The Effects of Agricultural Run-Off on Macroinvertebrate Communities in Irrigation Ditch and Natural Stream Ecosystems

BIOS 35503: Practicum in Environmental Field Biology II

Mary Alldred

2007

Abstract:

Macroinvertebrates are important indicators of stream health due to their sensitivity to abiotic changes and their extensive involvement trophic systems, yet little attention has been given to macroinvertebrate communities within stream-irrigation systems. In order to assess the effects of agricultural run-off on natural stream systems of the Flathead Reservation of Western Montana, I sampled macroinvertebrate communities within upstream and downstream irrigation ditch sites and natural stream sites upstream and downstream of irrigation inflows. I also monitored periphyton growth over a three week period and measured conductivity, dissolved oxygen, pH, and total suspended solids for each site. Results indicated lower macroinvertebrate diversity in irrigation ditch sites than natural stream sites, as well as a direct positive relationship between upstream and downstream diversity in irrigation ditches. Downstream irrigation ditch sites experienced a shift toward higher percent abundance of collector-gatherers and non-insect invertebrates as well as significantly higher values of total suspended solids. A significant relationship was found between total suspended solids and percent abundances of both collector-gatherers and non-insect invertebrates. These results underline the importance of including macroinvertebrate monitoring in future assessments of stream health.

Introduction:

Proper management of ecosystem services, such as agricultural irrigation, is crucial to the persistence of these services; therefore, a better understanding of the dynamics in ecosystems involved in supporting such services is essential (Palmer et al 2004). Depending on initial nutrient conditions within a natural stream, anthropogenic sources of inorganic nutrients such as those from agricultural run-off have the potential to increase or decrease species diversity within an ecosystem (Figure 1), altering the structure and function of that ecosystem (Vitousek et al 1997). For example, when exposed to increased nutrient levels, a low nutrient stream may shift to intermediate nutrient levels and experience increased diversity whereas a stream of intermediate nutrient concentrations may lose species diversity if nutrient levels increase.

Macroinvertebrates are important indicators of stream health since they represent a majority of trophic levels within a stream food web and are indicative of the amount of energy cycling through the ecosystem (Pimentel et al 1992). Additionally, macroinvertebrates show early sensitivity to changes in nutrient levels and other abiotic conditions within a stream. In practice, this sensitivity means that even initial stages of decreasing stream health will often be marked by decreasing macroinvertebrate diversity and a loss of complexity within the stream food web (Singer and Battin 2007). Therefore, the monitoring of overall abundance, richness, diversity, and community composition of macroinvertebrates within a stream is crucial to assessing the health of a stream ecosystem. However, little attention has been given to macroinvertebrate communities inhabiting irrigation ditches in comparison with those in natural stream systems of the Flathead Reservation (Herrera Environmental Consultants 2006).

Irrigation water for agricultural land within the Flathead Reservation is provided from a series of reservoirs and delivered to water rights holders via irrigation canals which I will refer to as “feeder” ditches for the purposes of this paper. Irrigation water that ultimately empties into Mission Creek and Post Creek originates at Mission Reservoir, and irrigation water that ultimately empties into Spring Creek originates at Pablo Reservoir. Run-off from agricultural property flows back into these ditches and is eventually delivered to natural streams at downstream irrigation ditch sites, which I will refer to as “irrigation inflow” ditches. Due to fertilizer use and organic waste from livestock, run-off may be enriched in organic nutrients such as ammonia and phosphate. In an agriculturally impacted area of Mission Creek, Herrera Environmental Consultants have observed high values for specific conductance (2006), a measure of ion concentration within water that is often associated with high nutrient loads.

This study will address three agriculturally impacted stream systems: Mission Creek, Post Creek, and Spring Creek. These stream systems have headwaters located in the Mission Mountains of Western Montana and can therefore be expected to contain relatively low nutrient concentrations at headwater sites. However, the sites sampled during the course of this study were located several miles downstream, beyond the confluence of several smaller tributaries. Since the river continuum concept postulates that nutrient concentrations, primary production, and biomass tend to increase with increasing stream order (Vannote et al 1980), I will assume for the purpose of my hypotheses that the systems sampled in this study have an initial state of intermediate nutrient concentrations.

The purpose of this study is to assess the effects of agricultural run-off, primarily from wheat and cattle fields, on macroinvertebrate communities within these three streams and an irrigation ditch feeding each. Assuming an initial intermediate nutrient concentration within these streams and high nutrient content within agricultural run-off, I hypothesize (1) that irrigation ditches will exhibit less overall diversity than natural streams, (2) that irrigation inflows will be less diverse than feeder ditch sites, and (3) that natural stream sites downstream of irrigation inflows will be less diverse than sites upstream of irrigation inflows. I further predict that low diversity will be associated with areas of high primary production (Figure 1), as a result of increased nutrient loads, and high specific conductance. Loss of diversity may also coincide with loss of trophic complexity in terms of percent composition of different functional feeding groups.

