Development of a Macroinvertebrate Index of Biological Integrity (MIBI) for Impounded Freshwater Wetland Ponds of Great Salt Lake, Utah

Final Report

Version 1.0

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"Dedicated to Understanding Complex Ecological Interactions"

SUMMARY

The unique ecological and economic importance of Great Salt Lake (GSL) and its associated wetland is well documented. However, useful methods for assessing and monitoring the health of GSL impounded freshwater wetland ponds using biocriteria do not exist and are needed. We are developing several GSL watershed based multi-metric tools that can be used to assess and monitor wetland health, including a macrophyte (plant) MIBI. This report focuses on development of a macroinvertebrate multimetric index of biological integrity, MIBI.

Extensive research and statistical analyses were conducted over the last several years (2010-2014) to better understand relationships between macroinvertebrate assemblages and the physical and chemical environment of GSL wetlands. In 2014, intensive preliminary multivariate and univariate statistical analyses showed that macroinvertebrate assemblages differed substantially by season and year. Thus, the development of the MIBI focused on July/August/September, 2010- 2013 data to account for this and to simplify and refine the indices. Abundance- based non-metric multidimensional scaling (NMS) and multi-response permutation procedure (MRPP) results confirmed that a useful MIBI could be developed based on northern (less impaired) and southern (more impaired) ponds.

Species are the primary ecological and evolutionary unit and each species has a unique niche and each responds to changes in the environment, uniquely. Therefore, the foundation of this macroinvertebrate MIBI was based on individual species (taxa) and resulted in an Indicator Taxa Metric.

Taxa richness, evenness, and diversity metrics are generally considered to be important for assessing water quality, however taxa richness did not respond to pond groupings. As a result, a taxa richness metric was developed based on overall taxa richness; evenness and diversity indices were not considered useful and were not used. Functional Feeding Groups (FFGs) are also important measures of ecological condition and were analyzed. FFG analyses conducted in this study are the first reported for GSL wetland ponds. Overall, predator taxa were by far the most diverse group in the wetland ponds, which is contrary to their role in stream ecosystems. Several other FFG metrics significantly differed between northern and southern ponds, including one of the most important FFGs, scrapers. Subsequently scrapers became another focus of this MIBI.

The MIBI presented in this report is testable and can be refined as needed. The next step is to determine causal factors responsible for macroinvertebrate assemblage structure shifts (e.g. chemicals, nutrients, plant habitat, taxa responses, water and pond management and water quality, etc.). A MIBI that uses plant indicators to assess GSL wetland ponds is also under development and can be merged into an assessment package.

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INTRODUCTION

"The most direct and effective measure of integrity of a water body is the status of its living systems"
(Karr and Chu 1997)

Great Salt Lake (GSL) Utah, U.S.A., the remnant of ancient Lake Bonneville, is the fourth largest terminal lake in the world and is recognized as a Hemispheric Site within the Western Hemisphere Shorebird Reserve Network. This status is largely due to extensive wetlands that border its shores. Approximately 75% of all wetlands in Utah (the second driest state in the U.S.) are found along the freshwater tributaries of Great Salt Lake, which total nearly 182,000 ha; over half of those wetlands (approximately 35,000 ha) are impounded and intensively managed ponds (Hoven et al. 2011, 2014, Miller et al. 2011, Miller 2014). Millions of birds use the lake and these ponds every year as they migrate from breeding grounds as far north as the Arctic to wintering areas as far south as Argentina (UDWQ 2014). The importance of GSL and associated wetland ponds to migratory birds, recreation, brine shrimp, and mineral industries and its significance to the ecology and economy of the region is well documented (Adler, 1999; Gwynn, 2002; Aldrich and Paul, 2002; Bioeconomics, 2012; SWCA, 2012; Utah Division of Forestry, Fire and State Lands 2013, UDWQ 2014).

Under the federal Clean Water Act and Utah state law, Utah Department of Water Quality (UDWQ) is responsible for 'restoring and maintaining the chemical, physical, and *biological* integrity' of GSL. Because of its uniqueness and wide diversity of habitats, UDWQ has designated GSL its own 'beneficial use-protection class', divided into five subclasses that include wildlife protection of "a quality sufficient for waterfowl, shorebirds, and other water-oriented wildlife, including their necessary food chain"(UDWQ 2014).

Biological assessments and biocriteria are one of the most important and useful management tools available for restoring and maintaining the biological integrity of waters such as the GSL wetland ponds. Assessments of taxa richness, composition, relative abundances or groups, and feeding relationships among resident organisms are the most direct measure of whether these waters meet the Clean Water Act's biological standards for aquatic life (Karr 1993, Karr and Chu 1997). Bioassessments have long been developed and widely used by management agencies for wadeable waters (i.e. streams and small rivers) in the U.S and worldwide, however, bioassessments have only just begun to be developed and implemented for freshwater wetlands. Wetland bioassessments that incorporate macroinvertebrate indices are practically non-existent and none, that we are aware of, exist that combine aquatic plant metrics and macroinvertebrate metrics for GSL wetlands (although Gray (2011) developed a generalized, limited macroinvertebrate index in response to nutrient impairment in GSL wetlands).

Multimetric **i**ndices of **b**iological **i**ntegrity (MIBIs)(a type of bioassessment) rely on empirical knowledge of how a wide range of biological attributes responds to varying degrees of human influence (Karr 1993, Karr and Chu 1997). The most useful MIBIs explicitly embrace several attributes of the biotic assemblages, including taxa richness, indicator taxa (e.g., tolerant and intolerant groups), and assessment of processes such as trophic structure, feeding strategies and other taxa traits. The goal of a MIBI is to measure and evaluate the consequences of human actions on biological systems (Karr 1993, Karr and Chu 1997) however, it should be emphasized that bioassessments, including MIBIs, are not science but are the link between scientists and managers, and thus some level of subjectivity (e.g. professional judgment and management objectives) is inherent and cannot be completely avoided. MIBIs are also not monitoring tools and should not be used as such, but are evaluative precursors to more intensive, stressor specific, monitoring programs.

This report focuses on the development of macroinvertebrate metrics within a MIBI for GSL impounded wetland ponds and is designed for use and in conjunction with a plant MIBI being developed by Hoven and Richards (2014). This MIBI is not intended as a site-specific monitoring tool and does not resolve specific anthropogenic causal factors associated with differences in metric values.

GSL Wetlands Water Chemistry: Selection of 'Less Impaired' vs. 'More Impaired' Ponds

An intensive analysis of water chemistry was conducted by Johnson et al. (2014) and Carling et al. (2012) that evaluated the relationships of surface, pore, and sediment water chemistries of GSL wetland ponds and was conducted in association with the development of this macroinvertebrate MIBI and the Hoven and Richards (2014) plant MIBI. The major findings by Johnson et al. (2014) and Carling et al. (2012) were that impounded wetland ponds had distinct chemistries from one another, clearly demonstrated in surface water and sediment chemistry. Their results also demonstrated that the impounded wetlands are generally characterized by a chemical spectrum bounded by 'less- impaired' northern wetland ponds on one side of the spectrum and more anthropogenic 'impaired' southern ponds on the other side of the chemical spectrum. The chemical characteristics of the southern ponds were anthropogenic-associated elements such as Fe, Sb, Ag, THg, MeHg, Cd, Tl, Cu, Zn, and Pb, and nutrients, particularly P; whereas the chemical characteristics of the northern ponds were major elements such as Na, Mg, Ca, Li, Mn, and Sr.

Johnson et al. (2014) and Carling et al. (2012) results are also consistent with less urbanization and other human economic activities occurring in the northern portion of GSL and more urbanization and human economic activity occurring in the southern portion occupied by the greater Salt Lake City metropolitan area, one of the fastest growing metropolitan areas in the U.S. However, the northern wetlands of GSL are not pristine and are also impacted by human economic activities, particularly agriculture but to a lesser extent than southern ponds (UDWQ 2014). Almost all of the northern and southern ponds are intensively managed for wildlife (e.g. waterfowl and other migratory birds) and the public relies on many of these ponds to provide the critical ecosystem service of water filtration and treatment, prior to entering GSL. Based on the water chemistry results of Johnson et al. (2014) and Carling et al. (2012), macroinvertebrate assemblage data were separated and grouped into northern 'less impaired' and southern 'more impaired' ponds for the development of the following macroinvertebrate MIBI.

METHODS

GSL Wetland Ponds

Seventeen impounded wetland ponds along the eastern shore of GSL were sampled on several occasions between 2010 and 2013 ((Figure 1, Figure 2, Figure 3, and Table 1). Seven of these ponds were part of a long- term study: PN, BR4C, BR5C, FB1, FB2, AM, and NS (Figure 1, Figure 2, Figure 3, and Table 1) and ten of the ponds were only sampled in 2012 (Figure 3, Table 1). See Table 1 for a description of the sample sites and month, year sampled.

GSL Wetland Long-Term Study Ponds

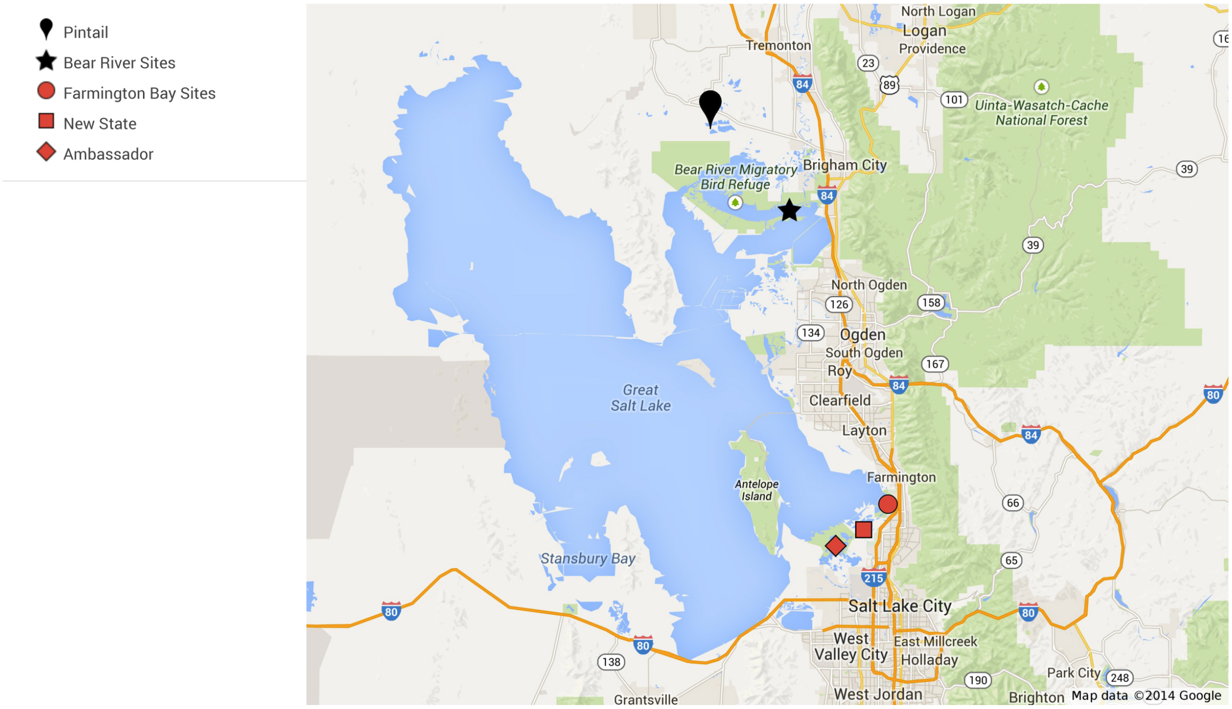


Figure 1. GSL wetland pond ‘long-term’ sample sites. See Table 1 for a description of study sites.

Figure 2, Northern GSL wetland pond sample sites (yellow pins). See Table 1 for a description of study sites.

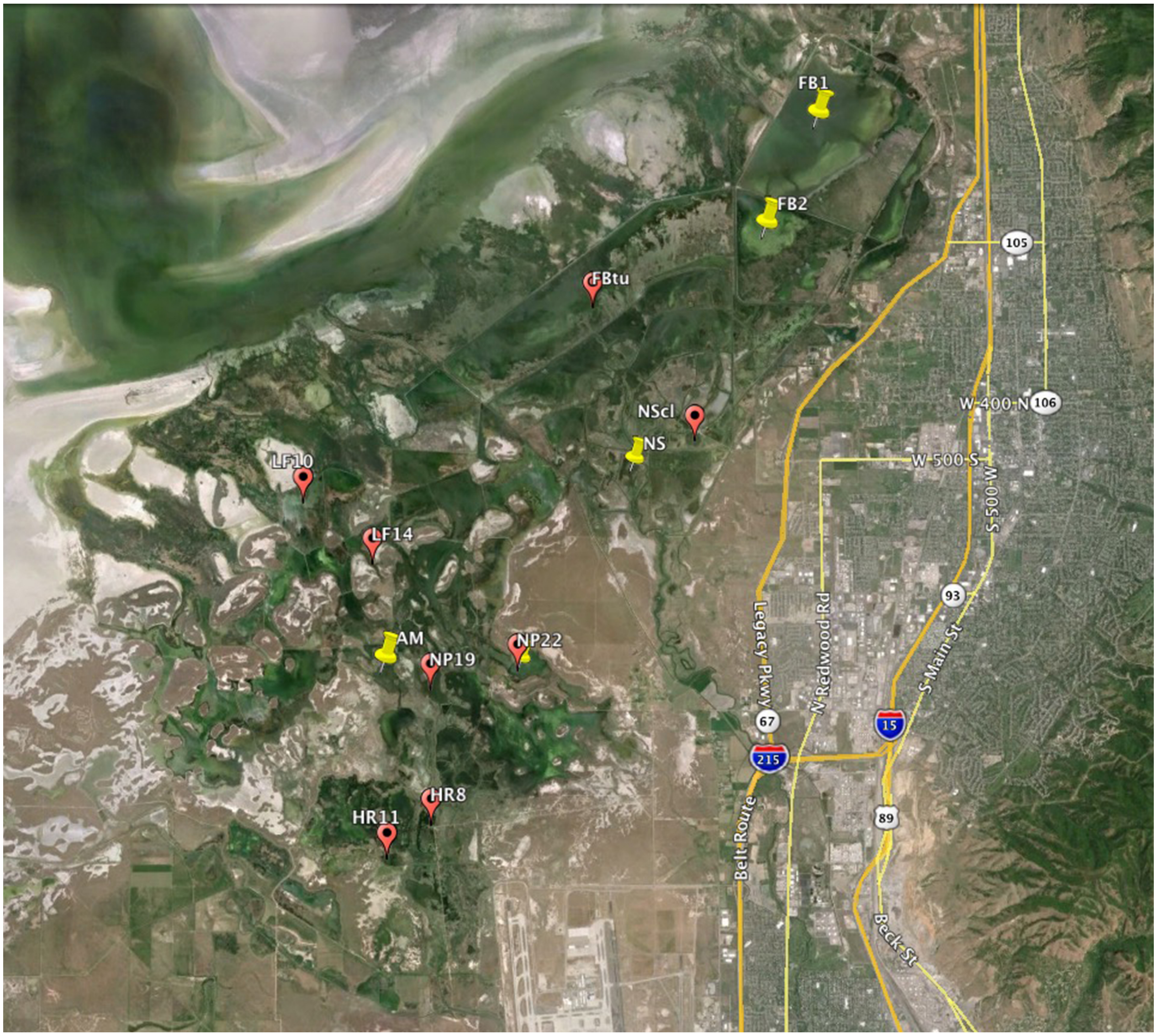


Figure 3. Southern GSL wetland ponds sample sites (yellow pins are 'long-term sites; orange teardrops are 2012 sites). See Table 1 for a description of sites.

Table 1. Description of macroinvertebrate sample sites.

Site Code	Wetland Pond Name	Dates Sampled (month; year)	Latitude	Longitude
AM	Ambassador Duck Club	6, 7, 9; 2010 8; 2011 6, 7, 8, 9; 2012 7, 9; 2013	40.848062	-112.027789
AM100	Ambassador Duck Club, Unit 100	6, 9; 2012	NA	NA
BR4C	Bear River WMA, Unit 4C	6, 7; 2010 6, 7, 8; 2012	41.430564	-112.123703
BR5C	Bear River WMA, Unit 5C	6, 7; 2012	41.425611	-112.097587
FB1	Farmington Bay WMA, Unit 1	6, 9, 10; 2010[a] 9; 2011[a] 6, 7, 8, 9; 2012[a] 7; 2013	40.941444	-111.930262
FB2	Farmington Bay WMA, Unit 2	6, 7, 9; 2010[a] 6, 7, 9; 2012 7, 9; 2013	40.922208	-111.942325
Fbtu	Farmington Bay WMA, Turpin Unit	7, 9; 2012	40.91010517	-111.9805407
HR8	Harrison Duck Club, Unit 8	7, 9; 2012	40.822977	-112.016493
HR11	Harrison Duck Club, Unit 11	7, 9; 2012	40.81737268	-112.0261484
LF10	Lake Front Gun Club, Unit 10	7, 9; 2012	40.87688751	-112.0452076
LF14	Lake Front Gun Club, Unit 14	7, 9; 2012	40.86644525	-112.0296367
NP19	Northpoint, Unit 19	7, 9; 2012	40.84539652	-112.0167341
NP22	Northpoint,Unit 22	7, 9; 2012	40.84861545	-111.9974911
NScl	New State, Clear Lake Unit	7, 9; 2012	40.88731831	-111.9578985
NS	New State	6,7,9,10; 2010 8; 2011 6, 7, 9; 2012 7, 9; 2013	40.882030	-111.972358
PN	Pintail Pond, Public Shooting Grounds	6, 7, 8, 9; 2010 8; 2011 7, 8, 9; 2012 7, 9; 2013	41.577774	-112.322215
WD	Widgeon Pond, Public Shooting Grounds	6; 2010	41.566129	-112.310880

[a] multiple samples taken at different locations within a pond

Field Sampling, Laboratory Sampling and Taxonomy

Dr. Theron Miller, Jordan River, Farmington Bay Water Quality Council, collected macroinvertebrate samples by sweeping in and around aquatic vegetation with a 500-micron mesh D-net. Dr. Miller has developed an alternative sampling method to the that recommended and practiced by UDWQ (UDWQ 2014) in order to capture more elusive taxa such as corixid bugs, an important waterfowl food source (Miller 2013 and Miller 2014). EcoAnalysts Inc., Moscow, ID, conducted macroinvertebrate taxonomy and counts on the 2010-2012 samples using a 500 organism fixed count method whereas, River Continuum Concepts, Manhattan, MT conducted taxonomy and counts on the

2013 samples using a combined fine and coarse fraction, 300 organism fixed count method. Taxonomic identification was to standard resolution, typically genus level. Discrepancies in taxonomic effort between labs were adjusted for by combining taxa when necessary. Potential differences in macroinvertebrate assemblages resulting from laboratory methods were not discernable (see Macroinvertebrate Assemblage Relationships MRPP Results).

Previous Analyses

Intensive preliminary analyses were conducted prior to the development of this MIBI (Richards 2013, Richards 2014, and unpublished data). These preliminary analyses showed that in addition to differing by pond, macroinvertebrate assemblages in GSL differed substantially by season; primarily June and October samples from July, August, and September samples. To reduce these seasonal effects and to simplify and refine the MIBI, the majority of the analyses and metrics in this report focused on July, August, and September data.

Spatial and Temporal Relationships of Macroinvertebrate Assemblages

Non-metric multidimensional scaling (NMS) ordination was used to visually compare macroinvertebrate assemblages. Ordination techniques are often more informative than hypothesis-testing approaches for exploring relationships between multivariate ecological assemblages or communities (McCune and Grace 2002). In general, ordination is the ordering of objects along axes according to their (dis)similarities; the main objective of ordination is to reduce many-dimensional relationships into a small number of more easily interpretable dimensions (i.e., axes on a plot). The strongest correlation structure in the data is extracted and is then used to position objects in ordination space. Objects that are close in the ordination space are more similar than objects distant in ordination space (McCune and Mefford 2011).

NMS was used in these analyses because it has been shown to be robust for ordination of taxa composition and is often more broadly applicable for ecological studies than other ordination techniques because it does not require relationships among variables to be linear (McCune and Mefford 2011; Peck 2010). NMS ordination permits the visualization of the multidimensional relationships of the macroinvertebrate assemblages into a more easily visualized, lower dimensional space. Dimensional reduction obviously creates some distortion in relationships between samples. The level of reduction in distortion is measured as 'stress'; where lower stress values equal less distortion. NMS plots with stress values lower than 15% (0.15) are typically considered to be a good representation of the data (McCune and Mefford 2011; Peck 2010).

Taxa abundances were square root transformed prior to NMS analyses using PC-ORD Version 6.0 (2011). The square root transformation helped to dampen the influence of highly abundant taxa (e.g. some Chironomidae taxa) and to balance assemblage relationships with rare and uncommon taxa (Gauch 1982; Efron and Tibshirani 1991; Cao et al. 1998) but did so to a lesser extent than a log + 1 transformation which would have over dampened the effects of the more abundant taxa considered important in waterfowl diets (Miller et al. 2013, Miller et al. 2014, UDWQ 2014). Taxa that occurred in less than three samples were removed from the data matrix to improve the resolution of the NMS analyses. A Sorensen (Bray-Curtis) distance measure was used in the NMS analysis and run for 250 iterations using the real data and 250 iterations in randomized Monte Carlo simulations. The Sorensen distance measure is based on pairwise comparisons between all sample pairs, therefore NMS ordinations were rotated using varimax rotation to maximize variation along the axes and extracted as univariate scores. The best model was chosen based on scree plots and final stress values. Centroid labels of northern and southern pond samples were added to the ordination 'maps' to better interpret the relationships between northern and southern sites. Post hoc proportion of variance represented by each axis was calculated based on the R^2 value between distance in the ordination space and distance in the original space. Individual taxa correlations with NMS axes were also calculated.

MRPP (multi-response permutation procedure), a non-parametric multivariate method was used to test the hypothesis of no differences in macroinvertebrate assemblage groups between month, year, and site groups (north vs. south). MRPP has the advantage of not requiring distributional assumptions such as multivariate normality and homogeneity of variance and thus is often preferred to MANOVA for analyzing multivariate ecological data (McCune and Grace 2002). A Sorensen (Bray-Curtis) distance measure was used on square root transformed macroinvertebrate abundances in this MRPP analysis. The chance-corrected within-group test statistic, *A* (and associated p-value) was used to evaluate the hypothesis of no difference in the spatial and temporal groupings (McCune and Grace 2002).

