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### The environmental gradients and plant communities of Bergen Swamp, N.Y., U.S.A.

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**The environmental gradients and plant  
communities of Bergen Swamp,**

**N.Y., U.S.A.**

**Aaron Hall**

**June 2005**

A thesis report submitted in partial fulfillment of the requirements  
For the degree of Master of Science in Environmental Science  
At Rochester Institute of Technology  
Rochester, New York 14623

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Thesis Advisor

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Director of Environmental Science

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## **Introduction**

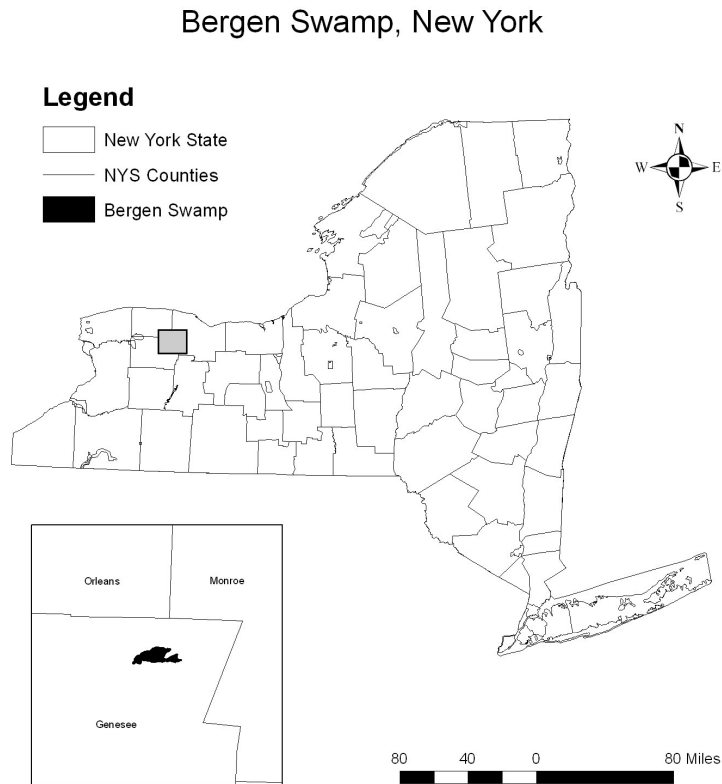
The Byron-Bergen swamp is a significant ecological feature in western New York. For more than a century ecologists and geologists have studied the area's rare plants, animals, and geology. Bergen swamp is a dynamic patchwork of ecotypes in which minimal disturbance has been caused by the human intrusions. Two notable exceptions to this were logging, primarily of white cedar (*Thuja occidentalis L.*), and peat mining (Muenscher, 1946). The swamp is now protected from these disturbances under the ownership of the Bergen Swamp Preservation Society (BSPS), whose sole purpose is to "preserve inviolate for all times" Bergen swamp ([www.bergenswamp.org](http://www.bergenswamp.org)).

## *Natural History*

Seischab (1977) defined Bergen Swamp as a rheotrophic mire due to the active deposition of a marl precipitate, of which the primary cation is calcium. However, there are many aquatic and terrestrial community types found there and it is commonly referred to in its entirety as a swamp. The 800-ha protected area is located in the northeast corner of Genesee County, New York, 24 miles west of the city of Rochester, and approximately three miles west of the village of Bergen (Figure 1) (Muenscher, 1946; Seischab, 1984; Futyma and Miller, 2001). The entire swamp complex is approximately six miles long and one and a half miles wide and is bisected by Sweden Rd., which runs from north to south. The primary area is west of this road and oval in shape, with a south-west to north-east oriented drumlin named Torpy hill which intrudes into the swamp from the northeastern direction (Walker, 1974). The swamp is generally very flat and has little

relief, with the exception of the Torpy Hill area leading down into the swamp itself, which is relatively steep. Most areas of the swamp are located between 590 and 600 feet above sea level (Muenscher, 1946).

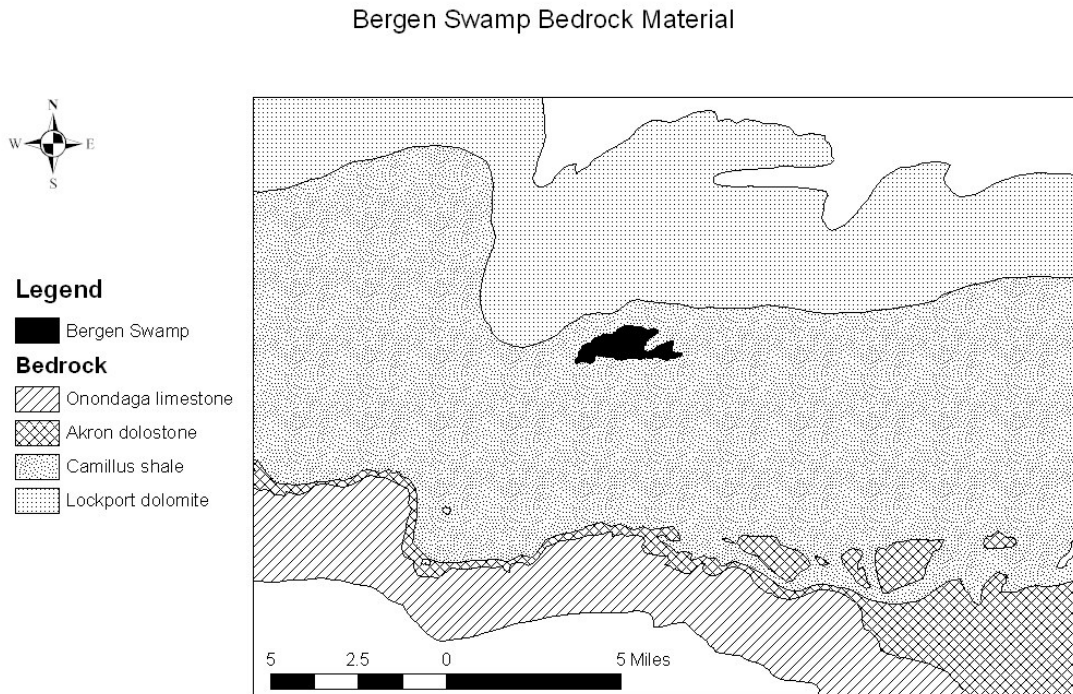
Figure 1: The geographic location of Bergen Swamp



Bergen swamp was formed by glacial activity, approximately 10,700 years before present (Futyma and Miller, 2001). It is situated in an east-west running depression which is underlain by Camillus Shale, part of the Salina formation of the Silurian age (Stewart and Merrell, 1937). To the north it is bounded by Lockport dolomite and to the

south by Onondaga limestone (Walker, 1974). The strike of all three of these formations is east-west (Figure 2). As the last glaciers passed over western New York, they gouged

Figure 2: The geology of Bergen Swamp and the surrounding area



out the softer Camillus shale, and left the more resistant Lockport dolomite and Onondaga limestone (Stewart and Merrell, 1937). This formed a large depression which was filled with glacial melt water. The western portion of this area was named Lake Tonawanda (Walker, 1974). Lake Tonawanda drained when the ice dams in the St. Lawrence River Valley melted, and only small local ponds remained under water (Walker, 1974). Bergen swamp is one of these remaining ponds, and is part of a string of

wetlands extending from the Genesee River west toward Lake Erie and the Niagara River (Stewart and Merrell, 1937).

