Appendix 9. BIOLOGICAL STUDIES AT SPRUCE HOLE BOG
FINAL REPORT

By

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PART 1. INTRODUCTION

1.1 Background and Objectives

Spruce Hole bog is the only remaining intact "kettlehole" bog in southeastern New Hampshire. Its uniqueness has been recognized by the National Park Service, which in 1972 designated the bog a National Natural Landmark. As bogs are ecosystems whose species composition is greatly influenced by water table characteristics and chemical composition of incoming water, development that impacts these variables can alter species composition and biological diversity of the community. Given the possible use of the Spruce Hole aquifer as a water source for Durham, questions have been raised about the possible impact of such development on Spruce Hole Bog.

Assessment of potential effects of development on any ecosystem first requires quantitative baseline information on the structure and natural dynamics of the biological community. Unfortunately, when the Spruce Hole aquifer became an issue in the late 1980's, relatively little was known about the vegetation, flora, and fauna of the bog. Consequently, the objectives of our research at Spruce Hole were to (1) determine what information was presently known about the distribution, abundance, and environmental relations of organisms in Spruce Hole, (2) produce a complete flora of the bog, (3) describe and map plant communities in the bog, (4) determine the recent history of bog vegetation, focusing on white pine, and (5) establish permanent vegetation plots for long-term monitoring.

1.2 What is a bog?

Bogs are just one type of peatland. Peatlands are natural wetland ecosystems "where soils are peat -- the partially or incompletely decomposed remains of plants and, to some extent, animals" (Johnson 1985). Peatlands occur where there is high precipitation or low evapotranspiration, cool temperatures, short growing seasons, high acidity, and where hydrologic conditions favor water accumulation and retention over all or much of the growing season (Damman and French 1987). Peatlands occur throughout much of the world, but are most common in the northern parts of North America and Eurasia.

Decomposition in peatlands occurs very slowly due to low oxygen concentrations and cold temperatures (van Breemen 1995). Extreme acidity further reduces rates of decay in some peatlands (Johnson 1985). Consequently, nutrients tend to be sequestered in the undecayed peat and are largely unavailable to living plants.

Peatlands are classified based on their nutrient status and three classes are commonly described: minerotrophic, oligotrophic, and ombrotrophic. Minerotrophic peatlands are enriched with nutrients, usually from surface water or ground water influx, and are commonly known as fens. Oligotrophic peatlands receive nutrients from surface water, ground water, and precipitation but rates of influx are very low and thus these peatlands are rather infertile. Ombrotrophic peatlands receive nutrients exclusively from atmospheric precipitation and are the most sterile of the three types (Johnson 1985, Gorham and Janssens 1992, van Breemen 1995). The term bog is usually restricted to ombrotrophic peatlands and the more extreme oligotrophic peatlands (Johnson 1985). Bogs are more acidic than fens

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primarily due to the ability of *Sphagnum* mosses to acidify their immediate surroundings (Moore and Bellamy 1974, Crum 1988, Andreas and Bryan 1990, van Breemen 1995).

Kettlehole bogs, such as that at Spruce Hole, are peatlands that occur in deep depressions formed long ago during deglaciation. Massive blocks of ice broke off of the retreating ice front, were surrounded or buried by glacial sediments, and later melted, leaving behind "kettles" (Longwell, Flint and Sanders 1969, p. 274). These basins were colonized by aquatic and emergent plants and later by terrestrial plants that colonized the accumulating peat over the millennia.

1.3 Peatlands in the Northeast

Peatlands are not common in the northeastern U.S. and, thus, have been of special interest to ecologists and conservation biologists (Johnson 1985). Over the past two decades, a concerted effort has been made to inventory and classify peatlands of the northeast based primarily on their plant species composition (see Worley and Sullivan 1980, Worley 1981, Damman and French 1987). These studies agree that the lack of detailed information about specific peatlands has prevented the development of firm generalizations about patterns of community structure and diversity in these ecosystems.

