The Relationship between land-cover and aquatic macroinvertebrate communities of four water bodies in Western Montana, USA

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Abstract

The health and biodiversity of streams is invaluable from both land management and wildlife preservation perspectives. We sampled 5 river, creek, and manmade ditch sites in western Montana to assess water quality and relate macroinvertebrate community diversity to adjacent land cover. In this study we quantitatively and qualitatively described the benthic macroinvertebrate communities of four different lotic systems. Diversity indexes were calculated including Simpsons (as the baseline response variable), richness, and Percent Model Affinity (PMA) along with several others and used in a stepwise regression to determine the best model to predict Simpson's Diversity. Aquatic macroinvertebrate richness and PMA were the best predictors of Simpson's Diversity based on p-Values and the AIC. Future studies should investigate both land cover and the physical and chemical characteristics in the water bodies studied.

Introduction

Streams are the blood vessels of the terrestrial ecosystem. Streams play a role in nutrient cycling and decomposition of plant material, and provide habitat to a variety of species of fish and macroinvertebrates. Streams are an important source of biodiversity within different landscapes, and benthic macroinvertebrates contribute to this biodiversity (Tonkin 2014). Biodiversity of streams provides an important food source for terrestrial animals, such as mink, which feed on freshwater mussels and crayfish, and bears, which prey on salmonid fish. A large portion of fish diet consists of macroinvertebrates, as different kinds of fish feed on various kinds of aquatic invertebrates. There is an evident biological cascade that depends on the large diversity provided a healthy stream ecosystem and good water quality. From headwaters to lower reaches, different communities of benthic macroinvertebrates exist (e.g., shredders such as stoneflies in headwaters, or caddisfly collector-gatherers in mid- and lower reaches). These communities contribute to the processing and downstream transport of dissolved organic matter (DOM) and fine particulate organic matter (FPOM) (Vannote et al. 1980) contributing to the cleanliness and health of the stream environment.

The Moiese Valley is a large agricultural community in Western Montana on the Flathead Reservation where like everywhere in the western United States is concerned about water quality in the current environmental climate. The agriculture in the area is largely industrial cattle, wheat, and hay all of which require large sums of water to produce (Vorosmarty et al. 2000). These industries also have a stress effect on the local water quality due to the nutrient loading produced from runoff of fertilizers or manure into streams or bodies of water. Today's industrial agriculture uses a variety of harmful methods in trying to maximize their yields and profits. Pesticides are intended to kill insects indiscriminately, herbicides intended to kill weeds may also damage the diversity of the native flora, and fungicides are used directly in waterways. All of these industrial agriculture measures are harmful to the adjoined aquatic systems.

A good indicator of ecological health is the diversity of species that the ecosystem houses. When too many stressors enter a riparian system the water quality goes down and the sensitive macroinvertebrates cannot survive in the system any longer (Palmer et al. 2010). According to the Hilsenhoff Biotic Index (Barbour et al.) caddisfy's and stonefly's are sensitive to pollution, right-handed snails and crawling water beetles are facultative, and left-handed snails and worms are pollution tolerant. There are several biodiversity indexes or equations meant to calculate water quality with a rating system such as Hilsenhoff's (HIB), there is also percent Ephemeroptera, Plecoptera, Trichoptera (EPT) (DeWalt et al. 1999) percent model affinity (PMA) (Novak & Bode 1992), percent Chironomidae, abundance, and richness.

Another possible indicator of stream health is the adjacent land cover. Along the same lines as the diversity of taxa within the stream indicating good quality water, the diversity of flora abutting a stream would be a signal of a healthy riparian ecosystem. We sampled five river, creek, and manmade ditch sites in western Montana to assess water quality and relate macroinvertebrate community diversity to adjacent land-cover (Weigel et al. 1999). The assessment consisted of a quantitative and qualitative study describing the benthic macroinvertebrate communities in four different lotic systems. Using the quantitative data different metrics were calculated (such as the HBI, EPT, richness, etc.). Along with our data a land-cover database provided by the Montana State Government website was used to assess the relationship between water quality within the system and the bordering environment.

Methods

Sampling Sites:

Five locations within a 15-kilometer radius of The National Bison Range were sampled with the kick net method. The locations were chosen to represent various levels of water quality with distinct adjacent land cover. Three of the sites are located in two of the tributaries to the Flathead River, the Mission River and the Jocko River. The other two sites are man made either a canal or a ditch used for agricultural irrigation.