The Camillus Shale of Bergen Swamp is overlain with a considerable amount of glacial drift (Stewart and Merrell, 1937). As the last glacier retreated, and as Lake Tonawanda drained, the entire area was covered by a mix of glacial till (Stewart and Merrell, 1937). This is the result of sedimentation while Lake Tonawanda was present, as well as glacial outwash over this sediment as the glacier was retreating. The combination of these two factors has led to a heterogeneous soil mixture in Bergen Swamp. The soils in Bergen Swamp can be divided into two main types. The first is underlain with a calcareous white substance known as marl. The second is underlain with organic humus, and there are many sub-categories of this soil type (Stewart and Merrell, 1937).

The most unique geological feature of Bergen Swamp is that it is one of only two areas in the northeast United States where marl is being actively deposited (Seischab, 1984). The other area is the Cedar Bog area of Ohio (Frederick, 1974; Seischab, 1984). There are, however, many areas of the country that have large marl deposits close to the surface. The largest of these are located in the coastal regions of the southeastern United States. The Florida everglades, an expansive wetland system on the southern tip of Florida, are mostly underlain with marl (Seischab, 1984). These marl deposits differ from those found in the northeast because they have not been influenced by glaciers.

There are also many marl deposits which can be found in glaciated regions. These deposits can be found in Indiana, Michigan, Wisconsin, Ohio, Minnesota, New York, and Alberta, Canada (Seischab, 1984).

The areas of Bergen Swamp where marl deposition occurs are frequently flooded with calcareous ground waters from the surrounding area. These waters flow over the calcium rich formations of Lockport dolomite to the north, and Onondaga limestone to the south (Seischab, 1984). The waters entering the swamp are considered to be very hard. Upon entering the swamp these waters flow at or near the surface, usually in intermittent streams which are rarely more than 30cm deep (Seischab, 1984). The deposition of marl occurs near the center of the eastern half of the swamp, mainly through a biochemical association with the alga chara (Bernard et al., 1983). In some areas of the swamp marl has accumulated to a depth of more than three meters (Seischab, 1984). There are also areas where the marl beds are interrupted vertically with peat layers, indicating a changing environment within the swamp due to a complex hydrologic regime (Futyma and Miller, 2001).

The unique geology and hydrology of Bergen swamp has had a dramatic influence on the plant and animal species that occur there. Many plant and animal species found in Bergen Swamp are locally endangered, threatened, or protected. The geology and hydrology of Bergen Swamp is solely responsible for the unique habitats in which these locally rare species live.

There is much evidence to support the assertion that Bergen Swamp has a more Boreal climate than the surrounding area. This boreal climate is usually associated with areas well to the north of Bergen, such as northern Minnesota, northern Michigan, and northern Wisconsin, as well as northern New York, Vermont, New Hampshire and Maine all the way to Newfoundland, Canada (Stewart and Merrell, 1937). There have been many studies looking at the species composition of these boreal habitats, and there is a



strong correlation to those species found in Bergen Swamp. Of the fifteen species listed by Transeua (1903) as being typical of a boreal swamp, seventy percent of them are reported in Bergen Swamp (Stewart and Merrell, 1937). This number could be much higher than reported by Stewart and Merrell, as the species list for Bergen Swamp has more than tripled since their study.

Even though Bergen Swamp is home to many locally rare species, it also harbors many weeds and exotic species. Agricultural areas border all of the swamp, providing seed sources for invasive and non-native species. Previous logging within the swamp and an overabundant white-tailed deer (*Odocoileus virginianus*) population have provided vectors for intrusion and has allowed many non-native and invasive species to gain a foothold in the swamp (Muenscher, 1946). It is unknown if these species have permanently altered the composition of the swamp, or if the native vegetation remains dominant.

A current study of the plant communities within Bergen Swamp would be very beneficial. This study could determine the current status and distribution of plant communities and compare and contrast to the communities found in past studies. This information would help to further understand the complex ecology of Bergen Swamp, and could be used by the BSPS as part of their management plan.

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**The plant communities of Bergen Swamp, NY, a  
rich minerotrophic mire**

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**Abstract:**

No survey of plant communities has been performed recently in the Bergen Swamp, NY, USA, a unique strongly minerotrophic mire with active marl deposition. In summer 2004, I established an array of randomly placed plots throughout Bergen Swamp to survey plant communities. The plant survey included stem counts of herbaceous plant species and shrubs within 1m square quadrats. I performed a Raup and Crick clustering analysis at two different spatial scales to group plant communities and found that there were five communities at the subplot level, and three communities at the plot level. I then used detrended correspondence analysis (DCA), an indirect gradient analysis, to infer and predict important local and landscape environmental gradients associated with the identified communities. Observed differences between spatial scales are possibly a result of micro-topological differences related to hummock and hollow formation. The major environmental gradients associated with plant communities were, in order of decreasing importance, depth to water table, hydrologic activity, and pH.

**Key Words:** marl, DCA, environmental gradients, plant communities, forested wetland

## **Introduction**

The Byron-Bergen swamp is a unique and significant ecological feature in western New York. For more than a century ecologists and geologists have studied the area's rare plants, animals, and geology. Bergen swamp is a dynamic patchwork of ecotypes which have been minimally disturbed by the intrusions of humans. Two notable exceptions to this were logging, primarily of white cedar (*Thuja occidentalis L.*), and peat mining (Muenscher, 1946). The swamp is now protected from these disturbances under the ownership of the Bergen Swamp Preservation Society (BSPS), whose sole purpose is to "preserve inviolate for all times" Bergen swamp ([www.bergenswamp.org](http://www.bergenswamp.org)).

Seischab (1977) defined Bergen Swamp as a rheotrophic mire due to the active deposition of a marl precipitate, with the primary cation being calcium. However, there are many aquatic and terrestrial community types found there and it is commonly referred to in its entirety as a swamp. The 800-ha protected area is located in the northeast corner of Genesee County, New York, 24 miles west of the city of Rochester, and approximately three miles west of the village of Bergen (Figure 1) (Muenscher, 1946; Seischab, 1984; Futyma and Miller, 2001). The entire swamp complex is approximately six miles long and 1.5 miles wide and is bisected by Sweden Rd., which runs from north to south. Bergen swamp was formed by glacial activity, approximately 10,700 years before present (Futyma and Miller, 2001). It is situated in an east-west running depression which is underlain by Camillus Shale, part of the Salina formation of the Silurian age (Stewart and Merrell, 1937). To the north it is bounded by Lockport dolomite and to the south by Onondaga limestone (Figure 2) (Walker, 1974).

The most unique geological feature of Bergen Swamp is that it is one of only two areas in the northeast United States where marl is being actively deposited (Seischab, 1984). The other area is the Cedar Bog area of Ohio (Frederick, 1974; Seischab, 1984). The geology of Bergen Swamp is directly responsible for the unique habitats in which locally rare species live.

There are, however, many areas of the country that have large marl deposits close to the surface. The largest of these are located in the coastal regions of the southeastern United States. The Florida everglades, an expansive wetland system on the southern tip of Florida, are mostly underlain with marl (Seischab, 1984). These marl deposits differ from those found in the northeast because they have not been influenced by glaciers. There are also many inactive marl deposits which can be found in glaciated regions. These deposits can be found in Indiana, Michigan, Wisconsin, Ohio, Minnesota, New York, and Alberta, Canada (Seischab, 1984).

