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Use of macroinvertebrates for assessment of water quality of ponds within the Northfield region of the Cannon River Watershed

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Abstract:

Water is one of Minnesota's most abundant and precious resources. Therefore, developing a deeper understanding of local water quality parameters can serve to assess conservation practices, to inform of aquatic areas needing closer monitoring in the future, and to appraise the ecological risks the watershed could pose on surrounding ecosystems. In this study, water quality analysis was considered on two levels, chemically and biologically to evaluate the current state of the St. Olaf Natural Lands' ponds. Temperature, pH, dissolved oxygen, turbidity, and nitrogen content were monitored over a three week period with eight sample sites. These measurements were coupled with collection of aquatic macroinvertebrates. Statistical analysis concluded that there was a significant difference in dissolved oxygen ($p=0.0000000187$), conductivity ($p= 0.000000426$), and nitrates ($p= 0.0228$) among the four ponds studied. Big Pond had the lowest count of macroinvertebrates and the highest species richness, coupled with high oxygen levels (16.0 ppm) and low turbidity. In contrast, Regents Pond and Soccer Pond both demonstrated DO levels below 3 ppm and low macroinvertebrate richness, which raises concern for the health of aquatic life in those areas. Furthermore, levels of nitrates were significantly higher (0.47 and 0.29 ppm respectively) in the Regents Pond sites. Future analysis of land use is needed to understand how the ponds are being modified by anthropogenic activities regarding their biological, physical, and chemical conditions.

Introduction:

The Cannon River Watershed in southeastern Minnesota is home to several cities and many species of wildlife and fish. The shear abundance of lakes, streams, and wetlands encompassed by the watershed proves to be an invaluable resource both environmentally and economically in areas such as Northfield, Faribault, and Owatonna. In recent studies conducted by the Minnesota Pollution Control Agency (MPCA) to determine if lakes and streams are meeting water quality standards, a vast majority failed to meet standards on a consistent basis. Significantly, fish and macroinvertebrate communities have shown a loss of sensitive species due to water pollution and habitat issues (DeZiel et al. 2014). Furthermore, the researchers speculate that land use changes in vegetation, loss of wetlands, ditching, urban development, and over application of fertilizers have all likely contributed to the observation of algal blooms, potentially unsafe swimming conditions, fishing advisories, drinking water impairments, and loss of sensitive aquatic species in these watershed ecosystems. Because the water's health is essential to human quality of life and to sustaining aquatic life, additional measures are needed in order to improve and protect water quality throughout the Cannon River Watershed.

Today, the Cannon River Watershed is comprised of a variable mix of agriculture, forest, and developed land (DeZiel et al. 2014). Each of these land use zones, including prairie, are represented in the Northfield, MN region of the watershed, and specifically the St. Olaf College Natural Lands will be the primary focus of this study. The natural lands are characterized by fifteen wetlands having been restored starting in 1992. These wetlands range in size from small ephemoral (temporary) ponds, up to 9 acres of surface water. All wetlands are surrounded by other natural areas (prairie and woodlands) to buffer them from agriculture and development runoff. The wetlands help with seasonal flood control, soil stability and ground water recharge as well as provide valuable wildlife habitat.

To assess the relative "impairment" level of the natural lands' watershed, four ponds were monitored chemically with subsequent sampling of macroinvertebrates. Aquatic species such as macroinvertebrates are often sensitive to changes in their habitats, making them bioindicators for the health of that entire habitat. Macroinvertebrates are useful in assessing the Northfield region of the watershed because they integrate information over longer periods, in comparison to chemical analyses which tend to present snapshots of the period when samples were taken. In fact, literature reviews of water assessments based on biological indicators identify at least 100 indices developed over the past ten years, in which about 60% are based on macroinvertebrates, more than for any other group of freshwater organisms (Uherek and Gouveia 2014). Furthermore, research indicates that some macroinvertebrates are very sensitive to stresses produced by pollution, habitat modification, or severe natural events, while others are more tolerant. Therefore, using macroinvertebrates for biomonitoring can provide significant insight into the health of an aquatic habitat by directly observing levels of diversity in response to ecological stressors.