The Ninepipe location is the northern most location it is a wetland conservation site used as flood control. There is a canal originating from The Ninepipe Wildlife National Refuge used for irrigation in the Moiese agricultural valley. This is a man made canal where the substrate is silt and vegetation, and the adjacent land-cover is completely grassland.

The Mission River site selected is right under where the Moiese Wetland Restoration site empties into the river. The restoration consists of several wetlands meant to take wastewater from the Moiese Valley industrial agricultural ditches and filter out the pollution. This particular location is of interest for the people of the Flathead Reservation because of the investment made to build the wetland restoration site and the quality of their water. The Mission site is largest river sampled with various sized coble substrate and the adjacent land-cover is half grassland and half riparian woodland and shurbland.

The Jocko River was sampled at two spots, the Upper Jocko site is an upstream-isolated-braded location and the Lower Jocko site is downstream in more developed area. The region in Western Montana where the Jocko runs is mostly agricultural and there are irrigation ditches that enter and exit between the two selected sampling sites. The adjacent land-cover to the Upper Jocko is grassland, opened developed, and riparian woodland and shrubland while the land-cover on the Lower Jocko is classified as major roads, and riparian woodland and shrubland.

Jerry's Ditch is a site that runs though a ranching property in Dixion, Montana. The assumption for this site is that the water quality is impaired due to the nutrient loading produced by the cattle on the property. The substrate in Jerry's Ditch is similar to Ninepipe, entirely composed of silt and vegetation. The land-cover adjacent to the ditch is classified as low intensity residential and cultivated crops. All the land-cover type classifications can be seen on the map in the appendix (figure 1).

Sampling Methods:

Each of the five sites were sampled three times on different dates: 27 June 2016, 5 July 2016, and 20 July 2016. Every sampling event consisted of three kick net sweeps with a 150 mesh kick net. The Jocko locations where there was diverse substrate additional samples were taken. Three kick net sweeps were taken in a riffle, run, and pool on the Jocko River at either the upper or lower location to get comprehensive samples of the entire river system. Each sample was strained and preserved in %95 Reagent Alcohol. Each sample was processed under magnification; every macroinvertebrate within the sediment and vegetative material was collected, identified to order according to Dr. J. Reese Voshell, Jr.'s 'A Guide To Common Freshwater Invertebrates of North America' and counted as present with the stream the sample was taken from (Table 2, Figures 2-6).

Statistical Analysis:

GPS coordinates taken at each sampling location were used in ArcMap (Esri 2013) along with land-cover classification data obtained from the Montana Government website. The buffer tool was used to create a 15-meter radius buffer around the sampling sites. Then the land-cover classification layer was clipped to just the 15-meter radius to obtain the percentage of land-cover type directly adjacent to each sampling site. There were seven land-cover types for all five of the sampling locations: Type1 is Northern Rocky Mountain lower montane riparian wooland and shrubland, Type2 is Rocky Mountain lower montane foothill and valley grassland, Type3 is cultivated crops, Type4 is open water, Type5 is major roads, Type6 low intensity residential, and Type7 is open developed.

Several metrics were calculated prior to statistical analysis from the raw macroinvertebrate count data. All the metrics are diversity indexes intended to relate the quality of the water or the stream health to the diversity and abundance of present macroinvertebrates. The baseline metric used was Simpsons index but also calculated for comparison: HBI, EPT, PMA, percent Chironomidae, abundance, and richness.

The type land-cover percentages and each of the metrics are used to preform a forward stepwise regression analysis in Systat Version 13 to obtain the Akaike Information Criterion (AIC) values given in Table 1. Using Simpsons diversity index as our standard for good quality water and a healthy stream habitat, we compared both the land-cover types and the calculated metrics against it as our initial analysis. As follow up analysis we took land-cover type and calculated metrics as individual categories and preformed the forward stepwise regression on them individually. A principle components analysis was also preformed in Systat Version 13 to visualize the relationships among all of the variables (figure 8). In R package “mvabund” (Wang et al. 2016) we preformed an ordination and a generalized linear model on the raw macroinvertebrate count data to visualize the similarities by groupings (figure 9). Because this is abundance data, which is typically non-normal “mvabund” takes that into account and is able to sort through the non-normalcy accordingly.

Results

The ordination ran in R shows clear groupings based on similarities in the raw count data. Each site had distinct taxanomic groups and varying abundance. The dominant family in the order Diptera in the Lower Jocko, Upper Jocko, and in Jerry’s Ditch was the Chironomidae. Jerry’s Ditch had the least total abundance with only 70 specimens collected, the Upper Jocko had the most abundance with 1067 specimens collected. The Mission site was the second most abundant with 735 collected specimens with the dominant order being Trichoptera.

