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SEVENTEEN YEARS OF CHANGE IN TWO *SPHAGNUM* BOGS IN NOBLE COUNTY, INDIANA

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ABSTRACT. This investigation continues long-term monitoring of vegetation change in Tamarack and Hickory Bogs at the Merry Lea Environmental Center in Noble County. Tamarack Bog was drained in 1899, accelerating its succession. Over the past 100 years, it has been visited by several notable scientists, who documented aspects of its vegetation, including Charles R. Dryer (1899), Charles C. Deam (1916), Ray C. Friesner (1935), and Alton A. Lindsey (1972). In 1993, A. L. Swinehart conducted the first systematic, quantitative study of Tamarack Bog, as well as Hickory Bog (a tiny *Sphagnum* bog nestled within the crest of an esker). The same quadrats used in 1993 were used in the present study (2010) to examine changes in the peatlands over the past 17 years. Indicator species analysis, multiple response permutation procedure, and non-metric multidimensional scaling were used to analyze changes in frequency, cover, and presence / absence. The flora in undisturbed Hickory Bog is unchanged, whereas, Tamarack Bog has exhibited significant change.

Keywords: Peatland, bog, *Sphagnum*, *Larix laricina*, succession

INTRODUCTION

The Indiana Department of Environmental Management estimates that 85% of Indiana's wetlands have been lost to drainage and filling since the 1780's. These losses included *Sphagnum* bogs and tamarack swamps. Based on the characteristic peatland soil, Houghton Muck, there was at least 62,087 ha (149,009 acres) of peatlands in Indiana (Swinehart 1997). Only a fraction of the associated plant communities has survived to the present, due to human activity.

While there are approximately 70 peatlands (bogs, fens, and forested peatlands) registered with the Indiana Department of Natural Resources, Division of Nature Preserves (IDNR-DNP) (most of which have some form of protection), peatlands with healthy, reproducing tamarack populations are few. Compilation of occurrence data from Purdue University's Kriebel Herbarium (PUL), Indiana University's Deam Herbarium (IND), the IDNR-DNP database, as well as from Blatchley & Ashley (1901), Dryer (1901), Taylor (1907), Lindsey et al. (1969), and Wilcox (1982), show that tamarack was once widespread in northern Indiana, occurring in 18 counties. Tamarack (and associated bog communities) has since disappeared from most of these sites. Tamarack communities at most of the remaining sites are not likely to survive long. Reconnaissance reports in the late 1970's by employees of the IDNR (1996) on the status of tamarack sites in Indiana, include statements such as, "most not vigorous", "four trees, seem to be dying", "Only about a dozen trees, further deterioration likely", and "Being enveloped by hardwoods".

Peatlands in Indiana naturally trend toward development into lowland forests dominated by *Acer rubrum* (Swinehart & Parker 2000). This has been reported by other investigators studying peatlands in the southern Great Lakes Region (Transeau 1905, Crow 1969, Sytsma & Pippen 1982, Crum 1988). While this occurs naturally at a relatively slow rate, drainage of peatlands accelerates the transition from the "bog-conifer type" community to a "hardwood-conifer type" community dominated by red maple (LeBarron & Neetzel 1942). A floating mat, typical of bogs, can rise and fall with changing water-levels, keeping the substrate saturated, but not covered with standing

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water. Drainage can ground floating mats, resulting in flooding of the substrate during water-level fluctuations. These conditions of intermittent flooding (and associated release of N and P from decomposition during dry spells) favor red maple (Moizuk & Livingston 1966). Water-level fluctuations, coupled with the shade created by a red maple canopy, negatively affect tamarack regeneration (Duncan 1954) and ultimately lead to their demise and the demise of the associated understory flora, especially in Indiana and other southern reaches of its natural range where climate may not be optimal.

Investigation of the current condition and rate of succession of Indiana's peatlands, especially tamarack swamps, is necessary to guide conservation management and restoration efforts. While many studies have characterized the standing vegetation of peatlands in the northern hemisphere, few have monitored changes in peatland vegetation by subsequent quantitative sampling (see Backéus 1972; Frankl & Schmeidl 2000; Gunnarsson et al. 2002; Pellerin et al. 2008).

The year 2010 marked the 17th year since Tamarack and Hickory Bogs in Noble County, Indiana, were systematically surveyed (Swinehart 1994). The objectives of the present study are to systematically sample the current flora of Tamarack and Hickory Bogs and compare the current flora with the flora recorded in 1993 to determine the rate and process of plant succession.

STUDY AREA

Tamarack Bog is located in Noble Township, Noble County, Indiana (SWQ, SWQ, Sec 7, T33N, R9E). Hickory Bog is located in Washington Township, Noble County, Indiana (NEQ, NEQ, Sec 12, T33N, R8E). Both bogs are situated within the boundaries of the Merry Lea Environmental Center of Goshen College (Figure 1). Both Hickory Bog (0.6 ha) and Tamarack Bog (14 ha) are surrounded by *Quercus-Carya* forest buffers which separate the bogs from adjacent agricultural fields (Swinehart *et al.* 2001). In 1993, Swinehart (1994) found that invasion by shade-tolerant trees (*Acer rubrum, A. saccharinum,* and *Quercus palustris*) within Tamarack Bog had reduced the remnant bog species to a 10,500 m^2 wet depression in the center of the wetland basin.

Hickory bog.—Hickory Bog was discovered by Swinehart in 1991 and is located on top of an esker which was formed during the retreat of the Saginaw Lobe of Late Wisconsin glaciation. This esker may have been formed by a high, narrow crack or tunnel in the Saginaw ice (Dryer 1901). The roof of this tunnel may have collapsed to create an open ice-walled canyon into which more glacial debris was deposited (Dryer 1901). However, it is more likely that this esker was formed from a tunnel, not a canyon, due to the presence of a layer of glacial till (derived from the roof of the tunnel) on top of the outwash deposit.

Tamarack bog.—Tamarack Bog was probably a floating mat of bog vegetation connected to Old Bear Lake by wetland prior to the lake's drainage *ca.* 1850 (Swinehart 1994). Dryer (1901) was the first scientist to record a visit to Tamarack Bog and noted its location within the same esker lake system as Hickory Bog. Dryer's visit occurred after the first drainage of Old Bear Lake, but prior to the second drainage of the lake system in November, 1899. Blatchley and Ashley (1901) visited High Lake shortly after the drainage in 1899, and took a photograph of the lake showing a mature tamarack forest in the background. A mature tamarack forest would need relatively firm substrate suggesting that the initial grounding of the mat of bog vegetation had occurred prior to the 1899 drainage. Charles Deam noted the presence of *Andromeda glaucophylla* in 1920, and in 1935 and 1938, Ray Friesner reported *Vaccinium oxycoccos* and *Sarracenia purpurea*, respectively (IDNR 1992). These qualitative reports indicate a bog community. Alton Lindsey conducted the first cursory floral survey in 1972 and reported *Cypripedium acaule*, *Lycopodium clavatum*, twenty living tamarack trees, and an open *Acer* canopy forming above the tamarack (Swinehart 1994).

The first quantitative study of the bog was conducted in 1993 (Swinehart 1994, Swinehart & Starks 1994). *A. glaucophylla, V. oxycoccos, L. clavatum*, and *S. purpurea* were absent and the population of *Larix laricina* was reduced to three living specimens. Lindsey visited the bog with Swinehart in 1993 and noted that the *Acer* canopy had closed significantly since 1972. Tree cover has also been shown to increase in drained bogs in Sweden and Switzerland (Freléchoux et al. 2000; Linderholm & Leine 2004). The drainage of Old Bear Lake caused grounding of the vegetative mat which increased

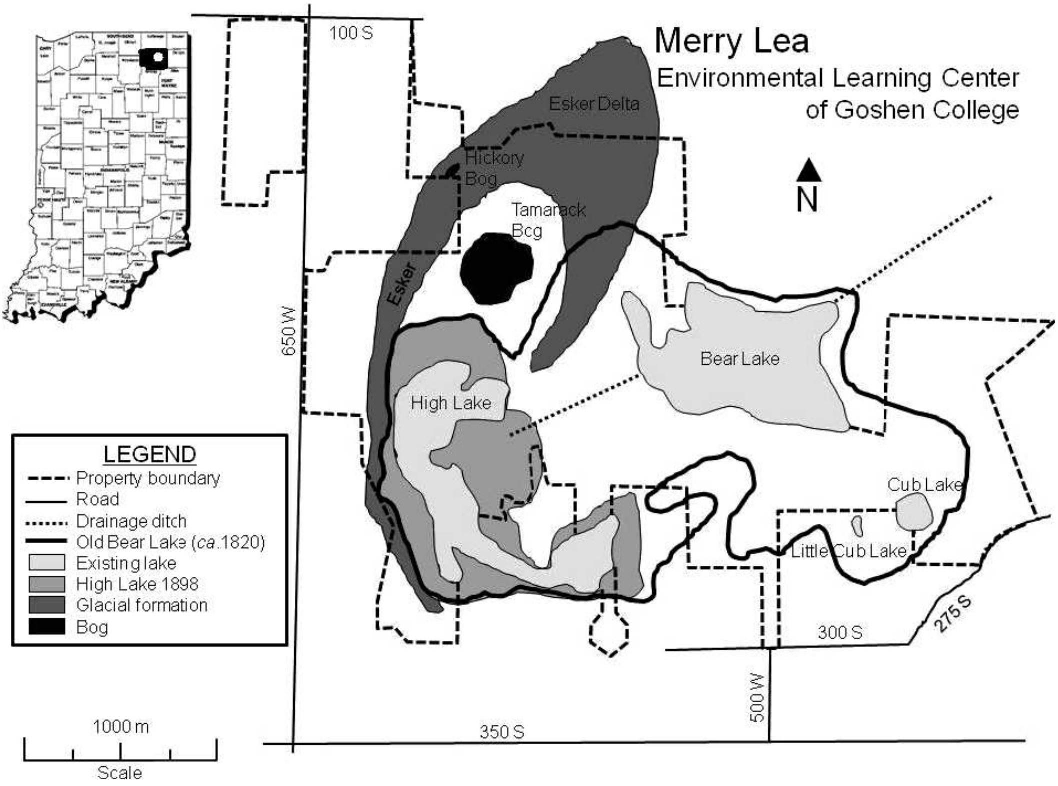

Figure 1.—Map of the study area showing the location of Hickory and Tamarack Bogs at the Merry Lea Environmental Learning Center of Goshen College (Secs. 12, 13 of T33N, R8E and Secs. 7, 17, 18, T33N, R9E).

available oxygen and nutrients for plant growth and accelerated the rate of succession towards a hardwood swamp from that of an open bog (Swinehart 1994).

MATERIALS AND METHODS

Herbaceous and woody vegetation were sampled using nested quadrats arranged systematically. Placement of quadrats was consistent with Swinehart (1994) in both bogs. Remains of permanent markers placed by Swinehart facilitated the re-establishment of the west-east baseline of Tamarack Bog and the southwest-northeast baseline along the long axis of Hickory Bog, with transects placed at twenty meter intervals perpendicular to each baseline. The presence of the permanent markers ensured that the quadrats were consistent with Swinehart's 1993 placement. Quadrats were placed at 15-m intervals along each transect in both bogs. Fourteen quadrats were established in Hickory Bog and thirty-seven in Tamarack Bog. The quadrats were nested. Aquatic, ground, and herbaceous layer vegetation was sampled using 1 m^2 quadrats. Shrubs and trees were sampled using 100 m^2 quadrats. The aquatic layer was comprised of submerged or floating plants; the ground layer was restricted to bryophytes; the herbaceous stratum was characterized as vegetation less than 1 m in height; the shrub layer was characterized as vegetation with diameter at breast height (DBH) $\leq$ 4 cm; the tree layer was characterized as vegetation with living stems $>$ 4 cm DBH. Shrub and tree data was not collected for Hickory Bog due to logistical problems associated with the treacherous floating mat. Percent frequency and percent cover were calculated for the herbaceous, ground, and aquatic layers in each bog. Percent frequency was calculated for each bog by dividing the number of quadrats in which a species was found by the total number of quadrats sampled in that bog. Percent cover was calculated by dividing the sum of observed cover values for each species in each bog by the total number of quadrats in that bog. Density, rather than percent cover, was calculated for the tree and shrub layers. Basal area was also calculated for the tree layer using a tape measure to determine DBH. Importance values were determined for each species in each bog by calculating the average of the relative frequency and relative cover. Taxonomic nomenclature of gymnosperms and angiosperms, ferns, mosses, and liverworts follows Voss (1980, 1985, 1996), Cobb (1963), Crum & Anderson (1981), and Conard (1956), respectively.

Analysis of the herbaceous layer and ground layer data was conducted using Non-metric multidimensional scaling (NMS), Multiple Response Permutation Procedure (MRPP) and Indicator Species Analysis (ISA). NMS provided a two dimensional graphical representation of the data, showing relative similarity of vegetation in the quadrats based on presence / absence, frequency, and cover. MRPP tested for difference in percent cover, percent frequency, and presence/absence of species between the two samplings. ISA identified the species that account for the greatest difference in percent cover, percent frequency, and presence / absence of species between two samplings.

The sampling of Tamarack Bog, for the present study, was conducted from June 10 – June 13, 2010. The sampling conducted in 1993 began on May 9 and ended on May 12. Because the differing months of collection (representing about 30 days) may have resulted in differences in cover related to early seasonal growth (rather than long-term successional changes), some species were removed from the statistical comparison of the two time periods. Based on observations of changes in spring growth between May and June of the species present, three species seemed likely to have added more significant foliage cover between May and June than the other species in the herbaceous layer. These were *Dryopteris spinulosa*, *Osmunda cinnamomea*, and *Rubus allegheniensis*. The same statistical test was conducted with the inclusion of these species for comparison.

RESULTS AND DISCUSSION

HICKORY BOG

Flora of hickory bog.—Eighteen vascular plant and three bryophyte species were identified in the sampling area in Hickory Bog (Table 1). The bog contains a number of species common to mineral-rich tall-shrub bogs, including *Cephalanthus occidentalis*, *Dulichium arundinaceum*, *Toxicodendron vernix*, *Triadenum fraseri*, and *Sphagnum fimbriatum*. Three species identified in the current study were not present in the previous study of Hickory Bog (Swinehart et al. 2001). These species, *Polygonum sagittatum*, *Carex echinata*, and *Cicuta bulbifera,* are common in wet areas in northern Indiana. Only one species, *Carex crinita*, from Swinehart's previous study of Hickory Bog was not found within the study area. This species may still be present in Hickory Bog because a qualitative survey was not conducted. There were no significant changes in the order of importance (based on importance values) of herbaceous flora in Hickory Bog, and *Sphagnum fimbriatum* remained the most important plant in the ground layer.

Statistical analysis.—Statistical examination of the herbaceous layer provides reliable indication of wetland status because the herbaceous layer changes more quickly than the higher layers in response to altered hydrology (Tiner 1999). MRPP indicated that the herbaceous community of Hickory Bog did not show statistical difference between 1993 and 2010 (p-value 0.275). Graphical confirmation was indicated by NMS with an ordination that did not display distinct groupings of quadrats (Figure 2). The relatively slow rate of succession of Hickory Bog is similar to that of Smith's Bog, another small *Dulichium* dominated bog in Cheboygan Co., MI. Woollett et al. (1926) predicted that the open water in Smith's bog would disappear in 10-20 years and be replaced by a *Carex* meadow followed by high-shrub species. However, Johns (1966) reported that "their predictions have not been justified by the intervening 34 years. The bog pool is scarcely smaller, and the water has certainly not disappeared". The study of another bog in northern Michigan exhibited similar slow rate of change. Following a series of dry years ending in 1927, Jewell and Brown (1929) expected Mud Lake to be completely covered by the sedge meadow of Mud Lake Bog during the next series of dry years. However in 1973, most of Mud Lake was still open water forty-six years later (Schwintzer & Williams 1974). Hickory Bog reflects the relatively slow rate of succession exhibited by these undisturbed bogs in northern Michigan.

Table 1.—Vegetation of Hickory Bog, Noble County, Indiana, June 2010 (14 quadrats). Percent frequency, percent cover, and importance values are listed for the herbaceous, ground, and aquatic layers. Relative values are listed in parentheses. "ND" means that the species was present, but no numerical data is available.

Layer/Species	% Freq.	% Cover	I.V.
HERBACEOUS LAYER			
Dulichiuma arundinaceum	43 (10)	21 (35)	23
Impatiens capensis	50 (12)	17 (28)	20
Cephalanthus occidentalis	36 (8)	7 (12)	10
Leersia oryzoides	57 (13)	4 (7)	10
Triadenum fraseri	29 (7)	3 (5)	6
Thelypteris palustris	36 (8)	1 (2)	5
Boehmeria cylindrica	29 (7)	1 (1)	4
Polygonum sagittatum	29 (7)	1 (1)	4
Bidens sp.	21 (5)	1 (2)	3
Unidentified sedges	21 (5)	1 (1)	3
Eupatorium perfoliatum	21 (5)	1 (1)	3
Galium sp.	21 (5)	0.4 (1)	3
Cicuta bulbifera	7 (2)	0.3 (0.5)	1
Carex echinata	7 (2)	0.2 (0.4)	1
Ilex verticillata	7 (2)	0.2 (0.4)	1
Onoclea sensibilis	7 (2)	0.2 (0.4)	1
Toxicodendron vernix	7 (2)	0.2 (0.4)	1
GROUND LAYER			
Sphagnum fimbriatum	14 (29)	3.1 (56)	42
Aulacomnium palustre	14 (29)	2 (32)	30
Leptodictyum riparium	21 (43)	0.4 (6)	17
AQUATIC LAYER			
Lemna minor	57 (100)	39 (100)	100
Wolffia sp.	ND	ND	ND

TAMARACK BOG

Flora of tamarack bog.—Twenty-six vascular plant and nine bryophyte species were identified within the sampling area in Tamarack Bog (Table 2). Many of these species are remnant bog species. The remnant tamarack bog species in the shrub layer include *Vaccinium corymbosum*, *Ilex verticillata*, *Aronia melanocarpa*, and *Nemopanthus mucronatus*. Remnant tamarack bog species of the herbaceous layer include *Maianthemum canadense*, *Trientalis borealis*, *Osmunda cinnamomea*, *Carex trisperma*, and *Rubus hispidus* (northern raspberry).

Cf. Nyssa sylvatica is the only tree species not previously recorded and may have been overlooked in previous investigations. It is found in other forested peatlands in northern Indiana (Swinehart et al. 2001).

Vascular plant species which were not previously observed in Tamarack Bog include *Viola* sp., *Boehmeria cylindrica*, *Polygonum virginianum*, *Leersia oryzoides*, and *Triadenum fraseri*. Each of these species is adapted to wet conditions. *Triadenum fraseri* is commonly found in bogs (Conway 1949). Swinehart (1994) noted the presence of *Viola* sp. in the wetland surrounding Tamarack Bog, but not in the bog proper.

There were no herbaceous species from the 1993 quadrats that were not found in the 2010 quadrats. However, there were some marked changes in importance. *Osmunda cinnamomea* replaced *Maianthemum canadense* as the most important species in the herbaceous layer (Table 2). The importance value of *O. cinnamomea* went from 8 in 1993 (ranked third; Swinehart & Starks 1994) to 27 in 2010, whereas the importance value of *M. canadense* went from 20 in 1993 (Swinehart & Starks 1994) to 9 in 2010 (ranked third). Likewise, *Trientalis borealis* declined in importance since 1993, from a value of 9 to 7 and from second most important to sixth most important. *Rubus hispidus*, *Rubus allegheniensis*, and *Acer rubrum*

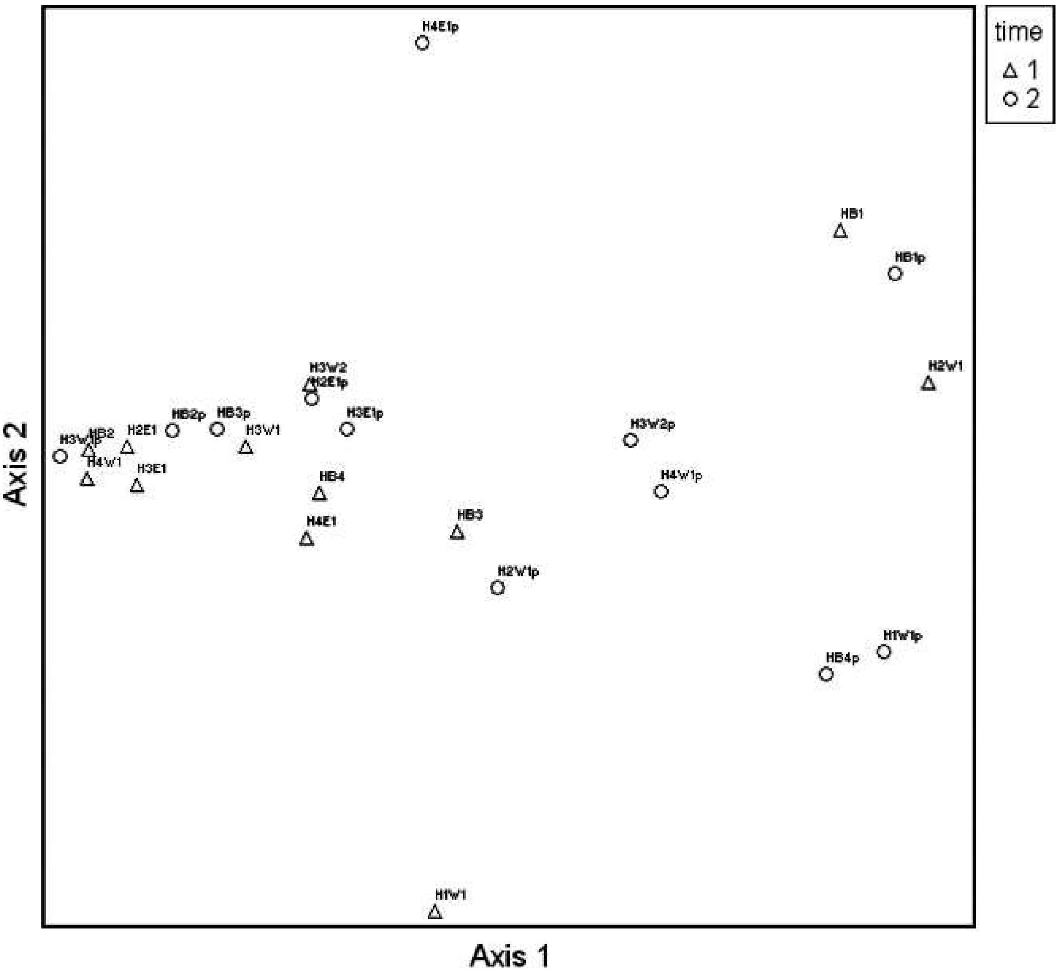

Figure 2.—Non-metric Multidimensional Scaling Ordination for Hickory Bog. Time 1 represents quadrats from 1993; Time 2 represents quadrats from 2010. Notations next to each data point identify individual quadrats.

(as seedlings) have surpassed *T. borealis* in importance since 1993 (Table 2).

Although they occurred outside of the quadrats, some effort was placed on searching for rare and notable species. All but one of the three living *Larix laricina* noted by Swinehart (1994) have died, and the *Cypripedium acaule* noted by Lindsey in 1972 and Swinehart in 1993 were not observed, nor were the *Lycopodium lucidulum* and *Lycopodium obscurum* that Swinehart found in 1993.

Statistical analysis.—MRPP indicates that the herbaceous community in Tamarack Bog from 1993 is statistically different from the herbaceous community in 2010 ($p<0.001$). NMS ordinations display the 1993 and 2010 quadrats as distinct clusters with little overlap regardless if the three late foliage species (*D. spinulosa, O. cinnamomea*, and *R. allegheniensis*) are included (Figure 3) or not (Figure 4). Qualitative change observed between Lindsey's 1972 survey and Swinehart's 1993 survey is confirmed by quantitative change between 1993 and 2010. Similar significant changes in bog communities have been observed in anthropogenically disturbed bogs located in Canada over a three decade period (Pellerin et al. 2008).

MRPP and NMS reveal significant change, but do not indicate what species account for the majority of the change. ISA identified *Ilex verticillata*, *Maianthemum canadense*, *Trientalis*

Table 2.—Vegetation of Tamarack Bog, Noble County, Indiana, June 2010 (37 quadrats). Percent frequency, density (D), basal area (BA), and importance values (IV) are listed for the tree layer. Percent frequency, density, and importance values are listed for the shrub layer. Relative values are listed in parentheses.

Layer/Species	% Freq.	D (#/ha)	BA (m^2/ha)	IV
TREE LAYER				
Acer rubrum	92 (54)	2 (69)	0.2 (73)	62
Prunus serotina	27 (16)	0.3 (8)	0.02 (9)	12
Quercus palustris	22 (13)	0.3 (8)	0.04 (17)	11
cf. *Nyssa sylvatica*	22 (13)	0.4 (10)	0.002 (1)	11
Ulmus americana	5 (3)	0.1 (3)	0.0006 (0.3)	3
Sassafras albidum	3 (2)	0.03 (1)	0.0001 (0.1)	1
SHRUB LAYER				
Ilex verticillata	86 (30)	5 (40)		35
Lindera benzoin	84 (29)	3 (19)		24
Rubus allegheniensis	30 (10)	4 (31)		21
Acer rubrum	19 (7)	0.4 (3)		5
Vaccinium corymbosum	19 (7)	0.3 (2)		4
cf. *Nyssa sylvatica*	19 (7)	0.3 (2)		5
Prunus serotina	11 (4)	0.2 (1)		2
Nemopanthus mucronatus	8 (3)	0.1 (1)		2
Aronia melanocarpa	5 (2)	0.08 (1)		1
Amelanchier sp.	3 (1)	0.03 (0.2)		1
Sassafras albidum	3 (1)	0.03 (0.2)		1

Layer/Species	% Freq.	%Cover	I.V.
HERBACEOUS LAYER			
Osmunda cinnamomea	68 (12)	30 (42)	27
Rubus hispidus	59 (10)	11 (15)	13
Rubus allegheniensis	38 (7)	9 (12)	9
Maianthemum canadense	76 (13)	4 (5)	9
Acer rubrum	73 (13)	4 (5)	9
Trientalis borealis	62 (11)	2 (3)	7
Dryopteris spinulosa	43 (8)	3 (5)	6
Ilex verticillata	24 (4)	2 (2)	3
Lindera benzoin	16 (3)	1 (2)	2
Viola sp.	16 (3)	1 (1)	2
Parthenocissus quinquefolia	16 (3)	1 (1)	2
Carex trisperma	11 (2)	1 (2)	2
Polygonum virginianum	11 (2)	1 (1)	1
Leersia oryzoides	11 (2)	1 (1)	1
Boehmeria cylindrica	8 (1)	0.4 (1)	1
Vaccinium corymbosum	8 (1)	0.2 (0.3)	1
Prunus serotina	8 (1)	0.1 (0.2)	1
Quercus palustris	8 (1)	0.1 (0.2)	1
Aronia melanocarpa	5 (1)	0.2 (0.3)	1
Triadenum fraseri	3 (0.5)	0.2 (0.2)	0.4
Bidens sp.	3 (0.5)	0.03 (0.04)	0.3
GROUND LAYER			
Pallavicinia lyellii	86 (43)	6 (46)	44
Aulacomnium palustre	35 (17)	2 (20)	19
Thuidium delicatulum	22 (11)	1 (12)	11
Sphagnum recurvum var. *tenue*	11 (5)	1 (11)	8
Sphagnum palustre	14 (7)	1 (10)	8
Tetraphis pellucida	19 (9)	1 (4)	7
Plagiothecium denticulatum	14 (7)	0.3 (3)	5
Leucobryum sp.	11 (5)	0.3 (2)	4
Lophocolea sp.	3 (1)	0.03 (0.2)	1

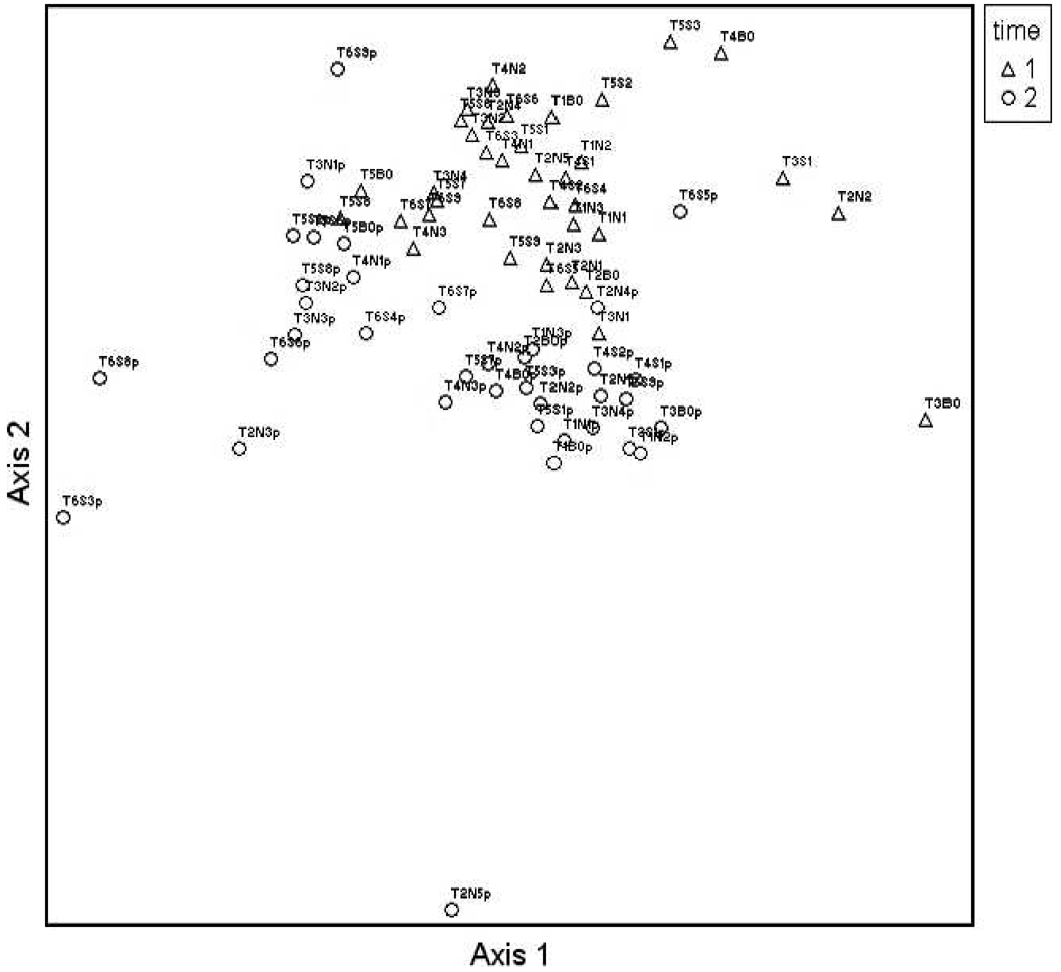

Figure 3.—Non-metric Multidimensional Scaling Ordination for Tamarack Bog including *Dryopteris spinulosa*, *Osmunda cinnamomea*, and *Rubus allegheniensis*. Time 1 represents quadrats from 1993; Time 2 represents quadrats from 2010. Notations next to each data point identify individual quadrats.

borealis, and *Viola* sp. as the indicator species which accounted for the majority of the difference between 1993 and 2010. ISA showed that *M. canadense* and *T. borealis* were more prominent in 1993, whereas *I. verticillata* and *Viola* sp. were more prominent in 2010. In Indiana, *M. canadense* and *T. borealis* are almost always found in tamarack bogs (Deam 1940). Additionally, *I. verticillata* is common in bogs and swamps almost exclusively in northern Indiana (Deam 1940). *Viola* sp. is a recent invader to the bog from the surrounding wetland. Although many communities occur along continuous gradients without definite boundaries (Whittaker 1975), bogs often have distinct species composition and abiotic settings which distinguish them from other surrounding communities (Kintsch & Urban 2002). Currently the boundary between the remnant bog community in Tamarack Bog and the surrounding swamp is beginning to disappear. The presence of *Viola* sp. as an indicator for 2010, coupled with the colonization of this species from the swampy wetland surrounding Tamarack Bog, shows that this community continues to rapidly transition from tamarack bog to hardwood swamp.

Neither Hickory Bog nor Tamarack Bog was directly altered by humans since the previous study in 1993. However, Tamarack Bog has exhibited significant change in the plant community, whereas Hickory Bog has not. The lack of significant change in vegetation in Hickory

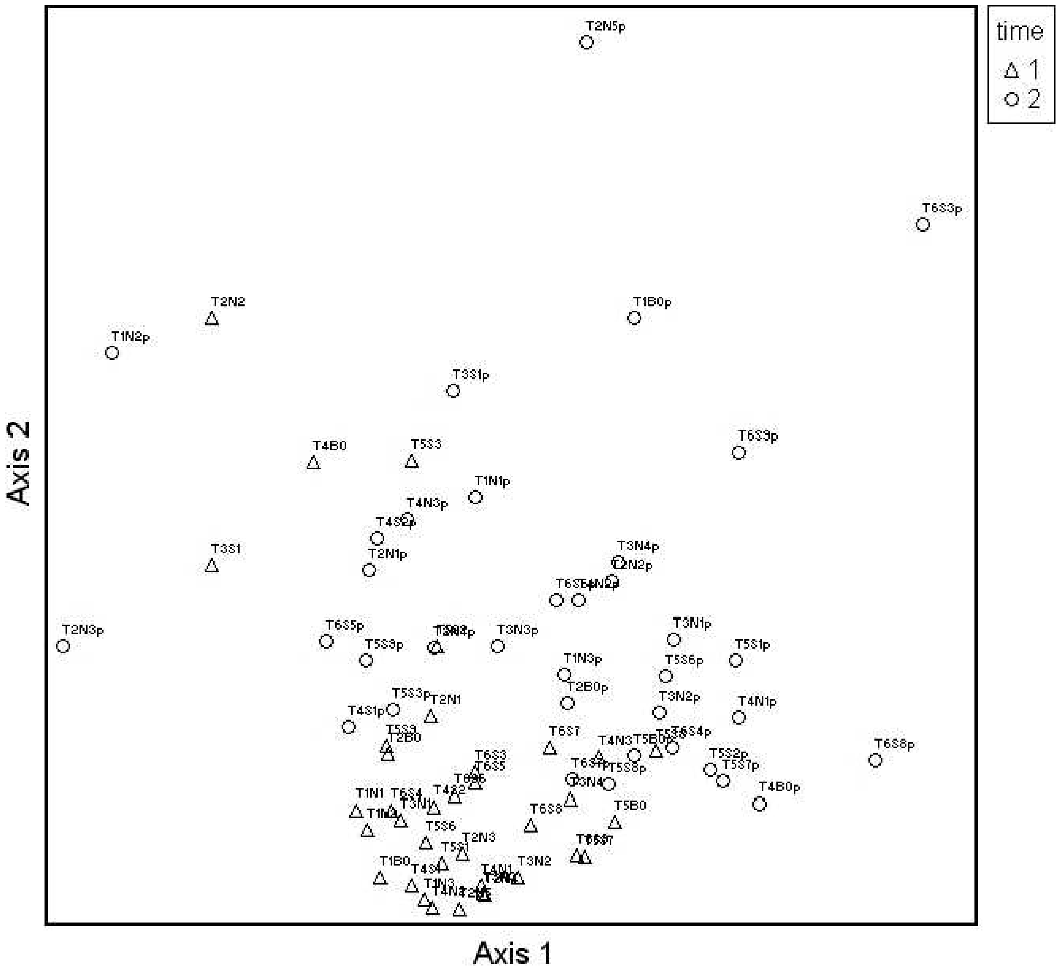

Figure 4.—Non-metric Multidimensional Scaling Ordination for Tamarack Bog excluding *Dryopteris spinulosa*, *Osmunda cinnamomea*, and *Rubus allegheniensis*. Time 1 represents quadrats from 1993; Time 2 represents quadrats from 2010. Notations next to each data point identify individual quadrats.

Bog is likely due to the persistence in edaphic conditions provided by the floating mat. So long as the floating mat persists, it can rise and fall with seasonal water-level changes, thus maintaining saturated conditions most suitable to peatland species. Thus, successional change is likely to be slow until the debris peat below the mat accumulates to the point where the mat becomes grounded. When the mat becomes grounded and can no longer sustain fully saturated conditions during low water levels (especially in the summer), oxidation in the surface of the peatland releases nutrients. This, along with the increased stability of the substrate favors pioneering marsh and swamp species, including trees. The authors speculate that the rate of succession of vegetation after the loss of the floating mat is much faster due to significant changes in edaphic conditions. Evidence for this appears to be provided by the significant changes that have taken place in Tamarack Bog in only 17 years (as well as other major changes over the past 100 years). Although the drainage of the lake, and subsequent grounding of the floating mat of Tamarack Bog, accelerated the initial transition from open bog to swamp, the rate of change after the grounding is probably consistent with what the rate of change would have been if the mat had grounded naturally by accumulation of sedimentary peat.

CONCLUSION

The degraded nature, rapid anthropogenic succession, and geographic isolation of the tamarack bogs in Indiana is such a potential hindrance to the natural establishment of these communities (with their unique genome) on newly exposed lakeshores and bog soils, that tamarack seedlings in the state are already a rare occurrence. Restoration and management of these rare communities in Indiana will be required to prevent their extirpation from the state.

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LITERATURE CITED

Backéus, I. 1972. Bog vegetation re-mapped after sixty years: studies on Skagershultamossen, Central Sweden. Oikos 23:384–393.

Blatchley, W.S. & G. Ashley. 1901. The lakes of northern Indiana and their associated marl deposits. Annual Report of the Indiana Department of Geology and Natural Resources. 136–9.

Conard, H.S. 1956. How to Know the Mosses and Liverworts. Wm. C. Brown Co., Dubuque, IA. 226 pp.

Conway, V.M. 1949. The bogs of central Minnesota. Ecological Monographs 19:173–206.

Crow, G.E. 1969. An ecological analysis of a southern Michigan bog. Mich. Bot 8:11–27.

Crum, H.A. 1988. *A focus on peatlands and peat mosses*. University of Michigan Press, Ann Arbor. 306 pp.

Crum, H.A. & L.E. Anderson. 1981. *Mosses of Eastern North America*. Columbia University Press, NY. 2 vols, 1328 pp.

Deam, C.C. 1940. Flora of Indiana. Indiana Dept. of Conservation, Division of Forestry, Indianapolis, Indiana, 1236 pp.

Dryer, C.R. 1901. Certain peculiar eskers and esker lakes of northeastern Indiana. The Journal of Geology 9:123–9.

Duncan, D.P. 1954. A study of the factors affecting the natural regeneration of tamarack (*Larix laricina*) in Minnesota. Ecology 35:498–521.

Frankl, R. & H. Schmeidl. 2000. Vegetation change in a South German raised bog: ecosystem engineering by plant species, vegetation switch or ecosystem level feedback mechanism? Flora 195:267–76.

Freléchoux, F., A. Buttler, F.H. Schweingruber & J.M. Gobat. 2000. Stand structure, invasion, and growth dynamics of bog pine (*Pinus uncinata var. rotunda*) in relation to peat cutting and drainage in the Jura Mountains, Switzerland (2000). Canadian Journal of Forest Research 30:1114–26.

Gunnarsson, U., N. Malmer & H. Rydin. 2002. Dynamics or constancy in *Sphagnum* dominated mire ecosystems: a 40-year study. Ecography 25:685–704.

IDNR. 1992. Indiana Department of Natural Resources, Division of Nature Preserves. Natural Heritage Database, Indianapolis, Indiana.

IDNR. 1996. Indiana Department of Natural Resources, Division of Nature Preserves. Natural Heritage Database, Indianapolis, Indiana.

Jewell, M.E. & H.W. Brown. 1929. Studies on northern Michigan bog lakes. Ecology 10:427–74.

Johns, R.M. 1966. Morphological and ecological study of *Physoderma dulichii*. American Journal of Botany 58:34–45.

Kintsch, J.A. & D.L. Urban. 2002. Focal species, community representation, and physical proxies as conservation strategies: a case study in the Amphibolite Mountains, North Carolina, U.S.A. Conservation Biology 16:936–47.

LeBarron, R.K. & J.R. Neetzel. 1942. Drainage of forested swamps. Ecology 23:457–465.

Linderholm, H.W. & M. Leine. 2004. An assessment of twentieth century tree-cover changes on a southern Swedish peatland combining dendrochronology and aerial photograph analysis. Wetlands 24:357–63.

Lindsey, A.A., D.V. Schmelz & S.A. Nichols. 1969. Natural Areas in Indiana and Their Preservation. Indiana Natural Areas Survey, Purdue University, West Lafayette, IN. 594 pp.

Moizuk, G.A. & R.B. Livingston. 1966. Ecology of red maple (*Acer rubrum* L.) in a Massachusetts upland bog. Ecology 47:942–950.

Pellerin, S., M. Mercure, A.S. Desaulniers & C. Lavoie. 2008. Changes in plant communities over three decades on two disturbed bogs in southeastern Québec. Applied Vegetation Science 12:107–18.

Schwintzer, C.R. & G. Williams. 1974. Vegetation changes in a small Michigan bog from 1917 to 1972. American Midland Naturalist 92:447–459.

Swinehart, A.L. 1994. An ecological investigation of three *Sphagnum*-bogs in Noble County, Indiana: Remnant communities of a region in transition. Masters dissertation, Central Michigan University.

Swinehart, A.L. 1997. The development and ecology of peatlands in Indiana. Ph.D. Disstertation, Purdue University, West Lafayette, Indiana. 303 pp.

Swinehart, A.L. & G.D. Starks. 1994. A record of the natural history and anthropomorphic senescence of an Indiana tamarack bog. Proceedings of the Indiana Academy of Science 103:225–39.

Swinehart, A.L. & G.R. Parker. 2000. The development and ecology of peatlands in Indiana. Amer. Midl. Nat 143:267–297.

Swinehart, A.L., G.E. Parker & D.E. Wujek. 2001. The structure and composition of vegetation in the lake-fill peatlands of Indiana. Proceedings of the Indiana Academy of Science 110:51–78.

Sytsma, K.J. & R.W. Pippen. 1982. The Hampton Creek wetland complex in southwestern Michigan, III. Structure and succession of tamarack forests. Mich. Bot 21:67–76.

Taylor, A.E. 1907. The peat deposits of northern Indiana. Ann. Rept. Indiana Dept. Geol. & Nat. Res 31:73–298.

Tiner, R. 1999. Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping. Lewis publishers, Boca Raton, Florida. 103.

Transeau, E.N. 1905–1906. The bogs and bog flora of the Huron River Valley. Bot. Gaz. 40:351–375, 418–448 (1905); 41: 17–42 (1906).

Voss, E.G. 1980. *Michigan Flora, Part I: The Gymnosperms and Monocots*. Cranbrook Institute of Science, Bulletin 55, Bloomfield Hills, MI. 488 pp.

Voss, E.G. 1985. *Michigan Flora, Part II: Dicots*. Cranbrook Institute of Science, Bulletin 59, Bloomfield Hills, MI. 724 pp.

Voss, E.G. 1996. Michigan Flora, Part III: Dicots Concluded. Cranbrook Institute of Science, Bulletin 61, Bloomfield Hills, MI. 622 pp.

Whittaker, R.H. 1975. Communities and Ecosystems. MacMillian, New York, New York. 31–2.

Wilcox, D.A. 1982. The effects of deicing salts on water chenistry and vegetation in Pinhook Bog, Indiana Dunes National Lakeshore. U.S. Department of the Interior, National Park Service, Midwest Region, Research/Resources Management Report MWR-2, 139 pp.

Woollett, E., D. Dean & H. Coburn. 1926. An ecological study of Smith's Bog, Cheboygan County, Michigan. Papers of the Michigan Academy of Science, Arts, and Letters 5:201–210.

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