Tree species diversity, richness, and community composition along a distance gradient at *Sphagnum* bogs in a northern hardwoods forest

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ABSTRACT

This study focused on tree species richness and diversity at *Sphagnum* bogs along an environmental gradient of distance from a bog. I hypothesized that tree species richness and tree species diversity would increase with increasing distance from *Sphagnum* bogs. I also explored the possibility that soil acidity and elevation could factor into a positive trend in species richness and species diversity along the distance gradient. This study was conducted by setting up stratified belt transects at eight different forested *Sphagnum* bog sites on the property of the University of Notre Dame Environmental Research Center (UNDERC). A marginally significant relationship was found between tree species richness and distance from a bog. However, there was no significant relationship between tree species diversity and distance from a bog. Furthermore, although pH and elevation showed high significance in relationship to the distance gradient, they were not significantly related to species richness.

INTRODUCTION

Research concerning the species diversity and species richness of wetland habitats has become increasingly important due to the modern challenges presented by habitat destruction, climate change, nutrient enrichment, and the spread of invasive species, which often contribute to rising extinction rates. Additionally, a better understanding of wetland dynamics can increase the probability of success of wetland restoration efforts.

Within the context of forest ecology, wetland habitats are unique in that they do not fit the general trend for tree species richness observed for terrestrial forests. Generally, tree species richness increases with latitudes approaching the equator due to the correlation between tree species richness and contemporary available energy (Currie and Paquin 1987). However, wetland vegetation deviates from normal patterns of species richness because it is most diverse at temperate latitudes (Crow 1993).

Environmental stressors such as acidity, flooding, cold, and salinity primarily control tree diversity in wetland areas (Kozlowski 1984, Tomlinson 1986, as cited by Keogh et al 1999). For example, stress from acidic peat, flooding, and cold temperatures can affect species richness of bogs (Keogh et al 1999). Bogs are oligotrophic (low in plant nutrients with oxygen rich deep water) and ombrotrophic (dependent on atmospheric deposition for nutrient input) wetlands. They are typically dominated by *Sphagnum* mosses, have a pH below 4.0, have low alkalinity, and have very small base cation concentrations in surface waters (Bedford et al. 1999). The presence of acidic peat, usually *Sphagnum* mosses, can cause competitive exclusion of other plants (van Breeman 1995). High flood duration can alter forest stand composition by increasing stress on trees (King 1995, Malecki et al 1983). Low temperatures cause chemical and metabolic reactions to slow down in plants and consequently slow down their water and nutrient uptake and growth (Larcher 1995). As a result, species richness in bogs is limited by the ability of individual tree species to tolerate these unique conditions; tree species richness in wetlands is typically low compared to species richness of terrestrial upland forests, which are not subject to constant stress.

Furthermore, forested wetlands diverge from yet another general trend of species richness. The species-area relationship predicts that as sample area increases, species richness also increases (MacArthur and Wilson 1967). However, Keogh et al (1999) found no significant relationship between species richness of forested wetlands and sample area; they also found that in peat forested wetlands, species richness declined with increasing area. They suggested this may be the case because, first, larger peat bogs are older, more acidic, and less nitrogen rich than smaller bogs, and as they expand they can cause mortality of trees (Vitt 1990, Glaser 1992 as cited by Keogh et al 1999). Second, large peat bogs may have less species richness because the greater central area, farther from the borders of other forest types, would be more difficult for tree species to invade. Third, topography has less impact on large *Sphagnum* bogs, so they have more homogenous landscapes than their smaller counterparts. Keogh et al suggested that any or all of these factors may account for the divergence of bog habitats from the species-area theory.

Succession of North American wetlands is primarily a function of glacial history, climate, and sometimes, logging activity (Bedford et al. 1999). Hydroperiod, which describes the duration, frequency, depth, and season of flooding, is the most important factor controlling wetlands (Lugo et al. 1990). Previous studies have held that species richness in *Sphagnum* bogs is more related to alkalinity-acidity gradients and hydrology than nutrient availability (Slack et al. 1980, Gorham et al. 1985 as cited by Bedford et al 1999). Furthermore, the relationship between various nutrient gradients and wetland vegetation is an area in need of further research in order to describe which nutrients limit plant growth and productivity (Bridgham et al 1996).

