Survey of Zooplankton Community Structure and Abundance in Agriculture-dominated Waterways in the Lower Sacramento River Watershed

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Executive Summary

Water column toxicity in California agriculture-dominated waterways is almost always associated with *Ceriodaphnia dubia* (an indicator zooplankton species) testing. While toxicity test results with *C. dubia* have been effective predictors of impacts on instream, resident biota there is very little information regarding zooplankton community structure and abundance in these low gradient, agriculture-dominated waterways in California or elsewhere. This dearth is unfortunate since zooplankton constitutes a pivotal role in aquatic food webs; zooplankton is significant food for fish and invertebrate predators and they graze heavily on algae, bacteria, protozoa, and other invertebrates. Therefore, the primary objective of this study was to conduct a limited-scope, preliminary survey of zooplankton abundance and diversity in agriculture-dominated waterways in the California Central Valley. Assessment of zooplankton temporal variation over a relatively short time-frame and potential association with environmental variables were also objectives.

Zooplankton were sampled at five sites located on agriculture-dominated waterways in the lower Sacramento River watershed. All sampling occurred toward the end of the irrigation season, beginning on August 20, 2004 and continued for seven weeks. Focus was on this period because previous studies have shown that acute toxicity to aquatic invertebrates is most frequent during this time.

A total of 13 taxa were identified during this study. Considering all sites, the most abundant taxa were, in order, rotifiers, cyclopoid copepods, chydorid cladocerans, *Ceriodaphnia*, and *Bosmina*. A highly variable (temporally) mix of rotifers, copepods, and cladocerans were observed at the five sites. No distinct temporal pattern, common to all sites, was noted. Considerable temporal and spatial (site-to-site) variability in abundance and taxa composition was observed in this study. It is important to carefully define spatial and temporal variation before attempting to assess the effects of anthropogenic stressors. Without such data the ability to distinguish impacts of anthropogenic activities is severely hampered.

Some correlations between zooplankton community composition metrics and environmental variables were statistically significant with both raw metrics and metrics normalized to site. Data indicated that low oxygen concentrations and high nutrient concentrations were associated with zooplankton biodiversity. The temporal and spatial scope of this project limited identification of more environmental variables potentially deterministic of zooplankton abundance and community structure.

Principle limitations of this study were limited taxonomic resolution, the paucity of reference conditions, and other zooplankton studies on low gradient waterways in the Central Valley for comparison.

The prominent characteristics of the zooplankton communities in agriculture-dominated waterways in the lower Sacramento River watershed were (1) small-bodied taxa dominated, (2) taxa richness was low, and (3) total zooplankton abundance was low. The scientific literature is replete with data documenting that insecticides and other stressors result in zooplankton communities with low taxa richness and consisting of small-bodied species. Prior to concluding that these characteristics are persistent, these waterways must be sampled in spring and early summer. In part, the above listed characteristics relate to the agriculture-dominated waterways being small (with exception of Sacramento Slough) with little upstream input. Nonetheless, taken together the characteristics manifested provide a persuasive signal that the communities in the agriculture-dominated waterways are stressed. While it appears clear that these zooplankton communities are stressed, our study was too limited spatially and temporally to effectively identify potential deterministic natural and anthropogenic factors.

Investigations of freshwater zooplankton community structure have significant potential for assessing aquatic ecosystem condition/health. Stressed communities are rather easily identified. Sampling is not labor intensive or costly. Taxonomic resolution to genus or species level is probably the most difficult component of such investigations.

Budget permitting, we recommend that the Central Valley Regional Water Quality Control Board continue zooplankton investigations in agriculture-dominated and other low gradient waterways of the Central Valley. Specifically, we suggest that there be follow-up on the five sites sampled in this study. Seasonal and year-to-year sampling is advised. We further recommend that a wider range of sites be sampled, ideally with a range of potential anthropogenic influences. While locating undisturbed sites is likely to be difficult, inclusion of less impacted/best attainable sites can assist in data interpretation. We advise temporal and spatial expansion of sampling so that natural variations in zooplankton can be defined. Without such knowledge discovery of anthropogenic influences is more difficult. Taxa resolution to genus, and preferably species, level will be more costly, but will significantly enhance data interpretation and comparability.

Introduction

The central message in Karr and Chu's (1999) book titled 'Restoring Life in Running Waters' is the accelerated and pervasive loss of aquatic biota in the United States. A combination of stressors contributes to these declines including habitat loss and degradation, dams and water diversions, sediment and chemical contaminants, introduced non-native species, overexploitation, secondary extinctions (loss of one species has cascading effects throughout the species assemblage), and climate change. Precipitous losses of biodiversity and population declines in aquatic ecosystems are well documented. Chemical pollution is a contributor to these phenomena (e.g., Christian, 1995). Ricciardi and Rasmussen (1999) presented evidence that (1) freshwater biota in the U.S. are disappearing five times faster than terrestrial species and three times faster than coastal marine mammals, (2) extinction rates of freshwater animals are accelerating, and (3) North American freshwater biodiversity is being depleted at the same rate as that of tropical rain forests. Master et al. (2000) also contend that freshwater species are the most vulnerable for extinction. Richter et al. (1997) concluded that the three leading threats to aquatic species are, in order, (1) agricultural non-point pollution, (2) alien species, and (3) altered hydrologic regimes. Wilcove et al. (2000) proposed that the three leading causes of the decline of aquatic biota are, in order (1) pollution, especially from agricultural origin (2) habitat degradation/loss, and (3) alien species. Wilcove and colleagues, as well as Allan and Flecker (1993), further concluded that 'the most overt and widespread forms' of aquatic ecosystem habitat alteration are by agriculture. Overall, habitat loss and destruction and exotic species invasions, are the most serious causes of biodiversity and abundance declines in aquatic ecosystems, but multiple stressors are almost certainly at work in most of these phenomena.

The greatest losses of biodiversity in the U.S. have occurred in Hawaii, Alabama, and California (Master et al., 2000). These authors also conclude that Hawaii and California are the states with the greatest percentage of species at risk of extinction. Many California aquatic species are listed as endangered or threatened under the federal Endangered Species Act (e.g., coho salmon, chinook salmon, steelhead trout, Delta smelt, Sacramento splittail, red-legged frog, yellow-legged frog, California freshwater shrimp—e.g., Brown and Moyle, 1993, 2004; Moyle, 1995, 2002; Moyle et al., 1995, 1996; Bennett and Moyle, 1996; Yoshiyama et al., 1998). Zooplankton populations in the Sacramento-San Joaquin estuary also are in decline (e.g.; Obrebski et al., 1992; Kimmerer and Orsi, 1996; Orsi and Ohtsuka, 1999; Kimmerer, 2002). Baxter et al. (2005) argue that many, but not all, estuary zooplankton species are in decline. While there are likely to be multiple factors involved in this zooplankton decline, Kimmerer has postulated that proliferation of introduced benthic clams that feed on phytoplankton and nauplii of some native zooplankton species is a contributing cause. Phytoplankton production is low in the Sacramento-San Joaquin estuary compared to most other estuaries (e.g., Cloern, 1996; Jassby et al., 2003). Kimmerer (personal communication) has hypothesized that the zooplankton decline is a contributing factor in the waning of estuary fish populations. Allan and Flecker (1993) pointed out that listings of threatened, endangered, and extinct species are very strongly biased towards vertebrates.

The State Water Resources Control Board (SWRCB) and Regional Water Quality Control Boards (RWQCB) have funded many projects that focused on water or sediment quality as well as on biological surveys of various environmental 'compartments' of agriculture-dominated and –influenced waterways in California. Data collected in these projects document insecticide-caused degradation (toxicity) of water column (de Vlaming et al., 2000, 2004a) and sediment (Weston et al., 2004) quality in several agriculture-dominated waterways. References in the cited publications support this contention. SWRCB and RWQCB supported studies (de Vlaming et al., 2004b, c; Markiewicz et al., 2005) also revealed that benthic macroinvertebrate (BMI) communities are most severely impacted in waterways where there is extensive agricultural land use. The BMI investigations provided evidence that multiple stressors associated with agricultural land use contributed to biological impacts.

Water column toxicity in California agriculture-dominated waterways is almost always associated with *Ceriodaphnia dubia* (an indicator zooplankton species) testing. While toxicity test results with *C. dubia* have been effective predictors of impacts on instream, resident biota (Waller et al., 1996; de Vlaming and Norberg-King, 1999; de Vlaming et al., 2000, 2001), there is very little information regarding zooplankton community structure and abundance in these low gradient, agriculture-dominated waterways in California or elsewhere. This dearth is unfortunate since zooplankton constitutes a pivotal role in aquatic food webs; zooplankton is significant food for fish and invertebrate predators and they graze heavily on algae, bacteria, protozoa, and other invertebrates. Therefore, the primary objective of this study was to conduct a limited-scope, preliminary survey of zooplankton abundance and diversity in agriculture-dominated waterways in the California Central Valley. Assessment of zooplankton temporal variation over a relatively short time-frame and potential association with environmental variables were also objectives.

Materials and Methods

Sampling sites

Sites were selected to represent a subset of natural and constructed agriculture-dominated waterways in the lower Sacramento River watershed associated with a portion of the irrigation season. Site locations are summarized in Table 1. Zooplankton samples were collected weekly at five primary sampling sites and, on one occasion, at four secondary sites. All sampling at the primary sites occurred toward the end of the irrigation season, beginning on August 20, 2004 and continuing for seven weeks. The irrigation season in this area of the Central Valley is approximately May through the end of September. The most intense irrigation is during the months of July, August, and September. It is during these months that the highest frequency of acute toxicity to aquatic invertebrates has been noted (e.g., de Vlaming et al. 2005). Sampling dates are summarized in Table 2.

Sampling methods

Zooplankton samples were collected using a 147µm mesh plankton net with attached dolphin bucket (also 147µm screen). A General Oceanics flow meter was mounted at the mouth of the net to gather flow data for calculating the volume of water strained for each sample. Sampling time varied, but generally was set at five minutes. If water velocity was sufficient to properly operate the flow meter, the net was held stationary in the water column. If water velocity was insufficient to operate the flow meter, the sample was collected by pulling the net through the water column. Attempts were made to sample each site at approximately the same time on each collection date. Three separate net drags (replicates) were taken at each site. The range of mean (of the three replicates) volume sampled at all sites on all sampling dates was 400 to 4350 liters. The mean volume of all 108 replicates collected in this study was 2368 liters. Once sampling was complete, the net was rinsed to wash any zooplankton clinging to the mesh into the dolphin bucket. The dolphin bucket was removed and the contents rinsed into a sample container. Five to ten milliliters of Lugol's solution was added to preserve the samples along with a label containing the site location, site code, date, time, sampler's initials, and replicate number. Internal labels were written in pencil as Lugol's stains paper black, yet the graphite remains visible. The same information was written on the sample jar lid in pencil. For most sites, on one occasion, a duplicate set of samples was taken for QA/QC purposes.

Water quality parameters were measured using a YSI 6600 multiprobe, and consisted of DO, pH, temperature, turbidity, chlorophyll, and specific conductance. A Hach DR-890 meter was used to measure total reactive phosphorous and nitrogen (nitrate). Depth was measured at the thalweg when possible. Velocity was measured with a Global Flow Probe FP101 or calculated using the General Oceanics meter readings. For hardness, alkalinity, and ammonia analyses a one-liter grab sample was collected in a plastic bottle and placed on ice for transport to the laboratory. Standardized EPA aquatic physical habitat forms were completed on the initial site visit (Barbour et al., 1999).

Sample processing

The first phase of sample processing consisted of removing 300 specimen from each sample to quantify zooplankton density and taxonomic composition. Each sample was first homogenized, then using a Hensen Stempel pipette, 1 mL aliquots were removed and placed onto a Ward counting wheel. Using a dissecting scope, zooplankton were counted and placed into a vial containing Lugol's solution. One-milliliter aliquots were repeatedly removed and processed until the target number of organisms was achieved, with the last aliquot being fully processed and any additional organisms placed into an "extra" vial. For each sample the number of aliquots removed was recorded to determine sample abundance, which was then used to determine zooplankton density per cubic meter of water at each site based on the flow meter data.