In New Hampshire, several peatlands, including Spruce Hole Bog, have been identified as unique ecological areas due to the rarity of habitat, vegetation, or of plant and animal species (Lyon and Bormann 1962, Favour 1971, Lyon and Reiners 1971, Bayless 1981, Johnson 1985, Hellquist 1994, Sperduto and Ritter 1994, Sperduto 1995). To date, however, only a few have been studied intensively enough to allow comparison with Spruce Hole Bog (Dunlop 1983, 1987, Fahey 1993, Fahey and Crow 1995, Hellquist 1994).

Dunlop (1983, 1987) mapped and described five major plant community types at Mud Pond Bog, a peatland in Hillsborough, New Hampshire. Fahey (1993) carried out a similar project in Ossipee, New Hampshire. She used computer techniques to identify five major plant communities in Pequawket Bog and provided a flora for nearby Heath Pond Bog. Hellquist (1994) described the vascular plant communities of Mud Pond Bog in Moultonborough, New Hampshire, and then carefully compared the flora of his bog with those studied by Dunlop and Fahey. He found that all four New Hampshire peatlands were very similar in plant species composition.

None of the studies mentioned above included bryophytes (mosses and liverworts) a conspicuous omission as members of the genus *Sphagnum* -- the peat mosses -- form the bulk of the peat in many peatlands and are known to be important regulators of water level and chemistry and, thus, presence or absence of plant species (Vitt and Slack 1975, Crum 1988, Gorham and Janssens 1992).

PART II. REVIEW OF EXISTING INFORMATION ON SPRUCE HOLE

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Spruce Hole Bog has been recognized as a unique ecological area by the U.S. National Park Service and is a registered National Natural Landmark. The Natural Landmark evaluation report (Favour 1971) states that "Spruce Hole Bog has exceptional value in that it is an ecological community significantly illustrating the characteristics of a typical *Sphagnum*-Heath bog localized in a specialized geological setting, i.e., it is a true kettle-hole bog." The bog is cited as being the last of six kettlehole bogs in southern New Hampshire.

Dr. Albion Hodgdon collected vascular plants at Spruce Hole Bog from 1931 to 1969 and his voucher specimens are housed in the Hodgdon Herbarium at the University of New Hampshire. Hodgdon's (1962, 1971) research is the only published botanical work done at Spruce Hole Bog. His species list was incomplete but he provided some information on the past extent of vascular plant assemblages. An unpublished report (Femino 1969), apparently the result of a student research project at the University of New Hampshire, listed 37 species of phytoplankton (algae) found in the bog pond in 1969. Another unpublished student paper provided data on tree ring widths of black spruce growing in the bog (Cummings 1969).

Invertebrates of the bog have received some study. Studies by Dr. Donald S. Chandler of the University of New Hampshire have revealed a diverse insect fauna of over 1700 species (Chandler 1996). Of particular interest are the banded bog skimmer dragonfly (*Williamsonia lintneri*), a species endemic to New England, and the blundering *Stenus* rove beetle (*Stenus mendosus*), which is only found in Spruce Hole Bog and one other bog in Connecticut. According to Dr. Chandler, the banded bog skimmer dragonfly was last collected at Spruce Hole Bog in 1950, while the rove beetle is abundant and has been collected through the 1980's. The bog elfin butterfly (*Incisalia laneeoriensis*), which is a specialized feeder on young foliage of black spruce (Johnson 1985) was last collected at Spruce Hole in 1897 but still may be extant. Specimens of these insects are located in the University of New Hampshire insect collection. Dr. Chandler, Department of Zoology, should be consulted for more detail concerning these organisms. Two specialized studies of bog invertebrates have been conducted at Spruce Hole. Debboun (1983) studied mosquitoes and Donaldson- Fortier (1993) studied mites associated with peat mosses.

PART III. THE FLORA AND VEGETATION OF SPRUCE HOLE BOG

3.1 Introduction

This part of the report describes the methods used to characterize the flora and map the vegetation of Spruce Hole Bog. Results are then presented and compared to the flora and vegetation of other New Hampshire peatlands.

