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Historical Assessments and Comparisons of Benthic Communities and Physical Habitat in Two Agricultural Streams in California's San Joaquin Watershed

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This study was designed to assess trends in physical habitat and benthic communities (macroinvertebrates) annually in two agricultural streams (Del Puerto Creek and Salt Slough) in California's San Joaquin Valley from 2001 to 2005, determine the relationship between benthic communities and both water quality and physical habitat from both streams over the 5-year period, and compare benthic communities and physical habitat in both streams from 2001 to 2005. Physical habitat, measured with 10 metrics and a total score, was reported to be fairly stable over 5 years in Del Puerto Creek but somewhat variable in Salt Slough. Benthic communities, measured with 18 metrics, were reported to be marginally variable over time in Del Puerto Creek but fairly stable in Salt Slough. Rank correlation analysis for both water bodies combined showed that channel alteration, embeddedness, riparian buffer, and velocity/depth/diversity were the most important physical habitat metrics influencing the various benthic metrics. Correlations of water quality parameters and benthic community metrics for both water bodies combined showed that turbidity, dissolved oxygen, and conductivity were the most important water quality parameters influencing the different benthic metrics. A comparison of physical habitat metrics (including total score) for both water bodies over the 5-year period showed that habitat metrics were more positive in Del Puerto Creek when compared to Salt Slough. A comparison of benthic metrics in both water bodies showed that approximately one-third of the metrics were significantly different between the two water bodies. Generally, the more positive benthic metric scores were reported in Del Puerto Creek, which suggests that the communities in this creek are more robust than Salt Slough.

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INTRODUCTION

Approximately 10.2% of the total value of agricultural production in the United States originated from California in 1987 with approximately half of this total, valued at $6.82 billion, coming from the San Joaquin Valley.[1] Abundant water and long growing seasons are two important factors responsible for the highly productive agricultural economy of California's 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. Foe[3] has reported that 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). 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]

Anthropogenic activities have created stressful conditions for freshwater ecosystems in the San Joaquin Valley; therefore, it is important to understand how these stressors may be impacting aquatic resources. One approach for assessing potential impairment in aquatic systems is to use the structure of resident benthic macroinvertebrates communities. Benthic macroinvertebrates are excellent baramoters for measuring ecosystem health because they 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.[6–16] Bioassessments provide a useful approach for integrating effects from physical, chemical, and biological stressors on aquatic organisms. Bioassessments are based upon the premise that the structure and function of an aquatic biological community can provide critical information about the quality of the surface water. 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 goals of this study were to: (1) assess trends in physical habitat and benthic communities (macroinvertebrates) annually at five sites in two agricultural streams (Del Puerto Creek and Salt Slough) in California's San Joaquin Valley from 2001 to 2005; (2) assess the relationship between benthic communities and physical habitat from both streams over the 5-year period; (3) assess the relationship between benthic communities and water quality parameters from both streams over the 5-year period; and (4) compare benthic communities and physical habitat in both streams from 2001 to 2005. These streams have been listed as impaired water bodies (303 (d) list) due to the presence of OP insecticides diazinon and chlorpyrifos (www.swrcb.ca.gov); therefore, biological expectations are somewhat low.

MATERIALS AND METHODS

Site Selection

Five sites in both Del Puerto Creek and Salt Slough were sampled annually in late spring of 2001–2005 (Figs. 1 and 2). The sites sampled covered approximately 8 and 14 miles in Del Puerto Creek and Salt Slough, respectively. The predominate land-use type in these water bodies is agriculture. The upstream site in Del Puerto Creek (DLP5) was above agricultural activity, but all the other sites were in areas dominated by agriculture. Downstream Salt Slough sites SSL1, SSL2 and SSL3 were located within the San Luis Wildlife Refuge and the Los Banos State Wildlife area; upstream sites SSL4 and SSL5 were in agricultural areas. 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[17]: temperature, specific conductivity, pH, dissolved oxygen, salinity and turbidity. Flow (m/s) was measured at all sites using a Swoffer flow meter.

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[18] and Harrington and Born.[19] The physical habitat metrics used for this study are based on nationally standardized protocols described in Barbour et al.[20] A total of 10

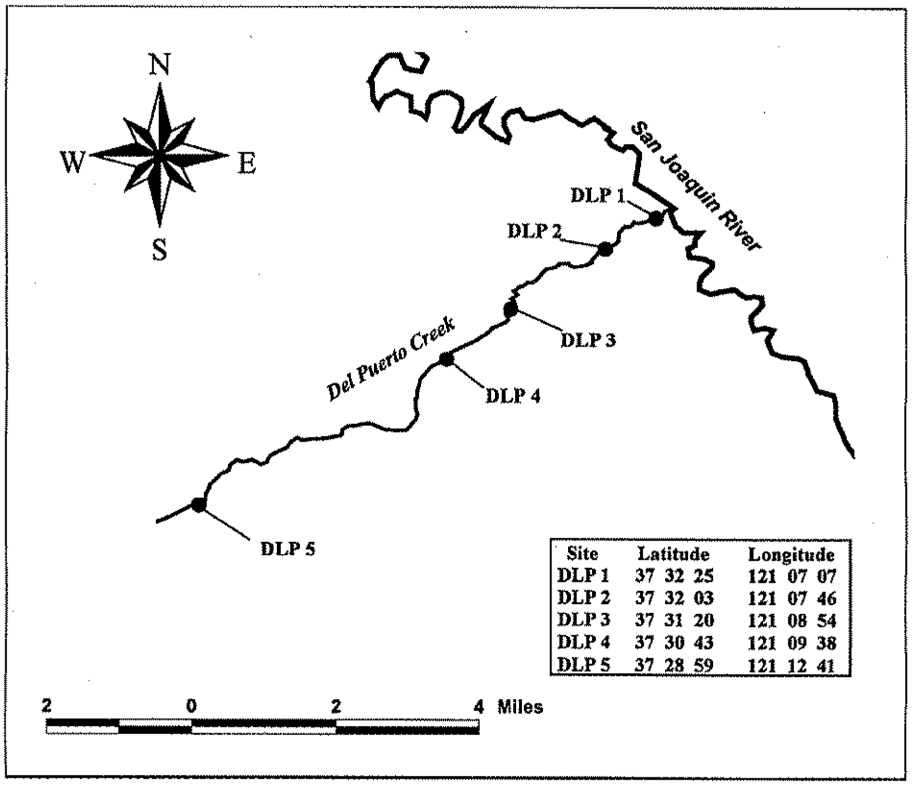
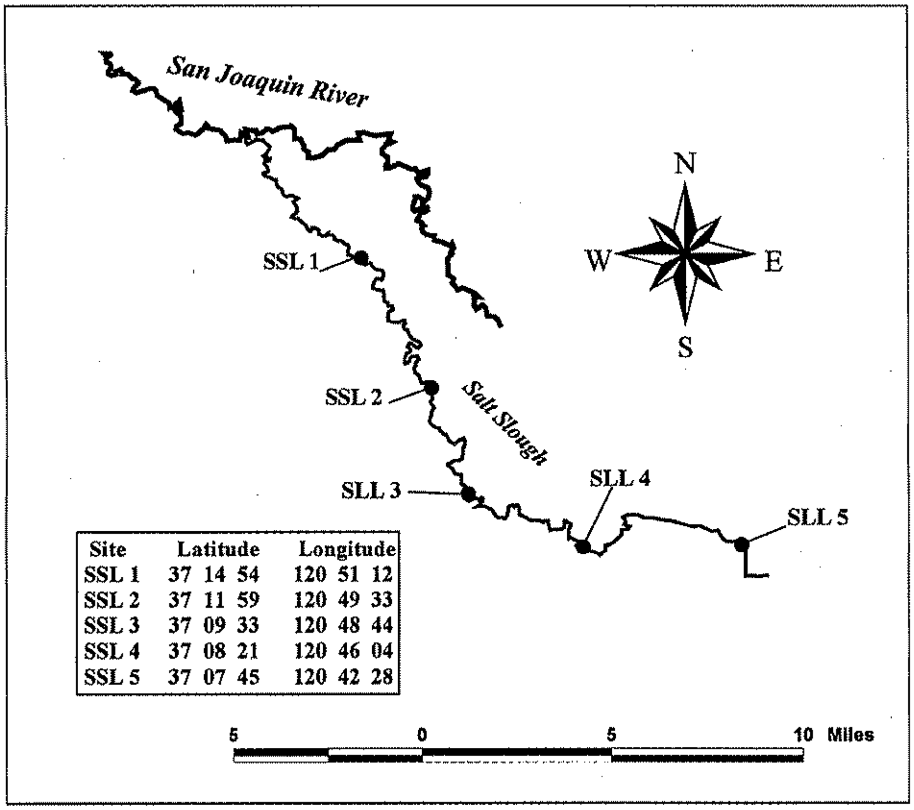


Figure 1: Del Puerto Creek (DLP) sample sites.

continuous metrics scored on a 0–20 scale as well as noncontinuous metrics including percent canopy, % gradient, and substrate composition were evaluated as previously described.[9–14]

Benthic Macroinvertebrate Assessments

Benthic macroinvertebrates were collected in the late spring of 2001, 2002, 2003, 2004 and 2005 from three replicate samples at five sample sites in both Del Puerto Creek and Salt Slough. The sample site selections and sampling procedures were conducted in accordance with methods described in Harrington and Born.[19] Sampling reaches were approximately equally spaced along the stream starting at the confluence. 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



Site	Latitude	Longitude
SSL 1	37 14 54	120 51 12
SSL 2	37 11 59	120 49 33
SSL 3	37 09 33	120 48 44
SSL 4	37 08 21	120 46 04
SSL 5	37 07 45	120 42 28

Figure 2: Salt Slough (SSL) sample sites.

available within the riffle. Benthic samples were taken using a standard D-net with 0.5 mm mesh starting with the most 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 streams, 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

Table 1: Comparison of individual water quality measurements for sites sampled from 2001-2005 in Del Puerto Creek and Salt Slough.

