Trip A4

ECOLOGY AND GEOMORPHOLOGY OF ZURICH BOG

NAN CRYSTAL ARENS

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INTRODUCTION

Zurich Bog is an approximately 650-acre wetland complex located in the Wayne County, New York town of Arcadia (Fig. 1). Four hundred fourteen acres of the site are owned and managed by the Bergen Swamp Society, a private non-profit organization that conserves five wetland preserves in western New York State. The Zurich Bog preserve is designated a U.S. Department of the Interior National Natural History Landmark. Access to and research in Zurich Bog requires a permit from the Bergen Swamp Society (www.bergenswamp.org). The land is managed as a conservation, education and research site and is not used for recreation.

The Zurich wetland complex is situated in the Erie-Ontario lowlands, nestled between two tall drumlins (greater than 600 ft. elevation, nearly 200 ft. above the bog surface) that form a natural basin in which the wetland developed. Coring in the bog by several groups documented clay-rich layered marl underlaying the peat. These marls are interpreted as sediments from Glacial Lake Iroquois (T. Curtin personal communication, 2019). Low permeability in this clay marl may have contributed to the retention of water in the wetland complex. A smaller drumlin (approximately 450 ft. elevation, Fig. 1) creates a topographic high—an "island" of mineral soil—within the preserve that offers additional substrate diversity and enhances the plant species richness of the site. The wetland complex is underlain by bedrock of the Lockport Formation, Middle Silurian-age dolostones with some limestone and halite, preserved as macroscopic euhedral crystals in some places. Bedrock is not visible in the preserve although glacial till and abundant erratics are visible on the drumlin island.

The Zurich wetland complex is a persistent wetland, with the water table remaining near the surface throughout the year, except in conditions of extreme regional drought. Following the nomenclature used by Johnson (1985), the Zurich wetland complex can be divided into four distinct zones based on substrate characteristics and hydrology. Marshes and swamps are characterized by mineral substrate, though their high water table commonly yields organic-rich soils. Marshes are characterized primarily by herbaceous vegetation and swamps are dominated by woody vegetation with an herbaceous understory. In contrast to wetlands developed on mineral soils, Johnson (1985) distinguished peatlands, which have entirely organic soils. Within peatlands, Johnson (1985) distinguished bogs and fens based on their water source. Bogs are ombrotrophic—fed almost entirely by rainwater. In contrast, fens are fed primarily by groundwater. This

contrast renders bogs oligotrophic (nutrient poor) and generally acidic. Fens have significantly higher nutrient content (eutrophic) due to the influence of groundwater percolating through mineral bedrock. Fens like those at Zurich Bog, which received groundwater from carbonate bedrock, can be rich in Ca^{++} and Mg^{++} and neutral to alkaline in pH due to the buffering influence of bedrock. These hydrologic contrasts control the vegetation associations on bogs and fens as plant species seek preferred substrates across the landscape. This feature of wetland ecology is well-illustrated at Zurich Bog.

The Zurich wetland complex is of considerable biological—particularly botanical—interest because its diversity of ecotypes leads to an unusually high diversity of plant species, including some listed as threatened and endangered by New York State and the U.S. Department of Interior Endangered Species Act. The wetland also contains a mixture of cool-climate early Holocene plants and those typical of the hypsothermal assemblage in the region. The persistence of cool-climate plants in this site further enhances species richness. A resident turtle, *Clyptemys muhlenbergii* (bog turtle), is also listed as threatened or endangered by both state and federal agencies.

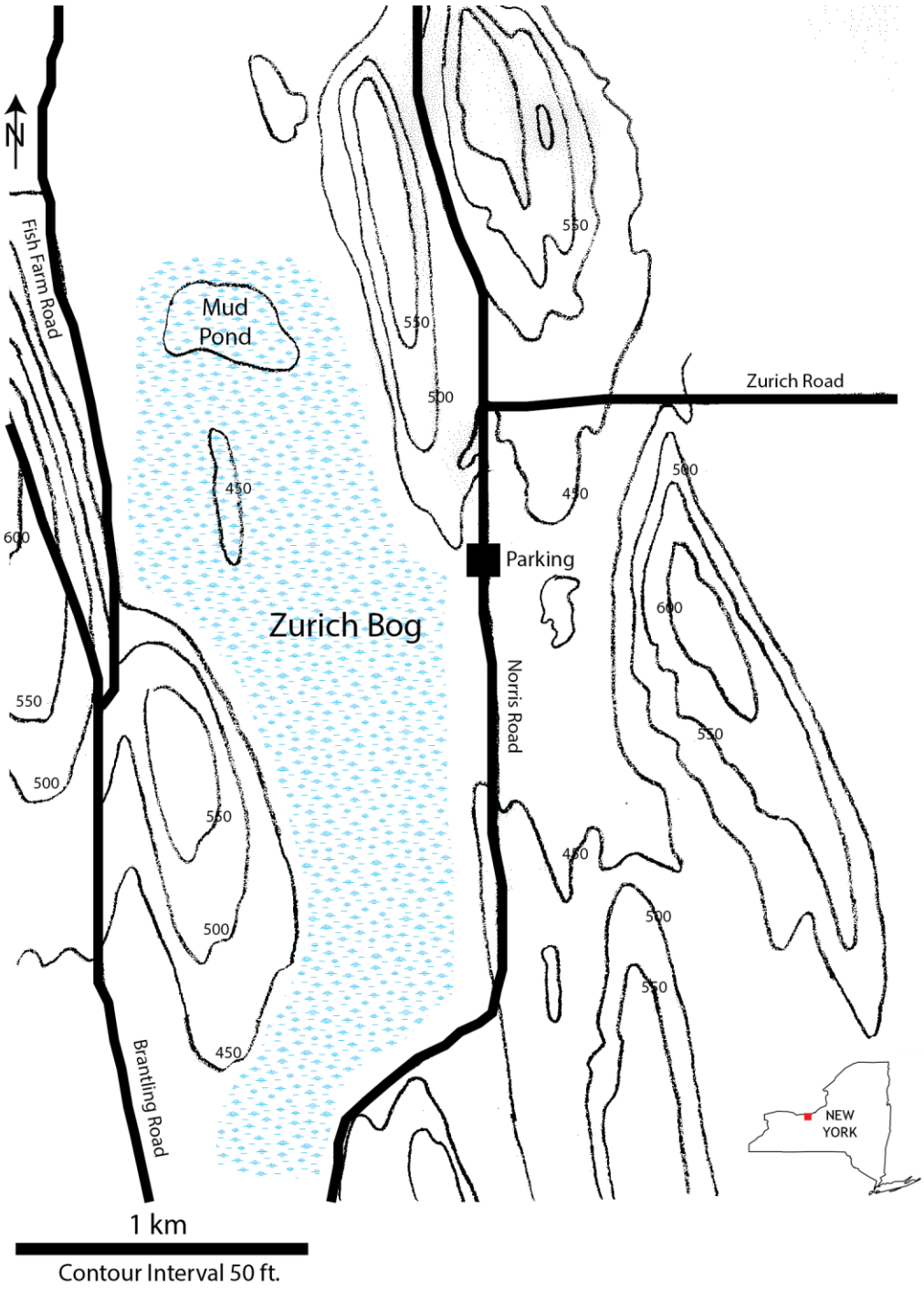

Figure 1: Topographic sketch map of the Zurich Bog wetland complex. Redrawn from the USGS 7.5 minute quadrangle Sodus, NY (2016).

Hydrology and Geochemistry

Wetlands, like the Zurich complex, are important components of watershed hydrology. They can absorb tremendous amounts of water during extreme rainfall events or rapid snow melt, making them vital to flood control. Goodwin (1931) estimated that the upper 20–50 cm of a bog may be up to 10% pore space, allowing for significant uptake of water. He measured a 7–12 cm rise in water table associated with a 1 cm rainfall event in an English fen (Goodwin, 1931). Conversely, bogs and fens release water slowly during precipitation deficit. Farmers to the north of the Zurich wetland complex have created irrigation channels to irrigate crops during the late summer and autumn drought.

The Zurich wetland complex can be divided in three main zones (Fig. 2): 1) drumlin island dominated by well-drained mineral soils derived from weathering of glacial till; 2) fen characterized by a floating sedge mat with a small area of open water in Mud Pond[1]; and 3) the *Sphagnum*-dominated bog and associated forested swamp.

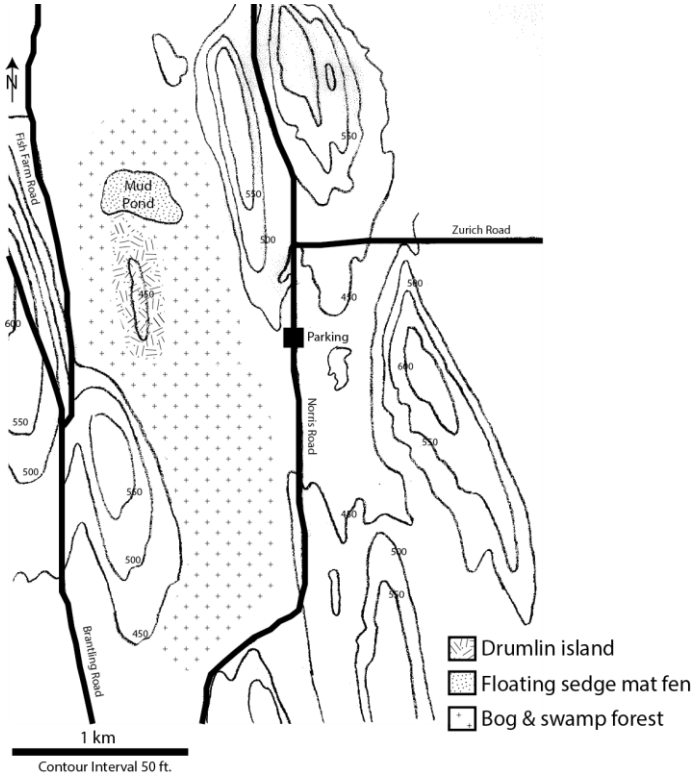

Figure 2: Distribution of hydrogeochemical zones within the Zurich Bog wetland. The Drumlin islands is characterized by well-drained mineral soils. The fen is a ground-water fed quaking bog. The bog and swamp zones are ombrotrophic peatlands with a variety of vegetation.

Floating Sedge Mat Fen

This section of the wetland complex is characterized by a dynamic combination of open water and a floating sedge mat (quaking bog) that supports other vegetation including shrubs and small trees. Over the last several decades, the area of open water has generally declined as the sedge mat and the other species it supports extend toward the interior of Mud Pond. Today, little open water is visible most years. The sedge

[1] In recent years, there has been little or no open water in Mud Pond. The pond's entire surface is covered in floating sedge mat.

mat overlays a zone of poorly consolidated, saturated peat that extends to depths of tens of meters. Groundwater flow is from the southwest to northeast in the fen (Halfman, 1999; Flusche, 2000), where water then mixes with flow derived from the *Sphagnum*-dominated bog. A piezometer field installed in the sedge mat fen during the late 1990s found very low and variable vertical flow that fluctuated seasonally. Low precipitation in 1999, the primary monitoring season, showed net infiltration (Flusche, 2000), which might be due to slow recharge and the resulting dropping of the groundwater table in response to drought.

Fen water is primarily derived from groundwater and is neutral to alkaline (pH = 6.6–7.3, Flusche, 2000) due to the influence of carbonates in the surrounding glacial till, which is derived from underlying carbonate bedrock. Ca^{++} dominates the fen water (39–110 ± 3 ppm, Flusche, 2000). Mg++ (9–26 ppm ± 1) and Cl- (26–84 ± 1 ppm) are also high, likely due to the halite-rich Lockport dolostone that underlays the region and from which the local till is derived. Nitrate and ammonia are low. Ion concentrations follow the pattern of flow from high in the southwestern part of the fen, where groundwater enters the system, to lower in the northeastern, where mixing with low-ion water from the *Sphagnum* bog dilutes ion concentrations (Flusche, 2000).

Sphagnum-Dominated Bog

Bogs receive their water exclusively from precipitation (Johnson 1985). This yields low pH (typically < 4.5) due, in part, to the low pH of source water (Gorham et al., 1985). In the case of the Zurich complex, isolation from airborne ion sources such as dust and air pollution limit further buffering. Biomass in the bog is dominated by several species of *Sphagnum* moss native to the northeast. Dominant *Sphagnum* further lowers pH by a combination of organic acids released by the living plants, uptake of buffering ions as micronutrients, and the activity of sulfur-metabolizing bacteria, which are both decomposers and commensals within the bog microbiome (Clymo, 1964). Bog water is also low in sulfate, nitrate and ammonia due to low input and rapid plant uptake of these macronutrients (Gorham et al., 1985). This nutrient poor environment provides a refuge for plants with limited nutrient needs (e.g., orchids like the prairie fringed orchid *Platanthera leucophaea*) and for charismatic carnivorous plants like sundews (e.g., *Drosera intermedia* and *D. rotundifolia*) and the purple pitcherplant (*Sarracenia purpurea*).

Water flow in bogs is generally through the upper, high-porosity layers of the peat, with deeper layers believed to be largely impermeable due to the loss of pore space during peat compression (Johnson, 1985). Siegel and Glaser (1987) challenged this notion with higher than expected $K_{horizontal}/K_{vertical}$ ratios in some Minnesota bogs. Although similar measurements have not been taken in the Zurich bog, geochemical measurements suggest mixing of low and high cation waters primarily at the surface (Flusche, 2000).

ECOLOGY AND BOTANY

This region is part of the Eastern Lake Section of the Central Lowland Floristic Province. Within the Zurich wetland complex, the hydrology of wetlands generally determines the distribution of plant and animal species. Bogs tend to harbor plants tolerant of low-nutrient conditions and saturated substrates. In contrast, fens will be dominated by species that can compete more successfully in higher-nutrient environments.

Several vegetation zones have been recognized in the Zurich wetland (Fig. 3): 1) mixed-hardwood and Hemlock (*Tsuga canadensis*) forest developed on the exposed drumlin island; 2) floating sedge mat fen; 3) *Sphagnum*-dominated bog; 4) *Arbovitae*-dominated swamp; and 5) Tamarack (*Larix laracina*) and black spruce (*Picea mariana*) swamp (Stauffer and Moosavi, 1991). While the drumlin and fen vegetation zones correspond directly to their hydrological counterparts described above, the ombrotrophic bog can be subdivided according to its successional status. In the northeast, ombrotrophic bogs begin with a *Sphagnum*-dominated association and, through time, succeed to shrub and tree-dominated assemblages that differ in species composition. In space, shrubs and trees enter the bog from its edges and successional assemblages develop in concentric zones (Dachnowski, 1912). Proga (1982) documented this concentric pattern in a series of vegetation transects across the bog.

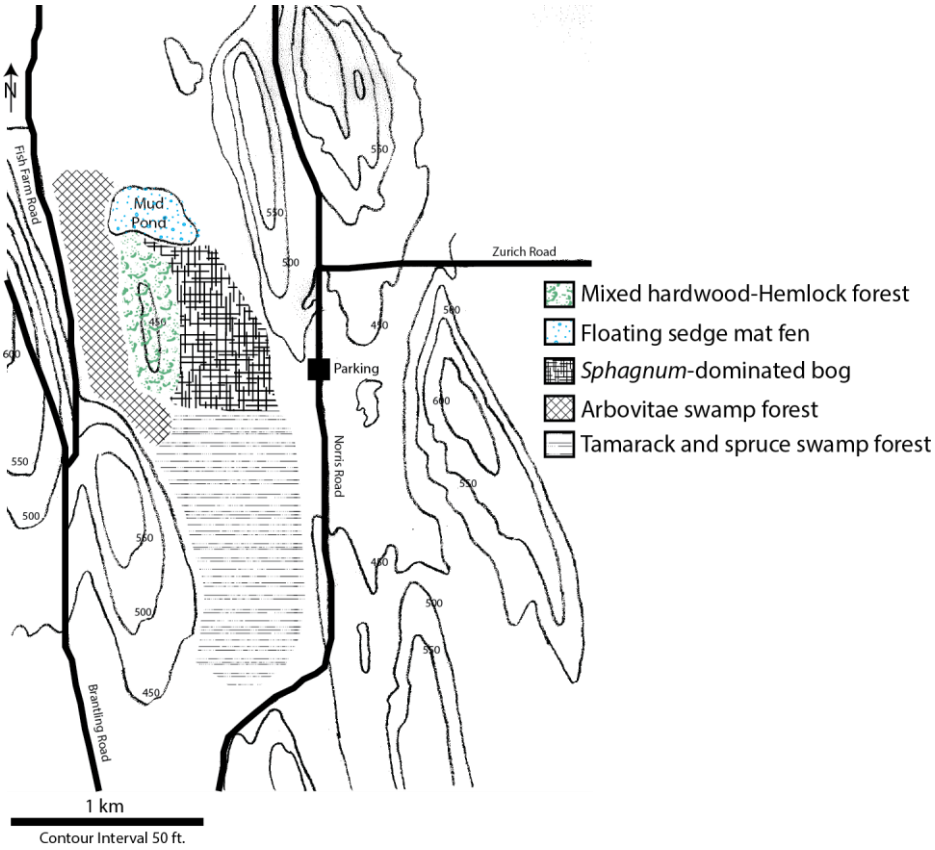

Figure 3: Distribution of vegetation zones within the Zurich Bog wetland. Vegetation parallels the distribution of hydrological zones with the additional overprint of successional status in the ombrotrophic peatlands. Redrawn and updated from Stauffer and Moosavi (1991).

Mixed Hardwood-Hemlock Assemblage

The mineral soils of the preserve's island drumlin are characterized by a mixed age stand of Eastern Hemlock (*Tsuga canadensis*). Although dominated by Hemlock, other hardwood species including mature red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), black cherry *(Prunus serotina*), red oak (*Quercus rubra*), beech (*Fagus grandifolia*), white pine (Pinus strobus), and tulip tree (*Liriodendron tulipifera*) can be found. Botanical enthusiasts have reported seedlings of American elm (*Ulmus americana*) within this small patch of forest. Understory herbs include false solomon's seal (*Smilacina racemose*), Indian cucumber (*Medeola virginiana*)

and several species of trillium (e.g., *Trillium grandiflorum* and *T. erectum*). In low-lying wet areas, grape fern (*Botrychium virginianum*) dominates.

An Interesting component of this vegetation is the mixed-age nature of the Hemlock stand. Whilst most hardwoods are fully mature with little regeneration, the Hemlock component includes stems of all age classes. To my knowledge, the Hemlocks of Zurich Bog have not been cored for age determination, but stem size suggests that some trees may be several hundred years old, perhaps predating European settlement of the area. This raises the interesting question of how this stand escaped clear-cutting during the colonization period. It seems likely that despite the value of both Hemlock and the other hardwoods as building and cabinetry species, the difficulty of traversing the bog made logging of this tiny patch or forest impractical. Furthermore, Hemlock is highly fire intolerant. Consequently, Hemlock stands are relatively rare in the Ontario Lowlands, where indigenous people historically managed forests with fire. The regenerating Hemlock stand may persist on Zurich's drumlin island because it was further protected from fire by the surrounding wetland. Although indigenous people used *Sphagnum* and other bog species for many purposes, there were few native plant resources on the drumlin island that were not present in more accessible parts of the surrounding landscape. Thus, the drumlin island might have served as a refuge for Hemlock.

Floating Sedge Fen

Floating fens, also known as quaking bogs, are relatively rare. They form during pond succession in which the drop off into the pond is too steep to allow vegetation to gradually build peat inward from the edges. They also require the high-nutrient fen environment to support sedges. To form the floating fen, a dense mat of sedge (e.g., *Scirpus* spp.) forms over poorly consolidated waterlogged peat. Such mats are generally 10–20 cm thick and dense enough to support an adult's weight. At Zurich Bog, the quaking bog is a delight to visitors who enjoy the "waterbed" sensation of walking across the fen.

Although tolerant of the wetland's saturated substrates, *Scirpus* and associated species like *Eleocharis* spp. and twig-rush (*Cladium mariscoides*) require high nutrient levels. Therefore, they are restricted to the fen. At the boundary between mineral soil and the fen (known as the lagg), nutrient loving plants such as cattail (*Typha angustifolia*) dominate. Lagg plants do not form the dense, weight-supporting mat characteristic of the fen itself and this is the spot where a misstep may cause visitors to sample the underlying peat! Within the last two decades, the lagg zone at Zurich Bog has been invaded by aggressive non-natives such as the common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*). Over time, the sedge mat has been colonized by water willow (*Decodon verticillatus*) that moves in from the margins. The sedge mat hosts abundant purple pitcherplant (*Sarracenia purpurea*), bog twayblade (*Liparis loeselii*), bladderworts, and club moss. The precise species composition, particularly for rare species, varies considerably over time likely due to changing hydrological and nutrient conditions. For example, bogbean has been reported within the fen association in the past but was absent during surveys in the mid-1980s (Stauffer and Moosavi, 1991). Whether this can be considered an extirpation or simply the waxing and waning of the distribution within the preserve is not known.

Sphagnum Bog

The *Sphagnum*-dominated bog is characterized by a peat substrate with low pH and very low nutrient conditions. This dramatically restricts the suite of vascular plants that can colonize this zone. Carnivorous plants capable of harvesting nitrogen from animal sources are common in this part of the preserve. Sundews (*Drosera intermedia* and *D. rotundifolia*) produce sticky liquid on the tips of hairs to capture small flying

insects. The purple pitcherplant (*Sarracenia purpurea*) captures insects and small vertebrates in a fluid-filled pitcher laced with digestive enzymes. A variety of orchids, including the threatened prairie white fringed orchid (*Platanthera praeclara*) are abundant.

Today, the edges of the *Sphagnum*-dominated bog are protected by a dense stand of highbush blueberry (*Vaccinium corymbosum*) and black huckleberry (*Gaylussacia baccata*). While tolerant of the low nutrient, acid soils, these species do not tolerate waterlogged substrates and thus cling to the edge of the zone.

The composition of the shrub component of the *Sphagnum* bog has changed significantly through time as a consequence of human activity. Between 1876 and 1900, bog peat was hand cut for florist's moss. This stripped vegetation to a depth of about one meter and removed living *Sphagnum* and other vascular plants. Following this disturbance, leatherleaf (*Chamaedaphne calyculata*) colonized the bog and became the dominant shrub. Peat harvest resumed from 1940 to 1943. Leatherleaf did not return in abundance at that site and the current association of highbush blueberry, huckleberry and black chokeberry (*Aronia melanocarpa*) colonized. Furthermore, the small white lady's slipper (*Cypripedium candidum*), ram's head lady's slipper (*C. arietinum*), and linear-leaf sundew (*Drosera linearis*) have not been reported in the bog between 1939 and 1982.

Swamp Associations

Two swamp forest associations are recognized within the preserve (Stauffer and Moosavi, 1991): one dominated by arborvitae (*Thuja occidentalis*, also known as northern white cedar) occurs to the west of the drumlin island, and the other dominated by black spruce (*Picea mariana*) and tamarack (*Larix laricina*) is found to the south and east. Both represent advanced successional stages in the bog ecotype. There is no clear evidence to explain the differences in species dominance in these swamps. It seems likely that priority of colonization determined the dominant trees and shrubs in these two areas.

Dynamic Vegetation

Any description of the Zurich wetland complex vegetation will necessarily be transient. Like all wetlands, the Zurich complex is in a state of succession that has transformed it from post-glacial ponds with substantial open water, through fen, bog and swamp forest associations. Over time, forest associations will dominate the whole preserve. Of course, human activity may reset the successional clock as it did when peat was harvested in the early 20th Century.

The nature of this natural succession calls managers to reflect on the goals of preservation. Is our goal to preserve the natural change in ecological systems, which may eventually lead to the extirpation or extinction of rare and cherished species? Alternatively, do we manage to maintain a particular snapshot of succession with a particular suite of species and associations? And if the latter, which moment in time do we choose to preserve? These questions become increasingly relevant as we enter a period of rapid climate change in which patterns of temperature and precipitation will change the hydrology and temperature range for this region in ways that may drift outside the preferences of some species that thrive in the reserve today.

VEGETATION HISTORY AND CLIMATE

No palynological reconstructions of the Zurich Bog vegetation have been published. However, post-glacial succession likely progressed as in other areas in the region. Early colonizers were likely grasses and sedges

along with low-bush willow (*Salix*), alder (*Alnus*) and birch (*Betula*) (Maenza-Gmelch, 1997). This association was followed by cold-tolerant pine, spruce and fir forests. At Zurich Bog today, *Picea mariana* is a relic of this association. Other cool-climate relics include tamarack (*Larix laricina*) found in the swamp association, and leatherleaf (*Chamaedaphne calyculata*), Labrador tea (*Ledum groenlandicum*) and cranberry (*Vaccinium oxycoccus*) found in the *Sphagnum*-dominated bog at at the edges of the fen. The presence of these cool-climate relics with other woody species associated with warmer winters (e.g., red maple, American beech, white pine and tulip tree) speak to the vegetation crossroad preserved by Zurich Bog. This mixture of warm- and cool-climate plants enhances species richness in this small area, as does the diversity of substrate types present in the preserve.

In contemporary discussions of climate change, wetlands play an outsized role for their relatively small area. By preserving plant biomass as peat, bogs and fens sequester carbon (Lamers et al., 1999). In addition, wetlands may release methane resulting from anaerobic microbial activity in peat. Whiting and Chanton (2001) report that wetlands have a net carbon sequestration effect. However, the greater infrared absorptivity of methane compared to CO_2 reduced the greenhouse gain due to carbon sequestration. They concluded that temperate wetlands like Zurich Bog have a small attenuating effect on greenhouse warming (Whiting and Chanton, 2001). This, coupled with the biological diversity and aesthetic beauty of wetlands like Zurich Bog provide ample reason to prioritize their preservation.

FIELD TRIP GUIDE

Field trip meeting point: Parking area of the Zurich Bog preserve 43° 08’ 45.7”N, 77° 02’ 53.77”W

Parking is limited to four vehicles.

We will proceed on foot into the reserve following established trail and boardwalk through the mixed hardwood association to the *Sphagnum*-dominated bog, Hemlock forest on the drumlin island, and onto the floating sedge mat fen. We will return by the same route.

Water-proof boots are recommended on the fen. Please stay on the established boardwalk and trail through the *Sphagnum* bog to prevent damage to delicate herbaceous plants.

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