The second phase of sample processing was taxonomic identification. Each sample vial was emptied onto the Ward counting wheel, with each taxon being enumerated and recorded on a data sheet. Rotifers were identified to phylum, copepods to family, and cladocerans to genus. To identify specimen to genus, individuals were removed and slide mounted for observation under a phase contrast compound scope. Samples for QA/QC taxonomic verification were examined by Ecoanalysts (Moscow, Idaho). All taxa identifications were in 100% agreement between ATL and Ecoanalysts for the 12 QA samples.

Statistical analyses

Nonparametric one-way ANOVAs (Kruskal-Wallis tests) were applied to compare zooplankton community composition among sites. Where between-site differences were detected, pairwise Wilcoxon rank sum tests were used to determine which sites were significantly different from one another. Normalized values for taxa metrics and proportional abundances were calculated so that the strength of associations between variables could be evaluated after removing 'noise' caused by differences among sites. Normalization was performed by subtracting the metric site median value from the value measured during each sampling event.

Spearman rank correlation was used to examine relationships between environmental parameters and individual metrics of zooplankton community composition or the proportional abundance of individual taxa. These analyses were performed using both non-normalized metrics and proportional abundance (some metrics were log transformed and all proportional abundances were arcsine square-root transformed) as well as using metrics and proportional abundance normalized to site median values.

Results

Zooplankton community composition

A total of 13 taxa were identified (Table 3) during this study. Rotifers and copepods were identified only to phylum and order, respectively, limiting taxonomic resolution. Considering all sites, the most abundant taxa were, in order, rotifiers, cyclopoid copepods, chydorid cladocerans, *Ceriodaphnia*, and *Bosmina*. Appendix A contains all the raw data.

Temporal abundance trends

Temporal variation of zooplankton abundance is summarized in Figure 1. No distinct temporal pattern, common to all sites, was noted. The high abundance in Sacramento Slough in Weeks 2, 6 and 7 was primarily due to cyclopoid copepods and rotifiers, respectively. High abundance in the Drain @ Browning Rd. in Weeks 2, 3, 6, and 7 was primarily related to rotifers, *Ceriodaphnia*, rotifers, and *Bosmina*, respectively. The high abundance in the Drain @ Hawkins Rd. in week five was associated mainly with the chydorid cladoceran *Alona*. Relative to the other sites, abundance at the two Willow Slough sites was low throughout the seven weeks of sampling. Temporal variation in community composition of copepods and cladocerans is depicted in Figures 2 and 3, respectively. Temporal variation was considerable and there was no consistent pattern among the sites.

A highly variable (temporally) mix of rotifers, copepods, and cladocerans were observed at the five primary sites (Tables 4 and 5). Proportional abundance of seven cladoceran taxa differed significantly among the sites (Table 6). Total zooplankton abundance was significantly lower, while taxa richness was higher, at the upstream Willow Slough site compared to all other sites, including the downstream Willow Slough site. The upstream site was characterized by a large population of mosquitofish (*Gambusia affinis*). That mosquitofish can have profound effects on zooplankton abundance, especially cladocerans and copepods, has been known for some time (e.g., Hurlbert et al., 1972a; Hurlbert and Mulla, 1981). Even at two sites in the same waterway (Willow Slough) proportional abundance of three cladoceran taxa differed significantly (Table 6). Differences of taxa proportional abundance between pairs of sites indicated that the zooplankton communities were most similar at the Sacramento Slough and Drain @ Browning Rd. sites (Table 7). Further investigation would be required to assess potential determinants of community structure similarities at these two sites. Sites ranked in order of taxa richness were Sacramento Slough, Drain @ Browning Rd., Drain @ Hawkins Rd., Willow Slough @ Rd. 24, and Willow Slough @ Rd. 98. That the Sacramento Slough site manifested the highest taxa richness is not surprising given that it is the most stable in terms of habitat, environmental variables, and hydrologic regime.

Two sites on the Winter's Canal (irrigation delivery waterway) were sampled once. Only rotifiers were found in these samples from the high flow waterway. Flow/velocity undoubtedly influences zooplankton community structure. For example, the density of cladocerans and copepods in the Sacramento River and Yolo Bypass was inversely correlated with flow (Sommer et al., 2004). To the contrary, flow at the five primary sites was very low such that it precluded analysis of this variable. Colusa Basin Drain and Wadsworth Canal, both of which deliver irrigation water and receive return flow, were also sampled on only one occasion. Zooplankton community structure in these two samples was most similar to that seen at the Drain @ Hawkins Rd. site. Similarities among these three sites are not immediately apparent.

Zooplankton community associations with environmental variables

Physical and chemical parameters measured at the sites are summarized in Table 8. Sacramento Slough was the deepest and widest waterway sampled. The mean depth of Sacramento Slough appearing in Table 8 is not indicative of depth at the thalwag, but rather at the point of sampling near the southern bank. Average conductivity was highest (and most variable) in the Drain @ Browning Rd. and Willow Slough @ Rd. 24; average conductivity was lowest at the Sacramento Slough sites. Turbidity was highest in the Drain @ Browning Rd. and Willow Slough @ Rd. 98; turbidity was consistently low in the Drain @ Hawkins Rd. The highest chlorophyll A measurements were seen in the

Drain @ Browning Rd., probably related to low flow and relatively high phosphorus concentrations.

Some correlations between zooplankton community composition metrics and environmental variables were statistically significant with both raw metrics and metrics normalized to site medians (Table 9; Figures 4 to 7). No statistically significant correlations between environmental variables and taxa abundance estimates were observed with either raw or site-normalized data. Dissolved oxygen concentration was positively correlated with zooplankton diversity as indicated by the Shannon diversity index (Table 9; Fig. 4) and negatively correlated with percent dominant taxon (Table 9; Fig. 5). These relationships suggest that low oxygen decreases zooplankton taxa richness and increases the taxon or taxa tolerant to low DO. Reactive phosphorus concentration was negatively correlated with cladoceran proportional abundance (Fig. 6). Temperature was positively correlated with copepod proportional abundance (Fig. 7). These correlations are strong patterns in the dataset, and are temporally consistent within sites as well as among sites.

Several other correlations between environmental parameters and zooplankton community metrics or between environmental parameters and the proportional abundances of various taxa were statistically significant when raw data or when site-normalized data were examined, but not both (Table 10). These patterns should be interpreted with caution, but may be worthy of further investigation. Correlations significant using raw data, but not significant using site-normalized data, may be an artifact of the low number of sites examined ($n = 5$), or alternatively may be patterns that only appear when among-sites differences in environmental and community parameters are considered. Correlations significant using site-normalized data, but not raw data, may be suspected as not holding true as generalized patterns, or alternatively may be patterns that appear only when between-site noise is reduced through normalization.

Replicate variability

Table 11 summarizes replicate variability for taxa metrics and percent abundance. Mininum significant difference (MSD) represents the minimum difference between two three-replicate samples necessary to have a 90% probability difference. MSDs were calculated using the three-replicate standard deviation of each taxon averaged over all samples in which the taxon was present. Abundance and metric mean values are presented for all taxa to place the MSDs and Coefficients of Variation (CV) in perspective. While some of the CVs are high, the high values are generally for percent proportional abundance of 'rare' taxa. CVs for percent proportional abundance of the more dominant taxa and for community metrics are in line with those reported in the published literature for zooplankton and benthic macroinvertebrate sampling.

Discussion

Community composition and abundance

Zooplankton taxonomic groups (rotifers, copepods, and cladocerans) identified in the low gradient, agriculture-dominated waterways in the lower Sacramento River watershed are consistent with those in freshwater rivers, streams, and lakes. Total abundance, taxa richness, and community structure in these agriculture-dominated waterways; however, was not consistent with data from other freshwater waterways. Zooplankton total abundance (density) in agriculture-dominated waterways was considerably less than in the Sacramento River and Yolo Bypass (Sommer et al., 2004) and the Sacramento-San Joaquin Delta (Orsi and Mecum, 1986). The most abundant taxa in the current study were rotifers, cyclopoid copepods, and chydorid cladocerans. This is rather typical for freshwater systems, even in constructed ponds in Switzerland (Knauer et al., 2005). However, in our study chydorids constituted approximately 48% of the cladocerans while about 10% of the cladocerans were *Bosmina*. Almost 100% of the copepods in this study were cyclopoids. Contrariwise, *Daphnia* and *Bosmina* are the dominant cladocerans in the Sacramento River and Yolo Bypass (Sommer et al., 2004). In the Sacramento-San Joaquin Delta *Bosmina* and *Daphnia* constitute approximately 61 to 82% and 25%, respectively, of cladocerans. Particularly notable characteristics of the zooplankton collected in the agriculture-dominated waterways are that they are small-bodied and taxa richness is low.

Grosholz and Gallo (2006) conducted a three year study on the Cosumnes River and its floodplain that included a zooplankton analysis. While the Cosumnes floodplain and river sites cannot be deemed true ‘references’, zooplankton communities in this waterway may be the best surrogate for comparisons to data collected in our study given the paucity of studies on low gradient waterways in the California Central Valley. Zooplankton abundance was considerably higher in the Cosumnes floodplain samples compared to the agriculture-dominated waterways in our study. Furthermore, cladocerans and calanoid copepods were more diverse and much more abundant in the Cosumnes floodplain samples. For example, 5 families and at least 13 genera of cladocerans were identified in the Cosumnes floodplain samples. Moreover, zooplankton community structures in the Cosumnes floodplain was definitely divergent compared to those in agriculture-dominated waterways.

Nutrients and zooplankton communities

Phosphorus concentration in many streams, rivers, and lakes ranges between 5 to 100 µg/L. Total abundance of small-bodied (microzooplankters) zooplankton (r^2=0.72) and large-bodied (macrozooplankters) species (r^2=0.86) were significantly correlated with phosphorus in the range of 1 to 50 µg/L (Pace, 1986). There is a positive relationship between abundance of zooplankton in this phosphorus concentration range. Phosphorus concentration in samples collected during this study ranged from 300 to 3000 µg/L. Our data reveal a negative correlation between cladoceran proportional abundance and phosphorus concentrations in this range. In the extensive investigation of Stemberger and Lazorchak (1994) nutrients (as indicated by total phosphorus) and chlorophyll A were found to be significant predictors of zooplankton assemblages. Specifically, high nutrient and chlorophyll A levels were indicative of zooplankton communities dominated by small-bodied species. Results in this study are consistent with those of Stemberger and Lazorchak.

Insecticides and other zooplankton community stressors

Hanazato (1998, 2001) reviewed the extensive literature related to adverse impacts of insecticides on zooplankton communities. He concluded that the following are recognized as effects of insecticides at the community and ecosystem levels: (1) induction of dominance by small-bodied species and (2) significant reduction of energy transfer efficiency from primary producers (algae and bacteria) to top predators. The shift from dominance by large-bodied species to small-bodied species induced by insecticides (most commonly studied: organophosphorus and carbamate insecticides) has been observed in multiple pond and mesocosm studies (Hurlbert et al., 1972b; Pabst and Boyer, 1980; Gliwicz and Sieniawska, 1986; Kaushik al., 1985; Day et al., 1987; Yasuno et al., 1988; Hanazato and Yasuno, 1990a; Hanazato, 1991a, 1998; Hanazato and Dodson, 1992, 1993; Havens and Hanazato, 1993; Havens, 1994a, b; Hanazato and Kasai, 1995). The insecticide-caused shift in zooplankton community structure typically is from large-bodied cladocerans to dominance by small-bodied rotifiers, and to a lesser extent, small-bodied copepods and cladocerans (Hurlbert et al., 1972b; Pabst and Boyer, 1980; Kaushik et al., 1985; Day et al., 1987; Hanazato and Yasuno, 1987, 1990a, b; Helgen et al., 1988; Yasuno et al., 1988; Hanazato, 1991a; Heimbach et al., 1992; Lozano et al., 1992; Havens and Hanazato, 1993; Havens, 1994a; Dodson and Hanazato, 1995; Hanazato and Kasai, 1995).