	Temperature (°C)					Specific Conductance (μmhos/L)					pH					Dissolved Oxygen (mg/L)				
Site	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05
DLP1	20.2	15.6	22.9	23.2	15.0	910	704	1199	1179	396.7	8.17	8.06	8.62	8.44	7.46	9	9.5	9.19	8.28	9.81
DLP2	23.7	20.6	25.6	25.6	17.3	900	709	1336	1165	426.4	—	8.58	8.82	8.53	7.74	5.9	8.8	9.19	7.93	9.48
DLP3	30.5	22.2	24.1	25.3	18.8	1086	742	1143	1254	446.5	8.51	8.34	8.12	8.53	8.58	4.7	9.1	8.06	7.43	10.47
DLP4	18.2	28.3	31.4	23.2	26.3	628	520	564	649	489	8.05	7.55	8.50	8.47	9.29	4.5	5.4	6.35	9.91	14.9
DLP5	22.1	22.7	18.7	20.6	22.9	992	1689	1287	1738	940	8.32	8.51	8.30	8.10	8.65	4.0	12.2	8.24	10.06	9.10
SSL1	22.1	18.5	28.6	24.6	19.2	989	1885	1957	1606	1270	7.62	7.69	7.68	7.73	7.64	2.8	6.4	5.37	7.26	7.12
SSL2	22.1	19.3	26.1	21.9	20.4	1011	1339	1844	1450	1190	7.73	7.43	7.37	7.60	7.51	3.2	6.0	5.12	7.07	6.62
SSL3	24.5	20.8	27.4	23.2	21.8	495	1256	1616	1435	1160	7.74	7.56	7.51	7.56	7.56	2.8	6.7	5.25	7.88	7.17
SSL4	20.6	23.5	24.6	18.9	21.9	542	1073	1139	951	990	7.30	7.75	7.35	7.59	7.59	2.9	7.4	5.44	6.81	7.57
SSL5	23.2	18.0	22.6	15.9	26.4	552	1473	956	2148	2490	7.37	7.37	6.96	7.39	8.04	2.7	4.8	4.06	6.08	10.41

	Salinity (ppt)					Turbidity (NTU)					Flow (m/s)				
Site	01	02	03	04	05	01	02	03	04	05	01	02	03	04	05
DLP1	0.4	0.4	—	0.6	0.2	103	84	3.33	81.3	116	0.60	0.58	0.64	0.75	0.24
DLP2	0.5	0.4	—	0.6	0.2	59	130	1.70	135	109	0.68	0.54	0.67	0.3	0.24
DLP3	0.5	0.4	—	0.6	0.2	25	112	1.93	64.5	80.5	0.39	0.54	0.52	0.37	0.42
DLP4	0.4	0.2	—	0.3	0.3	56	20	6.5	13.5	70.2	0.31	0.32	0.10	0.05	0
DLP5	0.5	0.9	—	0.9	0.2	0.64	1.1	1.53	1.13	0.56	0.27	0.13	0.22	0.05	0.26
SSL1	0.5	0.9	—	0.8	0.9	61	46	43.1	36.3	68.4	0.40	0.22	0.32	0.31	0.26
SSL2	0.5	0.8	—	0.8	0.9	78	41	80.1	49.7	74.3	0.30	0.29	0.24	0.27	0.40
SSL3	0.3	0.7	—	0.7	0.4	68	52	66.4	58.4	90.2	0.38	0.34	0.34	0.32	0.30
SSL4	0.3	0.6	—	0.5	0.2	65	52	60.3	56.1	70.3	0.31	0.18	0.14	0.05	0.18
SSL5	0.3	0.7	—	1.3	1.3	80	37	78.6	13.1	48.5	0	0	0	0	0

Table 2: Comparison of individual physical habitat metrics (0–20 scale) and total scores for sites sampled annually from 2001–2005 in Del Puerto Creek and Salt Slough.

	Epifaunal substrate					Embeddedness					Velocity depth/diversity					Sediment deposition					Channel flow status					Channel alternation					Frequency bends/riffles				
Site	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**
DLP1	9	10	13	15	12	7	8	12	13	10	16	17	16	11	11	14	12	15	14	10	19	14	16	15	20	15	14	15	15	14	18	15	15	13	11
DLP2	7	11	13	11	11	7	7	12	10	11	14	10	15	15	15	16	12	14	10	15	16	15	16	15	19	12	8	10	13	11	7	12	10	7	11
DLP3	6	10	12	10	11	5	4	6	9	13	7	10	9	10	15	7	12	11	10	13	15	16	14	15	18	13	14	14	11	11	7	14	11	10	13
DLP4	2	9	10	11	1	10	4	8	7	0	5	10	10	5	0	6	6	10	11	5	8	8	6	11	4	2	11	6	11	0	2	8	6	8	0
DLP5	10	3	13	6	12	11	16	13	5	16	13	3	9	5	10	11	13	11	11	15	9	7	14	8	20	17	16	17	16	20	15	9	11	11	10
SSL1	8	2	5	6	7	1	0	0	0	0	11	11	9	16	11	4	2	1	2	5	20	13	14	16	20	15	14	16	16	17	15	7	4	7	5
SSL2	5	1	6	6	5	1	0	0	1	0	12	13	6	6	11	5	2	6	2	4	19	14	19	18	20	16	15	16	16	18	7	1	5	4	4
SSL3	2	1	6	7	3	1	0	0	0	0	11	9	9	9	13	4	2	4	3	3	19	11	15	16	20	14	14	15	14	14	8	2	5	2	4
SSL4	6	6	8	7	4	0	0	0	1	0	12	6	7	6	14	2	3	5	1	1	20	13	19	16	18	15	13	13	12	15	11	5	6	2	2
SSL5	2	6	2	7	2	0	0	0	0	0	2	0	1	0	0	1	3	1	0	0	18	9	15	16	16	6	0	2	2	6	6	0	0	0	0

	Left Bank Stability					Right Bank Stability					Left Bank Veget. Protect.					Right Bank Veget. Protect.					Left Bank Ripar. Zone					Right Bank Ripar. Zone					Total Score Total Score				
DLP1	7	5	5	6	7	8	5	6	7	7	7	3	5	8	7	8	4	5	8	7	5	1	2	5	4	7	3	3	5	4	140	111	128	136	124
DLP2	2	3	4	6	7	2	3	2	4	0	2	3	4	7	6	2	3	1	3	0	1	1	3	3	3	1	1	3	3	0	89	89	107	105	109
DLP3	6	7	8	6	6	4	7	6	6	6	6	7	5	5	6	6	7	3	5	6	3	4	3	2	3	4	4	4	2	3	89	116	106	101	124
DLP4	5	6	5	7	0	3	7	4	7	1	5	4	3	6	1	3	4	3	6	1	4	1	2	1	1	4	1	2	1	1	59	79	75	91	15
DLP5	7	7	8	6	7	9	7	8	4	7	7	5	5	3	4	7	5	4	3	4	8	6	6	7	5	8	6	5	7	5	132	103	124	90	135
SSL1	7	5	3	2	5	6	3	3	6	6	8	6	3	3	7	6	6	3	6	7	9	8	6	6	8	9	8	3	6	7	119	85	70	93	105
SSL2	9	8	10	7	9	9	8	6	7	8	7	7	8	8	8	7	7	6	4	6	9	8	10	8	8	9	8	8	8	8	115	92	106	93	109
SSL3	8	6	6	6	8	8	6	7	6	7	6	7	6	7	7	6	7	6	7	6	8	4	3	2	3	5	5	5	2	5	100	74	87	84	93
SSL4	5	2	0	1	2	6	7	6	6	6	4	4	3	3	6	4	6	7	4	7	3	4	1	1	3	3	4	6	1	5	91	73	81	64	83
SSL5	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0	0	0	1	1	0	0	0	1	1	0	39	18	23	31	24

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lacking, alternative sampling methods for non-riffle areas were used as outlined in Harrington and Born.[19] This involved sampling the best available 1 × 2-foot sections of habitat throughout the reach using the same procedures described here. 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 if and 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.[19] 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.[21]

Statistical Analysis

Cluster analysis with average linkage, using the cluster procedure of SAS software system, was used to determine site grouping for both physical habitat and benthic metrics averaged over the 5-year period in both streams.[22] Comparisons among sites using habitat and benthic metrics were conducted using Euclidean distance.[23] Spearman's rank correlation was used to determine the relationship between benthic metrics and both water quality conditions and physical habitat metrics in each stream. Analysis of Covariance (ANCOVA) was used to determine temporal and longitudinal trends in both benthic and habitat metrics in both streams and also compare these metrics between streams. Principal Components Analysis (PCA) was used to determine the relationship among the various physical habitat metrics and benthic community metrics to identify metrics that covary.

