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Relationships among vegetation, surficial geology and soil water content at the Pocono mesic till barrens[1]

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EBERHARDT, R. W. AND R. E. LATHAM (Department of Biology, Swarthmore College, Swarthmore, PA 19081-1390). Relationships among vegetation, surficial geology and soil water content at the Pocono mesic till barrens. J. Torrey Bot. Soc. 127:115–124. 2000.—We examined relationships among vegetation, surficial geology, and soil water content in the Pocono till barrens, an assemblage of pitch pine-scrub oak-heath communities rich in rare species near Long Pond, Pennsylvania. Soil water content was measured using time domain reflectometry over three time periods in summer 1997 in four vegetation types (forest and three barrens communities) on two parent materials (Illinoian glacial till and upper Devonian sandstone bedrock). Wide variation in drought conditions among the time periods (quantified using the Keetch-Byram drought index) allowed for strong tests of differences in soil water-holding capacity among vegetation and parent material types. Soils of barrens and forests did not differ in water content at any depth or drought condition, which confirmed floristic evidence and earlier research that suggested pitch pine-scrub oak vegetation is not associated with xeric conditions. Disturbance history, and possibly the hypothesis of alternative community states, better explain the distinction between barrens and forests in the study area. Soils derived from till and bedrock had similar water contents at each time period, although bedrock soils may have been slightly wetter in the top 15 cm of the soil profile. This contradicts a presupposed relationship between parent material and soil water content and suggests that pitch pine-scrub oak vegetation might occur more extensively on mesic sites in northeastern Pennsylvania than previously thought. Contrary to expectation, barrens types did not differ in soil water content under any drought condition. These results suggest that rhodora barrens, which include diverse and abundant hydrophytes, are not restricted to sites relatively immune from drought. A testable alternative explanation is offered for the distribution of the rare rhodora barrens vegetation type.

Key words: alternative community states, barrens, Ericaceae, fire, heathlands, Illinoian glacial till, landscape, multiple stable points, natural communities, Pennsylvania, *Pinus rigida, Quercus ilicifolia, Rhododendron canadense,* soil moisture, species assemblages, time domain reflectometry.

The hallmarks of pitch pine-scrub oak (P.P.S.O.) communities are an open canopy of pitch pine (*Pinus rigida* P.Mill.), a tall shrub layer of scrub oak (*Quercus ilicifolia* Wang.), and an understory dominated by ericaceous shrubs. They occur scattered throughout the northeastern United States on sandy or shallow soils that are nutrient poor and have low moisture-holding capacity (McIntosh 1959; Milne 1985; Motzkin et al. 1996; Finton 1998). Wildfires occur frequently in P.P.S.O. communities. The dominant plant species are both fire-tolerant and pyrogenic. P.P.S.O. communities and tree-dominated pitch pine-oak forests often are referred to collectively as "pine barrens," because these vegetation types are broadly similar in species composition, substrate affinity and susceptibility to fire (Forman 1979; Olsvig 1980; Patterson et al. 1984; Seischab and Bernard 1991, 1996; Bernard and Seischab 1995). P.P.S.O. communities are a focus of biodiversity conservation efforts throughout the Northeast because they represent an unusual community type that supports an abundance of rare plant and insect species.

A major assemblage of P.P.S.O. communities occurs along the southern edge of the Pocono Plateau in northeastern Pennsylvania (41° 03′ N, 75° 30′ W), primarily on glacial till deposits of Illinoian age but also on upper Devonian sandstone bedrock and Wisconsinan drift. These "Pocono till barrens" remained undescribed until recently and appear to flout conventional wisdom about the relationship between P.P.S.O. communities and xeric site conditions (Latham et al. 1996). The majority of Pocono barrens soils have been characterized as loamy with moderate to high moisture-holding capacity; identical soil types support northern hardwood, mixed hardwood and hardwood-coniferous forests throughout the area (Lipscomb 1981; Fisher et al. 1962). Further, species considered char-

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acteristic of more mesic conditions than found at other P.P.S.O. sites occur throughout the Pocono barrens. *Sphagnum* spp. and the boreal wetland species *Rhododendron canadense* (L). Torr. are particularly abundant in one uncommon Pocono barrens type (rhodora barrens) that often occurs adjacent to wetlands and appears to have a seasonally high water table (Latham et al. 1996). The Pocono till barrens and vicinity support the highest concentration of globally rare plant and insect species in Pennsylvania, including populations of the variable sedge (*Carex polymorpha* Muhl.) and the flypoison bulb-borer moth (*Papaipema* sp. 1 [species description not yet published]) that are among the largest known.