3.1.1 Flora Flora were determined by examining the bog twice a week from late March through October in 1993 and then approximately weekly during the growing season of 1994 to confirm and extend the findings. Nomenclature followed Gleason and Cronquist (1991) for vascular plants, Crum and Anderson (1981) for mosses, and Crum (1991) for liverworts. Herbarium specimens of all species were deposited in the Hodgdon Herbarium (NITA) at the University of New Hampshire.

3.1.2 Vegetation Sampling Plant distribution and abundance data were collected in July 1993 along thirteen parallel transects separated from each other by 10 meters. Each transect was divided into eight-meter segments and one plot (1 meter by 1 meter in size) was placed randomly within each segment. For each plot, the species present were identified and listed, as well as their abundances. Abundance was measured as 'percent cover': the percent of the plot covered (in vertical projection) by the foliage of the species, estimated to the nearest five percent. In all, there were 113 sample plots. For mapping purposes the location of each transect and distance of each plot along the transect were recorded.

3.1.3 Classification of Communities Sample plots were classified based on species composition and abundance using the computer program TWINSPAN (Two-Way Indicator Species Analysis [Hill 1979]). The plant associations and distributions were then interpreted based on the TWINSPAN output.

3.1.4 Surveying and Vegetation Mapping The bog perimeter was surveyed by sighting and recording distances and angles to landmarks along the border between the *Sphagnum* mosses in the lagg (moat) and the surrounding forest. A compass and SONIN 150 ultrasonic distance meter were used to make these measurements. From these data a computer map of the bog was constructed on which the distribution of the plant communities was plotted based on sample plot locations and their classification. The appropriateness of the community boundaries on the map was checked in the field.

3.1.5 Basin Profile Data were collected for the basin profile by pushing an extendible metal probe into the peat until it reached solid ground. This was done at approximately 5 meter increments along two perpendicular transects. Depth to the surface of the accumulated peat in the center of the pond was measured by dropping a plumb bob on a string until it hit peat and then measuring the length of string that was submerged.

3.1.6 pH Measurement pH was measured within each of the designated plant communities in 1994 on the following dates: May 12; June 4, 18, 29; July 10: August 1 and 5. No community was sampled less than four times. Sampling involved pushing a 500 ml plastic bottle into the peat until it filled with water, then analyzing the contents using a BECKMAN Φ20 Series pH meter (Beckman Instruments, Inc. Fullerton C.A.) within two hours of sampling.

3.2 Results and Discussion

3.2.1 Dimensions of the Bog Spruce Hole Bog is rough1y oval in shape, approximately 152 m long, 80 m wide, and one hectare in area (Figure 1). A basin profile appears in Figure 2. Depth to peat in the center of the pond was 5.5 m. Depth to mineral substrate (sand and gravel) remains undetermined in the deepest portions as it exceeded the length of the probe (14m).

3.2.2 Flora In the following discussion of the flora of Spruce Hole Bog, common names will be used where they are available. Scientific names appear with common names in

Table 1. Many sedges, mosses, and liverworts have no widely used common names and, consequently, only scientific names will be used for these plants.

Fifty-three plant species representing 24 families were found in Spruce Hole Bog. Thirty-seven of these species were vascular plants: flowering plants, conifers, and ferns (Table 1). Sixteen were mosses and liverworts (bryophytes) (Table 2). Among the vascular plants, the heath and sedge families had the greatest number of species. Among the mosses and liverworts, peat mosses (the genus *Sphagnum*) were the most species-rich.

Many New Hampshire peatlands contain species that are endangered, threatened, or of "special concern" according to New Hampshire's Natural Heritage Inventory, Department of Resources and Economic Development (DRED 1995). Of these species only grass pink (*Calopogon tuberosus*) and pitcher plant (*Sarracenia purpurea*) have been documented at Spruce Hole Bog and both species are listed as being of "special concern." Hodgdon (1962, 1971) collected grass pink prior to 1960, but it could not be found during the field seasons of 1993-95. It should be noted, however, that some bog orchids, such as grass pink, flower intermittently, even where they are abundant (Johnson 1985). Pitcher plant was abundant at Spruce Hole Bog and did not appear to be declining (DRED 1995).