The aim of the study was to determine changes in the ecological condition of the habitats in four restored wetlands (ponds) in the natural lands of St. Olaf College, to assess the adequacy of runoff mitigation by natural areas including restored prairie and forest, existing forest, sustainable agriculture, and sites of architectural development. Macroinvertebrates were used as biomarkers since their relative diversity and abundance provide information about the quality of the environment (Balan et al. 2017). Specific objectives of this study were to:

1. Observe the effects of water chemistry on macroinvertebrate species richness and biodiversity.
2. Compare the overall health of ponds using chemical and biological water quality parameters (temperature, DO, conductivity, pH, turbidity, nitrates, ammonia).

3. Use data collected to make recommendations about future monitoring and conservation practices.

Methods:

Study Area:

The St. Olaf Natural Lands are home to several wetlands restored starting in 1992, in partnership with the U.S. Fish and Wildlife Service Wetland Restoration program. These wetland sites, originally drained years ago for agriculture, were again identified by surveying and analyzing topographic maps. In the wetland sites undergoing restoration, dikes were constructed and field drain tiles were destroyed if present. This area of restoration was the primary focus of this study due to their position within the Cannon River Watershed. The four wetlands observed in this study were Big Pond, Soccer Pond, Baseball Pond, and Regents Pond (Figure 1).

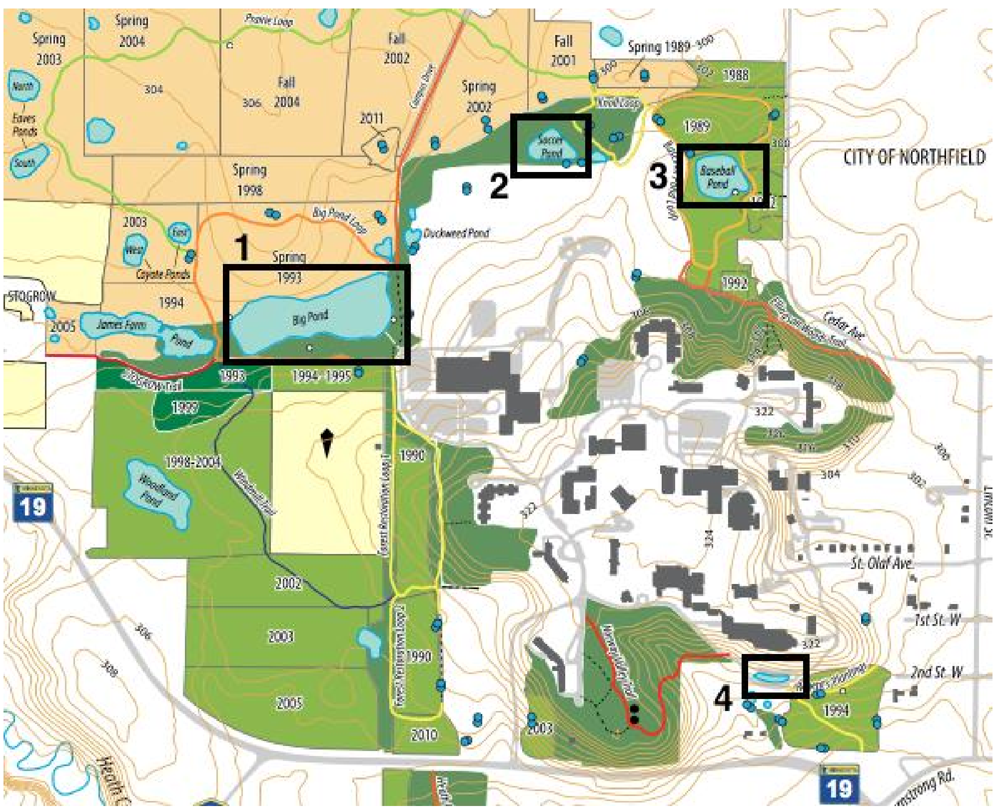

Figure 1. Map of St. Olaf Natural Lands indicating the four sites observed in this study: Site 1=Big Pond, Site 2= Soccer Pond, Site 3=Baseball Pond, Site 4= Regents Pond.