RESULTS

Water Quality and Flow

A temporal comparison of water quality data for the five Del Puerto Creek sites sampled annually from 2001 to 2005 in Table 1 showed the following: (1) temperature was generally lower for three of the five sites in 2005; (2) specific conductance was generally lower for most sites in 2005; (3) pH was fairly consistent among sites for all years; (4) dissolved oxygen was generally lower at most sites in 2001 when compared with other years; (5) salinity was consistent among sites for each year; and (6) turbidity was generally lower at most sites in 2003 and the turbidity at upstream site (DLP5) was always lower than the other sites every year. Flow was generally lower at most sites in 2005.

A temporal comparison of water quality data for the five Salt Slough sites sampled annually from 2001 to 2005 in Table 1 showed the following: (1) temperature was generally higher at most sites in 2003; (2) specific conductance was lower at all sites in 2001; (3) pH was fairly consistent among all sites for all years; (4) dissolved oxygen was consistently lower at all sites in 2001; (5) salinity was generally consistent among all sites for all years although slightly higher salinities (>1.0 ppt) were reported at SSL5 in 2004 and 2005; and (6) turbidity was lower at most of the sites in 2002. Flow was generally higher at most sites in 2001 and there was no flow reported at upstream site SSL5 for any year.

Physical Habitat

The total physical habitat scores in Del Puerto Creek (maximum of 200) for the 5-years ranged from 15 at DLP4 in 2005 to 140 at DLP1 (Table 2). Upstream site DLP4 consistently had lower total physical habitat scores when compared with the other four sites. The total physical habitat scores in Salt Slough from 2001 to 2005 ranged from 18 at SSL5 in 2002 to 119 at SSL1 in 2001 (Table 2). Total physical habitat scores at upstream site SSL5 were consistently lower than the other four sites across all years.

Trends analysis for the entire 5 years for the various continuous habitat metrics in Del Puerto Creek shows that there were no significant trends for any metric from 2001 to 2005 (Table 3). These data suggest that physical habitat in Del Puerto Creek was fairly stable over the 5-year period. In contrast, trends analysis for the continuous habitat metrics for the 5-year period in Salt Slough show temporal variability for bend riffle frequency and riparian buffer at the 0.05 significance level (Table 3). If the significance level is slightly increased to 0.10 then bank stability and total score were also variable over 5 years. These data suggest that physical habitat is somewhat variable over time Salt Slough.

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Table 3: Trends of physical habitat metrics over years (2001–2005) for Del Puerto Creek (DLP) and Salt Slough (SSL).

Creeks	Metric	2001	2002	2003	2004	2005	Trend	Trend *P*-value	Trend comparison
DLP	Epi Sub.	6.8	8.6	12.2	10.6	9.4	0.42	0.28	0.69
SSL	Epi Sub.	4.6	3.2	5.4	6.6	4.2	0.2	0.60	
DLP	Embedd	8.0	7.8	10.2	8.8	10	0.52	0.24	0.33
SSL	Embedd	0.60	0	0	0.4	0	−0.10	0.83	
DLP	Vel/Depth	11	10	11.8	9.2	10.2	−0.85	0.11	0.82
SSL	Vel/Depth	9.6	7.8	6.4	7.4	9.8	−0.68	0.20	
DLP	Sed dep	10.8	11	12.2	11.2	11.6	−0.04	0.91	0.55
SSL	Sed dep	3.2	2.4	3.4	1.6	2.6	−0.35	0.33	
DLP	Chann Fl.	13.4	12	13.2	12.8	16.2	0.06	0.88	0.79
SSL	Chann Fl.	19.2	12	16.4	16.4	18.8	0.23	0.60	
DLP	Chan Alt	11.8	12.6	12.4	13.2	11.2	−0.05	0.94	0.55
SSL	Chan Alt	13.2	11.2	12.4	12.0	14	−0.58	0.36	
DLP	Ben Riff	9.8	11.6	10.6	9.8	9.0	−0.67	0.17	0.16
SSL	Ben Riff	9.4	3	4	3	3	−1.63	0.002*	
DLP	Bank St.	10.6	11.4	11.2	11.8	9.6	−0.0	0.99	0.23
SSL	Bank St.	12	9	8.2	8.6	10.2	−1.14	0.09	
DLP	Bank Veg	10.6	9	7.6	10.8	8.4	−0.41	0.48	0.73
SSL	Bank Veg	10	10	8.7	8.8	10.8	−0.69	0.23	
DLP	Rip Buf	9	5.6	6.6	6.4	5.8	−0.31	0.56	0.10
SSL	Rip Buf	11	9.8	8.8	8.2	9.4	−1.57	0.005*	
DLP	T. Score	101.8	99.6	108	104.6	101.4	−1.32	0.71	0.33
SSL	T. Score	92.8	68.4	73.4	73	82.8	−6.32	0.09	

*$P < 0.05$.

A comparison of noncontinuous annual mean habitat characteristics in Table 4 for both Del Puerto Creek and Salt Slough shows that the following characteristics were generally consistent for all 5 years: % gradient, % boulder, and % bedrock. These noncontinuous habitat data in Table 4 show that % fines were the dominant substrate in Salt Slough in contrast to Del Puerto Creek where both gravel and cobble were present.

PCA was used to determine the relationship among habitat metrics for both streams over 5 years and identify metrics that covary (Table 5). Three eigenvalues exceeded 1 indicating that there were three important factors in these data. Total score, bank stability, channel alteration, bend riffle frequency, and velocity/depth/diversity were heavily loaded on Factor 1 (Table 6). Factor 2 was composed of embeddedness, sediment deposition, riparian buffer, epifaunal substrate, and bank vegetation. Channel flow status was the only metric to load on Factor 3.

Spatial cluster analysis of physical habitat metrics in Del Puerto Creek over the 5 year period showed that DLP1 and DLP5 were similar and DLP2 and DLP3 were similar (Fig. 3). DLP4 was different than the other four sites as the total physical habitat scores were consistently lower at this site. Spatial analysis of physical habitat metrics in Salt Slough showed that SSL1 and SSL3 were very similar and all sites but SSL5 formed a distinct group

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Table 4: Physical habitat characteristics for Del Puerto Creek and Salt Slough sampled annually from 2001–2005 that were not scored on a 0–20 scale.

	% Canopy					% Gradient					% Fines					% Gravel				
Site	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**
DLP1	67	86	77	54	71	1	1	1	1	1	55	55	20	40	70	20	40	40	50	20
DLP2	0	0	35	18	17	1	1	1	1	1	50	50	40	70	60	40	40	40	10	30
DLP3	8	39	20	1	4	1	1	1	1	1	60	50	50	80	60	40	40	40	20	30
DLP4	1	0	0	0	0	1	1	1	1	1	58	50	40	90	100	40	40	55	10	0
DLP5	0	0	0	0	0	1	1	1	1	1	20	20	20	40	15	50	60	50	40	80
SSL1	1	0	0	0	0	1	1	1	1	1	100	100	100	100	100	0	0	0	0	0
SSL2	0	0	0	0	0	1	1	1	1	1	100	100	100	100	100	0	0	0	0	0
SSL3	0	0	0	0	0	1	1	1	1	1	100	100	100	100	100	0	0	0	0	0
SSL4	0	0	0	0	0	1	1	1	1	1	100	100	100	100	100	0	0	0	0	0
SSL5	0	0	0	0	0	1	1	1	1	1	100	100	100	100	100	0	0	0	0	0

	% Cobble					% Boulder					% Bedrock				
Site	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**
DLP1	25	5	40	10	5	0	0	0	0	5	0	0	0	0	0
DLP2	10	10	20	10	0	0	0	0	10	10	0	0	0	0	0
DLP3	0	10	10	0	10	0	0	0	0	0	0	0	0	0	0
DLP4	2	10	5	0	0	0	0	0	0	0	0	0	0	0	0
DLP5	30	20	30	20	5	0	0	0	0	0	0	0	0	0	0
SSL1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSL2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSL3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSL4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSL5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5: Eigenvalues from PCA of habitat metrics for 2001-2005 for Del Puerto Creek and Salt Slough.

Factor number	Eigen Value	Proportion variance explained	Cumulative variance explained
1	5.5486	0.50	0.50
2	2.6790	0.24	0.75
3	1.0174	0.09	0.84
4	0.4440	0.04	0.88
5	0.3556	0.03	0.91
6	0.2907	0.03	0.94
7	0.2479	0.02	0.96
8	0.1985	0.02	0.98
9	0.1187	0.01	0.99
10	0.0996	0.01	1.00
11	0.0000	0.00	1.00

(Fig. 4). Physical habitat at upstream site SSL5 was different (generally more degraded) than the other four sites.

Spatial trends for the 5-year period for physical habitat metrics (10 metrics and total score) showed that the following metrics decreased significantly ($P < 0.05$) from downstream to upstream in Del Puerto Creek epifaunal substrate, velocity/depth/diversity, sediment deposition, channel flow and bend riffle frequency. In Salt Slough, velocity/depth/diversity, channel alteration, bend/riffle frequency, bank stability, bank vegetation, riparian buffer, and total habitat score decreased significantly from downstream to upstream.