Direct comparison of site conditions between Pocono barrens and nearby forests has been used to investigate whether edaphic and other site factors relate to plant community distributions. Previous work documented that seasonal patterns of water table depth in barrens and nearby forests did not differ during a year of relatively ordinary precipitation, but that water table depth differences did appear to relate to distinct barrens types (Latham et al. 1996). This research was restricted to three barrens sites in the region, all of which occurred on glacial till. One site included all studied examples of rhodora barrens and scrub oak barrens; the latter is the most abundant Pocono barrens type, characterized by dense thickets of *Q. ilicifolia.* Ordinary precipitation during the study made it impossible to determine whether barrens sites were subject to more severe drying during droughts. Information on water table depth also provides only indirect information about soil water content above the water table.

Here we describe research in which summer water content of barrens and forests soils was measured directly to clarify the relationship between vegetation and site conditions on the southern Pocono Plateau. Additional study sites were added to minimize confounding vegetation type and site. Recent land acquisitions by The Nature Conservancy provided the first opportunity to study Pocono barrens overlying Devonian sandstone. Specific questions addressed in this study include: (1) Do differences in soil water content correspond with the distinction between Pocono barrens and forests? (2) Do soils derived from Illinoian glacial till differ in water content from bedrock-derived soils? (3) Are the various Pocono barrens types distributed along a gradient of soil water content? (4) Of what use is information on the relationships among vegetation, surficial geology and soil water content to those working to protect and manage the Pocono till barrens?

Methods. SITE ESTABLISHMENT. We selected eight study areas scattered across 72-km^2 of the Pocono till barrens and adjacent forests near Long Pond (Table 1). The areas were chosen based on the plant communities (see below), surficial geology (determined from maps: Sevon 1975; Berg et al. 1977), slope, and owner permission. Areas with slopes <8% were chosen for the study; most have slopes <3%. Three of the eight study areas include two or three community types, and one contains both parent material types. Different community types or parent materials occurring close together are considered as distinct samples; thus it is possible that spatial autocorrelation might decrease the power of the test to distinguish differences among "treatments." In total, the study includes three forest samples and six barrens samples on Illinoian till and four barrens samples on Devonian bedrock. The barrens samples on till include two scrub oak barrens, two rhodora barrens, and two heath barrens, and on bedrock they include three scrub oak barrens and one rhodora barren (Table 1).

Communities are described by Latham et al. (1996). Scrub oak barrens have at least 50% cover of *Quercus ilicifolia* with widely spaced *Pinus rigida.* Heath barrens have at least 50% cover of a combination of *Kalmia angustifolia* L., *Vaccinium angustifolium* Ait., *V. pallidum* Ait. and *Gaylussacia baccata* (Wang.) K.Koch with sparse *Pinus rigida.* Rhodora barrens have at least 50% cover of low, mainly ericaceous shrubs, of which at least 50% are *Rhododendron canadense* (L.) Torr., with scattered *Pinus rigida.* Forests have at least 90% cover by trees, mainly northern hardwoods (dominated by *Fagus grandifolia* Ehrh., *Prunus serotina* Ehrh., *Betula alleghaniensis* Britt., *B. lenta* L., *Acer rubrum* L. and *A. saccharum* Marshall with frequent *Tsuga canadensis* [L.] Carr. and *Pinus strobus* L.) or red maple-oak (dominated by *Acer rubrum, Quercus alba* L. and *Q. coccinea* Muenchh.). Nomenclature follows Rhoads and Klein (1993).

Soil surveys (Fisher et al. 1962; Lipscomb 1981) indicate that soils underlying most plots are ultisols, inceptisols underlie a few plots, and all are classified as fine-loamy (Table 1).