3.2.3 Indicator Species Species found at Spruce Hole Bog that have been cited as indicators of nutrient-poor (oligotrophic or ombrotrophic) peatlands included black spruce, cotton-grasses, leatherleaf, sundew, false Solomon's seal, and some peat mosses (Jeglum 1971, Worley 1981, Johnson 1985). Some minerotrophic (slightly nutrient-enriched) indicator species also occurred, including cranberry, winterberry and a sedge, *Carex canescens* (Jeglum 1971, Worley 1981). Most of these species were typically found in or near the lagg (moat) or pond where peat conditions were less acidic (Table 3). The large number of oligotrophic/ombrotrophic indicator species and the low pH values suggested that Spruce Hole Bog is very infertile and acidic.

3.2.4 Vegetation Based on the presence and abundance of plant species in 113 meter-square plots, the computer program TWINSPAN identified five communities: (1) the lagg (moat) community, (2) the low shrub community (3) the *Sphagnum*/sedge lawn, (4) the tall shrub community, and (5) the bog forest community (Figure 4). The lagg community was divided into three phases: (1) the leatherleaf /water-willow phase (2) the cotton-grass phase and (3) the *Carex* phase.

The five communities can be aligned along a gradient of decreasing soil moisture as follows: lagg community, low shrub, *Sphagnum/*sedge lawn, tall shrub, and bog forest. Peat was least consolidated and the peat surface closest to the water table in the lagg community, while in the bog forest peat was well consolidated and slightly raised above the water table.

