creek when compared with Salt Slough. The % collectors and % non-insect taxa were also higher in Orestimba Creek when compared with Del Puerto Creek. In general most of these benthic metrics were not significantly different among Orestimba Creek, Del Puerto Creek, and Salt Slough sampled in 2001.

Twenty-three benthic metrics resulting from sampling Orestimba Creek in 2002 can also be compared with the same set of metrics collected from Salt Slough and Del Puerto Creek in the same year.[8] In contrast to the results reported above, none of the benthic metrics were significantly different ($p < 0.05$) among the three streams in 2002. These results suggest that benthic communities in Orestimba Creek are similar to two other agricultural streams in San Joaquin River watershed.

A comparison of benthic community data collected from an urban creek in Sacramento (Arcade Creek) in 2000 with our Orestimba Creek data collected in the same year showed significant differences for various metrics.[6] Shannon diversity and taxonomic richness were significantly higher in Orestimba Creek compared to Arcade Creek; % collectors were significantly higher in Arcade Creek. These data would suggest that the condition of benthic communities in Orestimba Creek (an agricultural stream) is higher than Arcade Creek (an urban stream).

Griffith et al.[10] used community metric and multivariate statistical approaches to assess the relationship between benthic communities and environmental variables in 95 wadeable streams in California's Central Valley in 1994 and 1995. Although these authors did not present benthic community by site their summary of benthic community data for all sites is in general agreement with our Orestimba Creek data as follows: (1) oligochaetes and chironomids were the dominant taxa; (2) percent tolerant taxa were generally dominant; (3) collectors were the dominant feeding guild; and (4) the abundance of EPT taxa was generally low for most sites.

Regulatory and Ecological Implications

The state of California has classified Orestimba Creek as an impaired water body (303d list) due to the presence of chlorpyrifos, diazinon, azinphos methyl, and DDE (www.swrcb.ca.gov). This water body was listed as impaired based on measured pesticide concentrations exceeding a threshold (water quality criteria). Unfortunately, the status of resident biological communities was not considered when this water body was classified as impaired because these data were not available. The benthic community data presented in this paper is therefore useful for providing another line of evidence for determining the biological condition of agricultural streams such as Orestimba Creek. A recent report by the National Research Council[26] addressing various issues associated with TMDLs and impaired water bodies stated that biological criteria should be used in conjunction with physical and chemical criteria to determine whether a water body is meeting its designated use. This National Research Council report further supports the use of biological data for determining the status (or potential impairment) of water bodies by stating that biological criteria are more closely related to designated uses of a water body than are chemical or physical measurements. A recent EPA report clearly supports the use of bioassessments for determining attainment of aquatic life based water quality standards by stating that bioassessment data are core indicators (critical or essential indicators).[27] This EPA report also endorses the use of multiple lines of evidence (chemical, toxicity, and bioassessment data) for making valid designations of impaired water bodies.[27]

Benthic communities in Orestimba Creek based on three years of sampling generally comprised tolerant species such as oligochaetes and chironomids.

Dominance by tolerant species is not surprising in this agricultural stream due to: (1) fluctuating flow conditions; (2) stressful water quality conditions such elevated temperature, low dissolved oxygen, and turbidity; (3) and less than optimal physical habitat. Historical data from permanent gauging stations near ORE 10 and ORE 8 show that in most years Orestimba Creek is ephemeral in the reach with no commercial agriculture but generally has continuous low flow (in non-drought years) in most of the lower reach which receives irrigation return water.[28] Daphnids (cladocerans) with a fairly high tolerance rating to general environmental stressors, but highly sensitive to chlorpyrifos[29] and diazinon[30] based on laboratory toxicity tests, were the sixth most dominant species in Orestimba Creek in 2002 comprising 4.6% of the total taxa adundance. The amphipod *Gammarus lacustris*, which is also considered sensitive to chlorpyrifos[29] and diazinon,[30] was the fourth most dominant species collected in Orestimba Creek in 2001 and the eighth most dominant species collected in 2000. The presence of these OP sensitive benthic species in Orestimba Creek suggests that the laboratory toxicity data used to generate the "effects benchmarks" for these OP insecticides may not accurately predict the status of resident biota.

Critical issues to address with the benthic community data from Orestimba Creek and other agricultural streams in California's Central Valley are: (1) What are the biological (benthic) expectations for these agricultural streams? and (2) Do these streams meet these biological expectations and are they impaired based on the status of resident benthic communities? Unfortunately, an agricultural reference stream is not available for this watershed to compare benthic communities with our Orestimba Creek data. Therefore, the traditional approach often used to interpret the status of benthic communities is not feasible. The presence of approximately 100 taxa in Orestimba Creek during each of three years of sampling implies that the benthic communities in this stream are fairly diverse, considering their ephemeral environments, but without a clear definition of benthic community expectations it is unknown if this water body is actually impaired. Extensive spatial and temporal assessments of benthic communities in concert with physical habitat assessments are needed in agricultural streams of California's Central Valley in order to identify the range of benthic community taxa assemblages by stream order and to identify potential reference sites.

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