Cladocerans tend to be more sensitive to insecticides than rotifers and copepods (e.g., Havens, 1994a). Invertebrate predators such as cyclopoid copepods are generally more tolerant to insectidices than cladocerans (e.g., Hanazato and Yasano, 1990c; Havens, 1994b). In addition to causing a shift to smaller-bodied species, insecticides have also been shown to affect zooplankton reproduction, delay maturation time, reduce size at maturity, and decrease cladoceran population growth rate (Hanazato, 1998, 1999, 2001). Insecticides affect chemical communications among zooplankters and induce morphological changes among cladocerans; both, in turn, alter community predator-prey interactions (Hanazato, 1991a, 1992, 1995, 1999; Hanazato and Dodson, 1992, 1993; Barry, 1998). For example, Hanazato (1991b) demonstrated that three organophosphorus insecticides (diazinon, fenitrothion, and temephos) and two carbamate insecticides (carbaryl and BPMC) induced morphological changes (‘helmet’ formation) in *Daphnia ambigua*. Two herbicides (thiobencarb and oxadiazon) and the fungicide IBP did not have the same effect. Zooplankton swimming behavior is frequently affected by insectidices which, in turn, alters predator-prey relationships (e.g., Farr, 1997; Dodson et al., 1995). The insecticide-caused affects on predator-prey relationships alters aquatic ecosystem dynamics and energy flow.

The significant reduction in effectiveness of food-web energy transfer from algae and bacteria relates, in part, to the fact that large cladocerans are highly effective algal grazers (e.g., Gliwicz, 1990). Furthermore, large cladocerans are the preferred food of planktivorous fish (e.g., Gliwicz, 1986). In this regard, insecticide alteration of zooplankton community structure has been shown to significantly reduce growth rates of juvenile planktivorous fish (Brazner and Kline, 1990).

Another point stated in the Hanazato (2001) review was that responses of zooplankton to toxicity tests are considered to be informative of relative impacts on the ecosystem as a whole, a position taken by de Vlaming et al. (1999, 2000, 2001). In another independent literature review Moore and Folt (1993) concluded that there is convincing evidence that insecticides (and other contaminants) and heat waves result in alterations in zooplankton community structure that favor small-bodied over large-bodied species. According to these authors, these shifts in zooplankton community structure have been shown to significantly alter aquatic communities affecting water clarity, rates of nutrient regeneration, and fish abundances. After investigation of a large number of zooplankton communities over a large geographical area Stemberger and Lazorchak (1994) reported that, “Small-bodied zooplankton assemblages represented by small cladocerans, rotifiers, ostracods, and cyclopoid copepods were associated with the most disturbed aquatic systems.”

Insecticides also synergize with other stressors to affect zooplankton communities. For example, carbaryl synergized with low oxygen concentrations to reduce juvenile growth rate, size at maturity, clutch size, and neonate size (Hanazato and Dodson, 1995). The effects of the two stressors were greater than either stressor independently. Experimental pond experiments have demonstrated that herbicide exposure indirectly affects zooplankton community structure and abundance (DeNoyelles et al., 1982).

Multiple studies have documented the occurrence of chlorpyrifos in California agriculture-dominated waterways at concentrations acutely lethal to cladocerans (de Vlaming et al., 2000, 2004a, 2005; Anderson et al., 2002; 2003a, b, 2006; Hunt et al., 2003; Phillips et al., 2004). The extensively used chlorpyrifos has been shown to be particularly harmful to cladoceran populations (for summary see Van der Hoeven et al., 1997). Many pond, mesocosm, and enclosure studies have confirmed that this organophosphorus insecticide greatly reduces zooplankters (e.g., Hurlbert et al., 1972b; Kersting and van Wijngaarden, 1982; Eaton et al., 1985; Siefert et al., 1989; Brock et al., 1992a, b; Leeuwangh, 1994; Lucassen and Leeuwangh, 1994; Van den Brink et al., 1995, 1996; van Wijngaarden et al., 1996; Van der Hoeven and Gerritsen, 1997; Sibley et al., 2000). In many of these studies phytoplankton blooms were associated with the loss of crustacean zooplankters. For example, Van den Brink et al. (2002) investigated the effects of chlorpyrifos and lindane mixtures on zooplankton communities in mesocosms. Zooplankton community structure was significantly altered at concentrations of 5% of the 48-hour LC_{50} (for both insecticides). Cladocerans were the most susceptible followed by copepods. Rotifer and phytoplankton density increased as cladoceran populations declined. In an earlier microcosm study, Van den Brink et al. (1995) reported that cyclopoid copepods and large daphnids were the most sensitive to sublethal concentrations of chlorpyrifos. Benthic macroinvertebrates also are considerably impacted by chlorpyrifos (e.g. Brock et al., 1992a, b, 1995; Pusey et al., 1994; Ward et al., 1995; Cuppen et al., 2002; Anderson et al., 2003a, b, 2006; Hunt et al., 2003; de Vlaming et al., 2005).

Temporal, spatial, and replicate variability

Considerable temporal and spatial (site-to-site) variability in abundance and taxa composition was observed in this study. In prior studies of low-gradient waterways in the Central Valley we emphasized the vital nature of understanding natural (i.e., independent of anthropogenic activities) temporal and spatial variation of aquatic species communities (de Vlaming et al., 2004b, c; Markiewicz et al., 2005). Zooplankton populations exhibit substantial spatial (e.g., Pinel-Alloul and Pont, 1991) and temporal heterogeneity (Sommer et al., 1986). Estimated species richness increases with the number of individuals and samples collected. Therefore, it is important to determine the sampling effort and temporal and spatial scale at which biodiversity should be assessed. Arnott et al. (1998) assessed crustacean zooplankton species richness at different temporal and spatial scales. Species detected increased with the number of spatial, intra-annual, and inter-annual samples collected. Single samples detected 50% of the annual species pool and 33% of the total estimated species pool. Single-year species richness estimates provided poor predictions of multiple-year richness. Large seasonal and year-to-year variations of zooplankton abundance in the Sacramento River and Yolo Bypass were reported by Sommer et al. (2004). Grosholz and Gallo (2006) also reported large intra-annual temporal variation of zooplankton community composition in the Cosumnes River floodplain. However, most investigations of aquatic invertebrate communities have been limited in scope, both spatially and temporally. We (de Vlaming et al., 2004b, c) advised that it is important to carefully define spatial and temporal variation before attempting to assess the effects of anthropogenic stressors. Without such data the ability to distinguish impacts of anthropogenic activities is severely limited.

Temporal and spatial variability have been perceived as an impediment to investigation and understanding zooplankton communities (e.g., Kratz et al., 1987). The impediment likely relates to the fact that understanding temporal and spatial variations in aquatic invertebrate communities requires consistent studies at many sites over seasons, multiple years, with sufficient replicate sampling. Given the differences in life histories of rotifers, cladocerans, and copepods it is probable that these groups will respond differently to environmental variables. For example, in a Wisconsin study all copepod and cladoceran taxa except *Bosmina* manifested greater spatial (among sites) than temporal (year-to-year) variation in abundance (Kratz et al., 1987). In contrast, rotifer populations were more temporally than spatially variable. Cladocera taxa were more temporally variable than were copepod taxa.

In a pond mesocosm zooplankton investigation Knauer et al. (2005) discovered that approximately 29% of the total variance in community structure was accounted for by year-to-year differences, whereas 11% was attributable to seasonal variation. Seasonal and year-to-year variability were much more significant than dominant species inter-replicate variability (coefficient of variability: 35 to 75%).

Similarity of environmental variables at sites does not necessarily equate to similarities in zooplankton communities (Jenkins and Buikema, 1998). These investigators gathered data to answer the question, do similar zooplankton communities develop in similar aquatic environments. They compared zooplankton community structure and function in 12 experimental ponds during one year of natural colonization and analyzed a suite of physical-chemical variables to evaluate the assumption of environmental similarity among ponds. Ponds were similar for the measured environmental variables. However, zooplankton communities were structurally different, as indicated by analyses of species presence/absence, colonization and species accrual curves, and taxa density and biomass. Dispersal (as evidenced by colonization history) was a determinant of new zooplankton communities because it did not occur rapidly or uniformly among similar ponds.

While there is consensus that neither plants nor animals are uniformly distributed (i.e., spatial heterogeneity is the norm) in nature there is no agreement regarding the explanation for this heterogeneity (e.g., Downing, 1986). Spatial heterogeneity is related to average population density and small-bodied zooplankton species, as seen in the current study, which show greater spatial heterogeneity than large-bodied species (e.g., Pinel-Alloul (1988). One line of thought is that spatial heterogeneity is a species specific characteristic reflecting the balance between the opposing behavioral tendencies to aggregate within, and migrate from, centers of population density (e.g., Taylor et al., 1978; Taylor, 1981a, b). This concept has stressed that migration between patches is rarely a random process. Another concept of spatial heterogeneity holds that it arises from the stochastic interplay of population demographic characteristics and environmental heterogeneity (e.g., Anderson et al., 1982). Downing (1986), however, concludes that environmental differences, demographic factors, evolved behavior, and statistical aritifact all play a role in spatial heterogeneity of species populations. This author argues that spatial heterogeneity estimates are biased and cannot be used to support or criticize models of species spatial distribution. Somewhat divergent from Downing's concept, Pinel-Alloul et al. (1988) contended that the deterministic factors that give rise to zooplankton heterogeneous spatial distributions have received little investigative attention. We would add to this suggestion that the determinants of natural- and anthropogenic-caused temporal variations also have been incompletely investigated. Hanazato and Yasuno (1990b) remind us that intrinsic factors are also involved in natural temporal variations of species abundance.

Sampling variation

There is general recognition that zooplankton sampling variability is large (e.g., Downing et al., 1987). A large body of data was analyzed by Downing et al. (1987) to appraise variance of replicate freshwater and marine zooplankton samples. They reported that variance is related to mean population density and volume of sample. Fewer replicate samples are required with increasing population density and sample volume. With the exception of three samples from two sites (two from Sacramento Slough and one from the drain @ Browning Road), site sample total zooplankton density in this study was less than 8 organisms/L. According to Downing et al., (1987), achieving a precision of p=0.2 (SE divided by mean population density) with a density of one to ten organisms/L and a sampling volume of 100 L, three to two replicates per sample are needed. The mean volume of all replicate samples in this study was 2368 L. Therefore, the three replicate samples per site taken in this study should accurately represent zooplankton density at the selected sites.

Central observations, conclusions, and recommendations

The prominent characteristics of the zooplankton communities in agriculture-dominated waterways in the lower Sacramento River watershed were (1) small-bodied taxa dominated, (2) taxa richness was low, and (3) total zooplankton abundance was low.

Prior to concluding that these characteristics are temporally persistent these waterways must be sampled in spring and early summer. In part the above listed characteristics relate to the agriculture-dominated waterways being small (with exception of Sacramento Slough) with little upstream input. Unfortunately, the Cosumnes River zooplankton data (Grosholz and Gallo, 2006) are not the ideal reference for agriculture-dominated waterways and equivalent undisturbed reference waterways are not that available. Nonetheless, taken together the characteristics manifested provide a persuasive signal that the communities in the agriculture-dominated waterways are stressed. While it appears clear that these zooplankton communities are stressed, our study was too limited spatially and temporally to effectively identify potential deterministic natural and anthropogenic factors. Activities (e.g., use of insecticides and other pesticides, nutrients, instream habitat and riparian vegetation alterations, sediment, and hydrologic variability) associated with agricultural land use almost certainly contribute stresses to these zooplankton communities. As indicated in our investigations on benthic macroinvertebrates in Central Valley agriculture-dominated waterways multiple stressors related to agricultural land use interact to impact communities (de Vlaming et al., 2004b, c; Markiewicz et al., 2005).

Investigations of freshwater zooplankton community structure have significant potential for assessing aquatic ecosystem condition/health. Stressed communities are rather easily identified. Sampling is not labor intensive or costly. Taxonomic resolution to genus or species level is probably the most difficult component of such investigations.

Budget permitting, we recommend that the Central Valley Regional Water Quality Control Board continue zooplankton investigations in agriculture-dominated and other low gradient waterways of the Central Valley. Specifically, we suggest that there be follow-up on the five sites sampled in this study. Seasonal and year-to-year sampling is advised. We further recommend that a wider range of sites be sampled, ideally with a range of potential anthropogenic influences. While locating undisturbed sites is likely to be difficult, inclusion of less impacted/best attainable sites can assist in data interpretation. We advise temporal and spatial expansion of sampling so that natural variations in zooplankton can be defined. Without such knowledge discovery of anthropogenic influences is more difficult. Taxa resolution to genus, and preferably species, level will be more costly, but will significantly enhance data interpretation and comparability.

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Tables 1-11

Table 1: Sampling sites in the zooplankton survey of agriculture-dominated Central Valley waterways.