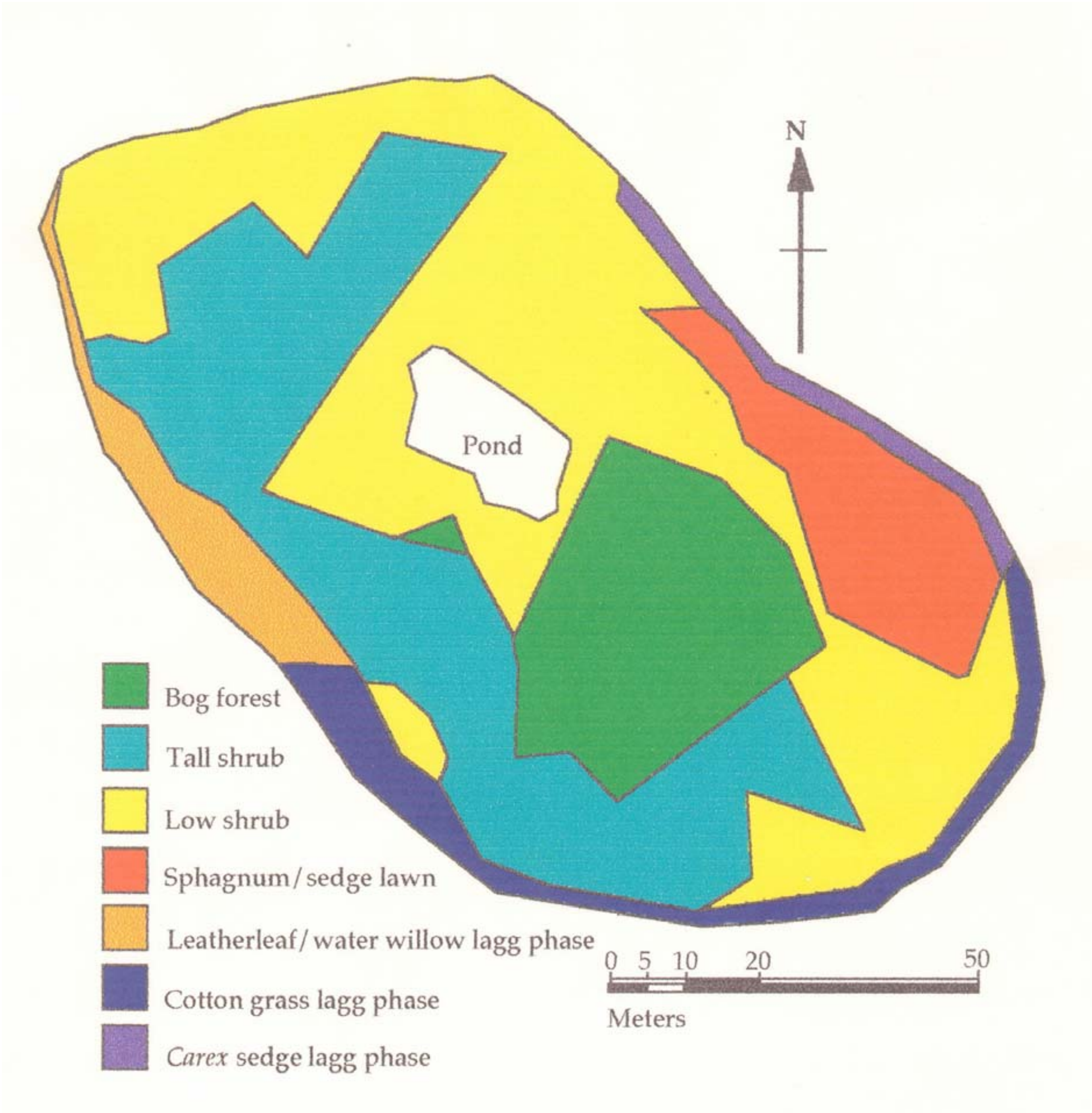

Figure 1. Vegetation map of Spruce Hole Bog. The five communities and three phases of the lagg community were delineated by mapping plots classified by the program TWINSPAN based on species composition and abundance.