Permanent census plots had been established

Table 1. Properties of the sites used in the study. "T.N.C." refers to The Nature Conservancy. Community types were identified in the field or, for 1938–39 and 1963, by aerial photo interpretation; abbreviations are: R, rhodora barrens; H, heath barrens; S, scrub oak barrens; M/OF, red maple-oak forest; NHF, northern hardwood forest; HF, hardwood forest of unknown type. Information on parent material was obtained from Berg et al. (1977) and Sevon (1975) and, where possible, was verified in the field; abbreviations are: T, Illinoian glacial till; B, Devonian bedrock. Soil classifications are from Lipscomb (1981) and E. Sheard (pers. comm.). Fire and vegetation history information was obtained from unpublished Pennsylvania Bureau of Forestry records and aerial photographs, respectively (Thompson 1995).

Owner	Community types	Parent material	Soil classification	Fires since 1932	Year of last fire	Vegetation in 1938–39	Vegetation in 1963
Private	H, M/OF	T	Fine-loamy, mixed, mesic Typic Fragiaquults; Fine-loamy, mixed, mesic Aeric Fragiaquults	?	?	?	?
T.N.C. and Monroe Co.	R, H, S	T	Fine-loamy, mixed, mesic Aquic Fragiudults; Fine-loamy, mixed, mesic Typic Fragiaquults; Fine-loamy, mixed, mesic Aeric Fragiaquults; Fine-loamy, mixed, mesic Typic Fragiaquepts	2–4	1957	Barrens	Barrens
T.N.C. and Monroe Co.	NHF	T	Fine-loamy, mixed, mesic Aquic Fragiudults; Fine-loamy, mixed, mesic Aeric Fragiaquults	0	Before 1932	HF	HF
T.N.C.	NHF	T	Fine-loamy, mixed, mesic Typic Fragiaquepts	0	Before 1932	HF, swamp	HF, some clearing
Pa. Game Commission	S	B	Fine-loamy, mixed, mesic Typic Hapludults	2–3	1962	Barrens	Barrens
T.N.C.	S	T, B	Fine-loamy, mixed, mesic Typic Hapludults	4–6	1963	Barrens	Barrens
T.N.C.	R, S	B	Fine-loamy, mixed, mesic Typic Hapludults	1–2	1963	Barrens	Barrens
Pa. Game Commission	R	T	Fine-loamy, mixed, mesic Aquic Fragiudults; Fine-loamy, mixed, mesic Typic Fragiaquults	3	1952	Barrens	Barrens

previously at four of the sites (Latham et al. 1996). Each plot includes four 1 × 1-m quadrats marked with steel reinforcement bar 3 m from the plot center in each of the cardinal compass directions. For this study four plots were chosen randomly as subsamples at each site. Using the same methodology in previously unstudied sites, four plots were established for each sample at points randomly chosen from coordinate grids. The longitude and latitude of each plot was found using a differential global positioning system (Trimble Pro XR, Sunnyvale, CA) to aid in relocation. These positions also were used to characterize the soils, fire history and recent successional trends of each plot from existing geographic information system data layers (Thompson 1995; Latham et al. 1996; Table 1).

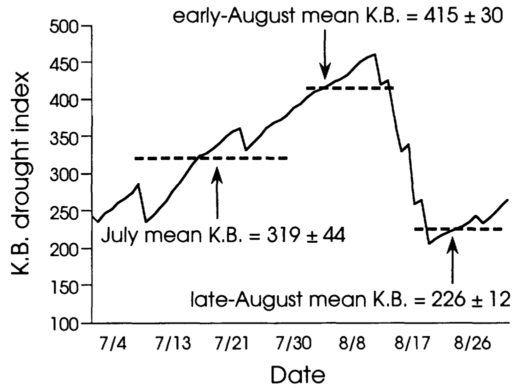

Fig. 1. Keetch-Byram drought index by day for Tobyhanna, Pennsylvania during July–August 1997, with mean (± 1 standard deviation) drought index values for each time period that soil water content measurements were taken.