The unique geology and hydrology of Bergen swamp has had a dramatic influence on the plant and animal species that occur there. Many plant and animal species found in Bergen Swamp are locally endangered, threatened, or protected. The geology and hydrology of Bergen Swamp is directly responsible for the unique habitats in which these locally rare species live.

The many unique habitats in Bergen Swamp have led researchers to support the assertion that Bergen Swamp has a more Boreal climate than the surrounding area. This boreal climate is usually associated with areas well to the north of Bergen with lower average annual temperatures, such as northern Minnesota, northern Michigan, and northern Wisconsin, as well as northern New York, Vermont, New Hampshire and Maine

all the way to Newfoundland, Canada (Stewart and Merrell, 1937). There have been many studies looking at the species composition of these boreal habitats, and there is a strong correlation to those species found in Bergen Swamp. Of the fifteen species listed by Transeua (1903) as being typical of a boreal swamp, seventy percent of them are reported in Bergen Swamp (Stewart and Merrell, 1937). This number could be much higher than reported by Stewart and Merrell, as the species list for Bergen Swamp has more than tripled since their study however I have not quantified this hypothesis.

Even though Bergen Swamp is home to many locally rare species, it also harbors many weeds and exotic species. Agricultural areas border all of the swamp, providing seed sources for invasive and non-native species. Previous logging within the swamp and an overabundant white-tailed deer (*Odocoileus virginianus*) population has provided vectors for intrusion and has allowed many non-native and invasive species to gain a foothold in the swamp (Muenscher, 1946). It is unknown if these species have permanently altered the composition of the swamp, or if the native vegetation remains dominant. A modern survey is necessary to determine how and if plant community structure has changed.

Plant communities have been shown to respond strongly to environmental gradients. These gradients are caused by the simultaneous pushing and pulling of opposing environmental factors. Environmental gradients are useful because they spread out otherwise indistinguishable features or patterns; much like a prism spreads out white light. Patterns of plant zonation represent species responses to environmental gradients (Keddy, 2000). Plants which have similar ecological tolerances will be found growing in close proximity to each other.



In wetland systems one of the most important environmental gradients is hydrology (Keddy, 2000). Bernard et. al (1983) used ordination analyses and found that within Bergen Swamp there is a complex environmental gradient of hydrology, soil organic matter and soil carbonate-carbon concentration. Futyma and Miller (2001) have also listed hydrology as a major factor within Bergen Swamp, proposing that drainage patterns can effect the distribution and maintenance of plant communities.

The purpose of this study was to compare and contrast the present composition and distribution of plant communities with those documented by earlier surveys (Stewart and Merrell, 1937; Muenscher, 1946; Seischab, 1984). This study also seeks to infer the important environmental gradients to which plant species are responding in Bergen Swamp.

### **Materials and Methods:**

Whereas previous studies within Bergen Swamp have been limited in their spatial coverage, this study covered almost the entire geographic area of the swamp to the west of Sweden road, as defined by randomly generated sample points. The extensive sampling that was carried out during the summer 2004 field season provided the required data for an overview of plant community composition and distribution within the swamp.

#### *Data collection*

Due to the sensitive nature of the vegetation and geology of Bergen Swamp, vegetative and environmental sampling was done utilizing the most unobtrusive methods possible. No permanent plots, markers, or trails were established and special care was

taken to tread as lightly as possible through sensitive areas such as where marl deposition occurs.

I established sampling points within the swamp using a Geographic Information System (GIS). I used the GIS to delineate the boundary of the swamp on a basemap of 2002 Digital Ortho Quarter Quads downloaded from the NYS GIS Clearinghouse ([www.nysgis.state.ny.us](http://www.nysgis.state.ny.us)), and then to generate random sample points within that boundary. I used The Arcview 8.3 software package, from Environmental Systems Research Institute, Inc. (ESRI), with the Animal Movement extension downloaded from the United States Geological Survey (USGS) (Hooge and Eichenlaub, 1997) to generate and map survey plots (Figure 3).

The Animal Movement extension allowed me to specify the number of points to be generated, minimal distance from the edge of the boundary for each point, and minimal distance between points. I set a minimum distance of 200 meters from the boundary and between points. I generated 35 random points within the Swamp boundary. I then manually added 6 additional points in small isolated areas where there are known to be sensitive and unique ecotypes and which might be missed by the random plot generation (Figure 3). Examples of these areas are where marl deposition occurs, and the sphagnum bog areas. This sampling layout provided excellent coverage of the entire swamp, and I hoped that all of the different ecotypes were represented in the sampling.

I navigated to each of the plots within Bergen Swamp with the use of Garmin Rino model 110 Global Positioning System (GPS) units. I downloaded the plots established in the GIS to the GPS units using the interface cable supplied with the GPS

units, and the use of the MN DNR Garmin software program acquired from the Minnesota Department of Natural Resources

(<http://www.dnr.state.mn.us/mis/gis/tools/acrvieview/extensions.html>).

At each sampling plot, I established two 30m transects. One oriented to magnetic north-south, and one oriented to magnetic east-west both with the 15m mark at the center of the sampling plot (Figure 4).

Subplots were located at both ends of each transect. Nested within each of the 2m x 2m subplots was a 1m x 1m subplot. The 1m x 1m subplot was oriented so that it is in the upper right hand corner of the 2m x 2m subplot when facing away from the center of the plot and sighting down the transect (Figure 4).

At each of the 1m x 1m subplots, I measured vegetation data as a stem count of all herbaceous plants identified to the species level whenever possible. Clonal plants were measured by an estimate of total stems.

I subjected the data to two types of analyses. The first was a hierarchical clustering analysis and the second was an indirect ordination analysis. Both of these analyses use r-type data to group species which are found in similar conditions. The hierarchical clustering analysis was used to distinguish among community groups within the ordination analysis. These community groups were then compared and contrasted with community groups found in past studies.

I performed a Raup and Crick (1979) hierarchical clustering analysis to define plant community types within the swamp. Raup and Crick is commonly used for presence and absence data and uses a randomization, or Monte Carlo, procedure. Raup and Crick compares the observed species with the distribution of randomly generated

replicates. It then clusters those species which occur together in both distributions and produces a dendrogram of related species as graphic output. The dendrogram is plotted against a similarity axis for interpretation. Each cluster in the dendrogram is analogous to a plant community type within the swamp. The plant communities are related through the hierarchy. The closer the node at which one community branches from another, the closer related those two communities are. I used a similarity value of 0.5 as a clustering criterion.

I ran the Raup and Crick analysis at two different spatial scales. The first scale was at the subplot level. This data set consisted of presence and absence data (converted from stem counts) for all the herbaceous species as sampled at the subplot (1m X 1m) level. This analysis used the 164 subplots sampled at each of the 41 sites within the swamp. I ran the second analysis at the plot level. This consisted of pooled subplot presence and absence data for each of the 41 sampling sites. I produced a separate dendrogram for each analysis (Hammer et al., 2001).