Sampling and Analytical Analyses:

The field work was carried out during Fall 2017, with data collection occurring once every week for a total of 3 weeks between October 20th and November 10th, 2017. The main chemical indicators of water quality were measured *in situ* using multiparametric digital probes (YSI Series). Parameters measured with the probe included: water temperature, pH, conductivity, and the concentration of dissolved oxygen in parts per million (ppm). These data were collected uniformly across all sites, with readings taken one meter from shore and the probe submerged to a depth of 10 cm. Each pond contained two equidistant sample sites for a total sample size of 8 per week. To collect data on ammonia and nitrogen content, water samples were also collected from each pond once per visit. Then, the samples were frozen and tested in the lab using SmartChem technology. The total sample size for this analysis was 24.

Biological Analyses:

For the ponds identified, macroinvertebrates were sampled in triplicate using 1 sq. ft. plots located one meter from the shore. Using a dip net, the upper 5 cm of the substrate was skimmed for each sample. In the lab, macroinvertebrates were organized, counted, and identified by order using sorting trays, microscopes, and identification keys. This process was repeated three times over three weeks for site one in each pond to gain a sufficient representation of the ponds' chemical and biological composition.

To statistically analyze the data, R-commander was used to perform one-way ANOVA tests comparing means of each chemical property recorded across all 8 sites. Based on prior research, it also seemed beneficial to calculate species richness, Shannon diversity index, and Simpson diversity index for the macroinvertebrate populations of each pond. The Simpson index represented the probability of selecting two individuals of the same species (Brower, Zar, vonEnde, 1998). The Shannon diversity index gave the numerical representation of the species richness and evenness (Brower, Zar, vonEnde, 1998). Then, a t-test was conducted to determine if the Simpson indices of each pond were significantly different from each other. This was signaled from a t-value different from the expected value. Furthermore, data for temperature and dissolved oxygen were graphed and analyzed via linear regression to observe trends between the two variables.

Results:

Chemical Results:

The eight ponds analyzed using ANOVA showed significant results for dissolved oxygen (p=0.0000000187), conductivity (p= 0.000000426), and nitrates (p= 0.0228) (Table 2). More specifically, Big Pond was characterized by dissolved oxygen levels above 15ppm, meanwhile Regents Pond and Soccer Pond showed values as low as 1.5 and 1.4ppm respectively (Tables 1 and 2, Figure 2). Conductivity was highest in Regents Pond site 1 (185.03 μS/cm) and lowest in Baseball Pond sites 1 and 2 (107.13 and 107.57 μS/cm, Tables 1 and 2, Figure 3). Nitrates were also highest in Regents Pond (0.47 and 0.30 ppm) in comparison to other sites which had concentrations of approximately 0.02ppm (Tables 1 and 2, Figure 4). Temperature, pH, turbidity, and ammonia showed insignificant results for this study (Table 2). Using linear regression to analyze temperature in relation to dissolved oxygen also showed no significant trend (R^2= 0.04482) (Figure 5).

Biological Results:

Overall, Big Pond demonstrated the lowest abundance of macroinvertebrates with the highest species richness (41 individuals, 5 orders) (Table 10). In contrast, the lowest species richness was observed in Baseball Pond (2 orders). All ponds were dominated by O. Amphipoda, except for Big Pond which was dominated by O. Ephimeroptera (Table 10). The calculation of the Shannon indices resulted in Big Pond having a larger index value (0.42) than all other ponds studied. Likewise, Big Pond had the largest Simpson index (0.48) of the three ponds studied (Table

10). Furthermore, data from Regents Pond produced a much lower value of 0.07 for both indices. To determine if the index values were significantly different, a t-test was conducted to compare Simpson index values between ponds. This resulted in significant differences between Big Pond (0.48) and both Regents Pond (0.07) and Soccer Pond (0.18). There were also significant differences between Baseball Pond (0.41) and Regents Pond (0.07), and Soccer Pond (0.18) and Baseball Pond (0.41) (Table 11).