Tree species richness is widely explored in current literature, but there is little discussion of overall tree species diversity (richness plus evenness) along environmental gradients at *Sphagnum* bog sites. My study focused on tree species richness and diversity at *Sphagnum* bogs along an environmental gradient of distance from a bog. I hypothesized that tree species richness and tree species diversity would increase with increasing distance from *Sphagnum* bogs. I predicted that elevation and soil pH would also increase with increasing distance from a bog. I also predicted that, if elevation and pH were related to distance, a relationship would exist between tree species richness and diversity and elevation and pH. As a second aspect of my study, I explored beta diversity across eight different bogs and analyzed similarities in tree community compositions. I predicted that bog sites closest to each other would be the most similar, due to the trends in overall forest type surrounding them.

MATERIALS AND METHODS

This study was conducted during June and July 2010 at the University of Notre Dame Environmental Research Center (UNDERC), located in Vilas County, Wisconsin and Gogebic County, Michigan. I set up stratified belt transects at eight different sphagnum bogs across UNDERC property. The bogs I used were Tender Bog, Ziesnis Bog, Jr. Bog, Beaver Bog, Cranberry Bog, Bolger Bog, Forest Service Bog, and North Gate Bog (Appendix A). Tender Bog, Ziesnis Bog, Jr. Bog, and Beaver Bog are centrally located on the property and also the closest together. These four sites, which are similar in appearance, are in a hardwood forest dominated by red maple (*Acer rubrum)*, bigtooth and quaking aspen (*Populus grandidentata* and *P. tremuloides)*, and balsam fir (*Abies balsamea).* Jr. Bog was the smallest bog sampled, and Tender, Ziesnis, and Beaver bogs were similar in size. North Gate Bog is located at the northeast end of property, and is surrounded by forest similar to that of Tender, Ziesnis, Jr., and Beaver bogs. Cranberry Bog is located on the westernmost side of the property and was the only site with Red Pine (*Pinus resinosa)* present; it was also the largest bog sampled from. Bolger Bog and Forest Service Bog are located at the southeast end of property. Bolger Bog was very different in appearance from the other sites, because the peat layer closest to the upland forest was covered in dead black spruce trees (*Picea mariana*) and no living trees. Forest Service Bog was unique because the surrounding forest was dominated by eastern hemlock (*Tsuga Canadensis)* (personal observations).

One transect was set up at each of the eight bogs, and transect locations were selected as random compass directions from the center of the bog. The total area surveyed was 200 m^2 for each bog site. Some transect locations were not completely random because I intentionally avoided sites where transects would cross roads or large anthropogenic disturbances. I set transects perpendicular to the open water of the bog, and transects were fifty meters long by four meters wide. In order to standardize transect placement according to distance from a bog, I set up each transect so that the first fifteen meters had a ground cover of sphagnum moss. There was usually an obvious transition from sphagnum to grassy or herbaceous ground cover. The other thirty-five meters of each transect continued outward from the edge of the sphagnum moss, also perpendicular to the open water of the bog.

I stratified each transect into ten sections, so that the belt transects represented a continuum of ten twenty square meter quadrats. For each quadrat, I measured elevation and soil acidity. I measured elevation using a Garmin Dakota 20 handheld GPS, and I measured soil pH using a Kelway soil tester. Within each quadrat, I sampled trees across 2 meters on each side of the transect belt. I considered a tree to be within a quadrat if it's trunk was within 2 meters left or right of the transect belt or if over fifty percent of it reached into the quadrat, and only trees or shrubs taller than 1.5 meters were sampled. I identified each tree by species and recorded the number of each species encountered within each $20m^2$ quadrat. If I could not identify a tree in the field, I took samples back to the lab for identification.

Statistics

For each of the eighty quadrats, species diversity was calculated using the Shannon-Weaver Diversity Index ($H = -\sum [p_i \ln p_i]$). The eight bogs served as replicates for the ten quadrats at each site. I calculated the average diversity across all bogs for each region of distance along the transects, numbered 1 though 10. This provided ten values of Shannon diversity, each representing increasing distance from a bog.