The second analysis I ran was an indirect ordination analysis using the Canoco for windows 4.5 software package (ter Braak and Smilauer, 2002). Ordination techniques have been shown to be very effective at interpreting environmental gradients, especially when the data are formatted in sample x species-unit matrices, such as in this study. In a sample x species–unit matrix sampling design there is an overwhelming amount of redundant information (Palmer, 1993). Many species will respond to the same environmental gradients, though the magnitude of their responses might be different. Ordination techniques are designed to maximize the correlations between sites and species composition at each site.

Ordination techniques fall under the broad category of correspondence analysis (CA). CA techniques can be further divided into two families. The first family of CA is called an indirect gradient analysis. In this analysis the environmental gradients are not measured directly, but they are inferred from the species composition data (Palmer, 1993). It is up to the user to interpret the species composition data and propose the environmental gradients that the species are responding to. One example of an indirect gradient analysis technique is detrended correspondence analysis (DCA). I used this analysis technique to determine the most important environmental gradients found within Bergen Swamp.

DCA is a good exploratory tool for the initial analysis of data and is especially useful when forming hypotheses for further analysis (Palmer, 1993). The environmental gradients interpreted by the user from DCA can be used in a later hypothesis test using a direct gradient analysis, such as CCA.

The output of DCA is an n-dimensional graph in which each axis represents an environmental gradient, and each species is a point in a scatter plot as defined by the axes. The most important environmental gradient to which the species respond is shown on axis one, the second most important gradient on axis two, etc. I ran the DCA at the same two spatial scales which as the Raup and Crick (1979) clustering analysis.

## **Results**

The Raup and Crick clustering analysis showed different results at the two different spatial scales (Figures 5 and 6). At the level of 0.5 similarity, there are five distinct clusters represented in Bergen Swamp at the subplot level. The five community

types I defined from the subplot level were (from left to right): the marl community, the bog community, the wet woods community, the rich woods community, and the marsh community. I named the community types based on the environmental differences required by the species present in each community. It should be pointed out that these names are an artificial construct used for descriptive purposes only. These communities are by no means mutually exclusive of each other. Many species can be found in more than one community type within the swamp, though their dominance may be different in each.

At the subplot level (Figure 5) the first branch of the hierarchy separated out one community group from all the rest. This is the most distinct community type found in Bergen Swamp, and is not closely related to the others.

The output for the plot level data (Figure 6) shows there was a difference between the two spatial scales. At a 0.5 similarity there are only three communities identified compared with five at the subplot level

The three community types from the plot level data are much more difficult to interpret. Whereas in the subplot level data the five clusters consisted of species commonly found growing together, the plot level data consisting of only three clusters did not have this characteristic. This is undoubtedly due to the difference in spatial scales between the two analyses.

The DCA at both scales shows the species response to environmental gradients. Those species that are close to one another on the graphs are those that are commonly found growing together. In this way community types can be loosely inferred from the DCA results. The environmental gradients at both the subplot and plot scale appear to be

the same as species responses are similar at both scales. Axis one (Figures 7-10) for both the subplot and plot scales represents depth to water table, with increased values on the DCA graphs having a shallower depth. This is the most important gradient within Bergen Swamp, accounting for about 80% of the variation in species distribution. This gradient is easily inferred by the species composition. Species such as false asphodel (*Tolfieldia glutinosa*), pitcher plant (*Sarracenia purpurea*), brook lobelia (*Lobelia kalmii*), and Rush species are found at the extreme wet end of this gradient where the depth to water table was smallest (Gleason and Cronquist, 1991). Species such as twisted stalk (*Streptopus roseus*), maidenhair fern (*Adiantum pedatum*), trillium species (*Trillium spp.*), and white snake root (*Eupatorium rugosum*) are found at the other end of this gradient, where the depth to water table was greatest (Gleason and Cronquist, 1991). Depth to water table as described in this study is a surrogate for soil moisture as described in Gleason and Cronquist, with an increased depth to water table indicating lower soil moisture, and vice versa.

Axis two (Figures 7 and 9), represents hydrologic activity with increased values on the DCA graph having higher hydrologic activity. Hydrologic activity is defined as the influence of small streams or local flooding, especially in the springtime during snow melt, on the plant composition. This could be a direct result of temporary inundations of water, or changing stream patterns throughout the course of a season, year, or many years. Characteristic species of areas of high hydrologic activity on axis two include narrow leaved cattail (*Typha angustifolia*), flat topped white aster (*Aster umbellatus*), spotted joe-pye weed (*Eupatorium maculatum*), and sensitive fern (*Onoclea sensibilis*). Characteristic species of areas of low hydrologic activity include Indian cucumber root

(*Medeola virginiana*), goldthread (*Coptis trifolia*), trillium species (*Trillium spp.*), and Canada mayflower (*Maianthemum canadense*) (Gleason and Cronquist, 1991).

The third axis of the DCA represents the third most important environmental gradient. Axis three (Figures 8 and 10) represents a pH scale with increased values on the DCA graph representing lower pH values. The interpretation of this axis is complicated by the presence of the marl community type, which is located in the middle of this axis. The pH of the marl is very alkaline due to the active precipitation of calcium from the groundwater. This precipitation only occurs in the marl plant community. The pH gradient observed in the rest of the swamp is independent of the influence of marl precipitation. For this reason the marl community type was not taken into account when I decided that the third axis represents a pH gradient. Species representing the alkaline end of this gradient include maidenhair fern (*Adiantum pedatum*), marsh fern (*Thelypteris palustris*), and enchanter's nightshade (*Circaea lutetiana*). Species representing the acidic end of this gradient include twisted stalk (*Streptopus roseus*), hay-scented fern (*Dennstaedtia punctilobula*) and white snakeroot (*Eupatorium rugosum*) (Gleason and Cronquist, 1991).

## **Discussion**

### ***Spatial Scale***

Both the Raup and Crick analysis and the DCA show that there is a significant difference in spatial scales between the subplot and plot data sets. I sampled the subplot data at a scale of 1m x 1m, and the plot data was created by pooling the four subplots for any one sampling point, giving the plot a scale of 30m.



The differences in spatial scale were most evident in the Raup and Crick analysis, with the subplot data being clustered into five community types, and the plot data being clustered into three. The differences are not as apparent in the DCA until it is combined with the Raup and Crick analysis. Taking the clusters from the Raup and Crick analysis and coding them into the output from the DCA gives a clear picture of the differences between the two spatial scales (Figures 7-10).

The increased number of clusters at the subplot scale gives the combined graphs more resolution than at the plot scale. This is most evident on axis three, where the two community types of rich woods and wet woods are separated in the subplot data (Figure 8). This separation does not occur in the plot level data because those two community types were not present in the clustering analysis. They were combined as part of a bigger cluster and resolution was lost.

The reason for this disparity in spatial scales is most likely because of micro-topography within the swamp and is probably directly related to hummocks and hollows. Hummocks are small areas that are slightly raised relative to the immediate surrounding area, which is referred to as a hollow. Examples of how hummocks can form in wetlands are tipup mounds from tree falls, channel building by animals (i.e. muskrat) (Vivian-Smith, 1997), or differential litter accumulation usually associated with different species of sphagnum moss (Nungesser, 2003). Any of these factors can lead to the development of hummocks and hollows, which are commonly believed to be a stable and self-maintaining topography (Nungesser, 2003).