Development of an Indicator Taxa Metric

The Fundamental Unit of Ecology

Species are the fundamental unit in ecology. Indeed, ecology is defined as, 'the science of how species interact with their environment'. The ecological concept of a species is best described by its *niche,* which is the sum of the habitat requirements that allow it to persist and reproduce (Grinnel 1917) or the role it plays in the community (Elton 1927). A species niche can also be considered as an *n-dimensional hypervolume*, where the dimensions are environmental conditions (e.g. light, nutrients, water quality, habitat, etc.) and the resources (e.g. food, etc.) that define a species' requirements (Hutchinson 1957). A species free of interference from other species and able to use the full range of conditions (biotic and abiotic) and resources necessary to survive and reproduce, occupies what is known as its *fundamental niche*. However, as a result of inter-specific competition, predation, and other interactions with other species, a species usually occupies a narrower niche, known as its *realized niche*. Therefore, each species directly or indirectly, uniquely responds to subtle changes in environmental conditions and community interactions and thus each species can provide unique information about those conditions.

The Clean Water Act specifies maintaining or improving 'biological integrity' of a water body, which is interpreted as having a full suite of native species interacting in a fully functioning ecosystem. As a result, most water quality management agencies include species (taxa)[1] richness as one of the most important metrics in their suite of metrics in MIBIs or as the sole metric in models such as RIVPAC O/E. However, most MIBIs fail to include taxon specific measures (i.e. indicator taxa) and lose the unique information individual taxa can provide. These indices rely on a selection of several metrics chosen from dozens of more generalized metrics, all of which require knowledge of individual taxa niches. As an example, functional feeding group (FFG) metrics, although useful measures of feeding guilds, require *a priori* knowledge of individual taxa functional feeding roles. A taxon's morphology and feeding habits must be known before it can be placed into a specific FFG. In addition, FFGs often lose valuable information by lumping taxa into generalized groupings. For example, all freshwater snails are broadly grouped as 'scrapers', but many snail taxa are selective feeders, have different feeding strategies, and have different life histories. Individual snail taxa,

[1] Because taxonomic identification of macroinvertebrates is often difficult at the species level, MIBIs typically report taxonomic levels as 'taxa'. Therefore, in this report the word 'taxa' or 'taxon' will be substituted for 'species'.

therefore, can alter periphyton and algal assemblages differently both temporally and compositionally, which can then alter ecosystem function depending on the 'scraper' taxa present. In addition, some metrics are based on reduced taxonomic resolution. Metrics based on reduced taxonomic resolution (e.g. Ephemeroptera richness, Chironomidae richness, etc.) lose much of the important, unique information that an individual ephemeropteran or chironomid taxon could have provided. Furthermore, in more than a few instances there are a greater number of metrics to choose from than there are taxa in the system being evaluated. To reiterate; all generalized metrics are based on different levels of knowledge of individual taxa and assumptions concerning their niches. Indices based entirely on generalized metrics or based purely on their statistical utility may or may not be useful at a regional scale or as a gross measure of biological integrity but are not likely very useful at the local, watershed scale where finer more relevant and useful measures can be applied. Therefore, the incorporation of individual taxa that respond to differences in habitat and water quality (i.e. an indicator taxa metric) should be the cornerstone of local, watershed scale MIBIs such as those used in GSL wetland ponds.

Northern vs. Southern Pond Indicator Taxa Analysis

Non- parametric box plots (medians, 25th to 75th percentiles, and ranges) of taxa raw abundances among northern vs. southern sites were examined to screen potential indicator taxa and their propensity to occur in either northern or southern ponds. Taxa with very low abundances in both groups (< 10 individuals/group) were subjectively removed from further consideration. Wilcoxon-Mann-Whitney rank sum-test comparisons of taxa abundances between northern and southern GSL wetland ponds were also conducted and an estimate of the probability that a random draw of a taxon was greater from a northern pond sample than a southern pond sample was computed.

Indicator taxa analysis (ITA) was used to detect and describe the value of different taxa for indicating northern and southern site groupings. Dufrêne and Legendre's (1997) method of calculating taxa indicator values was used. This method combined information on the concentration of taxa abundances (square root transformed) in northern or southern ponds and the faithfulness of occurrence of a taxon in that particular group. ITA produced maximum indicator values, IV_{max}, for each taxon in each group. Significance of IV_{max} was then tested using a Monte Carlo randomization method which randomly assigned sample units to groups 1000 times and calculated an IV_{max} each time. Probability of Type I error was the proportion of times that the IV_{max} from the randomized samples were equal to or greater than the original IV_{max}. The null hypothesis was that IV_{max} was not greater than would be expected by chance (i.e. that a taxon had no indicator value) (McCune and Grace 2002).

Taxa Richness

The number of taxa, Pielou's evenness, and Shannon and Simpson diversity indices were calculated and compared to assess differences in taxonomic richness and diversity between northern and southern sites. The number of taxa (i.e., richness) is the simplest and most straightforward measurement of diversity; however, the number of samples collected can affect it. A species accumulation curve was generated to help estimate how the difference in sample sizes may have affected taxa richness estimates and if some ponds had more or less taxa than predicted (null). Species accumulation curves are based on the theory of island biogeography (MacArthur and Wilson 1967); increased biodiversity (taxa richness) is directly related to area sampled and diversity estimates will increase with increased sampling effort. In addition, some taxa can be patchy and rare, while others evenly distributed and common.

RESULTS

Macroinvertebrate Assemblage Relationships

NMS analysis produced a good representative three-dimensional model (final stress = 0.13, at 80 iterations; final stability = < 0.001) with a cumulative R^2 of 0.83 (Axis 1 = 0.35, Axis 2 = 0.29, and Axis 3 = 0.19). In general, macroinvertebrate assemblages appeared to be fairly similar in all of the GSL wetland ponds (i.e. individual samples from each pond were often distributed throughout the plots) (Figure 4, Figure 5, and Figure 6). This was in part due to monthly and yearly differences in taxa abundances (see MRPP results) but most likely was because macroinvertebrate assemblages in all GSL wetland ponds are derived from a region wide taxa pool (i.e. gamma diversity) and many of these taxa can occur within any pond. However, some dissimilarities between northern and southern pond assemblages were apparent; the northern pond centroid of the 2-dimensional plots always occurred in the lower left region and the southern pond centroid always occurred in the upper right region (Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9). In addition, many, but not all, of the samples from each individual pond tended to cluster together regardless of month or year (i.e. beta diversity).

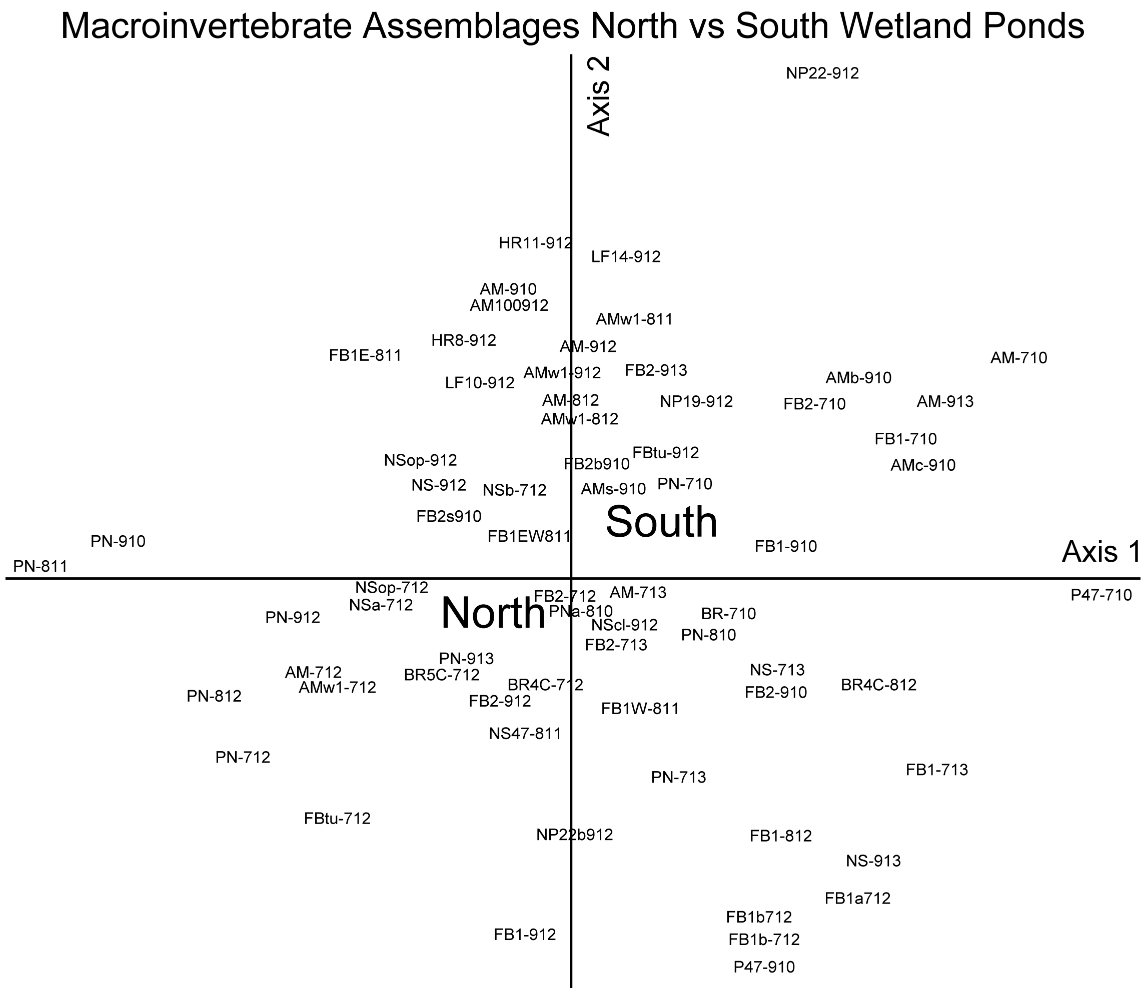


Figure 4. NMS Axis 1 and 2 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by sample. North and South labels are the centroids.

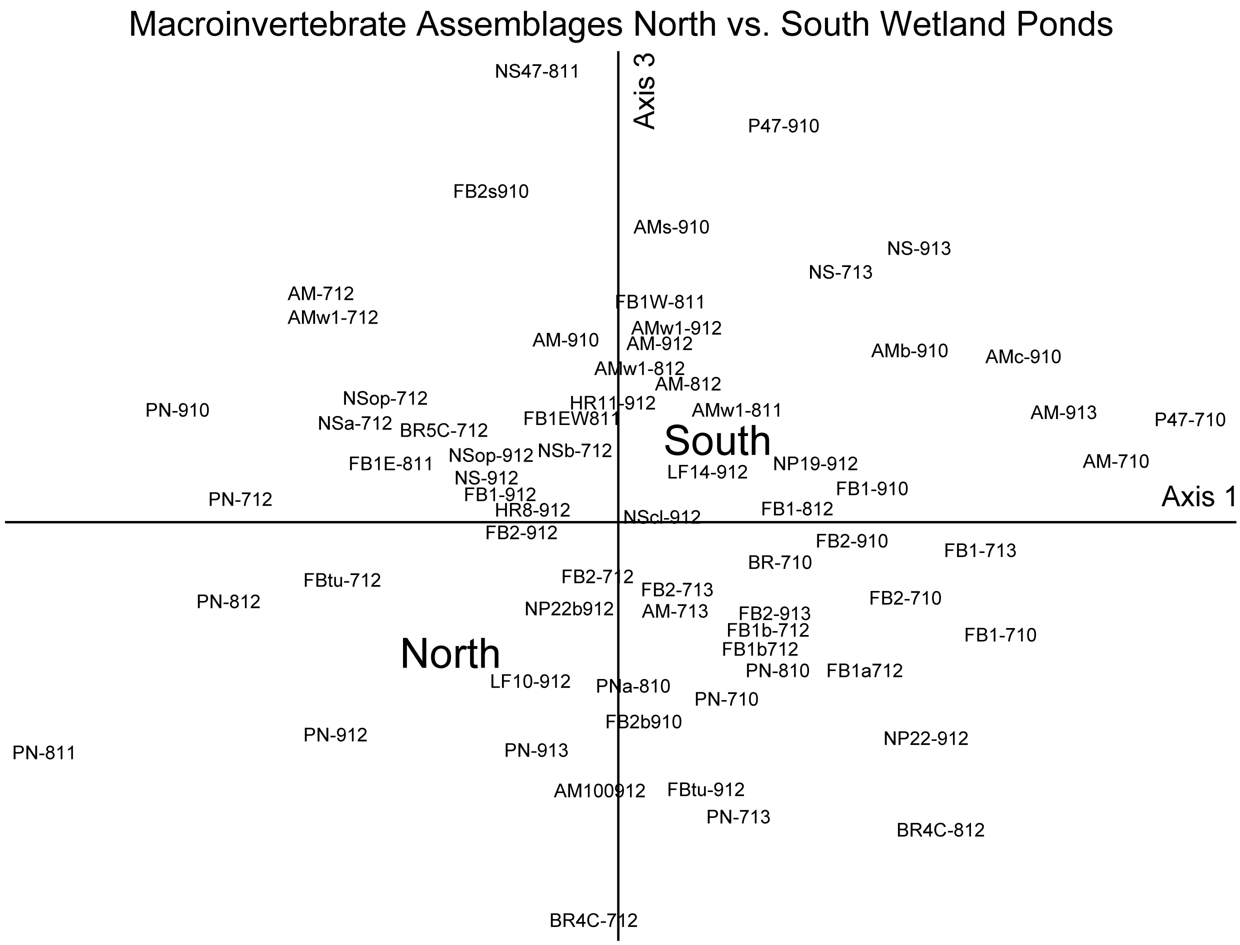


Figure 5. NMS Axis 1 and 3 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by sample. North and South labels are the centroids.

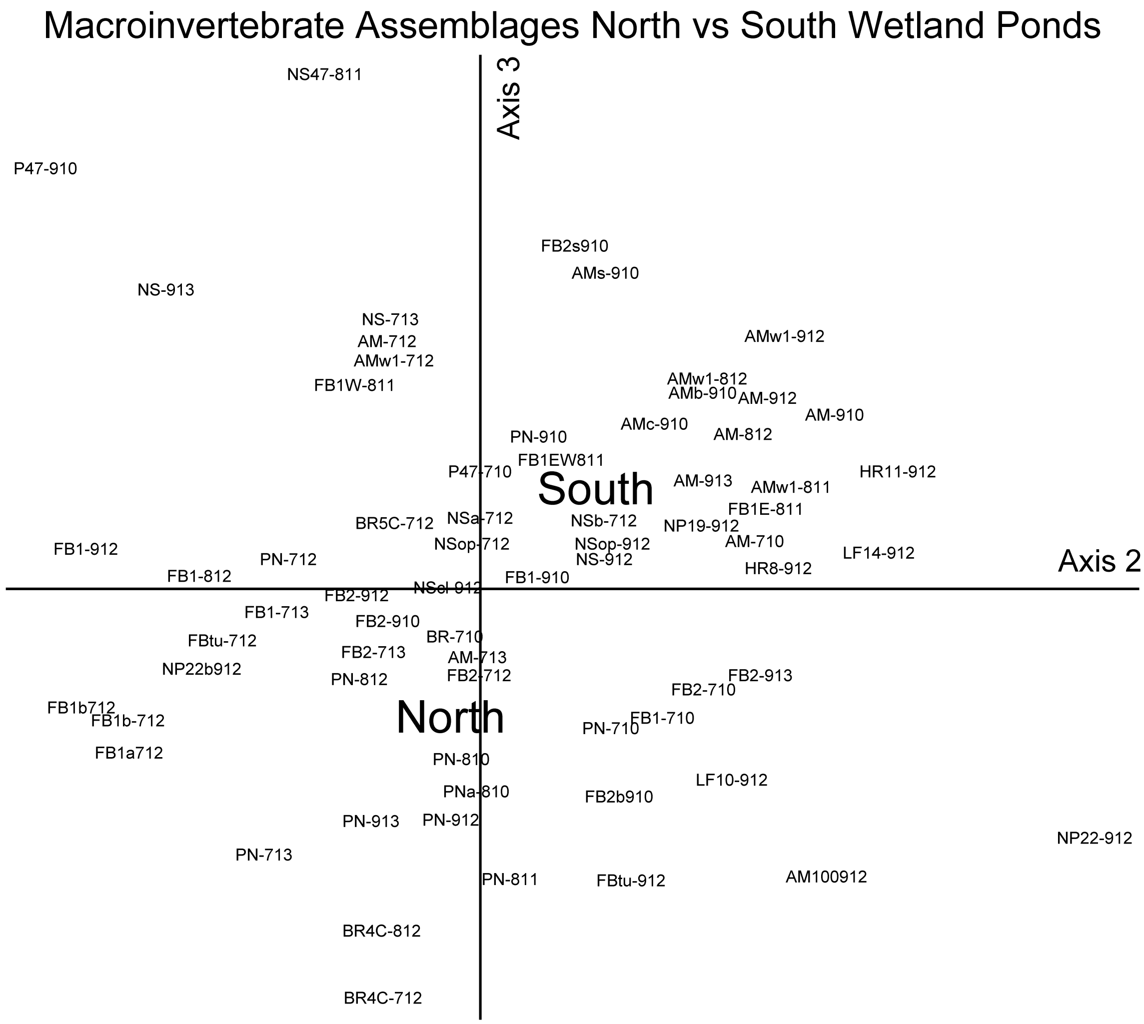


Figure 6. NMS Axis 2 and 3 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by sample. North and South labels are the centroids.

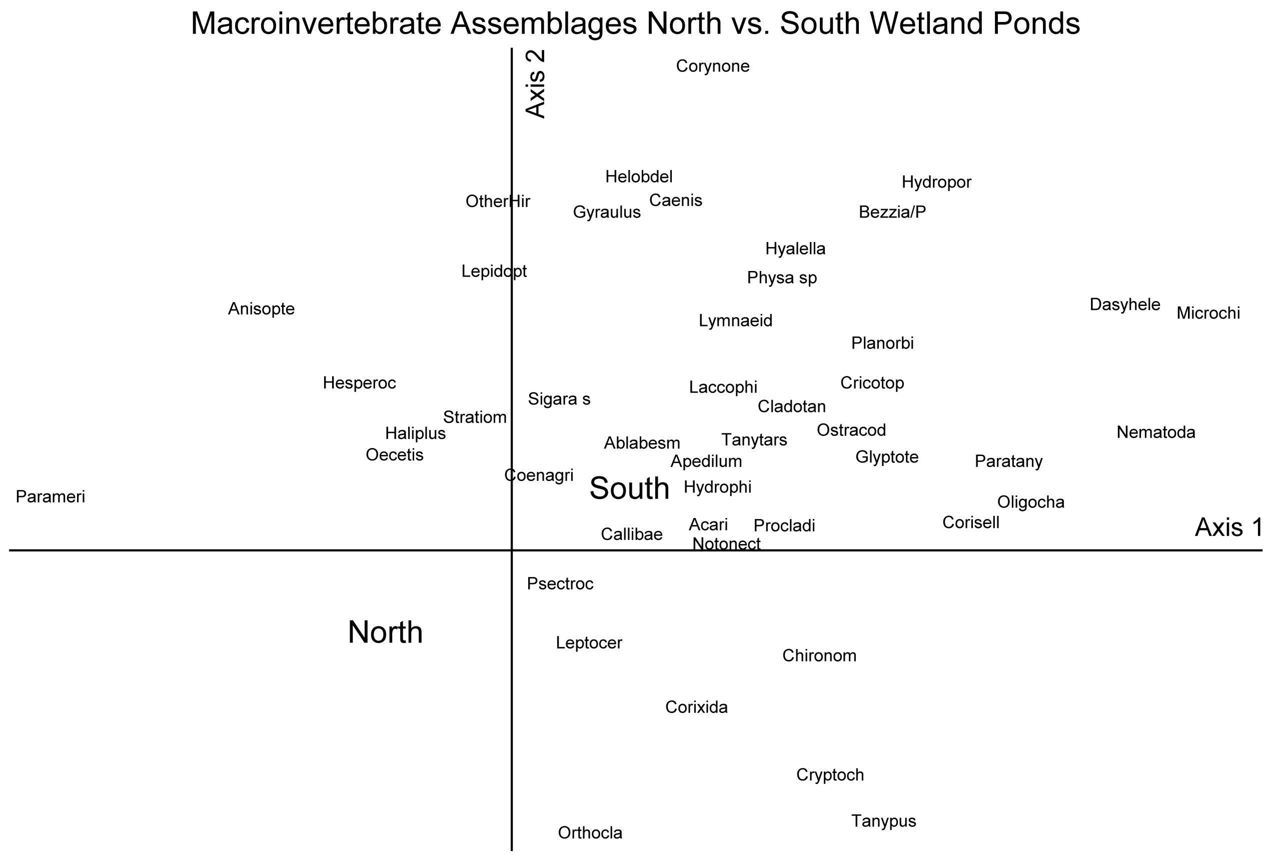


Figure 7. NMS Axis 1 and 2 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by taxon. North and South labels are the centroids.