Methods:

For each stream system—Mission Creek, Post Creek, and Spring Creek—I selected four sampling locations: one feeder ditch site, one inflow site, one upstream site, and one downstream site

(Figure 2). Each site contained three sampling plots, giving a total of 36 macroinvertebrate samples per sampling week. I sampled each plot in early summer during the week of July 2 through July 8 and again at the same locations in late summer, July 22 through 29.

At each sampling site, I collected benthic macroinvertebrates from pool areas using a 0.1 m^2 Surber sampler with a 363 µm Nitrex mesh. For each surber sampler, I disturbed the substrate with my hands, rubbing the surface of any cobble within the plot; several systems, including Mission Creek and Post Creek, were deep enough that they required the use of a snorkel to reach the substrate for sampling. Surber samples were washed into a white plastic bin and all visible macroinvertebrates were removed for further analysis. Macroinvertebrate samples were preserved in 70% alcohol (ethanol or isopropyl alcohol). Aquatic insects were identified to genus using a standard 10x Zeiss dissecting microscope and counted and all other invertebrates were identified to family and counted. The keys used were Merritt and Cummins (1996), *A Guide to Common Freshwater Invertebrates* (Voshell 2002), and *Pennak's Freshwater Invertebrates of the United States* (Smith 2001). I used the Shannon Index to calculate the taxa diversity of each sample and identified each genus or family to functional feeding group (Merritt and Cummins 1996) in order to characterize community composition.

To estimate periphyton growth, I placed a 0.01 m^2 white ceramic tile at each sampling plot for 21 days. At the end of this period, I collected submerged tiles, scraped periphyton from the surface and filtered each onto a separate pre-weighed, pre-dried filter. Samples were then dried for 24 hours and weighed to estimate periphyton biomass growth at each site. I also recorded temperature, dissolved oxygen, conductivity, and pH at each sampling site. I used a YSI Model 85 handheld oxygen, conductivity, salinity, and temperature system to measure these variables and a Hanna pH meter to measure pH.

Statistical analyses were conducted using Systat 10.0. I ran a three-way ANOVA to test for significant differences and interactions among sample period, stream system, and site type, with Shannon diversity as my response variable. I then ran Bonferroni post hoc tests on significant results. I ran a similar three-way ANOVA to test the same three factors with abundance as my response variable, again using Bonferroni post hoc tests for significant results. In order to explain the difference in irrigation inflow diversity (see results), I ran linear regressions with conductivity and feeder diversity as independent variables. I performed the same regressions for downstream sites with respect to conductivity and upstream diversity.

To test for shifts in community structure, I took the arcsine transforms of percent abundances of different functional feeding groups (predators, collector-gatherers, collector-filterers, scrapers, and shredders) for my response variables and ran one-way ANOVAs using site type as a factor. I also took the arcsine transform of percent abundance of non-insect macroinvertebrates and ran the same set of one-way ANOVAs. I used similar one-way ANOVAs to find differences in abiotic factors across site types.

Once significant differences were observed in both community structure and abiotic factors, I used linear regressions to find potential causes of community structure shifts. When graphs resembled parabolic curves, I used the squares of the abiotic factor values and the abiotic factor values to run a multiple regression. In cases where fewer abiotic data points existed than community data points (TSS for example), I took the average percent abundance at each abiotic data point and ran a regression with the arcsine transform of those averages. To assess periphyton growth data, I grouped data by stream system and ran a one-way ANOVA with site type as a factor and density of periphyton growth as a response variable. I also ran two regressions to test for relationships between periphyton growth and species abundance and diversity.

Results:

Diversity did not differ significantly between sampling periods (F=0.555, df=1, p=0.460), nor did sample period interact significantly with stream system (F=0.438, df=2, p=0.648) or site type (F=0.430, df= 3, p=0.733). No significant interaction occurred between stream system and site type (F=0.438, df=2, p=0.648). Across all three systems, taxa diversity was significantly lower in feeder and irrigation inflow ditch sites than in natural stream sites (F=10.565, df=68, p<0.001). A Bonferroni post hoc test revealed that feeder ditch diversity was significantly lower than both upstream (p<0.001) and downstream (p=0.001) sites; likewise, irrigation inflows were significantly less diverse than both upstream (p=0.004) and downstream (p=0.002) sites (Figure 3). Additionally, diversity differed across stream systems (F=4.757, df=2, p=0.013), with Mission Creek having higher diversity than Spring Creek (p=0.068) and Post Creek not differing significantly from either system (Figure 3). A linear regression shows a significant positive relationship between feeder diversity and irrigation inflow diversity (R^2=0.424, df=16, p=0.003) (Figure 4) but not between upstream and downstream sites (R^2=0.096, df=16, p=0.210).

Abundance followed a trend similar to diversity across sites, with significantly lower abundance in feeder sites (F=4.429, df=3, p=0.008). Macroinvertebrates in feeder ditches were less abundant than in upstream (p=0.003) or downstream (p=0.066) sites (Figure 5). Sample period (F=0.114, df=1, p=0.737) and stream system (F=2.642, df=2, p=0.082) did not differ significantly with respect to abundance. Sample period did not interact significantly with stream system (F=0.008, df=2, p=0.915) or site type (F=0.979, df=3, p=0.502), and system and site type did not interact significantly (F=0.734, df=6, p=0.625).