Species density for each quadrat was calculated by dividing the total number of trees by the area of $20m^2$. This provided the number of trees found per square meter. I then averaged the density for each distance region across all bogs.

Species richness for each quadrat was calculated as the number of different species found per quadrat. I then used the Sorenson-Dice Similarity Index ($QS= 2C/(A+B)$) to compare the similarity of species β diversity across bogs.

I also averaged the data for elevation, soil pH, and richness for each distance region. I then used least squares linear regressions to analyze the relationships between distance from a bog, elevation, soil pH, species diversity, density, and richness. Table 1 shows the averages of elevation, pH, species richness, species diversity, and tree density for each region of distance from the bogs. Finally, I graphed the community composition for each bog, showing the type and abundance of species at each quadrat (Appendix B).

RESULTS

The elevation gradient for individual bogs ranged between 5 ft and 23 ft, with Cranberry Bog and Ziesnis Bog showing the smallest change in elevation, and Bolger Bog and Beaver Bog showing the largest change in elevation. On average, elevation increased by about 14 ft, or 4.27 m, along the belt transects. I found that distance away from a bog showed a highly significant relationship to elevation [$F_{(1),(8)}$=844.332, P<0.001; R^2=0.991] (Figure 1).

The soil acidity measurements at bogs ranged from a pH of 3.5 to a pH of 6.3, with an average of 4.2 to 5.5. In general, Forest Service Bog had the highest soil pH and Ziesnis Bog had the lowest soil pH. Beaver Bog had the greatest change in soil acidity along the distance gradient, where the first quadrat had a pH of 3.5 and the last quadrat had a pH of 6. Soil acidity was significantly related to both distance from a bog [$F_{(1),(8)}$=20.403, P=0.002; R^2=0.718] and elevation [$F_{(1),(8)}$=22.351, P=0.001; R^2=0.736].

Average species richness per distance ranged from 2.13 (at 0 to 5m) to 3.38 (at 46 to 50m). The quadrat located at 11 to 15 m at Ziesnis Bog had the highest richness, with a total of 6 different species. The first three quadrats at Bolger Bog had a richness value of zero because no living trees were present. Also, the first quadrat at Jr. bog had no trees present because the *Sphagnum* mat only extended about 18 meters from the open water and so the first quadrat was very close to the open water. I found a marginally significant relationship between species richness and quadrat distance [$F_{(1),(8)}$=5.204, P=0.051; R^2=0.39], but least squares regressions of richness with elevation (p=0.066; R^2=0.36) and pH (p=0.345; R^2=0.11) were not significant.

Average Shannon-Weaver diversity per distance ranged from 0.6 (at 0-5m) to 0.9 (at 46-50m). The individual quadrat with the highest diversity of 1.63 was the third quadrat at Ziesnis bog, which also had the highest richness. Forest Service bog had a unique diversity gradient, because the middle twenty meters had only *T. canadensis* present, giving four quadrats a diversity index of 0. Average species diversity was not significantly related to distance (p=0.211; R^2=0.18), elevation (p=0.246; R^2=0.16), or pH (p=0.848; R^2=0.005). Average species diversity was the lowest at thirty meters along the gradient, or fifteen meters from the end of the *Sphagnum* moss (Figure 2).

The Sorenson-Dice similarity index was used to compare community composition across bogs, from which I constructed a dendrogram (Figures 3 and 4). North Gate Bog and Bolger Bog were the most similar, with a β index of 0.833. Next, Tender Bog and Jr. Bog had a β index of 0.824. Beaver Bog was similar to Tender and Jr. Bogs with a β index of 0.757, and Ziesnis Bog was similar to Beaver, Jr., and Tender bogs with a β index of 0.693. Tender, Jr., Beaver, and Ziesnis bogs were similar to North Gate and Bolger bogs by a β index of 0.641. Cranberry Bog and Forest Service Bog were similar with a β index of 0.533, and their similarity index to the other six bogs was 0.414.