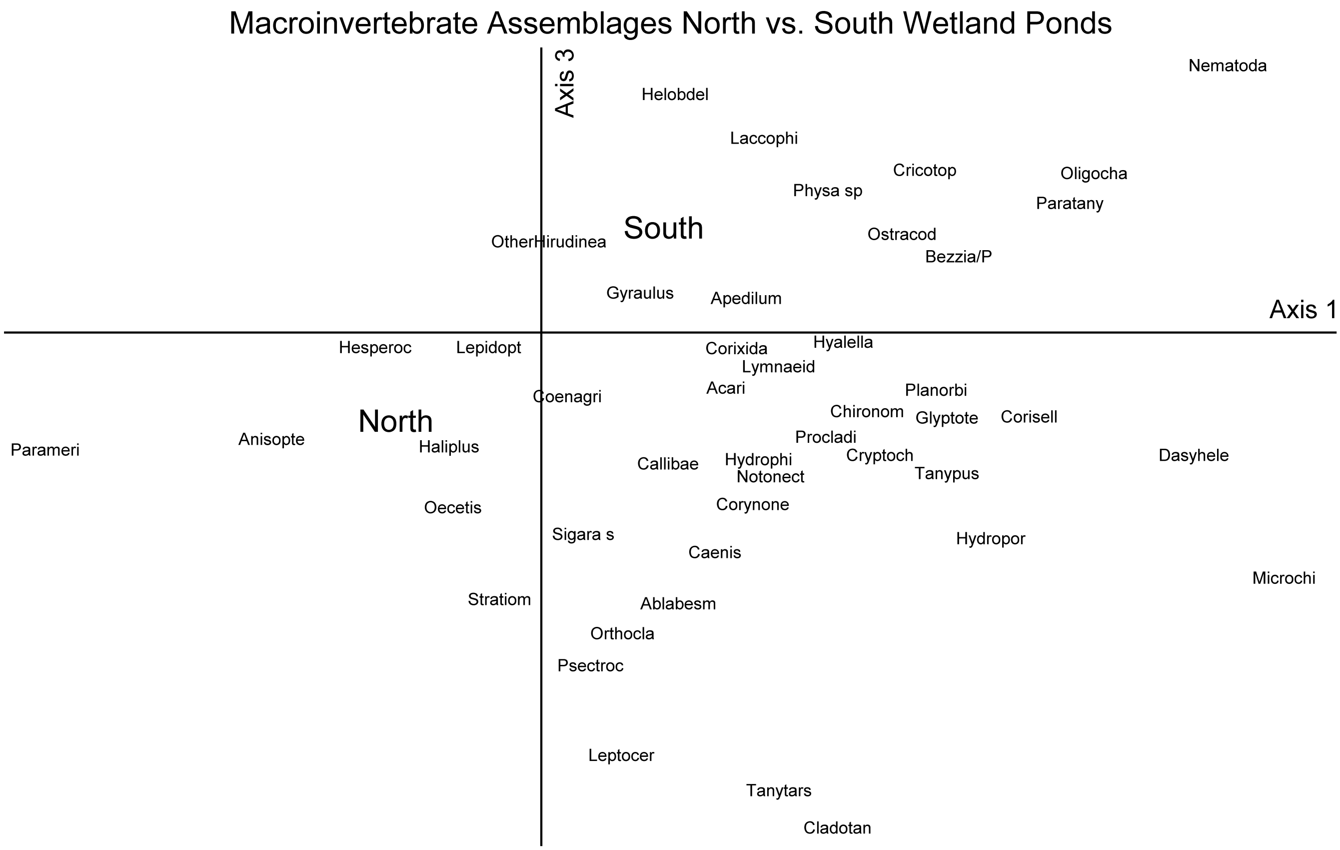


Figure 8. NMS Axis 1 and 3 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by taxon. North and South labels are the centroids.

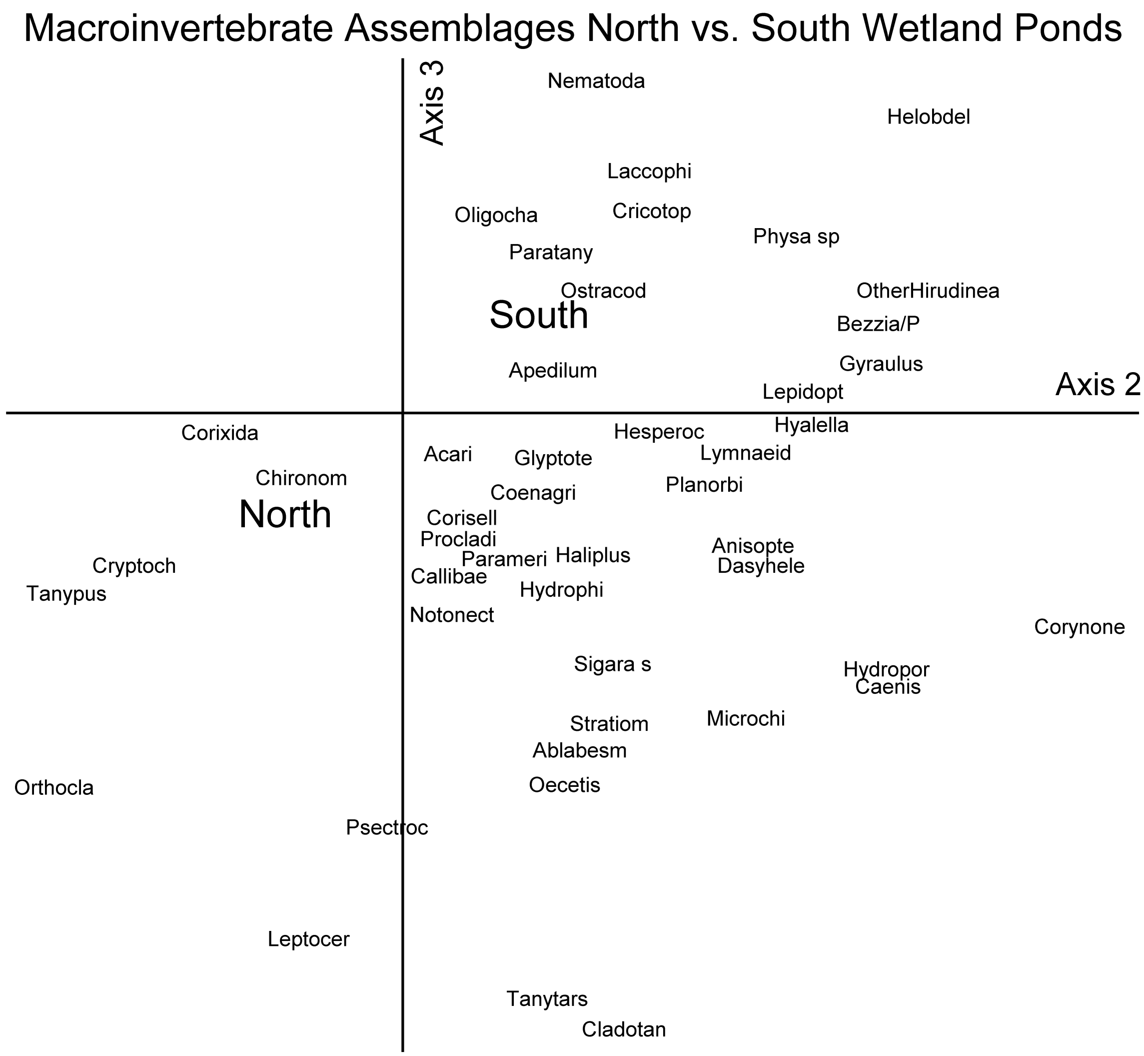


Figure 9. NMS Axis 2 and 3 for GSL northern vs. southern impounded wetland pond macroinvertebrate assemblages ordinated by taxon. North and South labels are the centroids.

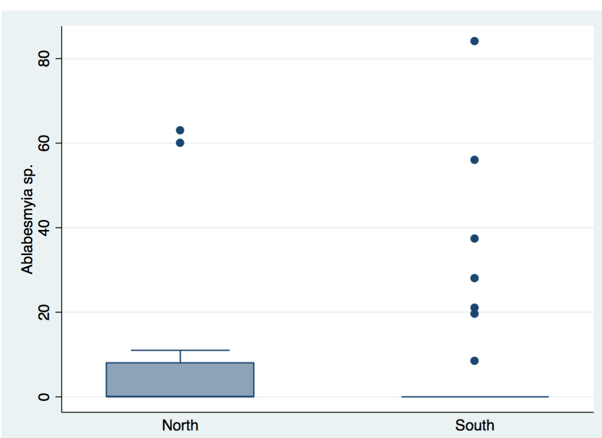
Many of the taxa that ordinated away from the center of the plots were also determined to be indicator taxa of northern or southern ponds (e.g. *Tanytarsus* sp., *Hyallela* sp. *Physa* sp., and *Oecetis* sp.) (See Indicator Taxa section). Taxa that occurred toward the centers of the plots were more generally distributed in both northern and southern ponds. Axis scores for sample sites are in Appendix 1; scores for taxa are in Appendix 2; and correlations between taxa and ordination scores are in Appendix 3.

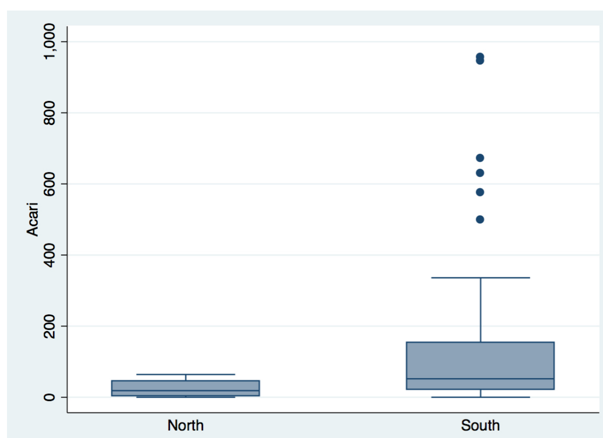
MRPP results also showed that macroinvertebrate assemblages in northern and southern pond are derived from a region wide pool of taxa (gamma diversity), which was reflected in a small, close to zero, *A* statistic of 0.03, but assemblages were different enough (beta diversity) for the *A* statistic to be significant (p-value < 0.01). Not unexpectedly, macroinvertebrate assemblages somewhat (but significantly) differed by month (A = 0.02, p-value = < 0.01) and year (A = 0.04, p-value < 0.01). Pairwise comparisons (not corrected for multiple comparisons) suggested that the July assemblages significantly differed from August and September assemblages but August and September assemblages did not (Appendix 4). The only non-significant differences in assemblages between years were the 2010 and 2013 assemblages (Appendix 4). Even though there were some monthly and yearly differences in assemblages, which influenced interpretation; significant differences in northern and southern pond assemblages were discernable. Thus, the combined results of NMS and MRPP supported the decision that an MIBI based on northern 'less-impaired' ponds and 'more-impaired' southern ponds was justified and could be developed.

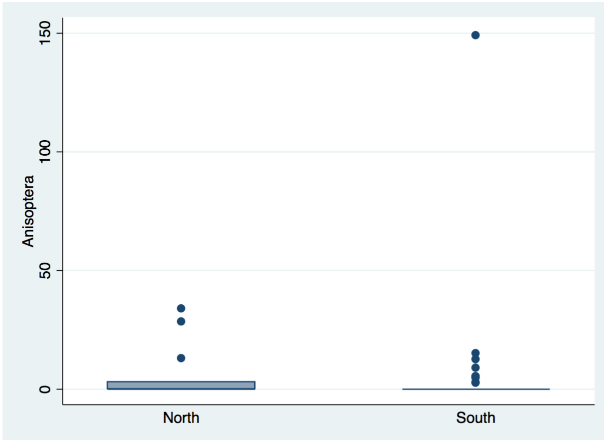
Indicator Taxa

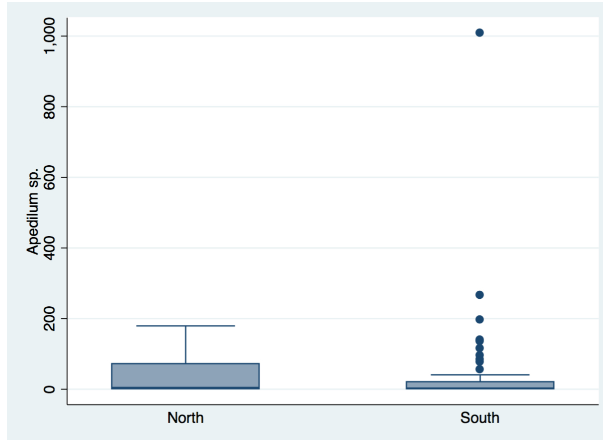
Northern vs. Southern Pond Taxa Abundances

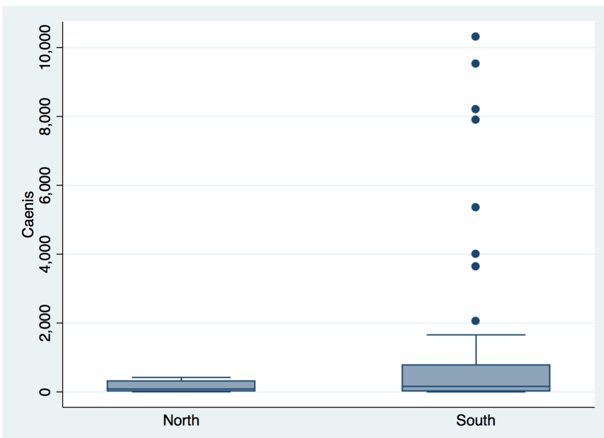
Many taxa occurred in greater abundance in either northern or southern ponds (Figure 10.) and were statistically more likely to occur in either northern or southern ponds (Table 2). Those taxa that significantly occurred in northern or southern ponds (p < 0.10) were included as indicators and incorporated into the indicator taxa metric (other taxa results are in Appendix 5). In addition, the likelihood that a taxon was sampled from a northern or southern pond is in Table 2.






Anisoptera
0
50
100
150
North
South


Apedilum sp.
0
200
400
600
800
1,000
North
South


Caenis
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4,000
6,000
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10,000
North
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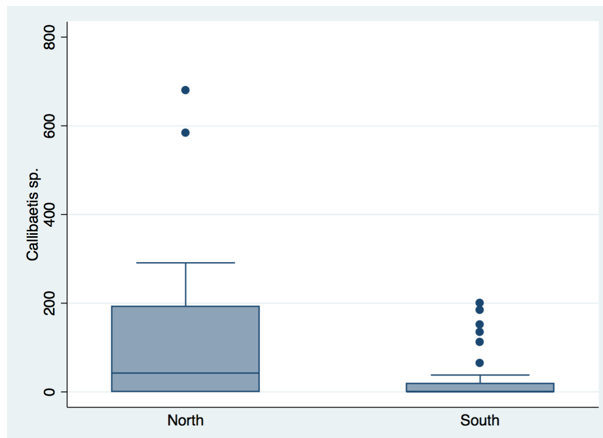
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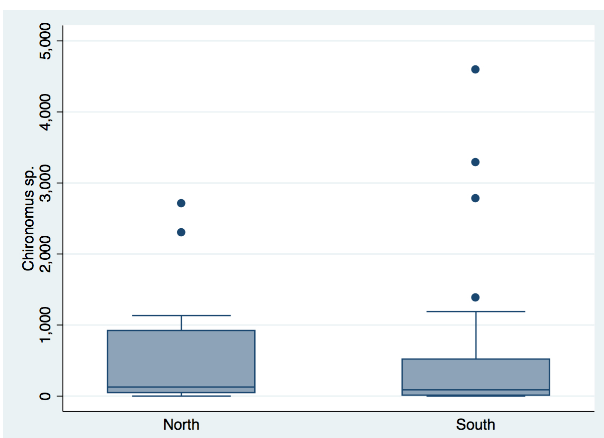
600
800
North
South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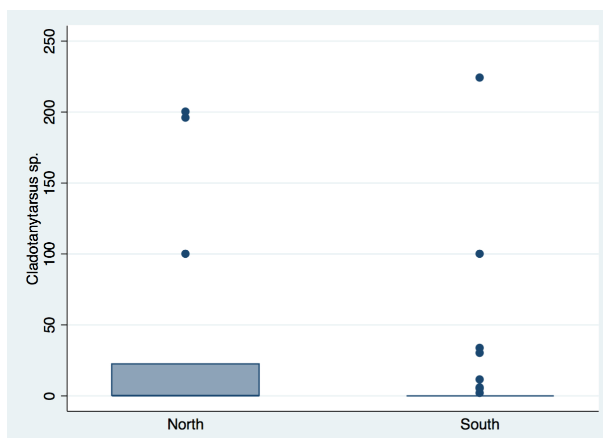
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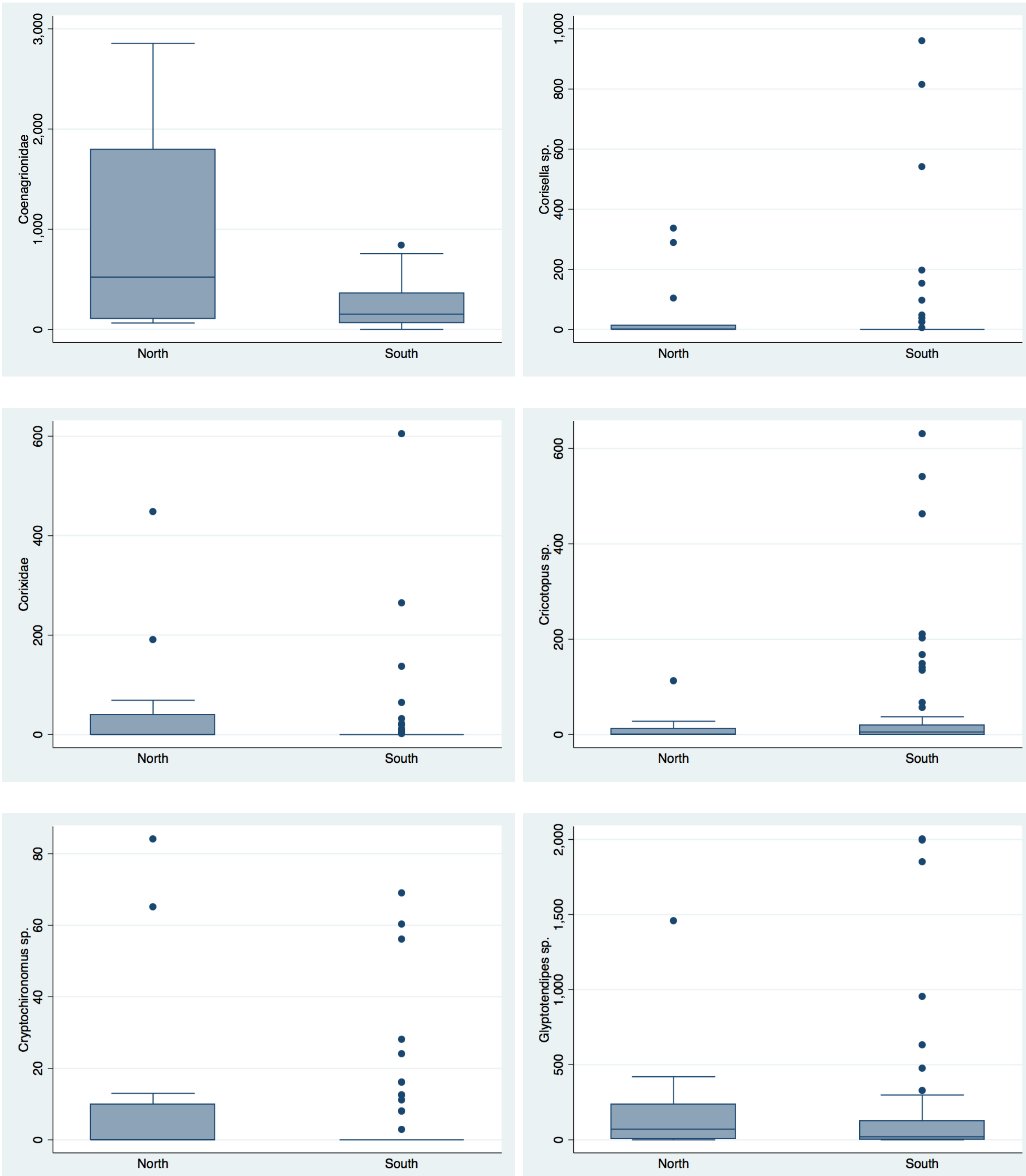
100
150
200
250
North
South


Coenagrionidae
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2,000
3,000
North
South
Corisella sp.
0
200
400
600
800
1,000
North
South
Corixidae
0
200
400
600
North
South
Cricotopus sp.
0
200
400
600
North
South
Cryptochironomus sp.
0
20
40
60
80
North
South
Glyptotendipes sp.
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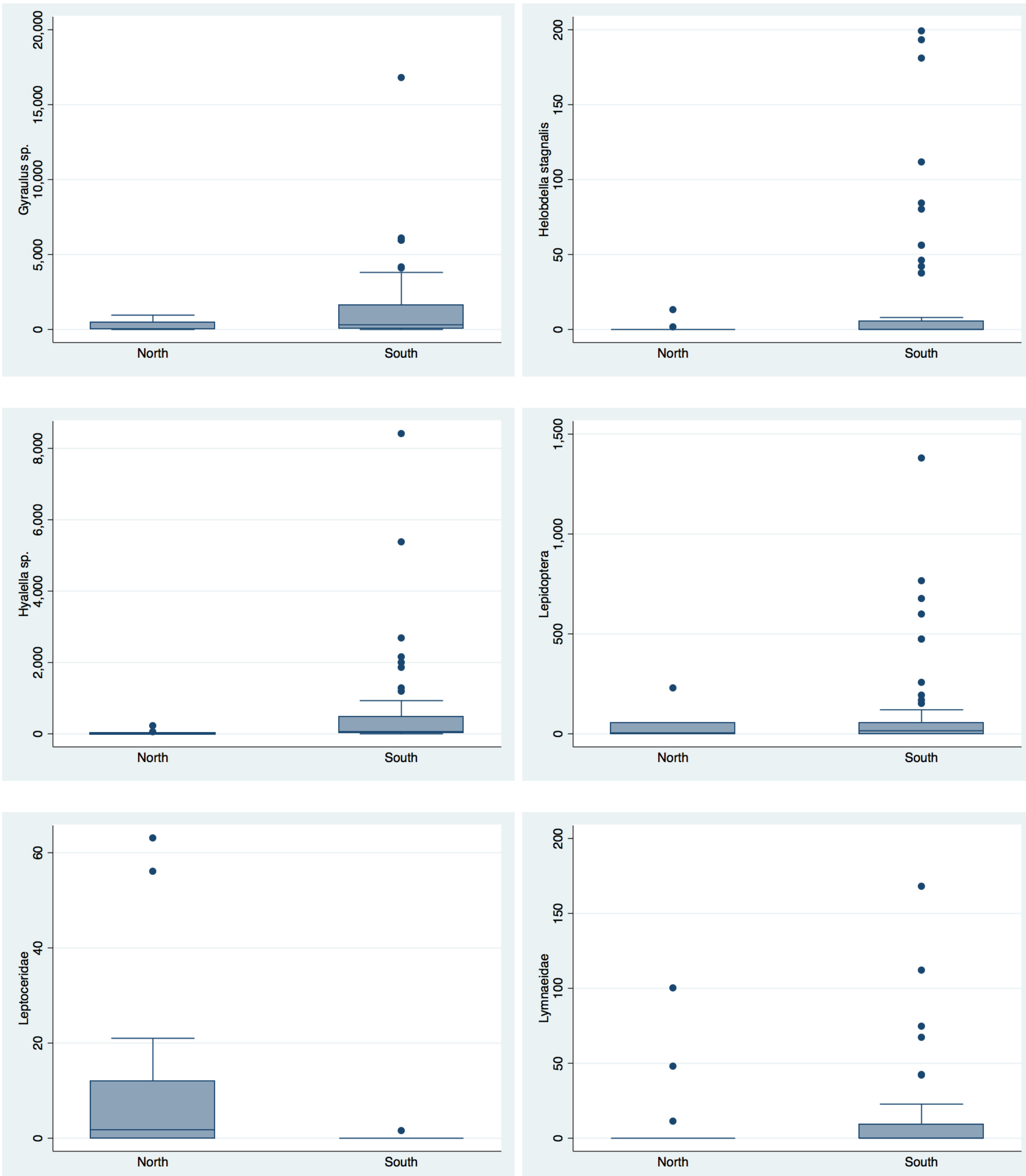
500
1,000
1,500
2,000
North
South