Discussion:

Big Pond had the lowest count of macroinvertebrates and the highest species richness, coupled with high oxygen levels (16.0 ppm) and low turbidity. Therefore, Big Pond can be considered a relatively healthy ecosystem due to its ability to support great biodiversity. In contrast to other sites that were dominated by O. Amphipoda (semi-tolerant to pollutants), this pond was dominated by O. Ephimeroptera (mayfly) which is semi-sensitive to pollutants. Mayflies are considered "indicator species" because they require a high amount of dissolved oxygen to live, and therefore they are indicative of the water in which they are living. In the ponds dominated by O. Amphipoda, data confirm the findings of the study conducted by the Minnesota Pollution Control Agency (2014) suggesting that macroinvertebrate communities across the watershed are showing a loss of sensitive species due to water pollution and habitat issues (DeZiel et al. 2014). Due to the shallow water columns observed and the patterns of runoff into Big Pond, we can predict that terrestrial zones (prairie and forest) play a significant role in buffering contaminants that originate through horizontal interactions between the wetland and its surrounding environment.

In contrast, Regents Pond and Soccer Pond both demonstrated DO levels below 3 ppm and low macroinvertebrate richness, which raises concern for the health of aquatic life in those areas. Although the edge effects of Soccer Pond are understudied, these results are consistent with prior research indicating that urbanized ponds with shoreline development have significantly lower species diversity (Gagne and Fahrig 2007). Furthermore, levels of nitrates were significantly higher (0.47 and 0.29 ppm respectively) in the Regents Pond sites. Therefore, it is possible that Regents Pond's loss of an essential 'vegetation buffer,' which controls the amount of nutrient influx in runoff, contributes to an increase in nitrates. Studies also show that an increase in such pollutants can lead to a decreased survivorship of some species (Sanzo and Hecnar 2006), and thus a decrease in species diversity which was observed in both sites.

Aquatic conservation and future studies

It is important to observe and manage the interaction of human land use on nearby aquatic systems in order to cause minimal negative impact on the natural ecosystem. Conservation efforts should be careful to take into account the potential effects of run-off at the Regents Pond site as well as at locations downstream from the source of pollution. Adding natural buffers at this site could significantly regenerate the health of the macroinvertebrate community as well as improve overall water quality. In the future, monitoring of all ponds in the St. Olaf Natural Lands, over an extended period of time, will be crucial to creating efficient policies of regulation and conservation that can improve the health of the watershed.

Conclusion:

Overall, this study attempted to gain a better understanding of the health of Northfield ponds using chemical and biological indicators of water quality. Local monitoring by citizens is an important component of monitoring the Cannon River Watershed and is recommended by the results of this study, whereby many freshwater zones are deemed "impaired" and several wetlands are showing the effects of elevated nutrient concentrations and reduction in sensitive macroinvertebrate species. Although the definition of a healthy ecosystem is debated in the literature, most researcher agree that a primary threat to freshwater ecosystems is the rapid changes occurring in land uses (Fierro et al. 2017). Therefore, identifying chemical and biological changes arising from anthropogenic impacts is crucial for managers and policy makers to make informed decisions towards improving the environment and, consequently, human health.

Acknowledgements:

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Figures and Tables:

Table 1. Table of raw measurements and calculated means for the 8 sites studied (BP=Baseball Pond, GP=Big Pond, RP=Regents Pond, SP=Soccer Pond).