The stepwise regression using all of the factors (land-cover type and the calculated metrics) gave PMA and richness as the leading predictor variables in determining water quality (Simpsons diversity) (Table 1).

Then we wanted to see what the leading predictor variable would be if we looked at each category individually, land-cover type and calculated metrics. When taking only the calculated metrics for stepwise regression against the Simpsons response variable both richness with a p-Value of 0.00 and a PMA p-Value of 0.048 gave us the lowest AIC value of -71.177. When taking land-cover type as the only predictor variables, Type1 is the strongest predictor variable with a p-Value of 0.004 and an AIC value of -49.771. The PCA shows a clear relationship between Simpsons, richness, abundance, Type1, and Type7.

Discussion

There is a clear positive relationship between Simpsons, richness, and Type1 land-cover. This means that the Northern Rocky Mountain lower montane riparian woodland and shrubland land-cover type is positively correlated with higher diversity of macroinvertebrate population. The higher the Simpsons diversity value or richness of species in a stream system would indicate good water quality and a healthy aquatic ecology.

It is natural that when analyzing all of the factors against the Simpsons response variable the richness and PMA are the leading predictor variables. When analyzing only the calculated metrics against Simpsons it makes sense that richness and PMA would also be the strongest predictor variables. The fact that richness got a p-Value of 0.00 when compared with Simpsons diversity index means that because richness is a factor in calculating Simpsons index you would expect there to be a direct relationship between the two metrics. Since the two, Simpsons and richness are so similar one could use richness in place of Simpsons as a quick estimate of the health of a stream and in turn water quality in the stream system (McGuire 2006).

The Principal Components Analysis also shows that there are similarities in Simpsons, richness, PMA, and Type1 but suggests that Type7, abundance, EPT, and Chiro may also be good indicators of diversity and water quality (figure 8). While the ordination confirms that the macroinvertebrate populations are consistent within each sampling location during the three separate sampling events.

Upper Jocko proved to be the most abundant site and this is likely because there were distinct substrate areas sampled separately but we chose to include the samples in our statistical models to enhance the strength of the analysis by utilizing all of the data we collected. Thus there was a variety of microhabitats that could be utilized by a diverse assemblage of benthic invertebrates. The Mission had a large number of Trichoptera, which are a sensitive taxa. The Upper Jocko and Mission had the highest Simpsons scores respectively (Table 2). The Upper Jocko had the least altered land-cover and was in an area classified as Northern Rocky Mountain lower montane riparian woodland and shurbland which was the land-cover type found to have the most influence on the macroinvertebrate diversity. The Mission site was in an area that had been developed as a wetland restoration site so the fact that it has the second best Simpsons scores and a high number of the sensitive taxa Trichoptera suggests that the water quality there is better than at either agricultural site (Jerry's Ditch and Ninepipe).

Clearly there is a relationship between land-cover type and the health of a lotic system (Wang et al. 2011). When choosing our sites we went out physically and looked for different types of lotic systems to compare. In future studies it would be interesting to find multiple locations with a certain land-cover classification and do replicates and then compare with other land-cover type replicates. Also we were not able collect other metrics such as velocity, temperature, dissolved oxygen, etc. that would be important in telling the whole story of what is going on in a river system.

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Tables

Table 1: This table gives the results of each forward stepwise regression done with the Simpson's Diversity Index as the response variable and Land-cover Types [Type1- Northern Rocky Mountain lower montane riparian wooland and shrubland, Type2- Rocky Mountain lower montane foothill and valley grassland, Type3- cultivated crops, Type4- open water, Type5- major roads, Type6- low intensity residential, Type7- open developed] and Calculated Metrics [EPT, PMA, HBI, percent Chironomidae, abundance, and richness] as the predictor variables.

Predictor Variables Inputs	Predictor Variables Selected	p-Value	R^2	AIC
Land-cover Type & Calculated Metrics	Richness, PMA	0.00, 0.048	0.805	-71.177
Land-cover Type	Type1	0.004	0.373	-49.771
Calculated Metrics	Richness, PMA	0.00, 0.048	0.805	-71.177

Table 2: Shows the number of each major family of macroinvertebrate counted at each location. These numbers were used to make the pie charts (figures 1-5). The range of Simpsons values are given, the Simpsons Diversity Index was calculated individually for each of the three sampling events at each location.