Benthic Communities

Approximately 3800 to 4300 individual macroinvertebrates were picked and identified from five Del Puerto Creek sites sampled annually from 2001 to

Table 6: Eigen vectors (factor scores) from PCA of habitat metrics for 2001–2005 for Del Puerto Creek and Salt Slough.

Habitat Metric	Factor 1	Factor 2	Factor 3
Factor 1			
Total	0.42	0.00	0.01
bankStab	0.34	−0.22	−0.29
Chan alt	0.34	−0.26	0.00
benRiff	0.34	0.23	0.06
Vel dpth	0.32	−0.01	0.30
Factor 2			
Embedded	0.24	0.43	−0.22
Sed dep	0.27	0.43	−0.11
RipBuff	0.23	−0.41	−0.28
Epi sub	0.26	0.37	0.19
BankVeg	0.31	−0.32	−0.17
Factor 3			
Ch flow	0.15	−0.22	0.79

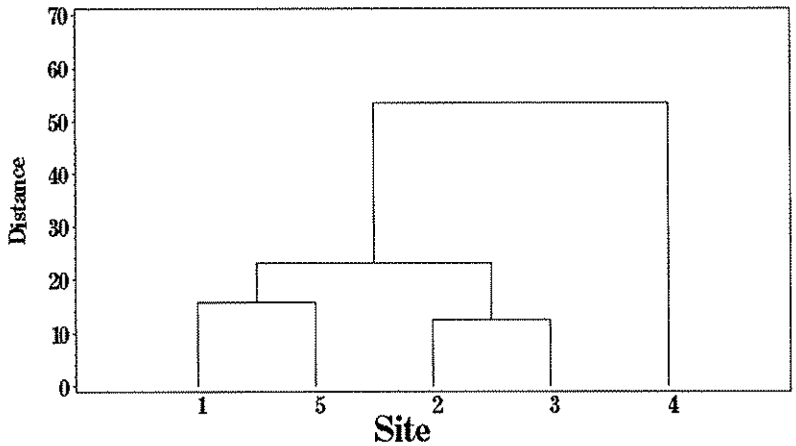

Figure 3: Cluster dendogram of Del Puerto Creek sites based on Euclidean distance of average habitat metric scores for the 5-year period using all continuous metrics collected in all years.

2005. The total number of taxa collected by year in Del Puerto Creek were 83 taxa in 2001, 95 taxa in 2002, 81 taxa in 2003, 69 taxa in 2004 and 86 taxa in 2005. Dominant taxa (50% cumulative %) were generally chironomids (aquatic insects) and oligochaetes (aquatic worms) for the 5-year period (Table 7). The chiromonid, *Simulium*, was generally the most dominant, or one of the most dominant taxa, for all 5 years except 2002. The gastropod, *Physa sp.*, was not a dominant species from 2001 to 2003 but became dominant in 2004 and 2005, thus suggesting a shift in dominant species.

Chironomid

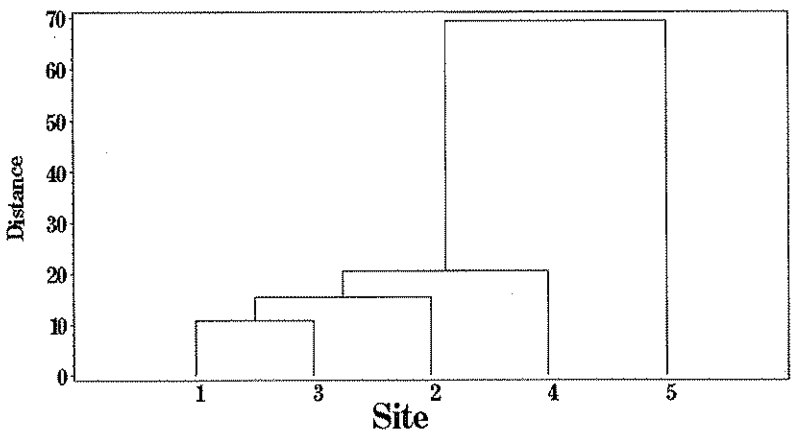

Figure 4: Cluster dendogram of Salt Slough sites based on Euclidean distance of average habitat metric scores for the 5-year period using all continuous metrics collected in all years.

Table 7: Total taxon abundance (50% cumulative %) for benthic macroinvertebrates collected in Del Puerto Creek annually from 2001–2005. A detailed presentation for all taxa for 2001,[9] 2002,[10] 2003,[11] 2004[12] and 2005[14] is available.

Year	Lowest Taxa	Higher Taxa	Total N	Total %	Cumulative %
2001	Cricotopus sp.	Chironomidae	597	15.5	15.5
	Nais communis/variabilis	Oligochaeta	500	12.9	28.5
	Simulium sp.	Chironomidae	483	12.5	41
	Cricotopus bicinctus	Chironomidae	393	10.2	51.2
2002	Slavina appendiculata	Oligochaeta	454	12.1	12.1
	Undetermined Tubificidae	Oligochaeta	411	10.9	23.0
	Cricotopus sp.	Chironomidae	401	10.7	33.7
	Helobdella stagnalis	Hirundinae	388	10.3	44
	Nais communis/variabilis	Oligochaeta	384	10.2	54.2
2003	Simulium sp.	Chironomidae	1104	28.4	28.4
	Nais communis/variabilis	Oligochaeta	562	14.5	42.9
	Dicrotendipes sp.	Chironomidae	314	8.1	50.9
	Cricotopus sp.	Chironomidae	310	8.0	58.9
2004	Simulium sp.	Chironomidae	1067	26.4	26.4
	Cyprídida	Ostracoda	834	20.7	47.0
	Physa sp.	Gastropoda	495	17.3	59.4
2005	Simulium sp.	Chironomidae	775	18.1	18.1
	Nais communis/variablilis	Oligochaeta	772	18.1	36.3
	Physa sp.	Gastropoda	467	10.9	47.3
	Cricotopus sp.	Chironomidae	311	7.3	54.6

In Salt Slough, 3100 to 4100 macroinvertebrates were picked and identified from five Salt Slough sites sampled annually from 2001 to 2005. The total number of taxa collected by year in Salt Slough were 70 taxa in 2001, 81 taxa in 2002, 65 taxa in 2003, 74 taxa in 2004 and 73 taxa in 2005. The amphipod, *Corophium spinicore*, (later changed to *Americorophium spinicore*) was consistently the most dominant taxa over the 5-year period (Table 8). This amphipod comprised 16 to 37% of the total taxa annually during the 5-year period. The chironomid, *Chironomus sp* and the gastropod (*Physa sp.* and/or *Physa/Physella*) were also dominant taxa in Salt Slough from 2001 to 2005.

Trends analysis for benthic metrics over 5 years in Del Puerto Creek showed variability in four of the metrics (Table 9). These data suggest that benthic communities in Del Puerto Creek are demonstrating some degree of change over time. A trends analysis for benthic metrics over the 5-year period for Salt Slough only showed a significant change for shredders and number of Trichoptera taxa, which suggests that the benthic communities have been fairly stable in this water body.

PCA was used to determine the relationship among benthic metrics for both streams over 5 years and identify metrics that covary (Table 10). Five eigenvalues exceeded 1, indicating that there were five important factors in these data. EPT taxa, number of Ephemeroptera taxa, sensitive EPT Index (%), EPT index, percent intolerant taxa, taxonomic richness, and number of trichoptera

Table 8: Total taxon abundance (50% cumulative %) for benthic macroinvertebrates collected in Salt Slough annually from 2001–2005. A detailed presentation for all taxa for 2001,[9] 2002,[10] 2003,[11] 2004[12] and 2005[14] is available.

Year	Lowest taxa	Higher taxa	Total N	Total %	Cumulative %
2001	Corophium spinicore	Amphipoda	508	16.3	16.3
	Chironomus sp.	Chironomidae	358	11.4	27.7
	Cricotopus sp.	Chironomidae	305	9.8	37.5
	Paratanytarus sp.	Chironomidae	292	9.3	46.8
	Undetermined Tubificidae	Oligochaeta	283	9.1	55.9
2002	Corophium spinicore	Amphipoda	1117	28.7	28.7
	Cricotopus sp.	Chironomidae	565	14.5	43.2
	Physa/Physella	Gastropoda	264	6.8	49.9
	Cricotopus bicinotus group	Chironomidae	222	5.7	55.7
2003	Corophium spinicore	Amphipoda	1373	37.1	37.1
	Physa sp.	Gastropoda	456	12.3	49.4
	Cricotopus sp.	Chironomidae	407	10.9	60.4
2004	Americorophium spinicore	Amphipoda	900	24.3	24.3
	Physa sp.	Gastropoda	435	11.8	36.2
	Cricotopus bicinctus group	Chironomidae	211	5.7	41.9
	Cricotopus sp.	Chironomidae	190	5.1	47
	Corbicula sp.	Bivalvia	171	4.6	51.6
	Tubificidae unid. imm.	Oligochaeta	164	4.4	56.1
2005	Americorophium spinicorne	Amphipoda	1044	25.4	25.4
	Physa sp.	Gastropoda	502	12.2	37.6
	Cricotopus sp.	Chironomidae	245	5.9	43.5
	Paratanytarus sp.	Chironomidae	242	5.9	49.4
	Americorophium sp.	Amphipoda	222	5.4	54.8

taxa were heavily loaded on Factor 1 (Table 11). Factor 2 was composed of percent dominant taxon, percent collectors-filterers, tolerance value, and Shannon diversity. Abundance and percent predators were dominant metrics in Factor 3. Factor 4 was composed of percent collectors-gatherers and percent tolerant taxa. Percent scrapers and percent shredders were dominant metrics in Factor 5.