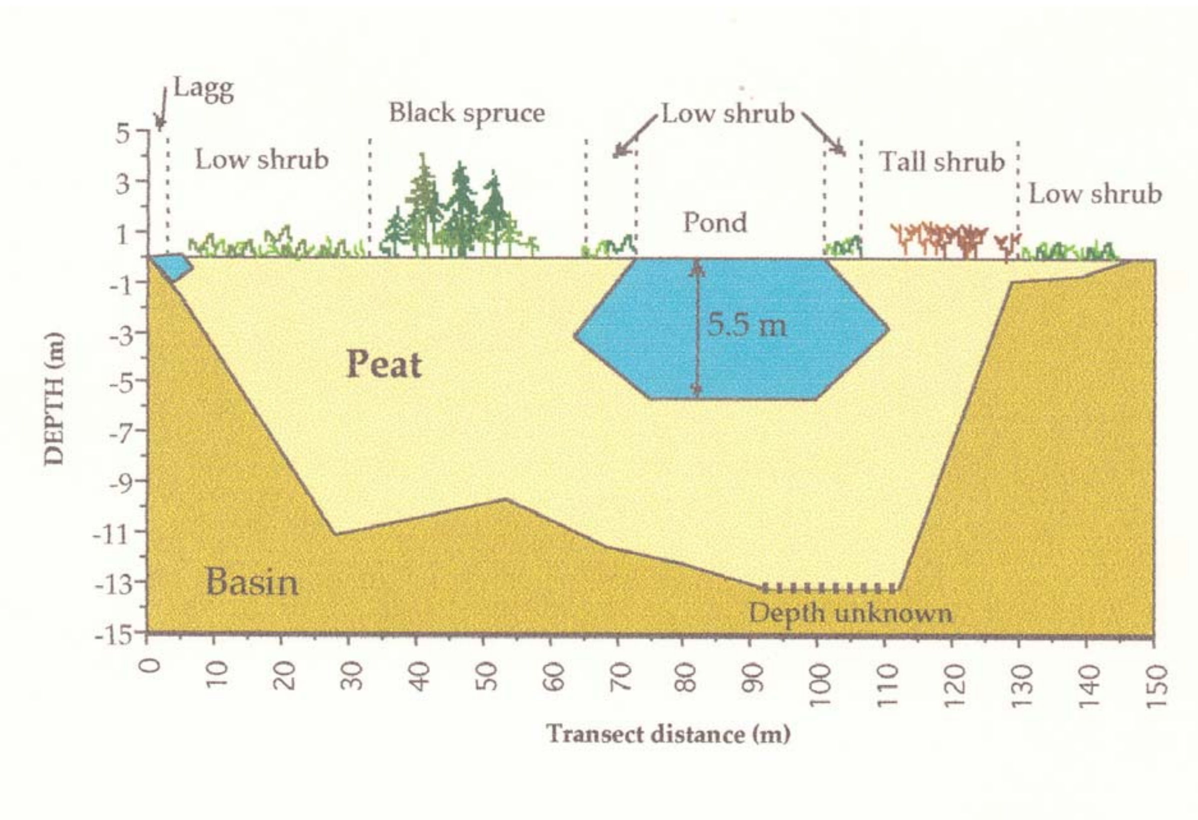

Figure 2. Basin profile of Spruce Hole Bog along a southeast to northwest transect. Depth to mineral substrate in the deepest portion of the basin is unknown.

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Table 1. Vascular plant flora of Spruce Hole Bog. Mean percent cover and frequency (%of plots in which the species occurs) are listed for those species that were included in the TWINSPAN analysis. Those species without abundance measures ere infrequent and did not occur in the sample plots. Listing of families follows Gleason and Cronquist (1991).

Common name	Scientific name	%Cover	% Frequency
ROYAL FERN FAMILY			
Cinnamon fern	*Osmunda cinnamomea* L.	3	19
PINE FAMILY			
Black spruce	*Picea mariana* (Miller) BSP	4	13
White pine	*Pinus Strobus* L.		
BIRCH FAMILY			
Black birch	*Betula lenta* L.	<1	<1
Gray birch	*Betula populifolia* Marshall	<1	<1
PITCHER PLANT FAMILY			
Pitcher plant	*Sarracenia purpurea* L.	<1	13
SUNDEW FAMILY			
Round-leaved sundew	*Drosera rotundifolia L.*	<1	39
HEATH FAMILY			
Male-berry	*Lyonia ligustrina* (L.) DC.	2	27
Black huckleberry	*Gaylussacia baccata* (Wangenh.) K. Koch.	4	21
Sheep laurel	*Kalmia angustifolia* L.	4	42
Bog laurel	*Kalmia polifolia* Wangenh.	<1	2
Leatherleaf	*Chamaedaphne calyculata* (L.) Moench.	14	52
Lowbush blueberry	*Vaccinium angustifolium* Aiton		
Highbush blueberry	*Vaccinium corymbosum* L.	20	58
Cranberry	*Vaccinium macrocarpon* Aiton	<1	4
Small cranberry	*Vaccinium oxycoccos* L.	<1	6
Creeping snowberry	*Gaultheria hispidula (*L.) Muhl.		
Wintergreen	*Gaultheria procumbens* L.		
Rhodora	*Rhododendron Canadense* (L.) Torr.		
PRIMROSE FAMILY			
Starflower	*Trientalis borealis* Raf.		
ROSE FANIILY			
Black chokeberry	*Aronia melanocarpa* (Michx.) Elliott	1	27
Shadbush	*Amelanchier canadensis* (L.) Medikus		
LOOSESTRIFE FAMILY			
Water-willow	*Decodon verticillatus* (L.) Elliot	13	35
HOLLY FAMILY			
Mountain holly	*Nemopanthus mucronatus (L.) Trel*.	2	6
Smooth winterberrv	*Ivex laevigata* (Pursh) Gray	<1	2
Winterberry	*Ilex verticillata* (L.)Gray	<1	8
MAPLE FAMILY			
Red maple	*Acer rubrum* L.	<1	28

Table 1. (Continued)