EVALUATION OF DROUGHT CONDITIONS. To quantify how drought conditions changed during summer 1997, Keetch-Byram (K.B.) drought index values were calculated using weather data collected at the Tobyhanna Army Depot, Tobyhanna, Pa., at an elevation close to that of the study area, 17 km away. Keetch and Byram (1968) developed their index of soil moisture "debt" relative to field capacity to predict wildfire danger. The K.B. index is calculated recursively; its value for a given day depends on its value on the previous day and the day's maximum temperature and precipitation. The K.B. drought index for a given area is initialized when soils are at field capacity. Although Tobyhanna has somewhat lower precipitation values than the study area, insufficient temperature and rainfall data exist from close weather stations.

In order to compare overall drought conditions during 1997 with past years, historical weather data collected at Tobyhanna (National Climatic Data Center, Asheville, NC) were used to calculate K.B. values for all years for which sufficient data exist (1962 to 1989 except 1985).

MEASUREMENT OF SOIL MOISTURE. At each plot, soil water content (percent volume) was measured during three time periods in July and August, 1997 using time domain reflectometry (T.D.R.; see Topp et al. 1980; Topp et al. 1996). T.D.R. allows for the non-destructive measurement of soil water content under field conditions. The particular T.D.R. instrument used (Model MP-917K, Environmental Sensors, Victoria, B.C.) has remotely-switched shorting diodes which allow for the simultaneous measurement of mean water content in the top four 15-cm sections of the soil profile (Hook et al. 1992). Measurements were taken using methods suggested by the manufacturer after at least 48 hours had passed following any rainfall event. New pilot holes were used for each measurement after significant differences were found between soil water contents measured in new pilot holes and old holes that had been plugged with high-density plastic probe replicas (paired *t*-test for 0 to 15-cm depth in early August: d.f. = 12; $t = 5.4$; $P = 0.0002$). For a given depth and time period the soil water content of a sample is the mean of the water content values measured at the four plots in that sample. Calibration with oven-dried soil was deemed unnecessary, since soil surveys classified soils as similarly fine-loamy in texture at all areas sampled and improvement in T.D.R. accuracy obtained by calibration in non-clay soils is small (Hook and Livingston 1996).

STATISTICAL ANALYSIS. The effects of gross vegetation type (forest vs. barrens), barrens type, and parent material on soil water content at each depth interval were tested using repeated measures analysis of variance (RMANOVA). The multivariate approach was used to test the effect of the time × independent variable interaction. One should interpret these results with caution since the data are inherently heteroscedastic (i.e., standard transformations do not equalize variances; Sokal and Rohlf 1995), although ANOVA is robust to violations of this assumption. The inequality of variances most likely results from different ranges of drought conditions that occurred during the time periods when soil wa-

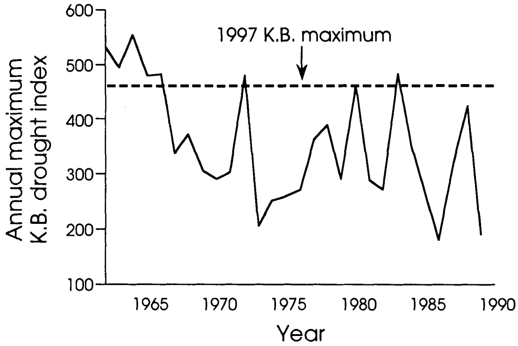

Fig. 2. Annual variation in maximum Keetch-Byram drought index value by year for Tobyhanna, Pennsylvania.

ter content was measured (Fig. 1 and see below). Variances do meet the assumptions of analysis of variance (ANOVA) when time is not considered as an effect. The effects of parent material and community type also are confounded since no forest and heath barrens samples occur on bedrock. The Statistica computer package (StatSoft, Inc., Tulsa, OK) was used to perform statistical tests.

Results. SEASONAL AND ANNUAL DROUGHT CONDITIONS. Keetch-Byram drought index values for 1997 show that regional drought conditions varied substantially among the three measurement periods (Fig. 1). Drought conditions increased throughout July to 12 August when the K.B. index peaked at 461. Approximately 7 cm of rain over the following six days ended the drought by late August.