Gyraulus sp.
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10,000
15,000
20,000
North
South
Helobdella stagnalis
0
50
100
150
200
North
South
Hyalella sp.
0
2,000
4,000
6,000
8,000
North
South
Lepidoptera
0
500
1,000
1,500
North
South
Leptoceridae
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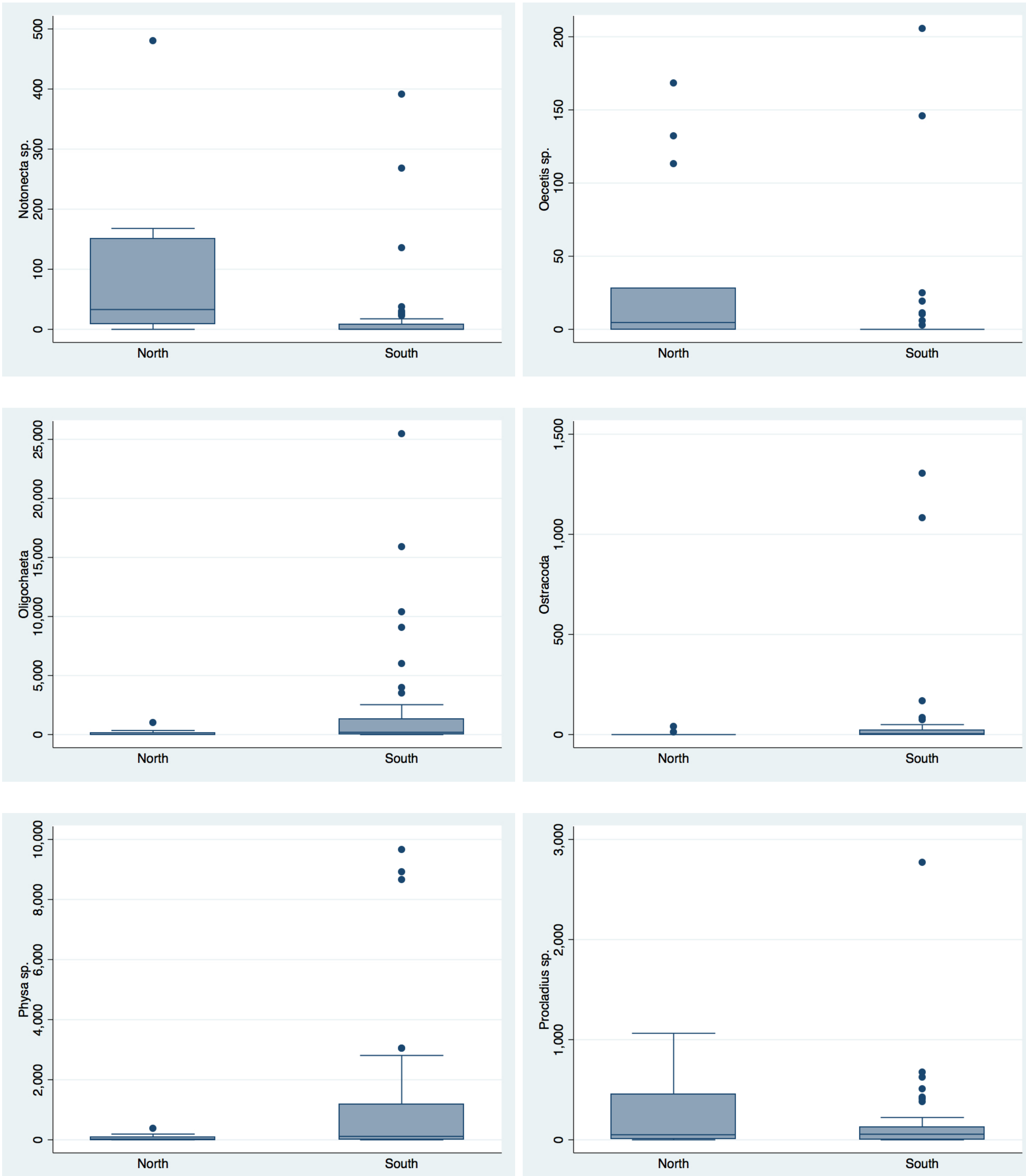
20
40
60
North
South
Lymnaeidae
0
50
100
150
200
North
South


Notonecta sp.
0
100
200
300
400
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North
South
Oecetis sp.
0
50
100
150
200
North
South
Oligochaeta
0
5,000
10,000
15,000
20,000
25,000
North
South
Ostracoda
0
500
1,000
1,500
North
South
Physa sp.
0
2,000
4,000
6,000
8,000
10,000
North
South
Procladius sp.
0
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2,000
3,000
North
South

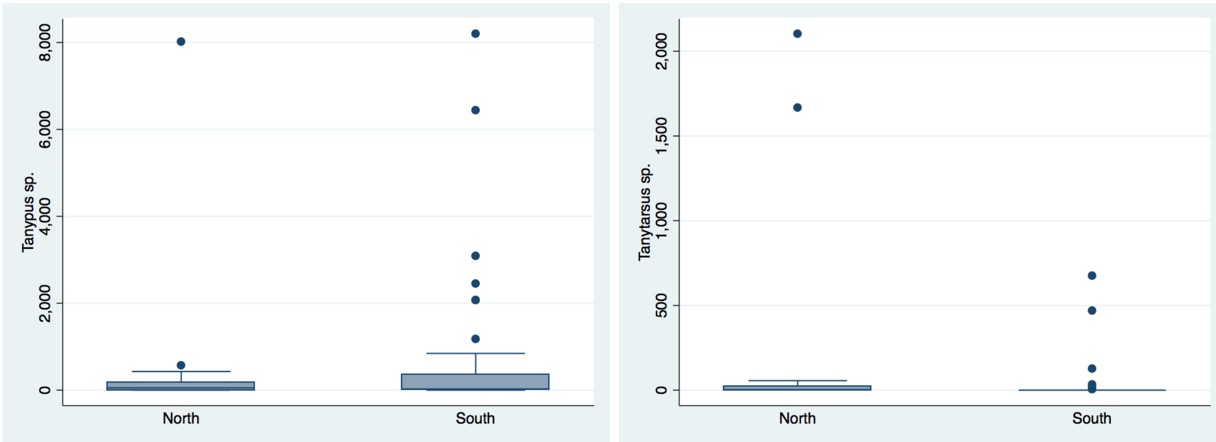

Figure 10. Taxa abundances in northern and southern wetland ponds. July, August, and September 2010-2013 samples; N = 68. Boxes are 25th to 75th percentiles, vertical lines are general range, horizontal lines within boxes are medians, and circles are outliers. See Table 2 for tests of significances.

Table 2. Taxa significantly associated with Northern or Southern Ponds.

Wilcoxon-Mann-Whitney Rank Sum-test. A positive Z-statistic indicates a taxon is more associated with northern ponds; a negative Z-statistic indicates taxon is more associated with southern ponds. Included in the table is an estimate of the probability that a random draw of a taxon is greater from a northern pond sample than a southern pond sample. For example, the probability that a sample that contained *Callibaetis* sp. was from a northern pond was 0.71; whereas the probability that *Hyalella* sp. was sampled from a northern pond was only 0.17 i.e. *Hyallela* sp. are more likely to occur in southern ponds.

Northern Pond Associated Taxa			
Taxon	**Z statistic**	**P-value**	**Probability Taxon sampled from a Northern Pond**
Leptoceridae	5.47	< 0.01	0.78
Notonecta sp.	4.22	< 0.01	0.84
Stratiomyidae	3.45	< 0.01	0.61
Oecetis sp.	2.83	< 0.01	0.68
Coenagrionidae	2.8	< 0.01	0.74
Tanytarsus sp.	2.81	0.01	0.68
Callibaetis sp.	2.5	0.01	0.71
Sigara sp.	2.37	0.02	0.68
Orthocladius Complex	2.04	0.04	0.56
Haliplus sp.	2	0.05	0.56
Cladotanytarsus sp.	1.94	0.05	0.62
Ablabesmyia sp.	1.86	0.06	0.61
Hydrophilidae	1.7	0.09	0.59

Southern Pond Associated Taxa			
Taxon	**Z statistic**	**P-value**	**Probability Taxon sampled from a Southern Pond**
Hyalella sp.	-3.813	< 0.01	0.83
Acari	-2.86	< 0.01	0.75
Oligochaeta	-2.75	0.01	0.74
Physa sp.	-2.49	0.01	0.72
Ostracoda	-2.55	0.01	0.70
Gyraulus sp.	-1.73	0.08	0.65

Indicator Taxa Analysis

Results of abundance based indicator taxa analysis for northern and southern wetland ponds follow. Quite a few taxa were determined to be significant ($p \leq 0.05$) indicators of the northern ponds (Table 3), while only one taxon was a significant indicator of southern ponds, Ostracoda. Other, non-candidate indicator taxa results are in Appendix 5.

Table 3. Northern and Southern Pond Indicator Taxa based on Indicator Taxa Analysis

Site	Taxon	IV	Mean	Std.Dev	p- value
Northern	*Notonecta sp.*	72.1	29.7	5.99	< 0.01
	Lepidoptera	27.3	7.9	3.84	0.00
	Oecetis sp.	39.7	17.9	5.42	0.00
	Leptoceridae	20.9	7	3.27	0.01
	Stratiomyidae	21.4	5.8	2.75	0.01
	Sigara sp.	43.9	25.1	5.77	0.01
	Tanytarsus sp.	33.3	17.3	5.49	0.01
	Callibaetis sp.	49.2	33.6	5.9	0.02
	Cladotanytarsus sp.	27.6	15.5	5.2	0.03
	Orthocladius sp.	13	6	2.6	0.04
	Arrenurus sp.	41.7	29	5.92	0.04
	Ablabesmyia sp.	25	14.5	5.06	0.05
Southern	Ostracoda	44.5	30.5	5.91	0.03

Indicator Taxa Metric Scoring

The indicator taxa metric score was developed by assigning scores to results from the two methods used to select indicator taxa (Table 2, Table 3, and Table 4). If a taxon appeared to be more abundant at a site using box plots and W-M-W ranked tests it was assigned a score of 1 or 'moderate' indicator of a site. If a taxon was selected based on abundance based indicator analysis it was assigned a score of 2 or 'good' indicator of a site. If the taxon was an indicator for northern ponds it was given a positive value, if it was an indicator from southern ponds it was given a negative value (Table 4). The rational for this scoring method was that box plot interpretation and non-parametric Wilcoxon-Mann-Whitney ranked tests were not as restrictive as indicator taxa analysis and northern taxa were more sensitive and southern taxa were less sensitive to anthropogenic impacts.

Table 4. Indicator Taxa Metric and Scoring for northern (less impaired) and southern (more impaired) ponds.

	Box Plots 25^{th} to 75^{th} percentiles (Score = 1 = Moderate)	**Indicator Taxa Abundance (Score = 2 = Good)**	**Final Score (Use highest score)**
Northern	*Ablabesmyia* sp.	*Ablabesmyia* sp.	2
	Callibaetis sp.	*Callibaetis* sp.	2
	Cladotanytarsus sp.	*Cladotanytarsus* sp.	2
	Coenagrionidae		1
	Haliplus sp.		1
	Hydrophilidae		1
	Leptoceridae	Leptoceridae	2
	Notonecta sp.	*Notonecta sp*.	2
	Oecetis sp.	*Oecetis* sp.	2
	Orthocladius Complex	Orthocladius Complex	2
	Sigara sp.	*Sigara* sp.	2
	Stratiomyidae	Stratiomyidae	2
	Tanytarsus sp.	*Tanytarsus* sp.	2
Southern	Acari		-1
	Gyraulus sp.		-1
	Hyalella sp.		-1
	Oligochaeta		-1
	Ostracoda	Ostracoda	-2
	Physa sp.		-1

Sample scores were then calculated by simply adding the final Indicator Taxa Metric scores. As expected, this resulted in an Indicator Taxa Metric (ITM) with very good discrimination between northern (less-impaired) ponds and southern (more-impaired) ponds (Wilcoxon-Mann-Whitney rank sum z = 5.02, p-value < 0.01)(

Figure 11). Descriptive statistics of Indicator Taxa Metric scores are in Table 5. All individual Indicator Taxon Metric sample scores are in Appendix 13.

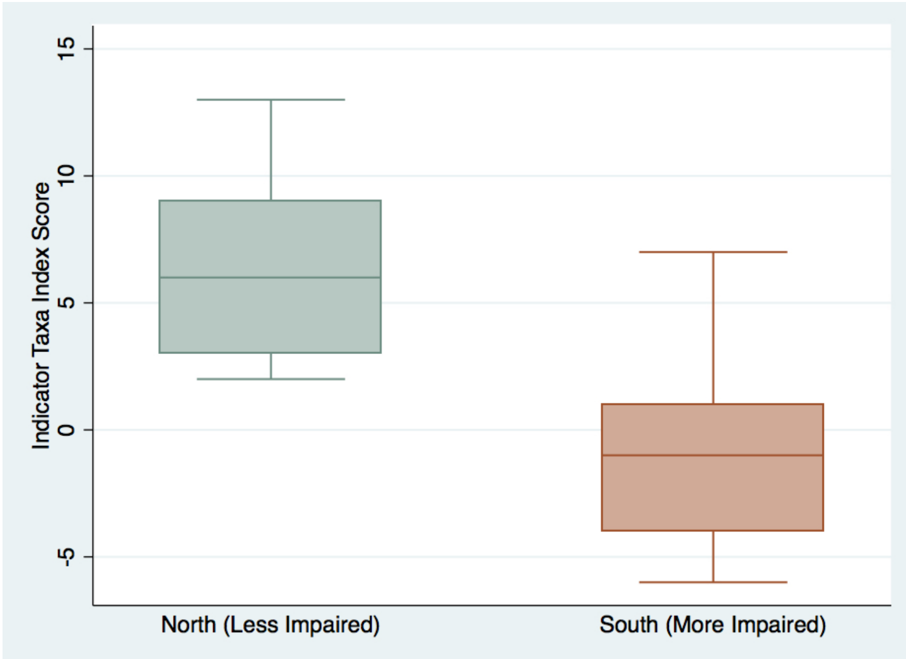

Figure 11. Comparison of Indicator Taxa Metric (ITM) scores between northern (less impaired) and southern (more impaired). Boxes are 25th to 75th percentiles, vertical lines are general range, horizontal lines within boxes are medians, and circles are outliers.

Table 5. Descriptive statistics of Indicator Taxa Metric scores for northern (less-impaired) and southern (more impaired) ponds (Wilcoxon-Mann-Whitney rank-sum test, z = 5.01; p-value < 0.01)

	N	Mean	St.Dev	Min	Q1	Median	Q3	Max
North (Less Impaired)	14	6.36	3.43	2.00	3.00	6.00	9.00	13.00
South (More Impaired)	54	-0.93	3.14	-6.00	-4.00	-1.00	1.0	7.00

There were twenty indicator taxa selected for the Indicator Taxa Metric (Table 4). This is a small number of individual taxa and about the median and mean of total taxa found in any one given sample (Figure 12). With this few number of important indicator taxa, ecological and biological attributes of each taxon should be relatively easy to compile from the literature and available data and a very good understanding of each taxon can be accomplished. Further refinement and identification of potential causal effects can then be accomplished.

Taxa Richness, Evenness, and Diversity

At least 100 different taxa occurred in the 2010-2012 GSL wetland samples (Table 6). There was a diverse range of phylogenies represented in the samples, which suggests that these wetlands have a wide range of environmental conditions and habitats. Diptera (true flies) taxa were by far the most diverse.

Richards (2014) made comparisons of evenness and diversity measures for northern and southern ponds using the 2010-2012 data but not for the 2013 data. This was because evenness and diversity measures are not likely important for these wetland ponds. Evenness is highly skewed in the wetland ponds with several taxa dominating the assemblages including chironomid, corixid, amphipod (i.e. *Hyallela* sp.), and gastropod (snail) taxa, which are considered some of the most important waterfowl and shorebird food items which are State of Utah designated beneficial uses. Thus the management goal of even and diverse macroinvertebrate assemblages in the impounded wetland ponds is not a primary goal.

Table 6. List of macroinvertebrate taxa found in 2010-2013 GSL wetlands samples. Some taxa were not identified beyond family or higher levels.

Insects (Non- Diptera)	Diptera	Non-Insects
Ephemeroptera	Ceratopogonidae	**Gastropoda**
Baetidae	*Bezzia/Palpomyia sp.*	*Fossaria* sp.
Callibaetis sp.	*Ceratopogona sp.*	*Gyraulus* sp.
Caenidae	*Dasyhelea sp.*	Lymnaeidae
Caenis sp.	Chironomidae	*Physa* sp.
Odonata	Chironomidae pupae	*Planorbella* sp.
Coenagrionidae	**Tanypodinae**	*Radix auricularia*
Coenagrion/Enallagma sp.	*Ablabesmyia sp.*	*Stagnicola* sp.
Lestidae	*Ablabesmyia (c.f. monilis)*	Planorbidae
Lestes sp.	*Procladius sp.*	**Annelida**
Aeshnidae	*Tanypus (c.f. neopunctipennis)*	Oligochaeta
Anax sp.	*Tanypus sp.*	*Erpobdella* sp.
Hemiptera	**Orthocladiinae**	Glossiphoniidae
Notonectidae	*Corynoneura sp.*	*Helobdella stagnalis*
Notonecta sp.	*Cricotopus sp.*	**Acari**
Corixidae	*Cricotopus sylvesteris gr.*	*Arrenurus* sp.
Corisella sp.	*Orthocladius complex*	*Eylais* sp.
Hesperocorixa sp.	*Orthocladius (Orthocladius)*	*Hydrachna* sp.
Sigara sp.	**Chironominae**	*Limnesia* sp.
Trichocorixa sp.	**Chironomini**	*Limnochares* sp.
Trichoptera	*Apedilium sp.*	Pionidae
Leptoceridae	*Cladopelma sp.*	*Piona* sp.
Nectopsyche sp.	*Chironomus sp.*	**Crustacea**

Oecetis sp.	*Chironomus (c.f. longipies)*	*Hyalella* sp.
Triaenodes sp.	*Cryptochironomus sp.*	Ostracoda
Lepidoptera	*Dicrotendipes sp.*	Cladocera
Crambidae	*Glyptotendipes sp.*	**Other**
Pyralidae	**Tanytarsini**	Nematoda
Coleoptera	*Cladotanytarsus sp.*	Turbellaria
Berosus sp.	*Micropsectra sp.*	Copepod
	Paratanytarsus sp.	
	Tanytarsus sp.	

Of the one hundred or so taxa that occur in the wetlands ponds (gamma diversity), only a subset was found in individual samples collected in July, August, and September 2010-2013 (Figure 12). The median number of taxa found in northern samples was 20 and southern ponds 18.5 (Figure 13 and Table 7). Although there was no significant difference in the number of taxa found in the northern ponds compared with the southern ponds (Figure 13), multivariate assemblage analysis (See Macroinvertebrate Assemblage Relationships section) and indicator species analysis (See Indicator Taxa section) showed that individual taxa occurrences were different between the two groups.

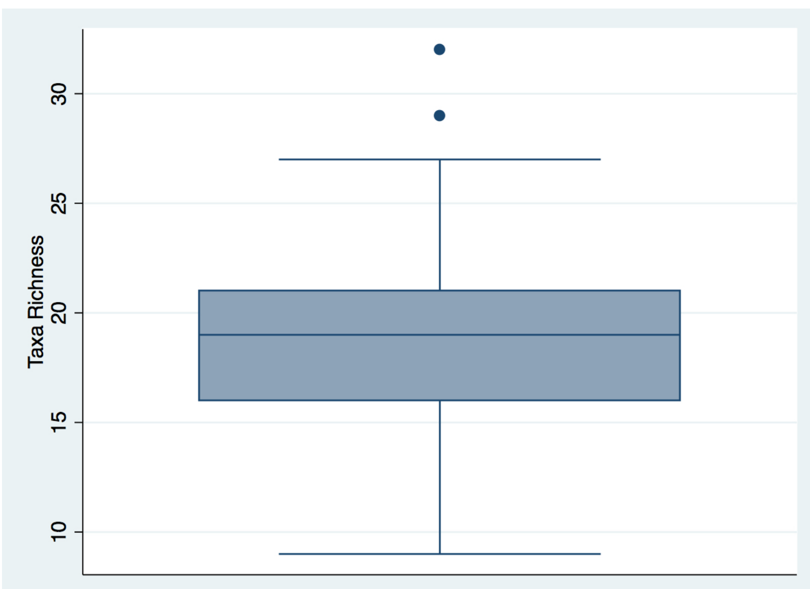

Figure 12. Taxa richness of all ponds; July, August and September 2010-2013. N = 68. Boxes are 25th to 75th percentiles, vertical lines are general range, horizontal lines within boxes are medians, and circles are outliers.

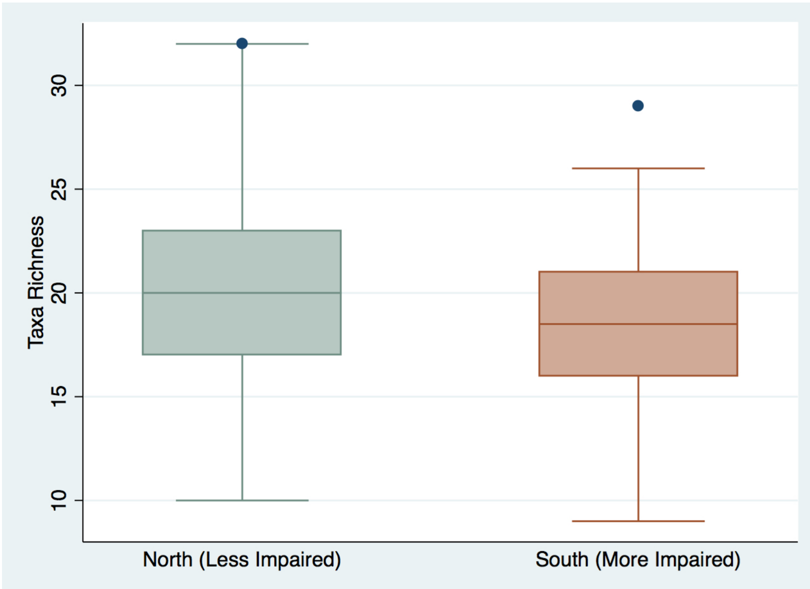

Figure 13. Taxa richness of northern vs. southern ponds; July, August and September 2010-2013. Boxes are 25th to 75th percentiles, vertical lines are general range, horizontal lines within boxes are medians, and circles are outliers. No significant difference between northern and southern ponds using W-M-M rank sum test (z = 1.39, p-value = 0.17).