Out of the tests on community shifts in terms of functional feeding groups (predators, collector-gatherers, collector-filterers, scrapers, and shredders), the only significant alteration in macroinvertebrate community structure involved a significant increase in percent abundance of collector-gatherers within irrigation inflow sites (ANOVA F=11.777, df=68, $p<0.001$) (Figure 6A). Irrigation inflows also contained a significantly higher percent abundance of non-insect invertebrates than any other site type (ANOVA F=25.931, df=68, $p<0.001$) (Figure 6B). Out of all abiotic factors tested, the most likely abiotic cause of these differences within irrigation inflows is a significantly higher amount of total suspended solids at these sites (ANOVA F=6.831, df=20, p=0.002) (Figure 7). After taking the arcsine transform of percent abundances, and squaring the values of total suspended solids, a linear regression confirmed a significant relationship between total suspended solids and percent abundances of both collector-gatherers ($R^2=0.843$, df=4, p=0.025) and non-insect invertebrates ($R^2=0.875$, df=4, p=0.016).

Periphyton results were inconsistent across stream systems. Mission Creek showed significantly greater periphyton growth in irrigation inflows and upstream sites (F=3.173, df=20, p=0.047). Post Creek showed a trend of greater periphyton growth in downstream sites (F=2.248, df=18, p=0.097), and Spring Creek showed a trend of greater growth in upstream sites (F=2.498, df=20, p=0.089). Periphyton had no significant relationship with either macroinvertebrate diversity ($R^2<0.001$, df=68, p=0.900) or abundance ($R^2=0.013$, df=68, p=0.357).

<u>Discussion</u>:

The explanation I believe best explains significantly lower diversity within irrigation ditch sites as opposed to natural stream sites (Figure 3) is that flow within irrigation ditches can be altered based upon water needs; as a result, irrigation ditch systems are analogous to temporary streams, which have been found to have lower diversity than permanent streams such as natural creeks (Williams 1996). This temporary nature of irrigation canal flow may also explain the direct relationship between diversity at feeder sites and diversity at inflow sites (Figure 4). Since irrigation ditches are effectively temporary streams, diversity would be dependent upon colonization by macroinvertebrates; therefore, differential colonization of upstream sites would directly affect diversity found downstream near irrigation inflows. Since feeder ditch sites represent only the beginning point of colonization, they would be expected to contain a lower abundance of macroinvertebrates than downstream irrigation sites receiving multiple inflows and additional colonization events (Figure 5).

Diversity differences may also be due to substrate differences between irrigation ditches and natural streams. Stewart et al (2003) found that macroinvertebrate communities experienced greater diversity in areas experimentally enhanced with cobble. In this study, natural streams tended to have a greater abundance of cobble than irrigation ditches, which had primarily silt and macrophyte substrates; therefore, natural streams could experience more diversity simply due to a more suitable substrate for macroinvertebrates. Likewise, the silt substrate of feeder ditches could explain why they had lower macroinvertebrate abundances than upstream and downstream sites (Figure 5). A negative relationship between nutrients in agricultural run-off and taxa diversity (Figure 1) may be a contributing factor in the difference between irrigation ditch and natural stream diversity, as my original hypothesis predicted; however, the fact that feeder and irrigation inflow sites have very similar diversities and radically different amounts of agricultural input would tend to discount this hypothesis.

Mission Creek likely has a slightly higher diversity (Figure 3) because it is a larger stream system than the other two systems; larger substrate area would provide habitats for a wider variety of species. However, since downstream diversity can be affected by diversity further upstream, as was observed for feeder and irrigation inflow sites, Mission Creek may also be more diverse since it has a larger number of tributaries joining the main stream.

Variability in periphyton growth data is largely a result of difficulty in the sampling procedure. Occasionally, tiles would become buried in silt or flip over, interfering in consistent treatment of tiles across sites. One tile was lost entirely during the sampling process. Additionally, assessing primary productivity through periphyton growth does not account for growth of macrophytes within stream and irrigation systems. All three of the irrigation inflow sites were marked by dense growth of macrophytes and emergent vegetation, which likely would have made the sites comparatively more productive than other sites but may have hindered periphyton growth by over-crowding and blocking sunlight. Additionally, since macroinvertebrates feed differentially on both periphyton and vegetation, assessing the presence of different types of primary producers may have better explained observed community shifts. Future studies should account for macrophyte and plant growth as well as periphyton growth when assessing primary productivity; one easy method would simply be to estimate percent cover of different types of primary producers at each site.