The maximum K.B. index value during 1997 (461) was the eighth highest annual maximum K.B. value for the period of record (Fig. 2). The mean (± 1 standard deviation) annual maximum K.B. value for the 27 years for which sufficient data exist is 360 ± 108.

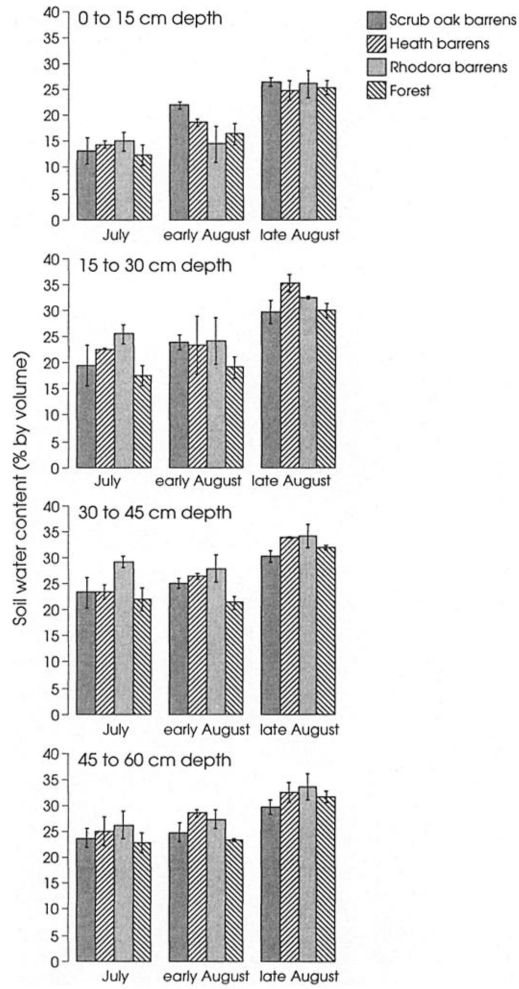

Fig. 3. Water content of barrens and forests soils measured in four depth intervals during three time period, July–August, 1997. Error bars show ± 1 standard error. Sample sizes are as follows: scrub oak barrens, $N = 5$; heath barrens, $N = 2$; rhodora barrens, $N = 3$; northern hardwood or maple-oak forest, $N = 3$. Areas with distinct community types within a given site are considered distinct samples.

SOIL MOISTURE. Soil water content varied with time during summer 1997, with the wettest conditions occurring in late August (Fig. 3–4). RMANOVAs conducted on data from all depths show significant effects of time on soil water content (Table 2a–c). However, barrens and forest did not differ significantly in soil water content, and there was no significant time × vegetation interaction (Table 2a). Mean soil water content was higher in barrens soils than in forest soils during July and early August (Fig. 3). In no depth interval or time period did forest soils have higher mean water content than barrens soils. There was a trend toward a time × vegetation interaction at 45 to 60 cm depth (Table 2a). Water content at this depth increased from July to early August in barrens but not in forest (Fig. 3). There was no significant interaction effect of time × vegetation at other depths.

No significant difference in soil water content existed between soils derived from Illinoian glacial till and Devonian bedrock (Table 2b, Fig. 4). However, in the upper 15 cm of soil there was a trend for soils derived from bedrock to have higher water content than those derived from Illinoian till. Parent material and time did