Site Description	Lat North	Long West	County
Willow Slough @ Rd. 24	38.6636	121.9059	Yolo
Willow Slough @ Rd. 98	38.6106	121.8027	Yolo
Drain @ Hawkins Rd. and Hwy. 113	38.3586	121.8233	Solano
Sacramento Slough @ Hwy. 113	38.9648	121.6713	Sutter
Drain @ Browning Rd. and Hwy 45	38.9685	121.8668	Colusa
Sites Sampled One Time			
Colusa Basin Drain @ Hwy 45	38.8809	121.8437	Colusa
Wadsworth Canal @ Franklin Rd.	39.1276	121.7555	Sutter
Winters Canal @ Rd. 27	38.6206	121.9974	Yolo
Winters Canal @ Capay & Hwy. 16	38.7074	122.0565	Yolo

Table 2: Sampling dates for each week of sampling.

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
Site Description:	8/20/04	8/23/04	8/26/04	8/27/04	9/2/04	9/3/04	9/9/04	9/10/07	9/16/04	9/17/04	9/23/04	9/24/04	9/30/04	10/1/04
Willow Slough @ Rd. 24			x		x		x		x		x		x	
Willow Slough @ Rd. 98	x		x		x		x		x		x		x	
Drain @ Hawkins Rd.& Hwy. 113		x	x		x		x		x		x		x	
Sacramento Slough @ Hwy. 113				x		x		x		x		x		x
Drain @ Browning Rd. & Hwy. 45				x		x		x		x		x		x

Table 3. Taxa collected during this study.

Cladocera		
	Bosminidae	
		Bosmina
	Chydoridae	
		Unidentified genera*
		Chydorus
	Daphnidae	
		Simocephalus
		Ceriodaphnia
		Unidentified genus
	Macrothricidae	
		Ilyocryptus
		Macrothrix
	Sididae	
		Diaphanosoma
Copepoda		
	Calanoida	
	Cyclopoida	
	Harpacticoida	
Rotifera		

* Individuals in this group were predominately of the genus *Alona*, but the remainder were not identified to genus.

Table 4. Range of zooplankton taxa percentage abundance in samples collected from agriculture-dominated waterway sites in the lower Sacramento River watershed.

Taxon	Category	Minimum %	Median %	Maximum %
Rotifera	Rotifer	0.0	30.7	100
Cyclopoida	Copepod	0.0	27.6	75.5
Calanoida	Copepod	0.0	0.2	10.9
Harpacticoida	Copepod	0.0	0.0	1.6
Bosmina	Cladocera	0.0	0.3	62.4
Chydoridae (other)	Cladocera	0.0	4.0	62.3
Ceriodaphnia	Cladocera	0.0	2.4	61.6
Macrothrix	Cladocera	0.0	0.0	42.2
Chydorus	Cladocera	0.0	0.4	13.4
Diaphanosoma	Cladocera	0.0	0.2	13.2
Ilyocryptus	Cladocera	0.0	0.0	9.6
Simocephalus	Cladocera	0.0	0.0	3.7
Cladocera sp.	Cladocera	0.0	0.0	0.6

Table 5. Range of zooplankton community metrics in samples collected from agriculture-dominated waterway sites in the lower Sacramento River watershed.

Metric	Min	Median	Max
Abundance (individuals/m^3)	126	1167	135111
Taxa Richness	1	7	12
Shannon Diversity	0.00	0.50	0.81
% Dominant Taxon	31	54	100
% Copepods	0	30	77
% Cladocera	0	9	75

Table 6. Zooplankton taxa and metrics with statistically significant differences among sites (Kruskal-Wallis test followed by pairwise Wilcoxon rank sum tests, $P < 0.05$). Sites marked by different letters were significantly different, sites marked by same letter not significantly different.

Taxon/Metric	Site	Min	Median	Max	
Bosmina	Sacramento Slough @ Hwy. 113	0	4	10.6	A
Bosmina	Drain @ Browning Rd. & Hwy 45	0	0.7	62.4	A B
Bosmina	Willow Slough @ Rd. 24	0	2.2	7.8	A B
Bosmina	Drain @ Hawkins Rd. & Hwy. 113	0	0.4	1.5	B
Bosmina	Willow Slough @ Rd. 98	0	0	0	C
Chydoridae (other)	Drain @ Hawkins Rd. & Hwy. 113	8.3	37.8	62.3	A
Chydoridae (other)	Willow Slough @ Rd. 98	3.7	11.9	49.8	A
Chydoridae (other)	Willow Slough @ Rd. 24	2.3	3.9	6.2	B
Chydoridae (other)	Drain @ Browning Rd. & Hwy 45	0	1	6.6	B
Chydoridae (other)	Sacramento Slough @ Hwy. 113	0	1.2	5.1	B
Diaphanosoma	Willow Slough @ Rd. 98	0	2.8	13.2	A
Diaphanosoma	Drain @ Browning Rd. & Hwy 45	0	1	12.3	A
Diaphanosoma	Sacramento Slough @ Hwy. 113	0	0.6	3.4	A
Diaphanosoma	Drain @ Hawkins Rd. & Hwy. 113	0	0	1.8	B
Diaphanosoma	Willow Slough @ Rd. 24	0	0	0.6	B
Simocephalus	Drain @ Hawkins Rd. & Hwy. 113	0	1.9	3.7	A
Simocephalus	Sacramento Slough @ Hwy. 113	0	0	0.7	B
Simocephalus	Drain @ Browning Rd. & Hwy 45	0	0	0	B
Simocephalus	Willow Slough @ Rd. 98	0	0	0	B
Simocephalus	Willow Slough @ Rd. 24	0	0	0	B
Abundance	Sacramento Slough @ Hwy. 113	1803	4782	135111	A
Abundance	Drain @ Browning Rd. & Hwy 45	599	5353	15505	A B
Abundance	Drain @ Hawkins Rd. & Hwy. 113	569	1002	4467	A B
Abundance	Willow Slough @ Rd. 98	464	903	2802	B
Abundance	Willow Slough @ Rd. 24	126	352	726	C
Ilyocryptus	Sacramento Slough @ Hwy. 113	0	0.6	9.6	A
Ilyocryptus	Willow Slough @ Rd. 24	0	0.7	4.2	A
Ilyocryptus	Willow Slough @ Rd. 98	0	0.3	7.9	A
Ilyocryptus	Drain @ Hawkins Rd. & Hwy. 113	0	0	0.2	B
Ilyocryptus	Drain @ Browning Rd. & Hwy 45	0	0	0.2	B
Chydorus	Sacramento Slough @ Hwy. 113	0	2.4	11.7	A
Chydorus	Drain @ Browning Rd. & Hwy 45	0	0.7	13.4	A B
Chydorus	Drain @ Hawkins Rd. & Hwy. 113	0	0.6	12.2	A B C
Chydorus	Willow Slough @ Rd. 24	0	0	2.8	B C
Chydorus	Willow Slough @ Rd. 98	0	0	0.3	C
Macrothrix	Willow Slough @ Rd. 24	0.3	1.2	42.2	A
Macrothrix	Drain @ Browning Rd. & Hwy 45	0	0.3	2.6	A B
Macrothrix	Willow Slough @ Rd. 98	0	0	0.3	B C
Macrothrix	Sacramento Slough @ Hwy. 113	0	0	0.5	C
Macrothrix	Drain @ Hawkins Rd. & Hwy. 113	0	0	0.3	C

Table 7. Summary of the number of statistically significant differences in taxa and metrics between pairs of sites. Higher numbers of significant differences indicate less similar zooplankton communities.

	Drain @ Harding	Willow Sl. @ 98	Willow Sl. @ 24	Drain @ 45
Sac. Slough	5	4	4	2
Drain @ 45	4	4	3	
Willow Sl. @ 24	5	5		
Willow Sl. @ 98	4			

Table 8. Mean physical and chemical parameters measured (± 95% confidence interval) over all sampling events.

Site	Depth (m) Mean ± 95% CI	Width (m) Mean ± 95% CI	pH Mean ± 95% CI	SC (uS/cm) Mean ± 95% CI	DO (mg/L) Mean ± 95% CI
Sacramento Slough @ Hwy. 113	1.55 ± 0.18	53 ± 7	7.26 ± 0.21	270 ± 13	7.0 ± 0.6
Drain @ Hawkins Rd. & Hwy. 113	0.93 +/- 0.06	7 +/- 1	7.60 +/- 0.16	401 +/- 19	8.0 +/- 0.7
Drain @ Browning Rd. & Hwy 45	1.31 +/- 0.74	10 +/- 3	7.49 +/- 0.25	673 +/- 225	6.0 +/- 1.6
Willow Slough @ Rd. 98	1.47 +/- 0.39	11 +/- 2	7.68 +/- 0.18	550 +/- 42	8.1 +/- 0.6
Willow Slough @ Rd. 24	1.60 +/- 0.60	8 +/- 1	7.45 +/- 0.31	691 +/- 126	7.0 +/- 1.9

Site	Temp (^{o}C) Mean ± 95% CI	Chlorophyll Mean ± 95% CI	Turbidity (NTU) Mean ± 95% CI	React. P (mg/L) Mean ± 95% CI	Nitrate N (mg/L) Mean ± 95% CI
Sacramento Slough @ Hwy. 113	21.9 ± 1.2	3.6 ± 2.0	13.2 ± 4.7	0.88 ± 0.27	1.43 ± 0.57
Drain @ Hawkins Rd. & Hwy. 113	19.5 +/- 1.4	3.8 +/- 2.2	1.0 +/- 1.1	0.81 +/- 0.21	1.99 +/- 0.77
Drain @ Browning Rd. & Hwy 45	19.8 +/- 2.8	7.4 +/- 2.4	50.1 +/- 24.3	1.53 +/- 0.67	1.27 +/- 0.57
Willow Slough @ Rd. 98	22.1 +/- 2.2	2.9 +/- 3.2	48.9 +/- 7.3	0.98 +/- 0.40	2.68 +/- 0.71
Willow Slough @ Rd. 24	21.4 +/- 2.6	2.8 +/- 1.3	23.4 +/- 8.8	1.02 +/- 0.45	3.47 +/- 1.52

Table 9. Nonparametric correlations between environmental parameters and zooplankton community metrics that were significant using both raw measurements and with metrics normalized to site medians.

		Non-normalized Correlation		Site-Normalized Correlation	
Environmental Parameter	Metric	Spearman Rho	*P*	Spearman Rho	*P*
DO (mg/L)	% Dominant Taxon	-0.4811	0.0030	-0.3859	0.0201
DO (mg/L)	Shannon Diversity	0.4670	0.0041	0.4079	0.0135
Reactive Phosphorus (mg/L)	% Cladocera	-0.4918	0.0023	-0.4173	0.0113
Temperature (^oC)	% Copepod	0.3473	0.0380	0.3381	0.0437

Table 10. Nonparametric correlations between environmental parameters, zooplankton proportional abundance, and community composition metrics that were statistically significant either using raw measurements or after normalizing metrics and abundance to site medians (Spearman's nonparametric correlation, P < 0.05). Significant results appear in bold, suggestive results are italicized (P < 0.1).