Taxa	Lower Jocko	Upper Jocko	Jerry's Ditch	Ninepipe	Mission
Chironomidae	326	492	50	15	63
Coleoptera	97	141	2	0	48
Diptera	6	111	4	8	53
Ephemeroptera	107	241	12	8	73
Plecoptera	4	41	0	0	5
Trichoptera	15	27	2	5	456
Worm	69	14	0	4	34
Scud	0	0	0	290	3
Simpsons Range	0.797-0.894	0.857-0.921	0.736-0.858	0.614-0.905	0.875-0.897

Figures

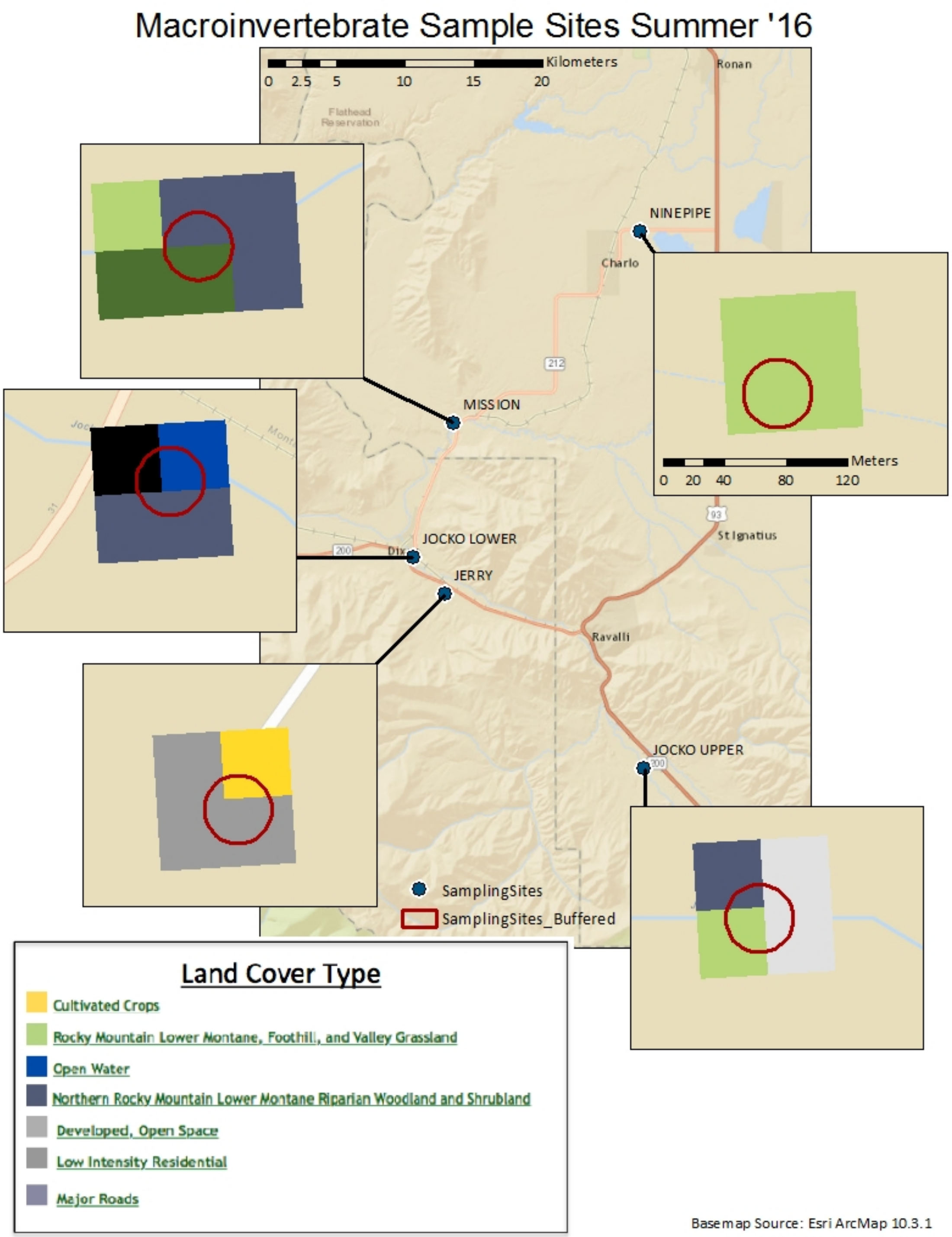
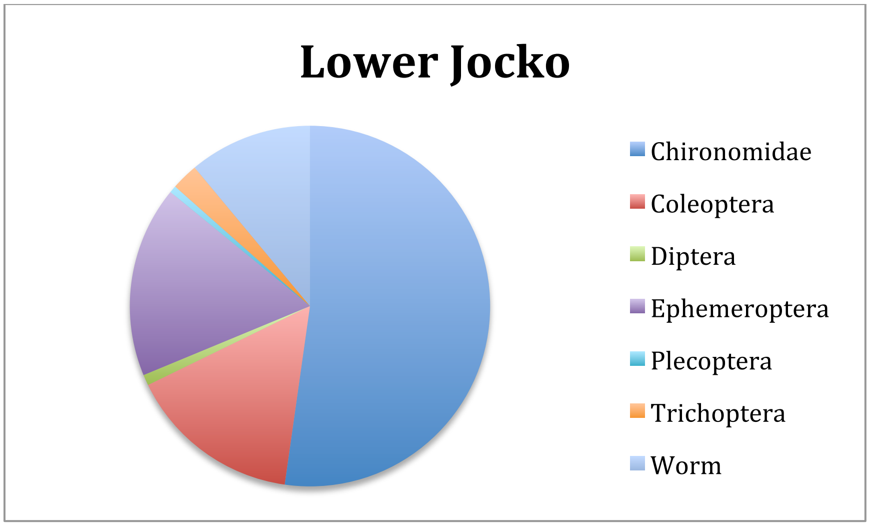
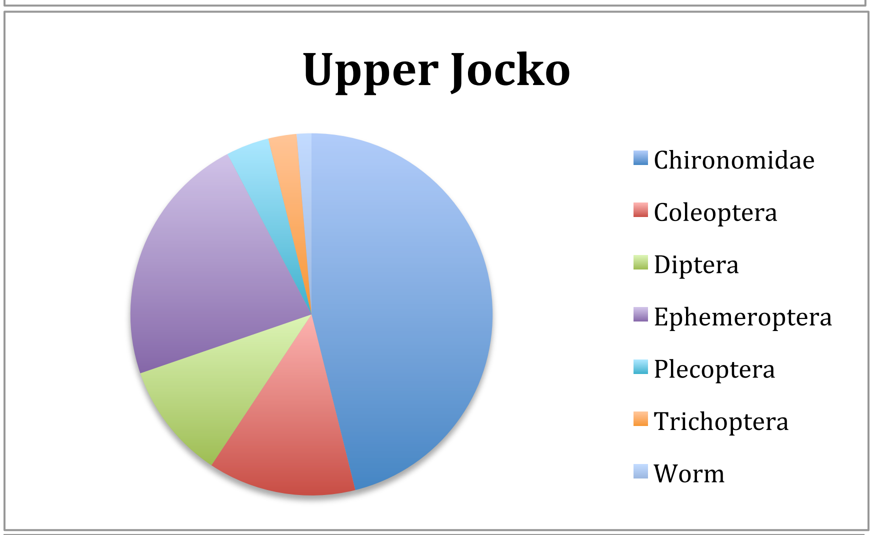
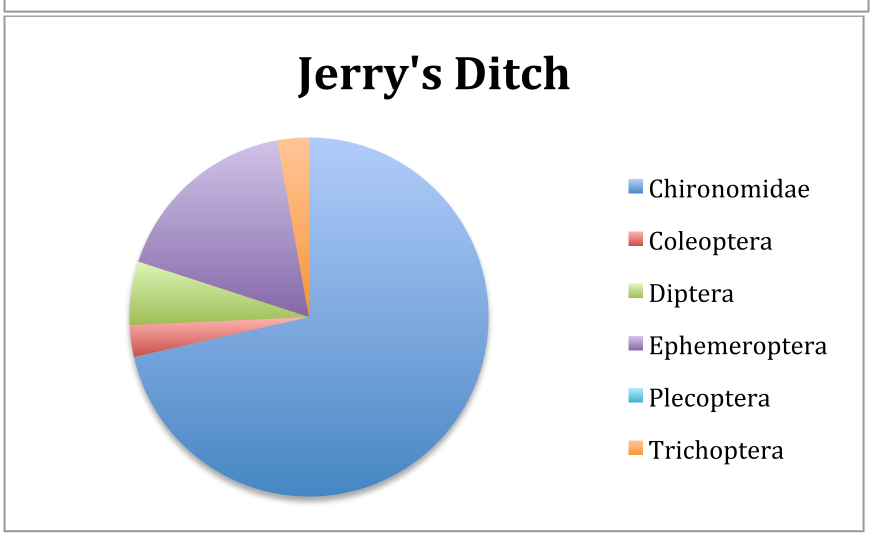
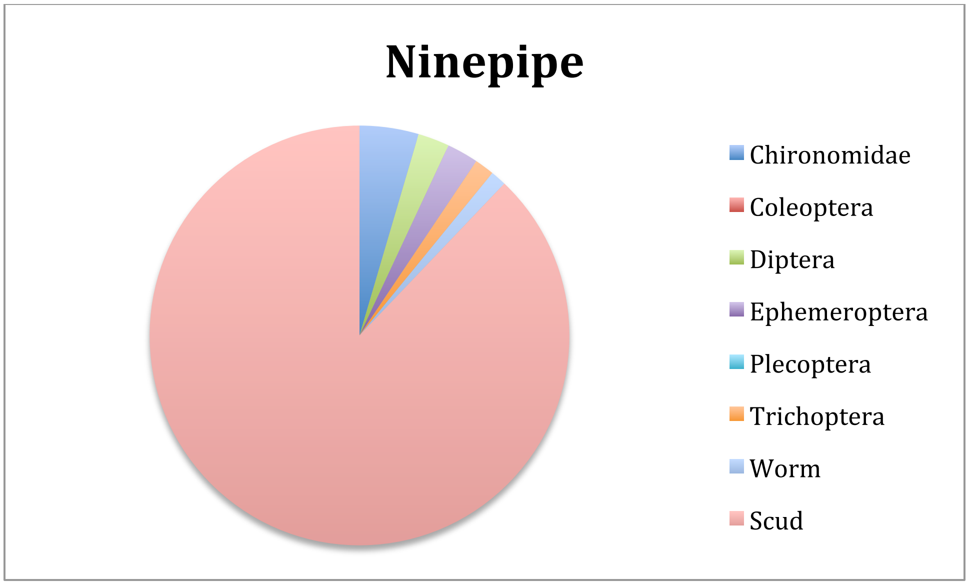