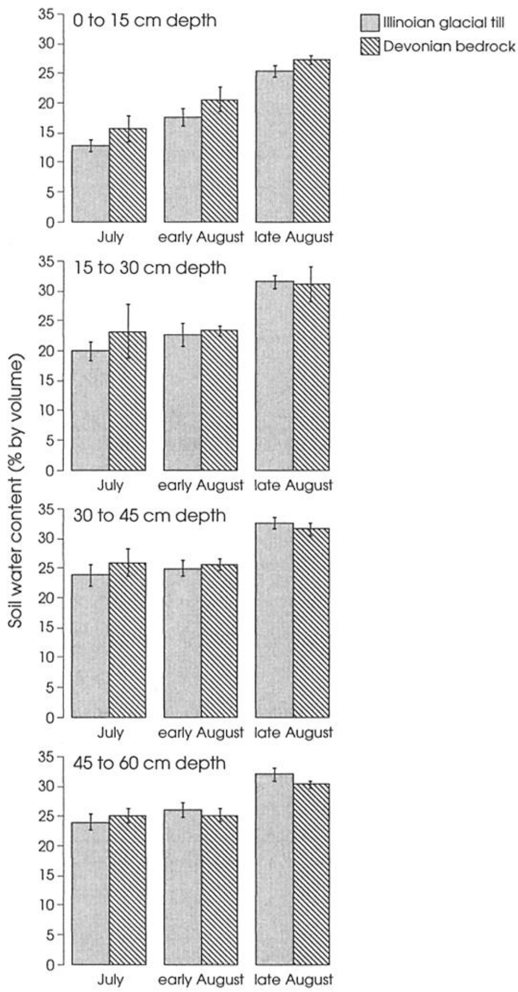

Fig. 4. Water content of soils derived from Illinoian till and Devonian bedrock measured in four depth intervals during three time periods, July–August, 1997. Error bars show ± 1 standard error. Sample sizes are $N = 9$ and $N = 4$ for till and bedrock, respectively. Areas with distinct parent materials within a given site are considered distinct samples.

not interact significantly to affect soil water content.

No significant difference in soil water content existed during summer 1997 among barrens types. In the upper 15 cm of soil there was a trend towards a time × barrens type interaction (Table 2c). Water content at 0 to 15 cm increased between July and early August in scrub oak and heath barrens but not in rhodora barrens (Fig. 3). There was no significant interaction effect of time × barrens type at other depths.

Discussion. Pitch pine-scrub oak vegetation is not associated with xeric conditions in the area we sampled on the southern Pocono Plateau, contrary to the pattern prevailing elsewhere in the region. Furthermore, soils derived from sandstone bedrock are not more xeric than soils derived from Illinoian glacial till, as was presupposed. Our results rule out soil moisture gradients as a cause of the abrupt landscape transitions between the Pocono till barrens and northern hardwoods forests, and they call for a reappraisal of the hypothesized link between elevated soil moisture and the distribution of the rare rhodora barrens type.

EFFECT OF DROUGHT CONDITIONS ON SOIL MOISTURE. Comparison of Keetch-Byram values shows that drought conditions varied throughout summer 1997. The driest period in early August was severe relative to peak drought conditions during past years. The seasonal pattern of drought conditions impacted soil moisture in all samples. Without exception, water content was highest during late August when drought conditions were least severe. In addition to explaining the seasonal variation in soil water content, the range and severity of drought conditions make comparisons of water content strong tests for differences in the soil water-holding capacity of different ecosystems. In particular, differences in water content among soils with different sand (i.e., coarse-textured) fractions become exaggerated during drought years (Kubiske and Abrams 1994).

MOISTURE STATUS OF POCONO BARRENS AND FOREST SOILS. The direct measurement of soil water content across the southern Poconos landscape confirms the findings of an earlier study (Latham et al. 1996) that forests and barrens did not differ in the presence, duration and depth of a high water table. Because barrens and forests did not differ in soil water content over a range of summer conditions that included a relatively severe drought, the Pocono barrens are best described as mesic. They have soils that hold enough water to support the non-barrens vegetation that occurs in the area, including northern hardwoods forest. At certain depths and drought conditions Pocono barrens soils may have even higher water contents than those of surrounding forests. Despite compositional and structural similarities, the Pocono till barrens do not occur on xeric substrates like other P.P.S.O. communities (McIntosh 1959; Milne 1985; Motzkin et al. 1996; Finton 1998).

Ongoing work has found no other soil factors considered likely to restrict the establishment

Table 2. Results of repeated-measures analysis of variance.

