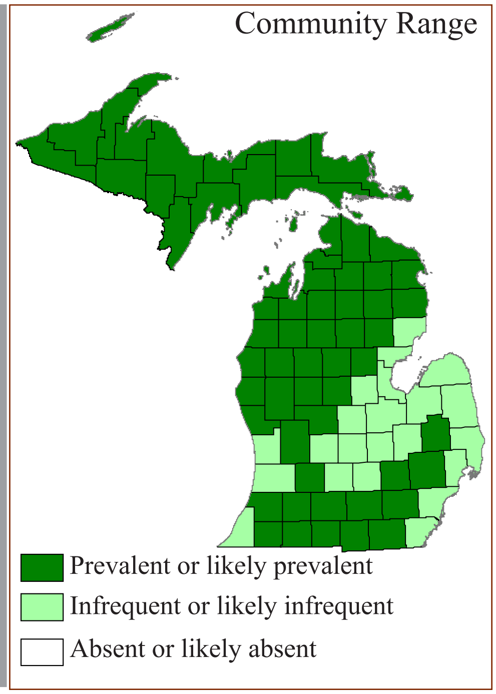
Bog Community Abstract


Photo by Joshua G. Cohen

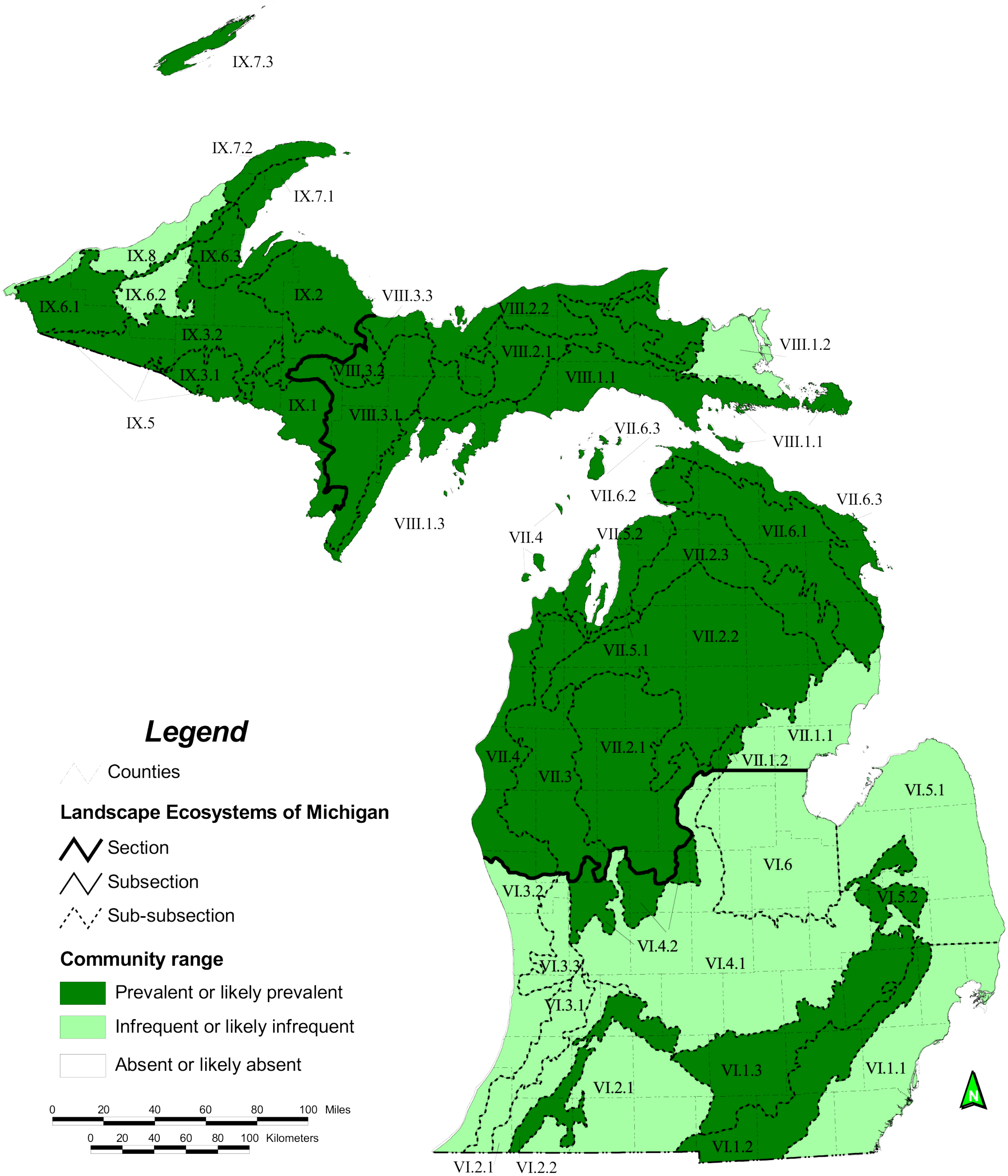


Overview: Bogs are nutrient-poor peatlands characterized by acidic, saturated peat and the prevalence of sphagnum mosses and ericaceous shrubs. Located in depressions in glacial outwash and sandy glacial lakeplains and in kettles on pitted outwash and moraines, bogs frequently occur as a floating mat on the margins of lakes and ponds. Fire occurs naturally during drought periods and can alter the hydrology, mat surface, and flora. Beaver-induced flooding also influences bogs.

Global and State Rank: G3G5/S4

Range: Bogs are a frequent peatland type of glaciated landscapes found throughout the northern hemisphere and are characterized by remarkably uniform floristic structure and composition across the circumboreal region (Curtis 1959). In North America, bogs are found throughout the glaciated Midwest (Michigan, Minnesota, Wisconsin, and northern portions of Illinois, Indiana, and Ohio) and the northeastern United States (New York, New Hampshire, Vermont, and Maine), and in Canada from the central provinces (Ontario, Manitoba, and Quebec) to the maritime provinces (Nova Scotia and New Brunswick) (Curtis 1959, Faber-Langendoen 2001, NatureServe 2006). Bogs exhibit subtle variations in overall species composition and physiognomy across north-south and east-west climatic gradients (Glaser 1992). In Michigan, bogs are common throughout the northern Lower Peninsula and the Upper Peninsula and are less common south of the climatic tension zone (Amon et al. 2002). Bogs and other peatlands occur where excess moisture is abundant (where precipitation is greater than evapotranspiration) (Halsey and Vitt 2000, Mitsch and Gosselink 2000). Conditions suitable for the development of bogs have occurred in the northern Lake States for the past 3,000 to 6,000 years following climatic cooling (Heinselman 1970, Boelter and Verry 1977, Miller and Futyma 1987). Sphagnum-dominated peatlands reached their current extent 2,000 to 3,000 years ago (Halsey and Vitt 2000).

Several other natural peatland communities also occur in Michigan and can be distinguished from ombrotrophic (nutrient-poor) bogs, based on comparisons of nutrient levels, vegetation, canopy closure, and groundwater influence. Bogs, peat-covered wetlands raised above groundwater influence by an accumulation of peat, receive inputs of nutrients and water primarily from precipitation (Gignac et al. 2000). Additional open wetlands occurring on peat include northern fen, prairie fen, poor fen, patterned fen, northern wet meadow, southern wet meadow, and intermittent wetland. Fens are minerotrophic (nutrient-rich) wetlands that are dominated by sedges, rushes, and grasses (Mitsch and Gosselink 2000). The hydrology of fens is influenced by groundwater, and as a result, fens have higher nutrient availability, increased alkalinity



Ecoregional map of Michigan (Albert 1995) depicting distribution of bog (Albert et al. 2008) (less acidity), and greater species richness compared to bogs, with poor fens being more similar to bogs in these attributes than the other fen types. In comparison to bogs, fens have greater importance by graminoids, and are less dominated by sphagnum mosses (*Sphagnaceae*), with brown mosses (*Amblystegiaceae*) being more prevalent. Intermittent wetlands are herb or herb-shrub dominated wetlands that experience fluctuating water levels seasonally and yearly and have soils that range from loamy sand and peaty sand to peaty muck and are very strongly acid to strongly acid. Northern and southern wet meadows are groundwater influenced wetlands that are strongly dominated by sedges and grasses, particularly *Carex stricta* (tussock sedge) and *Calamagrostis canadensis* (bluejoint grass). Like bogs, muskeg and poor conifer swamp are also nutrient-poor, acidic wetlands with a prevalence of sphagnum moss and ericaceous shrubs. However, these ombrotrophic peatlands exhibit a greater degree of canopy closure than bogs. Muskegs are characterized by clumped and scattered conifers, and poor conifer swamps are characterized by partial or closed canopy. Closed-canopy, minerotrophic peatlands include rich conifer swamp, a *Thuja occidentalis* (northern white cedar)- dominated system found north of the tension zone, and rich tamarack swamp, which is dominated by *Larix laricina* (tamarack) and occurs primarily south of the tension zone (Kost et al. 2007).

Rank Justification: Bogs are frequent features of the northern Great Lakes region, occurring throughout the northern Lower Peninsula and Upper Peninsula and occasionally south of the climatic tension zone. Analysis of General Land Office survey notes in Michigan suggests that bogs once occupied approximately 14,423 hectares (35,639 acres) (Comer et al. 1995). Although there are no precise estimates of current bog acreage in Michigan, in general, anthropogenic disturbance has decreased the extent of peatlands and significantly altered many systems. The northern Lake States contain over six million hectares (15 million acres) of peatland (Boelter and Verry 1977). Within the southern portion of their range, bogs typically occur as isolated pockets separated by large expanses of agricultural lands (Amon et al. 2002). Historically, widespread fires following logging in the late 1800s and early 1900s drastically altered many peatlands, either converting poor conifer swamp to open bog systems or destroying the peat and converting bogs to wetlands without organic soils (mineral soil wetlands) (Dean and Coburn 1927, Gates 1942, Curtis 1959, Miller and Futyma 1987). Logging of cedar, *Picea mariana* (black spruce), and tamarack from peatland systems also favored the conversion of forested peatlands to open, ombrotrophic bogs (Gates 1942, Dansereau and Segadas-Vianna 1952, Riley 1989). Beginning in the 1920s, effective fire control by the U.S. Forest Service and state agencies reduced the acreage of fires ignited by humans or lightning (Swain 1973). In landscapes where frequent fire was the prevalent natural disturbance affecting vegetative development, fire suppression has led to the conversion of open bogs to closed-canopy peatlands such as, poor conifer swamp (Curtis 1959, Riley 1989). Peat mining and cranberry farming are other anthropogenic disturbances that have degraded numerous bogs throughout the region (Gates 1942, Curtis 1959, Eggers and Reed 1997, Chapman et al. 2003). Michigan, along with Florida and Minnesota, is one of the leading peat producers in the United States (Miller 1981).

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Roads passing through bogs drastically alter the hydrologic regime and cause severe changes in species composition and structure (i.e., shrub encroachment).

In addition to direct impacts to vegetation, alteration of peatland hydrology from road building, creation of drainage ditches and dams, and runoff from logging has led to significant changes in bog composition and structure (Curtis 1959, Vogl 1964, Schwintzer and Williams 1974, Jeglum 1975, Riley 1989, Grigal 1990, Chapman et al. 2003, Asada et al. 2005). Bog vegetation is extremely sensitive to minor changes in water levels and chemistry (Siegel 1988, Riley 1989). Succession to more minerotrophic wetlands can occur as the result of increased alkalinity and raised water levels, which can cause the increased decomposition of acidic peats. Lowering of water tables from drainage can allow for tree and shrub encroachment into open bogs and the eventual succession to closed-canopy peatland. In addition, drainage of peatlands can result in the rapid decomposition of peat due to the creation of aerobic conditions (Curtis 1959). The dependence of bogs on precipitation for nutrients and water makes them especially susceptible to acid rain and air pollution (Gorham and Tilton 1978, Siegel 1988, Chapman et al. 2003). Atmospheric deposition can contribute nitrogen, sulphur, calcium and heavy metals to bogs (Damman 1990, Chapman et al. 2003). Dust-fall and atmospheric deposition from air pollution are serious threats to bog systems, particularly in the southern portion of their range, where bogs are surrounded by cultivated land and close to industrial and urban centers (Damman 1990). Eutrophication from pollution and altered hydrology can detrimentally impact bogs by generating conditions favorable for the establishment of invasive plant species (Riley 1989) and dominance by aggressive, common natives such as *Typha latifolia* (broad-leaved cat-tail) (Almendinger and Leete 1998).

Physiographic Context: Small ice-block basins and poorly-drained, level terrain are two landscape features particularly conducive to the development of peat (Boelter and Verry 1977). Bogs occur in kettle depressions on pitted outwash and moraines and in flat areas or shallow depressions on glacial outwash and glacial lakeplains (Lindeman 1941, Gates 1942, Curtis 1959, Bay 1967, Crow 1969, Henry et al. 1973, Boelter and Verry 1977, Glaser and Janssens 1986, Siegel 1988, NatureServe 2006, Kost et al. 2007). The overall topography of bogs is flat to gently undulating with microtopography characterized by hummocks and hollows (Heinselman 1963, Vitt and Slack 1975, Wheeler et al. 1983, Glaser et al. 1990, NatureServe 2006). The pronounced microtopography in these systems leads to extreme and fine-scale gradients in soil moisture and pH (Bridgham et al. 1996). Many bogs are oriented northwest to southeast, corresponding to the direction of glacial movement (Schwintzer 1978a). Bogs found in kettle depressions are associated with active or extinct glacial lakes (Curtis 1959). Within kettle depressions, bogs can occupy the entire basin or frequently occur as a mat (floating or grounded) on the margin of the remaining glacial lake (Vitt and Slack 1975, Schwintzer 1978a). When bogs occur along the edge of large bodies of water, they are found in sheltered bays or coves that are protected from wave and ice action, which can prevent the development of peat or erode existing peat mats (Gates 1942). Bogs occurring on former glacial lakebeds and drainageways tend to be more extensive than kettle bogs, which are limited in area by the size of the glacial ice-block that formed the basin (Lindeman 1941). The large peatlands of lakeplains and outwash plains are often over 100 acres while bogs found in kettle depressions typically range from 10 to 30 acres (Michigan Natural Features Inventory 2007).

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Bogs occurring on lakeplain tend to be more expansive than those found in kettle depressions.

Bogs within large wetland complexes typically occur adjacent to other peatland communities, often grading into poor conifer swamp, muskeg, or poor fen. More minerotrophic systems such as northern fen, prairie fen, shrub thicket, wet meadow, hardwood-conifer swamp, rich conifer swamp, and rich tamarack swamp can occur along the outer margins of bogs where groundwater seepage from the adjacent uplands is prevalent. As a general rule, the center of peatland complexes are most ombrotrophic, receiving primarily atmospheric inputs and exhibiting the greatest peat depths, while the borders are more minerotrophic, influenced by groundwater and characterized by shallower peat (Jeglum 1975, Damman 1986). Bogs within kettle depressions that contain active glacial lakes and ponds often border aquatic communities such as submergent marsh and emergent marsh. Bog mats can also occur as a vegetative zone within intermittent wetlands, coastal plain marsh, and wooded dune and swale complexes. A wide array of upland community types can occur adjacent to bogs; some of the more frequent neighboring upland systems include dry-mesic northern forest, dry northern forest, mesic northern forest, pine barrens, dry-mesic southern forest, and dry southern forest.

Hydrology: Climate, topography, near surface geology, soils, and vegetation influence the hydrology of bogs (Miller and Futyma 1987). Bogs are ombrotrophic to weakly minerotrophic peatlands, receiving inputs of water and nutrients primarily from ion-poor precipitation (Heinselman 1970, Verry 1975, Boelter and Verry 1977, Schwintzer 1981, Schwintzer and Tomberlin 1982, Siegel 1988, Riley 1989, Damman 1990, Glaser et al. 1990, Mitsch and Gosselink 2000, Bedford and Godwin 2003). No apparent inlets or outlets supply or drain bogs, which are isolated from groundwater influence as the result of peat accumulation (Dean and Coburn 1927, Schwintzer 1978b, Riley 1989, Swineheart and Parker 2000, Hoffman 2002). The rooting zone is influenced by inputs of atmospheric water and nutrients (Bedford and Godwin 2003).

The water-retaining capacity of sphagnum peat is tremendous and as a result, bogs are saturated, anoxic systems with water tables near the surface (Burns 1906, Dansereau and Segadas-Vianna 1952, Curtis 1959, Heinselman 1970, Schwintzer 1978b, Siegel and Glaser 1987, Bubier 1991, Glaser 1992, Eggers and Reed 1997). The stagnant surface waters of bogs are characterized by high acidity, low available nutrients, low specific conductivity, cool temperatures, anaerobic conditions, and high levels of dissolved organic matter that impart a brown color to the water (Gates 1942, Sjors 1950, Henry et al. 1973, Verry 1975, Schwintzer 1978a, Glaser et al. 1981, Wheeler et al. 1983, Riley 1989, Damman 1990, Bubier 1991, Glaser 1992, Fenton et al. 2005).

Studies of bog water and peat across the northern Great Lakes have found pH measurements to range from 3.2 to 4.7 (Heinselman 1970, Boelter and Verry 1977, Schwintzer 1981, Schwintzer and Tomberlin 1982, Wheeler et al. 1983, Riley 1989, Glaser et al. 1990). The high acidity of bogs limits the availability and uptake of essential mineral plant nutrients, which are inherently scarce in these systems because of the lack of groundwater input (Glaser 1992). Bogs are characterized by low primary productivity, which is correlated with the very low concentrations of available calcium, magnesium, nitrogen, phosphorous, and potassium in the surface water and peat (Heinselman 1963, Heinselman 1970, Schwintzer 1978a, Schwintzer 1981, Schwintzer and Tomberlin 1982, Wheeler et al. 1983, Richardson and Marshall 1986, Riley 1989, Glaser 1992, Bedford et al. 1999, Mitsch and Gosselin 2000).

Soils: The organic soils of bogs are composed of peat, which forms a continuous mat and can range in thickness from one to eight meters but is typically one to three meters deep (Heinselman 1965, Bay 1967, Heinselman 1970, Siegel and Glaser 1987). Depth of peat and soil moisture increase with peatland age and can vary within a site (Jeglum 1975, Taylor et al. 1988). Peat depth is typically greatest near the center of a peatland and decreases towards the peatland margin (Jeglum 1975). The rooting zone within bogs is quite shallow, typically confined to the upper 15 cm of the surface peat (Karlin and Bliss 1984, Glaser and Janssens 1986). Peat of bogs is characterized by high carbon content (Halsey and Vitt 2000).

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Sphagnum peat, which forms a continuous mat in bogs, is characterized by extreme acidity, cool temperatures, high water-retaining capacity, low nutrient availability, and low oxygen levels.

Photo by Adrienne L. Bozic

Peat is a fibrous network of partially decomposed organic material that is formed under anaerobic conditions (Heinselman 1963, Almendinger et al. 1986). The surface peats of bogs are dominated by saturated fibric peat, which is loosely compacted and spongy, contains partially decomposed sphagnum moss with fragments of wood and occasionally sedge. Like the surface water, peat soils are extremely acidic, cool, and characterized by low nutrient availability and oxygen levels (Burns 1906, Curtis 1959, Heinselman 1963, Heinselman 1970, Schwintzer and Williams 1974, Boelter and Verry 1977, Almendinger et al. 1986, Futyma and Miller 1986, Pepin et al. 2002). Fibric peat has high water-retaining capacity and large intercellular pores that permit rapid water movement (Boelter and Verry 1977, Swanson and Grigal 1989, Pepin et al. 2002). Peat composition changes with depth and is influenced by successional history of a given site. Generally, fiber content and hydraulic conductivity decrease with depth; deeper peats are more decomposed, have smaller pores, retain more water due to their proximity to the water table, and drain more slowly than surface peats (Curtis 1959, Verry 1975, Boelter and Verry 1977, Futyma and Miller 1986). Deep humidified peats can effectively seal basins and create a perched water table.

Climate: Peatlands develop in humid climates where precipitation exceeds evapotranspiration (Boelter and Verry 1977, Gignac et al. 2000, Halsey and Vitt 2000). The northern Lake States are characterized by a humid, continental climate with long, cold winters and short summers that are moist and cool to warm (Gates 1942, Boelter and Verry 1977, Damman 1990, Mitsch and Gosselink 2000). In Michigan, bogs are found within all four regions of the state classified by Albert et al. (1986) and Albert (1995). The mean number of freeze-free days is between 90 and 220, and the average number of days per year with snow cover of 2.5 cm or more is between 10 and 140. Annual total precipitation typically ranges from 740 to 900 mm, with a mean of 823 mm. The daily maximum temperature in July ranges from 24 to 32 °C (75 to 90 °F), the daily minimum temperature in January ranges from −21 to −4 °C (−5 to 25 °F), and the mean annual temperature is 7 °C (45 °F) (Albert et al. 1986, Barnes 1991). Temperatures vary less in bogs compared to the surrounding landscape because of the insulating effect of bogs' saturated peat carpet during the growing season and snow cover in winter (Burns 1906, Curtis 1959, Heinselman 1963, Glaser 1992). In Wisconsin, Curtis (1959) observed that at root level, temperatures during the growing season rarely exceed 15 °C (60 °F) and are usually between 7 and 13 °C (45 and 55 °F). In Minnesota peatlands, Heinselman (1963) found that the maximum soil temperature in August was 13.5 °C (56 °F) and the minimum soil temperature in late winter was −1 °C (30 °F). Bogs are characterized by moderating microclimates that are cooler in the summer, warmer in the winter, and more even throughout the year compared to the regional climate (Curtis 1959, Heinselman 1963, Bedford and Godwin 2003).

Natural Processes: Peatland formation is controlled by the interaction of climate, hydrology, nutrient supply, and vegetation (Miller and Futyma 1987). Peat establishment requires an abundant supply of water. As noted, ombrotrophic peatlands occur in regions where precipitation is greater than evapotranspiration and on sites with blocked drainage (Dansereau and Segadas-Vianna 1952, Boelter and Verry 1977, Mitsch and Gosselink 2000). Saturated and inundated conditions inhibit organic matter decomposition and allow for the accumulation of peat (Almendinger and Leete 1998). Under cool, anaerobic, and acidic conditions, the rate of organic matter accumulation exceeds organic decay (Schwintzer and Williams 1974, Damman 1988, Damman 1990, Bridgham et al. 1996, Mitsch and Gosselink 2000). Low levels of oxygen and high levels of acidity inhibit microorganisms and chemical actions that cause decay (Heinselman 1963, Miller 1981, Damman 1988, Mitsch and Gosselink 2000). Once sphagnum mosses become established on the peat mat, they maintain and enhance saturated, acidic, and cool conditions, which in turn promote continued peat development (Janssen 1967, Zoltai and Vitt 1995, Nicholson et al. 1996, Halsey and Vitt 2000). The ability of sphagnum to absorb and hold cations increases the acidity and decreases the nutrient availability of peatlands (Osvald 1935, Curtis 1959, Verry 1975, Vitt and Slack 1975, Boelter and Verry 1977, Halsey and Vitt 2000). In addition, bryophytes take up and sequester nutrients from precipitation, throughfall, and litter decomposition before it is available to trees (Halsey and Vitt 2000). Sphagnum moss, which has numerous pores, partitions, and capillary space, has an enormous water-holding capacity (Osvald 1935, Dansereau and Segadas-Vianna 1952, Curtis 1959, Bisbee et al. 2001). Sphagnum peat can hold 15 to 30 times its own weight in water (Miller 1981, Mitsch and Gosselink 2000). The accumulation of peat exerts control over a site's hydrology, biogeochemistry, and plant community composition (Bridgham et al. 1996). Peatlands not only alter landscape patterns but become the landscape (Brinson 1993).

Development and expansion of peatlands occurs via two distinct processes: lake-filling and paludification. Lake-filling or terrestrialization occurs in small lakes with minimal wave action, where gradual peat accumulation results in the development of a bog mat that can fill the basin or occur as a floating mat in the lake or as a grounded mat along the water's edge (Burns 1906, Gates 1942, Bay 1967, Curtis 1959, Heinselman 1963, Mitsch and Gosselink 2000). Bog succession in lake-filled basins typically proceeds from lake to marsh to fen to bog (Heinselman 1963, Boelter and Verry 1977, Schwintzer 1981, Futyma and Miller 1986, Klinger 1996, Swineheart and Parker 2000).

Photo by Joshua G. Cohen

Lake-filling or terrestrialization occurs in depressions where gradual peat accumulation results in the development of a bog mat.

Photo by Joshua G. Cohen

Floating mats of fen sedges, namely *Carex lasiocarpa* (wiregrass sedge), pioneer open water and generate interlacing masses of roots and rhizomes that are buoyed by the water. Organic matter then accumulates in the form of peat and is eventually invaded by sphagnum and ericaceous shrubs (Osvald 1935, Gates 1942, Crow 1969, Schwintzer and Williams 1974, Swineheart and Parker 2000). Fallen logs in kettle lakes and ponds can also provide the substrate for bog vegetation establishment and invasion of open water; *Chamaedaphne calyculata* (leatherleaf) is particularly adept at expanding along logs (Dean and Coburn 1927, Gates 1942, Dansereau and Segadas-Vianna 1952). The adventitious roots of leatherleaf, which can grow laterally above the water's surface, provide substrate for the establishment of sphagnum mosses (Asada et al. 2005). Peatland vegetation has been recorded advancing into kettle lakes at a rate of 2.1 cm/year (Schwintzer and Williams 1974). Estimates of vertical accumulation of bog peat range between 100 to 200 cm/1000 years (Mitsch and Gosselink 2000).

Succession in lake-filled peatlands can proceed from lake to marsh to fen to bog to muskeg or poor conifer swamp (Heinselman 1963, Boelter and Verry 1977, Schwintzer 1981, Futyma and Miller 1986, Swineheart and Parker 2000). Succession within peatland systems is not unidirectional but stochastic, with rates and pathways of succession determined by a complex array of interacting biotic and abiotic factors (Jasieniuk and Johnson 1982, Klinger 1996). Bogs can succeed to muskeg or remain as bogs and muskeg can succeed to poor conifer swamp or remain as muskeg depending on the site's hydrology (lowered water tables will allow for the establishment of trees), disturbance regime (fire and flooding will keep open systems open), and species composition (a seed source of conifer trees in the vicinity is required for forest succession and some ericaceous species can limit seedling establishment and tree growth). Another potential successional pathway is the conversion of poor conifer swamp to bog or muskeg through paludification (Heinselman 1970, Schwintzer 1981).

Paludification is the blanketing of terrestrial systems (often forests) by the overgrowth of peatland vegetation (Dansereau and Segadas-Vianna 1952, Heinselman 1963, Mitsch and Gosselink 2000). For both lake-filling and paludification, peat accumulates above the water table and the bog becomes isolated from the influence of groundwater (Heinselman 1970, Boelter and Verry

1977, Glaser and Janssens 1986, Miller and Futyma 1987, Mitsch and Gosselink 2000). Paludification implicitly follows terrestrialization. Terrestrialization causes the blockage of drainage by peat accumulation. As a result, downward percolation of water into the underlying mineral substratum is impeded and lateral movement is favored, leading to the swamping of ground adjacent to lake-filled basins and the eventual expansion of peatland vegetation (Futyma and Miller 1986). Paludified peatlands develop on flat areas, typically lakeplains, where peat develops vertically and spreads horizontally (Heinselman 1965, Boelter and Verry 1977). The lateral expansion of peatland into forested systems can result in increases in the water table and acidity and a subsequent decrease in soil temperatures, nutrient availability, decomposition rates, canopy cover, growth rates, and seedling establishment; a shift in species composition also occurs with swamp conifers, especially black spruce, becoming more prevalent (Klinger 1996, Harper et al. 2003, Ruel et al. 2004, Fenton et al. 2005, Harper et al. 2005). The accumulation of organic soils under forested peatlands can lead to the eventual conversion to bog or muskeg since thick sphagnum mats can limit tree establishment and growth.

Once established, bogs can persist for hundreds to thousands of years given stable hydraulic conditions. A discharge of alkaline groundwater at the peat surface of a bog, caused by a change in hydraulic head, can result in the conversion of bog vegetation to fen vegetation (Siegel and Glaser 1987, Glaser et al. 1990). Mixing of as little as 10% groundwater from underlying calcareous parent material with acid bog water is sufficient to raise the peatland pH from 3.6 to 6.8 (Glaser et al. 1990). Bogs are very sensitive to changes in pH and subsequent availability of nutrients; fen vegetation can replace bog flora when pH increases above 4.5 (Siegel 1988). However, conversions of bog to fen have seldom been reported in the literature (Glaser et al. 1990). More typically, bogs are converted to shrub swamp or swamp forest following the lowering of the water table. Water table lowering results in increased decomposition rates of organic matter and facilitates the invasion of bogs by opportunistic woody species (Almendinger and Leete 1998, Gignac et al. 2000).

Natural disturbance factors influencing bogs include fire, flooding, windthrow, and insects. Numerous bogs contain charcoal within their peat profiles (Curtis 1959, Heinselman 1963) and many researchers have reported fire as a significant part of bog's disturbance regime (Dean and Coburn 1927, Gates 1942, Curtis 1959). Surface fire can contribute to the maintenance of bogs by killing encroaching trees without completely removing the sphagnum (Curtis 1959, Vitt and Slack 1975). Many of the ericaceous plants that thrive in bogs are fire-adapted and often grow densely following fire (Wheeler et al. 1983). Fire severity and frequency in bogs is closely related to climatic change, fluctuations in water level, and landscape context. Prolonged periods of drought can allow the surface peat to dry out sufficiently to burn (Vogl 1964, Schwintzer and Williams 1974). When the surface peat of bogs burns, the fire releases organic matter from the peat, kills seeds and latent buds, stimulates decay, slows peat accumulation, and may expose mineral soil (Vogl 1964, Damman 1990, Jean and Bouchard 1991). Peat fires can convert bogs to more graminoid dominated peatlands such as intermittent wetlands or poor fens or if the peat is completely destroyed, to mineral soil wetlands such as northern wet meadow (Curtis 1959).

Photo by Joshua G. Cohen

Beaver flooding is an important disturbance factor influencing bogs.

Flooding can contribute to the development, expansion, and maintenance of bogs. Beaver, through their dam-building activities, can cause substantial hydrologic change to peatland systems, either causing flooding or the lowering of the water table, depending on the location of the peatland in relation to the dam (Gates 1942, Curtis 1959, Heinselman 1963, Jeglum 1975, Futyma and Miller 1986). Behind a beaver dam the water table is higher, while below it, drier conditions are generated (Jeglum 1975). Blocked drainage and flooding behind a beaver dam can facilitate sphagnum peat development and expansion (Heinselman 1963, Heinselman 1970). Prolonged flooding of poor conifer swamps can result in the death of canopy trees and conversion of forested peatlands to muskegs and bogs or even open systems dominated by marsh and fen vegetation (Asada et al. 2005). Roots of peatland trees are physiologically active near the surface and are quickly killed when the water table rises following flooding (Glaser and Janssens 1986). Within kettle bogs, flooding-induced tree mortality is greater on grounded bog mats compared to free floating mats; free mats float with rising water tables while grounded mats become inundated and have shallower aerobic zones (Schwintzer 1978a, Schwintzer 1979, Asada et al. 2005). Flooding can also cause grounded peat mats to become loosened from the bottom and float (Gates 1942, Asada et al. 2005). In addition to flooding, kettle bogs can be influenced by wave and ice action, which can prevent the expansion of bog mats by eroding shoreline vegetation (Gates 1942).

The lowering of the water table through beaver damming or climatic changes can also dramatically effect the species composition and successional trajectory of bogs. Lowering of a peatland's water table results in increased soil aeration, soil temperature, decomposition, nutrient availability, and consequently, tree growth (Jasieniuk and Johnson 1982, Liefers and Rothwell 1986, Liefers and MacDonald 1990, MacDonald and Yin 1999, Pepin et al. 2002). A low water table for a prolonged period of time can lead to the conversion of bog to shrub swamp or poor conifer swamp (Gignac et al. 2000).

The natural disturbance regime in bogs is influenced by wind. The Great Lakes region is one of the most active weather zones in the northern hemisphere, with polar jet streams positioned overhead much of the year. More cyclones pass over this region than any other area in the continental U.S. (Frelich and Lorimer 1991). Trees growing in bogs are particularly susceptible to windthrow because saturated sphagnum peat provides a poor substrate for anchoring trees (Burns 1906). As noted above, the living roots of woody peatland plants occur in a shallow rooting zone, generally restricted to the uppermost 15 cm where there is sufficient oxygen to maintain aerobic respiration (Karlin and Bliss 1984, Glaser and Janssens 1986). The poor drainage of bogs and the superficial rooting of trees results in numerous windthrows (Dansereau and Segadas-Vianna 1952, Curtis 1959, Eggers and Reed 1997). However, the short stature of many of the stunted canopy trees may provide them with some protection from wind (Groot and Horton 1994). Small-scale wind disturbance, along with insect herbivory contribute to the structural diversity of bogs by generating moderate pit and mound topography, standing snags, and woody debris, which is quickly enveloped by sphagnum moss.

Tree survival in bogs is also limited by insects and parasites. The plant parasite *Arceuthobium pusillum* (dwarf mistletoe) can cause mortality of black spruce (Coburn et al. 1933, Gates 1942). Three insect defoliators are most prevalent in peatlands, *Pristiphora erichsonii* (larch sawfly), *Coleophora laricella* (larch casebearer), and *Choristoneura fumiferana* (spruce budworm) (Curtis 1959, Newton and Jolliffe 1998). Spruce budworm defoliates both black spruce and *Abies balsamea* (balsam fir) but tends to be more detrimental to the later (Newton and Jolliffe 1998). Tamarack growing in peatlands often suffers from repeated defoliation by larch sawfly (Beckwith and Drooz 1956, Graham 1956, Curtis 1959, Tilton 1977, Girardin et al. 2005). The life of a given tamarack is typically characterized by a series of defoliation episodes, most of which are short in duration and of moderate intensity (Graham 1956). However, prolonged larch sawfly attacks can lead to extensive mortality of tamarack. Although a more recent pest in Michigan, the larch casebearer is beginning to cause heavy defoliation to tamarack, especially in the eastern and central Upper Peninsula.

Native ericaceous shrubs can profoundly limit the establishment and growth of conifer trees within bogs through competitive inhibition and the production of allelopathic compounds. Many of the ericaceous plants that thrive in bogs are fire-adapted and often resprout vigorously and grow densely following fire (Wheeler et al. 1983). Rapid and prolific resurgence of ericads, which resprout or sucker from underground organs, can directly limit tree seedling establishment and growth (Foster 1985, Zhu and Mallik 1994, Yamasaki et al. 1998). *Kalmia angustifolia* (sheep-laurel) has been found to produce allelopathic compounds that inhibit the growth and development of black spruce. These water-soluble and heat-stable substances hinder the primary root development of black spruce and are also believed to negatively impact the ecotomycorrhizal fungi associated with black spruce (Peterson 1965, Thompson and Mallik 1989, Zhu and Mallik 1994, Yamasaki et al. 1998). The negative effects of sheep-laurel on black spruce root growth are most pronounced under acidic condition (Zhu and Mallik 1994).

Photo by Joshua G. Cohen

Bogs are characterized by dominance of ericaceous shrubs (especially leatherleaf), a continuous mat of sphagnum mosses, and scattered, stunted conifers.

Vegetation Description: Bogs are characterized by a continuous carpet of sphagnum moss, a species-poor herbaceous layer, low ericaceous, evergreen shrubs, and widely scattered and stunted coniferous trees (Gates 1942, Curtis 1959, Verry 1975, Vitt and Slack 1975, Glaser et al. 1991, NatureServe 2006). Floristically, bogs are homogenous and of limited diversity, exhibiting remarkably uniform structure and composition across their wide range (Curtis 1959, Riley 1989). Slight variations in composition, especially within the shrub and tree layers, occur in Michigan bogs along a longitudinal gradient. Southerly bogs have a stronger deciduous tree and shrub component compared to the northern coniferous bogs. In addition, bogs that occur in fire-prone landscapes tend to have lower floristic diversity than bogs insulated from frequent fire. The harsh growing conditions of bogs (high acidity, low nutrient availability, and saturated peat) result in a unique but depauperate flora. Relatively few species have evolved the necessary adaptations to survive ombrotrophic conditions (Siegel 1988, Glaser 1992, Mitsch and Gosselink 2000). Bog plants have developed a diversity of adaptations to cope with low nutrient availability including carnivory, evergreen leaves, sclerophylly (thick epidermal tissue), tight nutrient cycles, and high root biomass and root to shoot ratios (Bridgham et al. 1996, Mitsch and Gosselink 2000). Very few introduced, weedy species are able to establish within unperturbed bogs and fens because of the unique growing conditions and competition from the adapted flora (Riley 1989).

Photos by Joshua G. Cohen

Insectivorous plants such as pitcher-plant (top left), bladderworts (top right), and sundews (bottom), have developed carnivorous adaptations to cope with the low nutrient availability of ombrotrophic peatlands.

Photo by Adrienne L. Bozic

In a study of bogs across eastern North America, Glaser (1992) found the native vascular bog flora to be limited to only 81 species and the mean number of species per bog to be below 26. For bogs within Michigan Natural Features Inventory's database (2007), the mean number of species per bog is approximately 30, a similarly low overall species richness. However, the mean number of species per 1 m^2 plot in kettle bogs in the northern Lower Peninsula of Michigan was found to be relatively high with fifteen by Vitt and Slack (1975) and fourteen by Schwintzer (1981), and a range of nine to twenty, indicating that bogs possess high levels of microhabitat heterogeneity. Species richness of bogs is related to geographical location, climatic factors, nutrient availability, and habitat heterogeneity (Glaser et al. 1990, Glaser 1992). Species diversity within bogs is strongly correlated to the hummock-hollow microtopography (Glaser et al. 1990); each individual hummock in a peatland is in essence a miniature ecosystem with distinct gradients in water and substrate chemistry, soil moisture, aeration, and nutrients (Karlin and Bliss 1984, Bridgham et al. 1996, Glaser et al. 1990). Within a given bog, floristic composition is determined by gradients in pH, light, soil moisture, depth to water level, fire frequency, and cation concentrations (nutrient availability) (Sjors 1950, Jeglum 1971, Henry et al. 1973, Jeglum 1974, Vitt and Slack 1975, Schwintzer 1978a, Glaser et al. 1981, Karlin and Bliss 1984, Vitt and Slack 1984, Bridgham et al. 1996, Nicholson et al. 1996, Locky et al. 2005).

Bogs are dominated by mosses from the *Sphagnaceae* and shrubs from the *Ericaceae*; other well-represented families include the *Cyperaceae*, *Orchidaceae*, and *Ranunculaceae* (Gates 1942, Curtis 1959, Heinselman 1970). The most important primary producers within bogs are ericaceous shrubs and sedges (Mitsch and Gosselink 2000). Bog flora is predominantly spring flowering and heliophitic (sun-loving) (Dansereau and Segadas-Vianna 1952, Curtis 1959). While bogs are dominated by plants that thrive under ombrotrophic conditions, occasionally minerotrophic indicators may be present in bogs at low cover. Plants found typically in more alkaline habitat such as *Betula pumila* (bog birch), *Carex aquatilis* (water sedge), and *Carex stricta* (tussock sedge), can occur sporadically in bogs when their roots extend beneath the bog mat to minerotrophic peat or mineral soil influenced by groundwater (NatureServe 2006).

Bryophytes play a critical role in determining the vegetation patterning and composition of peatlands, by affecting soil thermal regimes, hydrology, and nutrient availability (Bisbee et al. 2001). The continuous moss layer of bogs is dominated by sphagnum mosses, especially *Sphagnum magellanicum*, *S. angustifolium*, and *S. fuscum* (Vitt and Slack 1975, Schwintzer 1978a, NatureServe 2006). Additional mosses can include *S. capillaceum*, *S. capillifolium*, *S. compactum*, *S. cuspidatum*, *S. papillosum*, *S. recurvum*, and *Drepanocladus aduncus* (Gates 1942, Vitt and Slack 1975, Crum 1983, Riley 1989, Glaser et al. 1990). Bryophytes depend on a continuous source of water because they lack roots. The primary factor determining species composition of bryophytes is soil drainage (Bisbee et al. 2001).

Photo by Joshua G. Cohen

Hummock and hollow microtopography results in vertical zonation of sphagnum species that are sensitive to fine-scale gradients of moisture and pH.

The hummock and hollow microtopography of bogs allows for high levels of bryophyte diversity since individual species of sphagnum occur at specific elevations, exhibiting habitat partitioning (Vitt and Slack 1975, Wheeler et al. 1983, Vitt and Slack 1984, Riley 1989). Hollows support *S. magellanicum*, *S. cuspidatum*, and *S. papillosum* (Vitt and Slack 1975, Vitt et al. 1975, Heinselman 1970, Wheeler et al. 1983, Vitt and Slack 1984, Riley 1989). The lower, moist slopes of hummocks often support *S. magellanicum* and *S. recurvum,* while the drier hummock crests are dominated by *S. fuscum*, *S. capillaceum*, and *S. cappillifolium* (Vitt et al. 1975, Wheeler et al. 1983, Riley 1989). The vertical zonation of species or niche diversification corresponds to gradients in pH and moisture with the hollows being wetter and more alkaline than the drier and more acidic tops of the hummocks (Vitt et al. 1975, Wheeler et al. 1983, Karlin and Bliss 1984, Vitt and Slack 1984, Nicholson et al. 1996, Bridgham et al. 2006). In addition to microtopographic variation, gradients of light or sunfleck availability, determined by tree cover and spacing, also influence patterns of species composition and diversity (Vitt and Slack 1984, Bisbee et al. 2001).

The herbaceous layer of bogs is dominated by cy-peraceous plants and is often species depauperate. Fine-leaved sedges are more prevalent in bogs while broad-leaved sedges tend to dominate minerotrophic sites (Boelter and Verry 1977). Several sedges that are characteristic of bogs include *Carex oligosperma* (few-seed sedge), *C. pauciflora* (few-flower sedge), and *C. lasiocarpa* (wiregrass sedge). Other sedges that often occur in bogs are *C. limosa* (mud sedge), *C. paupercula* (boreal bog sedge), *C. rostrata* (beaked sedge), and *C. trisperma* (three-seeded sedge). Additional graminoids that thrive in bogs include *Cladium marisicoides* (twig-rush), *Dulichium arundinaceum* (three-way sedge), *Eriophorum angustifolium* (narrow-leaved cotton-grass), *E. spissum* (sheathed cotton-grass), *E. vaginatum* (tussock cotton-grass), *E. virginicum* (tawny cotton-grass), *Rhynchospora alba* (white beak-rush), *Scheuchzeria palustris* (arrow-grass), and *Scirpus* spp. (bulrushes). The following are prevalent bog herbs: *Epilobium angustifolium* (fireweed), *E. ciliatum* (fringed willow-herb), *Iris versicolor* (wild blue flag), *Menyanthes trifoliata* (bogbean), *Smilacina trifolia* (false mayflower), and *Triglochin maritima* (common bog arrow-grass). Insectivorous plants are common features of bogs and may include *Drosera rotundifolia* (round-leaved sundew), *Drosera intermedia* (spoon-leaf sundew), *Sarracenia purpurea* (pitcher-plant), and *Utricularia intermedia* (flat-leaved bladderwort). *Woodwardia virginica* (chain-fern) is one of few ferns that occur in bogs and is often common along the edges of bogs south of the climatic tension zone. Bogs frequently contain open pools of water or are surrounded by moats that contain emergent vegetation such as *Nuphar* spp. (pond-lilies) and *Nymphaea odorata* (sweet-scented water-lily).

The shrub layer of bogs is dominated by low, ericaceous shrubs with *Chamadaephne calyculata* (leatherleaf) as the most prevalent species. The dwarf shrub layer is typically less than a meter high and usually covers at least 25% of the bog area (Eggers and Reed 1997, NatureServe 2006). In addition to leatherleaf, the following heath shrubs are important components of bogs: *Andromeda glaucophylla* (bog rosemary), *Gaylussacia baccata* (huckleberry), *Kalmia angustifolia* (sheep-laurel), *K. polifolia* (bog laurel), *Ledum groenlandicum* (Labrador tea), *Vaccinium angustifolium* (low sweet blueberry), *V. macrocarpon* (large cranberry), *V. myrtilloides* (Canada blueberry), and *V. oxycoccos* (small cranberry). Ericaceous shrubs can stimulate sphagnum species through a scaffolding effect in which fast vertical sphagnum growth is facilitated by the physical support of shrub branches and adventitious roots (Fenton et al. 2005). Members of the *Ericaceae* generate compounds that contribute to the acidification of peatlands (Zhu and Mallik 1994). As noted above, ericads can inhibit conifer tree growth and establishment through direct competition and the production of allelopathic compounds.

Photo by Joshua G. Cohen

Bogs often contain open pools of water with emergent vegetation surrounded by a floating or quaking bog mat.

Photo by Michael A. Kost

Leatherleaf, which often dominates bogs, is fire-adapted and resprouts vigorously and grows densely following fire.

The tall shrub layer of bogs is less dense than the low shrub layer and is often restricted to the periphery of the bog. Tall shrubs typical of bogs include *Aronia prunifolia* (black chokeberry), *Nemopanthus mucranta* (mountain holly), *Salix pedicellaris* (bog willow), *Spiraea alba* (meadowsweet), *S. tomentosa* (steeplebush), and *Viburnum cassinoides* (wild-raisin). South of the climatic tension zone, *Cephalanthus occidentalis* (buttonbush), *Toxicodendron vernix* (poison sumac), and *Vaccinium corymbosum* (highbush blueberry) frequently occur within bogs or along their margins. As noted, bog birch can occur at low cover when it roots can extend beneath the bog mat to minerotrophic peat. *Alnus rugosa* (tag alder or speckled alder) often occurs along peatland margins.

Trees within bogs are widely scattered and stunted, seldom reaching a height of six meters (Wheeler et al. 1983, NatureServe 2006). Tree cover is often below ten percent (NatureServe 2006). Trees growing in peatlands have horizontally oriented root systems that are confined to the less saturated surface layers (the upper 10-20 cm) (Barnes and Wagner 1981, Karlin and Bliss 1984, Liefers and Rothwell 1986, Pepin et al. 2002). The most common canopy dominants are *Picea mariana* (black spruce) and *Larix laricina* (tamarack). Additional associates include *Pinus banksiana* (jack pine), *P. strobus* (white pine), and *Acer rubrum* (red maple), with red maple being more prevalent south of the climatic tension zone. (Above species lists were compiled from Michigan Natural Features Inventory database, Dean and Coburn 1927, Coburn et al. 1933, Osvald 1935, Gates 1942, Dansereau and Segadas-Vianna 1952, Curtis 1959, Heinselman 1963, Vogl 1964, Heinselman 1965, Bay 1967, Janssen 1967, Heinselman 1970, Schwintzer and Williams 1974, Vitt and Slack 1975, Vitt et al. 1975, Schwintzer 1978a, Glaser et al. 1981, Schwintzer 1981, Crum 1983, Wheeler et al. 1983, Vitt and Slack 1984, Futyma and Miller 1986, Miller and Futyma 1987, Riley 1989, Glaser et al. 1990, Glaser 1992, McLaughlin et al. 1994, Anderson et al. 1996, Eggers and Reed 1997, Mitsch and Gosselink 2000, Swinehart and Parker 2000, NatureServe 2006, Kost et al. 2007.)

Photo by Joshua G. Cohen

Scattered and stunted conifers are characteristic of bogs.

Michigan Indicator Species: black spruce, few-seed sedge, leatherleaf, pitcher-plant, sphagnum moss, and sundews.

Other Noteworthy Species: Bogs provide habitat for numerous rare insect species including *Appalachia arcana* (secretive locust, state special concern), *Atlanticus davisi* (Davis's shield-bearer, state special concern), *Boloria freija* (Freija fritillary, state special concern butterfly), *Boloria frigga* (Frigga fritillary, state special concern butterfly), *Calephelis mutica* (swamp metalmark, state special concern), *Erebia discoidalis* (red-disked alpine, state special concern butterfly), *Erynnis baptisiae* (wild indigo duskywing, state special concern), *Liodessus cantralli* (Cantrall's bog beetle, state special concern), *Merolonche dollii* (Doll's merolonche moth, state special concern), *Neoconocephalus lyrists* (bog conehead, state special concern), *Oecanthus laricis* (tamarack tree cricket, state special concern), *Orchelimum concinnum* (red-faced meadow katydid, state special concern), *Paroxya hoosieri* (Hoosier locust, state special concern), *Somatochlora incurvata* (incurvate emerald, state special concern dragonfly), and *Williamsoni fletcheri* (ebony boghaunter, state special concern dragonfly). Numerous butterflies and moths are restricted to bogs and fens because their food plants occur within these peatland systems (Riley 1989).

Rare herptiles that utilize bogs include *Acris crepitans blanchardi* (Blanchard's cricket frog, state threatened), *Clemmys guttata* (spotted turtle, state threatened), *Emydoidea blandingii* (Blanding's turtle, state special concern), *Nerodia erythrogaster neglecta* (copperbelly water snake, federal threatened and state endangered), *Pantherophilis spiloides* (gray rat snake, state special concern), *Pseudacris triseriata maculata* (boreal chorus frog, state special concern), *Sistrurus catenatus catenatus* (eastern massasauga, state special concern), and *Terrapene carolina carolina* (eastern box turtle, state special concern).

If suitable nesting trees or snags are available, *Haliaeetus leucocephalus* (bald eagle, state special concern), *Falco columbarius* (merlin, state threatened), and *Pandion haliaetus* (osprey, state special concern) can be found nesting in these systems and *Ardea herodias* (great blue heron, protected by the Migratory Bird Treaty Act of 1918) can establish rookeries. Other rare birds that could occur in bogs are *Botaurus* *lentiginosus* (American bittern, state special concern), *Circus cyaneus* (northern harrier, state special concern), *Coturnicops noveboracensis* (yellow rail, state threatened), *Falcipennis canadensis* (spruce grouse, state special concern), and *Picoides arcticus* (black-backed woodpecker, state special concern). *Gavia immer* (common loon, state threatened) establish nest sites on natural islands and bog-mats. Small mammals associated with bog habitat include *Sorex fumeus* (smoky shrew, state special concern) and *Cryptotis parva* (least shrew, state threatened). *Alces americanus* (moose, state special concern), *Canis lupus* (gray wolf, state threatened), and *Lynx canadensis* (lynx, state endangered) are important large mammals that utilize peatland habitat (Mitsch and Gosselink 2000).

In general, the population of animals is low in bogs because of the low productivity and unpalatability of bog vegetation, and high acidity of bog water (Mitsch and Gosselink 2000). *Melospiza georgiana* (swamp sparrow) and *M. melodia* (song sparrow) are typical bog songbirds. Common herptiles that frequent bogs include *Bufo americanus americanus* (eastern American toad), *Rana pipiens* (northern leopard frog), and *Thamnophis sirtalis sirtalis* (garter snake) (Riley 1989). Bogs provide important habitat for small mammals such as *Blarina brevicauda* (short-tailed shrew), *Castor canadensis* (beaver), *Microtus pennsylvanicus* (meadow vole), *Mustela vison* (mink), *Ondatra zibethicus* (muskrat), and *Sorex cinereus* (masked shrew) (Curtis 1959, Mitsch and Gosselink 2000). Both muskrats and beaver can profoundly influence the hydrology of bogs. Muskrats create open water channels through the bog peat and beavers can cause substantial flooding or drying through their dam-building activities (Gates 1942, Heinselman 1963).

Rare plants associated with bogs include *Betula populifolia* (gray birch, state special concern), *Carex wiegandii* (Wiegand's sedge, state special concern), *Empetrum nigrum* (black crowberry, state threatened), *Isotria verticillata* (whorled pogonia, state threatened), *Platanthera ciliaris* (orange- or yellow-fringed orchid, state endangered), *P. leucophaea* (prairie white-fringed orchid, federal threatened and state endangered), *Rubus acaulis* (dwarf raspberry, state endangered), and *Sarracenia purpurea f. heterophylla* (yellow pitcher-plant, state threatened). *Eleocharis radicans* (spike-rush, presumed extirpated from Michigan) was historically known from floating-mat bogs in Washtenaw County.

Conservation and Biodiversity Management: Bog is a widespread community type in the Great Lakes region that contributes significantly to the overall biodiversity by providing habitat for a unique suite of plants and wide variety of animal species. Numerous rare species are associated with bogs. By storing high levels of sequestered carbon and serving as carbon sinks, bogs and related peatlands play an important role in global geochemical cycles. Bogs also preserve paleo-environmental records; a wealth of information is stored in the remains of plants, animals, and atmospheric particles deposited and stored in bog peat profiles (Chapman et al. 2003).

The primary mechanism for preserving bogs is to maintain their hydrology. As noted, peatland systems are sensitive to slight changes in water chemistry. A serious threat to bog hydrology is posed by off-road vehicle traffic, which can drastically alter bog hydrology through rutting and peat compaction. Reducing access to peatland systems will decrease detrimental impacts. Avoiding the construction of new roads that traverse peatlands will help prevent unintended hydrologic alteration. Roads passing through or near peatlands can cause dramatic changes, including conversion to more minerotrophic, open wetlands in flooded areas and increased forest productivity where drying results from blocked drainage. The installation and maintenance of culverts under roads passing through peatlands can reduce flooding and drying (Jeglum 1975). Resource managers operating in uplands adjacent to bogs should take care to minimize the impacts of management to hydrologic regimes, especially increased surface flow into bogs. This can be accomplished by establishing no-cut buffers around bogs, avoiding road construction and complete canopy removal in stands immediately adjacent to bogs, and maintaining native vegetation types in the uplands around bogs. Elevation of a bog's water table and clear-cutting within a bog can result in the expansion of leatherleaf and sphagnum and a subsequent decrease in floristic diversity (Schwintzer 1979). In fire-prone landscape, where shrub and tree encroachment threatens to convert open wetlands to shrub-dominated systems or forested swamps, prescribed fire or selective cutting can be employed to maintain open conditions. Silvicultural management of bogs to preserve open canopy should be employed during the winter to minimize damage to the peat and impacts to the hydrologic regime.

Photo by Bradford S. Slaughter

Within fire-prone landscapes, prescribed fire should be allowed to burn from surrounding uplands across bogs.

Photo by Joshua G. Cohen

Monitoring and control efforts to detect and remove invasive species before they become widespread are critical to the long-term viability of bog. Particularly aggressive invasive species that may threaten the diversity and community structure of bogs include *Rhamnus frangula* (glossy buckthorn), *Typha angustifolia* (narrow-leaved cat-tail), *Typha* x*glauca* (hybrid cat-tail), *Phalaris arundinacea* (reed canary grass), and *Phragmites australis* (reed). At present, most of these invasive species appear to be restricted to the margins of bogs, where they occur in moats or ditches along roads and trails that border the community.

Research Needs: Bog has a broad distribution and exhibits subtle regional, physiographic, hydrologic, and edaphic variants. This variation throughout its range demands the continual refinement of regional classifications that focus on the inter-relationships between vegetation, physiography, hydrology, and successional history of the peat (Heinselman 1963, Fitzgerald and Bailey 1975, Barnes et al. 1982). Systematic sampling and analysis of bogs by vegetative zone that assess peat chemistry and quantitative measures of cover for both vascular and non-vascular species are greatly needed for bog classification efforts. Bogs and related community types (i.e., poor fen, muskeg, and intermittent wetland) can be difficult to differentiate (Heinselman 1963, NatureServe 2006). Research on abiotic and biotic indicators that help distinguish similar peatlands would be useful for field classification. Systematic surveys for bogs and related peatlands are needed to help prioritize conservation and management efforts.

Photo by Gary Reese

An important research need is to ascertain how landscape context influences fire frequency and severity in bogs.

Little is known about the fire regimes of bogs and the interaction of disturbance factors within these systems. Of particular importance is the study of how fire severity and periodicity are influenced by landscape context. Site-specific fire frequencies can be estimated by investigating fossil pollen and charcoal records stored in peat (Larsen and MacDonald 1998). Understanding the complex interaction of fire and changes in hydrologic regimes and climate is a critical research need. As noted by Hammerson (1994), beaver significantly alter the ecosystems they occupy. An important research question to examine is how the wetland ecosystems of the Great Lakes have been and continue to be affected by fluctuations in populations of beaver. Experimentation is needed to determine how best to prevent shrub and tree encroachment in bogs that are threatened by conversion to shrub thicket or conifer swamp. A better understanding is needed of the influence of direct and indirect anthropogenic disturbances on peatlands (Amon et al. 2002). Effects of management within bogs should be monitored to allow for assessment and refinement of management techniques. More research is needed to elucidate the relationship of chemical factors and nutrient levels to floristic community structure of peatlands (Amon et al. 2002). The examination of non-native plant establishment in bogs and means of controlling invasive species is especially critical. Given the sensitivity of peatlands to slight changes in hydrology and nutrient availability, it is important for scientists to predict how peatlands will be affected by global warming and atmospheric deposition of nutrients and acidifying agents (Heinselman 1970, Riley 1989, Bedford et al. 1999, Gignac et al. 2000, Mitsch and Gosselink 2000). Peat deposits are of great scientific interest because they contain historical ecological records in the form of fossils of plants and animals and organic matter that contributed to the deposit. Fossilized humans have even been found in non-decomposing bog peat; the bog people of Scandinavia were preserved for approximately 2,000 years (Mitsch and Gosselink 2000). Stratigraphical analysis of peat cores provides insights into past climatic change and associated vegetation change, floristic distribution, development of wetland ecosystems, and successional pathways of peatlands (Heinselman 1963, Glaser et al. 1981, Miller 1981, Glaser and Janssens 1986, Riley 1989, Gignac et al. 2000).

Bog often grades to poor conifer swamp where peat mats have become grounded.

Similar Natural Communities: coastal plain marsh, intermittent wetland, inundated shrub swamp, muskeg, northern fen, patterned fen, poor conifer swamp, poor fen, prairie fen, rich tamarack swamp, rich conifer swamp.

Other Classifications:

Michigan Natural Features Inventory (MNFI) Circa 1800 Vegetation: Bog (6121), and Muskeg/Bog (6124)

Michigan Department of Natural Resources (MDNR): D (treed bog), and V (bog)

Michigan Resource Information Systems (MIRIS): 62 (non-forested wetland), 612 (shrub/scrub wetland), and 622 (emergent wetland)

Integrated Forest Monitoring, Assessment, and Prescription (IFMAP): Floating Aquatic (621), Lowland Shrub (622), Emergent Wetland (623), and Mixed Non-Forest Wetland (629)

The Nature Conservancy National Classification: CODE; ALLIANCE; ASSOCIATION; COMMON NAME

IV.A.1.N.g; *Chamaedaphne calyculata* Saturated Dwarf-Shrubland Alliance; *Chamaedaphne calyculata / Carex oligosperma – Eriophorum virginicum* Dwarf-shrubland; Leatherleaf / Few-seed Sedge – Tawny Cottongrass Dwarf Shrubland; Leatherleaf Kettle Bog

IV.A.1.N.g; *Chamaedaphne calyculata* Saturated Dwarf-Shrubland Alliance; *Chamaedaphne calyculata – Ledum groenlandicum – Kalmia polifolia* Bog Dwarf-shrubland; Leatherleaf – Labrador-tea –Bog Laurel Bog Dwarf-Shrubland; Leatherleaf Bog

V.A.5.N.m; *Carex oligosperma – Carex lasiocarpa* Saturated Herbaceuos Alliance; *Carex oligosperma – Carex pauciflora – Eriophorum vaginatum / Sphagnum* spp. Herbaceous Vegetation; Few-seed Sedge – Few-flower Sedge – Tussock Cottongrass / Peatmoss Species Herbaceous Vegetation; Open Graminoid / Sphagnum Bog

NatureServe Ecological Systems Classification:

CES103.581: Boreal-Laurentian Bog

Related Abstracts: American bittern, black-backed woodpecker, Blanchard's cricket frog, Blanding's turtle, coastal plain marsh, eastern box turtle, eastern massasauga, eastern prairie fringed orchid, English sundew, great blue heron rookery, incurvate emerald, intermittent wetland, merlin, muskeg, northern fen, northern harrier, osprey, poor conifer swamp, poor fen, prairie fen, relict conifer swamp, rich conifer swamp, secretive locust, spotted turtle, yellow pitcher plant, and yellow rail.

References:

Albert, D.A. 1995. Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: A working map and classification. Gen. Tech. Rep. NC-178. St. Paul, MN: USDA, Forest Service, North Central Forest Experiment Station, St. Paul, MN. http://nrs.fs.fed.us/pubs/242 (Version 03JUN1998). 250 pp.

Albert, D.A., J.G. Cohen, M.A. Kost, B.S. Slaughter, and H.D. Enander. 2008. Distribution maps of Michigan's Natural Communities. Michigan Natural Features Inventory, Report No. 2008-01, Lansing, MI. 174 pp.

Albert, D.A., S.R. Denton, and B.V. Barnes. 1986. Regional landscape ecosystems of Michigan. University of Michigan, School of Natural Resources, Ann Arbor, MI. 32 pp. & map.

Almendinger, J.C., J.E. Almendinger, and P.H. Glaser. 1986. Topographic fluctuations across a spring fen and raised bog in the Lost River Peatland, northern Minnesota. Journal of Ecology 74(2): 393-401.

Almendinger, J.A., and J.H. Leete. 1998. Regional and local hydrogeology of calcareous fens in the Minnesota River Basin, USA. Wetlands 18(2): 184-202.

Amon, J.P., C.A. Thompson, Q.J. Carpenter, and J. Mines. 2002. Temperate zone fens of the glaciated Midwestern USA. Wetlands 22(2): 301-317.

Anderson, D.S, R.B. Davis, S.C. Rooney, and C.S. Campbell. 1996. The ecology of sedges (*Cyperaceae*) in Maine peatlands. Bulletin of the Torrey Botanical Club 123(2): 100-110.

Asada, T., B.G. Warner, and S.L. Schiff. 2005. Effects of shallow flooding on vegetation and carbon pools in boreal peatlands. Applied Vegetation Science 8: 199-208.

Barnes, B.V. 1991. Deciduous forest of North America. Pp 219-344 in Temperate deciduous forests ed. E. Röhrig and B. Ulrich. Elsevier, Amsterdam. 635 pp.

Barnes, B.V., and W.H. Wagner, Jr. 1981. Michigan trees: A guide to the trees of Michigan and the Great Lakes region. University of Michigan Press, Ann Arbor, MI. 383 pp.

Barnes, B.V., K.S. Pregitzer, T.A. Spies, and V. H. Spooner. 1982. Ecological forest site classification. Journal of Forestry 80(8): 493-498.

Bay, R.R. 1967. Ground water and vegetation in two peat bogs in northern Minnesota. Ecology 48(2): 308-310.

Beckwith, L.C., and A.T. Drooz. 1956. Tamarack mortality in Minnesota due to larch sawfly outbreak. Journal of Forestry 54: 268-269.

Bedford, B.L., and K.S. Godwin. 2003. Fens of the United States: Distribution, characteristics, and scientific connection versus legal isolation. Wetlands 23(3): 608-629.

Bedford, B.L., M.R. Walbridge, and A. Aldous. 1999. Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology 80(7): 2151-2169.

Bisbee, K.E., S.T. Gower, J.M. Norman, and E.V. Nordheim. 2001. Environmental controls on ground cover species composition and productivity in a boreal black spruce forest. Oecologia 129: 261-270.

Boelter, D.H., and E.S. Verry. 1977. Peatland and water in the northern Lake States. USDA, Forest Service, North Central Forest Experiment Station, St. Paul, MN. General Technical Report NC-31. 26 pp.

Braun, E.L. 1950. Deciduous forests of eastern North America. Hafner Press, New York, NY. 596 pp.

Bridgham, S.D., J. Pastor, J.A. Janssens, C. Chapin, and T.J. Malterer. 1996. Multiple limiting gradients in peatlands: A call for a new paradigm. Wetlands 16(1): 45-65.

Brinson, M.M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13(2): 65-74.

Bubier, J.L. 1991. Patterns of *Picea mariana* (black spruce) growth and raised bog development in Victory Basin, Vermont. Bulletin of the Torrey Botanical Club 118(4): 399-411.

Burns, G.P. 1906. Bog studies. Field studies in botany. University Bulletin, New Series, 7(14): 3-13. University of Michigan, Ann Arbor, MI.

Chapman, S., A. Buttler, A.-J. Francez, F. Laggoun Defarge, H. Vasander, M. Schloter, J. Combe, P. Grosvernier, H. Harms, D. Epron, D. Gilbert, and E. Mitchell. 2003. Exploitation of northern peatlands and biodiversity maintenance: A conflict between economy and ecology. Frontiers in Ecology and the Environment 1(10): 525-532.

Coburn, H., D. Dean, and G.M. Grant. 1933. An ecological study of Bryant's Bog, Cheboygan County, Michigan. Papers of the Michigan Academy of Science, Arts, and Letters 17: 57-65.

Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's presettlement vegetation, as interpreted from the General Land Office surveys 1816-1856. Michigan Natural Features Inventory, Lansing, MI. Digital map.

Crow, H.A. 1969. An ecological analysis of a southern Michigan bog. Michigan Botanist 8: 11-27.

Crum, H. 1983. Mosses of the Great Lakes forest. University of Michigan, Ann Arbor, MI. 417 pp.

Curtis, J.T. 1959. The vegetation of Wisconsin: An ordination of plant communities. University of Wisconsin Press, Madison, WI. 657 pp.

Damman, A.W.H. 1986. Hydrology, development, and biogeochemistry of ombrogenous peat bogs with special reference to nutrient relocation in a western Newfoundland bog. Canadian Journal of Botany 64: 384-394.

Damman, A.W.H. 1988. Regulation of nitrogen removal in sphagnum bogs and other peatlands. Oikos 51: 291-305.

Damman, A.W.H. 1990. Nutrient status of ombrotrophic peat bogs. Aquilo Series Botanica 28: 5-14.

Dansereau, P., and F. Segadas-Vianna. 1952. Ecological study of the peat bogs of eastern North America. I. Structure and evolution of vegetation. Canadian Journal of Botany 30: 490-520.

Dean, D., and H. Coburn. 1927. An ecological study of Linne Bog, Cheboygan County, Michigan with special reference to *Nemopanthus mucranata* (L.) Trelease. Papers of the Michigan Academy of Science, Arts, and Letters 8: 87-96.

Eggers, S.D., and D.M. Reed. 1997. Wetland plants and plant communities of Minnesota and Wisconsin. U.S. Army Corps of Engineers, St Paul, MN. 263 pp.

Faber-Langendoen, D., ed. 2001. Plant communities of the Midwest: Classification in an ecological context. Association for Biodiversity Information, Arlington, VA. 61 pp. & appendix (705 pp.).

Fenton, N., N. Lecomte, S. Legare, and Y. Bergeron. 2005. Paludification in black spruce (*Picea mariana*) forests of eastern Canada: Potential factors and management implications. Forest Ecology and Management 213: 151-159.

Fitzgerald, S., and R.E. Bailey. 1975. Vegetational characteristics of a circum-neutral bog, Barney's Lake, Beaver Island, Michigan. Michigan Academician 7(4): 477-488.

Foster, D.R. 1985. Vegetation development following fire in *Picea mariana* (black spruce) Pleurozium forests of South-Eastern Labrador, Canada. Journal of Ecology 73(2): 517-534.

Frelich, L.E., and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forests of the Upper Great Lakes region. Ecological Monographs 61(2): 145-164.

Futyma, R.P., and N.G. Miller. 1986. Stratigraphy and genesis of the Lake Sixteen peatland, northern Michigan. Canadian Journal of Botany 64: 3008-19.

Gates, F.C. 1942. The bogs of northern Lower Michigan. Ecological Monographs 12(3): 213-254.

Gignac, L.D., L.A. Halsey, and D.H. Vitt. 2000. A bioclimatic model for the distribution of Sphagnum-dominated peatlands in North America under present climatic conditions. Journal of Biogeography 27(5): 1139-1151.

Girardin, M.-P., E. Berglund, J.C. Tardiff, and K. Monson. 2005. Radial growth of tamarack (*Larix laricina*) in the Churchill Area, Manitoba, Canada, in relation to climate and larch sawfly (*Pristiphora erichsonii*) herbivory. Artic, Antarctic, and Alpine Research 37(2): 206-217.

Glaser, P.H. 1992. Raised bogs in eastern North America – Regional controls for species richness and floristic assemblages. Journal of Ecology 80: 535-554.

Glaser, P.H., and J.A. Janssens. 1986. Raised bogs in eastern North America: Transitions in landforms and gross stratigraphy. Canadian Journal of Botany 64: 395-415.

Glaser, P.H., G.A. Wheeler, E. Gorham, and H.E. Wright, Jr. 1981. The patterned mires of the Red Lake Peatland, northern Minnesota: Vegetation, water chemistry and landforms. Journal of Ecology 69(2): 575-599.

Glaser, P.H., J.A. Janssens, and D.I. Siegel. 1990. The response of vegetation to chemical and hydrological gradients in the Lost River Peatland, northern Minnesota. Journal of Ecology 78(4): 1021-1048.

Gorham, E., and D.L. Tilton. 1978. The mineral content of *Sphagnum fuscum* as affected by human settlement. Canadian Journal of Botany 56: 2755-2759.

Graham, S.A. 1956. The larch sawfly in the Lake States. Forest Science 2(2): 132-160.

Grigal, D.F. 1990. Elemental dynamics in forested bogs in northern Minnesota. Canadian Journal of Botany 69: 539-546.

Groot, A., and B.J. Horton. 1994. Age and size structure of natural and second-growth peatland *Picea mariana* stands. Canadian Journal of Forest Research 24: 225-233.

Halsey, L.A., and D.H. Vitt. 2000. Sphagnum-dominated peatlands in North America since the last glacial maximum: Their occurrence and extent. The Bryologist 103(2): 334-352.

Hammerson, G. 1994. Beaver (*Castor canadensis*): Ecosystem alterations, management, and monitoring. Natural Areas Journal 14(1): 44-57.

Harper, K.A., C. Boudreault, L. DeGrandpre, P. Drapeau, S. Gauthier, and Y. Bergeron. 2003. Structure, composition, and diversity of old-growth black spruce boreal forest of the Clay Belt region in Quebec and Ontario. Environmental Review 11: 79-98.

Harper, K.A., Y. Bergeron, P. Drapeau, S. Gauthier, and L. DeGrandpre. 2005. Structural development following fire in black spruce boreal forest. Forest Ecology and Management 206: 293-306.

Heinselman, M.L. 1963. Forest sites, bog processes, and peatland types in the Glacial Lake Region, Minnesota. Ecological Monographs 33(4): 327-374.

Heinselman, M.L. 1965. String bogs and other patterned organic terrain near Seney, Upper Michigan. Ecology 46: 185-188.

Heinselman, M.L. 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatland Natural Area, Minnesota. Ecological Monographs 40(2): 235-261.

Henry, R., B. Brooks, and C. Davis. 1973. Population density of *Larix laricina* in a sphagnum bog mat habitat. Michigan Academician 4: 529-535.

Hoffman, R. 2002. Wisconsin's natural communities. How to recognize them, where to find them. University of Wisconsin Press, Madison, WI. 375 pp.

Janssen, C.R. 1967. A floristic study of forests and bog vegetation, Northwestern Minnesota. Ecology 48(5): 751-765.

Jasieniuk, M.A., and E.A. Johnson. 1982. Peatland vegetation organization and dynamics in western subartic, Northwest Territories, Canada. Canadian Journal of Botany 60: 2581-2593.

Jean, M., and A. Bouchard. 1991. Temporal changes in wetland landscapes of a section of the St. Lawrence River, Canada. Environmental Management 15(2): 241-250.

Jeglum, J.K. 1971. Plant indicators of pH and water level in peatlands at Candle Lake, Saskatchewan. Canadian Journal of Botany 49: 1661-1676.

Jeglum, J.K. 1974. Relative influence of moisture aeration and nutrients on vegetation and black spruce growth in Northern Ontario. Canadian Journal of Forest Research 4: 114-126.

Jeglum, J.K. 1975. Vegetation-habitat changes caused by damming a peatland drainageway in northern Ontario. Canadian Field Naturalist 89(4): 400-412.

Karlin, E.F., and L.C. Bliss. 1984. Variation in substrate chemistry along microtopographical and water-chemistry gradients in peatlands. Canadian Journal of Botany 62: 142-153.

Klinger, L.F. 1996. The myth of the classic hydrosere model of bog succession. Artic and Alpine Research 28 (1): 1-9.

Kost, M.A., D.A. Albert, J.G. Cohen, B.S. Slaughter, R.K. Schillo, C.R. Weber, and K.A. Chapman. 2007. Natural communities of Michigan: Classification and description. Michigan Natural Features Inventory, Report Number 2007-21, Lansing MI. 314 pp.

Larsen, C.P.S., and G.M. MacDonald. 1998. Fire and vegetation dynamics in a jack pine and black spruce forest reconstructed using fossil pollen and charcoal. Journal of Ecology 86: 815-828.

Liefers, V.J., and R.L. Rothwell. 1986. Effects of depth of water table and substrate temperature on root and top growth of *Picea mariana* and *Larix laricina* seedlings. Canadian Journal of Forest Research 16: 1201-1206.

Liefers, V.J., and S.E. MacDonald. 1990. Growth and foliar nutrient status of black spruce and tamarack in relation to depth of water table in some Alberta peatlands. Canadian Journal of Forest Research 20: 805-809.

Lindeman, R.L. 1941. The developmental history of Cedar Creek Bog, Minnesota. American Midland Naturalist 25(1): 101-112.

Locky, D.A., S.E. Bayley, and D.H. Vitt. 2005. The vegetational ecology of black spruce swamps, fens, and bogs in southern boreal Manitoba, Canada. Wetlands 25(3): 564-582.

MacDonald, S.E., and F. Yin. 1999. Factors influencing size inequality in peatland black spruce and tamarack: Evidence from post-drainage release growth. Journal of Ecology 87: 404-412.

McLaughlin, J.W., J.C. Lewin, D.D. Reed, C.C. Trettin, M.F. Jurgensen, and M.R. Gale. 1994. Soil factors related to dissolved organic carbon concentrations in a black spruce swamp, Michigan. Soil Science 158(6): 454-464.

Michigan Natural Feature Inventory. 2007. Biotics database. Michigan Natural Features Inventory, Lansing, MI.

Mitsch, W.J., and J.G. Gosselink. 2000. Wetlands. John Wiley and Sons, Inc, New York, NY. 920 pp.

Miller, N. 1981. Bogs, bales, and BTU's: A primer on peat. Horticulture 59: 38-45.

Miller, N.G., and R.P. Futyma. 1987. Paleohydrological implications of Holocene peatland development in northern Michigan. Quaternary Research 27: 297-311.

NatureServe. 2006. NatureServe Explorer: An online encyclopedia of life [Web application]. Version 4.2. NatureServe, Arlington, VA. Available: http://www.natureserve.org/explorer (Accessed: March 03, 2005.)

Newton, P.F., and P.A. Jolliffe. 1998. Temporal size-dependent growth responses within density stressed black spruce stands: Competition processes and budworm effects. Forest Ecology and Management 111: 1-13.

Nicholson, J., L.D. Gignac, and S.E. Bayley. 1996. Peatland distribution along a north-south transect in the Mackenzie River basin in relation to climate and environmental gradients. Vegetatio 126: 119-133.

Osvald, H. 1935. A bog at Hartford, Michigan. Ecology 16(3): 520-528.

Pepin, S., A.P. Plamondon, and A. Britel. 2002. Water relations of black spruce trees on a peatland during wet years and dry years. Wetlands 22(2): 225-233.

Peterson, E.B. 1965. Inhibition of black spruce primary roots by a water-soluble substance in *Kalmia angustifolia*. Forest Science 11 (4): 473-479.

Richardson, C.J., and P.E. Marshall. 1986. Processes controlling movement, storage, and export of phosphorous in a fen peatland. Ecological Monographs 56(4): 279-302.

Riley, J.L. 1989. Southern Ontario bogs and fens off the Canadian Shield. Pp. 355-367 in Wetlands: Inertia or momentum, ed. M.J. Bardecki and N. Patterson. Federation of Ontario Naturalists, Don Mills, ON. 426 pp.

Ruel, J.-C., R. Horvath, C.H. Ung, and A. Munson. 2004. Comparing height growth and biomass production of black spruce trees in logged and burned stands. Forest Ecology and Management 193: 371-384.

Schwintzer, C.R. 1978a. Nutrient and water levels in a small Michigan bog with high tree mortality. American Midland Naturalist 100(2): 441-451.

Schwintzer, C.R. 1978b. Vegetation and nutrient status of northern Michigan fens. Canadian Journal of Botany 56: 3044-3051.

Schwintzer, C.R. 1979. Vegetation changes following a water level rise and tree mortality in a Michigan bog. Michigan Botanist 18: 91-98.

Schwintzer, C.R. 1981. Vegetation and nutrient status of northern Michigan bogs and conifer swamps with a comparison to fens. Canadian Journal of Botany 59: 842-853.

Schwintzer, C.R, and G. Williams. 1974. Vegetation changes in a small Michigan bog from 1917 to 1972. American Midland Naturalist 92(2): 447-459.

Schwintzer, C.R, and T.J. Tomberlin. 1982. Chemical and physical characteristics of shallow ground waters in northern Michigan bogs, swamps, and fens. American Journal of Botany 69(8): 1231-1239.

Siegel, D.I. 1988. Evaluating cumulative effects of disturbance on the hydrologic function of bogs, fens, and mires. Environmental Management 12(5): 621-626.

Siegel, D.I., and P.H. Glaser. 1987. Groundwater flow in a bog-fen complex, Lost River Peatland, northern Minnesota. Journal of Ecology 75(3): 743-754.

Sjors, H. 1950. On the relation between vegetation and electrolytes in north Swedish mire water. Oikos 2: 241-257.

Swain, A.M. 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quaternary Research 3: 383-396.

Swanson, D.K., and D.F. Grigal. 1989. Vegetation indicators of organic soil properties in Minnesota. Soil Science Society of America Journal 53: 491-495.

Swinehart, A.L., and G.R. Parker. 2000. Palaeoecology and development of peatlands in Indiana. American Midland Naturalist 143(2): 267-297.

Taylor, S.J., T.J. Carleton, and P. Adams. 1988. Understorey vegetation change in a *Picea mariana* chronosequence. Vegetatio 73(2): 63-72.

Thompson, I.D., and A.U. Mallik. 1989. Moose browsing and allelopathic effects of *Kalmia angustifolia* on balsam fir regeneration in central Newfoundland. Canadian Journal of Forest Research 19: 524-526.

Tilton, D.L. 1977. Seasonal growth and foliar nutrients of *Larix laricina* in three wetland ecosystems. Canadian Journal of Botany 55: 1292-1297.

Verry, E.S. 1975. Streamflow chemistry and nutrient yields from upland-peatland watersheds in Minnesota. Ecology 65(5): 1149-1157.

Vitt, D.H., and N.G. Slack. 1975. An analysis of the vegetation of sphagnum-dominated kettle hole bogs in relation to environmental gradients. Canadian Journal of Botany 53: 332-359.

Vitt, D.H., and N.G. Slack. 1984. Niche diversification of sphagnum relative to environmental factors in northern Minnesota peatlands. Canadian Journal of Botany 62: 1409-1430.

Vitt, D.H., H. Crum, and J.A. Snider. 1975. The vertical zonation of sphagnum species in hummock-hollow complexes in northern Michigan. Michigan Botanist 14(4): 190-200.

Photo by Joshua G. Cohen

Bogs frequently occurpy kettle depressions, as pictured above in Grand Traverse County, northern Lower Michigan.

Wheeler, G.A., P.H. Glaser, E. Gorham, C.M. Wetmore, F.D. Bowers, and J.A. Janssens. 1983. Contributions to the flora of the Red Lake Peatland, northern Minnesota, with special attention to *Carex*. American Midland Naturalist 110(1): 62-96.

Yamasaki, S.H., J.W. Fyles, K.N. Egger, and B.D. Titus. 1998. The effect of *Kalmia angustifolia* on the growth, nutrition, and ectomycorrhizal symbiont community of black spruce. Forest Ecology and Management 105: 197-207.

Zhu, H., and A.U. Mallik. 1994. Interactions between *Kalmia* and black spruce: Isolation and identification of allelopathic compounds. Journal of Chemical Ecology 20(2): 407-421.

Zoltai, S.C., and D.H. Vitt. 1995. Canadian wetlands: Environmental gradients and classification. Vegetatio 118: 131-137.

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Photo by Joshua G. Cohen

Floating bog mat, Luce County, Michigan.

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