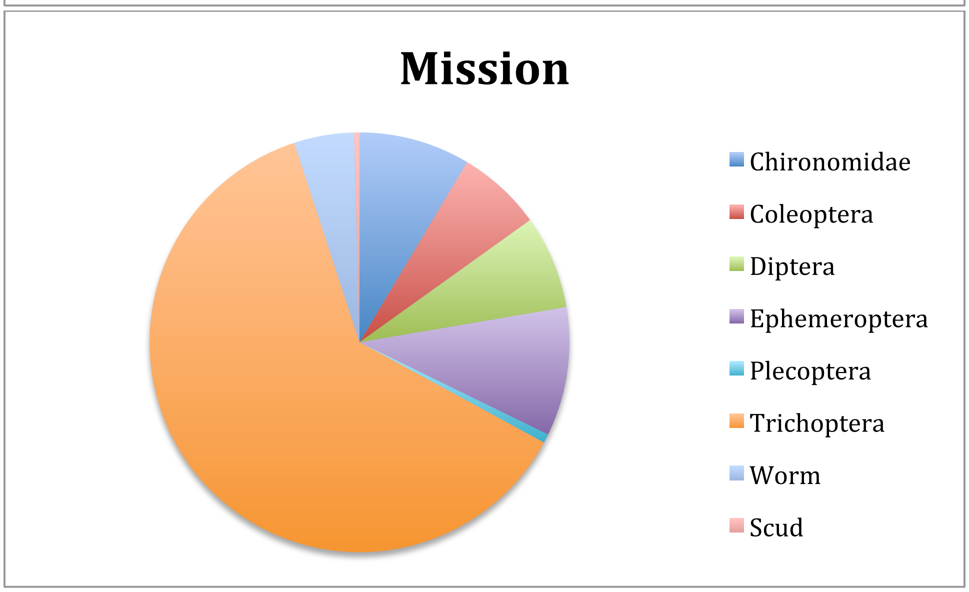
Figure 1: Map of sampling sites with land-cover types at each site.


Lower Jocko
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Plecoptera
Trichoptera
Worm


Upper Jocko
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Plecoptera
Trichoptera
Worm


Jerry's Ditch
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Plecoptera
Trichoptera





Figures 2-6: An individual pie chart for the most abundant families found at each site. The Jocko River and Jerry's ditch are similar in that the most abundant macroinvertebrate found at those sites are the Chironomidae which are mostly facultative. At Ninepipe the dominating macroinvertebrate are Scuds which are also mostly facultative. In Mission Trichoptera are the dominant taxa which are sensitive to pollution.