Depth (cm)	d.f.	*F*	Wilks' λ	Rao *R*	*P*
(a) RMANOVAs comparing soil water content of forests and barrens.					
0 to 15					
Forest/barrens	1, 11	1.3			0.271
Time	2, 10		0.05	100.2	0.000**
Interaction	2, 10		0.90	0.6	0.574
15 to 30					
Forest/barrens	1, 11	2.3			0.159
Time	2, 10		0.01	39.4	0.000**
Interaction	2, 10		0.87	0.8	0.493
30 to 45					
Forest/barrens	1, 11	2.2			0.169
Time	2, 10		0.12	37.5	0.000**
Interaction	2, 10		0.72	1.9	0.200
45 to 60					
Forest/barrens	1, 11	2.0			0.187
Time	2, 10		0.08	57.3	0.000**
Interaction	2, 10		0.56	4.0	0.053
(b) RMANOVAs comparing soil water content of different parent materials.					
0 to 15					
Till/bedrock	1, 11	4.6			0.055
Time	2, 10		0.05	102.7	0.000**
Interaction	2, 10		0.95	0.3	0.774
15 to 30					
Till/bedrock	1, 11	0.2			0.676
Time	2, 10		0.12	37.2	0.000**
Interaction	2, 10		0.83	1.1	0.385
30 to 45					
Till/bedrock	1, 11	0.1			0.807
Time	2, 10		0.15	27.7	0.000**
Interaction	2, 10		0.81	1.2	0.343
45 to 60					
Till/bedrock	1, 11	0.0			0.975
Time	2, 10		0.15	29.1	0.000**
Interaction	2, 10		0.79	1.3	0.307
(c) RMANOVAs comparing soil water content of different barrens types.					
0 to 15					
Barrens type	2, 7	0.7			0.529
Time	2, 6		0.03	89.7	0.000**
Interaction	4, 12		0.26	2.9	0.071
15 to 30					
Barrens type	2, 7	0.5			0.614
Time	2, 6		0.11	23.4	0.001**
Interaction	4, 12		0.66	0.7	0.617
30 to 45					
Barrens type	2, 7	2.2			0.184
Time	2, 6		0.12	21.7	0.002**
Interaction	4, 12		0.70	0.6	0.673
45 to 60					
Barrens type	2, 7	0.9			0.434
Time	2, 6		0.02	126.4	0.000**
Interaction	4, 12		0.59	0.9	0.495

and growth of forest species in barrens (A. W. Wibiralske, unpub. data). In the absence of anomalous site conditions, the disturbance history associated with these communities should be considered the primary determinant of barrens occurrence. Historical accounts, including those from botanists who compiled species lists that are closely similar to contemporary botanical inventories, demonstrate that the Pocono till barrens around Long Pond predate European settlement (Latham et al. 1996). As with other P.P.S.O. communities, there is some uncertainty about the changes in extent, composition, and structure that resulted from early European land-use practices (Motzkin et al. 1996), which in northeastern Pennsylvania included mid- to late nineteenth century clearcutting and subsequent fires. Others have noted the dramatic increase of scrub oak in northeastern Pennsylvania following these disturbances (Burham et al. 1947). State forest fire records dating from the 1930s to the present provide a detailed record of local fires, which in the study area around Long Pond primarily resulted from burning practices used from the late 1800s to the 1950s to encourage blueberry production (Latham et al. 1996). Consistent with the often-noted relationship between P.P.S.O. occurrence and fire, fire frequency appears to best predict the location of extant barrens that have persisted since 1938, the date of the earliest aerial photographs that show distribution of vegetation types (Latham et al. 1997).

Latham et al. (1996) hypothesized that the Pocono till barrens represent an alternative stable community state (*sensu* Wilson and Agnew 1992) to the more common forest vegetation found throughout the study area. According to this hypothesis, barrens vegetation is maintained through positive feedbacks driven by plant traits that encourage the spread of wildfire or restrict soil nitrogen availability, or both, following a disturbance of sufficient magnitude to allow for barrens species to become dominant (Petraitis and Latham 1999). The absence of xeric conditions does eliminate an alternative explanation for why barrens might occur in the study area. Acceptance of the notion of alternative community states for these ecosystems requires additional clarification, however, on what role (if any) human disturbances can play in the "vegetation-driven feedback loops" and "autogenic processes" central to state maintenance. Furthermore, it has yet to be demonstrated that nitrogen availability is restricted in the Pocono barrens, although such an effect has been documented in ecosystems of comparable species composition (e.g. Damman 1971).