Spatial cluster analysis of benthic community metrics from 2001 to 2005 at Del Puerto Creek showed that DLP1 and DLP2 were most similar although DLP4 and DLP3 were also similar (Fig. 5). Benthic communities at upstream site DLP5 were different than the other four sites. Spatial cluster analysis of the benthic community for the 5-year period at Salt Slough showed the following: SSL1 and SSL2 were similar; SSL3 and SSL4 were similar; and SSL5 was distinctly different than the other four sites (Fig. 6). The grouping of benthic community data in Salt Slough corresponded with the proximity of the sites to each other as downstream sites SSL1 and SSL2 are close together and SSL3 and SSL4 are also close together.

Spatial trends for the 5-year period for the 18 benthic metrics showed the following metrics increased significantly ($P < 0.05$) from downstream to upstream in Del Puerto Creek: abundance, EPT index, EPT taxa, number of

Table 9: Trends in benthic metrics over years (2001–2005) for Del Puerto Creek (DLP) and Salt Slough (SSL).

Creek	Metric	2001	2002	2003	2004	2005	Trend	Trend *P*-value	Trend comparison
DLP	Abundance	866	1361	2692	1495	2566	514	0.005*	0.12
SSL	Abundance	402	1228	764	966	1062	130	0.46	
DLP	ETP Index	0.06	0.01	0.02	0.01	0.04	0	0.85	0.50
SSL	ETP Index	0.03	0.02	0.03	0.04	0.01	−0.01	0.44	
DLP	EPT taxa	1.07	0.73	1.4	1.0	1.2	0.24	0.12	0.10
SSL	EPT taxa	0.93	0.67	0.93	0.87	0.53	−0.12	0.43	
DLP	# Eph. T.	0.80	0.47	0.93	1.0	1.0	1.0	0.21	0.047*
SSL	# Eph. T.	0.07	0.20	0	0.2	0.07	0.02	0.83	
DLP	# Tri T.	0.27	0.27	0.47	0	0.20	0.03	0.65	0.08
SSL	# Tri T.	0.87	0.47	0.93	0.67	0.47	−0.14	0.04*	
DLP	% Col-Fil	0.15	0.05	0.30	0.27	0.20	0.02	0.53	0.61
SSL	% Col-Fil	0.28	0.38	0.46	0.38	0.45	−0.0	0.94	
DLP	% Col-Gat	0.25	0.61	0.51	0.44	0.56	0.05	0.10	0.40
SSL	% Col-Gat	0.28	0.42	0.30	0.32	0.33	0.01	0.64	
DLP	% D. Taxa	0.30	0.38	0.44	0.54	0.34	0.03	0.13	0.33
SSL	% D. Taxa	0.33	0.42	0.53	0.41	0.41	0	0.88	
DLP	% Int. Tax	0	0	0	0	0.01	0	0.009*	0.06
SSL	% Int. Tax	0	0	0	0	0	−0	0.99	
DLP	% Pred	0.17	0.11	0.05	0.07	0.06	−0.03	0.003*	0.10
SSL	% Pred	0.12	0.11	0.04	0.15	0.07	−0.01	0.46	
DLP	% Scra	0.04	0.11	0.07	0.21	0.15	0.04	0.06	0.56
SSL	% Scra	0.11	0.08	0.19	0.15	0.14	0.02	0.27	
DLP	% Shr	0.03	0	0	0	0	−0.01	0.005*	0.57
SSL	% Shr	0.02	0	0	0	0	0	0.04*	
DLP	% Tol T.	0.51	0.43	0.46	0.50	0.50	−0	0.98	0.70
SSL	% Tol T.	0.58	0.47	0.48	0.48	0.55	0.01	0.60	
DLP	S. EPT I.	0	0	0	0	0	0	0.15	0.28
SSL	S. EPT I.	0	0	0	0	0	−0	0.92	
DLP	S. Div.	2.19	2.04	1.8	1.6	2.15	−0.06	0.25	0.49
SSL	S. Div.	2.19	1.94	1.58	2.06	1.94	−0.01	0.84	
DLP	T. Rich.	21	20.1	18.8	18.1	22.7	0.17	0.83	0.95
SSL	T. Rich.	20.8	19.9	16.1	19.3	20.7	0.1	0.89	
DLP	T. Value	7	7.07	6.89	7.19	7.35	0.10	0.43	0.64
SSL	T. Value	7.4	6.3	6.2	6.8	6.5	0.02	0.89	

$^*P < 0.05$.

Ephemeroptera taxa, number of Trichoptera taxa, number of intolerant taxa, and sensitive EPT index. In Salt Slough number of Trichoptera taxa, % collectors/filterers and % dominant taxa decreased significantly from downstream to upstream while % tolerant taxa and tolerance values increased from downstream to upstream.

Relationship of Physical Habitat and Benthic Communities

Rank correlation analysis for both water bodies combined showed that channel alteration, embeddedness, riparian buffer, and velocity/depth/diversity were the most important physical habitat metrics influencing the various benthic metrics (Table 12). Channel alteration was positively correlated with EPT index, EPT taxa, number of Trichoptera taxa, % collectors/filterers, % intolerant taxa, and taxonomic richness. Channel alteration was negatively correlated with % tolerant taxa and tolerance value. Embeddedness was positively

Table 10: Eigenvalues from PCA of benthic metrics for 2001–2005 for Del Puerto Creek and Salt Slough.

Factor number	Eigen value	Proportion variance explained	Cumulative variance explained
1	4.9263	0.29	0.29
2	3.7480	0.22	0.51
3	2.4362	0.14	0.65
4	1.2490	0.07	0.73
5	1.0600	0.06	0.79
6	0.8013	0.05	0.84
7	0.6882	0.04	0.88
8	0.5472	0.03	0.91
9	0.4268	0.03	0.93
10	0.3322	0.02	0.95
11	0.2275	0.01	0.97
12	0.1996	0.01	0.98
13	0.1577	0.01	0.99
14	0.1069	0.01	0.99
15	0.0734	0.00	1.00
16	0.0192	0.00	1.00
17	0.0000	0.00	1.00

correlated with abundance, EPT taxa, number of Ephemeroptera taxa, % intolerant taxa, sensitive EPT index, and taxonomic richness. Embeddedness was negatively correlated with % collectors/filterers. The riparian buffer metric was positively correlated with EPT index, EPT taxa, number of Tricoptera taxa, and % collectors/filterers and negatively correlated with % tolerant taxa

Trichoptera

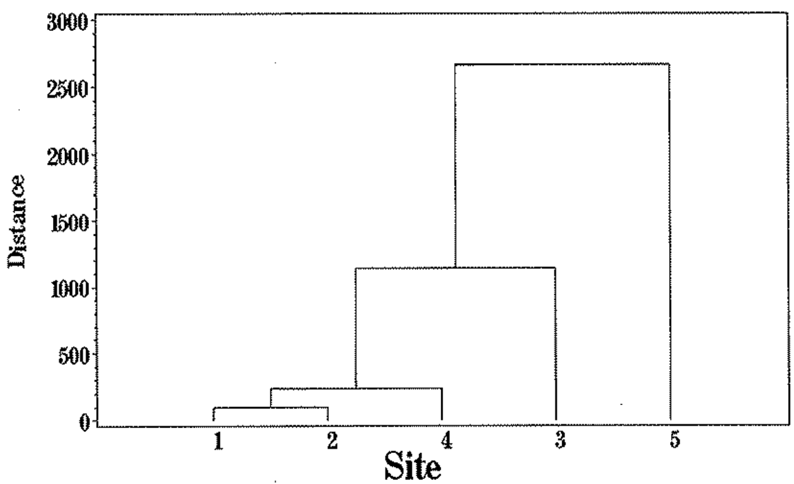

Figure 5: Cluster dendogram of Del Puerto Creek sites based on Euclidean distance of average benthic metric scores for the 5-year period using all continuous metrics collected in all years.

Table 11: Eigen vectors (factor scores) from PCA of benthic metrics for 2001–2005 for Del Puerto Creek and Salt Slough.