Hummocks and hollows affect plant distribution by providing micro-topographical differences in habitats. Vivian-Smith (1997) showed that small scale

variability in microtopography, on the order of 1-3cm, can produce highly significant differences in plant community structure. Vivian-Smith has also shown that species diversity, richness, and evenness were consistently greater in communities with increased micro-topography.

Hummocks and hollows are very common throughout all of Bergen Swamp. They are present at many scales; the largest I have observed are a couple meters tall from hummock to hollow. Hummocks located in Bergen swamp usually have a small footprint, rarely larger than 4m<sup>2</sup> (personal observation).

Hummocks and hollows with different species compositions are what account for the disparity between the two spatial scales. If a 1m x 1m subplot happened to land on a hummock, it would measure a different species composition than if it landed on a hollow, even though the hollow could be only a meter away. For this reason the plot level data loses resolution. The microtopography that might have been present in a subplot gets diluted when all four subplots are combined for the plot level data. The same amount of data is present in both the subplot and plot scales since the plot scale is pooled subplot data. The different sample numbers for the two analyses (164 for subplot, 41 for plot) therefore have no effect on the data distribution.

### ***Plant Communities: Past and Present***

One problem with the DCA method of community grouping arises in where to distinguish one community from another. This is further complicated by the nature of the plant communities at Bergen Swamp. Past studies (Stewart and Merrell, 1937; Muenscher, 1946; Walker, 1974) have grouped communities within the swamp, but

have also stated that these communities are by no means easily separable. Plants found to be dominant in one community type may be found in a number of other communities, though not as dominants. The Raup and Crick (1979) clustering analysis was run to remove the biases associated with interpreting the community types from the DCA output.

Stewart and Merrell (1937) divided the swamp into five different zones, each one showing “a well marked concentric or parallel arrangement”. These five zones were the open marl association, the secondary marl zone, the sphagnum association, the pine-hemlock zone, and the beech-maple zone. These zones, or plant communities, are comparable to the 5 community types found in this study. Stewart and Merrell listed the dominant and sub-dominant species for each of their zones, and I have compared and contrasted those species with the community clusters from the Raup and Crick analysis at the subplot level.

Two of Stewart and Merrell’s community types match up well with the Raup and Crick analysis. The combination of the open marl association and the secondary marl zone from their study is analogous to the marl community type of this study. Of the 21 species making up the marl community type in this study, Stewart and Merrell listed 10 of them as members of their open or secondary marl zones.

The other community type from Stewart and Merrell that matches well to the Raup and Crick analysis is the Beech-Maple-Birch climax forest. This community is analogous to the rich woods community of this study. Of the 11 species making up the rich woods community, Stewart and Merrell listed 5 of them in their Beech-Maple-Birch

community. Three other species from the Beech-Maple-Birch community are also found in this study, though not in the rich woods community.

The sphagnum bog association and pine-hemlock association from Stewart and Merrell did not agree with the findings of this study. Though some of the dominant species listed by Stewart and Merrell were present, they were not significantly grouped within any of the 5 clusters. Based on personal observation these two community types do presently exist within the swamp. The random sampling sites from this study did not adequately sample these communities, so they were not delineated in the Raup and Crick analysis. It might also be the case that these communities have decreased in size or changed locations since Stewart and Merrell's study in 1937.

Muenschler (1946) expanded upon the work done by Stewart and Merrell and greatly increased knowledge of plant species found in the swamp to 780 species, more than double the 372 previously described. He also revealed previously unreported plant associations and divided the swamp into ten zones, though none of them were considered to be mutually exclusive. These ten groups are aquatic plants, carex riparia swamp, alluvial soil plants, open marl bog, secondary marl bog, sphagnum bog, arbor-vitae swamp, alder swamp, pine-hemlock forest, and birch-maple-elm forest.

The best matched communities between this study and that done by Muenschler are the marl communities. Combining the open marl and secondary marl from Muenschler's study provides a good match to the marl community of this study. Of the 21 species making up the marl community of this study, Muenschler listed 12 of them as characteristic of his open marl and secondary marl community types. Also interesting to note, six of the species which Muenschler listed as members of his sphagnum bog zone

are members of the marl community from this study, indicating the close proximity and mixing of species from the two communities.

The other community from Muenscher's study that matched well with this study was the Beech-Maple zone. This zone is analogous to the rich woods community. Of the 11 species listed from this study, 5 of them were listed by Muenscher as characteristic of the Beech-Maple zone.

Species from the arbor-vitae swamp and pine-hemlock zone from Muenscher's study were also found in this study, but were not significantly grouped within any of the 5 clusters. This study found no species listed in the other five zones of Muenscher's study. This is likely a result of the limited temporal scope of this study that was restricted to a single summer field season.

There are many possible explanations for the differences between community types found in the past and those found in this study. One of the most important is the differences in how this study and past studies were carried out. This study used a random sample design to sample, analyze, and group community types. Past studies have not been so rigorous in their design, and analysis was done mainly through observations and not through statistical means. This study also used all the species sampled to determine community types, not just those thought to be dominant as listed by Stewart and Merrell (1937) and Muenscher (1946). Sampling in this study was not done in pre-determined community types, but instead was randomized and covered the entire geographic area of the swamp. Sampling was also not done at different times of the year or over the course of many years. Many early spring species were not found in this study which were found in previous studies.

Other than experimental differences between the studies, natural processes could also have had an effect on the differences in communities found. It has been 67 years since Stewart and Merrell's study, and 58 years since Muenscher's. Natural succession could have changed many community types over that time scale. Most likely to be changed would be pioneer community types such as the alder swamp described by Muenscher, of which no species were found in this study. The marl community could also have changed naturally over time. Seischab (1984) proposed that the marl community is being encroached from the outside by the Thuja forest at a rate of 4 inches per year and changed from the inside through hummock formation. Changes in hydrologic activity could also affect areas of marl deposition and standing water.

Diseases have also had a dramatic impact on the community structure of the swamp. Dutch elm disease has almost completely wiped out the American elm (*Ulmus americana*) which was once a dominant tree species within the swamp (Seischab, 1977). Continued harvesting of species such as Thuja occidentalis and the introduction of invasive species could also have affected community structure within the swamp. The foraging of a robust white-tailed deer population could also have affected plant communities over the last 67 years.

The two community types found in this study which were analogous to previous studies (the marl community and the rich woods) appear to have been relatively stable over the past 67 years. Although this does not quantify the distribution and area of these communities, it does indicate that certain communities within the swamp are more stable than others.

The other communities within the swamp appear to be very dynamic. This is most likely due to the changes in the environmental gradients to which they are responding, most notably hydrologic activity. The two community types that have changed the least are those on either end of the most important environmental gradient (depth to water table) within Bergen Swamp, as seen on axis one from the DCA (Figure 7). Also notice that the communities which have changed are those on the ends of axis two (hydrologic activity, Figure 7) and axis three (pH, Figure 8).

Plant community distribution is an indication of the stability or instability of the environmental gradients within the swamp. Depth to water table, and its associated communities at both ends, has remained relatively constant over the last 67 years. Hydrologic activity, on the other hand, has been much less stable, as indicated by shifting and changing community types within the swamp.

## **Conclusion**

The disparity between spatial scales within the swamp can be explained by differences in micro-topography, as related to hummock and hollow formation. This greatly increases the plant diversity and richness, and leads to a greater number of community types which can thrive within the swamp.