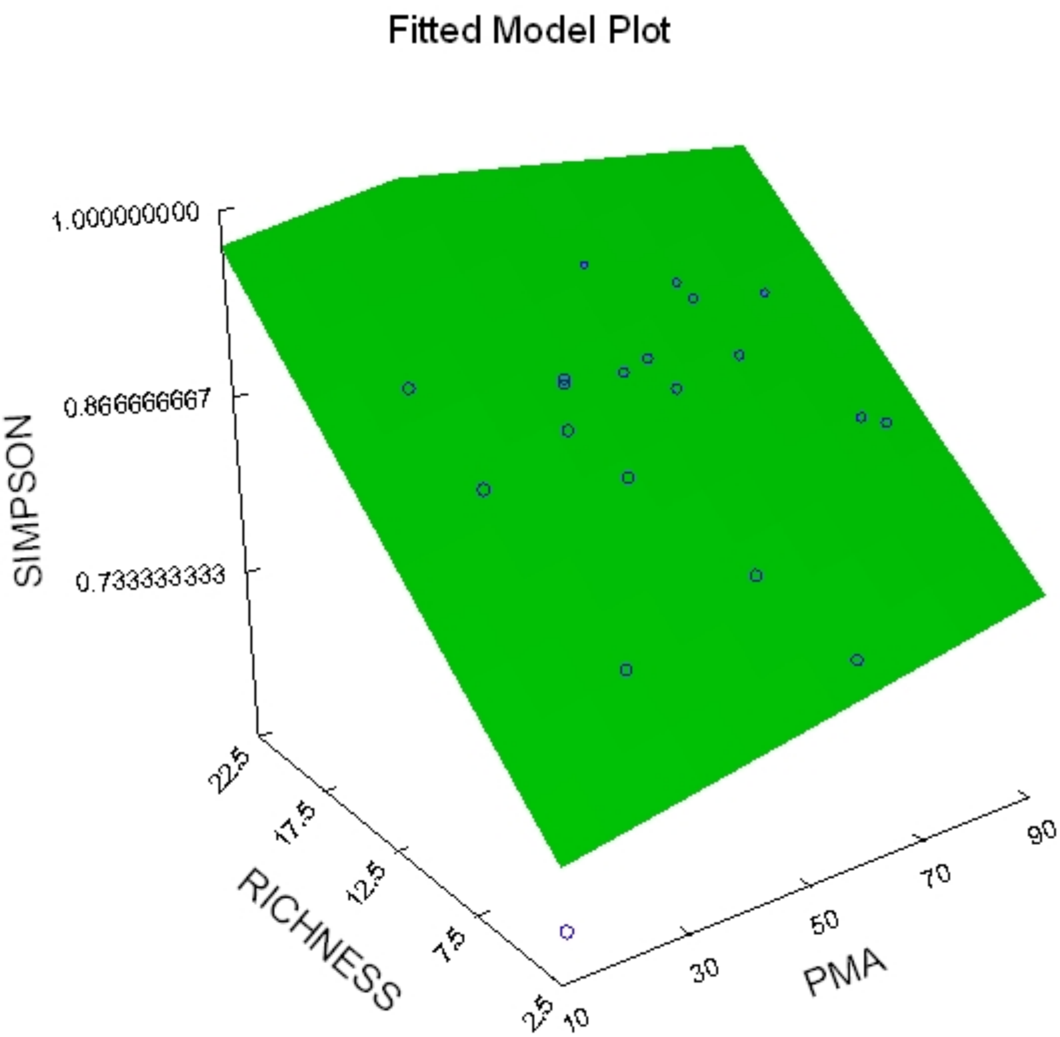


Figure 7: The result of the forward stepwise regression with inputs of all the factors i.e. land-cover type and calculated metrics, showing that richness and PMA are the strongest predictor variables in determining Simpsons diversity.