		Non-normalized Correlation		Site-Normalized Correlation	
Environmental Parameter	Taxon/Metric	Spearman Rho	*P*	Spearman Rho	*P*
Depth	Chydoridae (other)	**-0.3729**	**0.0194**	-0.0062	0.9712
Depth	Simocephalus	**-0.4435**	**0.0047**	0.1079	0.5312
Width	Diaphanosoma	**0.4547**	**0.0036**	0.0324	0.8514
Width	Abundance	**0.4448**	**0.0045**	0.0768	0.6562
Width	Rotifera	**0.3879**	**0.0194**	0.1617	0.3462
Width	Harpacticoida	**0.3189**	**0.0479**	*0.2919*	*0.0841*
Width	Simocephalus	**-0.3508**	**0.0286**	0.0794	0.6454
Width	Chydoridae (other)	**-0.3915**	**0.0137**	-0.0666	0.6997
Temperature	**Total Copepods**	**0.3473**	**0.0380**	**0.3381**	**0.0437**
Temperature	Cyclopoida	0.2075	0.2049	**0.3731**	**0.0250**
Temperature	Macrothrix	0.1258	0.4453	**0.3603**	**0.0309**
Temperature	Abundance	-0.2557	0.1161	**-0.4555**	**0.0052**
Temperature	Simocephalus	**-0.3162**	**0.0499**	-0.0234	0.8924
DO	Chydoridae (other)	**0.4902**	**0.0015**	0.1266	0.4619
DO	**Shannon Diversity**	**0.4670**	**0.0041**	**0.4079**	**0.0135**
DO	Chydorus	0.1300	0.4303	**0.3891**	**0.0190**
DO	Macrothrix	-0.0975	0.5547	**0.3976**	**0.0163**
DO	**% Dom Taxon**	**-0.4811**	**0.0030**	**-0.3859**	**0.0201**
pH	Cladocera sp.	**-0.3814**	**0.0166**	*-0.3196*	*0.0574*
pH	Ceriodaphnia	**-0.3944**	**0.0130**	-0.2518	0.1384
EC	Macrothrix	**0.6420**	**<.0001**	0.1768	0.3024
EC	Total Copepods	**0.4059**	**0.0140**	*0.2925*	*0.0834*
EC	Cyclopoid	**0.3784**	**0.0175**	*0.3247*	*0.0534*
EC	Chydorus	**-0.3585**	**0.0250**	0.0495	0.7745
EC	Abundance	**-0.5590**	**0.0002**	*-0.2922*	*0.0837*
Turbidity	Diaphanosoma	**0.4700**	**0.0025**	0.0538	0.7554
Turbidity	Simocephalus	**-0.5555**	**0.0002**	0.0260	0.8804
Chlorophyll	Chydoridae (other)	**-0.3555**	**0.0263**	0.0126	0.9421
Chlorophyll	Ilyocryptus	**-0.5317**	**0.0005**	-0.2333	0.1709
Nitrate Nitrogen	Rotifera	0.1691	0.3035	**0.3457**	**0.0389**
Nitrate Nitrogen	Cladocera sp.	-0.2467	0.1299	**-0.3740**	**0.0246**
Nitrate Nitrogen	Diaphanosoma	**-0.3302**	**0.0401**	-0.2289	0.1794
Nitrate Nitrogen	Abundance	**-0.3919**	**0.0136**	0.0710	0.6809
Reactive Phosphorus	Ceriodaphnia	*-0.2885*	*0.0749*	**-0.3781**	**0.0230**
Reactive Phosphorus	Shannon Diversity	**-0.3646**	**0.0288**	-0.2782	0.1003
Reactive Phosphorus	**Total Cladocera**	**-0.4918**	**0.0023**	**-0.4173**	**0.0113**

Table 11. Replicate level variability in zooplankton samples collected at all sites and sampling events.

Taxon/Metric	Grand Mean[1]	Range of Means	MSD[2]	Average CV (%)	Range of CVs
Rotifers	35	0 - 100	29	34	0 - 173
Cyclopoid	31	0 - 76	26	34	4 - 122
Calanoid	1	0 - 11	13	123	31 - 173
Herparcticoid	0	0 - 1	7	164	111 - 173
Chydoridae	13	0 - 62	16	50	2 - 173
Bosmina	3	0 - 62	13	98	20 - 245
Ilyocryptus	1	0 - 11	14	145	31 - 173
Ceriodaphnia	9	0 - 80	20	89	5 - 245
Diaphanosoma	2	0 - 13	11	105	21 - 245
Macrothrix	2	0 - 43	11	137	10 - 245
Chydorus (Chydoridae)	2	0 - 13	13	99	16 - 181
Unidentified Daphnid genus	0	0 - 1	3	139	70 - 173
Simocephalus	0	0 - 4	8	130	52 - 245
%Copepod	32	0 - 77	37	35	2 - 122
%Cladocera	33	0 - 84	25	29	4 - 126
%DomTaxon	59	34 - 100	33	13	0 - 42
Taxonomic Richness	5.5	1.0 - 8.8	3.8	17	0 - 61
Shannon Diversity	0.46	0.00 - 0.75	0.27	18	4 - 117

1) Means were calculated based on the 3 replicate samples collected during each sampling event at each site, and the grand average of these means was calculated.

2) MSD is the difference in means needed for a 90% probability of detecting a significant difference between zooplankton samples (90% statistical power) based on 3 replicate samples taken at each sampling event. The variance used in this calculation was the average variance of the replicate samples of all sampling events at all sites.

Figures 1-7

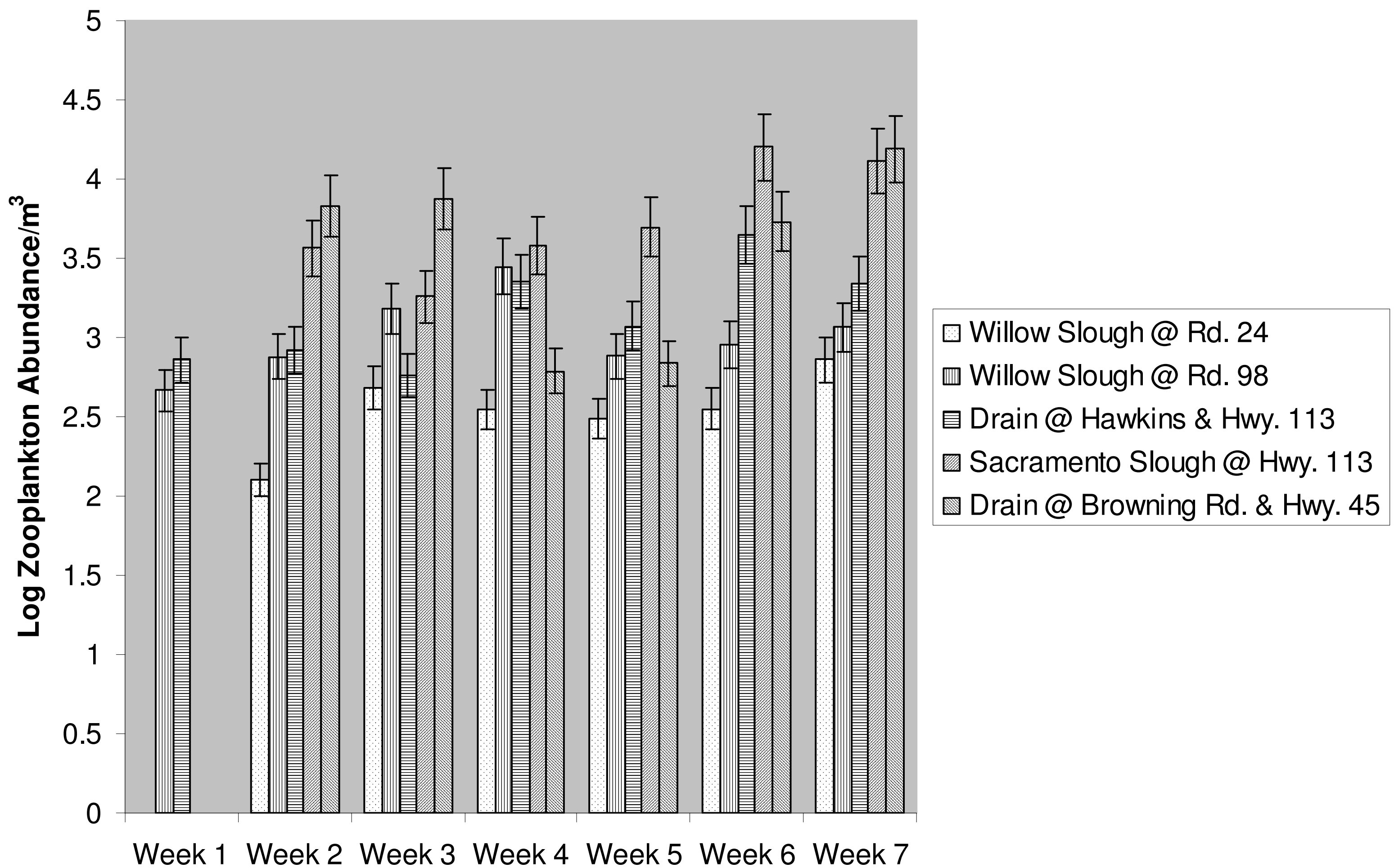

Figure 1. Temporal variation of zooplankton abundance in agricultural-dominated waterways of the lower Sacramento River watershed. Bars represent mean of three replicates, bracketed by 95% confidence intervals.

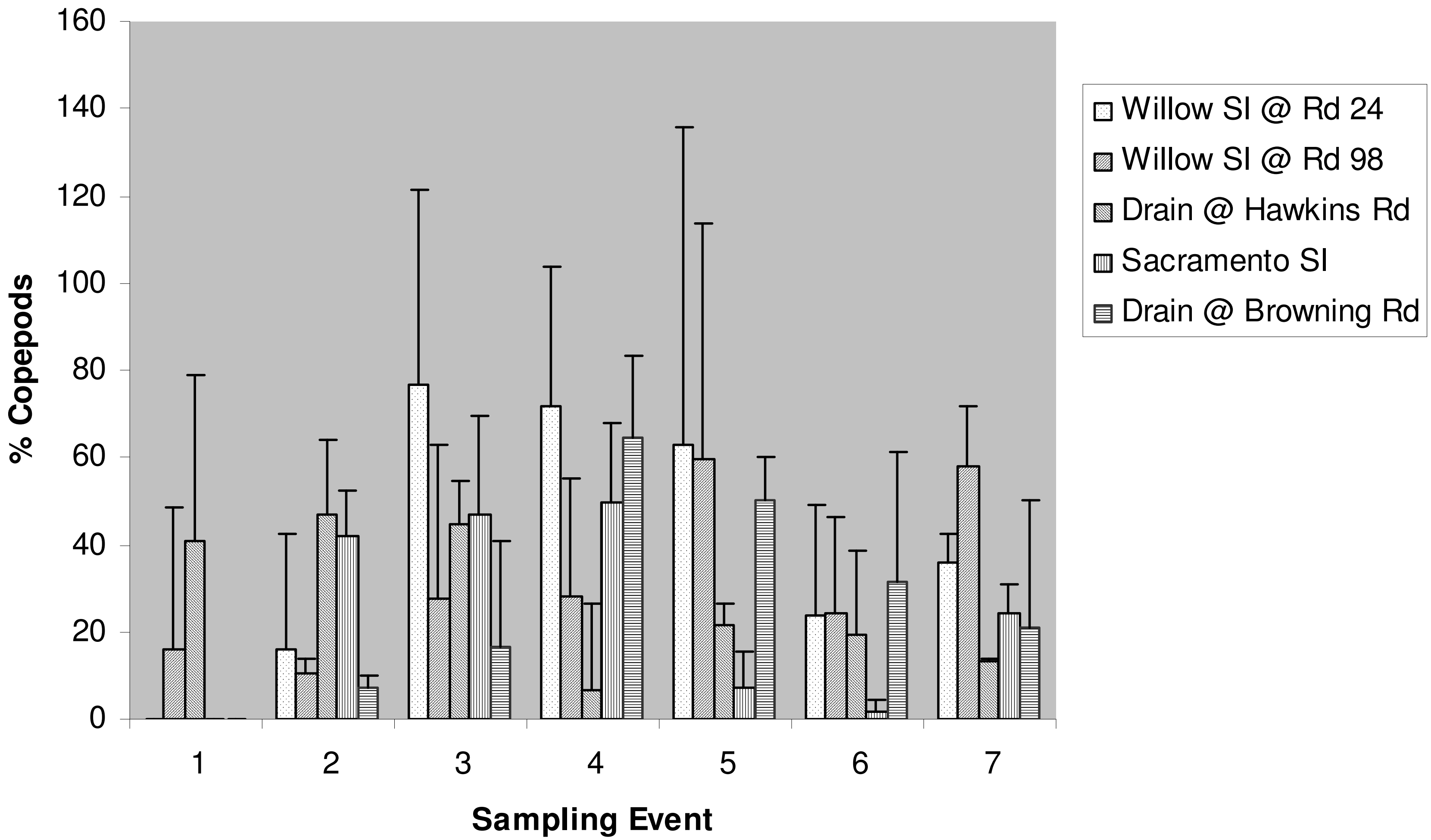

Figure 2. Proportional abundance of copepods during weekly sampling events (Mean ± 95% confidence intervals).