Benthic metric	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1					
EPT Taxa	0.43	−0.08	0.06	0.16	0.10
Number ephemeroptera taxa	0.37	0.07	0.20	0.11	0.17
Sensitive EPT index (%)	0.34	0.12	0.10	0.01	−0.13
EPT index (%)	0.33	−0.10	−0.12	0.12	0.11
Percent intolerant taxa (0–2)	0.31	0.13	0.16	0.12	−0.23
Taxonomic richness	0.30	0.21	−0.23	−0.22	−0.04
Number trichoptera taxa	0.30	−0.24	−0.16	0.15	−0.03
Factor 2					
Percent dominant taxon	−0.09	−0.41	0.25	0.20	0.03
Percent collectors-filterers	0.02	−0.41	−0.27	0.00	−0.12
Tolerance value	−0.13	0.40	0.26	0.17	0.11
Shannon diversity	0.16	0.37	−0.32	−0.25	−0.06
Factor 3					
Abundance	0.24	−0.01	0.42	0.09	0.21
Percent predators	0.06	0.23	−0.37	0.06	0.13
Factor 4					
Percent collectors gatherers	0.00	0.12	0.41	−0.55	0.17
Percent tolerant taxa (8–10)	−0.24	0.27	0.01	0.31	−0.05
Factor 5					
Percent scrapers	−0.01	0.22	0.12	0.37	−0.63
Percent shredders	−0.08	0.17	−0.18	0.43	0.60

Number of Plecoptera taxa were excluded because the data are zero for all cases.

and tolerance value. Velocity/depth/diversity was positively correlated with % collectors/filterers and negatively correlated with number of Ephemeroptera taxa, % scrapers, % tolerant taxa, and tolerance value.

Rank correlation analysis for non-continuous physical habitat metrics and benthic metrics showed that stream width was the most important habitat

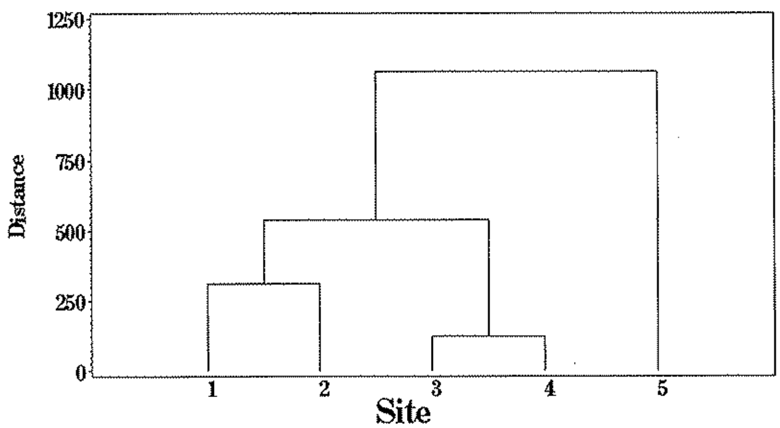

Figure 6: Cluster dendogram of Salt Slough sites based on Euclidean distance of average benthic metric scores for the 5-year period using all continuous metrics collected in all years.

Table 12: Correlations of benthic metrics with habitat metrics for 2001–2005 for Del Puerto Creek and Salt Slough.

Benthic metric	Epi sub	Embedded	Vel dpth	Sed dep	Ch flow	Chan alt	BenRiff	BankStab	BankVeg	RipBuff	Total
Abundance	0.28*	0.39*	−0.14	0.28*	−0.20	0.04	0.17	0.03	−0.23	0.00	0.10
	0.0481	0.0049	0.3410	0.0498	0.1692	0.8060	0.2422	0.8485	0.1043	0.9798	0.4833
EPT index (%)	0.03	0.20	0.12	0.06	−0.07	0.38*	0.16	0.32*	0.20	0.40*	0.28*
	0.8236	0.1744	0.4064	0.6588	0.6454	0.0068	0.2768	0.0237	0.1675	0.0044	0.0464
EPT taxa	0.15	0.38*	0.02	0.21	−0.06	0.44*	0.22	0.36*	0.11	0.41*	0.35*
	0.2844	0.0070	0.9021	0.1399	0.6642	0.0012	0.1191	0.0095	0.4459	0.0033	0.0116
Number ephemeroptera taxa	0.36*	0.61*	−0.03*	0.46*	−0.18	0.23	0.33*	0.17	−0.09	0.13	0.31*
	0.0098	0.0000	0.8599	0.0007	0.2029	0.1041	0.0201	0.2429	0.5458	0.3808	0.0264
Number trichoptera taxa	−0.20	−0.12	0.07	−0.23	0.13	0.51*	−0.03	0.45*	0.32*	0.59*	0.24*
	0.1659	0.4257	0.6408	0.1071	0.3713	0.0001	0.8611	0.0010	0.0223	0.0000	0.0982
Percent collectors filterers	−0.14	−0.26*	0.32*	−0.22	0.35*	0.42*	−0.18	0.35*	0.40*	0.44*	0.22*
	0.3326	0.0734	0.0228	0.1307	0.0127	0.0026	0.2128	0.0139	0.0042	0.0015	0.1230
Percent collectors gatherers	0.18	0.16	−0.06	0.24	−0.32*	−0.13	0.16	−0.05	−0.22	−0.19	−0.03
	0.2114	0.2522	0.6546	0.1002	0.0246	0.3758	0.2627	0.7369	0.1210	0.1956	0.8362
Percent dominant taxon	0.00	−0.16	0.05	−0.02	−0.06	0.15	−0.05	0.13	0.07	0.15	0.04
	0.9864	0.2640	0.7048	0.8982	0.6947	0.2836	0.7335	0.3794	0.6333	0.2882	0.7692
Percent intolerant Taxa (0–2)	0.22	0.39*	0.06	0.24	0.18	0.32*	0.18	0.21	0.03	0.14	0.30*
	0.1316	0.0048	0.6903	0.0873	0.2036	0.0246	0.2091	0.1351	0.8302	0.3367	0.0326
Percent predators	−0.02	0.02	0.18	0.01	0.11	0.06	0.17	−0.07	0.10	0.15	0.11
	0.8650	0.9134	0.2147	0.9343	0.4440	0.6577	0.2344	0.6245	0.4812	0.2849	0.4524
Precent scrapers	0.09	−0.07	−0.37*	−0.10	0.00	−0.15	−0.16	−0.18	−0.13	−0.25	−0.21
	0.5403	0.6149	0.0086	0.5037	0.9737	0.2918	0.2731	0.1989	0.3696	0.0860	0.1474
Percent shredders	−0.11	−0.09	−0.09	−0.05	0.14	−0.08	0.16	−0.14	−0.03	−0.05	−0.05
	0.4265	0.5561	0.5168	0.7526	0.3231	0.5996	0.2564	0.3483	0.8488	0.7552	0.7301
Percent tolerant taxa (8–10)	−0.18	−0.32	−0.29*	−0.24	0.24	−0.46*	−0.18	−0.48*	−0.33	−0.37*	−0.41
	0.2097	0.0241	0.0428	0.0998	0.0971	0.0009	0.2172	0.0004	0.0189	0.0089	0.0035
Sensitive EPT index (%)	0.05	0.50*	−0.14	0.30*	−0.12	0.27	0.13	0.21	−0.02	0.14	0.21
	0.7257	0.0003	0.3349	0.0371	0.4001	0.0625	0.3763	0.1507	0.8910	0.3386	0.1374
Shannon diversity	0.10	0.20	0.07	0.05	0.20	0.04	0.16	0.06	0.13	−0.01	0.15
	0.4761	0.1580	0.6407	0.7477	0.1670	0.8052	0.2799	0.6571	0.3747	0.9445	0.3092
Taxonomic richness	0.17	0.37*	0.18	0.17	0.21	0.30*	0.25	0.27	0.27	0.17	0.36*
	0.2443	0.0078	0.2080	0.2370	0.1461	0.0340	0.0816	0.0605	0.0593	0.2508	0.0108
Tolerance value	0.08	0.10	−0.35*	0.07	−0.13	−0.46*	0.07	−0.46*	−0.42*	−0.47*	−0.30
	0.5661	0.4881	0.0133	0.6227	0.3696	0.0007	0.6507	0.0007	0.0024	0.006	0.0323

* *P* value <0.05.
In each cell, the upper number is the correlation and the lower number the *P*-value for the null hypothesis that the correlation is equal to zero.

Table 13: Correlations of benthic metrics with stream metrics for 2001–2005 for Del Puerto Creek and Salt Slough.

