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MICHIGAN'S CLAY BLUFFS: THE DESCRIPTION AND COMPARISON OF AN EROSION-DEPENDENT NATURAL COMMUNITY

by

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A thesis submitted to the Graduate College in partial fulfillment of the requirements for the degree of Master of Arts Geography Western Michigan University August 2014

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The clay bluffs of Michigan are a natural community found along the shores of the Great Lakes. Groundwater is found to be critical to sustaining the alkaline wetlands on the face of the bluff as well as the source of most erosion events. The clay bluffs are unusual in their vegetation, disturbance regime and geographical context. This thesis focuses primarily on describing seeping clay bluffs and exploring the comparison to other natural communities. The purpose of this is twofold, to better understand the ways in which natural communities are described as distinct from one another, and to assess the distinctness of seeping clay bluffs as a community type. Jaccard’s index and hierarchical clustering can be used to compare vascular plants, landscape context and morphological characteristics of many different natural communities. These results suggest that clay bluffs are a distinct community.

Further research is needed to locate additional examples of seeping clay bluffs in Michigan and Wisconsin, as well as other Great Lakes states and provinces. Comparisons to other bluffs, seeping and dry, should be made to evaluate the value in recognizing their distinctiveness.
ACKNOWLEDGEMENTS

Many people have provided great amounts of time and patience in helping me complete this project. My interests in clay bluffs began with an excited phone call from William Martinus back in 2006. Bill’s findings on a new preserve for my employer, Southwest Michigan Land Conservancy (SWMLC), coupled with my ongoing restoration work in fens made for an enticing topic to explore. Brad Slaughter, Conservation Scientist and Lead Botanist for Michigan Natural Features Inventory, directed me towards the Wisconsin Department of Natural Resources (WDNR) description of clay seepage bluffs. Eric Epstein of the WDNR humored me for several phone calls and was kind enough to arrange a guided visit to Warnimont Bluffs. Joshua Cohen, Conservation Scientist and Lead Ecologist for MNFI, went out of his way to give me time and resources to better understand the science and art of natural community differentiation. Josh, Brad, and others at MNFI showed great patience with me as I made repeated inquiries into their methods, databases, and perspectives.

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on Landscape Ecology and Regional Planning helped me develop the core concepts introduced in this thesis. Dr. Todd Barkman gave me the guidance on how to assess natural communities when faced with data that just wasn’t cooperating. I can’t thank Dr. Kathleen Baker enough. She provided unending patience and encouragement when I thought I would never get this completed. Finally, thank you to my incredibly supportive wife, Erin Fuller. She reviewed, critiqued, encouraged, corrected my formatting for endless hours, and pulled many a night of solo-parenting on my behalf. Without her indomitable patience, support, and love, I would have never finished.

Nathaniel G. Fuller
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CHAPTER 1: INTRODUCTION

In 2005, Southwest Michigan Land Conservancy (SWMLC) received 127 acres of land as a bequest from William Erby Smith to own and manage as a nature preserve. Mr. Smith called his property “Wau-Ke-Na”, which means “forest by the water.” The preserve includes 1,300 feet of bluffs along the shore of Lake Michigan. SWMLC hired a professional ecologist, William Martinus, to inventory the property and were surprised when he found an unusual suite of plant species growing along a portion the bluff face where water was actively weeping (Martinus, 2007). The plants found were more commonly associated with coastal fens much farther north and prairie fens found along inland streams and rivers.

Seeping clay bluffs with similar plants were later discovered six miles south of Wau-Ke-Na when a lake-front property owned by the Stefan Family Trust was being evaluated by SWMLC for potential acquisition as a Casco Township preserve. This 100 foot high bluff is significantly taller than the Wau-Ke-Na bluff, but exhibited some similar characteristics. Seeping water on the face of the bluff supported some of the same wetland vegetation. Both had dense rush and sedge populations,

Figure 1: Known clay bluffs of southern Lake Michigan in 2008
distinctive displays of fringed gentian (*Gentianopsis procerd*) and great blue lobelia (*Lobelia siphilitica*), and patches of open marl and clay faces. Initial efforts to find a formal description of this plant assemblage were not successful so SWMLC staff took to referring to the natural community as a "vertical fen".

Further research at the time revealed that Michigan Natural Features Inventory (MNFI) did not have a description for this habitat type but a similar habitat, “clay seepage bluff” was described by Wisconsin’s natural features program (Epstein et al., 2002; Natural Communities of Wisconsin, 2008). This habitat type is known from Warnimont Park in Milwaukee, Wisconsin (for species list, see Appendix A). SWMLC invited MNFI ecologists to Wau-Ke-Na for their opinion on what natural community classification they would recommend but schedules did not allow for a site visit until 2011 when MNFI received funding to evaluate Great Lakes coastal natural communities for updated descriptions and distributions. MNFI staff included clay bluffs in their evaluation and did official surveys of Wau-Ke-Na and the Stefan Property. The ecologists concluded that not only were clay bluffs worthy of natural community distinction, but the Wau-Ke-Na site in particular was exceptional in its floristic diversity and the only site in the State worthy of a "Grade A" rank (Cohen, personal communication, 2011).

Reports from field visits by SWMLC staff, later confirmed by this author, revealed two more large regions of clay bluffs along the Lake Michigan shoreline in southwestern Michigan. The bluffs just south of St. Joseph, near Shoreham Park, appear to be largely altered, covered in large swatches of non-native species and used as dump sites. However some small remnants of functioning clay bluff community may still exist.
A large section of clay bluffs north of Benton Harbor and south of Covert, near an area called Mizpah Park, support some of the highest and most dramatic looking clay bluffs. No official site reviews have been conducted, but initial assessments of vegetation and structure suggest these could be important examples of clay bluff communities.

MNFI developed a natural community description for clay bluffs in 2013, including sites in the southwest and northern Lower Peninsula as well as along the Lake Superior shoreline in the Upper Peninsula. The community was awarded a "S2" rank which means it is considered "imperiled in the state because of rarity due to very restricted range, very few occurrences (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the state." Unfortunately little is understood about the conservation needs of these natural communities. Much of MNFI's description of natural processes for the clay bluffs comes from a term paper written by the author on clay bluffs for Landscape Ecology and Regional Planning, WMU GEOG 6670 (Fuller, 2009).

This thesis focuses on the seeping clay bluffs of Lake Michigan. The unusual setting of an alkaline wetland on near vertical slopes on the shores of a Great Lake make for a beautiful

Figure 2: Groundwater flows from the base of the bluffs of Wau-Ke-Na to Lake Michigan. Photo by Kalman Csia
location to study a fascinating natural community. Plant species that would excite botanists even in small numbers, such as fringed gentians (*Gentianopsis procera* and *G. crinita*) and grass-of-Parnassus (*Parnassia glauca*) can at times occur in the hundreds or even thousands. The weeping faces of the bluff create a cooler microclimate immediately adjacent to the extreme heat of exposed foredunes. The mineral rich water seeping from the porous layers of soil create small stalactites-like formations from overhanging lips and calcareous tufa forms below to join the clumps of clay oozing down to the base of the bluff. The portions of the bluff without the benefit of groundwater get sun-baked into hardened walls. It is a community of extremes, where one can easily slip on wet clay, tumble over pottery-hard surfaces, and land in loose sand (as the author experienced more than once).

One of the early biologists to study the natural communities of the Great Lakes was Dr. Henry C. Cowles who developed his concepts of natural succession studying the sand dunes of southern Lake Michigan (Cowles, 1899). Even after all his time in the sun-scorched dunes, Dr. Cowles said "there can be almost no habitat in our climate which impresses such severe conditions upon vegetation as an eroding clay bluff" (Cowles, 1901). The eroding nature of the seeping clay bluffs make them a dynamic natural

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Figure 3: Mineral-rich water creates small stalactite-like formations

Figure 4: Calcareous tufa forms from deposits of the mineral-rich seeps. Photo by William Martinus
community, changing from season to season and year to year as many natural processes work to radically alter the very structure of the community by wind, freezing and thawing, wave action, storm surges, and the unending flow of groundwater.

MNFI chose to include the bluffs of the Lake Michigan shoreline with those of the Lake Superior shoreline. The geographic context, geologic underpinnings, and vascular plant assemblages vary between these sites. These shoreline wetland communities should be compared to other wetland communities, shoreline communities, and each other to gauge levels of similarity. A better understanding of the ways clay bluffs are both similar and different to other natural communities will give context to conservation challenges such as habitat management and land protection prioritization.

Figure 5: When groundwater flows strong enough, it will form small streams out into Lake Michigan

Figure 6: Wind, water, and other natural processes make the clay bluffs one of the most “severe” conditions for plants to grow. Photo by Kalman Csia
Problem Statement

The clay bluffs in Michigan were not recognized as a natural community until recently and no comparisons with related habitat types exist. In order to preserve these rare and fragmented habitats, a greater understanding of their structure, function, distribution, and ecological context is necessary to make informed conservation decisions.

Objectives

1) Describe the clay bluff natural community found in southwest Michigan.

2) Compare this natural community to other shoreline and alkaline wetland communities found in Michigan.

3) Examine the potential role erosion has as a natural disturbance that sustains the herbaceous plant community.

4) Assess and summarize the conservation needs for clay bluffs.

The upcoming chapter will be a literature review to provide context on the geologic history and function of clay bluffs and other Michigan natural communities. It will review the way natural communities are described and how to measure their similarity to one another. Chapter 3 will cover the methods used to compare natural communities by evaluating vascular plants, landscape context, and morphological conditions. Chapter 4 will provide the results of the comparisons and also include a series of photos documenting bluff characteristics and erosion events. This is followed by a full discussion of the results, opportunities for further study, and potential implications for clay bluff community conservation.
CHAPTER 2: LITERATURE REVIEW

This literature review will cover the geologic history that formed clay bluffs and other natural communities of the Great Lakes region. It will then review how natural communities are distinguished from one another, often by means of associated vascular plants. To better understand the structure and functions of Michigan’s clay bluffs, the following sections will review alkaline wetland ecology and clay bluff erosion. The literature review will conclude with an examination of similarity methods that can be used to quantify the similarity of clay bluffs to other communities already described in Michigan.

Geologic History

During the Cretaceous period prior to 70 million years ago, much of the Midwest U.S. was covered by a warm shallow sea (Timble, 1980). Calcium-rich coral and shell fish were buried deep under soils and after enough time and pressure, changed into limestone. This limestone is the source of the alkalinity essential to the formation of many natural communities in the Midwest (Curtis, 1971). A series of glaciers moved through the region, scouring the ancient lake bottom and grinding it up into glacial till and distributing it across the modern-day Great Lakes region. As the climate warmed and the glaciers retreated, they left behind soils scraped clean of all vegetation (Curtis, 1971; Jibson et al., 1994; Grimm, 2005).

The shores of Lake Michigan were defined during the Wisconsin stage of glaciation around 10,000 years ago when the Laurentide ice sheet retreated (Bergquist, 1988, Jibson et al., 1994; Grimm 2005). Deep basins scoured by the lobes of the glaciers
became the Great Lakes. Winds and wave action helped sculpt these newly exposed habitats. Lighter soils such as sand and silt were blown by the prevailing westerly winds. Heavier clays and loams remained on the west side of Lake Michigan while the sand and silt piled up on the east side (Curtis, 1971; Greenberg, 2002). The layers of limestone remained buried under layers of soil and gravel, but in some cases were left near the surface.

The limestone and other soils of the Lake Michigan shoreline were deposited in a series of glacial scouring and retreat events around 10,000 years ago that have since been influenced by local climate and human development (Greenberg, 2002). Habitats are formed by the underlying geomorphology and are predictable by soil types and available moisture (Palik et al., 2000). The geographic features shaped by the glaciers created the underlying characteristics that help define Michigan’s natural communities. Glacial moraines across Michigan mark some of the historic extents of the glaciers, where they left piles of gravel as they melted back. The Kalamazoo moraine stretches from Hastings to Cassopolis. The Valparaiso moraine shadows the bottom end of Lake Michigan from just north of Grand Rapids, Michigan to the Wisconsin-Illinois border roughly 10 - 50 miles inland (Figure 7). These long gravel ridges provide an important groundwater recharge source that supports many groundwater-dependent wetlands across the region.
The Kalamazoo and Valparaiso moraines help define the watershed boundaries between the Kalamazoo, Black, and Paw Paw Rivers. The headwater streams that form at the base of the moraines are often rich in calcium as the water pushes through limestone, creating one of the richest collections of prairie fens in the Midwest. While the Kalamazoo and Valparaiso moraines influenced the development of many natural communities in the interior of southwest Michigan, the Lake Border moraines influenced the location of many natural communities along the lakeshore. It is appears possible that these Lake Border moraines are the source of alkaline water in seeping bluffs. This is covered in more detail on pages 78-82 in the Discussion section. The distribution of
various types of glacial deposits dictated whether the shoreline would be sandy dune, clay bluff, or a transition between the two communities.

The shoreline of Lake Michigan varied greatly during the various glacial stages. The modern day shoreline, about 570 feet above sea level, is only about 4,000 to 6,000 years old (Farrand, 1988). Approximately 13,000 years ago, the glaciers were undergoing their final retreat and Lake Chicago (precursor to Lake Michigan) was at record level of 640 feet above sea level (Figure 8).

Figure 8: The last glacial advance was around 13,000 years ago. Figure from Farrand, 1988.

By 11,000 – 10,000 years ago lake levels had dropped closer to 600 feet above sea level (Farrand, 1988) (Figure 9). During this time the climate was warming and the dominant natural community was shifting from taiga to a more forested one, dense with spruce. By 10,000 years ago the spruce were giving way to ash, elm and oak (Grimm,
Humans began moving into the region along with prairies as megafauna like mastodons and giant beavers moved north (Grimm, 2005; Yansa and Adams, 2012).

Figure 9: Around 10,000 years ago the outflow to the Atlantic Ocean was blocked and lake levels rose until an outlet to the Mississippi drainage was formed. Image from Farrand, 1988.

Around 9,500 years ago, the glaciers had retreated back far enough that an opening to the St. Lawrence Seaway was formed and the Great Lakes began rapidly draining to the north (Figure 10). Lake Michigan dropped to its lowest point; over 300 feet lower than we see today. The eastern shoreline would likely have been dozens of miles west of current day locations. Over the next few thousand years, isostatic rebound lifted the northern outlet, and Lakes Huron and Michigan began draining to the south into Erie, raising the lake levels back to close to 600 feet above sea level.
While this was happening the climate continued to warm and also became wetter. Within the Holocene era over the past 10,000 years, the climate has fluctuated by 3°C and pollen records show that plant communities fluctuated along with it (Hupy and Yansa, 2009). Different species would have taken turns playing dominant roles in the natural communities along the shoreline (Hupy and Yansa, 2009). The potential influence that these shifts in natural communities would have had in the development of clay bluffs vegetation is explored in the Discussion section (see pages 76-77).

The climate became generally more stable for next several thousand years after the glaciers retreated and the region began sorting itself into natural communities based largely on soils and moisture available, along with the occasional natural disturbance regime. However, now humans were actively managing the natural communities of the region and fire in particular became an important driver in natural community development.
establishment (Grimm, 2005; Hupy and Yansa, 2009). Many of the modern-day Midwest natural communities are recognized as at least somewhat dependant on fire to maintain their vegetative structure (Kost, et al 2007).

While the inland natural communities were being sculpted through a combination of climate, soils, and human uses, the shoreline communities were largely being sculpted by climate and Lake Michigan. Lake Michigan was impacting the adjacent landscape with waves, wind events, storm surges, seiches, and other similar erosion-causing events. The geomorphology of the shoreline was sculpted by these natural processes into a string of bluffs, dunes, marshes, swales, cobble shores and more.

These natural communities were further sculpted by human management choices involving burning, harvesting, and other resources uses. In the 1800s European settlers from the East made great impacts on the landscape through farming, fire suppression, non-native species introductions, and many other intentional and unintentional changes. It wasn’t until much of the landscape was fragmented and altered through human uses that people started trying to classify what remained into defined natural communities.

Natural Community Classifications

People have long been grouping, sorting, and classifying natural area habitats. There have been debates over the means of classification and how to accommodate for areas without well defined boundaries and/or shifting plant communities (Whittaker, 1962; Ulanowicz, 1980; Grossman et al., 1998). By the 1990s there were a variety of local, regional, and state-based classification systems in the United States (Grossman et al, 1998). In 1998, The Nature Conservancy worked with the Natural Heritage Programs
to develop a national standard for defining natural communities. This work uses vascular plants to define natural communities, while recognizing that there are often continua between community types (Grossman et al., 1998 FGDC - NVCS 2008). Around the same time, a national standard for classifying vegetation was established to facilitate collaborative management across regional boundaries (FGDC - NVCS 2008).

An effort was made to categorize the numerous state natural communities under plant associations by the Association for Biodiversity Information with support from representatives of the various Midwest state’s Natural Heritage programs (Faber-Langendoen, 2001). These plant communities incorporated many states natural community classifications, but there is often overlap or only partial matching between classifications as well as complete omissions of certain state identified communities. The difficulty in coordinating classifications and descriptions for wetland systems highlights the complexities and variations in nature.

Vascular plant lists are a commonly used single factor classification system for natural communities as they are relatively easy to measure and can reflect existing conditions of other factors such as soil and local climate (Ulanowicz, 1980; Grossman et al., 1998; Faber-Langendoen, 2001, FGDC – NVCS, 2008, others). Multifactor classifications can become complicated (Grossman et al., 1998) so plants are often the chosen group used to define a natural community. Even within this single factor there can be significant variability and it can be challenging to define specific parameters for a community. Examples of efforts to create such parameters, both successful and unsuccessful, have focused on describing oak savannas, alvars, and other communities (Nuzzo 1994; Reschke et al., 1999).
The National Vegetation Classification Standard uses a single factor classification system utilizes vegetation (Federal Geographic Data Committee, 2008). This standard is being used on a variety of scales from local detailed vegetation inventories to broader aerial imagery interpretation (Comer and Schulz, 2007). Mapping the location of these communities becomes a challenge on the national level as many are not large enough to be differentiated from a smaller scale (Comer and Schulz, 2007). Soils and geomorphology have been used to predict natural community location and restorability (Palik et al., 2000) and are the underlying features that influence vascular plant distributions. Therefore, in a more local context, differentiation by location and soils is a common addition to vegetation data. The clay bluffs of principle interest of this study have numerous alkaline seeps along their faces and bases. It was the plant associations found in these areas that first inspired investigation into the possibility that clay bluffs might be a natural community unto themselves. Alkaline wetland communities will be described in detail below.

Alkaline Wetland Ecology

The clay bluffs of Wau-Ke-Na, Casco Township Park, and Warnimont Bluffs have been documented by MNFI and the author to be alkaline communities (Fuller, 2009, Cohen personal communication, 2011). They have high pH groundwater weeping across their bluff faces creating narrow wetlands with species often associated with fen natural communities such as fringed gentian (*Gentianopsis procera*), grass-of-Parnassus (*Parnassia glauca*), Torrey’s rush (*Juncus torreyi*), and others. Alkaline wetlands are
found in all of the Great Lakes states and are often referred to as fens (Curtis, 1971; Faber-Langendoen, 2001; Greenberg, 2002). The term fen can be applied to a variety of habitats, including some acidic conditions as well as alkaline. In general, fens tend to be low in nutrients and often dominated by sedges and rushes. The terms applied to fens vary greatly between states. Michigan Natural Features Inventory (MNFI) identifies five different fen wetlands: coastal, northern, patterned, poor and prairie fens. Patterned and poor fens are acidic wetlands while the other three are alkaline. The Indiana Department of Natural Resources identifies marl beach, fen, forested fen, and calcareous seep. Five natural communities were identified as alkaline in Illinois: calcareous floating mat, graminoid fen, low shrub fen, tall shrub fen, and forested fen. Wisconsin’s natural heritage program describes boreal rich, calcareous, central poor, poor, and shore fen.

The fen communities described in Michigan each have an associated natural disturbance to reduce woody species density, which allows herbaceous vegetation to thrive (Bowles et al., 1996; Spieles et al., 2009; Middleton et al., 2006; Kost et al., 2007; Cohen and Kost, 2008a; Cohen and Kost 2008b). Prairie and northern fens rely largely on fire and beaver activity to reduce woody debris. Neither of these disturbances is likely on a weeping clay bluff.

Erosion has been shown to be a regular occurrence on clay bluffs. Significant erosion events like catastrophic slides and major slumps will remove large portions of soils, several meters at a time on occasion. This wipes out the woody plant material on the slope and leaves it open to colonization of herbaceous pioneering species. This is discussed further in the following section.
Bluff Ecology

Clay bluffs occur all around the world, but are particularly well known from a handful of locations in northern Europe, coastal United States, and the Great Lakes. Research on clay bluffs has focused on erosion due to its economic impact (Heinz Center, 2000, and many others). Many efforts have been made to better understand the factors that influence rates of erosion in clay bluffs and the list includes wave height, wave intensity, storm events, aspect, soil structure, groundwater pressure, rainfall, wind, bluff height, beach width, shoreline structures, and more (Sterrett and Edil, 1982; Buckler and Winters, 1983; Meadows et al, 1997; Chase et al., 2001; Dixon and Bromhead, 2002; Sallenger et al., 2002; Swenson et al., 2006, Dickson et al., 2007; Hapke et al, 2009).

In general, influences to erosion of clay bluffs are considered as either from adjacent water bodies or land. Many studies suggest that wave action from adjacent lakes or oceans is the greatest factor in creating erosion events on clay bluffs (Meadows et al., 1997; Hall et al, 2002; Sallenger, 2002; Swenson et al., 2006; others). Consequently, modeling efforts to predict erosion rates and location are largely based on water bodies adjacent to the bluffs and how lake/ocean levels, storm events, underlying topography, predominant winds, shoreline buffer size, and similar characteristics influence the way water reaches the base of the bluff instead of how groundwater may affect erosion (Dickson et al., 2007; Furlan, 2008; Walkden and Dickson, 2008; Hapke et al., 2009, Castedo et. al., 2013). The role of water levels and storm events in coastal erosion modeling has become more prevalent as climate change predictions include sea level rise and increased storm intensity (Bray and Hooke, 1997; Heinz Center, 2000; Dickson et al., 2007; Trenhaile, 2010; Vandamme et al., 2011; Trenhaile, 2011; Castedo et al., 2013).
The study sites for most of these articles are ocean-side bluffs (most often along the shores of the United Kingdom and occasionally on the Californian or Atlantic Coast of the United States) without apparently significant levels of groundwater influence.

However, some studies did include groundwater as a potential factor in the erosion of bluff faces. Those that did consider groundwater found it to be very significant, and in many cases it was a greater influence than wave action (Sterrett and Edil, 1982; Buckler and Winters, 1983; Chase et al., 2001; Dixon and Bromhead, 2002; Lee, 2004; Chase et al., 2007; Vandamme et al., 2011). In particular, studies of Lake Michigan’s bluff communities found groundwater to be extremely important in creating erosion (Sterrett and Edil, 1982; Buckler and Winters, 1983; Chase et al., 2001). These studies showed that the Lake Michigan clay bluffs often had layers of glacial material with lenses of permeable materials sandwiched between layers of impermeable clay. Water flow through the permeable layers was shown to be the major cause of significant erosion events (Sterrett and Edil, 1982; Buckler and Winters, 1983; Chase et al., 2001; Chase et al., 2007).

A detailed study of the bluff morphology and hydrology was undertaken at a site adjacent to the Warnimont Bluff site in Milwaukee, Wisconsin (Sterrett and Edil, 1982). Through the use of study wells and piezometers, researchers found that the layers of sand and fragmented till acted as aquifers at the base of the bluff. Likewise, jointed till at the top of the bluff influenced lip stability and increased the likelihood of a substantial erosion event. In his study of bluffs near the Casco Township site, Chase also found that groundwater was the most influential factor in erosion (Chase et al, 2001). In both
papers, Chase and Sterrett recommend altering groundwater flow through drain tiles to reduce erosion.

With a better understanding of the structure and function of the clay bluffs of southern Lake Michigan, a comparison to other natural communities is possible. There are many means of measuring similarity between natural systems, and these are reviewed in the following section.

**Similarity Methods**

Natural communities are defined in a number of different ways but tend toward the general idea that they are an assemblage of similar species (Curtis, 1959; Whittaker, 1965; Grossman et al., 1998; Gotelli, 2013; Lindquist 2013). Biotic similarity is a measure of how similar two or more groups of species are to each other. Similarity can be measured a number of different ways but the two most commonly used indices for ecological community comparison are Jaccard's and Sørenson's, which were designed to compare species assemblages (Baroni-Urbani and Buser, 1976; Belland, 1982; Birks, 1987; Real and Vargas, 1996; Rice and McDonald, 2005; Neto, 2009; Chen, 2010; Pilehvar, 2010; Holt, 2011; Lososova, 2012; Villeger, 2012; Deimeke, 2013, Gotelli, 2013). The Simpson's and Shannon's indexes are used to measure the diversity or richness of natural communities. The Jaccard's index compares the number of species in common to the total number of species (Jaccard, 1912). It is written as: 

\[ S_J = \frac{a}{a + b + c} \]

where \( S_J \) is the Jaccard similarity coefficient, \( a \) is the number of species in common between communities, \( b \) is the number of species unique to the first community, and \( c \) is the number of species unique to the second community. The closer \( S_J \) is to 1, the more
similar communities are to one another. The result is often multiplied by 100 and then described as a percentage. For example a Jaccard’s index result of 0.459 would result with the communities being described as 46% similar. Dissimilarity can then be described as 1 - S, so those same communities would be described as 54% dissimilar. However these descriptions can be deceiving, as the Jaccard's index number does not necessarily represent how truly alike sites may be as there can be randomness involved in the numbers and it is more accurate to speak of probabilities of similarity (Baroni-Urbani and Buser, 1976; Birks, 1987; Real and Vargas, 1996). Baroni-Urbani and Buser developed a table of probabilities for Jaccard's index that considered the number of attributes being compared (Baroni-Urbani and Buser, 1976). Research has also found that low Jaccard's index values don't necessarily mean low similarity and likewise high values don't necessarily mean high similarity. (Rice and Ballard, 1982).

The Sørensen index compares the number of species in common to the mean number of species in a single assemblage (Sørensen, 1948). The equation is similar to Jaccard’s index but greater weight is given to species in common between communities. It is written as: \( S_S = \frac{2a}{2a + b + c} \), where \( S_S \) is the Sørensen similarity coefficient, \( a \) is the number of species in common between both communities, \( b \) is the number of species unique to the first community, and \( c \) is the number of species unique to the second community. Like Jaccard, it is often multiplied by 100 and described as a percentage.

The Jaccard's index is a comparison of the total diversity rather than the local diversity comparison of the Sørensen index. Jaccard's index is therefore a better choice to assess the level of similarity between vascular plant inventories of clay bluffs and other alkaline wetland and shoreline natural communities (Real and Vargas, 1996). There have
been concerns that Jaccard’s and Sørensen indices overestimate the differences between datasets with small sample sizes or large numbers of rare species (Koleff, 2003; McDonald, 2005; Chao, 2005; Cardaso, 2009; Engen, 2011). However others have found Jaccard’s index remained a viable method of measuring biotic similarity in natural communities even with small sample sizes or in rare natural communities with rare species (Lapin, 1995; McKinney, 2004; Holt 2011).

Although the Jaccard’s and Sørensen indices are popular in the literature, in practice ecologists use more informal methods. In Michigan, MNFI ecologists are left to their professional discretion to decide whether or not a natural area is distinguishable as its own community type. After site visits in 2011, MNFI ecologists used their professional experience to determine that clay bluffs were dissimilar enough from other natural communities to be identified and described as their own community type. Because this determination was made without any objective or quantitative measures, the following chapters will examine different methods to determine similarity between many of Michigan’s natural communities, with a goal of providing a useful approach to differentiating and classifying natural community types.
CHAPTER 3: METHODS

Introduction

A comparison of vascular plants and community characteristics, including the role of natural disturbance, can help define the similarity of the clay bluffs natural community as compared to other Michigan and Midwest U.S. natural communities. Similarity measures can be used to help identify if they are truly a separate natural community or a subset of some other community. Once the defining characteristics and vegetation are identified, the description and distribution of clay bluffs communities, or any other potential natural community, would be better understood. This in turn allows for an assessment of the position of clay bluffs as an explicit natural community entity in relation to existing laws for conservation.

Comparisons were carried out at a variety of scales and levels of detail for 19 Michigan natural communities to examine which methodology provided the most useful results. The natural communities were chosen based on their proximity to the Great Lakes shoreline, alkaline wetland conditions, and identification as a fen community by Michigan Natural Features Inventory (MNFI). After initial work using solely Jaccard's similarity index with vascular plant lists that exhibited significant differences in detail, it became apparent that geographic and morphological context would be necessary to provide logical differentiation among community types. \

Three approaches to community differentiation are therefore compared in this work. The first approach was to assess natural community similarity by comparing vascular plant assemblages from multiple sources. The analysis was completed using both Jaccard's index and a hierarchical clustering assessment to produce dendrograms.
The second approach was use a hierarchical clustering assessment of natural communities according to their defining characteristics such as landscape context, soils, water availability, and natural processes. The third approach was to more closely examine the role natural disturbance plays in each natural community, with a particular focus on the importance of erosion in clay bluffs.

**Biotic Similarity by Vascular Plant Comparison**

Two methods were used to assess biotic similarity of natural communities by vascular plants. The first used Jaccard's index to evaluate similarity with vascular plant lists obtained from MNFI site assessments at both the species and genus levels. Initial assessment was done between sites identified as the same natural community to later compare against assessments between different communities. The second method used hierarchical clustering of communities based on a plant list developed from MNFI natural community abstracts.

**Jaccard's Index**

Vascular plant lists from the best representative natural communities have inventoried by MNFI over many years. In order to better understand the ways in which the chosen comparative methods would analyze individual descriptions of the same community type, a single well-defined community was selected for analysis. The clay bluffs community was purposely not chosen, because it has not yet been accepted as a clearly defined community. Because plant lists from coastal fen sites were the most comprehensive, coastal fens were used as examples to test the lists' values in comparing similarity at the species level between sites identified as the same community type.
Three coastal fen sites, Cheboygan State Park, El Cajon Bay, and Horseshoe Bay, were compared using lists at the species level (see locations in Figure 11).

![Figure 11: Coastal fen sites assessed for similarity](image)

Five community types (clay bluffs, coastal fen, open dune, prairie fen, and southern wet meadow) were chosen to test similarity at the genus level. The community types were chosen to get samples with a variety of landscape context, pH, and plant lists. MNFI collects plant lists when they do natural community assessments. These lists are intended to be rapid assessments of indicator species rather than detailed inventories (Cohen, personal communication, 2013). Plant lists from MNFI natural community documentation visits were compiled for each community type with each community represented by at least three different site lists. The list of genera associated with each
community type was developed by identifying any genus that occurred in multiple site lists. Jaccard’s index was used to evaluate the similarity between the five sample community types.

Hierarchical Clustering Analysis of MNFI Community Abstracts

MNFI maintains abstracts of natural communities on a website, http://mnfi.anr.msu.edu/communities/. Each of these abstracts contains sections providing an overview of the community, its landscape context, soils, natural processes, vegetation, rare plants and animals, similar natural communities, and additional noteworthy information. A list of vascular plants was created from the vegetation sections of 18 MNFI natural community abstracts.

The MFNI community abstract for clay bluffs does not include a description of characteristic vegetation. However, the Wisconsin DNR has vascular plant lists for clay bluffs (see Appendix B: Vegetation Lists from Warnimont Park). The biologist who generated the comprehensive vascular plant list for the Wau-Ke-Na site in Michigan also created a subset list of species found on the bluffs of Wau-Ke-Na (See Appendix A: Wau-Ke-Na Clay Bluff Report). These two sources were combined to form a representative plant list for clay bluffs and added to the list generated from the 16 other natural communities.

The comprehensive list of all the species identified in the abstracts and the bluff inventories was then placed into a table with the 17 natural communities (See Appendix C: Comprehensive Natural Community Species List). Each species was then attributed to
each natural community where it was identified in the abstracts. The table of comprehensive vascular plants was developed to identify which species were associated with which natural communities. The table was entered into SPSS to generate a dendrogram demonstrating which natural communities are most similar based on vegetation.

Some plant species are considered more indicative of certain habitats than others, such as pitcher plant (*Sarracenia purpurea*) for bogs and shrubby cinquefoil (*Potentilla fruticosa*) for fens. Floyd Swink and Gerould Wilhelm developed a rapid assessment tool based on this concept of indicative plants. By assigning values to species according to their affinity to remnant quality natural community, plant inventories could then be used to assess the quality of a site. This Floristic Quality Assessment (FQA) has been widely used for a variety of situations (Swink & Wilhelm, 1994). The FQA of Michigan was used to identify the “coefficient of conservatism” (C-value) for each of the species in the comprehensive list. Natural communities with a full representation of species should have a full suite of species with values ranging from 0 to 10, and ideally have a mean C value of 5 (Swink & Wilhelm, 1994). Since the Floristic Quality Assessment suggests that species with C values of 5 or greater are more indicative of an intact community, similarity analyses were then completed for species with C-values of 5 or greater. This should remove common species from the analysis not necessarily indicative of a certain natural community.

In order to see if certain guilds of vascular plants were more indicative of similarity than others, the master list was divided using the C-value selected plant list into two guilds: graminoids and forbs. A similarity analysis was then completed using SPSS.
to generate a dendrogram demonstrating which natural communities are most similar according to guild.

**Figure 12:** Fringed gentian (*Gentianopsis procera*) is a plant usually found in alkaline wetlands. Here it is pictured at the base of the clay bluffs of Wau-Ke-Na along with variegated horsetail (*Equisetum variegatum*). Photograph by William Martinus.

**Analysis of MNFI Geographical Context Descriptions**

In addition to vascular plant characteristics, MNFI also describes communities by using soils, landscape context, natural processes, and other characteristics. Because MNFI's plant lists for communities are intended for representation rather than complete inventory, and were compiled by different individuals with personal interpretation on what is representative, their value for similarity measures are limited. Comparing the geographical and morphological characteristics of a natural community provide additional perspective on similarity.
A review was completed of the plant lists and main characteristics for the known clay bluff sites as well as seventeen other natural communities as described by MNFI that are either a wetland with acid or alkaline conditions or a community found along the Great Lakes shoreline: alvar, bog, coastal fen, coastal plain marsh, great lakes marsh, interdunal wetlands, lakeplain wet prairie, lakeplain wet-mesic prairie, limestone bedrock lakeshore, limestone cobble shore, northern fen, open dunes, patterned fen, poor fen, prairie fen, southern wet meadow.

MNFI’s Natural Community Abstracts use seven main characteristics to define natural communities: dominant vegetation, characterization as a wetland or not, place in relation to Michigan’s climatic tension zone, basic soil type, pH, landscape context, and natural processes. A table was made to compare each natural community’s defining characteristics. In order to remove numerical bias when a community’s characteristic included multiple types (such as when a community is influenced by several natural processes) and normalize the data assessment, a potential score of 10 was given to each characteristic (Table 6). The 10 points were then divided amongst the differing aspects within a characteristic. For example, ten different types of natural disturbance were identified as important natural processes associated with the natural communities of study. Some communities, such as prairie fens had three types of natural processes so each was assigned a value of 3.3333. Clay bluffs had seven different natural processes associated with it so each was assigned a value of 1.429. Hierarchical clustering as implemented in SPSS 19.0 was used to examine similarities among all characteristics.

Adding weights to characteristics identified as integral to defining a community, such as soil type and water availability, might be justified (Palik et al., 2000).
initial hierarchical clustering was completed, soil and water availability characteristics values were doubled and the hierarchical clustering repeated. The choice to double the values was arbitrary and was an effort to examine how weighting affects results, not an example of identifying true similarity between communities.

Natural Disturbance Regimes

A number of alkaline and shoreline natural communities such as prairie fens and sand dunes have natural disturbances associated with them. Literature was reviewed that looked at the role natural disturbance plays in these systems. Particular focus was paid to literature that examined the role erosion plays in bluff communities. A table was developed that identifies natural communities and their associated natural disturbances, including estimated times between disturbances.

A series of photos were taken over multiple years and seasons, demonstrating the dynamic nature of the clay bluffs. When possible the photos were placed in a series to see if major slump events are evident and if so, what the time interval between events is. A DJI Phantom Vision 2 quadcopter with camera was used to document bluff areas that were difficult to access.
CHAPTER 4: RESULTS

Biotic Similarity by Vascular Plant Comparison

Jaccard's Index

The coastal fen natural community had the most comprehensive species lists of the inventories provided by MNFI. The three study sites combined to produce a list of 159 species. Lists of Jaccard index results of comparing coastal fen sites at the species ranged from 0.342 to 0.426. (Table 1). The Baroni-Urbani and Buser probability table suggests that these sites have a probability of similarity ranging from 0.01 to 0.10 (Baroni-Urbani and Buser, 1976). However it has been noted that low Jaccard's index numbers don't necessarily mean low similarity and consistency in numbers may be more important (Rice and Belland, 1982).

Table 1: Similarity between coastal fens using Jaccard's index at species level

<table>
<thead>
<tr>
<th>SPECIES LEVEL</th>
<th>Jaccard's Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Cheboygan State Park</td>
</tr>
<tr>
<td>Cheboygan State Park</td>
<td>x</td>
</tr>
<tr>
<td>El Cajon Bay</td>
<td>0.389</td>
</tr>
<tr>
<td>Horseshoe Bay</td>
<td>0.426</td>
</tr>
<tr>
<td>n</td>
<td>62</td>
</tr>
</tbody>
</table>

Using Jaccard's index to compare coastal fen sites at the genus level resulted in slightly higher similarity than at the species level. But results still showed relatively low similarity, ranging from .456 to .500 (Table 2). The Baroni-Urbani and Buser probability
Table 2: Similarity between coastal fens using Jaccard’s index at genus level

<table>
<thead>
<tr>
<th>GENUS LEVEL</th>
<th>Jaccard’s Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Cheboygan State Park</td>
</tr>
<tr>
<td>Cheboygan State Park</td>
<td>x</td>
</tr>
<tr>
<td>El Cajon Bay</td>
<td>0.485</td>
</tr>
<tr>
<td>Horseshoe Bay</td>
<td>0.500</td>
</tr>
<tr>
<td>n</td>
<td>49</td>
</tr>
</tbody>
</table>

Species lists of natural communities were combined to generate lists of associated genera for each natural community. Genus lists were compared for similarity between communities. Each community had approximately 50-100 genera associated with it. The range of similarity, 0.155 and 0.422, suggests that each natural community is unlike one another (Table 3). The most similar communities appeared to be prairie fens and southern wet meadows and the most dissimilar were open dunes and prairie fens. As a group the wetland communities were more similar to each other than the upland open dune community. The clay bluffs were most similar to coastal fen and prairie fen, both nutrient-poor alkaline marl-based communities, while the southern wet meadow community is a nutrient-rich muck-based community with occasional alkaline conditions.
Table 3: Similarity between natural communities using Jaccard’s index at genus level

<table>
<thead>
<tr>
<th>GENUS LEVEL</th>
<th>Clay Bluff</th>
<th>Coastal Fen</th>
<th>Open Dune</th>
<th>Prairie Fen</th>
<th>S. Wet Meadow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Bluff</td>
<td>X</td>
<td>0.382</td>
<td>0.224</td>
<td>0.333</td>
<td>0.280</td>
</tr>
<tr>
<td>Coastal Fen</td>
<td>0.382</td>
<td>X</td>
<td>0.223</td>
<td>0.294</td>
<td>0.245</td>
</tr>
<tr>
<td>Open Dune</td>
<td>0.224</td>
<td>0.223</td>
<td>X</td>
<td>0.155</td>
<td>0.186</td>
</tr>
<tr>
<td>Prairie Fen</td>
<td>0.333</td>
<td>0.294</td>
<td>0.155</td>
<td>X</td>
<td>0.422</td>
</tr>
<tr>
<td>Southern Wet Meadow</td>
<td>0.280</td>
<td>0.245</td>
<td>0.186</td>
<td>0.422</td>
<td>X</td>
</tr>
</tbody>
</table>

**Similarity Analysis by Hierarchical Clustering**

A table was created identifying over 300 vascular plants associated with 19 natural communities (see Appendix C). The number of species identified for each community ranged from 11 for lakeplain wet prairie to 90 for clay bluffs (Table 4). The discrepancy in number of species is a result of differences in plant diversity between communities, preferences of the abstract’s author, thoroughness of inventories, and other reasons explained in the Discussion section (see pages 73-76).
Table 4: Associated species totals for natural communities

<table>
<thead>
<tr>
<th>Natural Community</th>
<th># of Associated Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakeplain Wet Prairie</td>
<td>11</td>
</tr>
<tr>
<td>Lakeplain Wet Mesic</td>
<td>12</td>
</tr>
<tr>
<td>Open Dunes</td>
<td>22</td>
</tr>
<tr>
<td>Limestone Bedrock Shore</td>
<td>27</td>
</tr>
<tr>
<td>Limestone Cobble Shore</td>
<td>31</td>
</tr>
<tr>
<td>Great Lakes Marsh</td>
<td>32</td>
</tr>
<tr>
<td>Bog</td>
<td>36</td>
</tr>
<tr>
<td>Coastal Plain Marsh</td>
<td>37</td>
</tr>
<tr>
<td>Alvar</td>
<td>38</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Community</th>
<th># of Associated Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Wet Meadow</td>
<td>42</td>
</tr>
<tr>
<td>Patterned Fen</td>
<td>43</td>
</tr>
<tr>
<td>Coastal Fen</td>
<td>49</td>
</tr>
<tr>
<td>Interdunal Wetland</td>
<td>50</td>
</tr>
<tr>
<td>Poor Fen</td>
<td>51</td>
</tr>
<tr>
<td>Northern Fen</td>
<td>56</td>
</tr>
<tr>
<td>Prairie Fen</td>
<td>67</td>
</tr>
<tr>
<td>Clay Bluff</td>
<td>91</td>
</tr>
</tbody>
</table>

A similarity analysis was completed evaluating all species associated with the 19 natural communities, creating a dendrogram illustrating similarity (Figure 13). The dendrogram illustrates the similarity between natural communities based on shared plant species. The vertical dotted lines were added near the 3 and 8 point values to aid in visualizing groupings of communities that are more and less alike than others. For the purposes of comparisons, groupings to the left of the first vertical line were considered most similar with the potential of being gradations of the same natural community rather than distinct communities unto themselves. Groupings between the first and second vertical lines were considered somewhat similar but likely distinct. Those to the right of the second lines were considered extremely likely to be distinct communities.
Figure 13: Similarity of communities using all species

The dendrogram suggests that the clay bluffs are very dissimilar to all other communities while the lakeplain prairies and limestone shoreline communities are most similar to each other. There appear to be some groupings of somewhat similar communities of bog, poor fen and patterned fen as well as lakeplain prairies, open dunes, and limestone shores. When viewed in context of number of species, there appears to be some association between number of species and similarity/dissimilarity.

Hierarchical Clustering Comparisons with C-Values

A C-value was identified for each of the over 300 species in the master list. After clay bluffs' 90 species, the next longest species list was prairie fen with only 67 species (Table 5). The table below demonstrates the distribution of the number of species according to C-value group. The MNFI abstracts all included more species with C-values
greater than 4 than those below 4. The combined species list that made up the clay bluff list was divided almost evenly between species of C-values above and below 4. With 44 species of C-values less than 4, the clay bluff list had twice as many non-conservative plants as the next nearest community. By selecting species with C-values $> 4$, many common species not necessarily indicative of a particular community were removed (as explained in the Methods section on page 26).

Before selecting out species using C-values, the mean and median number of species (excluding the clay bluffs) for the communities was 37.75 and 37.5 respectively. 44 common species were removed from the combined clay bluff list, bringing its species list of 46 species closer to the new community mean of 27.9 and median of 27.5. While clay bluffs remained the community with the highest total number of species (46) it was within a few species of four other natural communities.
### Table 5: C-value groups

#### Number of Species in Each C-Value Group

<table>
<thead>
<tr>
<th>Location</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>C &gt; 4 Species</th>
<th>C &lt; 4 Species</th>
<th>Total Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alvar</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>25</td>
<td>13</td>
<td>38</td>
</tr>
<tr>
<td>Bog</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>30</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td>Coastal Fen</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>16</td>
<td>38</td>
<td>11</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Coastal Plain Marsh</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>30</td>
<td>7</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Clay Bluffs (Combined MI &amp; WI)</td>
<td>2</td>
<td>8</td>
<td>11</td>
<td>8</td>
<td>15</td>
<td>14</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>4</td>
<td>11</td>
<td>46</td>
<td>44</td>
<td>90</td>
</tr>
<tr>
<td>Great Lakes Marsh</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>Interdunal Wetland</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</table>
Hierarchical Clustering Comparison of Species with C > 4

In the dendrogram comparing communities by species with C>4, lakeplain wet prairie and lakeplain wet-mesic prairie were very similar as was limestone bedrock shore and limestone cobble shore (Figure 14). The clay bluff vascular plant list was recognized as most dissimilar of all communities that were compared. Groups of similarity appeared between some communities. Bog, poor fen, and patterned fen appeared to be grouped along with northern fen as their own category as were the lakeplain prairies, open dunes, and limestone shores. The similarity appeared to be largely the same as the results using the full species list.

![Hierarchical Clustering Comparison of Species with C > 4](image)

Figure 14: Similarity of communities using C>4 species

Hierarchical Clustering Comparison of Species with C > 5

Selecting C > 5 species shifted the groupings of communities significantly, moving the lakeplain prairies closer to Great Lakes marsh and southern wet meadow
while distancing them from the limestone shores (Figure 15). Clay bluffs are no longer the most dissimilar, and begin to show some similarity to the larger group of alkaline shoreline communities.

Figure 15: Similarity of communities using $C>5$ species
Hierarchical Clustering Comparison of Species with C > 6

By narrowing the species list even more to those with C > 6, clay bluffs move farther away from the group of alkaline shoreline communities (Figure 16). The acidic wetlands of bog, northern fen, patterned fen, and poor fen show greater similarity and form their own group while many of the alkaline wetlands are showing greater dissimilarity to each other.

**Figure 16: Similarity of communities using C>6 species**
Hierarchical Comparison of Forbs with \( C > 4 \)

A hierarchical assessment using just the forbs with \( C > 4 \) separates the clay bluffs completely from the other communities. 104 plant species were compared, with each community being represented by 2-26 species. The lakeplain wet prairie had the fewest species represented at 2, and the next fewest was bog at 4 species. The clay bluffs had the highest representation at 26 species and the next highest was interdunal wetland with 19. For the first time the wet and wet-mesic prairies are separated and the wet prairie is more closely aligned with the acidic wetlands (Figure 17).

![Rescaled Distance Cluster Combine](image)

**Figure 17: Similarity of communities using \( C > 4 \) forbs**
Hierarchical Comparison of Graminoids with C > 4

The graminoid comparison leaves most communities as dissimilar to each other with a few exceptions of lakeplain wet mesic prairie similar to open dunes and lakeplain wet prairie as well as the limestone shores being similar to each other (Figure 18). Only prairie fens are more dissimilar to other communities than clay bluffs. 77 plant species were compared, with each community being represented by 3-23 species. The lakeplain wet and wet-mesic prairies each had the fewest species represented at 3 along with limestone cobble shore, and the next fewest was open dune at 4 species. The prairie fen had the highest representation at 23 species and the next highest was northern fen with 18.

**Figure 18: Similarity of communities using C>4 graminoids**
The results of the hierarchical clustering assessment of natural communities by vascular plants suggest that by all means, clay bluffs are dissimilar from other natural communities. The clay bluffs are only one or two clades removed from being completely separate from the communities in all the assessments except for \( C > 5 \) species. In \( C > 5 \) species clay bluffs remain distinctive, not very similar to other natural communities. In contrast, the lakeplain prairies and limestone shorelines show consistent similarity to their respective partners. The acidic wetlands and some of the graminoid dominant communities such as southern wet meadow and Great Lakes marsh show varying similarity depending on the \( C \)-value being assessed.

**Natural Communities Descriptions**

Hierarchical clustering was then used to compare the 29 characteristics within the seven core types of geographic context used to describe the natural communities (Table 6) on following page).
<table>
<thead>
<tr>
<th>Table 6: Natural community characteristic scoring table</th>
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<td>Wave action</td>
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<td>Local water level fluctuations</td>
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<td>Drought</td>
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A dendrogram of results illustrates there are four other community types that are more similar to each other than clay bluffs are to any other community (Figure 19). Lakeplain wet-mesic prairie and lake-plain mesic prairies are shown to be very similar as are limestone bedrock shores and limestone cobble shores. Also more similar are prairie fens to southern wet meadows and coastal fens to Great Lakes marsh community types. Clay bluffs are shown slightly more similar to interdunal wetlands than prairie fens and southern wet meadows to the lakeplain prairies.

Figure 19: Similarity of communities using landscape context and geomorphological characteristics

The next closest community types to clay bluffs were found to be coastal fens and Great Lakes marshes, which in turn showed some similarities to the coastal rock based-communities. The first two clades of the natural communities seem to separate by conditions of acidic peat vs. alkaline other soils, and then by inland graminoid vs. coastal
shrub & herb and rocky shoreline. The exception to this grouping is the inclusion of coastal fen which is a graminoid dominated community. Bogs, poor fens, and patterned fens are all peat based communities typically found in northern Michigan, so the grouping is not unexpected. Open dunes were the only upland community tested by this method, and appeared to be relatively isolated as well.

These differences become more obvious when weights are applied to the characteristics (Figure 20). When the values of soil and water availability are increased as supported by literature (such as Palik et al., 2000), open dunes become obviously the most dissimilar of all communities, and other groups such as the collection of alkaline graminoid wetlands including southern wet meadow, prairie fen, coastal fen, and Great Lakes marsh become closer.

![Rescaled Distance Cluster Combine](image)

**Figure 20: Similarity of communities using weighted characteristics**
MNFI natural community abstracts include a section that lists communities that MNFI ecologists consider similar to the subject community. There is no formal process for identifying similarity, it is based on the knowledge and understanding of the communities by MNFI ecologists (Cohen, personal communication, 2013). The community similarities in the abstracts did not cross referenced exactly, but by including all references to one another, a table was developed showing which communities were considered similar. This table was then used to create a dendrogram illustrating hierarchical clustering of similarity (Figure 21).

![Dendrogram](image)

**Figure 21: Similarity of communities using MNFI abstract descriptions**
Natural Disturbance Regimes and Geographic Distribution

Each natural community abstract identified at least one natural process that creates a disturbance regime that alters the vegetative structure (Table 7). These were identified and aggregated by community and disturbance type.

Table 7: Natural disturbance regimes

<table>
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<th>Community Type</th>
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<th>Wind</th>
<th>Great Lakes water level</th>
<th>Storm surge / seiche</th>
<th>Fire</th>
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The most common forms of natural disturbance for the communities evaluated were fire and wind. Groundwater, Great Lakes water level, and storm surge were very common as well. The least common were erosion and drought which each only had two occurrences.

Photographic Documentation

Photographs were taken at four sites in Michigan between 2008 and 2014: Wau-Ke-Na Bluffs, Casco Township Nature Preserve (formally known as the Stefan Trust property), the bluffs just south of Mizpah Park, and the bluffs of Lakeside (see Figure 11 for locations). A fifth site was investigated at Shoreham Park just south of St. Joseph, but the development and alteration of the landscape was so pervasive that nearly no natural components remained and photo-documentation was not undertaken. Photographs were taken at Warnimont Bluffs in Wisconsin in 2009.

Wau-Ke-Na Bluffs

The Wau-Ke-Na bluffs are relatively lower than the other bluffs studied, rising up only about 30 feet above beach level as opposed to the 80 - 150 foot height of other bluffs (Figure 22). A series of photographs were taken at the base of the bluff over five years to document the vegetative succession of a fresh slump (Figure 23, Figure 24, Figure 25, Figure 26). Distinctive vegetation such as grass of Parnassus (*Parnassia glauca*), fringed gentian (*Gentianopsis prosera*), and variegated horsetail (*Equisetum variegatum*) are common along the base of the bluff (Figure 12, Figure 27) and had colonized the slump by 2013.
Some portions of the Wau-Ke-Na bluff have had different erosion events other than slumping. One portion has remained bare of all vegetation for over five years, perhaps because of a combination of steady water flow and regular scouring of ice (Figure 28, Figure 29). An area showing some signs of slumping and scouring in 2009, turned into a major erosion event the following year (Figure 30, Figure 31). A large tree had lost purchase of the lip of the bluff and fell towards the lake, exposing a large area of bare bluff face (Figure 32). By 2014, horsetail had spread into the vertical exposed area while other plants were restricted to the weeping spot with a small area of slumping (Figure 33).

Additional major erosion events appear likely to occur soon adjacent to the current exposed area as the lip of the bluff appears to be hanging down over the bluff face, perhaps creating more space for the herbaceous community to colonize (Figure 34). The area immediately south of the Wau-Ke-Na bluff seeps is on private property and has been converted into a paved trail, preventing any future establishment of the clay bluff natural community (Figure 35).
Figure 22: The bluffs of Wau-Ke-Na are relatively lower (~30') and more vegetated than others.

Figure 23: Fresh slumping at the base of a bluff at Wau-Ke-Na, April 2009
Figure 24: Four months after slumping, vegetation is established at the base of a bluff at Wau-Ke-Na, August 2009

Figure 25: Five months after slumping at the base of a bluff at Wau-Ke-Na, note deer trail to right of picture, September 2009
Figure 26: Five years after a slump event, the base of bluff is fully vegetated and woody plants are becoming established at Wau-Ke-Na, note deer trail to right of picture, July 2014

Figure 27: Grass of Parnassus (*Parnassia glauca*), Equisetum species, and mosses colonize exposed wet clay with calcium deposits at Wau-Ke-Na, August, 2009
Figure 28: Ice scouring an exposed weeping area along Wau-Ke-Na bluff, December 2009

Figure 29: Exposed weeping area along Wau-Ke-Na bluff, May 2014
Figure 30: Bluff face with some slumping at Wau-Ke-Na, December, 2009

Figure 31: Bluff face exposed at Wau-Ke-Na, July 2014
Figure 32: Exposed bluff face at Wau-Ke-Na, May, 2014

Figure 33: Plants pioneering the bluff face where water is available at Wau-Ke-Na, May, 2014
Figure 34: Additional slumping potential adjacent to open bluff face at Wau-Ke-Na, May, 2014

Figure 35: Paved trail down face of bluff next to Wau-Ke-Na, May 2014
Casco Nature Preserve Bluffs (formally Stefan Trust Property)

The Casco Nature Preserve is located south of the Wau-Ke-Na bluffs where the bluffs are much higher, reaching over 80 feet tall (Figure 36). Before the park was expanded in 2013, people would go off trail and scramble down the bluff on an informal trail which left lasting marks (Figure 37, Figure 38). For the sake of public safety, avoid the actively eroding portion of the bluff, and to protect the higher quality area of the bluff, a stairway was constructed in 2014 (Figure 39, Figure 40). The Casco bluffs have many layers of clay and sand that can be visible from a distance in the form of darkened soils (Figure 41).

Figure 36: Casco Nature Preserve bluffs are over 80’ in height
Figure 37: Eroded trail leading down bluff at Casco Township Nature Preserve, April, 2009

Figure 38: Eroded trail leading down bluff at Casco Township Nature Preserve, May, 2014
Figure 39: Newly constructed stairway at Casco Township Nature Preserve, May, 2014

Figure 40: Wet clay along stairway supports at Casco Township Nature Preserve, May 2014
Mizpah Park Bluffs

The Mizpah Park bluff area is all private property and is largely unstudied. The nearest public access is a little over a mile south of the site at Rocky Gap Park, 1/2 mile north of Benton Harbor. Wooded bluffs line the shore of Lake Michigan from Rocky Gap Park until the Whirlpool World Headquarters property where large bare faced bluffs rise well over 100 feet from the beach (Figure 42, Figure 46). Along the base of the bluff characteristic clay bluff species were common, such as a variety of equisetums, rushes, buffaloberry (*Shepherdia candensis*), and northern white cedar (*Thuja occidentalis*) (Figure 43, Figure 44).
Permission was granted by the Whirlpool Corporation to view the bluffs from above, where significant erosion events were obvious (Figure 45). A return visit with a quadcopter allowed much better documentation of the structure of the bluffs, including a distinctive weep line between layers of clay that appeared to be a layer of more porous rocky material (Figure 46, Figure 47). A layer of softer looking eroding material existing at the lip of the bluff, while below the weep line the bluff becomes much steeper and smoother (Figure 48, Figure 49).

Figure 42: Tall bluffs south of Mizpah Park, July 2014
Figure 43: Equisetum species and other clay bluff indicators growing along base of bluff south of Mizpah Park, July, 2014.

Figure 44: Northern White Cedar (*Thuja occidentalis*) and Buffaloberry (*Shepherdia candensis*) growing along the bluff south of Mizpah Park, July, 2014.
Figure 45: Significant erosion events occur on the bluff face, south of Mizpah Park, May, 2014

Figure 46: Bluff top view from a quadcopter 150' up from the base, south of Mizpah Park, July 2014
Figure 47: Weep line is evident along the bluff face, south of Mizpah Park, July 2014

Figure 48: Bluff face is steepest below the weep line, south of Mizpah Park, July 2014
Lakeside Bluffs

The shoreline in Lakeside was visited because the map of Michigan moraines showed a Lake Border moraine approaching the shoreline (Figure 7) and the digital elevation models showed steep slopes along the lakeshore (Figure 59). The bluffs in this area are highly developed (Figure 50). Though much of the bluffs are dominated by exotic invasive species such as privet (*Ligustrum vulgare*) and black locust (*Robinia pseudoacacia*) (Figure 51), there are significant portions that remain as woodland. There was little evidence of any groundwater seepage along the bluffs. Erosion along the bluffs appeared to be primarily from surface water events, and when it was evident, *Equisetum* species were present (Figure 52). A discussion with a local resident revealed that a portion of the bluff used to have wet clay and was known as “Clay Mountain”, but it is now dry and has large homes on top (Figure 53).
Figure 50: The bluffs of Lakeside are highly developed.

Figure 51: Much of the slopes are dominated by exotic invasive species such as privet.
Figure 52: Erosion is largely from surface water runoff. Equisetum is present in places along the base of the bluff.

Figure 53: The face of "Clay Mountain" was once wet, but is now covered with woody species and has homes built on top.
Warnimont Park was the original reference site that Wau-Ke-Na was compared to when SWMLC and MNFI staff tried to identify the appropriate classification of natural community. Despite the disparity in size (Figure 54) and vegetation above and below (Figure 55), the species lists of the bluff faces were remarkable similar (see Appendix A: Vegetation Lists from Warnimont Park, Appendix B: Wau-Ke-Na Clay Bluff Report).

During the visit in March of 2009, several significant erosion events had recently occurred (Figure 56). Due to the season and the extent of the erosion events, much of the herbaceous community was not evident. However distinctive woody species, such as paper birch (*Betula papyrifera*) and northern white cedar (*Thuja occidentalis*) were very common, especially along seep-fed streams (Figure 57). Weep lines were evident along the freshly eroded bluff faces as the saturated soils were much darker than the rapidly drying soils above. Different than the Mizpah Park bluffs, the different types of soils were not as easily distinguishable (Figure 58).
Figure 54: Warnimont Park bluffs reach 100' in height, March 2009

Figure 55: The shoreline at the base of the bluffs in Wisconsin is more cobble and less sand than in Michigan. Photo taken at Warnimont Park, March 2009
Figure 56: The clay bluffs had recent significant erosion events during the winter of 2008-9, shortly before a visit to Warnimont Bluffs, March 2009

Figure 57: Paper Birch (*Betula papyrifera*) and Northern White Cedar (*Thuja occidentalis*) grow in a ravine along stream formed by a weeping bluff at Warnimont Park, March 2009
Figure 58: Weep lines are evident in open bluff faces at Warnimont Park, March, 2009

Photo documenting visits month to month as well as year to year revealed interesting changes in bluff morphology and plant colonization. The fragile nature of the bluffs makes documentation difficult. The slick clay and steep slopes makes moving on the bluffs challenging and potentially dangerous. Foot traffic also had significant impacts on vegetation. Alternatives will be discussed later in the following chapter.
CHAPTER 5: DISCUSSION

Vascular plant comparisons using Jaccard's index suggested that there was fairly equal similarity among the natural community types examined. The similarity was of moderate strength, so it was difficult to make inferences other than the most general of sort. Comparisons were also challenged by the potential influence of a broad discrepancy in lengths of species lists. Landscape context and geologic structure comparisons between communities demonstrated that the clay bluff natural community showed less similarity to other communities than several other communities did to one another, helping validate its designation as a true distinctive community. Some natural communities were consistently found to be more similar to one another regardless of assessment method when context was considered; others, including clay bluffs, were consistently distinct.

Biotic Similarity by Vascular Plant Comparison

Jaccard's index values comparing species among natural communities were consistently well below 50 percent, which seemed to suggest there was minimal similarity between communities, much less individual sites. But perhaps more important than the seemingly low numbers were the differences in consistency between sites and communities. When species-level indices of a single long recognized community type, coastal fens, were examined the similarity ranged from 0.342 - 0.426 and the genus-level similarity ranged from 0.456 - 0.500. The Jaccard's index values between communities had a greater range, 0.155 - 0.422. This suggests that some of the communities were very different from some others while others were in the same range of value differences that the coastal fens were to one another. However some of the differences appeared possibly
associated with the length of plant lists being compared rather than a truly different species make-up.

The hierarchical dendrogram appeared to further demonstrate this, in that the length of species list seemed to be a greater predictor of community difference than actual species make-up. For example, the MNFI abstract for prairie fen lists similar natural communities as northern fen, southern wet meadow, coastal fen, and poor fen. However the dendrograms suggest that prairie fens are dissimilar from nearly every other community. This was likely due more to the length of species lists than actual differences between natural communities.

The length of species lists varied for a number of reasons. In some cases, certain natural communities are simply more diverse and support more species, such as species-rich prairie fens and species-poor limestone cobble shore. An additional challenge is that species lists within vascular plant inventories are typically for an entire site or preserve, rather than a specific natural community within that site. Most papers do not clearly distinguish which species are associated with which community evaluated at a site. Also, all of the lists examined, including site inventories and abstracts, were developed for a more representative purpose rather than exhaustive species accounts. The representative intent was taken to the extreme in the cases of lakeplain prairies, which were described as so rich and diverse in plant species that it would be too much to include in an abstract, so species were only spoken of in generalities and only about a dozen were identified. The result was that the two most botanically diverse communities were represented as the least diverse.
Despite trying to bypass the bias in results created by number of species documented by using the C values, species list lengths remained an issue at the C > 4 level. Selecting species out by increasing C values appeared to be successful in getting similarity results not overly biased by list length. The shift to C > 5 species seemed to find the right balance between scaling back species lists without reducing them to such small levels that the sample size was insufficient. With C > 6, the species lists were reduced to roughly the most conservative 15-30 species for each community. Such a highly selected group of plants showed some similarity results that were closer to those to the author’s experience and more consistent with results from the later natural community characteristic assessment, but such a small sample size may not be appropriate. When species lists were of similar length, groups of similar communities did start to appear that corroborated MNFI’s lists of similar communities. For example, the collection of bog, northern fen, patterned fen, and poor fen tended to stay together. However, unique pairings began occurring when species lists were narrowed down C>6 and with forbs or graminoids with C > 4. Paring the species lists down to this level is likely not recommended unless the species lists being used for comparison are very robust (with some community representation reduced to 2-4 species).

Separating the plant species into guilds of forbs with allies and graminoids with C > 4 did not appear to make an appreciable difference from the entire list at C>4. It appears that the C values are a greater filter than guilds of species. All the results of the hierarchical similarity assessments of vascular plants suggest that clay bluffs are indeed a stand alone natural community.
It is worth noting that the clay bluff species list used to compare against other natural communities was built from only two examples of clay bluffs, both known for their special plant communities. Additional inventories from a variety of bluffs would make a more representative list, more appropriate for comparisons. The bluffs used also were both weeping bluffs which support many wetland adapted species that would not be found on the faces of dry clay bluffs. A vascular plant comparison between weeping bluffs and dry bluffs would possibly result in the division of clay bluffs into two different natural communities.

**Natural Communities Descriptions**

The value in describing natural communities is that it allows people to better understand the quality and functions of the ecology around them. Knowing the distribution, frequency, and condition of natural communities is critical to conservation efforts. It is readily acknowledged that natural communities have many variations and often grade from one type to another with ambiguous edges. They are also dynamic, changing with shifts in climate, water availability, disturbance events, and other influences. Clay bluffs are no exception and there are many variations affected by a host of influences such as groundwater, aspect, surrounding local geology, local and regional land use, and others.

How the alkaline wetland species came to be established on the clay bluffs is unknown, but there are a number of possibilities. The assemblage of fen plants might have arrived independently over time by chance events blowing seeds from interdunal wetlands and via bird droppings from prairie fens and coastal fens. Or perhaps at some
point during the glacial retreat, coastal fens were much more common along the southern shores of what was to be Lake Michigan. During the era of low lake levels 9,500 years ago, perhaps coastal fens, lakeplain prairies, and alkaline wetland communities now extinct stretched for miles over the exposed shoreline. As the lake level rose and climate warmed, coastal fens were established farther north and the alkaline wetland plants remained in interdunal wetlands and along the clay bluffs along with the cedars and buffaloberry shrubs.

Regardless of how the plant assemblages of the clay bluff were established, they have since become a recognizable natural community, in many cases more distinctive than other communities with more subtle gradations between types. The geographic conditions of clay bluffs distinguish them from most other natural communities. The hierarchical assessment of natural communities created by reviewing geographic characteristics provided results more consistent with MNFI suggested similarity than the vascular plant assessment. The geographic context that these communities exist in, and help define them, are essential to consider when judging similarity. The clay bluffs may have similarity in vegetation to other alkaline wetlands, but their landscape context and natural processes separate them into their own distinct type.

When weights were applied, arbitrarily doubling the values of soil and water, the patterns of similarity for known natural communities better matches what MNFI describes as similar. Interdunal wetlands remained the most similar to clay bluffs, but the pair moved from being most similar to coastal fens and Great Lakes marsh to an assemblage of lakeplain prairies and coastal plain marsh. Regardless of the similarities between groups of wetland communities, the individual pairings tended to remain true
regardless of weighting. Clay bluffs remained well defined as a distinguishable community. The largest difference was in the separation of the bedrock based communities and the upland dune community. This exercise in experimenting with weights demonstrated that using a thoughtful weighted approach to assessment would have value.

The use of vascular plant indicator species are useful in distinguishing natural communities, but only after the geographic context of the site has been considered. It may seem simplistic to say that a handful of conservative plant species does not define a natural community as well as its place in the landscape, especially when the structure and location are as dramatic as clay bluffs, but it is useful to keep this in mind when reviewing other more subtle differences between communities. For example, a comparison between weeping and non-weeping clay bluffs may find them similar in many ways. The lack of wetland plants alone may not be enough to define the seeping bluffs as dissimilar enough to be distinguished as a stand alone community. But the combination of vegetative difference and the primary source of erosion, groundwater rather than storm surge, may be enough to distinguish the seeping clay bluffs as an individual community type.

Groundwater was determined to be an important geomorphologic component to clay bluffs for erosion concerns (Brown et al, 2005; Chase et al, 2007). It is also likely a very important influence on the local microclimate around bluffs. Where clay bluffs actively weep, erosion is increased and the temperature is lowered. These factors influence the flora that can be maintained at a site. The cold ground water supplements the cooling effect of Lake Michigan to create a microclimate where northern species can
survive (Figure 44, Figure 57). Botanical surveys of both the Warnimont Bluffs in Wisconsin and Wau-Ke-Na in Michigan noted species outside of their normal northern range (Martinus, 2007; Epstein et al., 2002).

Natural Disturbance Regimes and Geographic Distribution

Erosion is one of the main defining characteristics of clay bluffs. As a natural process, it was only recognized by MNFI as being a part of two natural communities, clay bluffs and open dunes. Storm surge also affects several shoreline natural communities, which some might consider a form of erosion. However, seeping clay bluffs are unique in that the erosion is caused largely by groundwater. It was discussed in the literature review that absent of groundwater, clay bluff erosion is caused mostly by the adjacent water body, but when groundwater is present, it is the dominant cause. This groundwater based erosion is critical to supporting the unusual alkaline wetland plants.

All the graminoid dominated natural communities have natural disturbances associated with them that reduce woody species cover. MNFI describes the clay bluffs as a mostly shrub and herb dominated natural community. However, the seeping bluffs have a significant grass, sedge, rush and horsetail component. These herbaceous graminoid and graminoid-like plants get shaded out by woody species over time. The bluffs are not likely to burn, especially the actively weeping ones. Beaver are not common along the Lake Michigan shoreline and the influence of storms and waves from the lake only reach the base of the bluff on occasion. Without erosion to remove the
woody species, the herbaceous plants would be displaced. The herbaceous plants that colonize the faces of bluffs require regular erosion events to set back the woody species.

The first group of plants to move in after an erosion event is horsetail species. They seem particularly well adapted to withstand the alternating wet and dry conditions as well as move vegetatively into the openings. Many erosion events leave the bluff face nearly smooth and vertical, leaving little space for seeds to collect and plants to establish themselves. However horsetail will move into an opening from all directions (Figure 32, Figure 33, Figure 43, Figure 47) The other pioneering species such as grasses and wind-dispersed forbs only seem to arrive after horsetail has an established presence or if some mounds remain from the erosion event (Figure 24, Figure 25, Figure 27).

The colonization of a bluff seems to be driven in large part by availability of water and purchase for seeds and roots. In some cases the steady water flow creates such conditions it seems impossible to establish vegetation. This might be to a combination of conditions including scouring by annual freeze thaw cycles. One area along the Wau-Ke-Na bluff remained bare of all vegetation for over five years (Figure 28, Figure 29). Aside from horsetail, shrubs were found to be active colonizers of the bluffs. Their low structure and spreading root systems make them well adapted to spreading across a windy and highly erodible landscape (Figure 26, Figure 44).

The vegetation of the clay bluffs was also notable in that the cool ravines provide a refuge for species more commonly associated north of the tension zone. Warnimont Park is known for being the southernmost location for northern white cedar (*Thuja occidentalis*) and paper birch (*Betula papyrifera*) in Wisconsin (Figure 57). Some of Michigan's southernmost documented locations of American mountain ash (*Sorbus*
americana), and buffaloberry (Shepherdia candensis) are found along the clay bluffs (Figure 44).

The frequent, almost continual in some cases, disturbance from erosion makes the clay bluffs vulnerable to invasion by disturbance-adapted non-native species such as black locust (Robinia pseudoacacia), giant reed (Phragmites australis), Canada thistle (Cirsium arvense), and others. During a visit with a landowner along the bluffs north of South Haven, it was explained that a local landscape management company had the strategy of reducing bluff erosion by cutting black locust repeatedly to encourage root sprouts and suckering. These kind of land management decisions come from people not understanding or appreciating clay bluffs as natural communities. Instead of recognizing the regular erosion events as a natural process, it is considered a nuisance at best and a liability to be stopped at all costs at worst.

Public access to the beach down the steep slopes of clay bluffs are a challenge to people and to the bluffs themselves as all sorts of methods have been used to move people up and down the bluffs. Foot traffic from deer as well as people left long lasting marks and was visible for over five years (Figure 25, Figure 26, Figure 37, Figure 38). Most common were long flights of stairs (Figure 39), but cable cars, paved trails (Figure 24), and complete excavation of bluff faces were observed as well (Figure 62). The longevity of stairs and trails was called into question by Chase and others (Chase et al., 2001) as the groundwater continues to erode past the foundations of the structures. This was evident at the stair system at Casco Township Park only weeks after its installation (Figure 40).
The public use and development of the bluffs in Shoreham Park and Lakeside may be what has eliminated the groundwater component of the bluffs. Exposed portions of clay bluff exist in the Shoreham Park area south of St. Joseph, Michigan, but the area is so altered by development and dumping that the bluffs bare no resemblance to a natural community. The Lakeside is very built up, but more natural vegetation remains on the slopes. Local residents of Lakeside spoke of a time of high erosion events in the 1980s (Lakeside resident, personal communication, 2014), which was a time of high Lake Michigan and ground water levels (Chase et al., 2001). They also spoke of during that time when the “children would come back from Clay Mountain all covered in wet clay” (Lakeside resident, personal communication, 2014). The author noted extensive amounts of relatively new development all along the top of the bluffs in both regions that included storm drain systems and yard drains that would prevent surface water infiltration into groundwater.

The Lakeside region was investigated because examination of maps of moraines revealed weeping clay bluffs occurred where moraines touched the Lake Michigan shoreline (Figure 7). Digital elevation model maps suggested the local Lake Border moraine in Lakeside may reach the lakeshore (Figure 59). While no seeping bluffs were found, investigations did not eliminate the potential that it may have at one time. The maps of moraines may prove to be an important filter in identifying potential seeping bluffs along the Lake Michigan coastline. Of particular interest would be locations with limited development where Lake Border moraines touch the shoreline (Figure 60). Similar to how the Kalamazoo and Valparaiso moraines are critical groundwater recharge
sources for fens (Spieles et al., 1999; Kost et al., 2007), Lake Border moraines may be the groundwater source for seeping bluffs.

Figure 59: Moraines of southwestern Michigan and clay bluff locations

In the Lower Peninsula of Michigan, there appears to several potential locations for weeping bluffs, particularly in the north northwest counties of Antrim, Benzie, Emmet, Grand Traverse, Leelanau, Manistee, Mason, and Oceana (Figure 60). A couple locations seem possible along the north shore of Lake Michigan in Mackinaw and Menominee counties. Greenberg describes three locations of seeping clay bluffs in the Chicago-Milwaukee metro area: Rosewood Park along with Fort Sheridan in Lake County, Illinois and Cliffside Park in Racine County, Wisconsin (Greenburg, 2002). At least three locations north of Warnimont Bluffs in Milwaukee seem plausible in
Manitowoc, Ozaukee, and Sheboygan counties (Figure 60). Seeping clay bluffs with associated alkaline wetland vegetation may also be possible in several locations along the southern shore of Lake Superior (Figure 7).

Figure 60: Morainic systems of Michigan. Map from Farrand, 1988. Markings and legend added by author.
Conservation Protection and Opportunities

If clay bluffs are to be preserved as a valued natural community in Michigan, the public will need to be educated about what they are and how they function. People are raised believing erosion is bad, just as Smokey Bear taught generations that wildfires were bad. It is counterintuitive to people that erosion can be a positive and natural process. There is little in the way of protections for clay bluff communities, as they are not well identified or recognized as in need of protection.

The two conservation laws for protecting the Lake Michigan shoreline in Michigan are the Critical Dunes Act (CDA) and the High Risk Erosion Area (HREA) designation. As the name suggests, the CDA is focused on protecting the dunes along the Great Lakes shoreline. The HREA includes both the designated critical dune areas as well as portions of the Great Lakes shoreline where the shoreline has been documented to have eroded rapidly over 15 years. An area designated as HREA is subject to increased setbacks for development. Of the 80 miles of shoreline in the three counties of southwest Michigan (Allegan, Van Buren, and Berrien), approximately 62 miles is designated as HREA (Figure 61).
Using a combination of topographic maps, moraine maps, on-line aerial images from www.bing.com and www.google.com, and ground-truthing, four regions together totaling approximately 20 miles of potential clay bluff habitat were identified. The
majority of these are forested bluffs without the characteristic herbaceous plant community on weeping bluff faces. Nearly all 20 miles of clay bluffs fall within an HREA (Figure 61). However, HREA designation does not prevent destruction of clay bluffs as has been witnessed along the Lake Michigan shoreline. With little in the way of legal protections for these bluffs, they are vulnerable to loss through indirect destruction by interruption of groundwater flow as well as direct destruction through development (Figure 62).

The importance of the groundwater causing the erosion of the bluffs cannot be emphasized enough as an ecological driver of these natural communities. As discussed in the literature review back on pages 18-20, research on clay bluffs from around the world has shown that when groundwater is a component of clay bluffs, other natural processes
become secondary. Revegetation of the slopes depends greatly on water availability as well as the angle and texture of the slope. The species of plants surrounding the erosion events will also influence which species get established, particularly if non-native invasive species are present, as they are likely to establish dominance and displace native species.

Conservation plans for the region have historically not recognized the clay bluffs as conservation priorities. Relatively recent invasive species management efforts to map and control species for early detection and rapid response identified kudzu (*Pueraria lobata*) and phragmites (*Phragmites australis*) on clay bluffs north of South Haven, Michigan. The presence of kudzu in an area long studied for erosion (Chase et al 2001) and where other exotic species have been planted such as phragmites and elephant ear (*Colocasia* species) (author site visit, 2009), highlights the lack of understanding and appreciation of clay bluffs in that people are willing to plant anything on the bluffs in an effort to stop erosion.

An effort to identify the most important sites in Michigan for biodiversity conservation was organized by the Michigan Department of Natural Resources and the southern portion of the Lower Peninsula was completed in 2011-2012. A team of conservation and resource professional developed a map of sites known to support good representations of natural communities, referred to as "biodiversity stewardship areas". This map includes the bluffs of Wau-Ke-Na and Casco Township Nature Preserve as they were the only documented clay bluffs in the region at the time the map was created (Figure 61). There have been other broad conservation strategies to protect biodiversity of Lake Michigan, such as the collaboration of MNFI and The Nature Conservancy to
write a technical report on strategies to conserve the biodiversity of Lake Michigan in 2012. This plan identifies areas within 2 km of Lake Michigan as important to keep in natural land cover (Pearsall et. al, 2012).

A site visit to the shoreline south of Mizpah Park revealed a long stretch of clay bluffs. Most of it was wooded and there was little evidence of weeping bluffs. However a significant stretch of bluff, across the street from Whirlpool World Headquarters, had an impressive display of clay bluffs. More clay bluffs were noted further north by the biologist who first identified the clay bluffs at Wau-Ke-Na while he was doing an invasive species inventory.

There are many opportunities for further study of these bluffs. Clay bluff research has largely focused on rates of erosion and the potential economic impact. As development continues along the bluffs, there is increasing importance to understand how these natural communities function at both geomorphological and vegetative levels. While groundwater is a known causal agent for erosion, the extent of the local groundwater sheds and their inputs are unknown. Studies to understand bluff erosion with the goal of prevention do not take into consideration the potential repercussions of success. Diverting groundwater to prevent erosion shifts the vegetation, and to what cost to local biodiversity?

There is currently little understanding of the role different plant species play in stabilizing the bluffs, creating areas for other species to get established, rate and means of plant colonization, and many other important factors in maintaining a natural community. The fauna associated with Lake Michigan's clay bluffs has also not been studied.
Observations of frogs, birds, and invertebrates suggest that the wetland component of these bluffs offer valuable water resources for a variety of wildlife.

Aside from zoning and setback ordinances, there are little to no protections for clay bluffs in Michigan. The extensive development along the lakeshore has left precious little left of clay bluffs in a natural state. In Wisconsin, where only a handful of examples are left, the State has designated the highest quality remnants as State Natural Areas, providing them additional levels of conservation protection. The clay bluffs of Michigan would seem to be worthy of similar protections.
CHAPTER 6: CONCLUSION

The clay bluffs of Michigan deserve their recognition as a distinct type of natural community. As a natural community they support their own suite of plant species in a landscape context that includes natural processes specialized to their location and geologic structure. The weeping nature of many of Michigan’s bluffs creates even more specialized conditions with groundwater-caused erosion as the key natural disturbance that dictates the physical structure of the community. Further study may find that seeping clay bluffs differ as much from dry clay bluffs as lakeplain wet prairies differ from lakeplain wet-mesic prairies or dry sand prairies from dry-mesic sand prairies.

The distribution of clay bluffs along the Lake Michigan shoreline in Michigan is not well documented. An increased awareness of the public of the rarity and biological value of these communities would likely bring forth further identification of sites by interested citizens. A systematic approach of moraine and topographic map assessment along with remote sensing and ground truthing could identify their distribution within a season. Of particular interest may be identifying the seeping clay bluffs, as they support the unusual alkaline wetland communities and appear to be refuges for disjunct plant species typically found farther north. With predicted changes in climate for the region, these cool and isolated locations may provide important refuges for plant species near the southern limit of their range.

With the unusual distribution of plant species, there is also the potential for unusual faunal distributions associated with the clay bluffs. There is the potential for some species of birds such as blackburnian warbler, pine siskin, and golden-crowned kinglet, to extend their range farther south than usual, taking advantage of vegetation
such as stands of northern white cedar (*Thuja occidentalis*) that are locally abundant along the bluffs. Due to their limited size, non-migratory fauna would likely be restricted to invertebrates. Since clay bluffs are most similar to interdunal wetlands and coastal fens, rare snails, moths, dragonflies associated with those communities might be also found in clay bluff communities. The weeping component of many clay bluffs create isolated wetland pockets that might be home to unusual assortments of faunal species.

Since groundwater-caused erosion is the most important natural process of these natural communities, clay bluff conservation will require a better understanding of local groundwater movement. Much still remains to be learned about the distributions and functions of clay bluff communities. This study only modestly observed the bluffs over five seasons. A more robust longer term study could reveal much more about the rates of re-vegetation of slopes. Questions remain about which plant species move into eroded areas most quickly, how do different plant species affect colonization of others species, and how do the different plant species affect erosion rates. There are also questions about the rate of the re-vegetation of different types of erosion events: minor slumps, large slumps, catastrophic slides. This study did not attempt to measure any aspects of the local groundwater shed, which would be critical to understanding the current and potential influences to the seeping component that helps define these bluffs.

Recognizing them as a true natural community type is a good first step towards their conservation. Perhaps someday there will be a Critical Bluff Act that can offer them similar protections as their more famous dune neighbors.
BIBLIOGRAPHY


Sørensen, T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. Kongelige Danske Videnskabernes Selskab. 5 (4), 1-34.


Appendix A: Vegetation Lists from Warnimont Park

### Preliminary Vegetation Survey – Warnimont Park Fen—North

- *Agrostis alba*—Redtop
- *Andropogon gerardi*—Big bluestem
- *Anemone virginiana*—Windflower
- *Aster firmus*—Swamp aster
- *Aster lateriflorus*—Calico aster
- *Aster novae-angliae*—New England aster
- *Aster umbellatus*—Flattop aster
- *Astragalus canadensis*—Canada milk vetch
- *Bromus ciliatus*—Ciliated brome grass
- *Bromus kalmii*—Prairie brome
- *Carex hystericina*—Bottlebrush sedge
- *Cirsium muticum*—Swamp thistle
- *Cornus stolonifera*—Red-osier dogwood
- *Desmodium canadense*—Canada tick-trefoil
- *Equisetum variegatum*—Small scouring-rush
- *Eriophorum angustifolium*—Narrow-leaved cotton-grass
- *Eriophorum viridi-carinatum*—Tall cotton-grass
- *Eupatorium maculatum*—Joe-Pye weed
- *Fragaria virginiana*—Strawberry
- *Gentiana procera*—Lesser fringed gentian
- *Lobelia kalmii*—Kalm’s lobelia
- *Lycopus americanus*—Cutleaf bugleweed
- *Monarda fistulosa*—Bergamot
- *Muhlenbergia glomerata*—Fen muhly grass
- *Muhlenbergia Mexicana*—Leafy satin grass
- *Panicum flexile*—Wiry panic grass
- *Panicum oligosanthes*—Few-flowered panic grass
- *Parnassia glauca*—Grass-of-Parnassus
- *Pedicularis lanceolata*—Swamp lousewort
- *Platanthera hyperborea*—Northern bog orchid
- *Poa compressa*—Canada bluegrass
- *Prunella vulgaris*—Selfheal
- *Rhamnus frangula*—Glossy buckthorn
- *Rhynchospora alba*—White beak-rush
- *Rudbeckia hirta*—Black-eyed Susan
- *Salix sp*—Willow
- *Scirpus atrovirens*—Green bulrush
- *Shepherdia canadensis*—Buffaloberry
- *Solidago graminifolia*—Grassleaf goldenrod
- *Solidago ohiosensis*—Ohio goldenrod
- *Sorghastrum nutans*—Indian grass
- *Spiranthes cernua*—Nodding ladies’-tresses orchid
- *Thuja occidentalis*—White cedar
- *Tofieldia glutinosa*—False asphodel
- *Triglochin palustre*—Small bog arrow-grass
- *Trisetum melicoides*—Melic grass
- *Typha angustifolia*—Cattail
- *Typha latifolia*—Cattail
Zizia aurea Golden Alexanders

*Non-native Species


**Preliminary Vegetation Survey – Warnimont Park Fen—South**

Aster laevis Smooth blue aster
Aster lateriflorus Calico aster
Aster novae-angliae New England aster
Aster puniceus Red-stemmed aster
Betula papyrifera Paper birch
Bromus ciliatus Ciliated brome grass
Carex aurea Golden sedge
Carex eburnea Ivory sedge
Carex hystericina Bottlebrush sedge
Carex sterilis Sterile sedge
Cirsium muticum Swamp thistle
Coreopsis palmate Coreopsis
Cornus stolonifera Red-osier dogwood
Desmodium canadense Tick-trefoil
Elaeagnus angustifolia Autumn-olive*
Eleocharis erythropoda Red-root spike-rush
Elymus canadensis Canada wild rye
Equisetum arvense Field horsetail
Equisetum hyemale Scouring-rush
Equisetum variegatum Variegated scouring-rush
Eriophorum angustifolium Narrow-leaved cotton grass
Fragaria virginiana Strawberry
Gentiana procera Lesser fringed gentian
Gentianella quinquefolia Stiff gentian
Glyceria striata Fowl manna grass
Iris virginica Iris
Juncus brachycephalus Short-headed rush
Juncus torreyi Torrey's rush
Juniperus communis Common juniper
Larix laricina Tamarack
Lobelia kalmii Kalm's lobelia
Lythrum alatum Winged loosestrife
Lythrum salicaria Purple loosestrife
Monarda fistulosa Bergamot
Muhlenbergia glomerata Fen muhly grass
Muhlenbergia Mexicana Leafy satin grass
Parnassia glauca Grass-of-Parnassus
Pedicularis canadensis Wood betony
Pedicularis lanceolata Swamp loosestrife
Platanthera hyperborea Northern bog orchid
Populus grandidentata Bigtooth aspen
Populus tremuloides Quaking aspen
Prenanthes alba White lettuce
Prunella vulgaris  Selfheal  
Ratibida pinnata  Gray-headed coneflower  
Rhamnus frangula  Glossy buckthorn*  
Rhynchospora capillacea  Hair beak-rush  
Rosa carolina  Prairie rose  
Rudbeckia hirta  Black-eyed Susan  
Salix sp  Willow  
Scirpus atrovirens  Green bulrush  
Shepherdia canadensis  Buffaloberry  
Smilacina stellata  Starry false Solomon's-seal  
Solidago graminifolia  Grassleaf goldenrod  
Solidago nemoralis  Gray goldenrod  
Solidago ohioensis  Ohio goldenrod  
Solidago riddellii  Riddell's goldenrod  
Solidago uliginosa  Bog goldenrod  
Spiranthes cernua  Nodding ladies'-tresses orchid  
Spiranthes magnicamporum  Great Plains Ladies'-tresses  
Thuja occidentalis  White cedar  
Tofieldia glutinosa  False asphodel  
Triglochin palustris  Slender bog arrow-grass  
Typha angustifolia  Narrow-leaved cattail  
Typha latifolia  Cattail  
Zizia aurea  Golden Alexanders

*Non-native Species

The Beach Slope Community of
Southwest Michigan Land Conservancy’s
Wau-Ke-Na Preserve

Text and photos by William Martinus

The beach slope community is composed of an interesting combination of micro-communities resulting from past erosion during periods of high water. Some small sections of existing bank appear to have withstood the most recent erosion cycle of the 1980s and that of the early 1950s, as evidenced by the presence of mature trees which extends the Mesic Forest community down the steep slope. The consistently level high bluff is approximately 30 feet above the lower beach base, and contains some portions that are extremely steep to nearly vertical, where recent erosion has exposed about 20 feet of boulder-studded, hardened clays overtopped by ten feet of sandy cross-bedded gravel.

Northern sections of the bank have been successfully stabilized by plantings of crown-vetch* (*Coronilla varia), marram grass, and Scotch pine. In areas where the Mesic Forest grows on the bank, a tree rarely occurring this far south in Michigan is showy mountain-ash (*Sorbus decora), one of two species native to Michigan (this may be the southernmost presently existing station). Another tree species present here, abundant in the distant north but very sparingly surviving this far south, is northern white cedar (*Thuja occidentalis). A couple reasons explain why both tree species are found far from their usual habitat: one is the close proximity to the cooling influence of Lake Michigan, and another is that where the clay slope is exposed, there results a local moderation of temperature due to numerous cool springs that weep over the semi-impervious clay. This micro-climate has produced an interesting, well-established micro-habitat over the years, even though partially disturbed.
by natural forces, it is perhaps many hundreds of years old. On the slumped water-soaked clay soil, plants associated with the calcareous fens and broad shorelines that are found along northern Lakes Michigan and Huron are species that also occur here: Kalm's St. John's-wort (Hypericum kalmianum), buffalo-berry (Shepherdia canadensis), grass-of-Parnassus (Parnassia glauca), smaller fringed gentian (Gentianopsis procera), fringed gentian (Gentianopsis crinita), and golden-fruited sedge (Carex aurea). Additional noteworthy species include variegated scouring rush (Equisetum variegatum), Torrey's rush (Juncus torreyi), great blue lobelia (Lobelia siphilitica), bog goldenrod (Solidago uliginosa), and Gillman's goldenrod (Solidago simplex).

Several springs form small temporary pools, eventually overflowing with ephemeral streamlets, which disappear into the sand. Grasses, sedges, rushes, flowers, and shrubs abound; a sample short list includes Canada wild-rye (Elymus canadensis), dark-green bulrush (Scirpus atrovirens), short-headed rush (Juncus brachycephalus), silverweed (Potentilla anserina), and blueleaf willow (Salix myricoides).

Vascular Plants of Wau-ke-na: North Tract Beach Slope

*Non-native Species

**Equisetaceae, Horsetail Family**
Equisetum variegatum Schleicher, Variegated Scouring Rush 8; locally abundant on beach slope

**Cupressaceae, Cypress Family**
Thuja occidentalis L., Northern White Cedar 4; rare sapling on beach slope

**Typhaceae, Cat-tail Family**
Typha angustifolia L., Narrow-leaved Cat-tail* 0; uncommon on beach
Typha latifolia L., Broad-leaved Cat-tail 1; local on beach

**Poaceae, Grass Family**
Ammophila breviligulata Fern., Marram Grass 10; dominant on beach
Elymus canadensis L., Canada Wild-rye 7; uncommon on beach slope
Panicum virgatum L., Switch Grass 4; local on beach
Phragmites australis (Cav.) Steudel, Common Reed 0; rare on beach by spring

**Cyperaceae, Sedge Family**
Carex aurea Nutt., Golden-fruited Sedge 3; locally abundant on beach slope
Scirpus atrovirens Willd., Dark-green Bulrush 3; uncommon in open damp areas on beach near spring

**Juncaceae, Rush Family**
Juncus brachycephalus (Engelm.) Buch., Short-headed Rush 7; common on beach near spring
Juncus canadensis La Harpe, Canadian Rush 6; uncommon on beach near spring
Juncus torreyi Cov., Torrey's Rush 4; uncommon on beach near spring

**Liliaceae, Lily Family**
Smilacina stellata (L.) Desf., Starry False Solomon-seal 5; common on beach slope

**Salicaceae, Willow Family**
Salix discolor Muhl., Pussy Willow 1; uncommon shrub on beach slope
Salix exigua Nutt., Sandbar Willow 1; uncommon clonal shrub on beach near springs
Salix myricoides Muhl., Blueleaf Willow 9; local shrub on beach near springs
Salix petiolaris J. E. Smith, Slender Willow 1; rare shrub on beach near springs

**Brassicaceae, Mustard Family**
Cardamine pensylvanica Willd., Pennsylvania Bittercress 1; uncommon in beach spring pools

**Saxifragaceae, Saxifrage Family**
Parnassia glauca Raf., Grass-of-Parnassus 8; locally abundant on clay beach slope

**Rosaceae, Rose Family**
Sorbus decora (Sarg.) Scheider, Showy Mountain-ash 4; rare small tree on beach slope to 3” dbh

**Aceraceae, Maple Family**
Acer saccharum Marsh., Sugar Maple 5; local dominant canopy tree in Mesic Forest 46” dbh

**Balsaminaceae, Touch-me-not Family**
Impatiens capensis Meerb., Spotted Touch-me-not 2; local in damp Mesic Forest and beach springs

**Guttiferae, St. John’s-wort Family**
Hypericum kalmianum L., Kalm's St. John's-wort 10; uncommon shrub on beach slope

**Elaeagnaceae, Oleaster Family**
Shepherdia canadensis (L.) Nutt., Buffalo-berry 7; rare shrub on beach slope

**Cornaceae, Dogwood Family**
Cornus stolonifera Michaux, Red-osier Dogwood 2; uncommon shrub on beach

**Gentianaceae, Gentian Family**
Gentianopsis crinita (Froel.) Ma, Fringed Gentian 8; locally common on clay beach slope
Gentianopsis procera (Holm) Ma, Smaller Fringed Gentian 8; rare on clay beach slope

**Campanulaceae, Harebell Family**
Lobelia siphilitica L., Great Blue Lobelia 4; common on clay beach slope

**Asteraceae, Aster Family**
Eupatorium perfoliatum L., Boneset 4; locally common in damp Mesic Forest, beach, and fields
Euthamia graminifolia (L.) Nutt., Common Flat-topped Goldenrod 3; uncommon on beach and in fields

Solidago gigantea Aiton, Late Goldenrod 3; uncommon on beach

Solidago juncea Aiton, Early Goldenrod 3; uncommon on beach slope

Solidago simplex Kunth, Gillman’s Goldenrod 10; uncommon on beach and beach slope

Solidago uliginosa Nutt., Bog Goldenrod 4; rare on beach near springs
Appendix C: Comprehensive Natural Community Species List

BRYOPHYTES
SPHAGNACEAE, Peat Moss Family
Sphagnum spp.

PTERIDOPHYTES
LYCOPODIACEAE, Club-moss Family
Lycopodiella inundata (L.) Holub, Inundated Clubmoss

EQUISETACEAE, Horsetail Family
Equisetum arvense L., Field Horsetail
Equisetum fluviatile L., Water Horsetail
Equisetum hyemale L., Common Scouring Rush
Equisetum laevigatum A. Braun, Smooth Horsetail
Equisetum variegatum Schleicher, Variegated Scouring Rush

DRYOPTERIDACEAE, Wood Fern Family
Onoclea sensibilis L., Sensitive Fern

OSMUNDACEAE, Royal Fern Family
Osmunda regalis L., Royal Fern

THELYPTERIDACEAE, Marsh Fern Family
Thelypteris palustris Schott, Marsh Shield Fern

GYMNOSPERMS
PINACEAE, Pine Family
Larix laricina (Du Roi) K. Koch, Tamarack
Picea glauca (Moench) Voss, White Spruce
Picea mariana (Mill.) BSP., Black Spruce
Pinus banksiana Lamb., Jack Pine
Pinus strobus L., White Pine

CUPRESSACEAE, Cypress Family
Juniperus communis L., Common Juniper
Juniperus horizontalis Moench, Trailling juniper
Thuja occidentalis L., Northern White Cedar

MONOCOTS
TYPHACEAE, Cat-tail Family
Typha latifolia L., Broad-leaved Cat-tail

POTAMOGETONACEAE, Pondweed Family
Potamogeton natans L., Common Pondweed

NAJADACEAE, Naiad Family
Najas flexilis (Willd.) Rostk. & Schmidt, Nodding Water-nymph

ALISMATACEAE, Water-plantain Family
Sagittaria latifolia Willd., Common Arrowhead

HYDROCHARITACEAE, Tape-Grass Family
Elodea canadensis Michx., Canadian waterweed
Vallisneria americana Michx., Eel Grass
POACEAE, Grass Family

Agropyron trachycaulum (Link), Wheatgrass
Agrostis hyemalis (Walter) BSP., Ticklegrass
Anmmophila breviligulata Fern., Marram Grass
Andropogon scoparius Michaux, Little Bluestem
Aristida necopina Shinners, Slimspike Threeawn
Bromus ciliatus L., Fringed Brome
Bromus kalmii Gray, Arctic Brome
Calamagrostis canadensis (Michaux) Beauv., Blue-joint Grass
Calamovilfa longifolia (Hooker) Scribner, Prairie Sandreed
Danthonia spicata (L.) R. & S., Common Wild Oat-grass
Deschampsia cespitosa (L.) P. Beauv., Tufted Hairgrass
Deschampsia flexuosa (L.) Trin., Wavy Hairgrass
Elymus canadensis L., Canada Wild-rye
Glyceria striata (Lam.) Hitchc., Fowl Manna Grass
Muhlenbergia glomerata (Willd.) Trin., Marsh Wild Timothy
Muhlenbergia mexicana (L.) Trin., Leafy Satin Grass
Muhlenbergia richardsonis (Trin.) Rydb., Mat Muhly
Panicum flexile (Gattinger) Scribn., Wiry Panicgrass
Panicum lindheimeri Nash, Slender-leaved Panicgrass
Panicum oligosanthes Schultes, Few-flowered Panicgrass
Panicum spretum Schult., Sand Panicgrass
Panicum virgatum L., Switch Grass
Poa palustris L., Fowl Meadow Grass
Sorghastrum nutans (L.) Nash, Indian Grass
Spartina pectinata
Sporobolus heterolepis A. Gray, Prairie Dropseed
Trietum melicoides (Michx.) Vasey ex Scribn., Purple False Oat

CYPERACEAE, Sedge Family

Bulbostylis capillaris (L.) Clarke, Densetuft Hairsedge
Carex aquatilis Wahl., Water Sedge
Carex aurea Nutt., Golden-fruited Sedge
Carex bebbii (Bailey) Fern., Bebb's Sedge
Carex buxbaumii (Wahl.), Buxbaum's Sedge
Carex capillaris L., Hair-like Sedge
Carex chondorrhiza L. f., Creeping Sedge
Carex comosa Nutt., Longhair Sedge
Carex crawei Dewey, Crawe's Sedge
Carex diandra Schrank, Lesser Paniced Sedge
Carex eburnea Boott, Bristle-leaved Sedge
Carex echinata Murray, Star Sedge
Carex exilis Dewey, Coastal Sedge
Carex flava L., Yellow Sedge
Carex garberi Fernald, Elk Sedge
Carex hysterica Wild., Porcupine Sedge
Carex lacustris Wild., Lake-bank Sedge
Carex lasiocarpa Ehrl., Woollyfruit Sedge
Carex leptalea Wahlenb., Bristlystalked Sedge
Carex limosa L., Mud Sedge
Carex livida (Wahlenb.) Willd., Livid Sedge
Carex oligosperma Michx., Fewseed Sedge
Carex pauciflora Lightf., Fewflower Sedge
Carex pellita Muhl. ex Willd., Woolly Sedge
Carex praera Dewey ex Alph. Wood, Prairie Sedge
Carex richardsonii R. Br., Richardson's Sedge
Carex rostrata Stokes, Beaked Sedge
Carex sartwellii Dewey, Sartwell's Sedge
Carex scirpoidea Michx., Northern Singlespike Sedge
Carex sterilis Willd., Dioecious Sedge
Carex stipata Willd., Awl-fruited Sedge
Carex stricta Lam., Tussock Sedge
Carex viridula Michx., Little Green Sedge
Carex vulpinoidea Michaux, Fox Sedge
Cladium mariscoides (Muhl.) Torr., Smooth Sawgrass
Cyperus rivularis Torr., Slender Flatsedge
Dulichium arundinaceum (L.) Britton, Three-way Sedge
Eleocharis compressa Sull., Flatstem Spikerush
Eleocharis elliptica Kunth, Elliptic Spikerush
Eleocharis erythropoda Steudel, Creeping Spike-rush
Eleocharis palustris (L.) Roem. & Schult., Common Spikerush
Eleocharis quinqueflora (Hartmann) O. Schwarz, Fewflower Spikerush
Eleocharis robbinsii Oakes, Robbins' Spikerush
Eleocharis rostellata (Torr.) Torr., Beaked Spikerush
Eriophorum angustifolium Honck., Narrow-leaved Cotton Grass
Eriophorum spissum Fern., Dense Cotton Grass
Eriophorum viridi-carinatum (Engelm.) Fern., Tall Cotton Grass
Fimbristylis autumnalis (L.) Roem. & Schult., Autumn Sedge
Hemicarpha micrantha (Vahl) Pax, Dwarf Bulrush
Rhynchospora alba L. Vahl, White Beak Rush
Rhynchospora capillacea Torr., Hair Beak Rush
Rhynchospora capitellata (Michx.) Vahl, Brown Beak Rush
Rhynchospora macrostachya A. Gray, Horned Beak Rush
Schoenoplectus acutus (Muhl. ex Bigelow) Á. Löve & D. Löve, Hardstem Bulrush
Schoenoplectus pungens (Vahl) Palla, Three-square
Scirpus atrovirens Willd., Dark-green Bulrush
Scirpus smithii A. Gray, Smith's Tufted Bulrush
Scleria triglomerata Michx., Tall Nut Rush
Trichophorum cespitosum (L.) Hartm., Tufted Bulrush

XYRIDACEAE, Yellow-eyed Grass Family
Xyris torta Sm., Yellow-eyed Grass

ERIOCAULACEAE, Pipewort Family
Eriocaulon septangulare With., Pipewort

JUNCACEAE, Rush Family
Juncus balticus Willd., Baltic Rush
Juncus biflorus Ell., Two-flowered Rush
**LILIACEAE, Lily Family**
- *Aletris farinosa* L., Colic Root
- *Smilacina stellata* (L.) Desf., Starry False Solomon-seal
- *Smilacina trifolia* (L.) Desf., False Mayflower
- *Tofieldia glutinosa* (Michx.) Pers., False Asphodel
- *Zigadenus elegans* Pursh ssp. glaucus (Nutt.) Hultén, White Camas

**IRIDACEAE, Iris Family**
- *Iris versicolor* L. Harlequin Blue Flag
- *Iris virginica* L. Southern Blue Flag

**ORCHIDACEAE, Orchid Family**
- *Arethusa bulbosa* L., Dragon's Mouth
- *Cypripedium calceolus* var. *Parviflorum* Salisb., Yellow Lady-slipper
- *Cypripedium candidum* Willd., White Lady-slipper
- *Platanthera hyperborea* (L.) Lindl., Northern Green Orchid
- *Pogonia ophioglossoides* (L.) Ker Gawl., Snake-mouth Orchid
- *Spiranthes cernua* (L.) L. C. M. Rich., Nodding Ladies'-tresses
- *Spiranthes magnicamporum* Sheviak, Great Plains Ladies' Tresses
- *Spiranthes tuberosa* Raf. Little Ladies' Tresses

**DICOTS**

**SALICACEAE, Willow Family**
- *Populus balsamifera* L., Balsam Poplar
- *Populus grandidentata* Michaux, Largetooth Aspen
- *Populus tremuloides* Michaux, Quaking Aspen
- *Salix candida* Flueggé ex Willd., Hoary Willow
- *Salix cordata* Michx., Heartleaf Willow
- *Salix discolor* Muhl., Pussy Willow
- *Salix exigua* Nutt., Sandbar Willow
- *Salix myricoides* Muhl., Blueleaf Willow
- *Salix pedicellaris* Pursh, Bog Willow
- *Salix petiolaris* J. E. Smith, Slender Willow
- *Salix serissima* (L.H. Bailey) Fern., Autumn Willow

**MYRICACEAE, Bayberry Family**
- *Myrica gale* L., Sweetgale

**BETULACEAE, Birch Family**
- *Alnus rugosa* (Duroi) Sprengel, Speckled Alder
- *Betula alleghaniensis* Britton, Yellow Birch
Betula pumila L. Bog Birch
ULMACEAE, Elm Family
    Ulmus americana L., American Elm
URTICACEAE, Nettle Family
    Pilea pumila (L.) A. Gray, Clearweed
POLYGALACEAE, Smartweed Family
    Polygonum amphibium L., Water Knotweed
    Rumex orbiculatus A. Gray, Great Water Dock
SANTALACEAE, Sandalwood Family
    Comandra umbellata (L.) Nutt., Bastard Toadflax
    Geocaulon lividum (Richardson) Fernald, False Toadflax
CARYOPHYLLACEAE, Pink Family
    Arenaria stricta Michaux, Rock Sandwort
    Cerastium arvense L., Field Chickweed
CERATOPHYLLACEAE, Hornwort Family
    Ceratophyllum demersum L., Coon's Tail
CABOMBACEAE, Water Shield Family
    Brasenia schreberi J.F. Gmel., Watershield
NYMPHAEACEAE, Water-lily Family
    Nymphaea odorata Aiton, Fragrant Water-lily
RANUNCULACEAE, Buttercup Family
    Anemone virginiana L., Thimbleweed
    Aquilegia canadensis L., Wild Columbine
    Ranunculus fascicularis Bigelow, Early Buttercup
    Thalictrum dasycarpum Fisch. & Avé-Lall., Purple Meadow-rue
BRASSICACEAE, Mustard Family
    Arabis hirsuta (L.) Scop., Hairy Rock Cress
    Cakile edentula (Bigelow) Hooker, Sea-rocket
    Lepidium virginicum L., Common Peppergrass
SARRACENIACEAE, Pitcher-plant Family
    Sarracenia purpurea L., Pitcher Plant
DROSERACEAE, Sundew Family
    Drosera anglica Huds., English Sundew
    Drosera intermedia Hayne, Spoonleaf Sundew
    Drosera rotundifolia L., Roundleaf Sundew
SAXIFRAGACEAE, Saxifrage Family
    Parnassia glauca Raf., Grass-of-Parnassus
ROSACEAE, Rose Family
    Aronia prunifolia (Marsh.) Rehder, Chokeberry
    Fragaria virginiana Miller, Wild Strawberry
    Physocarpus opulifolius (L.) Maxim., Ninebark
    Potentilla anserina L., Silverweed
    Potentilla arguta Pursh, Prairie Cinquefoil
    Potentilla fruticosa L., Shrubby Cinquefoil
    Potentilla palustris (L.) Scop., Marsh Cinquefoil
    Prunus pumila L., Sand Cherry
    Prunus virginiana L., Choke Cherry
    Rosa carolina L., Pasture Rose
Sorbus decora (Sarg.) Scheider, Showy Mountain-ash
Spiraea alba Duroi, Meadowsweet
Spiraea tomentosa L., Steeplebush

FABACEAE, Legume Family
Desmodium canadense (L.) DC., Showy Ticktrefoil
Lathyrus japonicus Willd., Beach Pea
Lathyrus palustris L., Marsh vetchling

EUPHORBIACEAE, Spurge Family
Euphorbia polygonifolia L., Sea Side Spurge

ANACARDIACEAE, Cashew Family
Rhus aromatica Aiton, Fragrant sumac
Toxicodendron vernix (L.) Kuntze, Poison Sumac

AQUIFOLIACEAE, Holly Family
Ilex mucronata (L.) Trel., Mountain Holly
Ilex verticillata (L.) A. Gray, Michigan Holly

ACERACEAE, Maple Family
Acer rubrum L., Red Maple

BALSAMINACEAE, Touch-me-not Family
Impatiens capensis Meerb., Spotted Touch-me-not

RHAMNACEAE, Buckthorn Family
Rhamnus alnifolia L'Hér., Alderleaf Buckthorn

CLUSIACEAE, St. John’s-wort Family
Hypericum canadense L., Canada St. John’s-wort
Hypericum kalmianum L., Kalm's St. John's-wort
Triadenum fraseri Triadenum fraseri (Spach) Gleason, Marsh St. Johnswort
Triadenum virginicum (L.) Raf., Virginia Marsh St. Johnswort

VIOLACEAE, Violet Family
Viola lanceolata L., Lance-leaved Violet
Viola nephrophylla Greene, Northern Bog Violet

ELAEAGNACEAE, Oleaster Family
Shepherdia canadensis (L.) Nutt., Buffalo-berry

LYTHRACEAE, Loosestrife Family
Decodon verticillatus (L.) Elliott, Swamp Loosestrife
Lythrum alatum Pursh, Winged Loosestrife
Rotala ramosior (L.) Koehne, Wheelwort

ONAGRACEAE, Evening-primrose Family
Epilobium angustifolium L., Fireweed
Epilobium ciliatum Raf., Fringed Willowherb

HALORAGACEAE, Water-milfoil Family
Proserpinaca palustris L., Mermaid Weed

APIACEAE, Carrot Family
Cicuta bulbifera L., Bulblet-bearing Water Hemlock
Zizia aurea (L.) W.D.J. Koch, Golden Alexanders

UMBELLIFERAE, Parsley Family
Eryngium yuccifolium Michx., Rattlesnake Master

CORNACEAE, Dogwood Family
Cornus amomum Miller, Pale Dogwood
Cornus foemina Miller, Gray Dogwood
Cornus stolonifera Michaux, Red-osier Dogwood

ERICACEAE, Heath Family
  Andromeda glaucophylla Link, Bog-rosemary
  Arctostaphylos uva-ursi (L.) Sprengel, Bearberry
  Chamaedaphne calyculata (L.) Moench, Leatherleaf
  Gaylussacia baccata (Wangenh.), Box Huckleberry
  Kalmia angustifolia L., Sheep Laurel
  Kalmia polifolia Wangenh., Bog Laurel
  Ledum groenlandicum Oeder, Labrador Tea
  Vaccinium angustifolium Aiton, Low Sweet Blueberry
  Vaccinium corymbosum L., Highbush Blueberry
  Vaccinium macrocarpon Aiton, Large Cranberry
  Vaccinium myrtilloides Michx., Canada Blueberry
  Vaccinium oxycoccos L., Small Cranberry

PRIMULACEAE, Primrose Family
  Lysimachia quadrifolia Sims, Narrow-leaved Loosestrife
  Lysimachia terrestris L., Swamp Candles
  Lysimachia thyrsiflora L. Tufted Loosestrife
  Primula mistassinica Michx., Mistassini Primrose

GENTIANACEAE, Gentian Family
  Gentiana andrewsii Griseb., Closed Gentian
  Gentianella quinquefolia (L.) Small, Agueweed
  Gentianopsis crinita (Froel.) Ma, Fringed Gentian
  Gentianopsis procera (Holm) Ma, Smaller Fringed Gentian

MENYANTHACEAE, Buckbean Family
  Menyanthes trifoliata L., Buckbean

ASCLEPIADACEAE, Milkweed Family
  Asclepias incarnata L., Swamp Milkweed
  Asclepias syriaca L., Common Milkweed

BORAGINACEAE, Borage Family
  Lithospermum caroliniense (Walter ex J.F. Gmel.) MacMill., Carolina puccoon

LAMIACEAE, Mint Family
  Calamintha arkansana (Nutt.) House, Limestone Calamint
  Lycopus americanus W. P. C. Barton, Cut-leaved Water-horehound
  Lycopus uniflorus Michaux, Northern Bugleweed
  Monarda fistulosa L., Wild-bergamot
  Prunella vulgaris L., Self-heal
  Pycnanthemum virginianum (L.) T. Dur. & B.D. Jacks., Common Mountainmint
  Scutellaria galericulata L., Marsh Skullcap

SCROPHULARIACEAE, Figwort Family
  Agalinis purpurea (L.) Pennell, Purple False Foxglove
  Castilleja coccinea (L.) Spreng., Scarlet Indian Paintbrush
  Pedicularis canadensis L., Wood-betony
  Pedicularis lanceolata Michx., Fen Betony
  Veronicastrum virginicum (L.) Farw., Culver's Root

LENTIBULARIACEAE, Bladderwort family
  Pinguicula vulgaris L., Common Butterwort
  Utricularia cornuta Michx., Horned Bladderwort
Utricularia intermedia Hayne, Flat-leaved Bladderwort
Utricularia vulgaris L., Great Bladderwort

Rubiaceae, Madder Family
Cephalanthus occidentalis L., Buttonbush
Galium asprellum Michx., Rough Bedstraw
Galium boreale L., Northern Bedstraw
Galium trifidum L., Small Bedstraw

Caprifoliaceae, Honeysuckle Family
Symphoricarpos albus (L.) S.F. Blake, Snowberry
Viburnum cassinoides L., With Rod
Viburnum lentago L., Nannyberry

CAMPANULACEAE, Harebell Family
Campanula aparinoides Pursh, Marsh Bellflower
Campanula rotundifolia L., Harebell
Lobelia kalmii L., Bog Lobelia
Lobelia siphilitica L., Great Blue Lobelia

ASTERACEAE, Aster Family
Antennaria neglecta Greene, Field Pussytoes
Artemisia campestris L., Wild Wormwood
Aster borealis (T. & G.) Prov., Rush Aster
Aster dumosus L., Bushy Aster
Aster laevis L., Smooth Aster
Aster lateriflorus (L.) Britton, Calico Aster
Aster nemoralis Aiton, Bog Aster
Aster novae-angliae L., New England Aster
Aster umbellatus Miller, Flat-topped Aster
Cirsium muticum Michx., Swamp Thistle
Cirsium pitcheri (Eaton) T. & G., Pitcher's Thistle
Coreopsis palmata Nutt., Prairie Coreopsis
Coreopsis tripteris L., Tall Coreopsis
Eupatorium maculatum L. Joe Pye Weed
Eupatorium perfoliatum L., Boneset
Euthamia caroliniana (L.) Greene ex Porter & Britton Slender Goldentop
Euthamia graminitofolia (L.) Nutt., Common Flat-topped Goldenrod
Liatris spicata Willd., Marsh Blazing Star
Prenanthes alba L., Rattlesnake-root
Ratibida pinnata (Vent.) Barnhart, Yellow Coneflower
Rudbeckia hirta L., Black-eyed Susan
Senecio paucerculaa (Michx.) Á. Löve & D. Löve, Balsam Ragwort
Silphium terebinthinaceum Jacq., Prairie Dock
Solidago canadensis L., Canada Goldenrod
Solidago gigantea Aiton, Late Goldenrod
Solidago graminifolia (L.) Salish., Common Grass-leaved Goldenrod
Solidago houghtonii Torr. & A. Gray, Houghton's Goldenrod
Solidago juncea Aiton, Early Goldenrod
Solidago nemoralis Aiton, Gray Goldenrod
Solidago ohiensis Riddell, Ohio Goldenrod
Solidago patula Muhl., Swamp Goldenrod
*Solidago riddellii* Frank, Riddell’s Goldenrod
*Solidago simplex* Kunth, Gillman’s Goldenrod
*Solidago uliginosa* Nutt., Bog Goldenrod
*Symphyotrichum firnum* (Nees) Nesom., Smooth Swamp Aster
*Symphyotrichum puniceum* (L.) Löve & Löve, Purple-stemmed Aster
*Tanacetum bipinnatum* (L.) Sch. Bip. Lake Huron Tansy
*Vernonia spp.*, Ironweed spp.