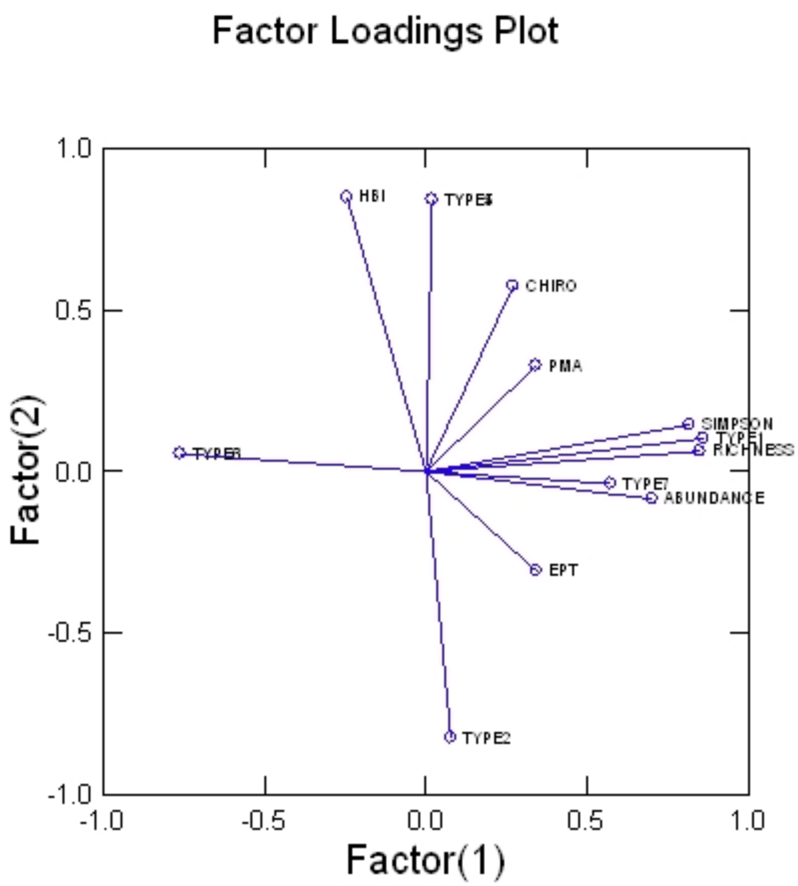


Figure 8: Principle Components Analysis preformed in Systat. This graph shows that there are strong similarties between Simpsons, Type1 land-cover, and richness at our sites but there seems to be a weaker yet still present relationship between the previous mentioned metrics and EPT and PMA.

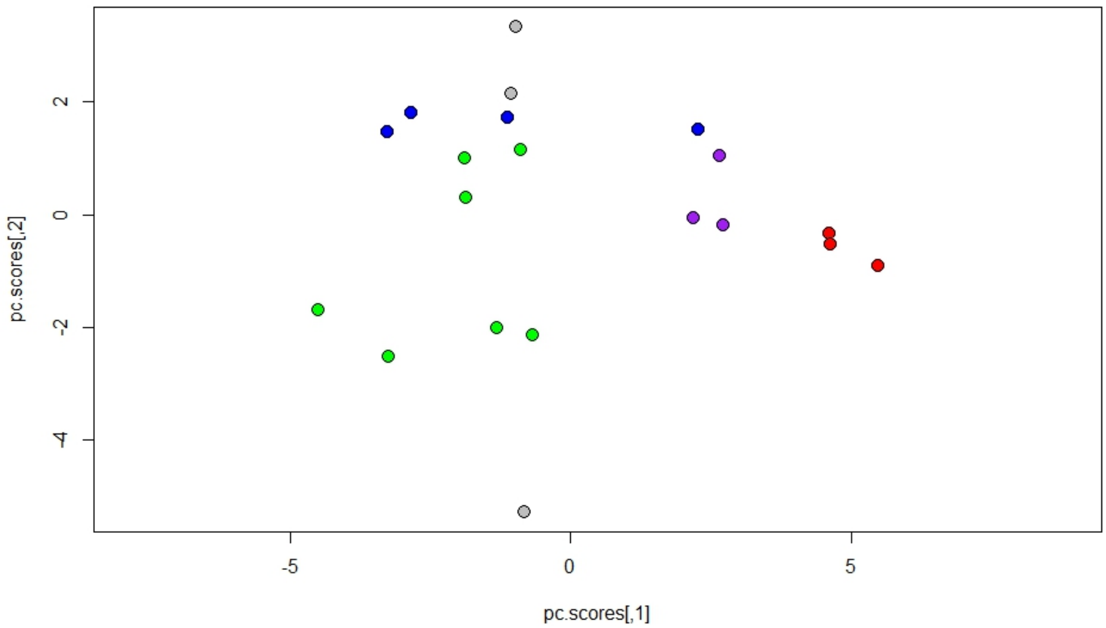


Figure 9: In R package "mvabund" we preformed an ordination and a generalized linear model on the raw macroinvertebrate count data to visualize the similarities by grouping. The sites are color coded: Mission- grey, Ninepipe- red, Jocko Upper- green, Jerry's Ditch- purple, Jocko Lower- blue. There are spatial distinctions from each sample collected at each site. The macroinvertebrate communities remained constant throughout the sampling period (late June to late July 2016).