Sample ID	Date	Temp (C)	DO (mg/L)	Conductivity	pH	Turbidity (%)	NO3 (ppm)
BP-1	10/28/17	3.6	7.34	114.9	8.6	31.43	0.0569
	11/3/17	3.1	7.74	101.4	9.3	34.69	0.4883
	11/7/17	3.4	5.23	105.1	3.0	58.23	0.0876
		3.37	**6.77**	**107.13**	**6.97**	**41.45**	**0.21**
BP-2	10/28/17	3.5	8.82	109.6	8.3	73.17	-0.0034
	11/3/17	3.9	8.32	106.2	9.0	100.00	0.0171
	11/7/17	5.7	12.58	106.9	5.7	58.24	0.0603
		4.37	**9.91**	**107.57**	**7.67**	**77.14**	**0.02**
GP-1	10/28/17	3.6	13.7	145.1	8.3	54.55	0.0046
	11/3/17	3.6	14.65	139.6	8.6	54.57	0.0307
	11/7/17	4.5	19.65	143.7	4.5	32.63	0.0364
		3.90	**16.00**	**142.80**	**7.13**	**47.25**	**0.02**
GP-2	10/28/17	3.0	14.04	147.1	8.3	50.00	0.0364
	11/3/17	3.0	15.94	139.2	8.4	29.28	0.0228
	11/7/17	2.3	16.45	146.8	2.8	50.78	0.008
		2.77	**15.48**	**144.37**	**6.50**	**43.35**	**0.02**
RP-1	10/28/17	7.3	4.41	178.6	8.2	68.33	0.7569
	11/3/17	4.7	3.28	172.6	8.3	39.61	0.1992
	11/7/17	4.2	1.71	203.9	3.7	72.46	0.4621
		5.40	**3.13**	**185.03**	**6.73**	**60.13**	**0.47**
RP-2	10/28/17	5.7	2.76	145.5	8.1	39.29	0.1161
	11/3/17	4.2	0.96	145.2	8.4	74.67	0.6169
	11/7/17	3.6	0.78	165.9	4.1	100.00	0.1537
		4.50	**1.50**	**152.20**	**6.87**	**71.32**	**0.30**
SP-1	10/28/17	4.6	1.05	109.7	8.2	29.41	0.0125
	11/3/17	3.2	1.58	130.4	8.6	54.56	0.0193
	11/7/17	2.6	1.57	131.8	2.4	71.46	0.0193
		3.47	**1.40**	**123.97**	**6.40**	**51.81**	**0.02**
SP-2	10/28/17	3.9	7.84	128.3	8.2	89.74	0.0057
	11/3/17	3.4	5.63	138.9	8.5	80.39	0.0193
	11/7/17	3.3	7.45	142.8	3.3	57.65	0.0649
		3.53	**6.97**	**136.67**	**6.67**	**75.93**	**0.03**

Table 2. Table of means for chemical parameters with significance values.

Sample ID	Temp (℃)	DO (mg/L)	Conductivity	pH	Turbidity (%)	NO3 (ppm)	NH3 (ppm)
BP-1	3.37	6.77	107.13	6.97	41.45	0.21	0.41
BP-2	4.37	9.91	107.57	7.67	77.14	0.02	0.04
GP-1	3.90	16.00	142.80	7.13	47.25	0.02	0.15
GP-2	2.77	15.48	144.37	6.50	43.35	0.02	0.20
RP-1	5.40	3.13	185.03	6.73	60.13	0.47	0.14
RP-2	4.50	1.50	152.20	6.87	71.32	0.30	0.12
SP-1	3.47	1.40	123.97	6.40	51.81	0.02	0.10
SP-2	3.53	6.97	136.67	6.67	75.93	0.03	0.04
p-value	**0.0773**	**0.0000000187*** **	**0.000000426*** **	**1**	**0.165**	**0.0228***	**0.0593**

Table 3. ANOVA Table for temperature.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	14.15	2.0218	2.322	0.0773
Residuals	16	13.93	0.8708		

Table 4. ANOVA Table for dissolved oxygen (DO).