Shifts in macroinvertebrate communities toward higher percent abundances of collector-gatherers and non-insect invertebrates are typical of anthropogenically impacted stream systems (Bourassa and Cattaneo 1998, Dodds and Welch 2000, Twichell et al 2002). Cuffney et al (1984) found a direct relationship between availability of fine particulate organic matter and percent abundance of non-insect invertebrates; they further observed a community shift to small collector-gatherers following experimental nutrient enrichment in streams. Considering that collector-gatherers subsist on suspended organic matter in streams, increased abundance of macroinvertebrates in productive streams would follow due to increased availability of organic carbon. Irrigation inflows in this study had a significantly higher amount of total suspended solids than any other site type (Figure 7), which is one approximation of available organic carbon in the water column. The relationship between total suspended solids and relative abundances of both collector-gatherers and non-insect invertebrates is best described by a parabolic curve (Figure 8). This relationship would seem to indicate a positive relationship at low values of total suspended solids, followed by a leveling off and decrease at high values of total suspended solids. A compensation point likely exists beyond which increasing levels of available carbon are no longer beneficial to collector-gatherers and non-insects and actually may result in decreasing abundances of each. This point may be due to limitation in some other nutrient or increased competition within this community. Another explanation could involve the ratio of organic to inorganic matter within these suspended solids. If additional inputs of suspended solids into a creek are increasing the amount of inorganic matter but not organic matter available, high concentrations of total suspended solids could actually increase the difficulty of foraging for collector-gatherers. The ratio of organic matter to inorganic matter could be tested relatively easily by measuring the total mass of total suspended solids before and after burning; the difference in mass would represent the mass of organic material in the sample.

Considering diversity, shifts in macroinvertebrate community, and increases in total suspended solids, irrigation inflows showed more signs of anthropogenic alteration than any other site type. This difference likely exists because irrigation inflows receive the most direct inputs of nutrients through agricultural run-off, have relatively smaller volumes, and run only temporarily during the course of the year. Though the upstream and downstream sites of natural creeks showed no change, this study illustrates that lotic systems exposed directly to nutrients in agricultural run-off (irrigation inflows) and physical manipulation (feeder ditches) do experience decreased macroinvertebrate diversity and shifts in macroinvertebrate communities. These changes could have consequences for higher trophic levels including amphibian and fish communities on a larger scale (Dodds and Welch 2000) and are therefore worthy of attention in future stream monitoring efforts, both within the Flathead Reservation and for all anthropogenically impacted lotic systems. Use of overall macroinvertebrate diversity or observation of certain macroinvertebrate indicator species, such as collector-gatherers, could provide a valuable addition to stream health assessments.

Acknowledgements:

I would like to think the Confederated Salish and Kootenai Tribes for access to tribal property for the purposes of this study. Thanks also to Professor Jennifer Tank and Chris Fitzpatrick for their help in designing this study. Participants in sampling included students of the UNDERC-West class of 2007, teaching assistants Mara Irby and Geoffrey Gailey, and director Gretchen Gerrish. Abiotic data such as nutrient concentrations and total suspended solids were provided by fellow student Richard LaBrie. I would further like to thank Professor Gary Belovsky and Gretchen Gerrish for their help in data analysis and project planning and Gretchen Gerrish for her assistance in editing this paper.

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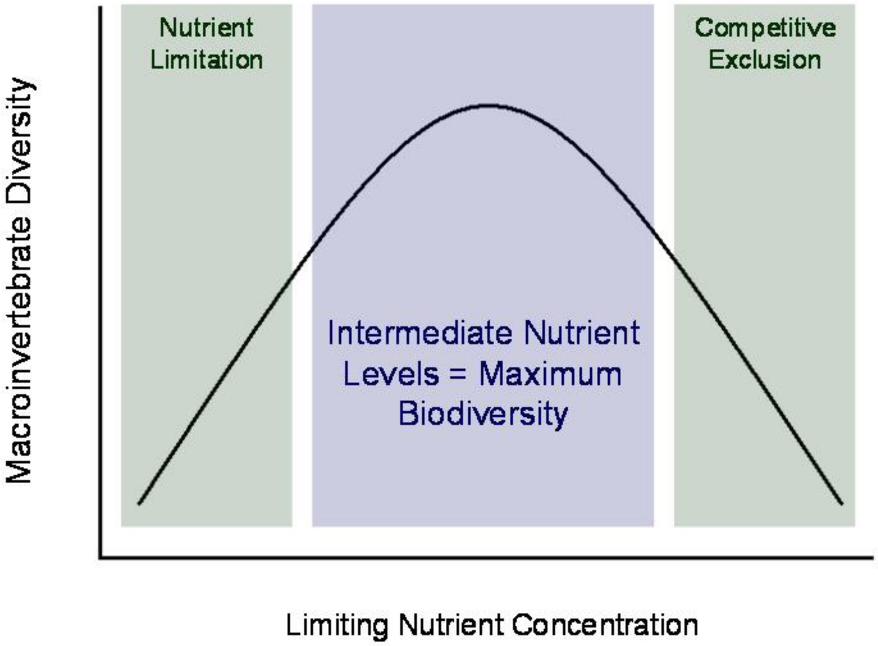


Figure 1: Simplified trend in macroinvertebrate diversity with respect to dissolved nutrient concentrations in aquatic systems. Anthropogenic sources of inorganic nutrients have the ability to shift communities to higher or lower levels of species diversity (Vitousek et al 1997), illustrated by a shift to the right along the graph.