Table 7. Descriptive statistics of taxa richness for northern and southern ponds (July, August and September 2010-2013).

	N	Mean	Std. Dev.	Median	Q1	Q3	Min/Max
All Ponds	68	18.79	4.47	19	16	21	9/32
Northern Ponds	14	20.29	5.33	20	17	23	10/32
Southern Ponds	54	18.41	4.19	18.5	16	21	9/29

In a previous report by Richards (2014) without 2013 data, the observed number of taxa sampled in Pintail Pond (northern) was significantly greater than predicted from a species area curve generated by the data, contrarily, the observed number of taxa sampled in the southern ponds was significantly less than predicted by the species area curves. This further illustrates that northern ponds are likely less impaired than southern ponds (i.e. greater diversity adjusted for sample size).

Total abundances

Macroinvertebrate total abundances per sample did not significantly differ between northern (less impaired) and southern (more impaired) ponds (Figure 14 and Table 8). Abundances can be used as a crude surrogate for more expensive biomass estimates and are a frequently used metric in management programs. Although abundances did not significantly differ between northern and southern ponds, in general southern pond abundances appeared to be slightly greater which may have been due to indirect effects of more nutrients in southern ponds. However, because abundances did not significantly differ between northern and southern ponds, an abundance (biomass) metric was not included in this MIBI although an abundance metric should be considered in future versions of this MIBI.

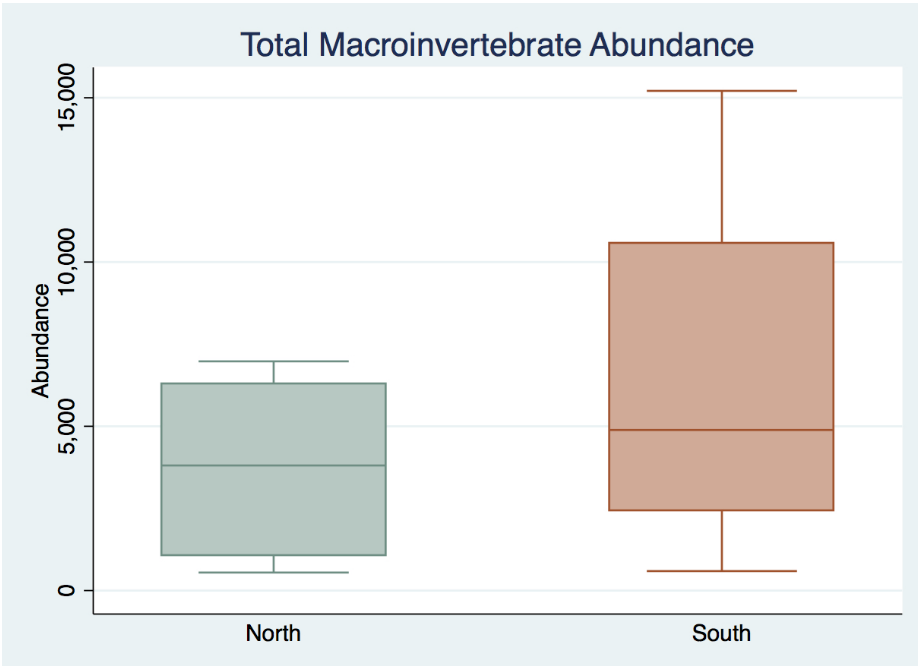

Figure 14. Total taxa abundances in northern and southern ponds. W-M-W rank test Z = -1.46; p-value = 0.15

Table 8. Descriptive statistics of total taxa abundances in northern and southern ponds.

	Mean	Std. Dev.	Median	Max	Min	1Q	3Q
North	4415.25	4039.71	3806.50	15988.00	548.00	1066.00	6282.19
South	11410.88	19866.60	4888.00	110880.00	592.00	2436.00	10565.33

Functional Feeding Groups

Introduction

Almost nothing is known about functional feeding group (FFG) relationships in wetland ponds and in particular Great Salt Lake (GSL) wetland ponds. In this report we provide a much-needed understanding of FFGs in GSL wetland ponds.

Methods

Ninety-eight taxa from samples collected between 2010-2013 were used to understand functional feeding group (FFG) ecology in Salt Lake wetland ponds. These taxa were assigned to functional feeding groups (FFGs) based on EPA (2014) and SAFIT (Richards and Rogers 2011). A list of taxa and their FFGs are in Appendix 7.

Results

Functional Feeding Group Ecology in Salt Lake Wetland Ponds

Results of these analyses provide us with a decent understanding of the overall relative proportions of FFGs in SL wetland ponds and the differences in ponds. Very few studies have evaluated FFGs in wetland ponds and none in GSL wetland ponds.

It appears that unlike many stream ecosystems; predator taxa in GSL wetland ponds contribute proportionally more than any other FFG group, at least in July, August, and September. Predator taxa accounted for between 30 and 38% of the FFG taxa (Figure 15, Figure 16, Figure 17, Figure 18, and Table 9).

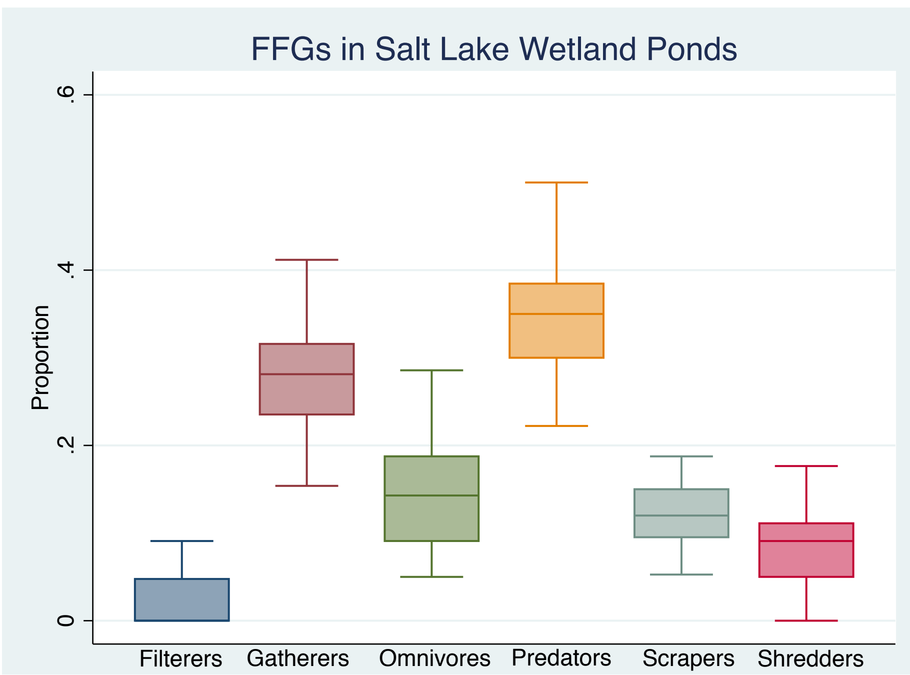

Figure 15. Comparison of relative proportion of FFGs taxa based in GSL wetland ponds for July, August, September 2010-2013 samples. Bars are 25th to 75th percentiles, vertical lines are general range, and horizontal lines in boxes are medians.

Table 9. Descriptive statistics of relative proportion of FFG taxa for July, August, September 2010-2013 samples from all ponds.

FFG	Mean	Std. Dev.	C.V.	Median	25th	75th
Gatherers	0.28	0.07	0.26	0.28	0.24	0.32
Filterers	0.02	0.03	1.53	0.00	0.00	0.05
Omnivores	0.14	0.07	0.48	0.14	0.09	0.19
Predators	0.36	0.08	0.23	0.35	0.30	0.38
Scrapers	0.12	0.04	0.34	0.12	0.10	0.15
Shredders	0.08	0.04	0.49	0.09	0.05	0.11

The following pie chart (Figure 16) is a simplification of Figure 15 and shows the mean values for FFGs in GSL wetland ponds.

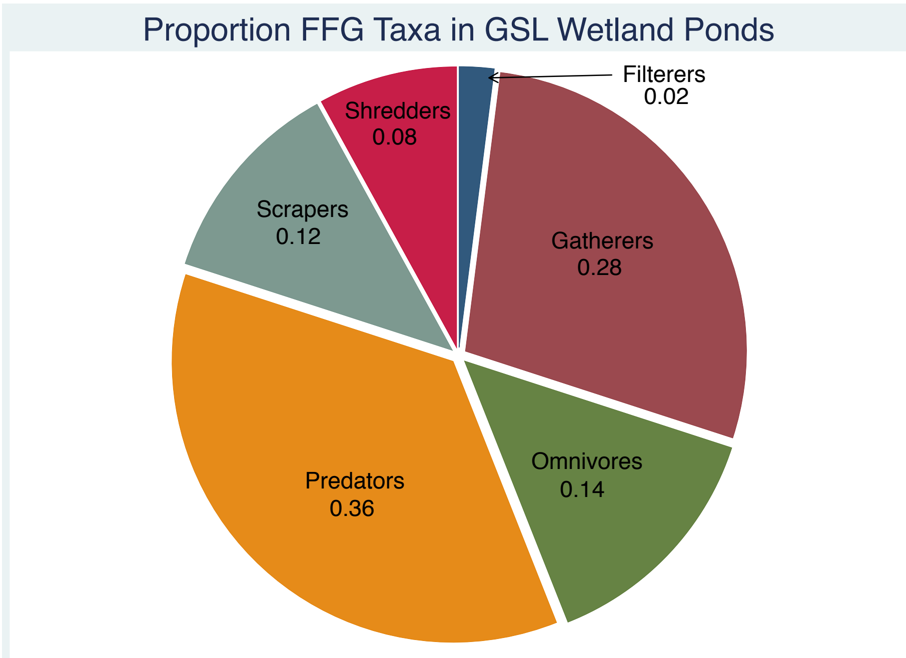

Figure 16. Proportion of FFGs in GSL wetland ponds based on taxa richness. July, August, and September 2010-2013 (mean values).

Relationships of FFGs based on abundances (Figure 17) were somewhat different than FFGs based on taxa richness. Predators were less proportionate and scrapers a greater proportion based on abundances than on richness (Figure 16 and Figure 17).

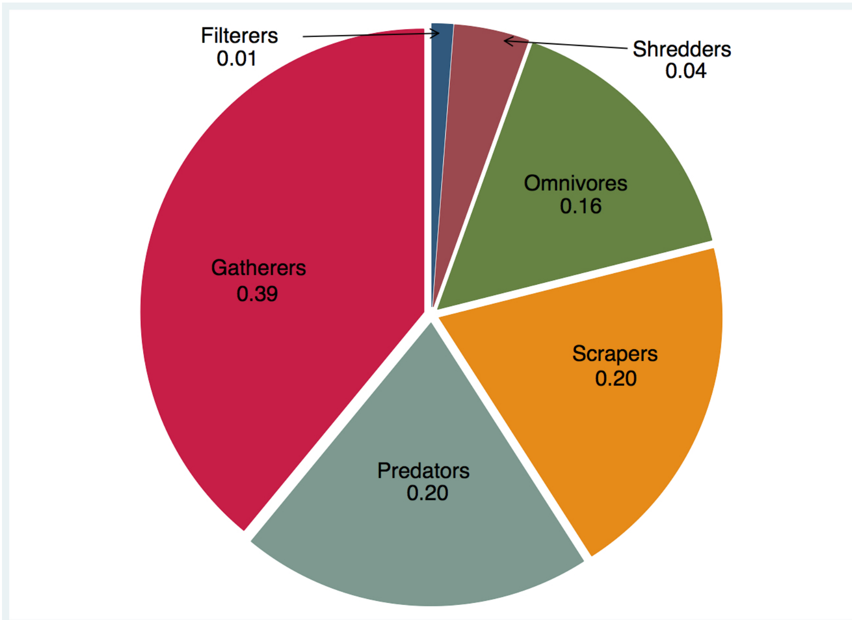

Figure 17. Proportion of FFGs in GSL wetland ponds based on abundances. July, August, and September 2010-2013 data.

Abundance based relative proportions of FFGs also differed between northern and southern ponds (Figure 18, Figure 19, and Table 10). Filterers and predators were a significantly greater proportion in northern ponds than southern ponds (Figure 18, Figure 19, and Table 10). Summary statistics of abundance based relative proportions of FFGs are in Table 11.

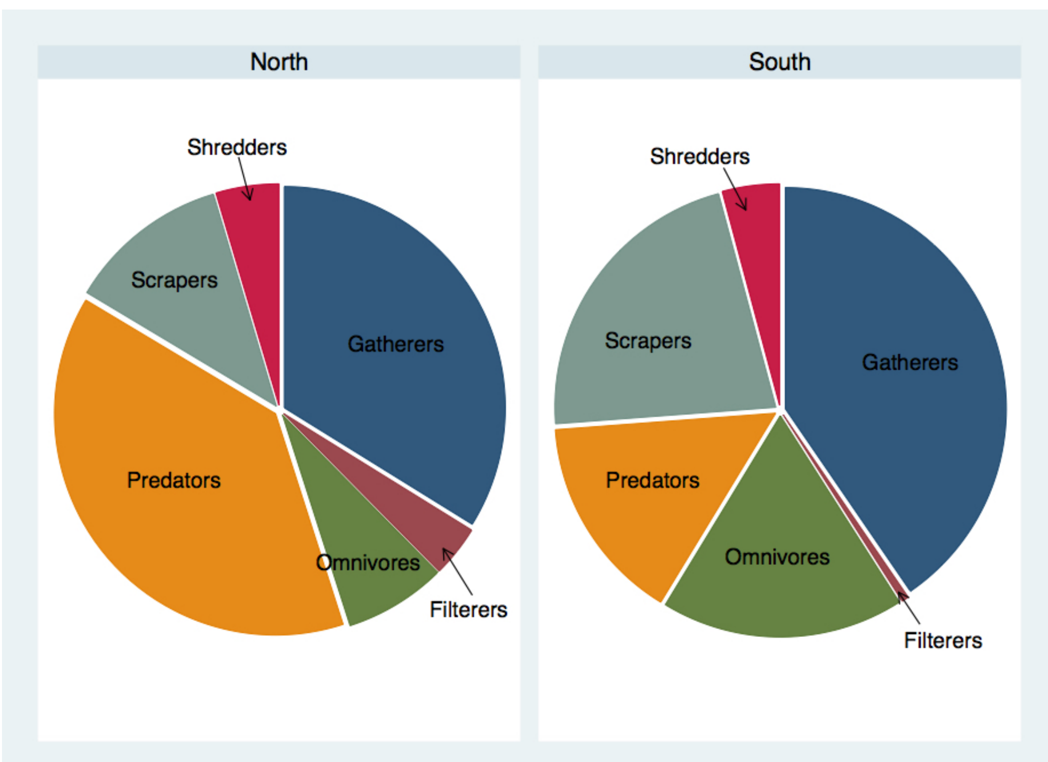

Figure 18. Comparison of Functional Feeding Groups (FFG) between northern and southern ponds based on abundances. July, August and September 2010-2013 data means.

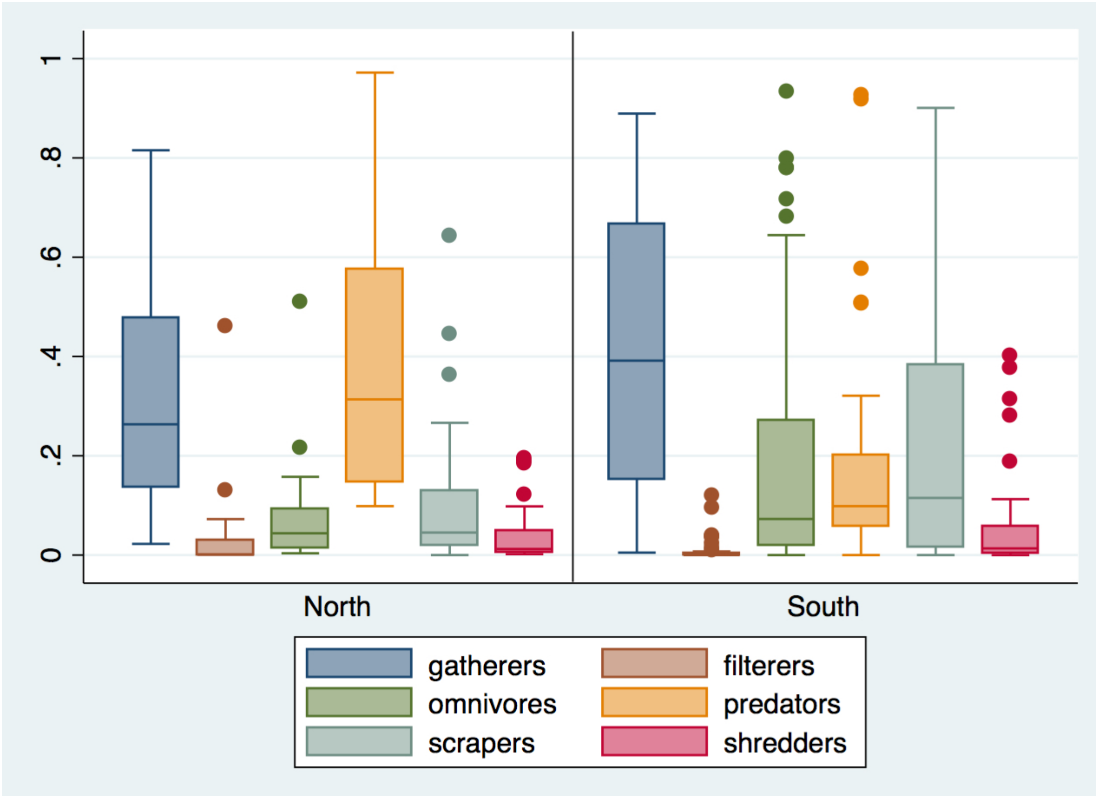

Figure 19. Abundance based FFGs in northern and southern ponds. Boxes are 25th to 75th percentiles, vertical lines are general range, horizontal lines within boxes are medians, and circles are outliers.

Table 10. W-M-W rank sum test of FFG richness, proportional richness, and abundances between northern (less-impaired) and southern (more impaired). July, August, and September 2010-2013 data

FFG Taxa Richness	**T**	**P value**
Filterers	0.87	0.25
Gatherers	1.62	0.20
Omnivores	0.06	0.79
Predators	4.76	0.03
Scrapers	0.81	0.33
Shredders	5.00	0.01
FFG Proportional Taxa Richness	**T**	**P value**
Filterers	0.62	0.34
Gatherers	0.01	0.99
Omnivores	1.70	0.19
Predators	1.30	0.25
Scrapers	6.89	0.01
Shredders	1.07	0.30
FFG Abundance	**T**	**P value**
Filterers	2.07	0.04
Gatherers	-0.90	0.37
Omnivores	-1.70	0.09
Predators	5.00	< 0.01
Scrapers	-1.24	0.22
Shredders	0.59	0.55

Table 11. Summary statistics of proportion FFGs abundance based. July, August, and September 2010-2013.

	FFG	Mean	Std. Dev.	Median	Max	Min	1Q	3Q
North	Gatherers	0.34	0.24	0.26	0.82	0.02	0.14	0.48
	Scrapers	0.12	0.16	0.05	0.64	0.00	0.02	0.13
	Shredders	0.05	0.06	0.01	0.20	0.00	0.01	0.05
	Predators	0.38	0.26	0.31	0.97	0.10	0.15	0.58
	Filterers	0.04	0.10	0.00	0.46	0.00	0.00	0.03
	Omnivores	0.07	0.11	0.04	0.51	0.00	0.01	0.09
South	**FFG**	**Mean**	**Std. Dev.**	**Median**	**Max**	**Min**	**1Q**	**3Q**
	Gatherers	0.40	0.27	0.39	0.89	0.00	0.15	0.67
	Scrapers	0.22	0.26	0.12	0.90	0.00	0.02	0.38
	Shredders	0.04	0.07	0.01	0.40	0.00	0.00	0.06
	Predators	0.15	0.16	0.10	0.93	0.00	0.06	0.20
	Filterers	0.01	0.02	0.00	0.12	0.00	0 .00	0.00
	Omnivores	0.18	0.23	0.07	0.93	0.00	0.02	0.27

FFG: Scrapers (i.e. Snails)

Snail taxa had to be grouped to family level because of poor taxonomy and low abundances of some taxonomic groups that could have been misidentified as another taxon or was not indefinable at a higher taxonomic resolution.

Results

Planorbidae (mostly *Gyraulus* sp.), Physidae, and all snail abundances combined were significantly greater in southern ponds than northern ponds. This is consistent with indicator taxa analyses; *Physa* sp. and *Gyraulus* sp. were indicators of southern ponds.