DISCUSSION

Along the distance gradient, I found a marginally significant relationship between tree species richness and distance away from a bog. This finding is consistent with the literature, which emphasizes the impact of environmental stressors on tree species richness in bogs. However, there was no significant relationship between species richness and elevation or pH along the distance gradient. This is particularly interesting because elevation and pH were significantly related to increasing distance from the bogs, but did not relate to species richness. Although previous studies have focused on the alkalinity-acidity gradient when examining species richness in bogs, this approach did not adequately explain the relationship between species richness and distance for my study. Other environmental factors, such as nutrient gradients, may be the controlling factor in the relationship between tree species richness and the distance gradient. My results supported my hypothesis that richness would increase with distance from a bog, but did not support my predictions that pH and elevation would play an obvious role in the relationship. Future studies should explore the possibility of other factors, such as Nitrogen abundance, as potential controllers of the relationship between tree species richness and the distance gradient for bogs at UNDERC.

Results concerning species diversity were all nonsignificant. This is probably because the forest types surrounding the sampled bogs were quite varied. The large drop in average species diversity along the middle of the distance gradient is most likely due to the inclusion of Forest Service Bog, where the middle twenty meters were completely dominated by *T. canadensis*, giving a diversity index of zero. When I excluded Forest Service

Bog from the regression, average diversity no longer decreased midway along the distance gradient. However, it remained the case that diversity did not change significantly along a distance gradient. As a result, I could not reject a null hypothesis that there is no relationship between species diversity and distance from a bog.

Concerning the results of the similarity comparison, I did not expect North Gate Bog and Bolger Bog to be the most similar, because they are located over 2000 meters apart. Within the boundaries of my $200m^2$ plots, they shared five species in common: speckled alder, quaking aspen, red maple, balsam fir, and black spruce. Only two species were different between them – North Gate Bog had white pine, and Bolger Bog had sugar maple. However, I did expect Tender, Jr., Beaver, and Ziesnis bogs to be similar due to their nearness, and this expectation was satisfied. At all of these four sites, tamarack, black spruce, balsam fir, red maple, yellow birch, white birch, quaking aspen, and speckled alder were present.

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Table 1: Averages of elevation, pH, species richness, density, and species diversity for eight *Sphagnum* bogs across a distance gradient.

Distance* (m)	**Avg Elevation** (ft)	**Avg pH**	**Avg Richness**	**Avg Density** (total/area)	**Avg Diversity**
0 to 5	1707.9	4.2	2.13	0.419	0.6094
6 to 10	1709.6	4.2	2.88	0.456	0.8893
11 to 15	1710.1	4.6	3.00	0.363	0.8670
16 to 20	1712.1	4.7	3.00	0.531	0.8171
21 to 25	1713.9	5.0	2.88	0.475	0.7516
26 to 30	1715.5	5.6	2.63	0.394	0.7034
31 to 35	1717.3	5.5	2.75	0.381	0.7430
36 to 40	1719.1	5.4	3.00	0.388	0.8429
41 to 45	1719.3	5.3	3.00	0.544	0.8741
46 to 50	1721.3	5.2	3.38	0.513	0.9215