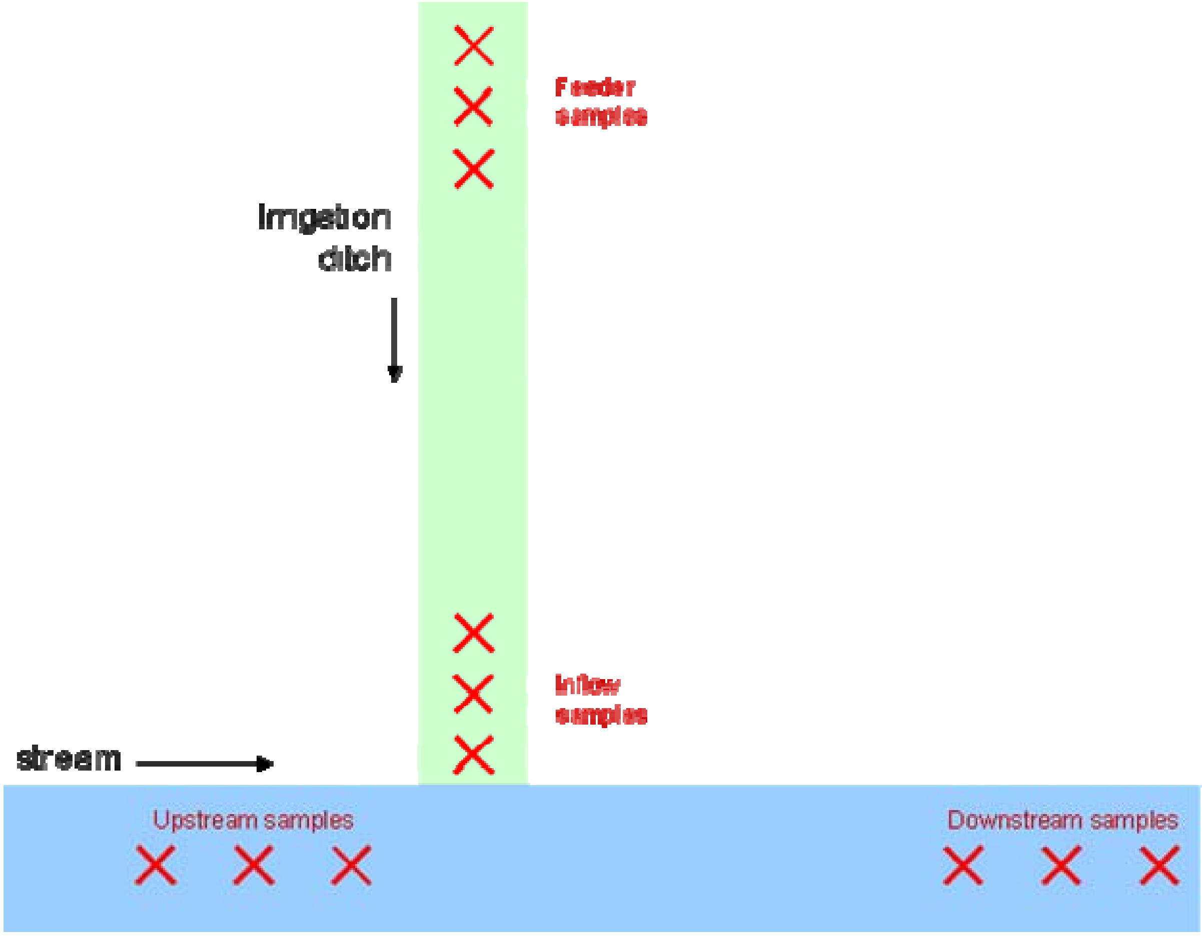


Figure 2: Diagram of sampling locations for one replicate system. Each system contains four sampling locations: one feeder site, one inflow site, one upstream site, and one downstream site. Red Xs indicate sampling plots, and arrows indicate direction of flow.

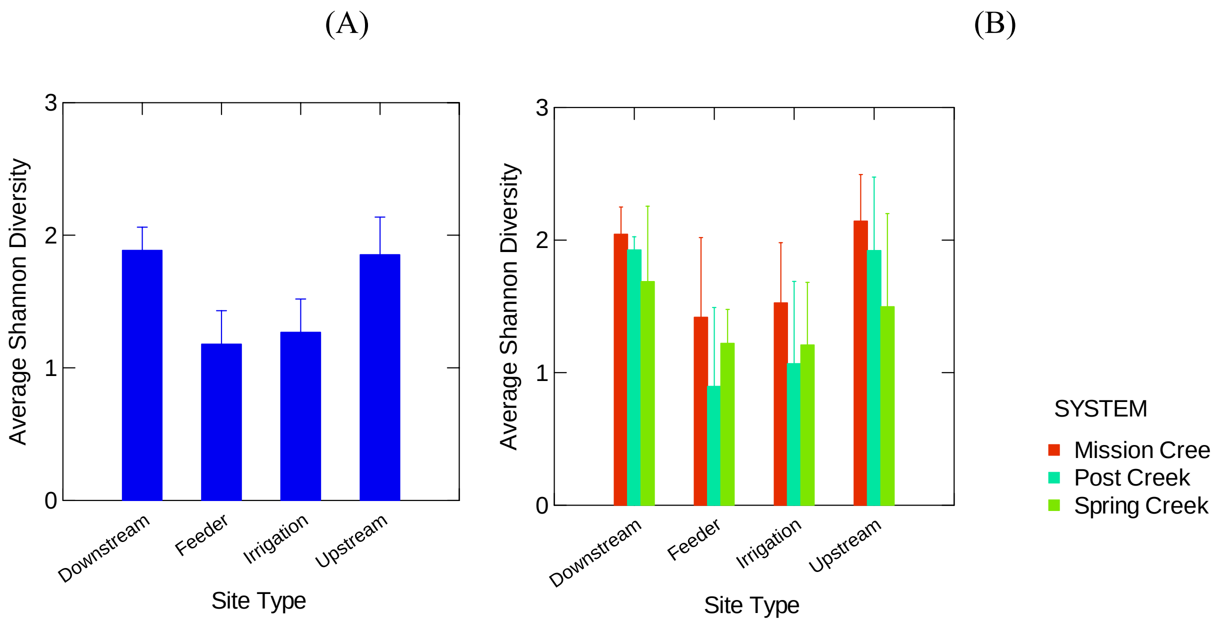


Figure 3: (A) Taxa diversity differed significantly across site types (F=10.565, df=68, p<0.001), with feeder sites less diverse than both upstream (p<0.001) and downstream (p=0.001) sites and irrigation inflows also less diverse than both upstream (p=0.004) and downstream (p=0.002) sites. (B) This trend persisted throughout all three systems, though Mission Creek was significantly more diverse than Spring Creek across different site types (0.068).

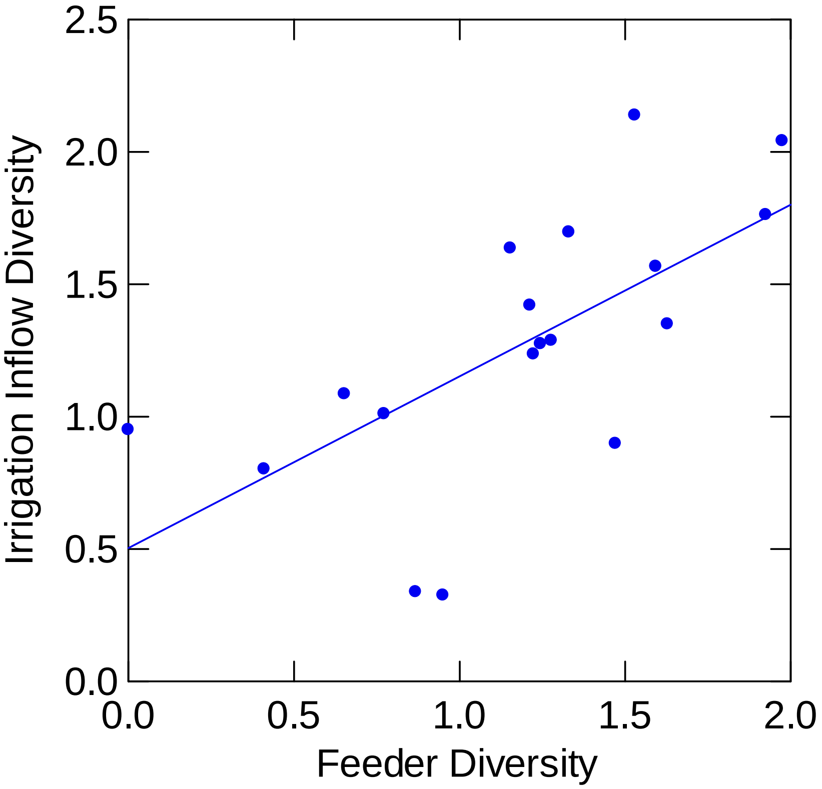


Figure 4: Macroinvertebrate diversity within feeder ditches is significantly related to macroinvertebrate diversity further downstream at irrigation inflows ($R^2=0.424$, df=16, p=0.003).