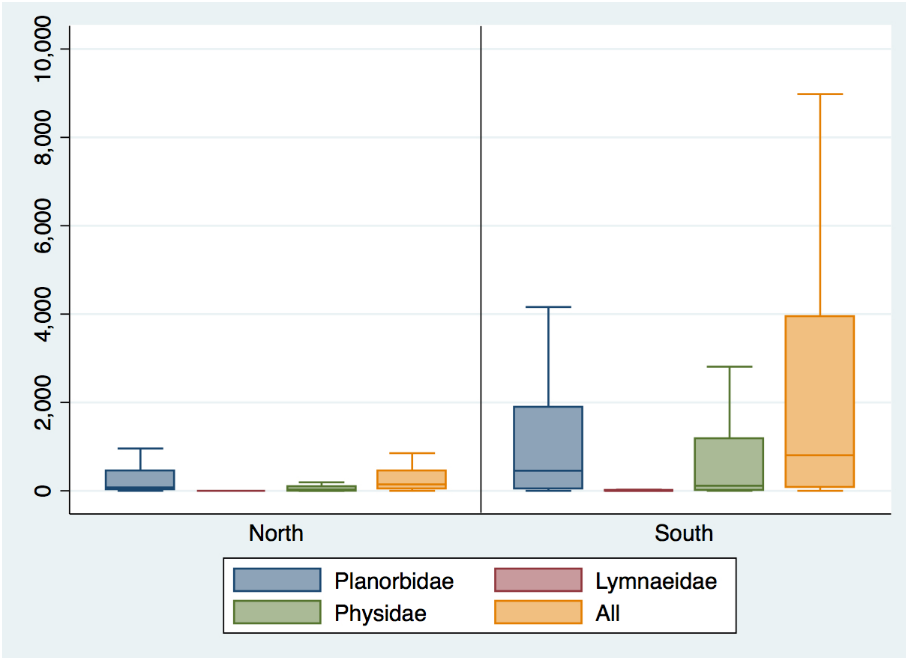

Figure 20. Snail family abundances in northern vs. southern ponds. Boxes are 25th to 75th percentiles, vertical lines are general range and horizontal lines within boxes are medians. Abundances of Planorbidae, Physidae, and families combined were significantly greater in southern ponds than northern ponds.

Table 12. Descriptive statistics of snail family abundances in northern and southern ponds.

	Snail Family	Mean	Std. Dev.	Median	Max	Min	1Q	3Q
North	Planorbidae	257.20	327.79	76	957.17	0.00	27.98	454.83
	Physidae	69.39	103.83	25.19	365.23	0.00	1.25	88.00
	Lymnaeidae	23.12	70.65	0.00	264.48	0.00	0.00	0.00
	All	349.72	455.16	145	1586.90	0.00	44.80	456.09
South	Planorbidae	1508.95	2686.39	454.66	16800.00	0.00	50.4	1891.89
	Physidae	1106.92	2170.78	114.24	9663.87	0.00	10.50	1176.00
	Lymnaeidae	11.929	30.22	0.00	168.00	0.00	0.00	9.33
	All	2627.80	4011.38	804.01	19320.00	0.00	84.033	3944.89

Table 13. Snail Family Abundances, W-M-W rank sum test North (N=14) vs. South (N=54)

Snail Family	Z statistic	p-value
Planorbidae	-1.88	0.05
Lymnaeidae	-0.96	0.33
Physidae	-2.49	0.01
All	-2.36	0.02

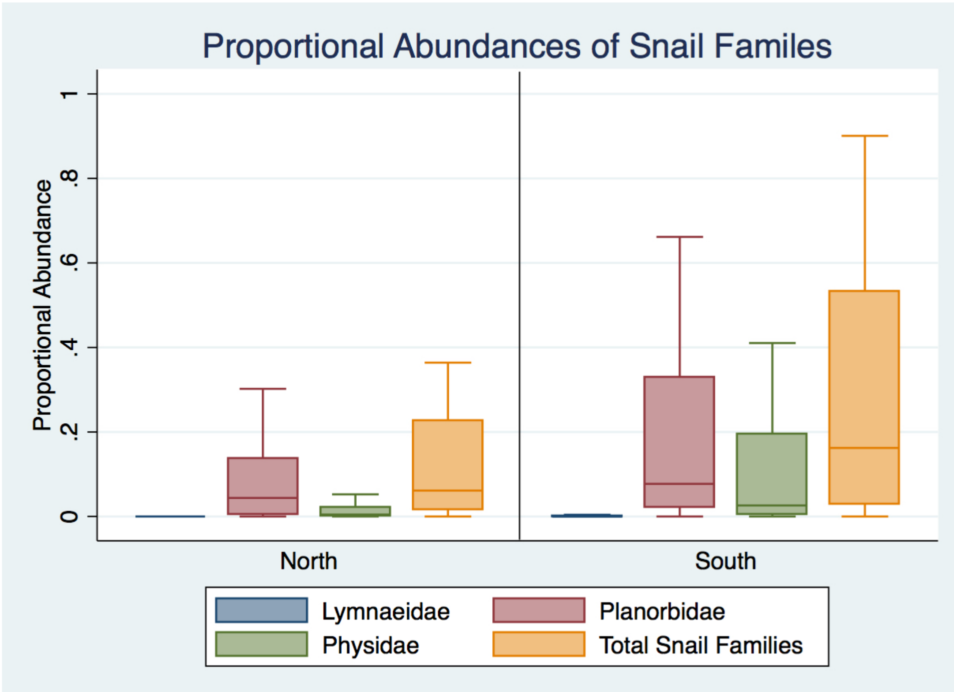

Figure 21. Snail family proportional abundances in northern vs. southern ponds. Boxes are 25th to 75th percentiles, vertical lines are general range and horizontal lines within boxes are medians. Proportional abundances of Physidae were significantly greater in southern ponds than northern ponds, all relative abundances of families combined were greater in southern vs. northern ponds but not significantly (Table 14 and Table 15).

Table 14. Descriptive statistics of snail family proportional abundances in northern and southern ponds.

	Snail Family	Mean	Std. Dev.	Median	Max	Min	1Q	3Q
North	Planorbidae	0.12	0.18	0.04	0.64	0.00	0.01	0.14
	Physidae	0.02	0.02	0.00	0.06	0.00	0.00	0.02
	Lymnaeidae	0.00	0.01	0.00	0.04	0.00	0.00	0.00
	All	0.14	0.18	0.06	0.64	0.00	0.02	0.23
South	Planorbidae	0.18	0.20	0.08	0.66	0.00	0.02	0.33
	Physidae	0.11	0.16	0.03	0.59	0.00	0.01	0.20
	Lymnaeidae	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	All	0.29	0.29	0.16	0.90	0.00	0.03	0.53

Table 15. Snail families proportional abundances (compared to total macroinvertebrate abundances) W-M-W rank sum test North (N=14) vs. South (N=54). July, August, September 2010-2013.

Snail Family	Z statistic	p-value
Planorbidae	-1.02	0.31
Lymnaeidae	-1.05	0.29
Physidae	-2.27	0.02
All	-1.68	0.09

Macroinvertebrate MIBI

The following MIBI was developed from the analyses presented in this report and synthesized from research previously conducted by the author and colleagues (i.e. Miller, Hoven Johnson, Carling, etc.). There are three classifications of condition (e.g. levels of 'impairment' 'stress', etc.): 1) Further investigation *not recommended*; 2) further investigation *strongly recommended*; and 3) further investigation *recommended*.

Table 16. Proposed GSL impounded wetland pond macroinvertebrate MIBI. Based on data collected and condensed from 17 ponds, 96 samples, July, August, and September 2010-2013.

Metric	Further Investigation		
	Not Recommended	**Strongly Recommended**	**Recommended**
Indicator Taxa			
Indicator Taxa Score	> 3.00	< 1.00	1.00 to 3.00
Richness Measures			
Taxa Richness	≥17.00	≤ 16.00	NA
Predator Richness	> 7.00	< 5.00	5.00 to 6.00
Shredder Richness	≥ 2.00	< 2.00	NA
FFG Measures			
Proportion Scraper Richness	< 0.11	> 0.15	0.11 to 0.15
Proportion Filterers Abundance	> 0.00	0.00	NA
Proportion Predators Abundance	≥ 0.15	< 0.15	NA
Proportion Physidae Abundance	< 0.05	≥ 0.05	NA
Proportion Snail Abundance	< 0.25, > 0.10	> 0.25	< 0.10

Scores and ranges of scores for each of the metrics in the MIBIs were subjectively based on 25th to 75th percentiles, means, and medians (Table 5, Table 7, Table 8, Table 9, Table 11, Table 12, and Table 14). There was overlap in ranges of scores in a few instances therefore; those scores were estimated. Again, these scoring systems as well as all MIBIs are subjective and are easily modifiable with additional data or consultation with other experts.

Ponds with sample scores that range in the 'Further investigation not recommended' category are likely in good condition. Ponds with sample scores that range in the 'Further investigation strongly recommended' category are likely in 'poorer' condition. Reasons for their low scores need to be investigated. Ponds with sample scores that range in the 'Further investigation recommended' category are in between the two other categories and a simple re-investigation of the data used to produce these scores may be all that is needed to place in a different category or additional action is recommended, including collection of additional samples, etc.

There are several potential problems and concerns with FFGs in this MIBI. Filterer taxa richness was low in most ponds including BR and PN with often only one or two taxa in a sample. Therefore, their occurrences or absences may be due to numerous reasons and less weight should be placed on this metric. Change in predator richness may simply be because presence/absence of those taxa had nothing to due with their FFG. The predator FFG is a difficult metric to quantify in terms of its response to impairment and most IBIs have a wide range of values associated with this metric. In all instances where FFG metrics recommend further investigation, examination of individual taxa identities is suggested. Knowledge of individual taxa is the basis of all metrics including diversity metrics. There will likely be a need to weight the ITM and possibly Taxa Richness metrics more than FFG metrics, pending additional data analyses.

Macroinvertebrate Taxa in Relation to Plant Metrics

Introduction and Background

Causal factors determining macroinvertebrate MIBI scores and selection of metrics were not analyzed in this report other than the initial choice to separate northern (less impaired) ponds from southern (more impaired) ponds based on water chemistry. However, this MIBI was developed in conjunction with a plant metric MIBI (Hoven et al. 2014) and concurrent macroinvertebrate and plant metric data were collected 2010-2012. The following section provides a brief background on macroinvertebrate and plant associations in GSL wetland ponds and a preliminary analysis of those relationships.

Macroinvertebrate assemblages in GSL impounded wetland ponds are intimately linked with primary producers. Macroinvertebrate assemblages in impounded wetlands and lakes, including those analyzed in this study have been described as either, “base” assemblages associated with the shallow water profundal habitats (Barnes and Toole 1981, Gray 2009, Gray 2010, Shiozawa and Barnes 1977) or “phytophilous” (living or feeding on plants) assemblages which are more closely associated with the macrophyte and submergent aquatic vegetation (SAV) community (Cyr and Downing 2006, Feldman 2001, Gray 2009, and Gray 2010).

All else being equal, heterogeneous habitats (e.g. macrophytes) will have more macroinvertebrate taxa diversity than homogenous habitats (profundal). This is obvious in the impounded wetland ponds where relatively homogenous silt and mud (2-dimensional) substrates typically have less macroinvertebrate diversity (Miller et al. 2011, Gray 2009, and Gray 2010) than do multi storied (3-dimensional) macrophyte canopies. Macrophyte habitats can increase macroinvertebrate diversity in several ways:

1) Considerable increased total surface area compared to relatively flat silt and mud substrates;

2) Substantial increased amounts of periphyton food resources growing on the surface of the macrophytes;

3) Increased security for prey taxa and cover for predators;

4) Increased surface area for egg laying and development and;

5) For a few macroinvertebrate taxa, increased food resources due to direct consumption of the macrophyte tubers, leaves, drupelets, flowers, or seeds, etc.

For example, Miller et al. (2011), found that many GLS wetland macroinvertebrate taxa were positively correlated with 'good' water quality macrophyte metrics including the following taxa:

Callibaetis sp. (Ephemeroptera),
Aeshnidae (Odonate),
Coenagrionidae (Odonate),
Notonecta sp. (Hemiptera),
Ephydridae (Diptera),
Stratiomyidae (Diptera),
Leptoceridae (Trichoptera)
Oecetis sp. (Trichoptera),
An unidentified lepidopteran taxon,
Stagnicola sp. (Gastropoda),
Ostracoda, and
Sigara sp. (Hemiptera)
Chironomus sp. (Chironomidae),
Cladotanytarsus sp. (Chironomidae) and
Arrenurus sp. (Acari).

Habitat preferences for these many of these taxa are poorly understood. Contrarily, oligochaetes were negatively correlated with drupelets ($g \cdot m^2$) and *Limnesia* sp. (Acari), Pionidae (Acari), and *Hyalella* sp. (Amphipoda) were negatively correlated with % SAV. Little is known about habitat characteristics of these Acari (mites) taxa, although *Hyalella* sp. was shown to occur in greater abundances in filamentous algae and duckweed in these same ponds (Gray 2011). *Physa* sp. (Gastropoda) and *Stagnicola* sp. (Gastropoda) were negatively correlated with % Surface Light-sub canopy (Miller et al. 2011).

Miller et al. (2011) results were similar to Gray (2011) who combined individual macroinvertebrate taxa into a PMI (phytophilous macroinvertebrates) category and then compared PMI with a single categorical metric, SAV cover. Miller et al. (2011) elected to compare individual taxa with several additional plant metrics for higher resolution. This higher resolution allowed for better insights into the relationships between macroinvertebrates and plant communities in the GSL impounded wetlands. The recently developed plant MIBI for GSL wetland ponds by Hoven and Richards (2014) refined the work conducted by Miller et al. (2011) and narrowed the number of plant metrics to ten highly informative plant metrics (Table 17).

Methods

Macroinvertebrate samples were collected in conjunction with the plant metrics used by Hoven and Richards (2014) from 2010-2012. Pearson rank correlations were conducted between macroinvertebrate taxa abundances and these plant metrics.

Results

Correlations between macroinvertebrate taxa and plant metrics are in (Table 17) and were very similar to Miller et al. (2011). These results show that macroinvertebrate assemblages are linked with primary producers and water quality attributes that the plant metrics represent. Even though primary producers are likely the most important factors; environmental and ecological factors other than plant metrics affect macroinvertebrate assemblages and more intensive statistical analyses are required to determine which are the primary causal factors in their distribution and abundances.

Table 17. Pearson rank correlations (τ) of raw taxa abundances with plant metrics proposed by Hoven et al. 2014 for GSL wetland pond plant IBI.

All correlations were significant at $p \leq 0.05$. 2010-2012 data (no comparable plant data for 2013 macroinvertebrate data). For a detailed description of plant metrics and how they relate to water quality see Hoven and Richards (2014).

Positive Correlation									
	Poor Water Quality Indicators		**Good Water Quality Indicators**						
% Total Mat	**% Algae on SAV**	**% BDS on SAV**	**% Forageable SAV**	**Tubers (gm^2)**	***Stuckenia* drupelets (gm^2)**	***Ruppia* drupelets (gm^2)**	***Stuckenia* and *Ruppia* Drupelets (gm^2)**	**Branch Density**	**SAV Condition Index**
Physa	*Bezz/Palpomy*	*Hydrachna*	*Callibaetis*	*Physa*			Coenagrnidae	*Sigara*	*Sigara*
Bezz/Palpom	Crambidae			*Gyraulus*				*Callibaetis*	
H. stagnalis	*Physa*			*Arrenurus*				*Oecetis*	
Crambidae	Lymnaeidae								
Erpobdella	*Gyraulus*								
Laccphilus	*Enochrus*								
Pionidae	*Caenis*								
	Hygrotus								

Negative Correlation									
	Poor Water Quality Indicators		**Good Water Quality Indicators**						
% Total Mat	**% Algae on SAV**	**% BDS on SAV**	**% Forageable SAV**	**Tubes gm^2**	***Stuckenia* drupelets gm^2**	***Ruppia* Drupelets gm^2**	**SRDrup**	**Branch Density**	**SAV Condition Index**
Oecetis	*Corisella*	*H. stagnalis*	*Cladotanytarsus*	*Tanypus*	*Notonecta*	Bezz/Palpomy	*Pseudchironomus*	*Procladius*	Nematoda
Corisella	*Cryptochironomus*		*Cryptochironomus*	*Chironomus*		Pionidae		*Hyalella*	Oligochaeta
Procladius	*Triaenodes*		*Hyalella*						*Hyalella*
Triaenodes	*Tanypus*		*Tanypus*						Pionidae
Tanypus			*Procladius*						
Cryptochironomus									

Note: The analyses presented in this section on macroinvertebrate relations to plant metrics has been complemented with more detailed analyses and additional data in a supplemental report by Richards 2015.

DISCUSSION AND CONCLUSION

The macroinvertebrate MIBI presented in this report can be a useful management tool for assessments of water quality in GSL wetland ponds and does not require overly intensive or costly measurements and analyses. This MIBI is also very flexible, amenable to revision, and the addition of other metrics pending further research, analyses and professional evaluation. As with all MIBIs, final scoring was subjective, a necessary trade-off when incorporating scientific analyses into management decision making tools.

Only about 20 taxa were found to be responsive to differences in northern (less impaired) and southern (more impaired) ponds, including several important in shorebird and waterfowl diets. Therefore, there does not appear to be any need for an exhaustive array of additional metrics or conversely a need to roll up the metrics into one overall score that would provide little or no guidance as to causal effects. The latter is a poor choice and likely a disservice to GSL wetland ecosystem assessments. However, some of the metrics presented could be considered redundant and removed if an understanding of ecological processes such as functional feeding groups is not considered important, although this is not recommended. A much better approach would be to increase biological and ecological knowledge and understanding of each of these few taxa and adjust the MIBI accordingly. Each of these taxa has a unique and important story to tell concerning water quality and ecological conditions.

In addition to variability associated with sample collection, laboratory taxonomy and subsampling added considerable variability and an unknown amount of error resulting in less resolution between pond groups. As one example, determining the genus of snail taxa that were classified as only to Lymnaeidae would help considerable in knowing whether these specimens were *Stagnicola* sp. or a different lymnaeid genus. Rolling up of taxa into lower taxonomic groupings also added error. These errors are mostly unavoidable considering the cost of laboratory analyses. Genetic barcoding is a promising new method that if used will reduce these errors substantially (Richards et al. 2014 etc.) Development of a barcoding program is highly recommended. Genetic barcoding will also increase the number of taxa, especially rare or uncommon taxa that are collected in samples, those taxa which aren't observed in subsamples and go unreported when using standard taxonomic subsampling methods. The author of this report, Dr. Miller, and the Jordan River Farmington Bay Water Quality Council are leading the effort to develop genetic barcoding for use in assessing and monitoring GSL wetland ponds and other waters in UT.

This MIBI was not explicitly developed for the designated beneficial use of waterfowl and shorebird diets but for overall water quality, including nutrients and metals. However, waterfowl and shorebird diets were implicit in this MIBI. For example, several midge (e.g. *Ablabesmyia* sp., *Tanytarsus* sp., etc.: Family Chironomidae) taxa were included in the Indicator Taxa Metric and are important in bird diets, as well as are snail taxa. Some midge taxa abundances such as *Chironomus* sp., another important food item, did not differ between northern and southern ponds. If midge taxa were only identified at the family level then important information would have been lost. Other reasons why this MIBI did not focus on bird diets were the seasonal variability in food items, the large number of different species of wetland associated bird species, each with different dietary preferences, and the lack of diet information. Also, this MIBI focused on summer month sample collection (July, August, and September) to reduce error associated with seasonal macroinvertebrate variability. Thousands of waterfowl use GSL wetland ponds in spring and autumn and not during summer months. A MIBI that is designed exclusively to assess bird food item production in certain GSL wetland ponds should be considered. Standing crop biomass estimates and possibly secondary production studies would be very useful. Macroinvertebrate abundances are crude surrogates for standing crop biomass and if samples are only collected annually, they are not an estimate of secondary production. However, standing crop biomass is likely a very good metric for assessing bird diet water quality. There were limited biomass (measured as dry weight) data available from 2010 and 2012 data (N = 11 northern pond, N = 23 southern pond) used in this study. For those data available, taxa biomasses were grouped into large taxonomic groups: Acari, Annelida, Chironomidae, Coleoptera, Crustacea, Diptera, Ephemeroptera, Gastropoda, Oligochaeta, Other, Trichoptera, and Total. Of those taxonomic groups, three had significantly greater biomass in southern ponds: Acari, Crustacea (primarily *Hyallela* sp.), and Oligochaeta. Two groups, Trichoptera and Other (everything else including Corixids and Odonates) had significantly greater biomass in northern ponds (Table 18).

Table 18. Taxa with significantly different biomasses in northern vs. southern ponds. 20100-2012 data.

Taxon	z	p-value
Acari	-1.92	0.05
Crustacea	-3.11	< 0.00
Oligochaeta	-2.89	0.01
Other	3.48	< 0.00
Trichoptera	3.30	< 0.00

Greater biomass of *Hyallela* sp. in southern ponds is likely beneficial to waterfowl and greater biomass of Trichoptera in northern ponds is likely a good indicator of less impairment overall. Further studies that focus on macroinvertebrate standing crop biomass and secondary production are necessary to assess and monitor water quality associated with waterfowl and shorebird diets and other water quality indicators.

Taxa richness, evenness, and diversity metrics are the foundations of assemblage comparisons and evaluations. Most management agencies MIBIs incorporate a taxa richness metric and most incorporate evenness and diversity metrics. However, evenness and diversity metrics are likely not important for GSL wetland pond management because the designated beneficial use of these waters is for wildlife, particularly waterfowl and shorebirds, which require greater abundances of fewer taxa and hence less evenness and diversity. The use of a phytophilous macroinvertebrate metric was not considered useful because wetland pond samples are inevitably collected in macrophytes and the great majority of taxa collected would be tend to be phytophilous.

Decisions to list ponds as impaired based on future sampling and this or any MIBI should also not be attempted before more closely examining the data. Errors throughout the process accumulate and it cannot be over stated that MIBIs are assessment tools and should only be used to initiate further investigations.

Northern pond taxa aren't necessarily 'good' taxa and other factors affect their distribution and abundances. For the most part, most taxa found in GSL wetland ponds are considered warm water and pollution tolerant (e.g. Hillsenhoff Biotic Index), although Ephemeroptera and Trichoptera taxa are generally considered less tolerant of impairment and were more likely to occur in northern ponds. Increased abundances of snails in southern ponds, particularly *Physa* sp. and *Gyraulus* sp. were likely due to increased periphyton on macrophytes. Snails are the most important bio control of algae and diatoms growing on macrophytes in GSL wetland ponds. Lower abundances of these snail taxa is likely due to lower amounts of algae growing on macrophytes but could be due to other major water quality impairments. For example, Hoven et al. (2013) and other members of the Willard Spur Science Panel documented a severe decline (zero abundance) in snail abundances in Willard Spur (a large area of freshwater in GSL) in 2012. It is unknown if this was due to limited sampling effort or an actual snail extinction event in Willard Spur. A decreased amount of algae on macrophytes was not observed and did not appear to be the cause of this event. Algal grazing snails are extremely important in controlling algae on macrophytes and in maintaining the health of GSL wetland ponds and the cause of any extinction event should be closely examined. Therefore, too many or too few snails are not beneficial.

We are also evaluating responses of each of the indicator taxa identified in this report to the plant metrics, chemistry and nutrient measurements, and water management and water quality data to isolate the main factors or combination of factors that determine their abundances, presence/absences, and biomass. Impounded GSL wetland ponds are intensively managed including the duration, timing, and water levels in a pond. Many are completely dried on a regularly basis. Sources of inflows also vary, as does their location in the landscape. Each pond varies as to whether highly invasive and ecosystem-altering species such as carp, invasive snails (e.g. *Radix auricularia*), or crayfish are present. These factors need to be evaluated to better manage the unique GSL wetland pond ecosystems.

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APPENDICES

Appendix 1. Non-metric multidimensional scaling results by sample site: Axis 1-3 coordinates. N = 68 samples. July, August, and September 2010-2013 data.

	Axis 1	Axis 2	Axis 3
AM-710	1.28225	0.64104	0.09324
AM-712	-0.87244	-0.32131	0.61972
AM-713	0.01602	-0.0847	-0.20987
AM-812	-0.08818	0.51268	0.40607
AM-910	-0.27915	0.85117	0.42729
AM-912	-0.03326	0.67507	0.4707
AM-913	1.05599	0.50634	0.2546
AM100912	-0.3088	0.8013	-0.78398
AMb-910	0.77931	0.57999	0.41982
AMc-910	0.97746	0.36757	0.40077
AMs-910	0.03065	0.24134	0.79699
AMw1-712	-0.87244	-0.32131	0.61972
AMw1-811	0.05764	0.71025	0.23701
AMw1-812	-0.08818	0.51268	0.40607
AMw1-912	-0.03326	0.67507	0.4707
BR-710	0.39501	-0.14289	-0.1557
BR4C-712	-0.19367	-0.35882	-1.10186
BR4C-812	0.82338	-0.36027	-0.92605
BR5C-712	-0.51131	-0.32846	0.14048
FB1-710	0.92815	0.39121	-0.36892
FB1-713	1.0218	-0.61683	-0.13922
FB1-812	0.54393	-0.82026	0.0023
FB1-910	0.55974	0.0658	0.00037
FB1-912	-0.23727	-1.11945	0.07476
FB1a712	0.77268	-1.00983	-0.45998
FB1b-712	0.4815	-1.13512	-0.34093
FB1b712	0.4815	-1.13512	-0.34093
FB1E-811	-0.73847	0.64816	0.17914
FB1EW811	-0.25693	0.09661	0.30675
FB1W-811	0.09337	-0.43028	0.53457
FB2-710	0.64968	0.49884	-0.29364
FB2-712	-0.11281	-0.08829	-0.25666
FB2-713	0.04335	-0.23745	-0.18289

FB2-910	0.62454	-0.32739	-0.11652
FB2-912	-0.31211	-0.40871	-0.0464
FB2-913	0.1153	0.64711	-0.25603
FB2b910	-0.03208	0.27396	-0.57492
FB2s910	-0.47281	0.15814	0.86716
FBtu-712	-0.81483	-0.76513	-0.16538
FBtu-912	0.16628	0.30467	-0.79398
HR11-912	-0.2209	0.99277	0.27824
HR8-912	-0.42672	0.69414	0.02495
LF10-912	-0.38437	0.56571	-0.52951
LF14-912	0.06083	0.94989	0.06396
NP19-912	0.27204	0.5063	0.14562
NP22-912	0.65507	1.50949	-0.68342
NP22b912	-0.1086	-0.81507	-0.15759
NS-713	0.54463	-0.31166	0.67458
NS-912	-0.48796	0.25048	0.08947
NS-913	0.83774	-0.89788	0.75409
NS47-811	-0.25324	-0.50743	1.31674
NSa-712	-0.65706	-0.08691	0.15565
NSb-712	-0.27171	0.23786	0.1488
NScl-912	0.05964	-0.17646	-0.02607
NSop-712	-0.65706	-0.08691	0.15565
NSop-912	-0.49412	0.25049	0.11388
P47-710	1.52656	-0.08341	0.27702
P47-910	0.49737	-1.22123	1.06982
PN-710	0.13491	0.26766	-0.39495
PN-712	-1.08734	-0.57921	0.04686
PN-713	0.24257	-0.64096	-0.72654
PN-810	0.33145	-0.12365	-0.4746
PN-811	-1.70495	0.00275	-0.78878
PN-812	-1.17388	-0.39251	-0.26671
PN-910	-1.4697	0.07927	0.36815
PN-912	-0.93589	-0.15248	-0.63561
PN-913	-0.40586	-0.27941	-0.65329
PNa-810	-0.06495	-0.09902	-0.56078

Appendix 2. Final non-metric multidimensional scaling results by taxon: Axis 1-3 coordinates. N = 36 taxa. July, August, and September 2010-2013 data.

Taxon	Axis 1	Axis 2	Axis 3
Ablabesm	0.09635	0.13586	-0.38195
Apedilum	0.20282	0.14524	0.02744

Arrenuru	-0.14513	0.19299	0.00899
Bezzia/P	0.45606	0.53681	0.10699
Caenis	0.15595	0.49603	-0.32565
Callibae	0.10063	-0.00274	-0.17663
Chironom	0.40905	-0.12969	-0.12062
Cladotan	0.33783	0.21196	-0.69606
Coenagri	-0.03324	0.09746	-0.10752
Corisell	0.6209	0.0809	-0.14075
Corixida	0.22462	-0.21015	-0.01271
Corynone	0.14766	0.69846	-0.26304
Crambida	-0.11573	0.37366	-0.02629
Cricotop	0.44838	0.29071	0.20134
Cryptoch	0.45875	-0.30853	-0.18606
Dasyhele	0.78982	0.4164	-0.19581
Glyptote	0.47935	0.17507	-0.11404
Gyraulus	0.0409	0.49162	0.0331
Helobdel	0.07952	0.54946	0.31003
Hesperoc	-0.30547	0.21125	-0.02875
Hyalella	0.33594	0.44789	-0.03902
Libellul	-0.6332	0.26595	-0.04296
Limnesia	0.33372	-0.15165	-0.12838
Lymnaeid	0.14513	0.4948	0.01415
Nematoda	0.8312	0.22758	0.33684
Notonect	0.2416	0.0136	-0.19325
Oecetis	-0.23966	0.1043	-0.42847
Oligocha	0.69337	0.13873	0.19784
Ostracod	0.41819	0.22387	0.12129
Paratany	0.64609	0.1706	0.16603
Physa sp	0.29902	0.4277	0.17526
Pionidae	0.37253	0.11706	-0.02981
Procladi	0.3507	0.05266	-0.17665
Sigara s	-0.03466	0.16035	-0.27803
Tanypus	0.55287	-0.34753	-0.1932
Tanytars	0.28498	0.148	-0.70282

Appendix 3. Pearson and Kendall Correlations of Taxa with Ordination Axes N= 68

Taxon	Axis 1			Axis 2			Axis 3		
	r	R^2	tau	r	R^2	tau	r	R^2	tau
Ablabesm	0.063	0.004	0.015	0.097	0.009	0.065	-0.324	0.105	-0.315

Apedilum	0.215	0.046	0.086	0.169	0.028	0.113	0.038	0.001	-0.077
Arrenuru	-0.161	0.026	-0.21	0.234	0.055	0.169	0.013	0	0.026
Bezzia/P	0.251	0.063	0.107	0.323	0.104	0.178	0.077	0.006	0.201
Caenis	0.142	0.02	0.091	0.493	0.243	0.352	-0.386	0.149	-0.349
Callibae	0.104	0.011	0.021	-0.003	0	0.022	-0.239	0.057	-0.12
Chironom	0.647	0.419	0.424	-0.225	0.05	-0.217	-0.249	0.062	-0.25
Cladotan	0.167	0.028	0.034	0.115	0.013	-0.059	-0.45	0.203	-0.321
Coenagri	-0.075	0.006	0.066	0.242	0.058	0.286	-0.318	0.101	-0.175
Corisell	0.301	0.091	0.142	0.043	0.002	-0.131	-0.089	0.008	-0.017
Corixida	0.15	0.022	0.001	-0.153	0.023	-0.22	-0.011	0	0.006
Corynone	0.089	0.008	0.057	0.463	0.214	0.34	-0.208	0.043	-0.063
Crambida	-0.115	0.013	-0.148	0.407	0.166	0.24	-0.034	0.001	-0.088
Cricotop	0.424	0.18	0.224	0.301	0.091	0.244	0.249	0.062	0.295
Cryptoch	0.371	0.138	0.274	-0.273	0.075	-0.297	-0.197	0.039	-0.166
Dasyhele	0.336	0.113	0.24	0.194	0.038	0.106	-0.109	0.012	-0.076
Glyptote	0.531	0.282	0.403	0.212	0.045	0.14	-0.165	0.027	-0.197
Gyraulus	0.06	0.004	-0.055	0.793	0.628	0.651	0.064	0.004	0.134
Helobdel	0.062	0.004	-0.05	0.472	0.223	0.363	0.318	0.101	0.333
Hesperoc	-0.208	0.043	-0.298	0.158	0.025	0.096	-0.026	0.001	0.086
Hyalella	0.35	0.122	0.191	0.51	0.26	0.469	-0.053	0.003	0.083
Libellul	-0.351	0.123	-0.315	0.161	0.026	0.075	-0.031	0.001	0.088
Limnesia	0.383	0.147	0.229	-0.191	0.036	-0.212	-0.193	0.037	-0.143
Lymnaeid	0.103	0.011	-0.072	0.384	0.147	0.175	0.013	0	0.122
Nematoda	0.259	0.067	0.203	0.078	0.006	0.002	0.137	0.019	0.173
Notonect	0.233	0.054	-0.025	0.014	0	0.037	-0.244	0.059	-0.06
Oecetis	-0.167	0.028	-0.16	0.079	0.006	-0.021	-0.39	0.152	-0.315
Oligocha	0.652	0.425	0.524	0.143	0.02	0.024	0.243	0.059	0.302
Ostracod	0.332	0.11	0.128	0.195	0.038	0.135	0.126	0.016	0.126
Paratany	0.382	0.146	0.265	0.11	0.012	0.026	0.128	0.016	0.177
Physa sp	0.38	0.145	0.168	0.595	0.355	0.561	0.291	0.085	0.258
Pionidae	0.53	0.281	0.402	0.182	0.033	0.165	-0.055	0.003	-0.015
Procladi	0.547	0.299	0.451	0.09	0.008	-0.009	-0.36	0.13	-0.339
Sigara s	-0.03	0.001	-0.129	0.152	0.023	-0.027	-0.315	0.1	-0.273
Tanypus	0.599	0.358	0.424	-0.412	0.17	-0.336	-0.273	0.075	-0.225
Tanytars	0.141	0.02	0.068	0.08	0.006	-0.017	-0.456	0.208	-0.315

Appendix 4. Multiple response permutation procedure (MRPP) results output

```
Groups were defined by values of: NorthSouth
Input data has:       68 Samples  by     36 Taxa
Weighting option: C(I) = n(I)/sum(n(I))
Distance measure: Sorensen (Bray-Curtis)
```

```
     GROUP:     1
Identifier:     2
      Size:    54      0.61354704    = Average distance
Members:
 AM-710   AM-712   AM-713   AM-812   AM-910   AM-912   AM-913   AM100912
 AMb-910  AMc-910  AMs-910  AMw1-712 AMw1-811 AMw1-812 AMw1-912 FB1-710
 FB1-713  FB1-812  FB1-910  FB1-912  FB1a712  FB1b-712 FB1b712  FB1E-811
 FB1EW811 FB1W-811 FB2-710  FB2-712  FB2-713  FB2-910  FB2-912  FB2-913
 FB2b910  FB2s910  FBtu-712 FBtu-912 HR11-912 HR8-912  LF10-912 LF14-912
 NP19-912 NP22-912 NP22b912 NS-713   NS-912   NS-913   NS47-811 NSa-712
 NSb-712  NScl-912 NSop-712 NSop-912 P47-710  P47-910

     GROUP:     2
Identifier:     1
      Size:    14      0.59153322    = Average distance
Members:
 BR-710   BR4C-712 BR4C-812 BR5C-712 PN-710   PN-712   PN-713   PN-810
 PN-811   PN-812   PN-910   PN-912   PN-913   PNa-810

        Test statistic: T =      -9.1338489
           Observed delta =      0.60901478
           Expected delta =      0.63030548
        Variance of delta =      0.54334092E-05
        Skewness of delta =      -1.0874007

        Chance-corrected within-group agreement, A =    0.03377839
          A = 1 - (observed delta/expected delta)
          Amax = 1 when all items are identical within groups (delta=0)
          A = 0 when heterogeneity within groups equals expectation by chance
          A < 0 with more heterogeneity within groups than expected by chance

        Probability of a smaller or equal delta, p =    0.00000085

****************************** MRPP finished ******************************
15 Dec 2014, 10:42:40



        Groups were defined by values of: YearCode
        Input data has:      68 Samples  by     36 Taxa
        Weighting option: C(I) = n(I)/sum(n(I))
        Distance measure: Sorensen (Bray-Curtis)

     GROUP:     1
Identifier:     1
      Size:    17      0.61068082    = Average distance
Members:
 AM-710   AM-910   AMb-910  AMc-910  AMs-910  BR-710   FB1-910  FB2-710
 FB2-910  FB2b910  FB2s910  P47-710  P47-910  PN-710   PN-810   PN-910
 PNa-810

     GROUP:     2
Identifier:     3
      Size:    36      0.60181332    = Average distance
Members:
```

```
 AM-712   AM-812   AM-912   AM100912 AMw1-712 AMw1-812 AMw1-912 BR4C-712
 BR4C-812 BR5C-712 FB1-710  FB1-812  FB1-912  FB1a712  FB1b-712 FB1b712
 FB2-712  FB2-912  FBtu-712 FBtu-912 HR11-912 HR8-912  LF10-912 LF14-912
 NP19-912 NP22-912 NP22b912 NS-912   NSa-712  NSb-712  NScl-912 NSop-712
 NSop-912 PN-712   PN-812   PN-912

     GROUP:     3
Identifier:     4
      Size:     9      0.58699093    = Average distance
Members:
 AM-713   AM-913   FB1-713  FB2-713  FB2-913  NS-713   NS-913   PN-713
 PN-913

     GROUP:     4
Identifier:     2
      Size:     6      0.60098891    = Average distance
Members:
 AMw1-811 FB1E-811 FB1EW811 FB1W-811 NS47-811 PN-811

        Test statistic: T =      -6.8465861
           Observed delta =      0.60199567
           Expected delta =      0.63030548
        Variance of delta =      0.17097239E-04
        Skewness of delta =     -0.63276937

        Chance-corrected within-group agreement, A =    0.04491444
          A = 1 - (observed delta/expected delta)
          Amax = 1 when all items are identical within groups (delta=0)
          A = 0 when heterogeneity within groups equals expectation by chance
          A < 0 with more heterogeneity within groups than expected by chance

        Probability of a smaller or equal delta, p =    0.00000218


------------------------------------------------------------------
PAIRWISE COMPARISONS
Note: p values not corrected for multiple comparisons.

      Groups (identifiers)
       Compared           T            A            p
       2010  vs.2012     -6.58487041    0.03293986    0.00005778
       2010  vs.2013     -0.77668907    0.00735554    0.19860243
       1  vs.      2     -2.82206528    0.03112722    0.01246521
       3  vs.      4     -3.99090205    0.02526086    0.00308643
       3  vs.      2     -2.40811649    0.01714572    0.02697085
       4  vs.      2     -4.60850422    0.07866968    0.00049251
------------------------------------------------------------------

***************************** MRPP finished *****************************
15 Dec 2014, 10:44:04



        Groups were defined by values of: MonthCod
        Input data has:      68 Samples  by     36 Taxa
        Weighting option: C(I) = n(I)/sum(n(I))
```

```
        Distance measure: Sorensen (Bray-Curtis)

     GROUP:     1
Identifier:     2
      Size:    24      0.61490156    = Average distance
Members:
 AM-710   AM-712   AM-713   AMw1-712 BR-710   BR4C-712 BR5C-712 FB1-710
 FB1-713  FB1a712  FB1b-712 FB1b712  FB2-710  FB2-712  FB2-713  FBtu-712
 NS-713   NSa-712  NSb-712  NSop-712 P47-710  PN-710   PN-712   PN-713

     GROUP:     2
Identifier:     3
      Size:    13      0.62403950    = Average distance
Members:
 AM-812   AMw1-811 AMw1-812 BR4C-812 FB1-812  FB1E-811 FB1EW811 FB1W-811
 NS47-811 PN-810   PN-811   PN-812   PNa-810

     GROUP:     3
Identifier:     4
      Size:    31      0.61696678    = Average distance
Members:
 AM-910   AM-912   AM-913   AM100912 AMb-910  AMc-910  AMs-910  AMw1-912
 FB1-910  FB1-912  FB2-910  FB2-912  FB2-913  FB2b910  FB2s910  FBtu-912
 HR11-912 HR8-912  LF10-912 LF14-912 NP19-912 NP22-912 NP22b912 NS-912
 NS-913   NScl-912 NSop-912 P47-910  PN-910   PN-912   PN-913

        Test statistic: T =      -3.8720963
           Observed delta =      0.61759002
           Expected delta =      0.63030548
        Variance of delta =      0.10783816E-04
        Skewness of delta =     -0.76817139

        Chance-corrected within-group agreement, A =    0.02017350
          A = 1 - (observed delta/expected delta)
          Amax = 1 when all items are identical within groups (delta=0)
          A = 0 when heterogeneity within groups equals expectation by chance
          A < 0 with more heterogeneity within groups than expected by chance

        Probability of a smaller or equal delta, p =    0.00179663


------------------------------------------------------------------
PAIRWISE COMPARISONS
Note: p values not corrected for multiple comparisons.

      Groups (identifiers)
       Compared            T             A             p
       July  vs.August     -1.94934282   0.01422079    0.04655680
       July  vs.  Sept     -4.36874766   0.02021844    0.00148663
       Aug  vs.   Sept     -1.22987264   0.00703408    0.11451483
------------------------------------------------------------------

****************************** MRPP finished ******************************
15 Dec 2014, 10:45:36
```

Appendix 5. Indicator Taxa Analysis results outputs.

```
MONTE CARLO test of significance of observed maximum
indicator value for Codes
  4999 permutations.
Random number seed:        588
```

Taxon	Max group 1 = northern pond 2 = southern pond	Observed Indicator Value (IV)	IV from randomized groups: Mean	IV from randomized groups: Std. Dev.	p-value
Ablabesm	1	25	14.5	5.06	0.0558
Aeshnida	1	11.4	6.9	3.44	0.1044
Acari	2	3.9	7.9	3.88	0.9128
Acricoto	2	1.9	2.9	2.13	1
Apedilum	2	26.3	33.3	5.82	0.9762
Arrenuru	1	41.7	29	5.92	0.0394
Berosus	1	11.7	7	3.25	0.1032
Bezzia/P	2	21.1	18.8	5.53	0.2761
Callibae	1	49.2	33.6	5.9	0.021
Cladotan	1	27.6	15.5	5.2	0.0278
Corisell	1	21.5	17.9	5.46	0.223
Corixida	1	24	19.6	5.62	0.1748
Corynone	2	19.6	16.4	5.45	0.2224
Crambida	2	37.1	31.7	5.75	0.1684
Cricotop	2	42.7	39.1	5.64	0.2188
Cryptoch	1	21.4	19.7	5.6	0.2957
Dasyhele	1	7.3	10.9	4.34	0.7854
Ephydrid	1	5.1	6	2.66	0.7307
Erpobdel	2	9.3	7.9	4	0.5801
Haliplus	1	12.7	6	2.76	0.077
Helobdel	2	27.2	21.3	5.75	0.1506
Hesperoc	2	11.4	17.9	5.35	0.9962
Hydrachn	1	6.6	4.7	2.26	0.215
Hydrophi	1	10.3	9	4.01	0.4171
Hydropor	1	3.6	6.9	3.22	1
Hygrotus	1	7.1	2.9	2.13	0.2046
Laccophi	2	9.3	8	3.79	0.5127
Lepidopt	1	27.3	7.9	3.84	0.0022
Leptocer	1	20.9	7	3.27	0.0068
Leptophl	1	7.1	2.9	2.13	0.2046
Libellul	2	7.6	12.7	4.76	0.9592
Limnesia	2	43.8	34	5.69	0.0694

Limnocha	1	7.1	2.9	2.13	0.2028
Lymnaeid	2	22.8	25.1	5.77	0.5713
Microchi	2	1.9	3	2.16	1
Nectopsy	1	7.1	2.9	2.11	0.1994
Nematoda	2	10.2	10.9	4.48	0.4069
Notonect	1	72.1	29.7	5.99	0.0002
Oecetis	1	39.7	17.9	5.42	0.003
Orthocla	1	13	6	2.6	0.0384
Ostracod	2	44.5	30.5	5.91	0.0328
Parachir	2	1.9	3	2.18	1
Parameri	1	11.1	7.9	3.87	0.1204
Paratany	2	13.8	13.7	4.97	0.3961
Planorbi	1	6.4	11	4.51	1
Psectroc	1	4.4	6	2.7	0.8624
Pseudoch	2	1.9	2.9	2.12	1
Pyralida	2	6.9	9.1	3.99	0.7387
Radix au	2	3.7	4.8	2.16	1
Scirtida	1	7.1	3	2.15	0.2084
Sigara s	1	43.9	25.1	5.77	0.0122
Stictota	1	7.1	2.9	2.13	0.2046
Stratiom	1	21.4	5.8	2.75	0.0074
Sympetru	1	5.3	4.7	2.06	0.3631
Tnytarsi	1	7.1	2.9	2.13	0.2046
Tanytars	1	33.3	17.3	5.49	0.0144
Theromyz	1	5.1	4.8	2.25	0.3875
Triaenod	1	28.6	7.1	3.32	0.0012
Tropiste	1	7.1	2.9	2.13	0.2046
Turbella	2	3.7	4.7	2.23	1

```
-----------------------------------------------------
      Averages          13.6927   9.84   3.09  0.3015
-----------------------------------------------------
* proportion of randomized trials with indicator value
  equal to or exceeding the observed indicator value.
  p = (1 + number of runs >= observed)/(1 + number of randomized runs)
Maxgrp = Group identifier for group with maximum observed IV


Randomization test for sum of IVmax
    1040.6     = observed sum of IVmax across all Codes
             0 = number of randomization runs with sum of IVmax >= observed
value
          4999 = number of randomization runs
```

```
       0.00020 = p

************************ Indicator values finished ************************
15 Dec 2014, 11:16:06
```

Appendix 6. Taxa abundances northern vs. southern ponds. W-M-W rank test Z statistic, p-value, and probability the taxon was sampled from a northern pond

Taxon	Z statistic	P-value	Probability Taxon sampled from Northern Pond
Ablabesmyia sp.	1.86	0.06	0.61
Acari	-2.86	< 0.01	0.25
Anisoptera	1.60	0.11	0.60
Apedilum sp.	0.02	0.98	0.50
Bezzia/Palpomyia sp.	-1.22	0.22	0.42
Caenis	-0.789	0.43	0.43
Callibaetis sp.	2.50	0.01	0.71
Chironomus sp.	0.88	0.38	0.58
Cladotanytarsus sp.	1.94	0.05	0.62
Coenagrionidae	2.80	< 0.01	0.74
Corisella sp.	1.11	0.27	0.57
Corixidae	1.16	0.25	0.58
Corynoneura sp.	1.42	0.16	0.41
Cricotopus sp.	-1.39	0.17	0.38
Cryptochironomus sp.	0.89	0.37	0.56
Dasyhelea sp.	0.30	0.77	0.52
Other Hirudinea	-0.23	0.82	0.49
Glyptotendipes sp.	0.89	0.37	0.58
Gyraulus sp.	-1.73	0.08	0.35
Haliplus sp.	2.00	0.05	0.56
Helobdella stagnalis	-1.57	0.12	0.39
Hesperocorixa sp.	-0.09	0.93	0.49
Hyalella sp.	-3.813	<0.01	0.17
Hydrophilidae	1.70	0.09	0.59
Hydroporinae	0.21	0.84	0.51
Laccophilus sp.	-1.17	0.24	0.45
Lepidoptera	-0.43	0.66	0.46
Leptoceridae	5.47	< 0.01	0.78
Lymnaeidae	-1.00	0.32	0.43
Microchironomus sp.	-0.51	0.61	0.49
Nematoda	-0.69	0.49	0.47
Notonecta sp.	4.22	< 0.01	0.84
Oecetis sp.	2.83	< 0.01	0.68
Oligochaeta	-2.75	0.01	0.26
Orthocladius Complex	2.04	0.04	0.56
Ostracoda	-2.55	0.01	0.30
Paramerina sp.	1.14	0.25	0.55
Paratanytarsus sp.	-1.02	0.31	0.44
Physa sp.	-2.49	0.01	0.28

Planorbidae	0.22	0.83	0.51
Procladius sp.	0.58	0.56	0.55
Psectrocladius sp.	0.55	0.58	0.52
Sigara sp.	2.37	0.02	0.68
Stratiomyidae	3.45	< 0.01	0.61
Tanypus sp.	0.02	0.99	0.50
Tanytarsus sp.	2.81	0.01	0.68

Appendix 7. List of taxa and functional feeding group (FFG) for all samples 2010-2012 (GC = gatherer; PR = predator; OM = omnivore; SC = scraper; SH = shredder; FC = filterer).