**Sphagnum* ground cover ends at 15 meters

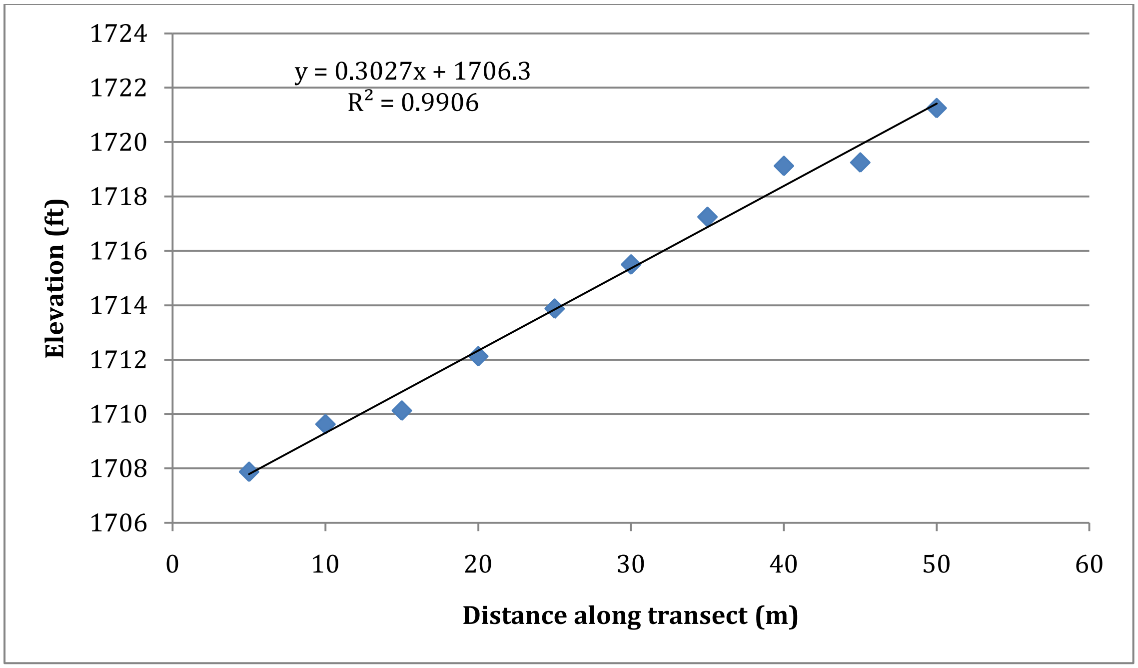


Figure 1: Average elevation of quadrats from eight *Sphagnum* bogs is significantly related to increasing distance away from the bogs [$F_{(1),(8)}$=844.332, P<0.001; R^2=0.991].

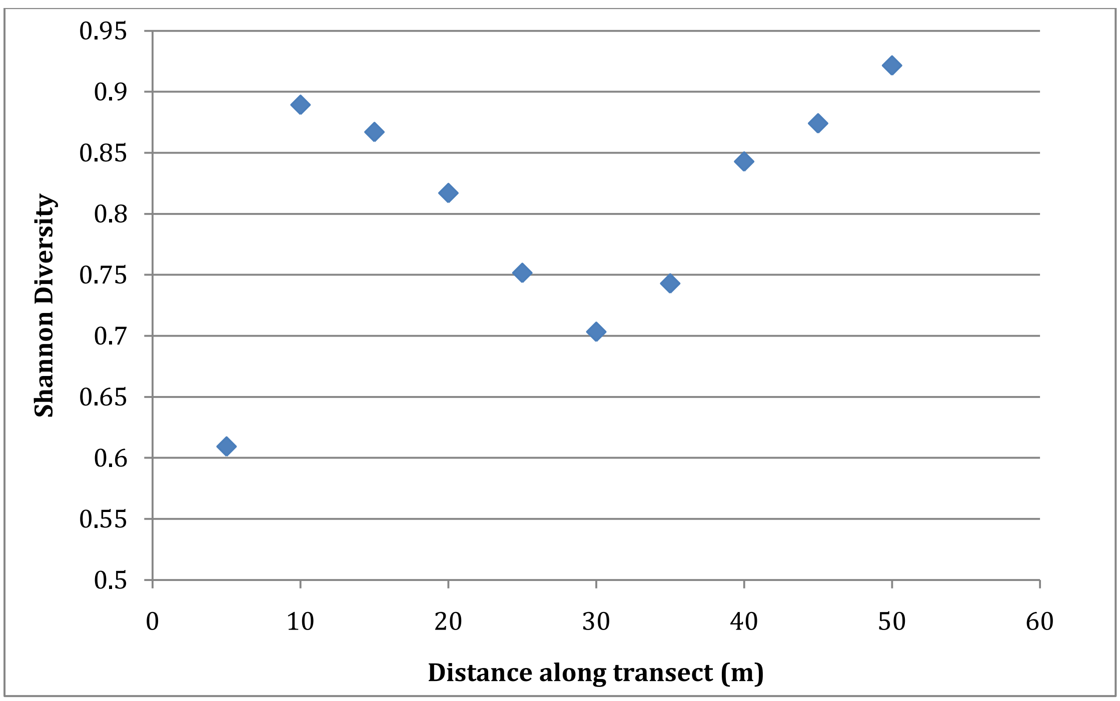


Figure 2: Average species diversity was the lowest at thirty meters along the gradient, or fifteen meters from the end of the *Sphagnum* moss. There is no significant relationship (p=0.211; R^2=0.18).