The plant communities in Bergen Swamp are distributed along distinct environmental gradients. The most important of these gradients is depth to water table, which accounts for about 80% of the variation between communities. The next two most important gradients are hydrologic activity and pH.

Depth to water table has been stable over the last 67 years, as have been the two plant communities responding strongest to this gradient: the marl community and the rich woods community. Hydrologic activity within the swamp is highly variable at many scales as are the communities responding to this gradient: the bog community, wet woods community, and marsh community.

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Figure 1: The geographic location of Bergen Swamp

Figure 2: The geology of Bergen Swamp and the surrounding area

Figure 3: Bergen Swamp sample points generated using a GIS

Figure 4: Plot surveys. Two 30m transects, one running north-south and the other running east west first laid out. At the end of each transect a 2m X 2m subplot, with a nested 1m X 1m plot was established. Abiotic and herbaceous data was recorded within these subplots. All woody stems between 2cm DBH and 10cm DBH and within 1m of the North-South transect were recorded as shrubs. All woody stems greater than 10cm DHB and within 5m of the North-South transect were recorded as trees.

Figure 5: Raup and Crick Analysis at the subplot level (see Table 1 for species acronyms). At a 0.5 similarity 5 community types are established. They are, from left to right, the marl community, the bog community, the wet woods community, the rich woods community, and the marsh community.

Figure 6: Raup and Crick Analysis at the plot level (see Table 1 for species acronyms). At a 0.5 similarity only 3 community types are established. These communities are not easily distinguished based upon their species compositions.

Figure 7: Axes 1 and 2 of the DCA at the subplot level combined with the Raup and Crick Analysis at the subplot level (see Table 1 for species acronyms). Each of the different color groups represents a plant community which was determined from the Raup and Crick Analysis at the subplot level (Figure 2).

Figure 8: Axes 1 and 3 of the DCA at the subplot level combined with the Raup and Crick Analysis (see Table 1 for species acronyms). Each of the different color groups represents a plant community which was determined by the Raup and Crick Analysis at the subplot level (Figure 2).

Figure 9: Axes 1 and 2 of the DCA at the plot level combined with the Raup and Crick Analysis (see Table 1 for species acronyms). The different color groups represent community types determined by the Raup and Crick Analysis at the plot level (Figure 3).

Figure 10: Axes 1 and 3 of the DCA at the plot level combined with the Raup and Crick Analysis (see Table 1 for species acronyms). The different color groups represent community types determined by the Raup and Crick Analysis at the plot level (Figure 3).

Table 1: Herbaceous plant species

Acronym	Common name	Scientific name
BogCra	Bog Cranberry	<i>Vaccinium macrocarpon</i> Aiton
Bonese	Boneset	<i>Eupatorium perfoliatum</i> L.
BraFer	Bracken Fern	<i>Pteridium aquilinum</i> (L.) Kuhn
BroLeaCa	Broad Leaved Cattail	<i>Typha latifolia</i> L.
BroLob	Brook Lobelia	<i>Lobelia kalmii</i> L.
BunBer	Bunchberry	<i>Cornus Canadensis</i> L.
CanMay	Canada Mayflower	<i>Maianthemum canadense</i> Desf.
CinFer	Cinnamon Fern	<i>Osmunda cinnamomea</i> L.
ClaBed	Clayton's Bedstraw	<i>Galium trifidum</i> L.
Colfoo	Coltsfoot	<i>Tussilago farfara</i> L.
ComRee	Common Reed	<i>Phragmites australis</i> (Cav.) Trin.
EncNig	Enchanter's Nightshade	<i>Circaea lutetiana</i> L.
EveWoo	Evergreen Woodfern	<i>Dryopteris</i> spp. Adans.
FalAsp	False Asphodel	<i>Tofieldia glutinosa</i> (Michx.) Pers.
FalSolS	False Solomon's Seal	<i>Smilacina racemosa</i> (L.) Desf.
FlToWhAs	Flat Topped White Aster	<i>Aster umbellatus</i> Miller.
FoaFlo	Foamflower	<i>Tiarella cordifolia</i> L.
GolRag	Golden Ragwort	<i>Senecio</i> L.
GolThr	Goldthread	<i>Coptis trifolia</i> (L.) Salisb.

GraPar	Grass of Parnasus	<i>Parnassia glauca Raf.</i>
HaySceFe	Hay-scented Fern	<i>Dennstaedtia punctilobula (Michx.) Moore.</i>
HeaAll	Heal All	<i>Prunella vulgaris L.</i>
HelOrc	Helleborine Orchid	<i>Epipactis helleborine (L.) Crantz</i>
HemPar	Hemlock Parsley	<i>Conioselinum chinense (L.) BSP.</i>
HogPea	Hog Peanut	<i>Amphicarpaea bracteata (L.) Fern.</i>
HorTai	Horsetail	<i>Equisetum L.</i>
IndCucRo	Indian Cucumber Root	<i>Medeola virginiana L.</i>
IndGra	Indian Grass	<i>Sorghastrum nutans (L.) Nash.</i>
MadDogSk	Mad Dog Skullcap	<i>Scutellaria lateriflora L.</i>
MaiFer	Maidenhair Fern	<i>Adiantum pedatum L.</i>
ManGra	Manna Grass	<i>Glyceria R.</i>
MarFer	Marsh Fern	<i>Thelypteris palustris Schott.</i>
NarLeaCa	Narrow Leaved Cattail	<i>Typha angustifolia L.</i>
NewYorFe	New York Fern	<i>Thelypteris noveboracensis (L.) Nieuwl.</i>
NodBel	Nodding Bellwort	<i>Uvularia perfoliata L.</i>
NorBed	Northern Bedstraw	<i>Galium boreale L.</i>
PitPla	Pitcher Plant	<i>Sarracenia purpurea L.</i>
PoiIvy	Poison Ivy	<i>Toxicodendron radicans (L.) Kintze.</i>
PurSteAs	Purple Stemmed Aster	<i>Aster puniceus L.</i>
		<i>Solidago ohioensis Riddell</i>
PurSteGol	Purple Stemmed Goldenrod	<i>Solidago houghtonii T. &amp; G.</i>
ReeCanGr	Reed Canary Grass	<i>Phalaris arundinacea L.</i>

RicCutGr	Rice Cut Grass	<i>Leersia hexandra Sw</i>
RouLeaGo	Rough Leaved Goldenrod	<i>Solidago patula Muhl.</i>
RouLeaSu	Round Leaved Sundew	<i>Drosera rotundifolia L.</i>
RusSpp	Rush spp.	<i>Juncus spp.</i>
SenFer	Sensitive Fern	<i>Onoclea sensibilis L.</i>
SleToo	Slender Toothwort	<i>Cardamine angustata O. E. Schulz.</i>
SmoLeaGo	Smooth Leaved Goldenrod	<i>Solidago gigantean Aiton.</i>
SpoJew	Spotted Jewelweed	<i>Impatiens capensis Meerb.</i>
SpJoPyWe	Spotted Joe-Pye Weed	<i>Eupatorium maculatum L.</i>
Staflow	Starflower	<i>Trientalis borealis Raf.</i>
TalMeaRu	Tall Meadow Rue	<i>Thalictrum pubescens Pursh.</i>
TrilSpp	Trillium sp.	<i>Trillium sp. L.</i>
TwiSta	Twisted Stalk	<i>Streptopus roseus Michx.</i>
VirCre	Virginia Creeper	<i>Parthenocissus quinquefolia (L.) Planchon.</i>
WatHor	Water Horehound	<i>Lycopus americanus L.</i>
WhiLet	White Lettuce	<i>Prenanthes alba L.</i>
WhiSnaRo	White Snake Root	<i>Eupatorium rugosum Houttuyn</i>
WilSar	Wild Sarsparilla	<i>Aralia nudicaulis L.</i>
WilStr	Wild Strawberry	<i>Fragaria virginiana Duchesne</i>
WilHer	Willow Herb	<i>Epilobium sp.</i>
Wingre	Wintergreen	<i>Gaultheria procumbens L.</i>
AltLeaDo	Alternate Leaf Dogwood	<i>Cornus alternifolia L.f.</i>
AmeLar	American Larch	<i>Larix laricina (Duroi)</i>