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	703.8	100.54	34.09	0.0000000187***
Residuals	16	47.2	2.95		

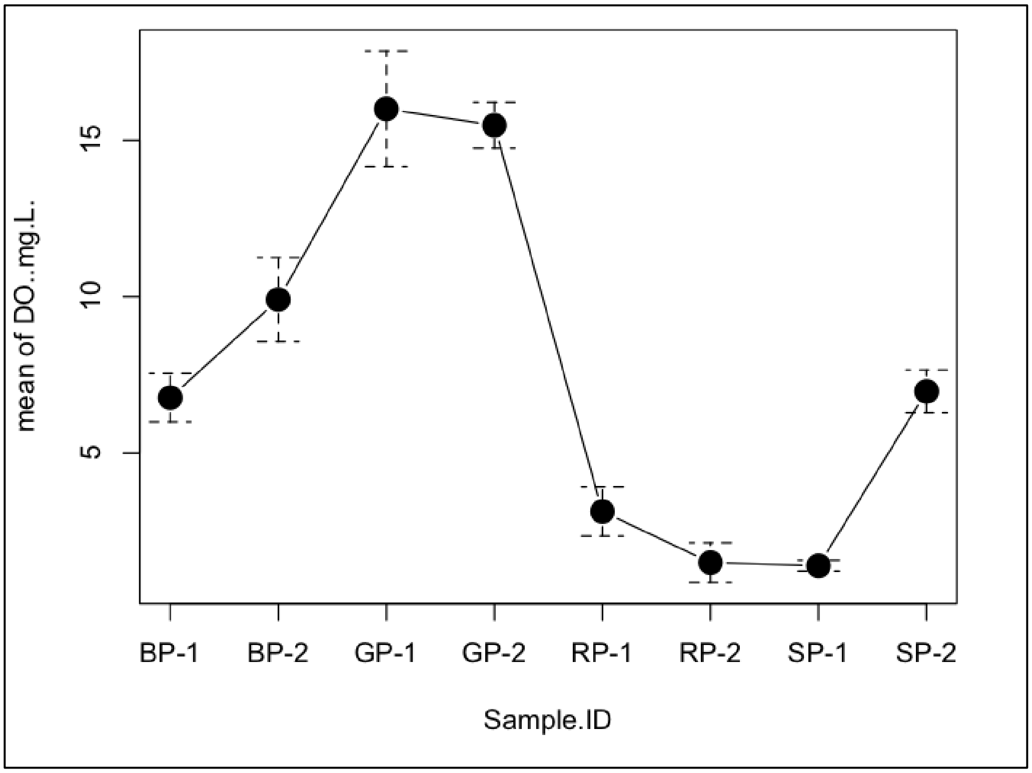

Figure 2. Plot of Means for dissolved oxygen (DO).

Table 5. ANOVA Table for conductivity.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	13658	1951.2	22.1	0.000000426***

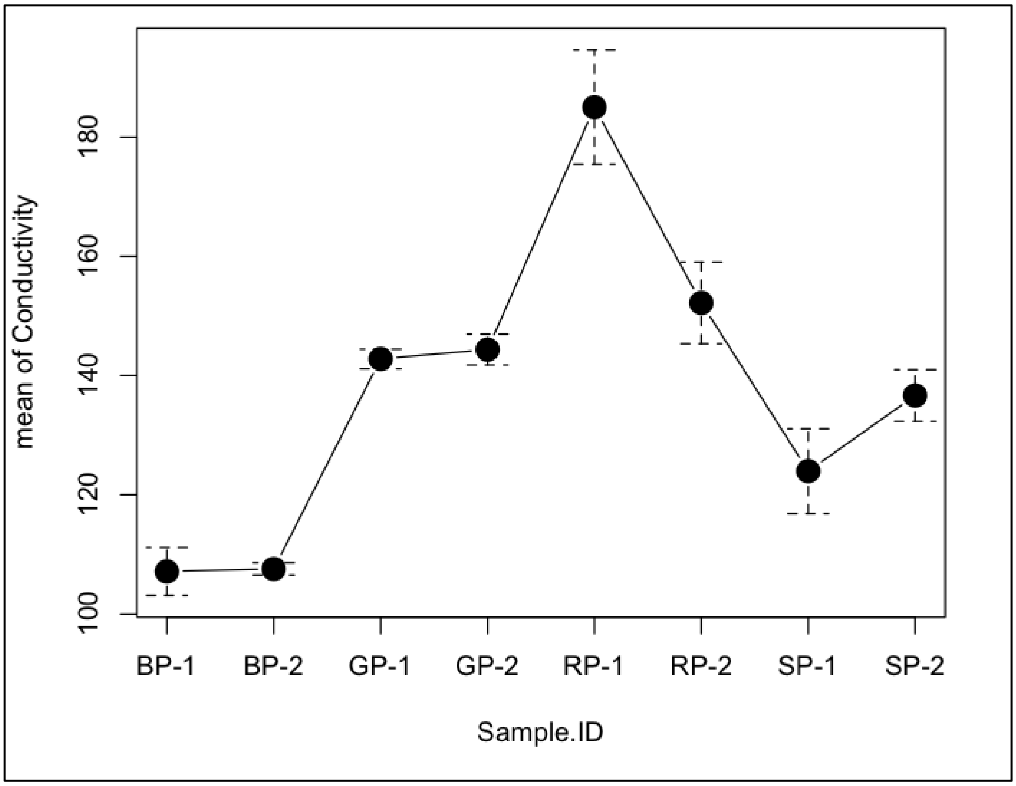

Figure 3. Plot of Means for conductivity.

Table 6. ANOVA Table for pH.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	3.39	0.485	0.061	1
Residuals	16	127.34	7.959		

Table 7. ANOVA Table for turbidity.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	4529	646.9	1.76	0.165
Residuals	16	5882	367.6		

Table 8. ANOVA Table for nitrates.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	0.6232	0.08902	3.296	0.0228*
Residuals	16	0.4322	0.02701		

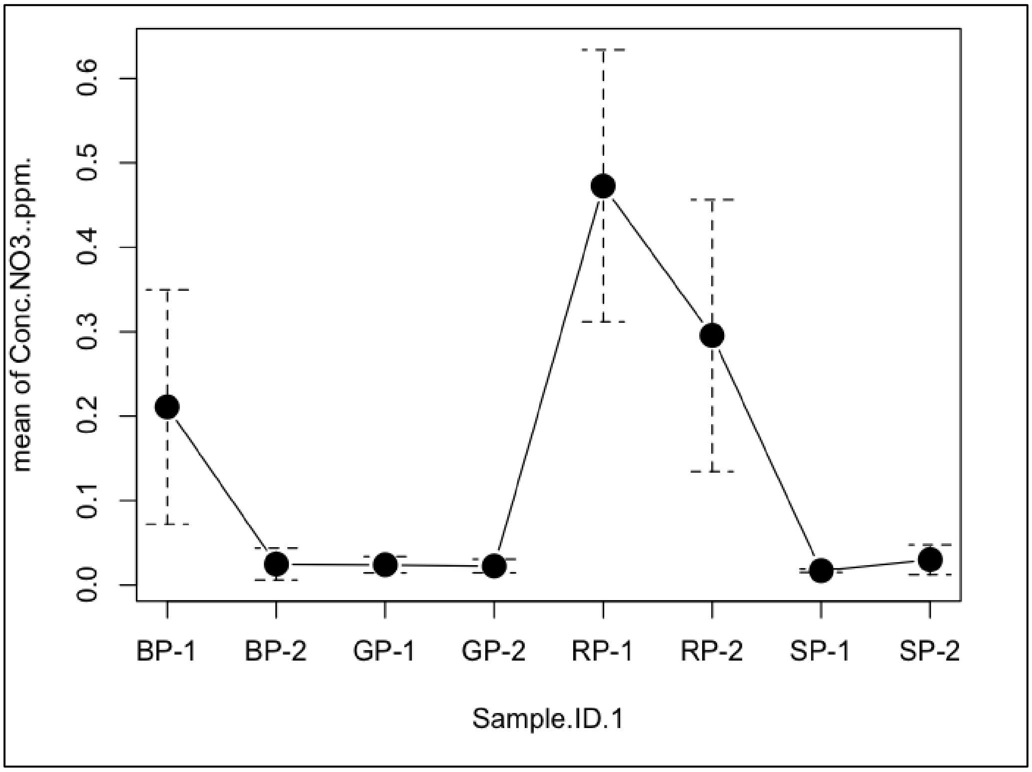

Figure 4. Plot of Means for nitrates (ppm).