Benthic metric	Stream width	Stream depth	Velocity	Percent canopy
Abundance	−0.35*	−0.11	−0.13	−0.02
	0.0131	0.4337	0.3705	0.8983
EPT index	0.10	−0.13	−0.01	−0.20
	0.5020	0.3850	0.9513	0.1675
EPT taxa	−0.04	−0.14	−0.06	−0.21
	0.9368	0.3223	0.6884	0.1461
Number ephemeroptera taxa	−0.43*	−0.18	−0.05	−0.04
	0.0018	0.2228	07515	0.8080
Number trichoptera taxa	0.56*	−0.03	−0.05	−0.34*
	0.0000	0.8373	0.7490	0.0156
Percent collectors filterers	0.69*	0.24	0.29*	−0.12
	0.0000	0.0920	0.0376	0.4047
Percent collectors gatherers	−0.39*	−0.17	−0.13	0.26
	0.00560	0.2459	0.3649	0.0636
Percent dominant taxon	0.24	0.15	0.07	−0.14
	0.0999	0.2951	0.6252	0.3398
Percent intolerant taxa (0–2)	−0.11	−0.04	−0.05	−0.15
	0.4615	0.7708	0.7355	0.2995
Percent predators	−0.02	−0.07	0.11	0.07
	0.8971	0.6171	0.4272	0.6302
Percent scrapers	−0.18	0.32*	−0.44*	−0.21
	0.2145	0.0249	0.0012	0.1503
Precent shredders	−0.06	−0.29*	0.03	0.03
	0.6789	0.0391	0.8213	0.8277
Percent tolerant taxa (8–10)	−0.11	0.19	−0.20	−0.02
	0.4639	0.1828	0.1559	0.8672
Sensitive EPT index (%)	−0.19	−0.16	−0.13	−0.11
	0.1866	0.2824	0.3725	0.4342
Shannon diversity	−0.14	−0.10	0.01	0.18
	0.3182	0.4800	0.9365	0.2220
Taxonomic richness	−0.09	−0.08	0.04	0.11
	0.5389	0.5950	0.7847	0.4631
Tolerance value	−0.55*	−0.09	−0.30*	0.11
	0.0000	0.5324	0.0317	0.4519

*P value < 0.05.
In each cell, the upper number is the correlation and the lower number the P-value for the null hypothesis that the correlation is equal to zero.

metric correlated with the various benthic metrics (Table 13). Stream width was positively correlated with number of Trichoptera taxa and % collectors/filterers and negatively correlated with abundance, number of Ephemeroptera taxa, % collectors/gatherers and tolerance value. Velocity was positively correlated with % collectors/filterers and negatively correlated with % scrapers and tolerance value. Stream depth was positively correlated with % scrapers and negatively correlated with % shredders. Percent canopy was negatively correlated with number of Trichoptera taxa.

Relationship of Water Quality and Benthic Communities

Correlations of water quality parameters and benthic community metrics for both water bodies combined showed that turbidity, dissolved oxygen, and conductivity were the most important water quality parameters influencing the different benthic metrics (Table 14). Turbidity was negatively correlated with abundance, EPT Index (%), EPT taxa, number of Ephemeroptera taxa, and sensitive EPT taxa. Turbidity was positively correlated with percent tolerant taxa. Dissolved oxygen was positively correlated with abundance, percent collectors/gatherers, and sensitive EPT index and negatively correlated

Table 14: Correlations of benthic metrics with water quality parameters for 2001–2005 for Del Puerto and Salt Slough.

Benthic Metric	Temperature	Conductivity	pH	Dissolved Oxygen	Salinity	Turbidity
Abundance	−028*	0.15	0.27	0.35*	0.14	−0.35*
	0.0493	0.3121	0.3121	0.0131	.3751	0.0119
EPT index (%)	0.06	0.12	0.09	−0.17	−0.00	−0.34*
	0.6767	0.3987	0.5348	0.2298	0.9850	0.0172
EPT taxa	−0.04	0.28	0.18	0.03	0.13	−0.42*
	0.7645	0.514	0.2124	0.8416	0.4088	0.0022
Number	−0.11	0.14	0.40	0.24	0.06	−0.44*
ephermeroptera taxa	0.4342	0.3219	0.0043*	0.0914	0.6939	0.0015
Number trichoptera	0.07	0.32*	−0.20	−0.27	0.18	−0.20
taxa	0.6232	0.0221	0.1600	0.576	0.2795	0.1637
Percent collectors	0.15	0.39*	−0.27	−0.19	0.25	0.09
filterers	0.3042	0.0052	0.654	0.1762	0.1229	.5196
Percent collectors	−0.02	−0.17	0.22	0.42*	−0.10	−0.05
gatherers	0.8743	0.2360	0.1252	0.0027	0.5524	0.7449
Percent dominant	0.08	0.29*	−0.12	−0.01	0.19	−0.05
taxon	0.5700	0.0432	0.4112	0.9571	0.2505	0.7438
Percent intolerant	−0.16	−0.07	.0.20	0.16	−0.13	−0.24
taxa (0–2)	0.2578	0.6346	0.1686	0.2602	0.4098	0.0894
Percent predators	−0.25	0.12	−0.07	−0.09	0.22	0.09
	0.0819	0.4230	0.6509	0.5161	0.1634	0.5317
Percent scrapers	−0.09	−0.05	−0.04	0.09	−0.01	−0.16
	0.5547	0.7135	0.7986	0.5139	0.9385	0.2542
Percent shredders	0.17	−0.14	−0.02	−0.34*	−0.13	0.03
	0.2273	0.3409	0.8676	0.0162	0.4312	0.8608
Percent tolerant	−0.13	−0.19	−0.17	−0.12	−0.05	0.34*
taxa (8–10)	0.3587	0.1787	0.2527	0.4250	0.7591	0.0167
Sensitive EPT index	−0.03	0.11	0.27	0.29*	0.03	−0.36*
(%)	0.8266	0.4449	0.0623	0.0381	0.8387	0.0104
Shannon diversity	−0.24	−0.23	0.04	−0.00	−0.16	0.16
	0.0913	0.1141	0.7658	0.9735	0.3356	0.2717
Taxonomic richness	−0.35*	−0.07	0.08	0.11	−0.08	0.11
	0.0127	0.6426	0.5675	0.4291	0.6285	0.4482
Tolerance value	−0.13	−0.34*	0.18	0.13	−0.18	0.01
	0.3505	0.0161	0.2086	0.3761	0.2800	0.9321

*$P < 0.05$.
In each cell, the upper number is the correlation and the lower number the P-value for the null hypothesis that the correlation is equal to zero.

with percent shredders. Conductivity was positively correlated with number of Trichoptera taxa, percent collectors/filterers, and percent dominant taxa and negatively correlated with tolerance value.

Comparison of Physical Habitat and Benthic Communites Between Streams

Eight of the 11 physical habitat metrics (including total habitat score) were significantly different between Del Puerto Creek and Salt Slough (Table 15). In general, most of the habitat metrics were higher (more positive) in Del Puerto Creek including the total physical habitat score.

A comparison of benthic metrics over the 5-year period in both streams showed that 6 of the 17 metrics were significantly different between the two streams (Table 16). Generally, the higher benthic scores in Del Puerto Creek (i.e., abundance, # Ephemeroptera taxa) suggest that the communities in this creek are more robust than in Salt Slough.

DISCUSSION

Water Quality

Turbidity and dissolved oxygen were two of the most important water quality parameters affecting the various benthic metrics in both Del Puerto Creek

Table 15: Comparison of mean physical habitat metrics (mean over both stations and years) for Del Puerto (DLP) and Salt Slough (SSL).

Creek	Metric	Mean	*p*-value
DLP	Epi Sub	9.52	
SSL	Epi Sub	4.8	0.000*
DLP	Embedd	8.9	
SSL	Embedd	0.20	0.000*
DLP	Vel/depth	10.4	
SSL	Vel/depth	8.2	0.03*
DLP	Sed dep	11.4	
SSL	Sed dep	2.6	0.00*
DLP	Chann Fl	13.5	
SSL	Chann Fl	16.6	0.0007*
DLP	Chan Alt	12.2	
SSL	Chan Alt	12.6	0.79
DLP	Ben Riff	10.16	
SSL	Ben Riff	4.48	0.000*
DLP	Bank St.	10.9	
SSL	Bank St.	9.6	0.30
DLP	Bank Veg	9.3	
SSL	Bank Veg	9.6	0.77
DLP	Rip Buf	6.7	
SSL	Rip Buf	9.4	0.009*
DLP	T. Score	103	
SSL	T. Score	78	0.009*

* $p < 0.05$.

Table 16: Comparison of mean benthic community metrics (means over both stations and years) for Del Puerto Creek (DLP) and Salt Slough (SSL).

Creek	Metric	Mean	*p*-value
DLP	Abundance	1796	
SSL	Abundance	884	0.009*
DLP	EPT Index	0.03	
SSL	EPT Index	0.03	0.97
DLP	EPT Taxa	1.08	
SSL	EPT Taxa	0.79	0.32
DLP	# EPL T	0.84	
SSL	# EPL T	0.11	0.007*
DLP	# Tri. T	0.24	
SSL	# Tri. T	0.68	0.002*
DLP	% Col-Fil	0.20	
SSL	% Col-Fil	0.39	0.006*
DLP	% Col-Gath	0.47	
SSL	% Col-Gath	0.33	0.02*
DLP	% D. Taxa	0.40	
SSL	% D. Taxa	0.42	0.53
DLP	% Int Taxa	0	
SSL	% Int Taxa	0	0.27
DLP	% Pred	0.09	
SSL	% Pred	0.10	0.66
DLP	% Scra	0.11	
SSL	% Scra	0.14	0.60
DLP	% Shr	0.01	
SSP	% Shr	0.01	0.95
DLP	% Tol T	0.48	
SSP	% Tol T	0.51	0.20
DLP	S. EPT I	0	
SSP	S. EPT I	0	0.07
DLP	S. Div	1.97	
SSP	S. Div	1.94	0.82
DLP	T. Rich	20.15	
SSP	T. Rich	19.36	0.59
DLP	T. Value	7.10	
SSP	T. Value	6.64	0.05*

*$p < 0.05$.

and Salt Slough. Turbidity was reported to be negatively correlated with five benthic metrics. This is not surprising since turbidity is generally considered to be a surrogate for a well-documented stressor in water bodies—sediment loading. The U. S. EPA has listed sediment as the number one source of impairment nationwide on its list of impaired water bodies.[24] Other investigators have also reported that sediment has negative effects on benthic macroinvertebrates.[25] The spatial scale of turbidity was more pronounced in Del Puerto Creek than Salt Slough. Upstream site DLP5 (site above all agricultural activity) had consistently lower turbidity values for all 5-years likely due to reduced sediment coming from eroded soil in irrigated agricultural fields. Seven benthic metrics (i.e., abundance, EPT index) were also reported to increase at the upstream site in Del Puerto Creek in concordance with the lower turbidity values at this site.

Dissolved oxygen was reported to be positively correlated with benthic metrics such as abundance, % collectors/gatherers, and sensitive EPT index. In general, dissolved oxygen values were higher in Del Puerto Creek (mean ~ 8.5 mg/L across all stations and years) than Salt Slough (mean ~5.8 mg/L across all stations and years). Potentially stressful dissolved oxygen values (< 5.0 mg/L) as reported by Lee and Jones-Lee[26] were also more common in Salt Slough than Del Puerto Creek. The increased frequency of reported stressful dissolved oxygen measurements corresponds to the presence of less robust benthic communities in Salt Slough. It should be noted however that dissolved oxygen is only one of many stressors that may impact the status of benthic communities in this water body.

Physical Habitat

Physical habitat in streams is the place where organisms such as benthic macroinvertebrates live. In streams, habitat structure generally means the physical structure of the channel and near channel environments. However, riparian areas along stream banks are also critical for determining the instream habitat structure (i.e., vegatation along stream banks can reduce sediment load). The habitat assessments conducted concurrently with the benthic community assessments during this 5-year study were used to determine the suitability of the physical environment for aquatic biota such as benthic macroinvertebrates.

vegetation

Impaired physical habitat (including sediment loading as previously discussed) has been identified as a major stressor to aquatic life in California streams.[13] Altered physical habitat structure is also considered one of the major stressors of aquatic systems throughout the United States resulting in extinctions, local expirations and population reductions of aquatic fauna.[27,28] Identifying degraded physical habitat in streams is particularly critical for bioassessments as failure to do so can sometimes hinder investigations on the effects of toxic chemicals or other water quality related stressors. Rankin[28] has reported that 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. 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 this area.

A 5-year trend comparison of physical habitat metrics in both streams produced contrasting results with the eleven habitat metrics (including total habitat score) that were evaluated. Habitat metrics in Del Puerto Creek did not show a significant change from 2001 to 2005, thus suggesting a fairly stable habitat over time. In contrast, various habitat metrics in Salt Slough were reported to change over the 5-year period therefore suggesting that some variability in habitat was occurring over time. The stream with the more stable habitat over time, as well as superior habitat scores, (Del Puerto Creek) also had more robust benthic communities. This finding is in agreement with previous studies that have reported the importance of physical habitat for benthic communities.[28–30]

Historical comparisons of our physical habitat data from Del Puerto Creek and Salt Slough with other streams in the San Joaquin River watershed is problematic due to both limited available data and consistent methods of habitat assessments. A comparison of Orestimba Creek (a creek in Stanislaus County near Del Puerto Creek) total physical habitat scores by year from 2001 to 2005 with Del Puerto Creek and Salt Slough showed that Orestimba Creek total physical habitat scores were significantly higher that Salt Slough physical habitat scores in 2001, 2002 and 2003.[9–11] However, there were no significant differences among total physical habitat scores for Orestimba Creek, Del Puerto Creek and Salt Slough in 2004 and 2005.[12,14]

Griffith et al.[29] evaluated physical habitat in 95 wadeable streams in California's Central Valley in 1994 and 1995 using protocols described by Lazorchak et al.[31] Different field methods were used in these studies therefore exact comparisons with our physical habitat data is not possible. Griffith et al.[29] generally concluded that physical habitat in most of these California Central Valley streams is poor due to insufficient substrate heterogeneity and instream habitat. Our physical habitat data from 5-years of sampling both Del Puerto Creek and Salt Slough generally supports the conclusion by Griffith et al.[29]

A comparison of physical habitat in the two water bodies sampled in this study showed that habitat in Del Puerto Creek was generally of higher quality than Salt Slough. These two water bodies also had different flow regimes and instream habitat sediment. The upstream Salt Slough site had no flow and all Salt Slough sites were dominated by % fines in the bottom sediment. In contrast, all sites in Del Puerto Creek had some degree of flow and the substrate in various sites was heterogeneous consisting of a combination % fines, % gravel, and % cobble. In summary, the physical habitat in both of these streams was different although Del Puerto Creek was expected to be more suitable for robust benthic communities.

Benthic Communities

The most dominant taxa found in Del Puerto Creek during this 5-year study were oligochaetes and chironomids. Oligochaetes are generally found in stressful environments while chironomids can be either sensitive or tolerant to environmental stressors depending on the species.[19,30] Benthic communities were reported to change in Del Puerto Creek over the 5-year period as abundance, %

intolerant taxa, % predators, and % shredders showed a significant change. A significant increase in abundance and % shredders suggests that the condition of the benthic communities has improved. A spatial analysis of benthic community data in Del Puerto Creek over 5-years shows that abundance and various metrics associated with EPT taxa were also found to increase from downstream to upstream. This is logical as upstream site DLP5 is located in an area above agricultural activity.

The most dominant taxa in Salt Slough from 2001 to 2005 was the amphipod, *Corophium spinicore*, the chironomid *Chironomus* and the gastropod *Physa sp.* and/or *Physa / Physella*. Amphipods are generally considered sensitive to environmental stressors.[19] However, dominance by one species that comprises 16 to 37% of the total taxa annually during the 5-year period in Salt Slough suggests a stressful environment. As reported above for Del Puerto Creek, dominance by chironomids can be related to either a stressed or unstressed environment. Gastropods are generally a tolerant species that increase in stressful environments.[19]

Benthic communities were reported to be fairly stable over time in Salt Slough as only 2 of the 18 benthic metrics were reported to significantly change during the 5-year period. A decrease in number of Trichoptera taxa (number of caddisfly families) over 5-years suggests some degree of increased impairment in Salt Slough. A spatial evaluation of benthic community data in Salt Slough over the 5-year period shows that % collectors/filterers (a trophic guild that increases in stressed environments) and percent dominant taxa decreased from downstream to upstream while % tolerant taxa and tolerance value (taxa that increase in stressed environments) increased from downstream to upstream. The spatial trends for these benthic metrics that showed a significant change is somewhat conflicting in terms of identifying benthic metrics associated with stressful conditions, particularly when attempting to relate agricultural activities to benthic community impairment. Upstream sites SSL4 and SSL5 are both located in agricultural areas and SSL is basically a lentic environment (no flow) while the three downstream sites in Salt Slough are located in Wildlife Refuge areas.

Q2 Correct spelling for lentic.

Comparisons of benthic community data from Del Puerto Creek and Salt Slough with other benthic data in the San Joaquin River watershed is difficult due to limited published historical data. A previous 3-year study in Orestimba Creek (a creek in close proximity to Del Puerto Creek) reported that both oligochaetes and chironomids were the dominant taxa in this creek.[13] We reported a similar finding in this study for benthic communities collected in Del Puerto Creek over a 5-year period. However, it appears that the benthic community structure we reported in Salt Slough is somewhat different than Orestimba Creek.

A previous study using both community metric and multivariate statistical approaches to determine the relationship between benthic communites and environmental variables was conducted in 95 wadeable streams in California's Central Valley in 1994 and 1995.[29] A summary of these data is in general agreement with our Del Puerto Creek data, and to a lesser extent to our Salt Slough data, as Griffith et al.[29] reported: (1) oligochaetes and chironomids were the dominant taxa; (2) percent tolerant taxa were dominant; and (3) the abundance of EPT taxa was generally low for most sites.

A comparison of benthic communities in the two water bodies evaluated in this study generally showed that benthic communities based on 5-years of data were more robust in Del Puerto Creek when compared with Salt Slough. The higher quality physical habitat in Del Puerto Creek ,as previously discussed, is a likely factor responsible for the the superior status of benthic communities in this creek when compared with Salt Slough.

SUMMARY

Results from this 5-year study suggested that stressful water quality conditions and poor physical habitat can negatively affect benthic communities in agricultural dominated water bodies in the San Joaquin River watershed. Both of the water bodies examined in this study have been listed as impaired (303 d list by the State of California) based on the presence of organophosphate insecticides diazinon and chlorpyrifos. Our results suggest that other stressors such as poor water quality and physical habitat may also be impacting biological assemblages in these water bodies as well. Benthic communities in one waterbody (Del Puerto Creek) were somewhat variable over a 5-year period while benthic communities in the other water body (Salt Slough) were fairly stable over this time period. Benthic communities in both streams were generally dominated by tolerant species which is not surprising given the occasional presence of stressful water quality conditions and poor physical habitat. The question of whether the benthic communities in these two impaired streams have attained their "biological expectations" given the presence of multiple stressors (including pesticides) is appropriate. The 5-year mean number of taxa in Del Puerto Creek (83 taxa) and Salt Slough (73 taxa) implies that these streams have fairly diverse benthic communities, despite dominance by tolerant species. However, it is unclear what other benthic taxa would be expected in these environments even if physical habitat and water quality were optimal and pesticides were completely eliminated.

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