NorBay	Northern Bayberry	<i>Myrica pensylvanica</i> Mirbel.
BluberSp	Blueberry spp.	<i>Vaccinium</i> spp.
HorJun	Horizontal Juniper	<i>Juniperus horizontalis</i> Moench.
LabTea	Labrador Tea	<i>Ledum groenlandicum</i> Oeder
ShrCin	Shrubby Cinquefoil	<i>Potentilla fruticosa</i> L.
Spibus	Spicebush	<i>Lindera benzoin</i> (L.)
WhiCed	White Cedar	<i>Thuja occidentalis</i> L.

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Figure 1:

### Bergen Swamp, New York

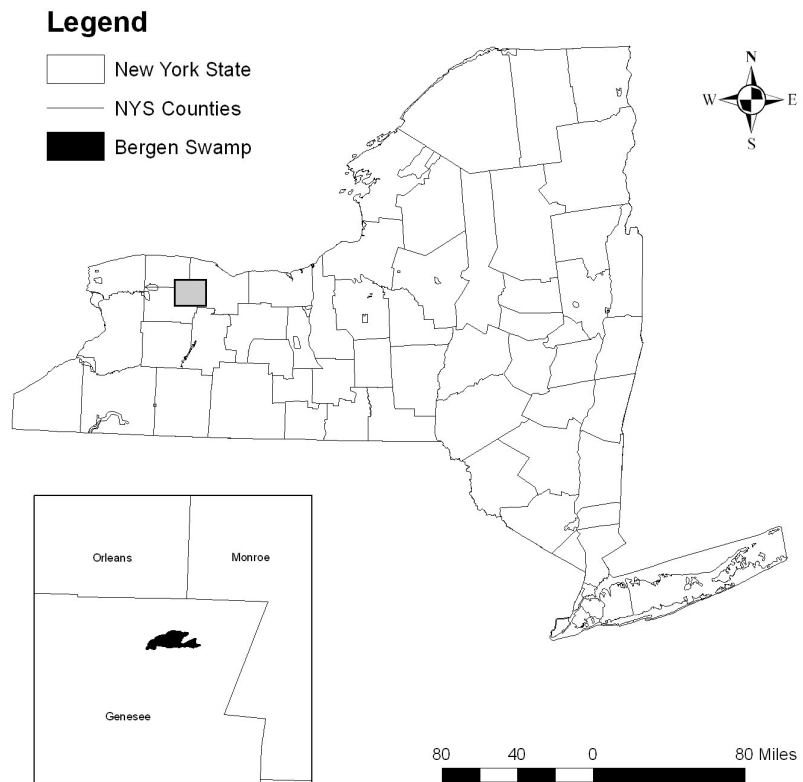


Figure 2:

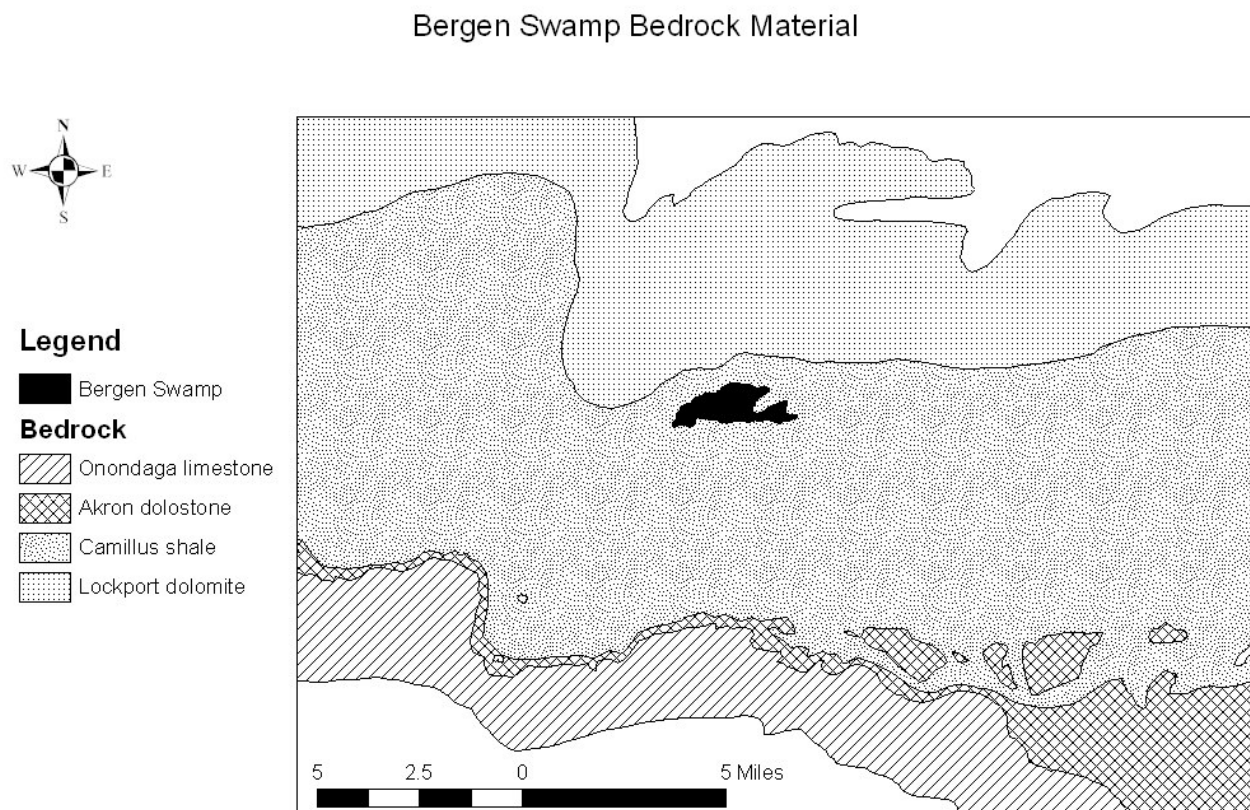


Figure 3:

Bergen Swamp sample points

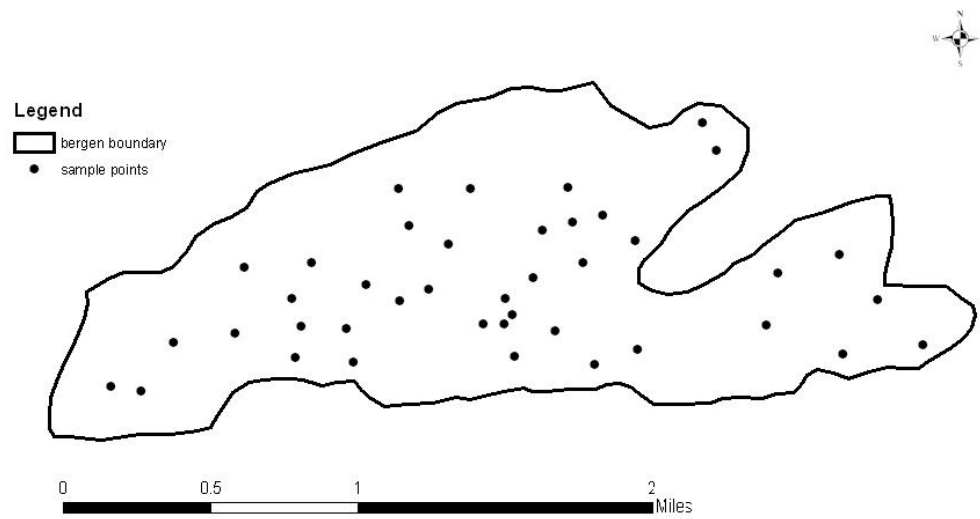


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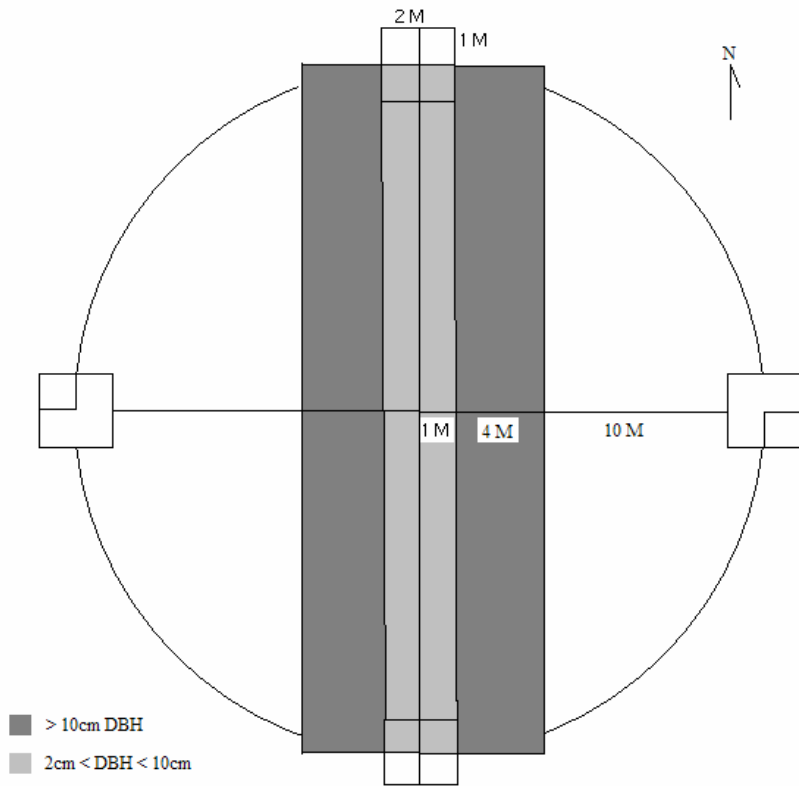


Figure 5:

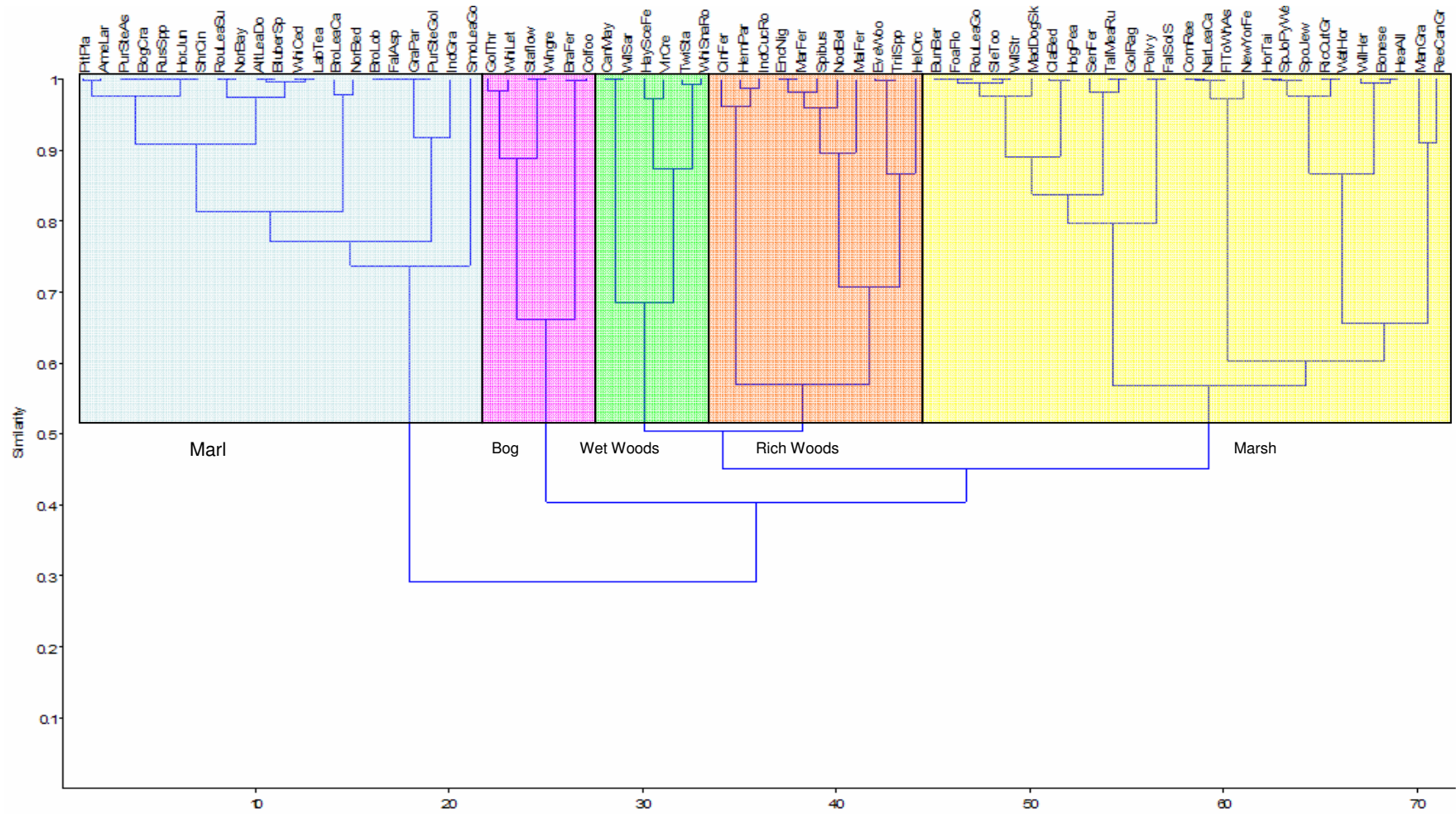


Figure 6:

