Distribution of macroinvertebrate assemblages of irrigation ditches and streams in western Montana, in relation to physiochemical characteristics

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Abstract

In recent decades, the relationships between environmental conditions and community structures of stream macroinvertebrates have been investigated in many parts of the world. It is well recognized that assemblage structure changes with alterations in catchment or local land use. Despite the large distribution of irrigation canals flowing through thousands of acres of agricultural land, aquatic macroinvertebrate community composition and diversity are largely unstudied in this region of western Montana. We evaluated the relative importance of multiple physiochemical parameters that influenced the ecology of benthic macroinvertebrate assemblages in thirteen reaches of agricultural ditches and thirteen streams on the Flathead Indian Reservation. Univariate (e.g., diversity) and multivariate (ordination) metrics were used to assess changes in assemblage composition associated with agricultural land use. Multiple regression revealed significant relationships between macroinvertebrate communities and measured physiochemical variables, especially water temperature. There was a considerable amount of variation in assemblage distribution, though comparison of macroinvertebrate samples showed that ditch and stream assemblages were significantly different.

Introduction

The northwestern U.S. is confronting water resource issues stemming from climate change, changing agricultural practices, and increasing urbanization (Carlisle and Hawkins 2008; Graf et al. 2016). As changes to the landscape continue, the need to understand how riparian alterations will affect water quality and aquatic life becomes apparent. Biological monitoring utilizes a wide array of organisms and their response to their surrounding environment to measure the quality of environmental conditions and determine the overall status of lotic habitats (Early et al. 2002). Benthic macroinvertebrates are the most commonly used taxonomic group because they live in close association with the substrate, complete the majority of their life cycles underwater, have known pollution tolerances, are sedentary in nature, have widespread distribution, and are comparatively easy to collect and identify (Early et al. 2002; Feeley et al. 2012; Ferreira et al. 2014).

Biological assessments utilize various qualitative and quantitative indices to relate water quality to the condition of biological communities (Early et al. 2002; Feeley et al. 2012). The abundance and richness among macroinvertebrates are simple measures often used in assessments; species-poor systems are generally assumed to have degraded water quality. Certain taxa are known to be more sensitive to pollutants and other stressors (Ferreira et al. 2014). Groupings of sensitive taxa such as the presence of EPT, which measures of the proportion of individuals in the orders Ephemeroptera, Plecoptera, and Trichoptera are used as an indicator of a healthy stream. Altered environmental conditions can adversely affect EPT taxa richness and composition.

Macroinvertebrate assemblages are sensitive to environmental conditions and reflect the physical and chemical conditions of the ecosystem (Ferreira et al. 2014). They are also known to respond rapidly to changes in water quality. For these reasons, relationships between the physiochemical environmental characteristics of a waterbody and the taxa richness and community structure of macroinvertebrates inhabiting it are of particular importance in agricultural areas. Agricultural land use often results in multiple stressors (e.g., elevated nutrients and fine sediments).

The region around Flathead Lake in northwest Montana has long-served as a locale resplendent with natural resources, including fish, wildlife, forests, and the natural waterways that serve those features. Yet, the location is considered a semi-arid region based on its average fourteen inches of precipitation annually. Located in northwestern Montana, the Flathead Indian Irrigation Project supplies irrigation to approximately 127,000 acres of agricultural land on the Flathead Indian Reservation. This century-old irrigation system includes approximately 1,300 miles of canals and lateral irrigation channels, largely to provide water to cropland and the cattle industry. Despite the large distribution of irrigation canals flowing through thousands of acres of agricultural land, aquatic macroinvertebrate community composition and diversity are largely unstudied in this region of western Montana. To understand patterns of aquatic macroinvertebrate communities, diversity, and metrics for assessing lotic ecosystem health, we selected thirteen reaches of agricultural ditches and thirteen streams on the Flathead Indian Reservation (Figure 1). Five of the total 26 sites I sampled in 2017 were also sampled for aquatic macroinvertebrates in 2016, which provided an opportunity to not only compare aquatic macroinvertebrate metrics across ditches and streams, but to compare metrics between years.

The aim of this work was to evaluate the importance of and identify relevant physiochemical parameters influencing the distribution of the macroinvertebrate community in waterways on the Flathead Reservation. Special attention was paid to the distribution of the dominant and pollution-sensitive taxa. The study also attempts to determine the validity of extensively used biotic indices in providing preliminary assessment of the Flathead Reservation’s current stream condition across land use. Irrigation ditches and natural streams can differ in land use, ecological conditions, and geomorphology, so it was hypothesized that: 1) ditches and streams would differ in assemblage structure and composition, and 2) different aquatic metrics would explain diversity in each site.

Materials and Methods

Study area

The majority of the irrigation ditches were located along Moiese Valley Road in Charlo, MT, a valley characterized by cattle ranching, wheat, and corn fields (Figure 1). Stream sites were situated on the National Bison Range and on Moiese Valley Road. In addition, two reaches of the Jocko River, a major tributary of the Flathead River, were selected because we hypothesized that this site would be the least impacted by anthropogenic stressors, and therefore would serve as a reference stream for this study.

Water quality

To illustrate the variation in the physical habitat structure in waterways with different land uses, water temperature, dissolved oxygen (DO), total dissolved solids (TDS), and electrical conductivity were all measured in the field using a multiparameter probe.

Benthic macroinvertebrates

Benthic macroinvertebrates were collected from 26 sites over a period of 24 days between the end of June and mid-July. At each location, samples were collected through the use of a D-frame kick net (500 µm mesh). Benthic macroinvertebrates are not uniformly distributed across a waterbody, occurring in higher abundances in certain habitats and patches, so collection covered all different substrates and habitats at each site. In some areas with the presence of large stones, these were picked up and organisms removed by gently wiping the rock surfaces and dislodging attached organisms into the kick net.

Collected organisms and detrital material were returned to the laboratory for processing and preserved in 70% ethanol. The macroinvertebrates were sorted from the debris, identified to the lowest possible taxon (usually family level) according to *An Introduction to the Aquatic Insects of North America* (edited by R.W. Merritt, K.W. Cummins, M.B. Berg), and counted under a dissecting microscope.

Using the macroinvertebrate data, the following biological metrics were calculated: taxon richness, % EPT, % EPT family richness, and Simpson’s Diversity Index. Simpson’s is a measure of diversity that takes the number of taxa present and abundance of each taxa into account. With this index, 0 represents infinite diversity and 1, no diversity. A widely accepted biological scoring system was calculated to determine the current condition of the ditches and streams: Hilsenhoff's Biotic Index (HBI), which estimates the overall tolerance of the community in a sampled area, weighted by the relative abundance of each taxonomic group (Deborde et al. 2016).

Data analyses

I performed multiple linear regression using taxon richness, % EPT, % EPT family richness, Simpson's Index, and HBI, as response variables, and all water quality variables as predictors.

Principal Coordinates Analysis (PCoA; R Program version 1.0.136) was used to visualize similarities in the taxonomic composition of benthic assemblages between ditch and stream sites, as well as amongst several 2016 sites. PCoA is a distance-based ordination method that reduces the dimensionality of community data into two axes, which facilitates interpretation of the ordination (Oksanen 2015; vegan tutor). Vectors were fitted to PCoAs to interpret the direction and strength of water quality variables and specific taxa, and how these variables influenced the grouping of the 26 sites. Vectors were fitted to PCoA ordinations using the function "envfit" in the vegan package of R (Oksanen 2015). A Permutational Multivariate Analysis of Variance Using Distance Matrices (PERMANOVA) was performed to determine if the visual assessment of the communities of the ditches and streams in ordination space was significant, and determine if the macroinvertebrate assemblages varied significantly between ditch and stream sites. In addition, univariate ANOVAs (using the R library 'mvabund' for multivariate abundance data) were performed to determine which taxa abundance differed significantly between ditches and streams (Wang et al. 2016). ANOVAs were performed within the 'mvabund' package because of the inherent nature of macroinvertebrate community data to have a strong mean-variance relationship, which mvabund accounts for, unlike parametric ANOVAs.

Results

Physiochemical characteristics

The study waterways had a wide range in environmental conditions. The water chemistry varied widely among sites, but was very similar in ditch and stream sites, with 9.32 mg l^{-1} DO (± 1.25), TDS 135 ppm (± 31), conductivity 233.31 μS cm^{-1} (± 39.44), and a water temperature of 20.4° (± 2.5) on average. Maximum taxa richness was not correlated with temperature, DO, TDS, or conductivity. Results from ANOVAs showed that these variables were not significantly different between ditch and stream sites ($p > 0.05$). In addition, ditch and stream sites were not clearly separated based on the PCoA ordination of water quality variables (Figure 2).

Composition of macroinvertebrates

48 distinct taxa were collected throughout this study, and each site on average had a richness of 12 ± 5 (Table 1); taxa richness varied among sites. Average taxa richness in the ditches was 10 ± 5 taxa and that of streams was higher (average 14 ± 4). In total, 34 taxa were detected in ditch samples, 44 in stream samples.

Ten taxa represented 85% of the total number of individuals overall (Table 1). Baetidae and Gammaridae were the most abundant taxa, representing 20% and 18% of the community, respectively. Chironomidae accounted for 12% and Simuliidae 8%. The gastropod families

Planorbidae, Physidae, and Lymnaeidae represented more than 16% of the total. Hydropsychidae, Elmidae, and Helicopsychidae represented 10% of the total.

Macroinvertebrates and water quality relationships

The HBI ranged from 2.87, indicating excellent water quality, to 6.39, which indicates fairly poor water quality. A total of five streams were ranked excellent and very good, according to HBI: Lower Jocko (2.87), Upper Jocko (3.30), Mission Wetlands (3.52), Mission 2 (4.06), and Mission 1 (4.13). In addition, Simpson's Index ranged from 0.48 to 0.88, with an average 0.71.

Each physiochemical parameter was considered separately in relation to the occurrence of macroinvertebrates. The most abundant pollution-sensitive taxa according to the Hilsenhoff Biotic Index (Table 2), in which Helicopsychidae and Heptageniidae were dominant, were collected in places with similar water chemistry. Samples with the highest pollution-sensitive taxa richness were observed in stream sites with low water temperatures (between 12 and 18°), average TDS (between 124 and 147 ppm), and average-to-high conductivity (between 250 and 293 $\mu S\ cm^{-1}$) and DO (between 9.49 and 10.9 $mg\ l^{-1}$).

The multiple regression, with water quality measurements as predictors of macroinvertebrate richness, diversity, and EPT, showed that the macroinvertebrate communities were significantly influenced by temperature (considered independently in the multivariate analysis). Temperature significantly predicted HBI ($\beta = 2.90$, $p < 0.01$), % EPT ($\beta = -2.09$, $p < 0.05$), and % EPT family richness ($\beta = -3.56$, $p < 0.005$). As temperature of the water decreased, richness, diversity, and EPT increased; while an increase in temperature also increased HBI. In contrast, DO, TDS, and conductivity showed no significant effects on the macroinvertebrate communities. TDS-conductivity-temperature-DO showed significance on % EPT ($R^2 = 0.40$, $F_{4,21} = 5.25$, $p < 0.005$) and % EPT family richness ($R^2 = 0.42$, $F_{4,21} = 5.49$, $p < 0.005$).

Macroinvertebrate assemblages related to site category

In general, ditch sites exhibited low EPT (15.5%), and this was dominated almost exclusively by Ephemeroptera (Figure 3a). No Plecoptera were identified in ditch samples. On the contrary, EPT was the absolutely dominating metric in the stream sites (Figure 3b), comprising half of the macroinvertebrates. Within that, Ephemeroptera (32%) was the most abundant taxon and Trichoptera (17%) was the second most abundant taxon. Gastropoda contributed more to community composition of ditches (26.5%) than of streams (10%). While Gammaridae contributed equally to community composition (18%) of ditch and stream sites, this taxomic group had a higher occurrence in ditches (12 of 13 sites) compared to streams (only 7 sites). Both ditches and streams varied among samples, with differences in macroinvertebrate abundance and composition.

Results from ANOVAs showed that HBI ($F_{1,24} = 10.95$, $p < 0.005$), % EPT ($F_{1,24} = 12.51$, $p < 0.005$) and % EPT family richness ($F_{1,24} = 19.26$, $p < 0.0005$) were significantly different between ditch and stream sites. HBI was significantly higher in ditches and EPT was significantly higher in streams, which supports my findings in the bar graphs presented above.

The PCoA ordination plot for macroinvertebrates did not show a distinct difference between ditch and stream sites (Figure 4a). The sites were situated in ordination space with some interspersion of ditch and stream sites, indicating some sites, regardless of being classified as ditch or stream, had similar macroinvertebrate assemblages. The correlation vectors superimposed on the PCoA plot show the relevance of the taxonomic groups and physiochemical parameters in the differentiation of the ditches and streams, based on their macroinvertebrate assemblages (Figure 4b). As a general trend, Coenagrionidae, Physidae, Corixidae, and Amphipoda were more abundant in ditches, while Elmidae, Perlodidae, and Baetidae were more abundant in streams. Stream assemblages were also characterized by DO (Figure 4c), which supports my findings in the multiple linear regressions presented above.

The taxa composition bar graphs, ANOVA tests, and PCoA ordination plots indicated some dissimilarity in the composition of macroinvertebrates in ditch and stream sites. This separation was confirmed by the PERMANOVA test ($F_{1,24} = 2.86$, $p < 0.01$); comparison of macroinvertebrate samples showed that ditch and stream assemblages were significantly different. Samples contained one taxon (Hydrophilidae) that was more abundant in ditches compared to streams (Deviance = 14.18, $p < 0.05$).

Yearly biological monitoring

In comparing macroinvertebrate data from five mutual sites in 2016 (Figure 5a) and 2017 (Figure 5b), we can see that the Mission Wetlands maintained a consistent macroinvertebrate assemblage. In general, samples from 2017 displayed higher EPT than in 2016, characterized by an increase in the relative abundance of Ephemeroptera, Trichoptera, and Plectoptera. There was a decrease in Chironomidae in Jerry’s Ditch and Gammaridae at Ninepipes.

The PCoA ordination comparing 2016 and 2017 macroinvertebrate assemblages (Figure 6) does not support the information presented in Figure 5. According to the PCoA, the composition of macroinvertebrates at Jerry’s Ditch this year was similar to that of last year. In addition, 2016 Upper Jocko was more similar to 2017 Mission Wetlands than to the 2017 Upper Jocko, though a majority of the macroinvertebrates at Mission this year were Trichoptera.

Discussion

As expected, we found that macroinvertebrate assemblages differed significantly among irrigation ditches and natural streams. However, despite a significant difference in composition, only one taxon was found to be the major driver of this significance. In addition, water chemistry conditions differed widely among ditch and stream sites, though there were no significant differences. This variability was clearly observable in the scatter of the sites in the ordination plots, and may support the notion that streams are highly heterogeneous. We were able to predict that temperature of the water influences the quality of the aquatic system (based on HBI and EPT).

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Figures and Tables

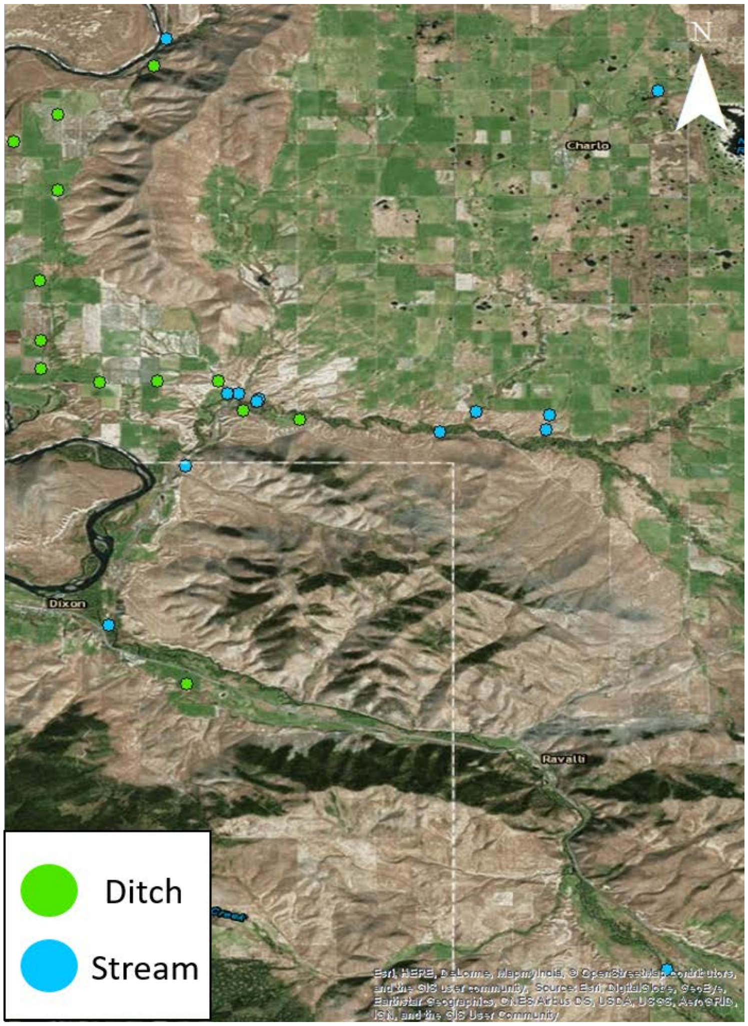

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Fig. 1. Locations of the study sites in the Flathead Indian Reservation.

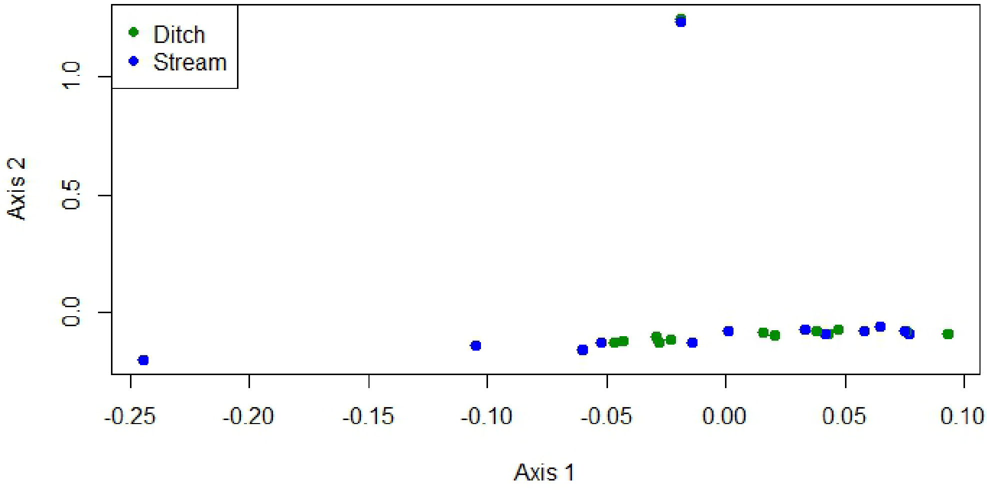

Fig. 2. Results of Principal Coordinates Analysis (PCoA) of physiochemical parameters.

Table 1. Taxonomic groups and relative abundances of each taxon in the Flathead Indian Reservation (the names of the 10 dominant taxa are in bold).

AMPHIPODA		HEMIPTERA	
Gammaridae	17.74	Corixidae	0.91
ANNELIDA		LEPIDOPTERA	
Hirudinea	0.54	Noctuidae	0.01
BIVALVIA		Petrophila	0.03
Sphaeriidae	0.60	ODONATA	
COLEOPTERA		Aeshnidae	0.10
Dytiscidae	0.57	Coenagrionidae	0.65
Elmidae	3.70	Gomphidae	0.01
Gyrinidae	0.12	Lestidae	0.45
Haliplidae	0.01	Libellulidae	0.16
Hydrophilidae	0.07	PLECOPTERA	
COLLEMBOLA	0.04	Perlidae	0.35
DECAPODA		Perlodidae	0.09
Astacidae	0.41	Pteronarcyidae	0.06
Palaemonidae	0.06	PULMONATA	
DIPTERA		Ancylidae	0.51
Simuliidae	8.45	**Lymnaeidae**	3.73
Chironomidae	12.42	**Physidae**	5.04
Ceratopogonidae	0.09	**Planorbidae**	7.82
Dixidae	0.35	TRICHOPTERA	
Empididae	0.03	Brachycentridae	1.13
Stratiomyidae	0.01	Glossosomatidae	1.41
Syrphidae	0.04	**Helicopsychidae**	2.63
Tipulidae	0.20	**Hydropsychidae**	3.74
EPHEMEROPTERA		Hydroptilidae	0.04
Baetidae	19.87	Leptoceridae	0.06
Caenidae	0.16	Limnephilidae	0.83
Ephemerellidae	0.73	Philopotamidae	0.01
Heptageniidae	1.76		
Leptohyphidae	1.87		
Leptophlebiidae	0.39		

Table 2. For the Hilsenhoff Biotic Index (HBI), organisms are assigned a tolerance number from 0 to 10 pertaining to that group's known sensitivity to organic pollutants; 0 being most sensitive, 10 being most tolerant (the names of the 16 pollution-sensitive taxa are in bold).

AMPHIPODA		HEMIPTERA	
Gammaridae	4	Corixidae	5
ANNELIDA		LEPIDOPTERA	
Hirudinea	10	Noctuidae	NA
BIVALVIA		Petrophila	NA
Sphaeriidae	6	ODONATA	
COLEOPTERA		**Aeshnidae**	8
Dytiscidae	5	Coenagrionidae	6
Elmidae	4	**Gomphidae**	3
Gyrinidae	4	Lestidae	3
Haliplidae	5	**Libellulidae**	2
Hydrophilidae	5	PLECOPTERA	
COLLEMBOLA	5	**Perlidae**	2
DECAPODA		**Perlodidae**	2
Astacidae	6	**Pteronarcyidae**	0
Palaemonidae	6	PULMONATA	
DIPTERA		Ancylidae	6
Simuliidae	6	Lymnaeidae	6
Chironomidae	6	Physidae	8
Ceratopogonidae	6	Planorbidae	7
Dixidae	1	TRICHOPTERA	
Empididae	6	**Brachycentridae**	1
Stratiomyidae	7	**Glossosomatidae**	1
Syrphidae	10	**Helicopsychidae**	3
Tipulidae	3	Hydropsychidae	4
EPHEMEROPTERA		Hydroptilidae	4
Baetidae	5	Leptoceridae	4
Caenidae	6	**Limnephilidae**	3
Ephemerellidae	1	**Philopotamidae**	3
Heptageniidae	3		
Leptohyphidae	4		
Leptophlebiidae	3		

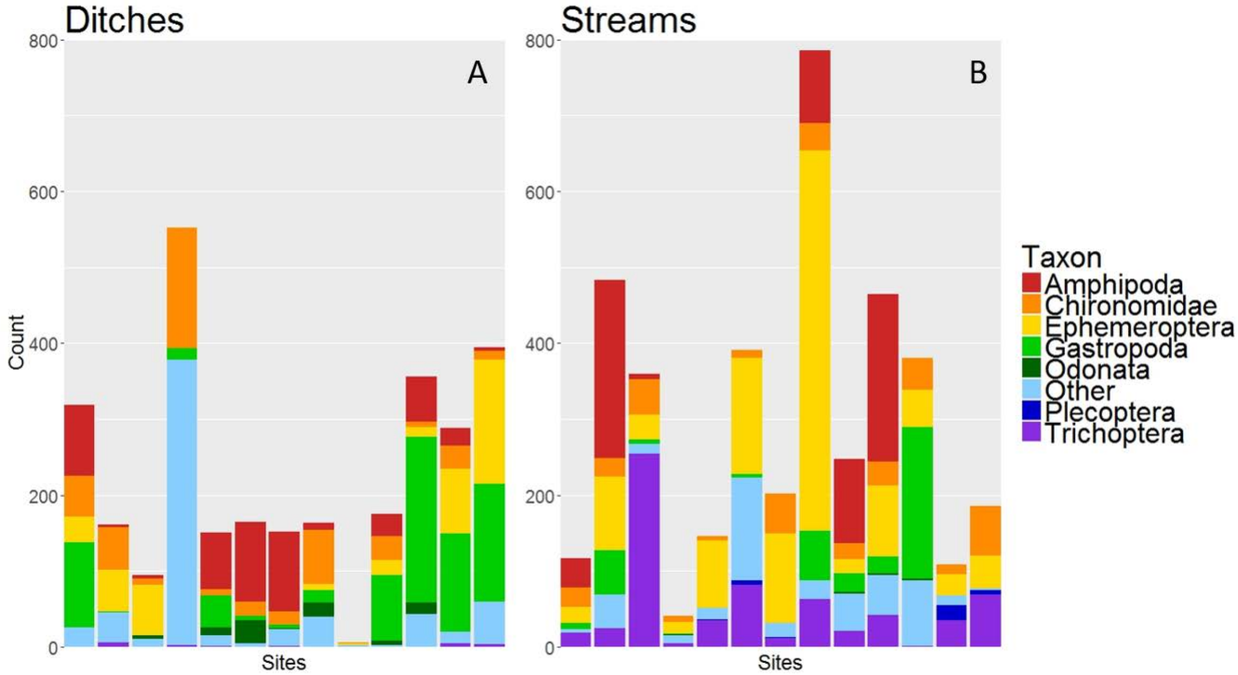

Fig. 3. Composition of dominant and pollution-sensitive taxa per site type: (A) ditches and (B) streams.

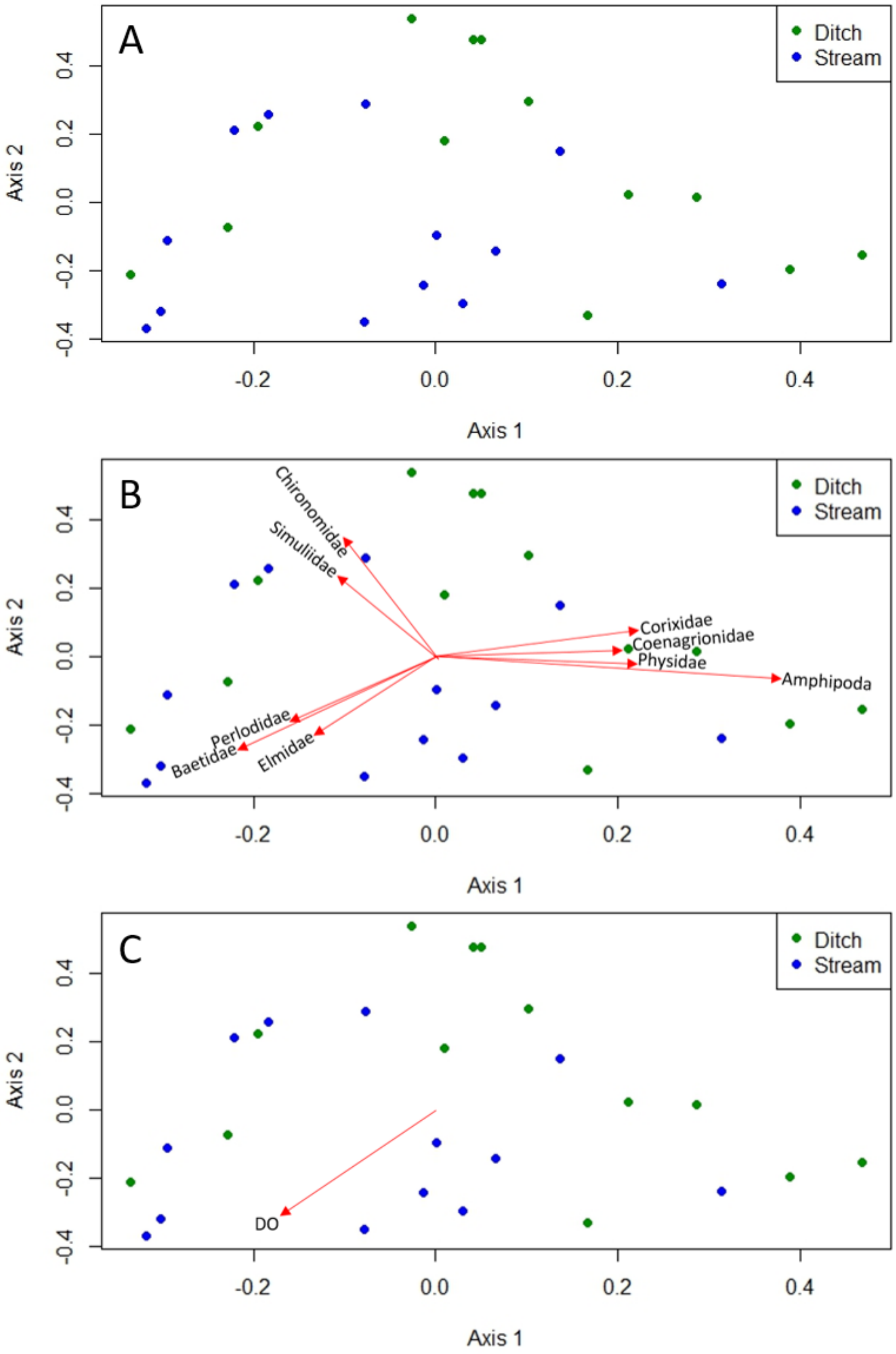

Fig. 4. Results of Principal Coordinates Analysis (PCoA) of (A) macroinvertebrate assemblages, (B) overlain with macroinvertebrate correlation vectors, and (C) overlain with physiochemical parameters. For both B and C, vectors on the ordination were significant at the *p* = 0.05 level.

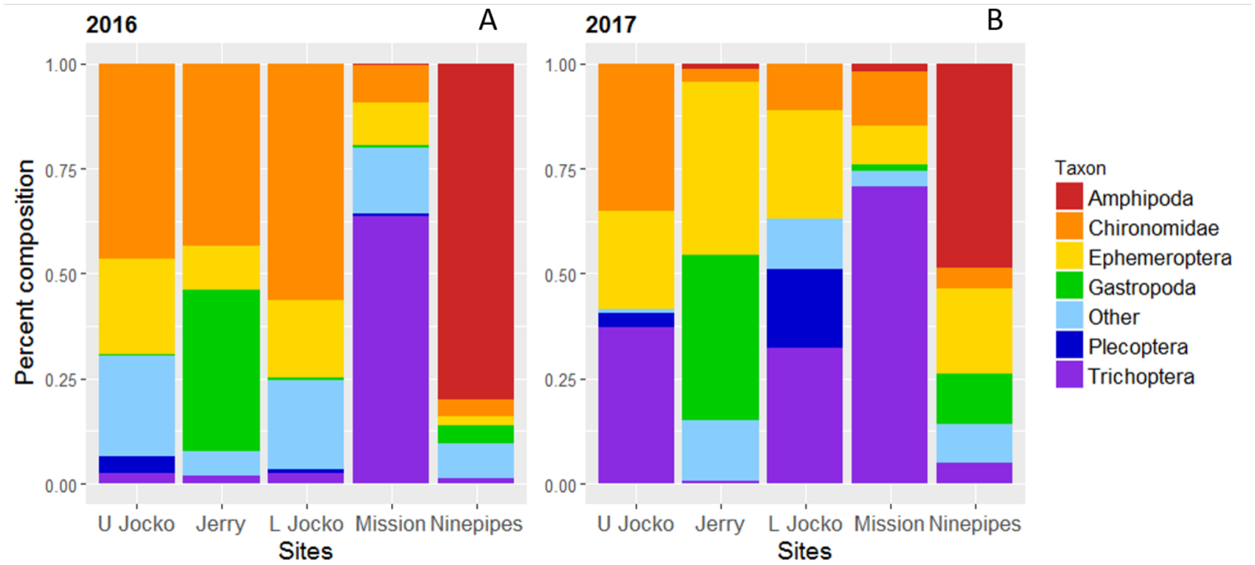

Fig. 5. Relative abundance of macroinvertebrate taxa collected from each sampling site over a period of two years: (A) 2016 and (B) 2017.

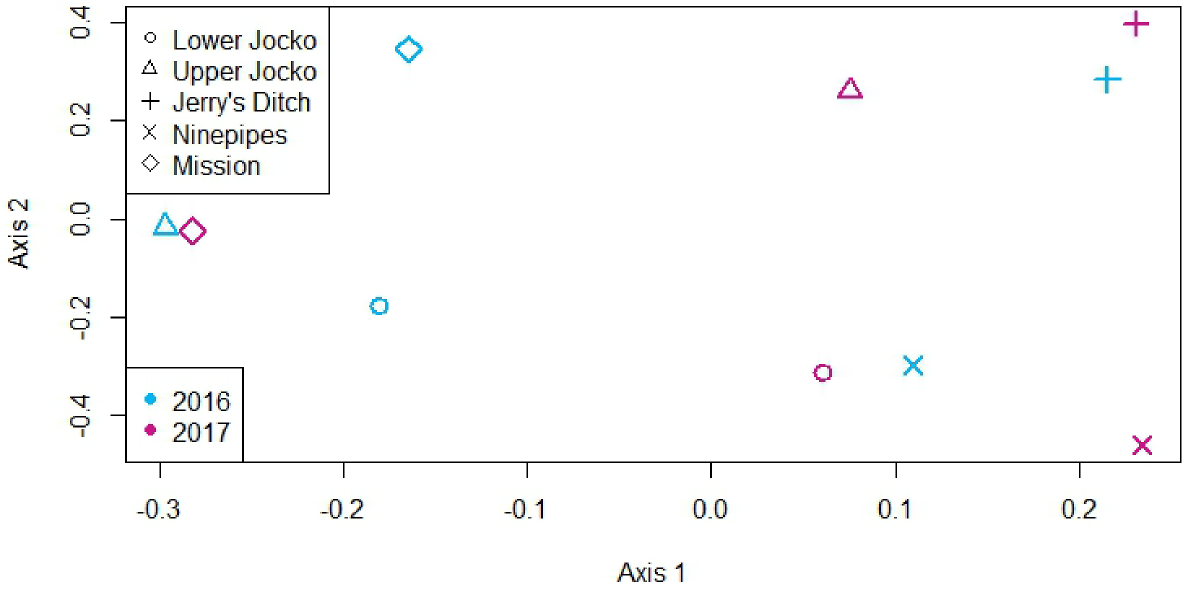

Fig. 6. Results of Principal Coordinates Analysis (PCoA) of macroinvertebrate assemblages in 2016 and 2017.