Table 9. ANOVA Table for ammonia.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Sample ID	7	0.2847	0.04067	2.568	0.0593
Residuals	15	0.2376	0.01584		

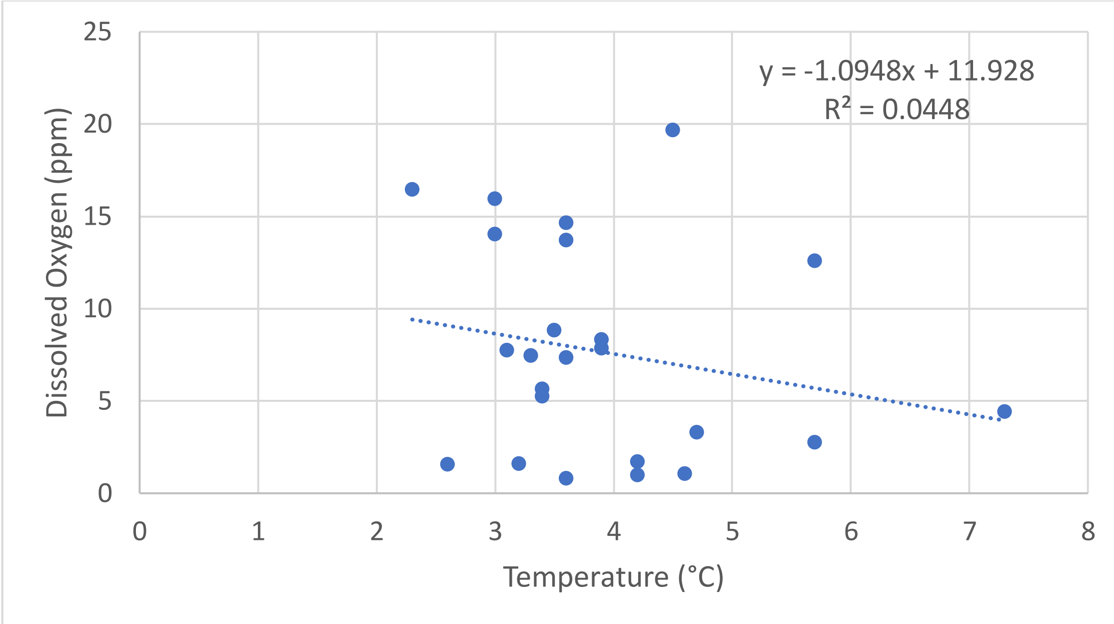

Figure 5. Linear Regression of the relationship between temperature and dissolved oxygen.

Table 10. Raw counts of taxa found in each pond, including species richness and Shannon and Simpson diversity indices.

Taxon Name (order)	**Regents Pond**	**Baseball Pond**	**Soccer Pond**	**Big Pond**
O. Amphipoda	161	61	58	4
O. Diptera		24	4	
O. Ephimeroptera				30
O. Hemiptera (corixidae)				4
O. Hemiptera (notonectidae)	1		1	1
O. Odonata (zygoptera)	5			3
Physidae			1	
Richness	3	2	4	5
Total Individuals	167	85	64	41
Shannon (H')	**0.07**	**0.26**	**0.17**	**0.42**
Simpson (Ds)	**0.07**	**0.41**	**0.18**	**0.48**

Table 11: T-test comparison of Simpson indices by pond.

	Regents Pond	**Baseball Pond**	**Soccer Pond**	**Big Pond**
Regents Pond	NA	NA	NA	NA
Baseball Pond	**-6.750840**	NA	NA	NA
Soccer Pond	-1.568784	**3.077738**	NA	NA
Big Pond	**-4.423142**	-0.688129	**-2.779113**	NA

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