FFGs derived from EPA and SAFIT.

Taxon	FFG
Ablabesmyia sp.	GC
Aeshnidae	PR
Acari	PR
Acricotopus sp.	GC
Anax sp.	PR
Apedilum sp.	GC
Arrenurus sp.	PR
Baetidae	GC
Berosus sp.	OM
Bezzia/Palpomyia sp.	PR
Caendae	GC
Caenssp	GC
Callibaetis sp.	GC
Ceratopogonidae	PR
Chironomus sp.	GC
Cladotanytarsus sp.	GC
CngrnEnallagma sp.	PR
Cnagrnidae	PR
Corisella sp.	PR
Corixidae	PR
Corynoneura sp.	GC
Crambidae	SH
Cricotopus sp.	GC
Cryptochironomus sp.	PR
Dasyhelea sp.	GC
Diptera	OM
Dolichopodidae	OM
Dytiscidae	PR
Enochrus sp.	GC
Ephydridae	OM
Erpobdella sp.	PR
Erythiscollocata	PR

Erythemis sp.	PR
Eylais sp.	PR
Fossaria sp.	SC
Gastropoda	SC
Glossiphoniidae	PR
Glyptotendipes sp.	SH
Gyraulus sp.	SC
Haliplus sp.	OM
Helbdllsp	PR
Helobdella stagnalis	PR
Hesperocorixa sp.	PR
Hyalella sp.	GC
Hydrachna sp.	PR
Hydrphilidae	OM
Hydrophilus sp.	PR
Hydroporinae	OM
Hygrotus sp.	PR
Laccophilus sp.	PR
Lepidoptera	SH
Leptoceridae	OM
Leptophlebiidae	OM
Lestes sp.	PR
Libellulidae	PR
Limnesia sp.	PR
Limnochares sp.	PR
Lymnaeidae	SC
Microchironomus sp.	GC
Nectopsyche sp.	OM
Nematoda	OM
Ntncta sp.	PR
Notonectidae	PR
Oecetis sp.	PR
Oligochaeta	OM
Orthocladius Complex	GC
Ostracoda	OM
Parachironomus sp.	PR
Paramerina sp.	PR
Paratanytarsus sp.	GF
Peltodytes sp.	OM
Physa sp.	SC
Pionasp.	PR
Pionidae	PR
Planorbella sp.	SC
Planorbidae	SC
Procladius sp.	PR

Psectrocladius sp.	GC
Pseudochironomus sp.	GC
Pyralidae	SH
Radix auricularia	SC
Scirtidae	PR
Sigara sp.	PR
Sphaeromias sp.	PR
Stagnicola sp.	SC
Stictotarsus sp.	PR
Stratiomyidae	GC
Sympetrum sp.	PR
Tanypodinae	OM
Tanypus sp.	OM
Tnytarsini	OM
Tanytarsus sp.	CF
Theromyzon sp.	PR
Triaenodes sp.	SH
Trichocorixa sp.	PR
Trichoptera	OM
Tropisternus sp.	PR
Turbellaria	OM

Appendix 8. FFGs Richness and total taxa for all samples 2010-2012

Sample	Gatherers	Filterers	Omnivores	Predators	Scrapers	Shredders	Total
AM100612	7	1	3	6	0	2	19
AM100912	8	1	2	7	2	2	22
AM-610	3	0	3	4	0	1	11
AM-612	4	0	3	6	2	1	16
AM-710	7	0	4	7	2	1	21
AM-712	3	0	3	7	2	2	17
AM-812	5	0	3	4	2	2	16
AM-910	4	0	1	10	2	2	19
AM-912	4	0	3	5	2	2	16
AMb-910	4	0	5	5	3	1	18
AMc-910	4	1	4	7	2	1	19
AMs-910	8	2	4	7	3	1	25
AMw1-612	4	0	3	6	2	1	16
AMw1-712	3	0	5	7	2	2	19
AMw1-811	6	0	2	6	3	1	18
AMw1-812	5	0	3	5	2	2	17
AMw1-912	4	0	3	5	3	2	17

BR4C-612	9	1	1	9	2	3	25
BR4C-712	6	1	3	6	1	2	19
BR4C-812	4	1	2	6	1	3	17
BR5C-612	7	0	2	11	2	2	24
BR5C-712	6	0	2	11	2	1	22
BR-610	7	1	4	4	1	1	18
BR-710	6	1	3	10	2	2	24
FB1-1010	4	0	2	7	2	2	17
FB1-610	5	0	1	4	2	1	13
FB1-612	4	0	2	6	0	0	12
FB1-710	7	1	2	6	3	1	20
FB1a712	4	0	2	6	0	0	12
FB1b712	2	0	3	6	1	1	13
FB1-812	3	0	3	6	0	1	13
FB1-910	6	0	3	8	3	1	21
FB1-912	3	0	3	6	2	2	16
FB1b-712	2	0	3	6	1	1	13
FB1E-811	5	0	1	11	3	1	21
FB1EW811	6	1	3	15	3	1	29
FB1s1010	1	0	1	4	2	2	10
FB1W-811	5	1	3	8	2	1	20
FB2-610	8	0	3	5	2	1	19
FB2-612	6	0	3	7	2	2	20
FB2-710	9	0	2	4	2	1	18
FB2-712	7	0	2	7	3	2	21
FB2-910	6	1	3	8	2	1	21
FB2-912	6	1	2	5	3	2	19
FB2b910	6	0	1	6	3	1	17
FB2s910	7	0	1	6	2	1	17
FBtu-712	5	0	3	5	2	1	16
FBtu-912	3	0	1	5	2	2	13
HR11-612	5	0	3	7	2	2	19
HR11-912	2	0	1	10	3	2	18
HR8-612	9	0	4	13	4	2	32
HR8-912	5	0	6	7	2	1	21
LF10-612	4	0	3	4	2	1	14
LF10-912	5	1	1	6	2	1	16
LF14-612	6	1	4	10	3	2	26
LF14-912	6	0	1	2	2	2	13
NP19-612	9	0	4	7	1	2	23
NP19-912	5	1	1	5	2	2	16
NP22-912	4	1	1	5	3	2	16
NP22b912	9	1	4	8	2	1	25
NS47-811	10	1	1	10	2	2	26
NS-612	6	0	3	11	2	1	23
NSa-712	6	0	2	10	3	1	22

NSb-712	5	0	2	7	3	2	19
NS-912	6	0	3	6	3	2	20
NScl-612	4	0	1	5	1	1	12
NScl-912	6	1	2	5	3	2	19
NSop-612	6	0	3	13	2	1	25
NSop-712	6	0	2	10	3	1	22
NSop-912	6	0	4	7	3	2	22
NSopb612	5	0	2	7	3	2	19
P47-610	2	0	3	0	2	1	8
P47-710	3	1	2	3	2	0	11
P47-910	2	0	3	3	1	0	9
P47b1010	2	0	1	3	3	2	11
P47s1010	1	1	0	4	3	1	10
PN-610	7	2	3	5	3	1	21
PN-710	9	0	6	12	3	2	32
PN-712	4	0	2	10	2	2	20
PN-810	9	2	5	7	3	1	27
PN-811	2	0	2	5	0	1	10
PN-812	4	0	1	8	1	3	17
PN-910	4	0	1	5	2	2	14
PN-912	7	1	1	7	2	2	20
PNa-810	6	0	3	6	3	2	20
PNs-610	5	1	3	7	3	2	21
WD-610	10	1	1	7	3	1	23

Appendix 9. Proportional FFGs Richness and total taxa for all samples 2010-2012

Samples	Gatherers	Filterers	Omnivores	Predators	Scrapers	Shredders
AM100612	0.37	0.05	0.16	0.32	0.00	0.11
AM100912	0.36	0.05	0.09	0.32	0.09	0.09
AM-610	0.27	0.00	0.27	0.36	0.00	0.09
AM-612	0.25	0.00	0.19	0.38	0.13	0.06
AM-710	0.33	0.00	0.19	0.33	0.10	0.05
AM-712	0.18	0.00	0.18	0.41	0.12	0.12
AM-812	0.31	0.00	0.19	0.25	0.13	0.13
AM-910	0.21	0.00	0.05	0.53	0.11	0.11
AM-912	0.25	0.00	0.19	0.31	0.13	0.13
AMb-910	0.22	0.00	0.28	0.28	0.17	0.06
AMc-910	0.21	0.05	0.21	0.37	0.11	0.05
AMs-910	0.32	0.08	0.16	0.28	0.12	0.04
AMw1-612	0.25	0.00	0.19	0.38	0.13	0.06
AMw1-712	0.16	0.00	0.26	0.37	0.11	0.11
AMw1-811	0.33	0.00	0.11	0.33	0.17	0.06
AMw1-812	0.29	0.00	0.18	0.29	0.12	0.12

AMw1-912	0.24	0.00	0.18	0.29	0.18	0.12
BR4C-612	0.36	0.04	0.04	0.36	0.08	0.12
BR4C-712	0.32	0.05	0.16	0.32	0.05	0.11
BR4C-812	0.24	0.06	0.12	0.35	0.06	0.18
BR5C-612	0.29	0.00	0.08	0.46	0.08	0.08
BR5C-712	0.27	0.00	0.09	0.50	0.09	0.05
BR-610	0.39	0.06	0.22	0.22	0.06	0.06
BR-710	0.25	0.04	0.13	0.42	0.08	0.08
FB1-1010	0.24	0.00	0.12	0.41	0.12	0.12
FB1-610	0.38	0.00	0.08	0.31	0.15	0.08
FB1-612	0.33	0.00	0.17	0.50	0.00	0.00
FB1-710	0.35	0.05	0.10	0.30	0.15	0.05
FB1a712	0.33	0.00	0.17	0.50	0.00	0.00
FB1b712	0.15	0.00	0.23	0.46	0.08	0.08
FB1-812	0.23	0.00	0.23	0.46	0.00	0.08
FB1-910	0.29	0.00	0.14	0.38	0.14	0.05
FB1-912	0.19	0.00	0.19	0.38	0.13	0.13
FB1b-712	0.15	0.00	0.23	0.46	0.08	0.08
FB1E-811	0.24	0.00	0.05	0.52	0.14	0.05
FB1EW811	0.21	0.03	0.10	0.52	0.10	0.03
FB1s1010	0.10	0.00	0.10	0.40	0.20	0.20
FB1W-811	0.25	0.05	0.15	0.40	0.10	0.05
FB2-610	0.42	0.00	0.16	0.26	0.11	0.05
FB2-612	0.30	0.00	0.15	0.35	0.10	0.10
FB2-710	0.50	0.00	0.11	0.22	0.11	0.06
FB2-712	0.33	0.00	0.10	0.33	0.14	0.10
FB2-910	0.29	0.05	0.14	0.38	0.10	0.05
FB2-912	0.32	0.05	0.11	0.26	0.16	0.11
FB2b910	0.35	0.00	0.06	0.35	0.18	0.06
FB2s910	0.41	0.00	0.06	0.35	0.12	0.06
FBtu-712	0.31	0.00	0.19	0.31	0.13	0.06
FBtu-912	0.23	0.00	0.08	0.38	0.15	0.15
HR11-612	0.26	0.00	0.16	0.37	0.11	0.11
HR11-912	0.11	0.00	0.06	0.56	0.17	0.11
HR8-612	0.28	0.00	0.13	0.41	0.13	0.06
HR8-912	0.24	0.00	0.29	0.33	0.10	0.05
LF10-612	0.29	0.00	0.21	0.29	0.14	0.07
LF10-912	0.31	0.06	0.06	0.38	0.13	0.06
LF14-612	0.23	0.04	0.15	0.38	0.12	0.08
LF14-912	0.46	0.00	0.08	0.15	0.15	0.15
NP19-612	0.39	0.00	0.17	0.30	0.04	0.09
NP19-912	0.31	0.06	0.06	0.31	0.13	0.13
NP22-912	0.25	0.06	0.06	0.31	0.19	0.13
NP22b912	0.36	0.04	0.16	0.32	0.08	0.04
NS47-811	0.38	0.04	0.04	0.38	0.08	0.08
NS-612	0.26	0.00	0.13	0.48	0.09	0.04

NSa-712	0.27	0.00	0.09	0.45	0.14	0.05
NSb-712	0.26	0.00	0.11	0.37	0.16	0.11
NS-912	0.30	0.00	0.15	0.30	0.15	0.10
NScl-612	0.33	0.00	0.08	0.42	0.08	0.08
NScl-912	0.32	0.05	0.11	0.26	0.16	0.11
NSop-612	0.24	0.00	0.12	0.52	0.08	0.04
NSop-712	0.27	0.00	0.09	0.45	0.14	0.05
NSop-912	0.27	0.00	0.18	0.32	0.14	0.09
NSopb612	0.26	0.00	0.11	0.37	0.16	0.11
P47-610	0.25	0.00	0.38	0.00	0.25	0.13
P47-710	0.27	0.09	0.18	0.27	0.18	0.00
P47-910	0.22	0.00	0.33	0.33	0.11	0.00
P47b1010	0.18	0.00	0.09	0.27	0.27	0.18
P47s1010	0.10	0.10	0.00	0.40	0.30	0.10
PN-610	0.33	0.10	0.14	0.24	0.14	0.05
PN-710	0.28	0.00	0.19	0.38	0.09	0.06
PN-712	0.20	0.00	0.10	0.50	0.10	0.10
PN-810	0.33	0.07	0.19	0.26	0.11	0.04
PN-811	0.20	0.00	0.20	0.50	0.00	0.10
PN-812	0.24	0.00	0.06	0.47	0.06	0.18
PN-910	0.29	0.00	0.07	0.36	0.14	0.14
PN-912	0.35	0.05	0.05	0.35	0.10	0.10
PNa-810	0.30	0.00	0.15	0.30	0.15	0.10
PNs-610	0.24	0.05	0.14	0.33	0.14	0.10
WD-610	0.43	0.04	0.04	0.30	0.13	0.04

Appendix 10. Summary statistics for FFG proportional richness July/August/2010/2012 northern ponds (N = 9) vs. southern ponds (N = 17)

	FFG	Mean	Max	Min	Std.Dev.	25th Percentile	75th Percentile
PN/BR	Filterer	0.07	0.12	0.05	0.03	0.05	0.09
	Gatherer	0.30	0.41	0.18	0.08	0.27	0.35
	Omnivore	0.07	0.12	0.03	0.04	0.05	0.11
	Predator	0.38	0.55	0.22	0.11	0.35	0.47
	Scraper	0.09	0.15	0.05	0.04	0.06	0.10
	Shredder	0.08	0.12	0.04	0.03	0.05	0.11
	Total	1.00	1.00	1.00	0.00	1.00	1.00
	FFG	**Mean**	**Max**	**Min**	**Std.Dev.**	**25th Percentile**	**75th Percentile**
AM/FB/NS	Filterer	0.04	0.08	0.00	0.03	0.00	0.06
	Gatherer	0.35	0.45	0.26	0.06	0.31	0.38
	Omnivore	0.06	0.11	0.00	0.02	0.05	0.08
	Predator	0.37	0.50	0.22	0.09	0.30	0.46
	Scraper	0.11	0.18	0.00	0.05	0.10	0.14
	Shredder	0.06	0.13	0.00	0.05	0.00	0.10

	Total	1.00	1.00	1.00	0.00	1.00	1.00

Appendix 11. Summary statistics for FFG richness July/August/September 2010/2012 northern ponds (N = 11) vs. southern ponds (N = 42)

		Gatherer	Filterer	Omnivore	Predator	Scraper	Shredder
PN/BR	Mean	5.91	0.55	2.64	8.00	2.00	2.00
	Max	9.00	2.00	6.00	12.00	3.00	3.00
	Min	4.00	0.00	1.00	5.00	1.00	1.00
	Std.Dev.	1.87	0.69	1.63	2.37	0.77	0.63
	25th percentile	4.00	0.00	1.00	6.00	1.00	2.00
	75th percentile	7.00	1.00	3.00	10.00	3.00	2.00
Others	Mean	5.02	0.31	2.60	6.19	2.21	1.40
	Max	9.00	2.00	6.00	10.00	3.00	2.00
	Min	2.00	0.00	1.00	2.00	0.00	0.00
	Std.Dev.	1.87	0.52	1.23	1.82	0.78	0.63
	25th percentile	4.00	0.00	2.00	5.00	2.00	1.00
	75th percentile	6.00	1.00	3.00	7.00	3.00	2.00
Total	Mean	5.21	0.36	2.60	6.57	2.17	1.53
	Max	9.00	2.00	6.00	12.00	3.00	3.00
	Min	2.00	0.00	1.00	2.00	0.00	0.00
	Std.Dev.	1.88	0.56	1.31	2.06	0.78	0.67
	25th percentile	4.00	0.00	2.00	5.00	2.00	1.00
	75th percentile	6.00	1.00	3.00	7.00	3.00	2.00

Appendix 12. Summary statistics for FFG proportional richness July/August/September 2010/2012 northern ponds (N = 11) vs. southern ponds (N = 42)

		Gatherers	Filterers	Omnivores	Predators	Scrapers	Shredders
PN/BR	Mean	0.28	0.03	0.12	0.38	0.09	0.10
	Max	0.35	0.07	0.19	0.50	0.15	0.18
	Min	0.20	0.00	0.05	0.26	0.05	0.04
	Std.Dev.	0.05	0.03	0.05	0.08	0.03	0.05
	25th	0.24	0.00	0.07	0.32	0.06	0.06
	75th	0.32	0.05	0.16	0.47	0.11	0.14
Others	Mean	0.28	0.02	0.15	0.35	0.12	0.08
	Max	0.50	0.09	0.33	0.56	0.19	0.15
	Min	0.11	0.00	0.05	0.15	0.00	0.00
	Std.Dev.	0.08	0.03	0.07	0.08	0.04	0.04

	25th	0.23	0.00	0.09	0.30	0.11	0.05
	75th	0.32	0.05	0.19	0.38	0.15	0.11
Total	Mean	0.28	0.02	0.14	0.36	0.12	0.08
	Max	0.50	0.09	0.33	0.56	0.19	0.18
	Min	0.11	0.00	0.05	0.15	0.00	0.00
	Std.Dev.	0.07	0.03	0.07	0.08	0.04	0.04
	25th	0.24	0.00	0.09	0.30	0.10	0.05
	75th	0.32	0.05	0.19	0.38	0.15	0.11

Appendix 13. Indicator taxa metric scores for each sample.

Sample Pond	Indicator Taxa Metric Score
AM-710	-2
AM-712	-2
AM-713	4
AM-812	-2
AM-910	1
AM-912	-4
AM-913	0
AM100912	7
AMb-910	-6
AMc-910	-4
AMs-910	0
AMw1-712	-1
AMw1-811	0
AMw1-812	-2
AMw1-912	-4
BR-710	9
BR4C-712	9
BR4C-812	5
BR5C-712	2
FB1-710	3
FB1-713	-2
FB1-812	-4
FB1-910	2
FB1-912	-2
FB1a712	-3
FB1b-712	-4

FB1b712	-4
FB1E-811	4
FB1EW811	2
FB1W-811	-1
FB2-710	0
FB2-712	4
FB2-713	2
FB2-910	0
FB2-912	4
FB2-913	-2
FB2b910	1
FB2s910	-1
FBtu-712	2
FBtu-912	2
HR11-912	-1
HR8-912	-1
LF10-912	9
LF14-912	-2
NP19-912	0
NP22-912	4
NP22b912	2
NS-713	6
NS-912	-2
NS-913	-1
NS47-811	6
NSa-712	6
NSb-712	-2
NScl-912	3
NSop-712	6
NSop-912	-1
P47-710	0
P47-910	0
PN-710	13
PN-712	6
PN-713	8
PN-810	8
PN-811	4
PN-812	11
PN-910	4
PN-912	7
PN-913	15

PNa-810	8