	Cranberry	Northgate	Forest Service	Bolger	Tender	Junior	Ziesnis	Beaver
Cranberry								
Northgate	0.4							
Forest Service	0.533	0.167						
Bolger	0.533	0.833	0.333					
Tender	0.556	0.667	0.400	0.667				
Junior	0.706	0.714	0.429	0.714	0.824			
Ziesnis	0.500	0.706	0.353	0.588	0.700	0.737		
Beaver	0.632	0.625	0.375	0.625	0.737	0.778	0.667	

Figure 3: The Sorenson-Dice Similarity Index was used to compare β diversity of tree species across the eight bog sites.

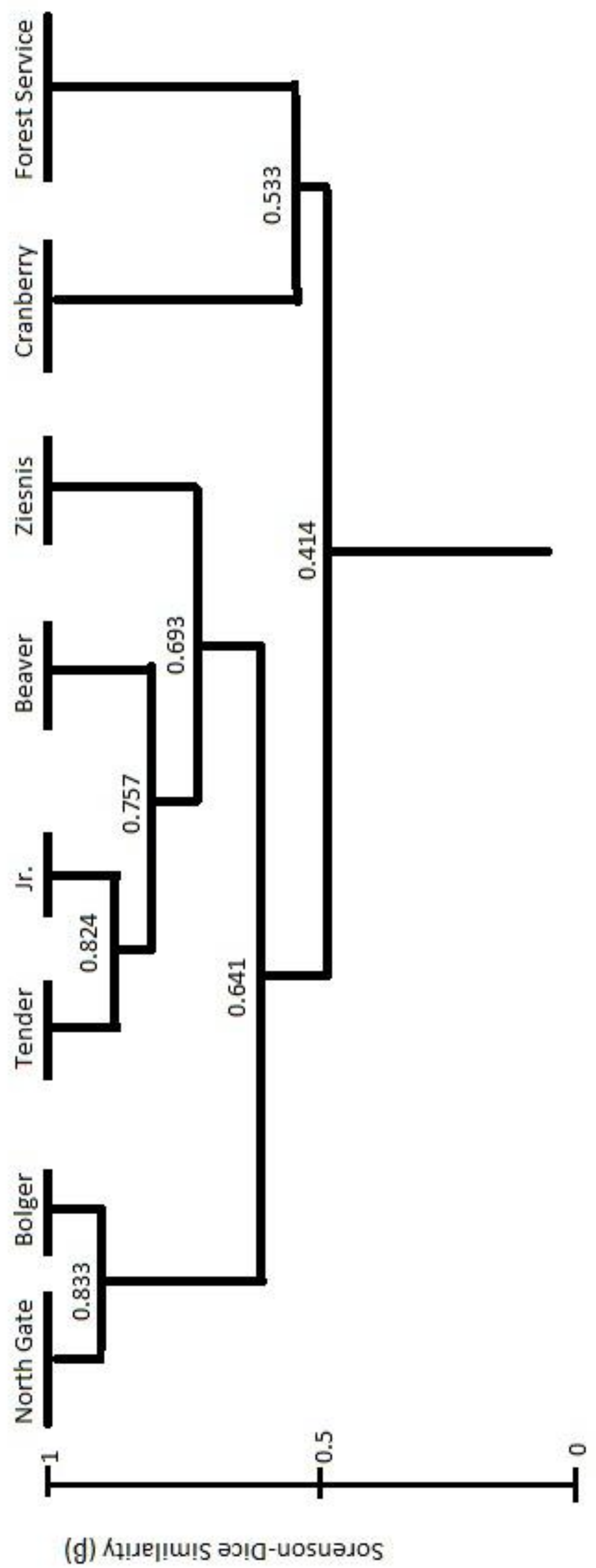
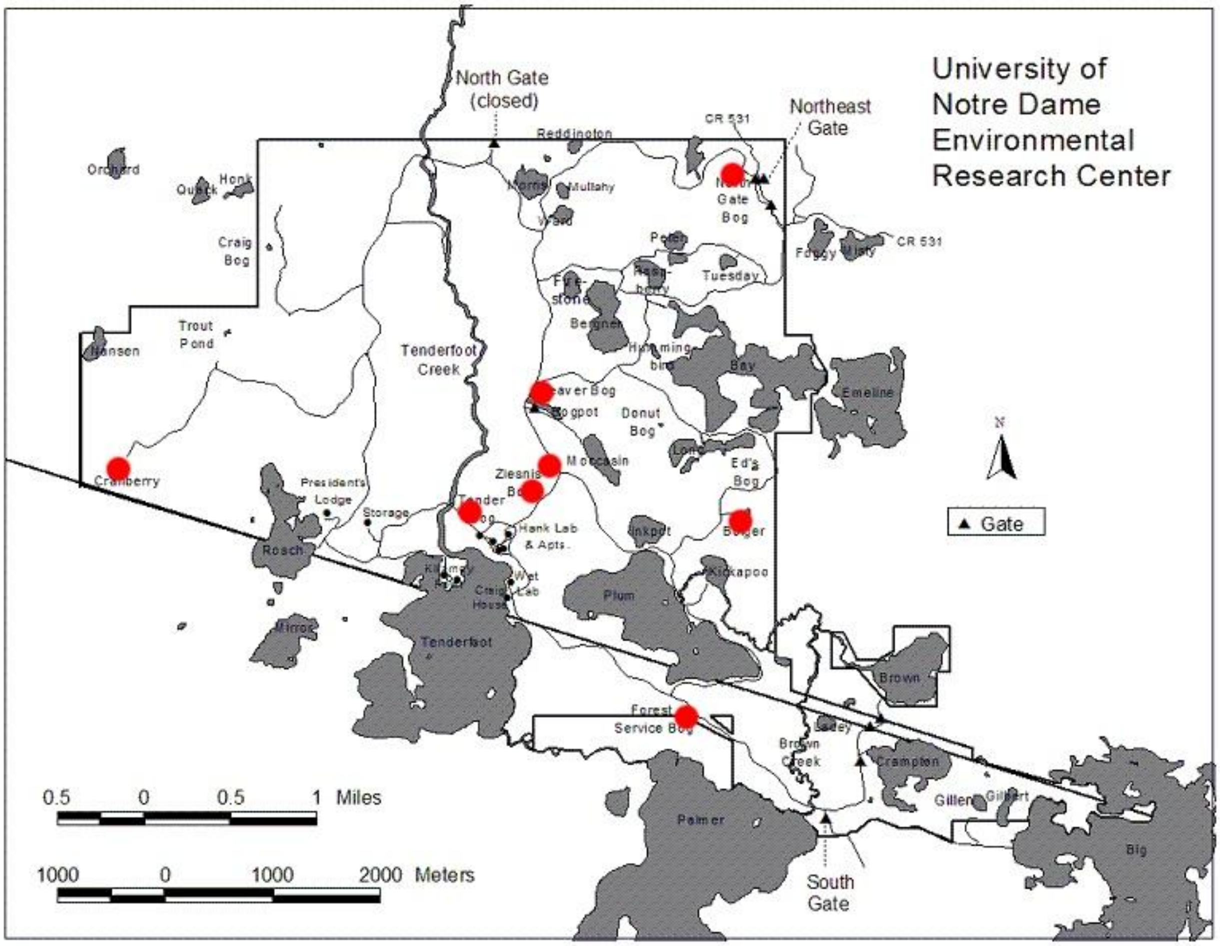
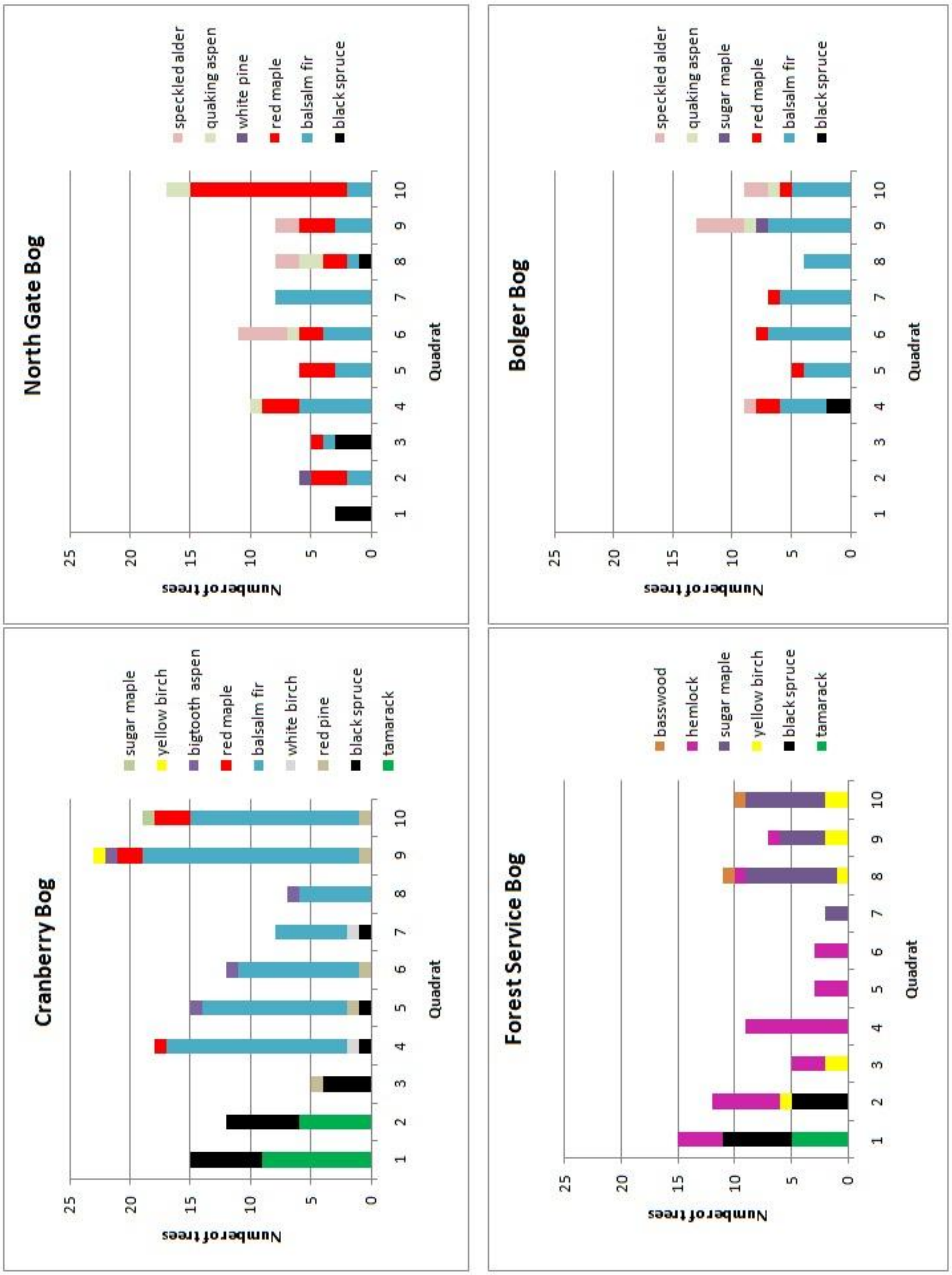


Figure 4: Dendrogram of similarity between eight *Sphagnum* bog sites

Appendix A: Map of sampled bog sites on UNDERC property, highlighted as red dots.



Appendix B: Community composition of tree species for each bog site. The type and abundance of species encountered is shown for each quadrat.



Appendix B continued: