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Hydrology, Water Chemistry, and Vegetation Characteristics of a Tamarack Bog in Bath Township, Ohio: Towards Restoration and Enhancement[1]

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ABSTRACT. The current state of the Bath Tamarack Bog has raised concern about the health and function of the system. Only 6 tamarack (*Larix laricina*) trees remain, while deciduous trees, particularly red maple (*Acer rubrum*) and invasive species such as glossy buckthorn (*Rhamnus frangula*) and multiflora rose (*Rosa multiflora*), dominate the bog. Our purpose was to assess the physical, chemical, and biological properties of the tamarack bog. Environmental and biological properties of Bath Tamarack Bog were measured from May 2001 through November 2002. In 2001, the center of the bog experienced water levels below those typically found in bogs, yet experienced normal water levels in the following year. Water chemistry results indicate the pH is much greater than that characteristic of a typical bog, ranging from 5.94 to 7.41. Nutrient levels fluctuated and were generally higher for calcium, potassium, and phosphate than a typical bog, while nitrogen levels remained low. These results indicate that the bog is not functioning normally and is in decline. The degradation of the bog is most likely due to anthropogenic activity. Ditching occurred between 1963 and 1969 and seems to have induced the progression of red maple trees and invasive species into the bog by lowering water levels. Since 1938, the first aerial photo we have record of, the bog has reduced to approximately a third of its size, which is approximately 1.99 hectares. The bog appears to be in a late successional stage, rapidly changing to a forested wetland. We discuss possible management and restoration efforts needed to restore or enhance the tamarack bog, including 1) planting *Sphagnum* mats, 2) introducing tamarack seedlings, 3) controlling invasive species, and 4) maintaining the hydrology close to the soil surface. All of these measures are suggested in association with educational outreach.

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INTRODUCTION

Today, wetlands occupy less than half the area they occupied a century ago (Moser and others 1996; Mitsch and Gosselink 2000). Similarly, the lower 48 states of the United States have lost over 50% of its wetland area (Dahl 1990). Ohio has lost 90% of its wetland area, with an estimated 195,000 ha remaining (Dahl 1990). Ohio's wetlands presently cover about 1.8% of the state (Dahl 1990). Those wetlands remaining serve an important environmental and economic resource; wetlands regulate water flow, recharge groundwater supplies, provide flood control (Carter 1996), and are habitat for diverse biological communities (Mitsch and Gosselink 2000; Keddy 2000). Wetlands also retain essential sediments and nutrients while effectively buffering ecosystems against contamination by removing toxins from effluents and reducing the concentration of excess nitrogen and phosphorus from crop field drainage (Kadlec and Knight 1996; Mitsch and Gosselink 2000).

Wetlands are classified on the basis of their hydrology, vegetation, and substrate, and include five major types: marsh, bog, fen, swamp, and wet meadow, all of which can be found in Ohio (Mitsch and Gosselink 2000; Keddy 2000). Our study focuses on a subcategory of the bog wetland type, called a tamarack bog. Bogs, including tamarack bogs, are freshwater wetlands found in northern glaciated regions that receive more rainfall than they lose through evapotranspiration (Mitsch and Gosselink 2000). The substrate is largely composed of organic peat and is usually rainwater fed leading to ombrotrophic (low nutrient) conditions. However, the addition of surface runoff into the bog can lead to higher nutrient levels. Anoxic conditions below the surface of the peat, together with the chemical characteristics of the peat itself, lead to very slow decomposition and a thick accumulation of the peat layer (Hughes 2000; Van Breemen 1995). In addition, due to the presence of *Sphagnum* moss, the pH in bogs is normally very low, usually <4.2 (Van Breemen 1995). Bogs are also characterized by a stable water level. Characteristic vegetation varies considerably in bogs depending upon the process by which the bog was formed, the environmental conditions (especially temperature, rainfall, and water level), the age of the bog, and the current stage of succession in the bog (Potter 1947; Glaser 1992). Generally, in addition to *Sphagnum* spp., leatherleaf (*Chamaedaphne calyculata*), bog myrtle (*Myrica gale*), black spruce (*Picea mariana*), and tamarack trees (*Larix laricina*) grow in bogs.

Tamarack bogs are unique ecosystems containing a variety of interesting and rare species. These include cottongrass (*Eriophorum virginicum*), leatherleaf (*Chamaedaphne calyculata*), pitcher plant (*Sarracenia purpurea*), sundew (*Drosera rotundifolia*), pink lady slipper orchid (*Cypripedium acaule*), and of course,

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tamaracks (*Larix laricina*) (Larsen 1982). Tamaracks are deciduous conifers also known as larches, and can be found in Northeast Ohio ringing kettle holes, associated with boreal fens, and also found in shallow, infilling lakes (Andreas and Osterbrock 1985). Tamaracks range from Newfoundland west to Alaska and south to Ohio and West Virginia (Duncan 1954; Little 1979). In Ohio, tamaracks have been found in Bath, Flatiron Lake, Kent, Singer Lake, and Triangle Lake, but also occur in other sites.

In bog environments, the tamarack is able to establish because of a tolerance for the acidic conditions created by *Sphagnum* mosses (Tilton 1978; Larsen 1982; Johnston 1990). However, tamaracks are intolerant of both competitors and low light conditions (Duncan 1954). In well-established bogs, tamarack populations may be found in associations with *Sphagnum* mosses, various sedges, carnivorous plants, ericaceous shrubs, and a few species of deciduous and evergreen trees (Larsen 1982; Dennison and Berry 1993).

There are very few tamarack bogs remaining in Ohio due to changes in land use and the consequence that tamaracks are at the southern extent of their range in Ohio, and therefore preservation and restoration efforts for these unique ecosystems must be a priority. For example, the Bath Tamarack Bog, in Summit County, is in a state of decline and has led to concerns regarding future enhancement or restoration plans. Human activities (for example, ditching) and the encroachment of woody and invasive species are distinct threats. We predict that the ditching would have altered the natural hydrology of the tamarack bog. The Bath Tamarack Bog is located in the Bath Nature Preserve (BNP), an area set aside by the township residents for recreational and educational purposes. The question of whether or not to implement management practices is still being considered.

The objective of this descriptive study was to measure environmental and biological properties of the Bath Tamarack Bog and to use the information gathered to assist in recommendations for renovation and enhancement of the bog, as well as identifying further areas of research. Delineation of the present bog, analysis of water chemistry, and hydrology are the main focus, but vegetative characteristics and a historical analysis based on aerial photographs have also been investigated. In addition, a detailed investigation has been done on red maple trees within the bog. It is hypothesized that anthropogenic causes led to the progression of red maple trees, as well as other invasive species, into the bog.

MATERIALS AND METHODS

Study Site

Bath Nature Preserve (BNP) is a 404-acre (163.62 ha) parcel located in the glaciated plateau of northeastern Ohio (Fig. 1a). The property (formerly part of tire manufacturer Raymond Firestone's country estate) is now owned by Bath Township, and preserves healthy examples of habitats such as open grasslands, mature mixed deciduous forests, wetlands, streams, and ponds. Notably, the preserve includes a tamarack bog, located in the southeast section (Fig. 1b).

In Spring 2001, the perimeter of the bog was delineated with a Garmin GPS unit. The wet area encompassing the small stand of tamaracks is 0.6 ha. The current inflow drainage area associated with the ditches entering and passing through the bog were estimated using United States Geological Survey (USGS) photomaps and Arc View GIS 3.2. Area measurements were derived from the USGS data in Arc View by polygon outlining.

Vegetation

In July 2000, a general walking survey of the tamarack bog was conducted to identify as many plant species as could be found. Voucher specimens were collected and are located at the University of Akron. The major plant focus within the bog was the tamaracks. In April 2001, the bog was surveyed in order to locate and GPS all the tamaracks. Diameter at breast height (DBH) of the tamaracks was taken and these measurements were used to estimate age. In addition, three 50 m transects were randomly located within the bog. Along each transect all of the trees were counted, identified, and DBH measured.

Hydrology

Three water table wells were placed in the approximate center of the bog and monitored on a monthly basis beginning in May 2001. Wells consisted of perforated PVC piping that was 6.35 cm in diameter and 4.5 m in length. The wells were sunk, capped, and marked with a Garmin GPS unit. These wells were monitored from 5 May 2001 to 9 November 2001.

A more detailed monitoring of the bog hydrology began in June 2002. The bog was surveyed in order to locate areas of hydrological inflow and outflow, identified by the observation of flowing water. These areas were located along the edge of the bog. A 100 m transect was established which ran from the area of inflow to the area of outflow, bisecting the bog (Fig. 1c). Water table wells, identical to the wells used in the previous monitoring, were placed at the ends of the transect and every 20 m in-between. Hence, the transect included a total of 6 water table wells. These wells were capped and marked with a Garmin GPS unit. Water level monitoring took place every two weeks from 17 June 2002 until 18 November 2002.

For the 2001 data, the water level values for the 3 wells in the center of the bog were averaged resulting in a single value. For the 2002 data, the mean water level value was calculated for the 4 wells in the middle of the bog.

Water Chemistry

Monthly water samples were taken from depression sites in the middle of the bog beginning in May 2001. The pH was measured in the field using an Accumet Portable Laboratory. All water chemistry analysis was done at the University of Akron using kits from Palintests Ltd. and read with a YSI 9100 Photometer. The following nutrients were measured: calcium, potassium, phosphate, nitrate, and ammonia. Monitoring continued from 13 May 2001 to 9 November 2001.

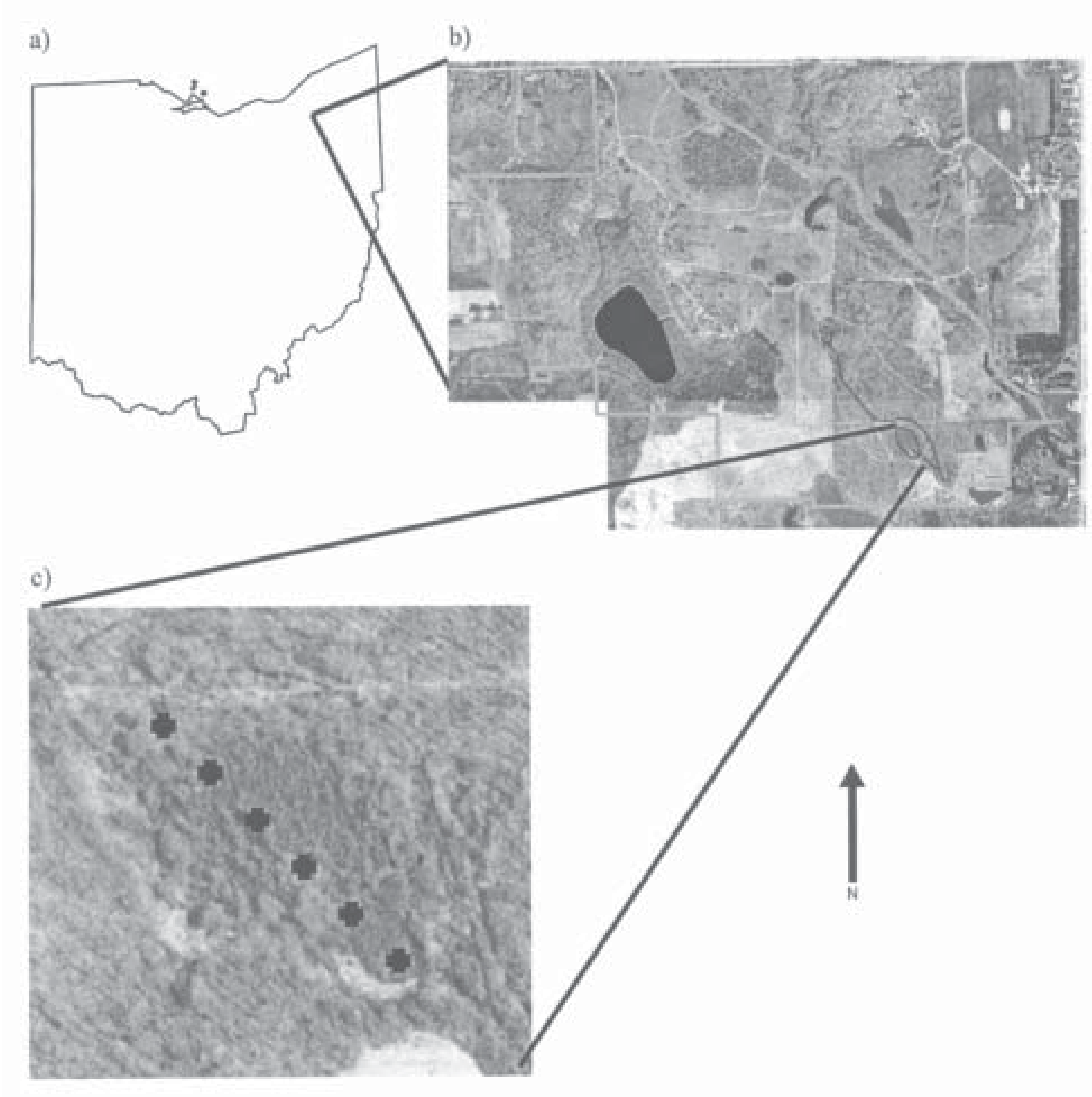

FIGURE 1. Location map of study site; where a) is Ohio, b) is the Bath Nature Preserve, and c) is the Tamarack Bog. The crosses in the Tamarack Bog represent the transect of water level wells located in the bog.

A more detailed monitoring of the bog's water chemistry occurred between 17 June 2002 and 5 November 2002. Water samples from the surface inflow, surface outflow, and depression sites at the center of the bog were collected on a monthly basis. As in the previous monitoring, pH was measured in the field and samples were analyzed for nutrient concentrations at the lab using identical methods. Due to malfunctions of the pH probe, these data have been excluded from this report. Again, calcium, potassium, phosphate, nitrate, and ammonia were measured.

As in the hydrology analysis, the nutrient concentration values from the middle of the bog in the 2001 and 2002 monitoring periods are reported as cumulative data.

Peat Depth

In Spring 2002, peat depth was measured, up to a maximum of 4.5 m, by manually pushing a 1.0-in diameter, 4.57 m long metal rod into the peat. Peat depth was estimated based on the point at which it was not possible to push the rod further into the ground. Obviously, peat depth greater than 4.57 m could not be quantified. Two transects, one running north and the other east-west, through the center of the bog were marked, and peat depth was measured at 10-m intervals for a total of 50 m both east and west and 90 m north.

History: Aerial Photographs

Six aerial photographs of the research area (1938, 1951, 1963, 1969, 1975, and 1995) were collected from Summit Soil and Water Conservation District and from Akron Metropolitan Area Transportation System (AMATS). The photographs were scanned and any differences in scale were adjusted using Corel Photoshop. The photographs were analyzed visually to quantify loss of wetland and standing water area and to note any changes in the landscape.

Investigation of *Acer rubrum* (Red Maple)

In November 2002, all red maple trees were identified along the aforementioned transect, beginning approximately 20 m outside of both ends and extending outward approximately 5.0 m either side. The location and DBH of each tree was determined using a Garmin GPS unit and DBH measuring tape, respectively. In addition, the age of the trees were determined by removing a core sample from the tree with an increment borer. Smaller trees, generally less than 10 cm in diameter, could not be cored because the increment borer would not attach to these trees. The core samples were taken back to the lab, where the rings were enumerated. Arc View was used to place the trees according to their GPS onto an aerial map of the bog.

RESULTS

Vegetation

Only 6 live tamaracks are in the bog. The trees were located towards the northern extent of the moss hummocks near the channelized flow of water draining the area. No seedlings or young trees were found. Extensive growth of small deciduous trees over the majority of the moss hummocks was typical.

The following woody species were identified along the Winter 2001 transects: tamarack (*Larix laricina*), red maple (*Acer rubrum*), alder (*Alnus* spp.), wild cherry (*Prunus virginiana*), blueberry (*Vaccinium corymbosum*), sumac (*Toxicodendron vernix*), glossy buckthorn (*Rhamnus frangula*) multiflora rose (*Rosa multiflora*), and honeysuckle (*Lonicera* spp.). Flora identified in the walking survey (Summer 2000) is listed in Table 1. A state endangered plant, the two-seeded sedge (*Carex disperma*), is included among the flora growing in the bog.

Hydrology

The tamarack wetland receives water from both direct precipitation and runoff from the surrounding drainage area north of the bog. Two ditches from the northern portion of the drainage area lead to the northern edge of the tamarack bog. The ditch to the west ends at the northern edge of the wetland creating marshy conditions within a buried pipeline right-of-way. The eastern ditch continues southward along the eastern edge of the wetland. Approximately fifty yards north of the wetland outlet, the eastern ditch is met by a channel from the interior of the wetland.

The hydrology of the bog center demonstrated more variance in the 2001 season than the 2002 season (Fig. 2). In 2001, the water levels of the middle fluctuated from a high of –2.0 cm to a low of –20.0 cm. In 2002, the hydrology of the bog was more stable, ranging from +2.0 cm to –3.0 cm. The inflow and outflow both demonstrated high variance with the inflow being more severe. Inflow water levels ranged from 0.0 cm to –32.0 cm, while outflow levels ranged from 0.0 cm to –17.0 cm.

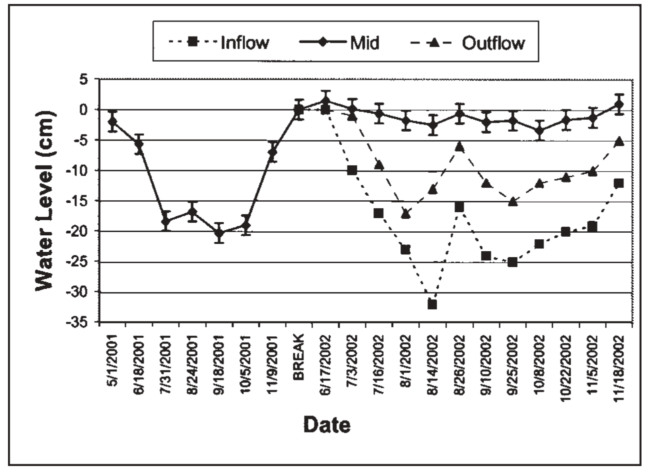

FIGURE 2. Water levels of the Bath Tamarack Bog. There is a break in the data between 9 November 2001 and 17 June 2002. The term "BREAK" on the x-axis refers to the break in data collection with respect to the middle of the bog. Error bars represent +1 standard error.

Water Chemistry

The pH, calcium, potassium, phosphate, nitrate, and ammonia levels for 2001 and 2002 are detailed in Figure 3 (a–f). pH (Fig. 3a) shows little variation between May and November of 2001, but quite high values from 6.0 to 7.7. Calcium (Fig. 3b) tended to increase in the fall. Generally the inflow values were greater than mid- and outflow. Similar to calcium, potassium (Fig. 3c), phosphate (Fig. 3d), nitrate (Fig. 3e), and ammonia (Fig. 3f) had high values in October. The highest ammonia values were detected in the outflow (Fig. 3f).

Peat Depth

Peat depth is detailed in Table 2 and exceeded 4.5 m at the center of the bog. While following in a northward direction from the center of the bog, peat depth remained greater than 4.5 m for a 60 m distance. Peat depth began declining by 70 m and was absent by 90 m. While traveling west from the center of the bog, the peat depth gradually declined until the edge of the bog was reached just prior to the 50 m distance. The eastward transect remained at a depth greater than 4.5 m for 20 m at which point peat depth dipped then became greater than 4.5 m once again. However, at 50 m, peat depth declined dramatically.

History: Aerial Photographs

The 1938 aerial photograph of the bog, the oldest available, shows a bog of approximately 5.6 ha and provides evidence for standing water at the southeast end of the bog (Fig. 4a). Standing water is apparent in both the 1951 (Fig. 4b) and 1963 (Fig. 4c) photographs as well. In addition, gas lines appear to have been in-

TABLE 1

Floral list of Bath Tamarack Bog with authorities.

Scientific Name	Common Name
Vascular plants (Gleason and Cronquist 1991)	
Acer rubrum L.	Red maple
Acer saccharum Marshall	Silver maple
Achillea millefolium L.	Yarrow
Alliaria petiolata (Bieb.) Cavara & Grande	Garlic mustard
Alnus incana rugosa Regel	Speckled alder
Carex atlantica var. *capillacea*[*P] (L. Bailey) Cronq.	Howe's sedge
Carex disperma[*E] Deway	Two-seeded sedge
Cornus amomum Miller	Silky dogwood
Dryopteris spp.	Wood fern
Equisetum arvense L.	Field horsetail
Fraxinus nigra Marshall	Black ash
Ilex verticillata (L.) A. Gray	Winterberry
Juncus effuses L.	Common rush
Larix laricina[*P] (Du Roi) K. Koch	Tamarack
Lonicera spp.	Honeysuckle
Onoclea sensibilis L.	Sensitive fern
Osmunda cinnamomea L.	Cinnamon fern
Osmunda regalis L.	Royal fern
Phalaris arundinacea L.	Canary grass
Phragmites australis (Cav.) Trin.	Common reed
Prunus virginiana L.	Wild cherry
Rhamnus frangula L.	Glossy buckthorn
Rosa multiflora Thunb.	Multiflora rose
Rosa palustris Marshall	Swamp rose
Scirpus atrovirens Willd.	Dark green bulrush
Toxicodendron vernix (L.) Kuntze	Poison sumac
Ulmus americana L.	American elm
Vaccinium corymbosum L.	Highbush blueberry
Non-vascular plants (Crum and Anderson 1981)	
Brachythecium rivulare Schimp.	
Calliergonella cuspidate (Hedw.) Angstr.	
Climacium americanum Brid.	
Leptodictyum riparium (Hedw.) Warnst.	
Leucobryum glaucum (Hedw.) Angstr.	White cushion moss
Platygrium repens (Brid.) Schimp.	
Sphagnum palustre L.	Sphagnum
Tetraphis pellucida Hedw.	
Thuidium delicatulum (Hedw.) Angstr.	The delicate fern moss

[*E]Refers to plant species that are classified as state endangered by ODNR.
[*P]Refers to plant species that are classified as potentially threatened by ODNR.

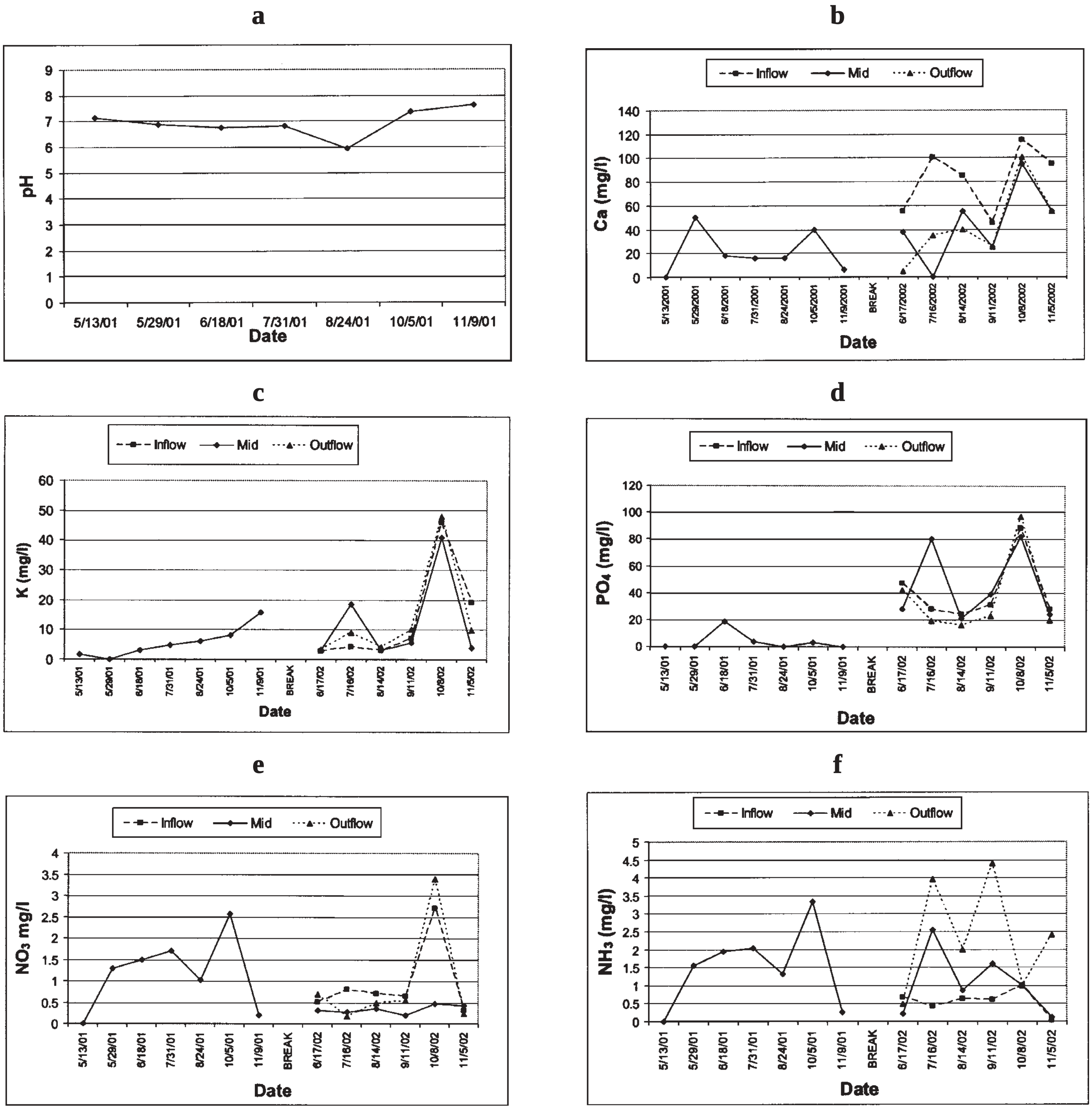

FIGURE 3. Water chemistry measurements; where a) is pH levels from the center of the Bath Tamarack Bog, b) is calcium levels, c) is potassium levels, d) is phosphate levels, e) is nitrate levels of the Bath Tamarack Bog, and f) is ammonia levels of the Bath Tamarack Bog. There is a break in the data between 9 November 2001 and 17 June 2002. The term "BREAK" on the x-axis refers to the break in data collection with respect to the middle of the bog.

stalled, crossing through the northern end of the bog in the 1963 photograph. The 1969 aerial photograph (Fig. 4d) shows two ditches present, one through the center of the bog and the other along the east side of the bog. Standing water is not present in this photograph, suggesting that the ditches were constructed between 1963 and 1969. The 1979 aerial photograph (Fig. 4e) shows little change occurring in the area. Lastly, the 1995 (Fig. 4f) photograph is the most recent and is more or less consistent with the current condition of the tamarack bog and surrounding area. The wet area encompassing the small stand of tamaracks is 1.99 ha.

Investigation of *Acer rubrum* (Red Maple)

As expected, tree size was positively correlated with age. Larger, older trees, approximately 30-45 years in age were found around the edges of the bog. Smaller, younger trees, 20 to 25 years of age, appeared to be encroaching towards the center. Very young trees, most probably less than 15 years of age were found closer to the center of the bog. However, approximately a 40 m distance along the transect at the center of the bog, was

TABLE 2

Peat depth in Bath Tamarack Bog.

Distance from center (m)	East	West	North
0	4.57*	4.57*	4.57*
10	4.57*	1.83	4.57*
20	4.57*	3.09	4.57*
30	2.60	2.08	4.57*
40	4.57*	1.50	4.57*
50	1.46	0.00	4.57*
60	N/A	N/A	4.57*
70	N/A	N/A	2.50
80	N/A	N/A	2.15
90	N/A	N/A	0.00

*Peat depth greater than 4.57 m.

void of red maple trees. Overall, the invasion of red maple trees seems to have taken place somewhere between 30-45 years ago.

DISCUSSION

The tamarack bog at the BNP is in a late successional phase. Unchecked, it is likely that the transition to a terrestrial forest will be rapid. We recognize that it may not be feasible to restore the bog. It was concluded by the NRC (2001) that peatland restoration is generally not very successful. However, since bogs are rare in Ohio, and they serve an invaluable educational role, we suggest concrete ways of enhancing the present bog and possibly delaying the inevitable succession towards a terrestrial forest.

The hydrological and water chemistry data obtained from the bog at the BNP aid in describing the health of this wetland. The water table for a typical bog is at or near the surface throughout the year with little fluctuation (Mitsch and Gosselink 2000). There is also practically no surface flow in a bog system, with the major input being provided by precipitation. Due to ditching and other anthropogenic activity (a natural gas line north of the bog), the tamarack bog has a known source of inflow and outflow. It was predicted that this activity should have affected the hydrology of the wetland. In 2001, the center of the bog experienced below-normal water levels. However, the bog demonstrated a typical hydrological regime at its center in the following year. This annual contrast may be due to differences in precipitation levels and average seasonal temperature. In the year 2001, the nearby Akron-Canton airport received 835.66 mm precipitation, compared to 1033.02 mm in 2002. The spring of 2002 was the third wettest spring on record. The ability of the bog to partially exhibit normal hydrological levels, even in drier years, is probably due to the high peat depth in the system. The water table of the bog drops well below the surface in the summer months at the inflow and outflow. Both these areas experienced fluctuations throughout the 2002 monitoring period. These fluctuations, while not drastic, may be facilitating the invasion of the wetland by vegetation not associated with bogs.

By definition, bogs are systems low in nutrients and exhibit an acidic environment. However, the bog at the BNP had a pH as high as 7.41. In general, the tamarack bog had higher than normal levels of nutrients. Calcium was high throughout the bog in both years. Calcium carbonate, which was only monitored in 2001, was also found in high concentrations, possibly causing the high pH of the system. In 2002, potassium and phosphate demonstrated similar high levels and fluctuations in all areas of the wetland. These nutrients were found in lower levels the previous year. Nitrate was the only nutrient that was consistently found in the low concentrations typical of a bog. The outflow and middle samples contained high, fluctuating concentrations of ammonia, while the inflow exhibited lower levels. Ammonium, which was also only monitored in 2001, reached concentrations similar to ammonia. In the fall months, there seemed to be high concentrations of many nutrients in all areas of the bog. This event may be due to leaching of nutrients from recently fallen leaves. The high concentrations of nutrient in this system may be due to inputs from outside the bog through surface flow. However, the immediate water catchment area surrounding the bog is relatively undisturbed and consists mostly of a mixed beech, oak, and maple forest, except for a mowed gas line that traverses the northern top of the bog (Fig. 1). Potential inputs and changes in water level could be disrupting the functions of this system causing an increase in pH. These disruptions could also be causing the loss of *Sphagnum* moss and tamarack trees, while favoring the encroachment of invasive species.

The monitoring of the bog at the BNP demonstrates that this wetland is not functioning as a true bog. The bog is losing its important characteristics (for example, low pH and low nutrient levels) and typical bog vegetation is becoming sparse. *Sphagnum* cover is sparse, which is most likely due to changes in hydrology and canopy shading, thus the typically acidic bog conditions cannot be maintained. Invasive non-bog species are now encroaching into the bog. It is recommended that certain measures be taken to restore the bog and prevent it from becoming a forested wetland.

The invasion of the tamarack bog by red maple trees indicates the transition of the tamarack bog to a forested wetland. Red maples are designated as facultative wetland plants and are commonly found in floodplain forests and swamps. The age of the red maple trees coincide with the same time that the ditches were installed into the bog, between 30 and 45 years ago. This probably led to lower water levels and grounding of the peat mat. Once the peatland is grounded, it enabled the seeds to germinate and the saplings to survive in previously flooded conditions. Once the young maples became established, this likely reduced the ability of tamarack saplings to compete, resulting in their loss (see Table 3 for a comparison of the habitat requirements of

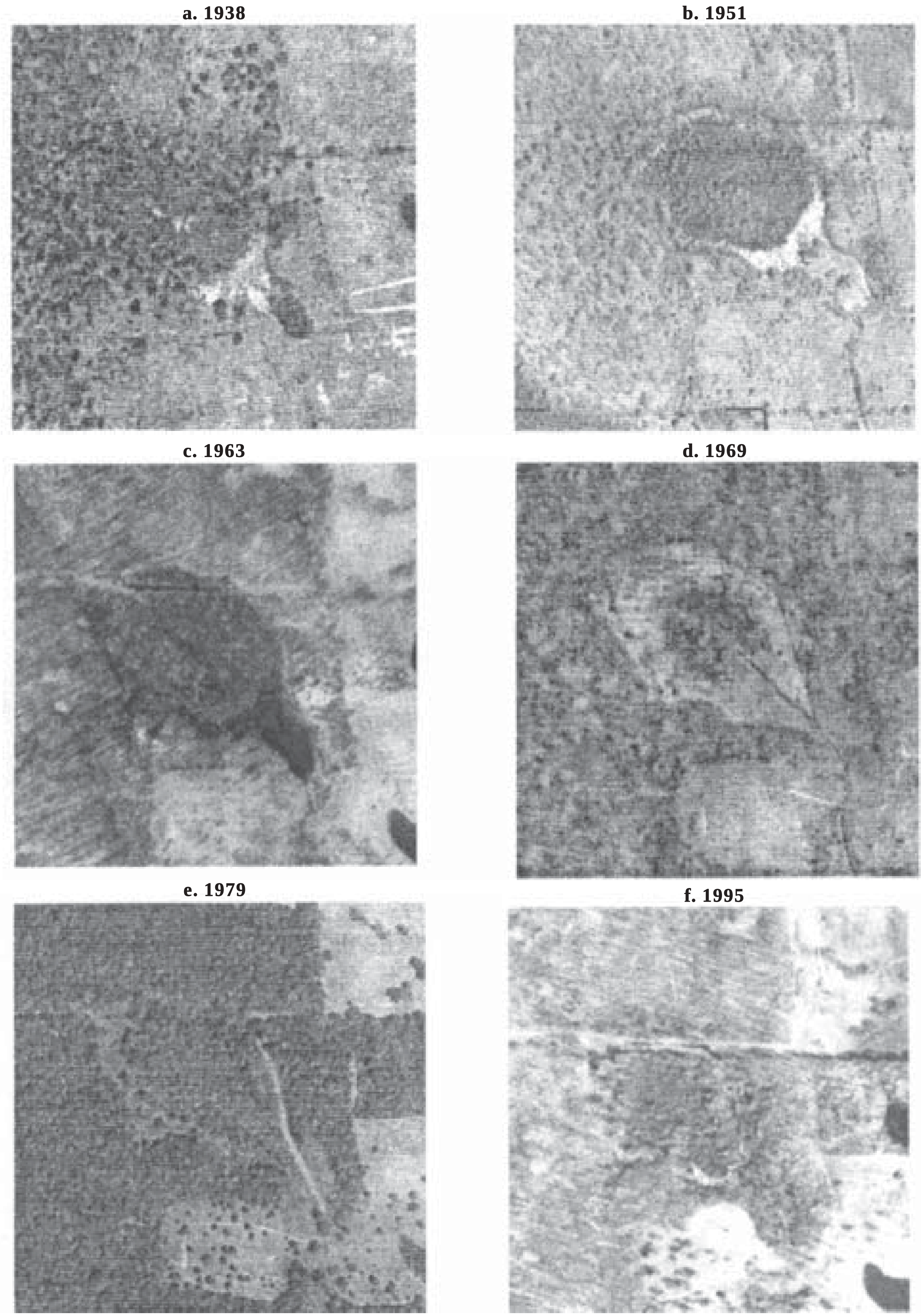

FIGURE 4. Aerial photographs of the Bath Tamarack Bog.

TABLE 3

Comparison between tamarack trees and red maples (Farrar 1995; Burns and Honkala 1990).

	Tamarack Trees		Red Maple Trees	
	Adults	Juveniles	Adults	Juveniles
Height	65 feet		60-90 feet	
Tolerate Flooding	Yes	No	2 yrs.	Yes
Tolerate Saturated Soil	Yes	Yes	Yes	Moderately
Tolerate Low Light	No	No	Yes	Yes
Tolerate Competition	No	No	Yes	Yes
Heavy Seed Crop	Every 6 years		Every spring	

red maples and tamarack trees). Red maple trees are native to the United States and can probably succeed in a wider range of habitats than any other forest species in North America. They are able to tolerate a wide range of soil types, textures, moisture, pH, elevation, and light (Hepting 1971).

In a study of 10 peatlands in Indiana, all exhibited successional trends towards lowland forests dominated by red maple trees (Swinehart and Parker 2000). The peatlands lacked black spruce and northern white cedar, as does the Bath Tamarack Bog, and thus did not develop into the typical muskegs and cedar swamps of the North but into red maple swamps. This seems to be typical of later stage peatlands in the southern Great Lakes Region (Swinehart and Parker 2000). In the case of the Bath Tamarack Bog, it is believed that while this may be the natural successional fate of this system, it was accelerated by the installation of the ditch. Evidence seems to support the hypothesis that anthropogenic causes induced the red maple trees and invasive species to progress into the bog.

Environmental Assessment and Recommendations

Assessment of the Tamarack bog reveals a bog in the later stages of succession. We suggest possible steps that could be taken towards restoration. In addition, direction for future work is readily apparent from current observations.

Figure 5 shows the effects of the identified hazards on the bog. Invasive species and ditching have both contributed to the loss of tamarack and *Sphagnum* via changes in vegetation and hydrology. The goals of any restoration should be to increase the cover of sphagnum and the number of tamaracks in the bog. Further goals, such as a self-sustaining population of tamaracks may not be practical (NRC 2001).

Recommendations for Enhancement

To achieve the goals of increased *Sphagnum* and tamaracks, the initial hazards that contributed to their loss need to be addressed. Solutions to the invasive species problem are more apparent than those of the hydrology.

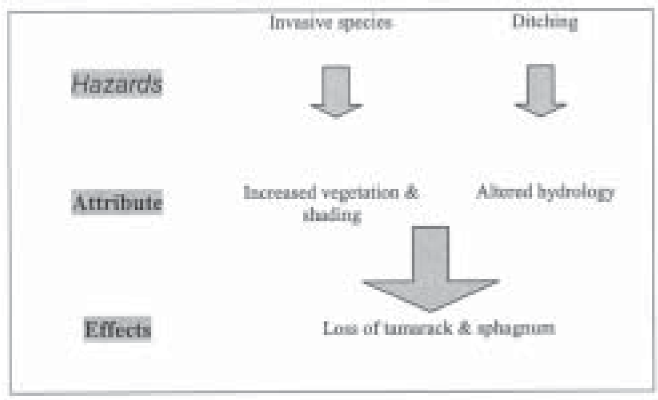

FIGURE 5. Hazards affecting the Bath Tamarack Bog.

Tamarack Management

Tamarack management programs must be able to provide, at minimum, the following conditions:

1. Maintenance of constant water levels, especially for seedling establishment.
2. Removal of other trees, particularly red maple, which compete with and shade adults and seedlings.
3. Removal of invasive species, especially glossy buckthorn, which compete with and shade seedlings.
4. Space seedlings to limit intraspecific competition.
5. Seed or seedling source from multiple regions, but preferably limited to southern population genotypes, to reduce the amount of inbreeding (Park and Fowler 1983).

Invasive species and Their Control

The Tamarack bog at BNP currently has two major invasive species, glossy buckthorn (*Rhamnus frangula*) and multiflora rose (*Rosa multiflora*) both of which tolerate a wide range of habitats. The multiflora rose is primarily found along the edges of the bog, whereas the buckthorn is found in the center of the bog near the tamarack trees.

Multiflora rose is a shrubby vine that can exist for several years as low growing runners. This growth habit makes it difficult to find until it has become well established. Once it does appear in an area, it can persist for long periods of time due mainly to a persistent seed bank that can remain viable for up to twenty years (Underwood and Stroube 1986; ODNR 2001). Glossy buckthorn is characterized by a rapid growth rate and an extensive root system. Its primary method of dispersal is through fruits eaten by birds (Converse 1999; ODNR 2001). These shrubs are able to attain a height of twenty feet, posing a serious threat to tamarack seedlings.

Removal of invasive species would release their competitive effect on tamaracks. It would potentially allow for the establishment of juvenile tamaracks, which are particularly susceptible to shading. Additionally, the past drainage and consequent alteration of the hydrology of the bog may have facilitated the invasion of these species. Re-establishing the previous hydrology may exclude them from the site.

Hydrology

Restoration of the bog's hydrology is extremely complicated because current data is not well understood and there are information gaps. Site monitoring revealed that water levels in the bog were consistent with a typical bog. However, water quality analysis revealed a high pH and higher than normal nutrient levels. A better understanding of water and nutrient inflow is necessary before steps can be taken. For example, an apparent first step is to fill the drainage ditch. It is unknown how this will affect water levels in the bog, especially since they now appear normal. A complete survey of the bog's water budget is needed. A model of the water budget will allow for prediction of possible consequences of altering the flows in or out of the bog. Continued and long term monitoring would need to be coupled with any actions to remediate hydrology.

Conclusions

Important information has been collected towards understanding the current state of the BNP bog. Some immediate steps must be implemented if the goal is to slow the succession of the bog to a forest. Removing invasives and planting bog species, such as tamarack seedlings and *Sphagnum*, would be a good first step towards enhancing the bog. A better understanding of the hydrology of the bog is necessary.

The tamarack bog is an irreplaceable and rare habitat type that benefits the community. The tamarack bog could be utilized for educational purposes, not only for understanding a bog community but also as a case study for restoration and enhancement and the inevitable consequences of ecological succession. In addition, the bog houses *Carex disperma*, the two-seeded sedge, a plant species considered state endangered, as well as two potentially threatened plant species, *Carex atlantica* var. *capillacea* (Howe's sedge) and *Larix laricina* (tamarack). Controlled public access could be made to the bog with the addition of a boardwalk. The bog not only adds diversity to the BNP but also houses rare species of ecological significance.

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