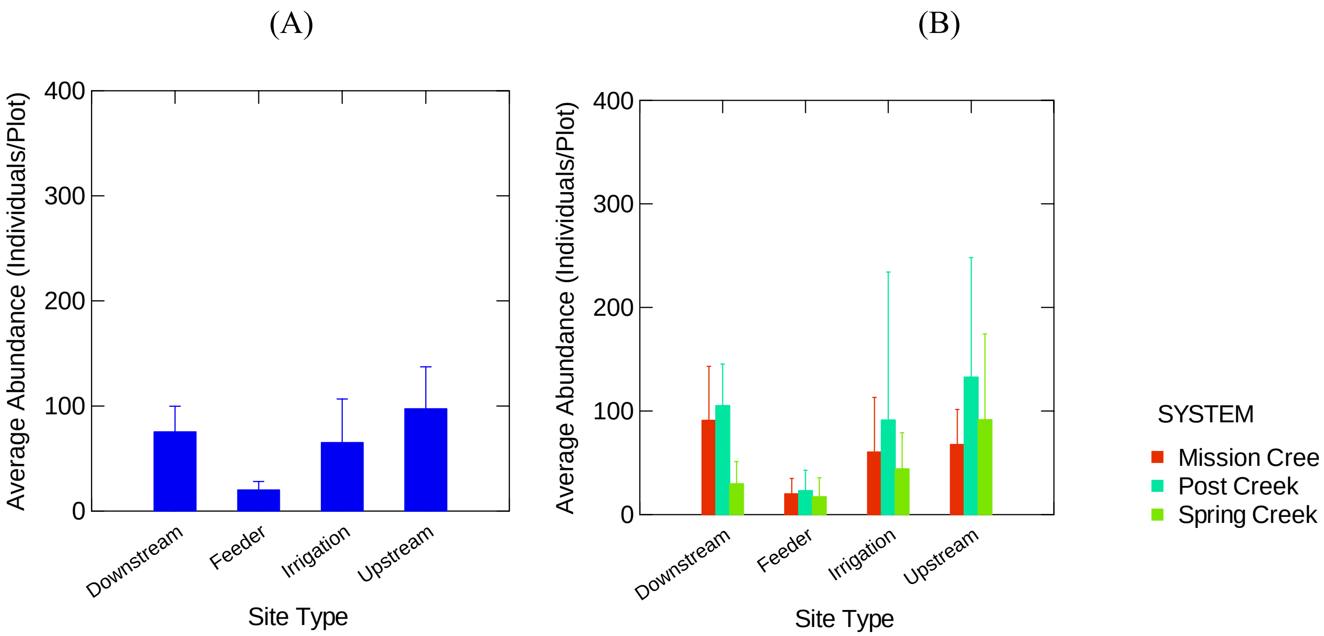


Figure 5: (A) Abundance differed significantly across site types (F=4.429, df=3, p=0.008), with significantly lower abundance in feeder sites than in upstream (p=0.003) or downstream sites (p=0.066). (B) This trend persisted within each stream system, with no significant differences in abundance among stream systems (F=2.642, df=2, p=0.082).

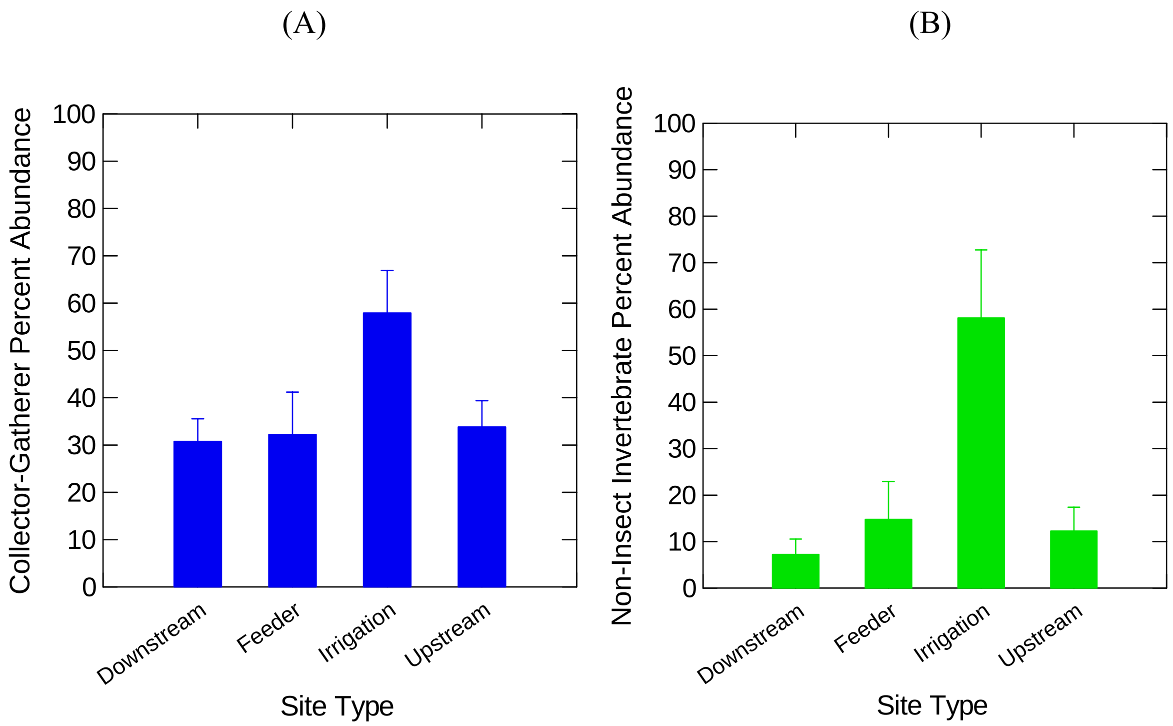


Figure 6: (A) Collector-Gatherer percent abundance was significantly higher in irrigation inflows than in all other site types (F=11.777, df=68, p<0.001). (B) Percent abundance of non-insect invertebrates was likewise significantly greater in irrigation inflows (F=25.931, df=68, p<0.001).

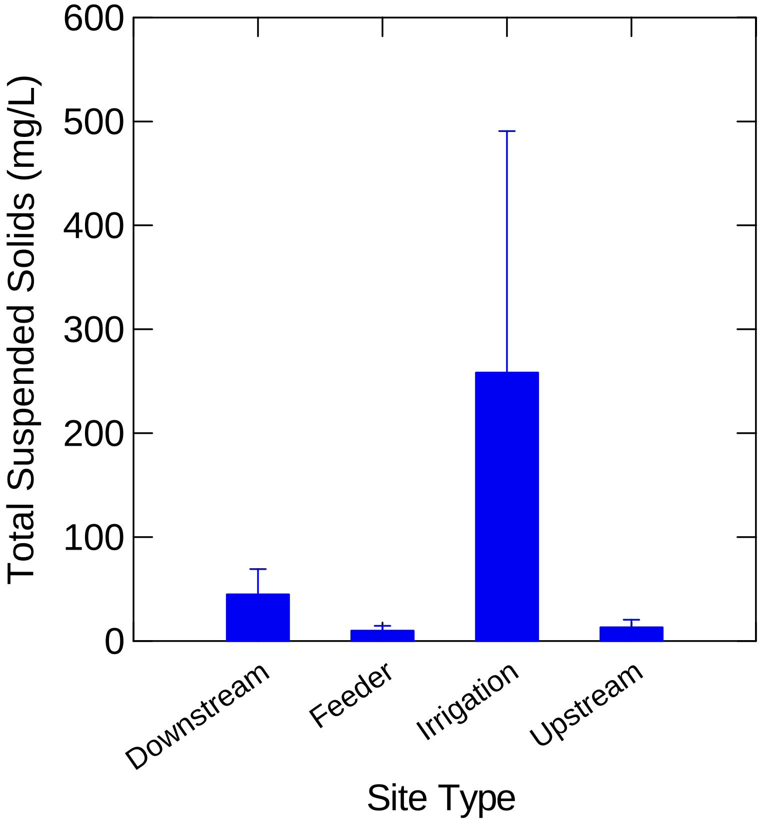
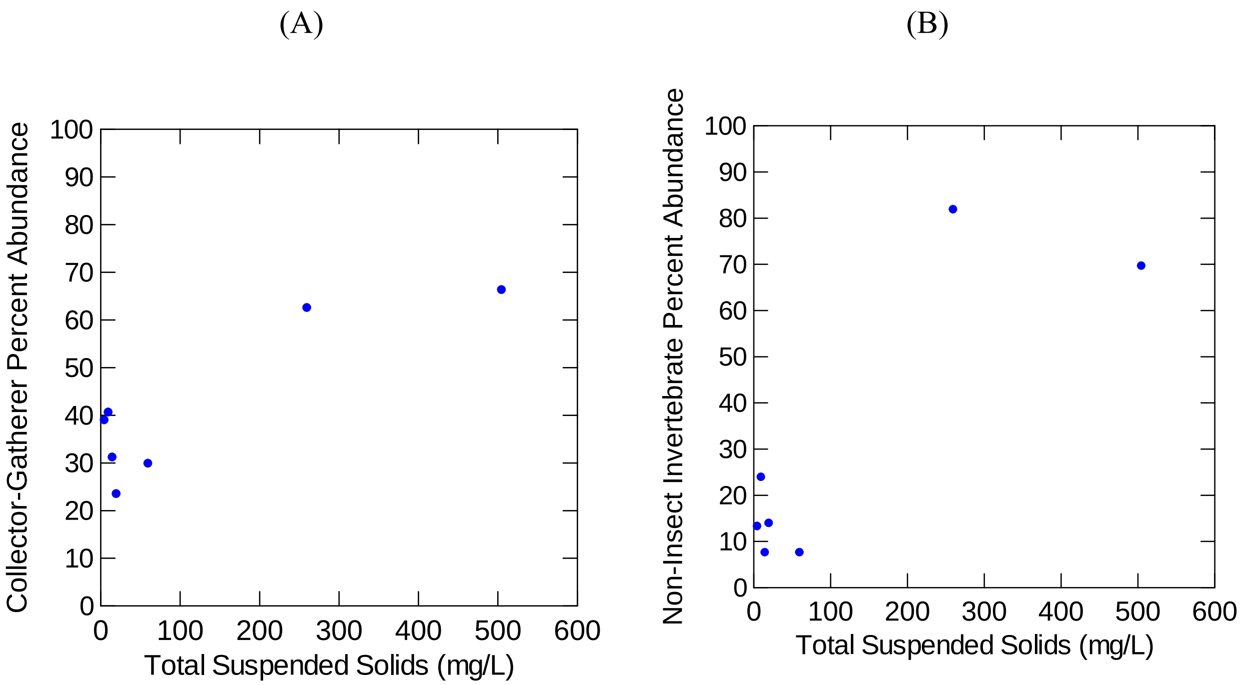


Figure 7: Amounts of total suspended solids in irrigation inflows were significantly greater than in all other site types (F=6.831, df=20, p=0.002).



(Where is the third irrigation ditch? Was this mission?)

Figure 8: Amount of total suspended solids is related via a polynomial relationship to both (A) collector-gatherer percent abundance (R^2=0.843, df=4, p=0.025) and (B) non-insect invertebrate percent abundance (R^2=0.875, df=4, p=0.016).