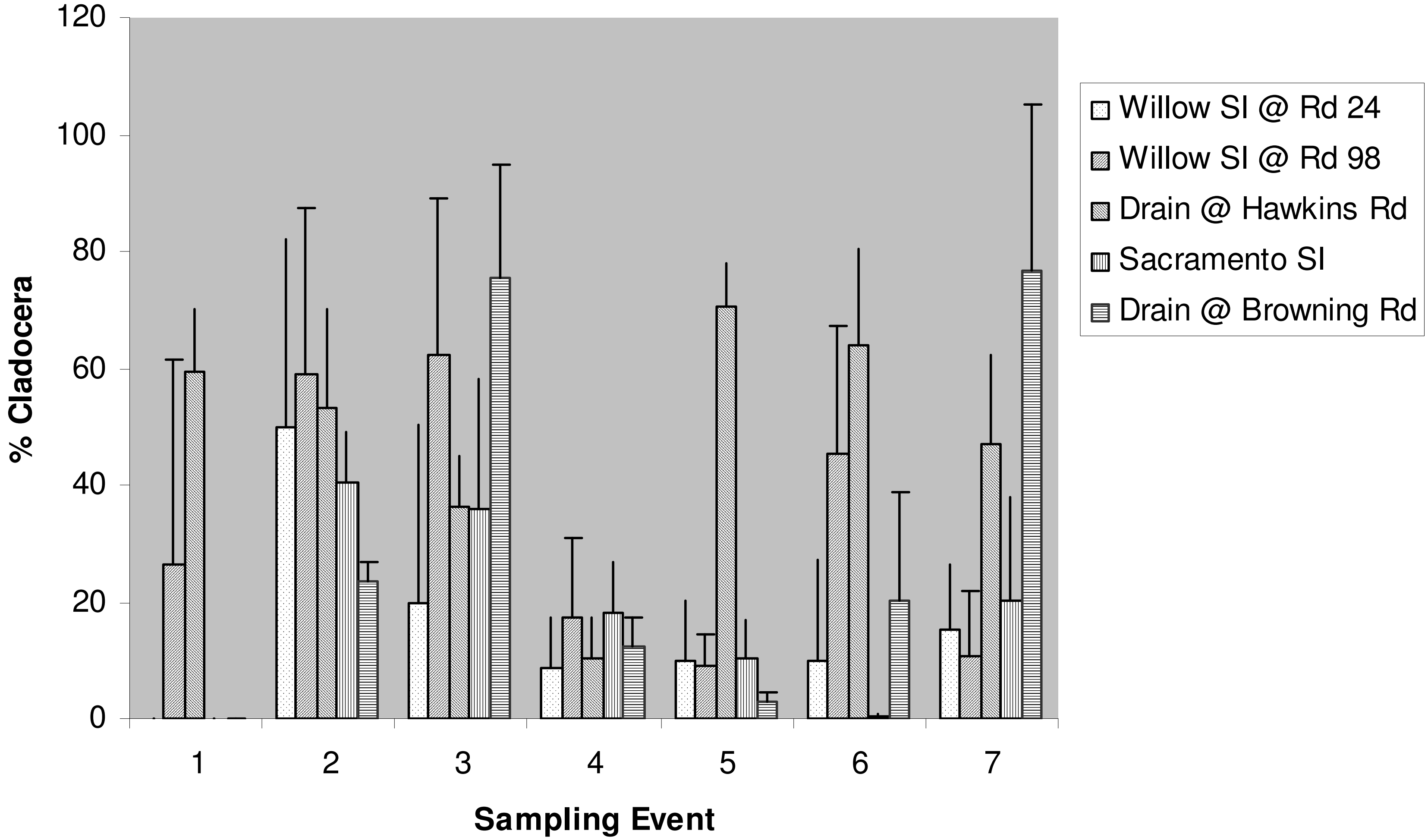

Figure 3. Proportional abundance of Cladocera during weekly sampling events (Mean ± 95% confidence intervals).

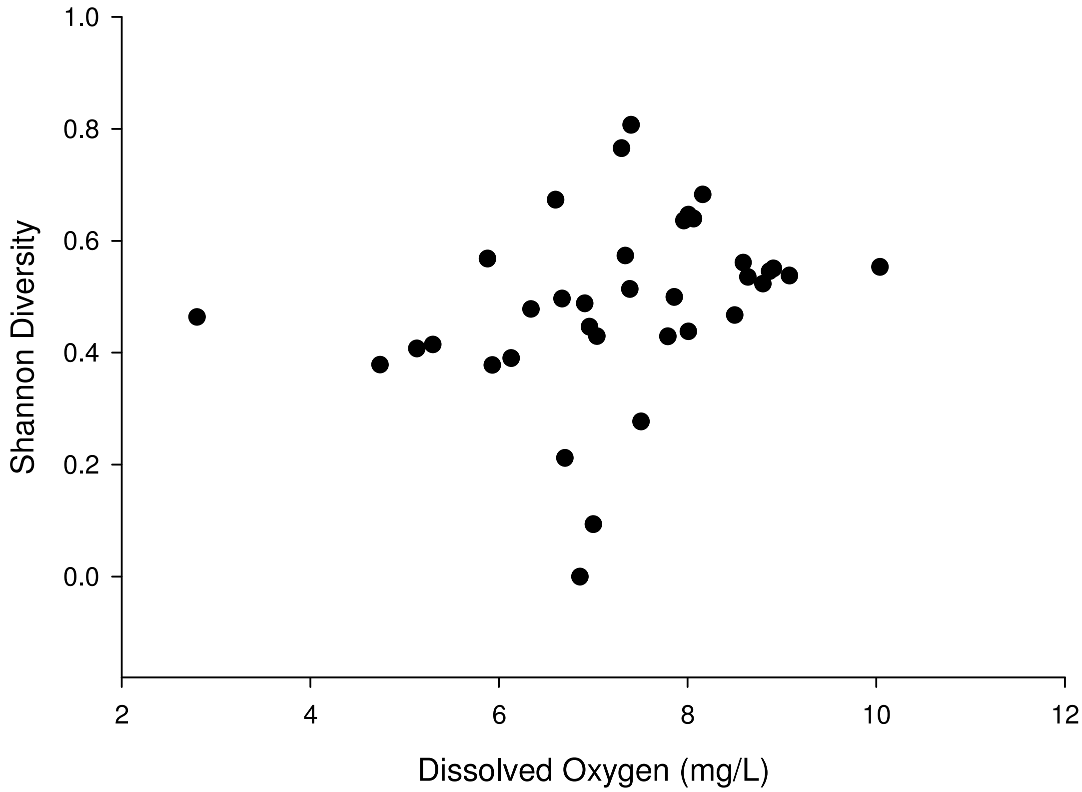

Figure 4. Relationship between Shannon Diversity index and dissolved oxygen (Spearman's nonparametric correlation, rho = 0.4670, *P* = 0.0041).

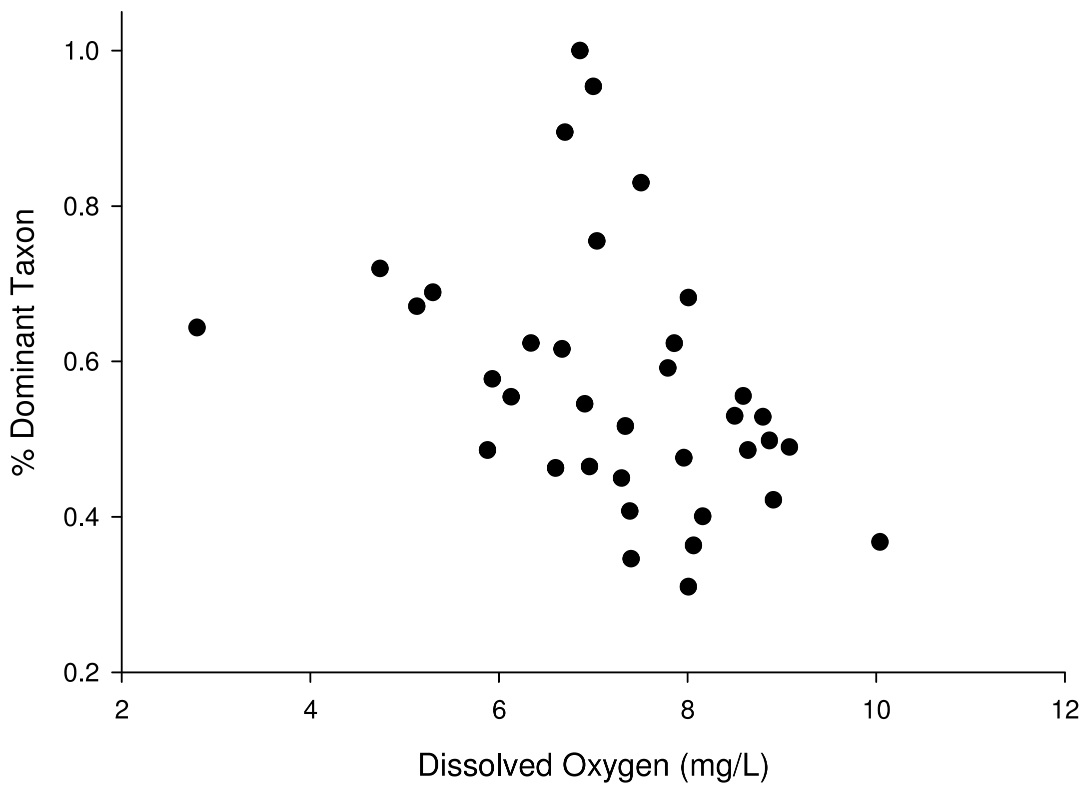

Figure 5. Relationship between most common taxon proportional abundance and dissolved oxygen (Spearman's nonparametric correlation, rho = -0.4811, P = 0.0030).

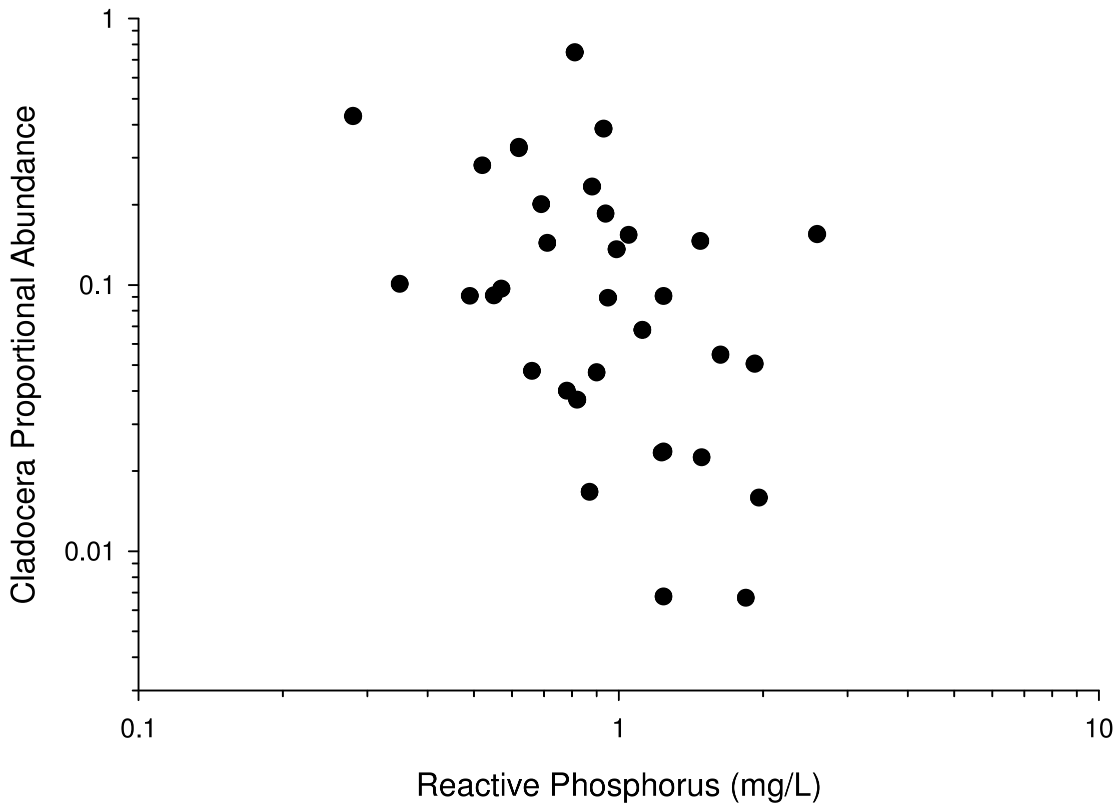

Figure 6. Relationship between cladoceran proportional abundance and reactive phosphorus concentration (Spearman's nonparametric correlation, rho = -0.4918, P = 0.0023).