RELATIONSHIPS BETWEEN SOIL WATER CONTENT AND SURFICIAL GEOLOGY. Past research has emphasized the distinctive characteristics of Pocono P.P.S.O. communities that occur on glacial till (Latham et al. 1996), in part because soils derived from the area's sandstone bedrock were presumed to have lower water-holding capacity than till-derived soils. Here we suggest, at least for the study area in the vicinity of Long Pond, that the similarity between P.P.S.O. communities on different parent materials has not been sufficiently appreciated. During summer 1997 soils derived from till and bedrock had comparable water content at all depths and drought conditions. The top 15 cm of bedrock-derived soils even may have had slightly higher water content than soils derived from till. Consistent with the documented wet conditions, bedrock barrens in the vicinity of Long Pond support mesic species (R. Eberhardt, unpub. data), in contrast to other barrens on the Pocono escarpment and north of the study area (R. Eberhardt and R. Latham, pers. obs.). P.P.S.O. communities that include an abundance of mesic species, though extremely rare throughout the northeastern United States (Latham et al. 1996), may be more common on the southern Pocono Plateau than previously thought.

SOIL MOISTURE OF DIFFERENT BARRENS TYPES. Contrary to expectation, no difference in soil water content existed during summer 1997 among Pocono barrens types across a range of drought conditions. Thus rhodora barrens, which support abundant and diverse wetland species, are not restricted to sites that remain relatively wet during the growing season. The occurrence of rhodora barrens might instead be explained by seasonally high water tables not apparent during the study (Latham et al. 1996). Anoxic conditions following snowmelt may suppress intolerant species and allow for the persistence of *R. canadense* and other rhodora-barrens-restricted hydrophytes such as *Carex stricta* Lam. and *Gentiana linearis* Froel. It should be emphasized, however, that the previous water table study investigated only one relatively restricted area of rhodora barrens which may be unrepresentative of this barrens type throughout the southern Pocono Plateau (see Introduction). Some rhodora barrens do appear less susceptible to seasonal inundation than in that particular area (R. Eberhardt, pers. obs.). If rhodora barrens occurrence is subject to environmental control, alternative community state models for this barrens type should be re-evaluated.

The trend towards an interaction effect of time × barrens type on water content in the upper 15 cm of soil lacks a clear explanation. However, it lends added support to the conclusion that barrens plant communities judged as most mesic based on species composition paradoxically may not occur on the least drought-prone soils. Scrub oak barrens, which include the lowest cover and diversity of mesic species (Latham et al. 1996; R. Eberhardt, unpub. data), had the highest mean soil water content during the drought in early August.

IMPLICATIONS FOR CONSERVATION AND MANAGEMENT. The Pocono till barrens have exceptional conservation value as an example of the P.P.S.O. vegetation type and as habitat for a large concentration of rare plant and insect species. The wet soil conditions documented in this study give the Pocono till barrens added significance by distinguishing them from other P.P.S.O. assemblages. These wet conditions may also have facilitated the particularly rapid succession into forest and woodland that has occurred since fire suppression (Thompson 1995; Latham et al. 1997). These findings lend added urgency to the use of prescribed burning in maintaining remnant barrens and possibly in restoring a portion of the barrens lost to succession after fire suppression.

The possibility that rhodora barrens occur in upland areas immediately adjacent to wetlands and subject to spring inundation deserves further study. In this scenario, increased water diversion for municipal supply or other uses might compromise the rhodora-dominated community, which is the rarest and highest in species diversity of the mesic barrens types (Latham et al. 1996). Protecting and maintaining this community effectively will depend on a better understanding of links between its unique species composition and seasonal flooding.

The unexpected occurrence of mesic conditions and species in barrens overlying bedrock suggests that the distinctive mesic barrens vegetation type may be more extensive around Long Pond than previously thought. It also raises the possibility that some of the P.P.S.O. communities elsewhere in the region occur in association with similar site conditions and support mesic species. Unexplored occurrences of this unusual assemblage of rare and disjunct species might still await discovery.

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