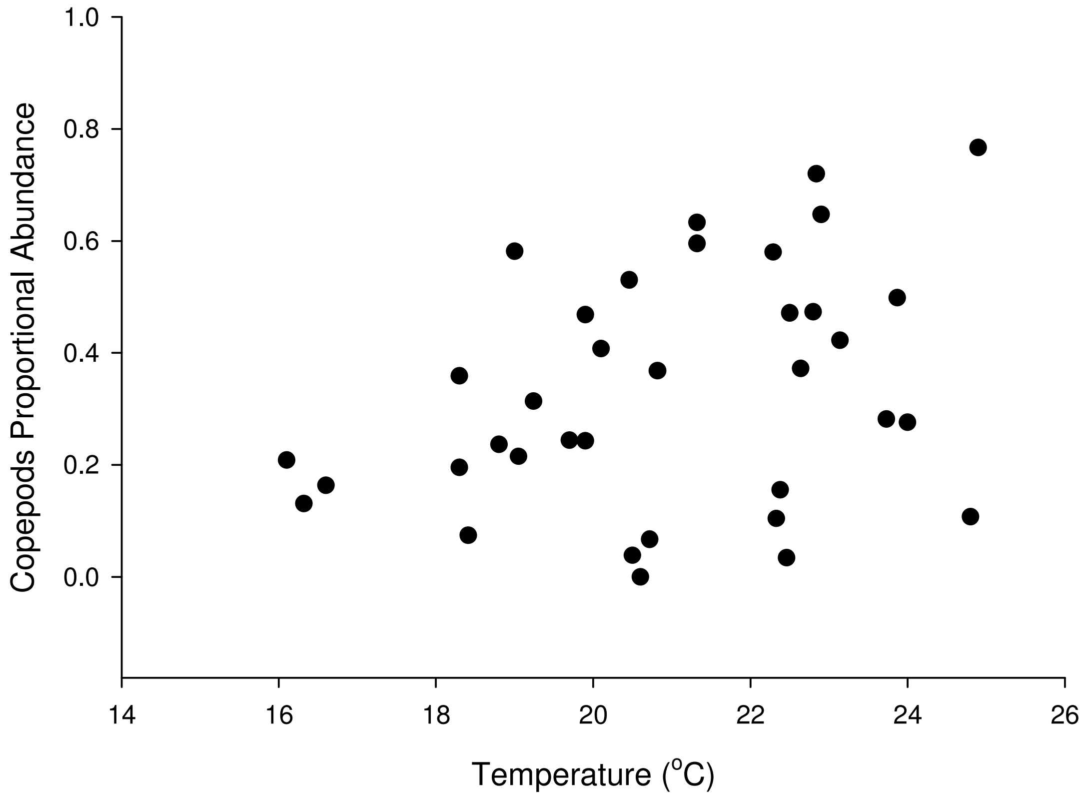

Figure 7. Relationship between copepod proportional abundance and temperature (Spearman's nonparametric correlation, rho = 0.3473, P = 0.0380).

Appendix A

Willow Slough @ 24

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/26/2004																		
0746	60	19			21	13				107							220	220
0747	150	31			2	2	3	2	1	104							295	295
0748	60	67			5					107							239	239
Cumm	270	117			28	15	3	2	1	318							754	251
9/2/2004																		
0767	30	162	6		9	36	9	39		9							300	1200
0768		260	4		8	18				7							297	1010
0769		253			11	16				17							297	1400
Cumm	30	675	10		28	70	9	39		33							894	1203
9/9/2004																		
0782	87	176			14			23									300	960
0783	63	216					4	6	6								295	820
0784	23	252			22					3							300	890
Cumm	173	644			36		4	29	6	3							895	890
9/16/2004																		
0797	36	208	21	6	16	13											300	890
0798	190	76	8		7		5				4						290	365
0799	14	176	68		22	9	6			5							300	900
Cumm	240	460	97	6	45	22	11			5	4						890	718
9/23/2004																		
0815	188	106				6											300	770
0816	196	55			10	20		11		5							297	790
0817	218	51			11	15		5									300	524
Cumm	602	212			21	41		16		5							897	695
9/30/2004																		
0836	131	100			18		24			17							290	520
0837	156	95	4		23						13						291	1400
0838	146	115	3		14		13				12						303	340
Cumm	433	310	7		55		37			17	25						884	753
Site Cumm	1748	2418	114	6	213	148	64	86	7	381	29						5214	752

Willow Slough @ 24

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/26/2004																			
0746	5	76560	78880	<0.1	1.5	6	7.95	477	8.91	22.38	1	18.5	100	0.28	1.5	62.3	2.0	112	
0747	5	78880	81151													61.0	1.9	154	
0748	5	81151	83701													68.5	2.2	111	126
Cumm																			
9/2/2004																			
0767	5	141652	144397	<0.1	>2	7	7.43	N/A	N/A	24.9	N/A	N/A		1.24	1.4	73.8	2.3	518	
0768	5	144397	146590													58.9	1.9	546	
0769	5	146590	150872													115.1	3.6	387	484
Cumm																			
9/9/2004																			
0782	5	186500	189454	<0.1	>2	8	7.41	696	4.74	22.84	2.5	20.4		0.9	2.9	79.4	2.5	385	348
0783	5	189454	192710													87.5	2.7	298	
0784	5	192710	195625													78.3	2.5	362	
Cumm																			
9/16/2004																			
0797	5	232220	235275	<0.1	>2	9	7.53	827	7.34	21.32	4.3	40		1.49	4	82.1	2.6	345	307
0798	5	235275	237023													47.0	1.5	247	
0799	5	237023	240285													87.7	2.8	327	
Cumm																			
9/23/2004																			
0815	5	282716	284976	<0.1	1.5	8	7.03	778	5.13	18.8	4	18		1.23	5.2	60.7	1.9	404	355
0816	5	284976	287382													64.7	2.0	389	
0817	5	287382	289673													61.6	1.9	271	
Cumm																			
9/30/2004																			
0836	5	310800	311919	<0.1	0.6	8	7.35	675	9.08	18.3	2	20		0.95	5.8	30.1	0.9	551	726
0837	5	311919	313120													32.3	1.0	1381	
0838	5	313120	314752													43.9	1.4	247	
Cumm																			
Site Cumm																			

Willow Slough @ 98

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/20/2004																		
0727	20	23			12		16	4									75	75
0728	210	31			33		19	2									295	1300
0729	227	18			35		18	2									300	1800
Cumm	457	72			80		53	8									670	1058
8/26/2004																		
0749	134	28			106		13	19									300	2200
0750	66	30			189			12	3								300	1500
0751	77	36			155			20	12	3							303	2200
Cumm	277	94			450		13	51	15	3							903	1967
9/2/2004																		
0770	49	36	4		98		3	105	2	3							300	1900
0771	18	79	2	1	70			124	6								300	4000
0772	24	116	10		46			98	6								300	4400
Cumm	91	231	16	1	214		3	327	14	3							900	3433
9/9/2004																		
0785	167	71	2		10				50								300	4500
0786	115	117	3		20				42								297	8400
0787	204	58			3				26		3						294	4500
Cumm	486	246	5		33				118		3						891	5800
9/16/2004																		
0800	71	200			15				6								292	1000
0801	157	100			12				21								290	1500
0802	47	220		3	6		3		18								297	1700
Cumm	275	520		3	33		3		45								879	1400
9/23/2004																		
0818	86	99	4				4		27								298	2600
0819	85	51	6					21	39								310	2600
0820	96	54	3						39								282	1800
Cumm	267	204	13				4	21	105								890	2333
9/30/2004																		
0833	71	165	21	3				3	6		3						296	2600
0834	110	151	21						11								298	2800
0835	98	155	2				2		8								297	1600
Cumm	297	471	44	3			2	3	25		3						891	2333
Site Cumm	2132	1838	78	7	1147		78	410	322	6	6						6024	2618

Willow Slough @ 98

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/20/2004																			
0727	5	0	2602	N/A	>2.0	10	8	500	8.01	24.8	-0.4	51	85	0.55		69.9	2.2	34	
0728	5	2602	5108	N/A												67.3	2.1	615	
0729	5	5108	7979	N/A												77.2	2.4	743	464
Cumm																			
8/26/2004																			
0749	5	67700	70768	<0.1	>2.0	10	7.43	570	8.87	22.33	-1.8	43.6		0.49	2.2	82.4	2.6	850	
0750	5	70768	73546													74.7	2.3	640	
0751	5	73546	76857													89.0	2.8	787	759
Cumm																			
9/2/2004																			
0770	5	131240	132183	calc	0.9	9	7.75	N/A	N/A	24	N/A	N/A		0.93	3.1	25.3	0.8	2388	
0771	5	132183	136050													103.9	3.3	1226	
0772	5	136050	141652													150.5	4.7	931	1515
Cumm																			
9/9/2004																			
0785	5	178730	180340	<0.1	1.6	12	7.53	528	6.91	23.73	9	58		0.99	2.8	43.3	1.4	3312	
0786	5	180340	183200													76.9	2.4	3481	
0787	5	183200	186508													88.9	2.8	1612	2802
Cumm																			
9/16/2004																			
0800	5	225800	227360	<0.1	1.3	15	7.79	608	7.79	21.32	5.2	54		1.63	1.4	41.9	1.3	760	
0801	5	227360	229878													67.7	2.1	706	
0802	5	229878	232320													65.6	2.1	825	764
Cumm																			
9/23/2004																			
0818	5	273400	276122	<0.1	1.3	12	7.54	602	8.01	19.7	4	34		1.48	3.9	73.1	2.3	1132	
0819	5	276122	279958													103.1	3.2	803	
0820	5	279958	282716													74.1	2.3	773	903
Cumm																			
9/30/2004																			
0833	5	302780	305715	<0.1	1.2	11	7.75	495	8.8	19	0	53		0.82	2.7	78.9	2.5	1050	
0834	5	305715	307510													48.2	1.5	1849	
0835	5	307510	310769													87.6	2.7	582	1160
Cumm																			
Site Cumm																			

Winter's Canal

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/20/2004																		
0730	300																300	11000
0731	300																300	12000
0732	297																297	12000
Cumm	897																897	11667
0733	145	7	48														200	200

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/20/2004																			
0730	5	13742	17732	calc	2.5	5	8.06	329	8.83	25.9	6	12	124	0.47		107.2	3.4	3267	3175
0731	5	17732	22232					332			1.2	13				120.9	3.8	3160	
0732	5	22232	26824													123.4	3.9	3097	
Cumm																			
0733																			

Sycamore Slough

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/23/2004																		
0734		50	3		7						7	230	1				298	18000
0735		50	2		11							232	1				296	27000
0736		34			9							249	3				295	57000
Cumm		134	5		27						7	711	5				889	16900

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/23/2004																			
0734	5	42208	44638	0.1	2	20	6.94	540	6.82	22.8	4.2	48.2	86	1.59		65.3	2.1	8778	
0735	5	44638	47927													88.4	2.8	9729	
0736	5	47927	50171													60.3	1.9	3010	7172
Cumm																			

Wadsworth Canal

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/23/2004																		
0740		81			76						9	132					298	1500
0741		111			60		9				48	72					300	710
0742		121		4	80						60	25					290	690
Cumm		313		4	216		9				117	229					888	967

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/23/2004																			
0740	5	50220	51877	calc	>2.0	20	6.98	271	9.05	23.1	0.4	1	123	1.33		44.5	1.4	1073	
0741	5	51877	53182													35.1	1.1	645	
0742	5	53182	54500													35.4	1.1	620	779
Cumm																			

Unknown Drain @ Hawkins

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/23/2004																		
0737		120	14		97									60		4	295	3300
0738		115	3		128									40	4	5	295	3210
0739		111			138									48	4		301	2700
Cumm		346	17		363									148	8	9	891	3070
8/26/2004																		
0743		142			136			15							9		302	3100
0744		120			132			33							15		300	3500
0745		153	3		117			18									291	2800
Cumm		415	3		385			66							24		893	3133
9/2/2004																		
0761	43	168			69			12			3						295	1600
0762	19	162			108			11			11						311	790
0763	6	150			138						6						300	2700
0764	105	114			78			3									300	1200
0765	84	114			78			24									300	1200
0766	81	103			102	5					6				3		300	1100
Cumm	338	811			573	5		50			26				3		1806	1192
9/9/2004																		
0779	216	48			33										3		300	14000
0780	262	6			27	3		6									304	4300
0781	269	6			15			6									296	8000
Cumm	747	60			75	3		12							3		900	8767
9/16/2004																		
0794	34	63			189	3		2			2					6	299	3800
0795	20	59			182	6		3	10		2				3	15	300	7900
0796	19	72			192	3			6	3						9	304	4008
Cumm	73	194			563	12		5	16	3	4				3	30	903	5236
9/23/2004																		
0812	46	84			121	4		15	2		13				12		297	14000
0813	55	48			143	3		33			18						300	17000
0814	49	43			163			17			16				12		300	17000
Cumm	150	175			427	7		65	2		47				24		897	16000
9/30/2004																		
0830	135	38			67			14			31				10		295	4700
0831	125	39			84	9	2	6			30				7		302	4500
0832	99	36	4		76	4		32			48						299	5600
Cumm	359	113	4		227	13	2	52			109				17		896	4933
Site Cumm	1667	2114	24		2613	40	2	250	18	3	186			148	82	39	7186	6047

Unknown Drain @ Hawkins

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/23/2004																			
0737	5	26888	31253	<0.01	1	6	7.45	444	7.39	20.1	3.8	0	71	0.94		117.3	3.7	896	
0738	5	31253	37227	<0.01												160.5	5.0	637	
0739	5	37227	42208	<0.01												133.9	4.2	642	725
Cumm																			
8/26/2004																			
0743	5	54480	58762	<0.01	0.9	6	7.45	392	6.96	19.9	10	2		0.35	1.5	115.1	3.6	858	
0744	5	58762	63428													125.4	3.9	889	
0745	5	63248	67721													120.2	3.8	742	830
Cumm																			
9/2/2004																			
0761	5	109000	112413	<0.01	0.9	7	7.4	390	8.5	20.46	2.5	-0.4		0.66	1.7	91.7	2.9	556	
0762	5	112413	116456													108.6	3.4	232	
0763	5	116456	119933													93.4	2.9	920	
0764	5	119933	127820	<0.01	0.9	6	7.56	388	10.04	20.82	2.1	-0.4		0.78	3.4	211.9	6.7	180	
0765	5	127820	129530													46.0	1.4	832	
0766	5	129530	131240													46.0	1.4	762	580
Cumm																			
9/9/2004																			
0779	5	165400	170373	<0.01	0.9	8	7.58	372	7.51	20.72	3	2.4		0.87	1.6	133.6	4.2	3336	
0780	5	170373	174108													100.4	3.2	1364	
0781	5	174108	178719													123.9	3.9	2056	2252
Cumm																			
9/16/2004																			
0794	5	210300	214625	<0.01	1	10	7.74	398	7.86	19.05	2.8	1		1.12	0.6	116.2	3.6	1041	
0795	5	214625	220670													162.4	5.1	1549	
0796	5	220670	225783													137.4	4.3	929	1173
Cumm																			
9/23/2004																			
0812	5	260670	264340	<0.01	1	7	7.97	423	7.96	18.3	4.5	0.5		1.05	1.9	98.6	3.1	4521	
0813	5	264340	268910													122.8	3.9	4408	
0814	5	268910	273416													121.1	3.8	4471	4467
Cumm																			
9/30/2004																			
0830	5	294400	296465	<0.01	0.8	8	7.63	401	8.16	16.32	2	3		0.69	3.2	55.5	1.7	2697	
0831	5	296465	299085													70.4	2.2	2035	
0832	5	299085	302659													96.0	3.0	1857	2197
Cumm																			
Site Cumm																			

Sac Slough @ 113

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/27/2004																		
0752	44	108			17	19	18	43	7		37						293	9800
0753	51	84	13	7	22	11	33	29	7		37						294	7500
0754	88	115	3		6	7	34	37			10						300	2300
0755	62	84	6	6	13	6	35	46	2	4	28						292	2600
0756	37	173			10		17	15	11		31				6		300	5400
0757	26	140		8		24	24	20	4		44						290	5700
Cumm	308	704	22	21	68	67	161	190	31	4	187				6		1769	5550
9/3/2004																		
0773	53	115			13		15	92			11						299	2600
0774	48	140			7	14	4	63	2		21		4				303	1800
0775	52	164	7		17	21		24			18						303	1800
Cumm	153	419	7		37	35	19	179	2		50		4				905	2067
9/10/2004																		
0788	103	140			3	24	5	6	8		6						295	4800
0789	121	123	5			31	3	9									292	4600
0790	61	168	3	3	3	39		20			3						300	5400
Cumm	285	431	8	3	6	94	8	35	8		9						887	4933
9/17/2004																		
0803	235	26	4			19		12			7						303	6300
0804	242	18	6			9	3	15			5						298	6600
0805	265	10			2	12		4	1		2						296	5200
Cumm	742	54	10		2	40	3	31	1		14						897	6033
9/24/2004																		
0821	300																300	94000
0822	300																300	52000
0823	300																300	75000
0824	284	8				1											293	36000
0825	287	9									3						299	33000
0826	277	17							2		1						297	35000
Cumm	1748	34				1			2		4						1789	54167
10/1/2004																		
0839	160	65			7	30		8	11		14						295	19000
0840	154	70			8	28		9	13		16						298	21000
0841	180	81				20	2	4	6		3						296	9700
Cumm	494	216			15	78	2	21	30		33						889	16567
Site Cumm	3253	1814	37	24	128	287	190	429	74	4	285		4		6		6535	14886

Sac Slough @ 113

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/27/2004																			
0752	5	96400	99416	<0.1	1.5	40	7.22	268	7.4	22.64	1.7	14.8	142	0.62	1	81	2.5	3851	
0753	5	99416	102104													72.2	2.3	3307	
0754	5	102104	104688													69.4	2.2	1055	
0755	5	104688	106565	<0.1	1.5	40	7.34	269	7.3	22.8	2.7	26.3	142	0.62	1.2	50.4	1.6	1642	
0756	5	106565	108151													42.6	1.3	4035	
0757	5	108151	108985													22.4	0.7	8100	3665
Cumm																			
9/3/2004																			
0773	5	160860	161941	<0.1	1.7	51	7.31	299.6	6.6	22.5	N/A	10		0.52	0.5	29	0.9	2850	
0774	5	161941	164250													62	1.9	924	
0775	5	164250	165555													35.1	1.1	1635	1803
Cumm																			
9/10/2004																			
0788	5	205600	207178	<0.1	>1.5	50	7.02	275	5.88	23.87	3.3	12.5		1.12	2.1	42.4	1.3	3605	
0789	5	207178	208784													43.2	1.4	3394	
0790	5	208784	210240													39.1	1.2	4395	3798
Cumm																			
9/17/2004																			
0803	5	256300	257910	<0.1	1.4	60	7.47	284	6.7	22.46	8	11		1.24	1.5	43.3	1.4	4637	
0804	5	257910	259266													36.4	1.1	5768	
0805	5	259266	260633													36.7	1.2	4508	4971
Cumm																			
9/24/2004																			
0821	5	290700	291646	<0.1	1.5	60	6.86	260	6.86	20.6	3	9		1.11	1.4	25.4	0.8	117758	
0822	5	291646	292054													11	0.3	151042	
0823	5	292054	292705													17.5	0.5	136532	
0824	5	292705	293095	<0.1	1.5	60	7.19	260	7	20.5	0.5	9		1.24	2.7	10.5	0.3	109394	
0825	5	293095	293640													14.6	0.5	71758	
0826	5	293640	294444													21.6	0.7	51590	106346
Cumm																			
10/1/2004																			
0839	5	325000	326994	<0.1	1.3	60	7.63	248	8.59	19.9	6	13		.057	1.1	53.6	1.7	11292	
0840	5	326994	328115													30.1	0.9	22201	
0841	5	328115	330102													53.4	1.7	5785	13093
Cumm																			
Site Cumm																			

Unknown Drain @ Hwy 45

	Rotifers	Cyclopoid	Calanoid	Herparcticoid	Chydoridae	Bosmina	Cladocera 1	Cladocera 2	Cladocera 3	Cladocera 4	Cladocera 5	Cladocera 6	Cladocera 7	Cladocera 8	Cladocera 9	Simocephalus	Count	Sample Abundance
8/27/2004																		
0758	200	20			2			61	3		2		3				291	20000
0759	207	20						63	10								300	29000
0760	207	24	2		1			48	16	2							300	22000
Cumm	614	64	2		3			172	29	2	2		3				891	23667
9/3/2004																		
0776	30	63			3			163	37		3						299	22000
0777	33	15			3			226	20		3						300	21000
0778	12	66	3					165	54								300	21000
Cumm	75	144	3		6			554	111		6						899	21333
9/10/2004																		
0791	61	194			23			11		4							293	1600
0792	54	208			20	3				7							292	1400
0793	84	158	3		14	4			3	12	7						285	2200
Cumm	199	560	3		57	7		11	3	23	7						870	1733
9/17/2004																		
0806	122	153			6	3		2	4								290	2300
0807	103	181	2		4				3								293	1900
0808	112	176			6				2	3							300	1900
0809	158	118	12		9					3							300	1500
0810	181	113				6											300	640
0811	160	182	9						3								300	1200
Cumm	837	869	23		25	9		2	12	6							1783	1573
9/24/2004																		
0827	212	54			8					6	20						300	2500
0828	121	105			12	3	2			6	51						300	1300
0829	103	122			15	3				5	49						297	1400
Cumm	436	281			35	6	2			17	120						897	1733
10/1/2004																		
0842	6	97	3			140		3	45		6						300	42000
0843	7	30				222			21		18						298	51000
0844	9	57				198			30		6						300	41000
Cumm	22	184	3			560		3	96		30						898	44668
Site Cumm	2183	2102	34		126	582	2	742	251	48	165		3				6238	15784

Unknown Drain @ Hwy 45

	Sampling Duration	Meter Start	Meter Stop	Velocity	Depth	Width	pH	EC	DO	Temp	Chlorophyll	Turbidity	Habitat Score	Phosphate	Nitrogen	Distance Sampled	Volume Sampled	Abundance per m^3	AVG Site Abundance
8/27/2004																			
0758	5	83700	87782	<0.1	1.6	10	7.02	0.495	5.3	18.41	3.3	46.9	80	0.88	0.5	109.7	3.4	5806	
0759	5	87782	91585													102.2	3.2	9037	
0760	5	91585	96387													129	4.1	5429	6758
Cumm																			
9/3/2004																			
0776	5	150200	152847	<0.1	2.8	9	7.4	400.6	6.67	16.6	N/A	39		0.81	0.4	71.1	2.2	9580	
0777	5	152847	156314													93.2	2.9	7178	
0778	5	156314	160860													122.2	3.8	5474	7501
Cumm																			
9/10/2004																			
0791	5	195600	198557	<0.1	1.3	11	7.41	869	2.8	22.9	8.8	34		1.92	1.4	79.5	2.5	641	
0792	5	198557	201981													92	2.9	485	
0793	5	201981	205610													97.5	3.1	718	615
Cumm																			
9/17/2004																			
0806	5	240300	242927	<0.1	1.3	12	7.56	812	5.93	22.29	10.3	32		1.96	2.1	70.6	2.2	1038	
0807	5	242927	246572													98	3.1	618	
0808	5	246572	249773													86	2.7	703	
0809	5	249773	252429	<0.1	1.3	12	7.8	827	6.13	23.14	7.6	25		1.84	1.5	71.4	2.2	669	
0810	5	252429	254076													44.3	1.4	461	
0811	5	254076	256212													57.4	1.8	666	692
Cumm																			
9/24/2004																			
0827	5	289689	290335	<0.1	0.2	4	7.77	941	8.64	19.24	5	93		2.59	1.7	17.4	0.5	4586	
0828	5	290335	290513													4.8	0.2	8655	
0829	5	290513	291102													15.8	0.5	2817	5353
Cumm																			
10/1/2004																			
0842	5	314700	317555	<0.1	0.7	10	7.49	365	6.34	16.1	10	81		0.71	1.3	76.7	2.4	17434	
0843	5	317555	321658													110.3	3.5	14731	
0844	5	321658	325044													91	2.9	14350	15505
Cumm																			
Site Cumm																			