Common name	Scientific name	%Cover	% Frequency
CASHEW FAMILY			
Poison sumac	*Toxicodendron vernix* (L.) Kuntze	<1	9
BLADDERWORT FAMILY			
Bladderwort	*Utricularia geminiscapa* Benj.	<1	3
HONEYSUCKLE FAMILY			
Withe-rod	*Viburnum nudum* L. var. cassinoides T.&G.		
SEDGE FAMILY			
Conifer cotton-grass	*Eriophorum tenellum* Nutt.	1	20
Tussock cotton-grass	*Eriophorum vaginatun* L. var. *spissum* (Fern.)B. Boivin	<1	5
Tawny cotton-grass	*Eriophorum virginicum* L.		
Sedge	*Carex canescens* L.	2	7
Three-seeded sedge	*Carex trisperma* Dewey var. *billingsii* Knight	2	12
Beak-rush	*Rhynchospora alba* (L.) Vahl.	1	2
LILY FAMILY			
False Solomon's seal	*Smilacina Trifolia* (L.) Desf.	<1	2

In the following discussion the Spruce Hole plant communities will be described in order of increasing 'dryness' of the substrate. Comparison with communities of other peatlands in the region will be made. It should be kept in mind, however, that community types are quite variable from bog to bog and that the amount of detailed literature available for comparison is small compared to the estimated hundreds of peatlands in the northeast.

3.2.5 The lagg community Computer analysis identified a distinct plant community located in the lagg or moat of the bog. The lagg was located between the upland forest and the bog mat, where water was present during most of the growing season but no mat of consolidated peat formed (Figure 1). The lagg vegetation and peat were not cohesive and would not support the weight of a person. The lagg community was dominated by one species of peat moss, *Sphagnum cuspidatum,* and had three phases: (1) the leatherleaf/water-willow phase (2) the cotton-grass phase, and (3) the *Carex* phase. Each phase was named according to the plant species co-dominating with *S. cuspidatum* (Table 4). The *Carex* lagg phase occurred in a narrow band along the northeast margin of the bog and was densely mantled with a sedge, *Carex canescens.* The leatherleaf/water-willow phase was very similar to the low shrub community in the northern reaches of the bog. The peat substrate, however, was not solid here and *Sphagnum cuspidatum* rather than *S. recurvum* dominated. The cotton-grass phase of the lagg community occupied a thin band, no more than five meters wide, around the southern end of the bog.

Table 2. Bryophyte flora of Spruce Hole Bog. Mean percent cover and frequency (% of plots in which the species occurs) are listed for those species that were included in the TWINSPAN

analysis. Those species without abundance measures were infrequent and did not occur in the sample plots.

Family	Scientific name	% Cover	% Frequency
Aulacomniaceae	*Aulacomnium palustre* (Hedw.) Schwaegr.	<1	8
Dicranaceae	*Diranum flagellare* Hedw.		
	Diranum ontariense Peters		
	Diranum polysetum Sw.		
	Diranum scoparium Hedw.		
Hylocomiaceae	*Pleurozium schreberi* (Brid.) Mitt.		
Sphagnaceae	*Sphagnum cuspidatum* Erh. ev Hoffm,	10	14
	Sphagnum recurvum P. -Beauv.	41	80
	Sphagnum capillifolium (Erh.) Hedw. var. *tenellum* (Schimp.) Crum	<1	20
	Sphagnum fuscum (Schimp.) Klinggr.	<1	4
	Sphagnum magellanicum Brid.	39	76
	Sphagnum fimbriatum Wils. *ex* Wils. & J.D. Hook		
Amblystegiaceae	*Warnstorfia fluitans* (Hedw.) Loeske*		
Calypogejaceae	*Calypogeja mulleriana* (Schiffn.) K. Mull.		
Cephaloziaceae	*Cephalozia plenicaps* (Aust.) Lindb.		
Ptilidiaceae	*Ptilidium pulcherrinum* (Web.) Hampe		

* *Warnstorfia fluitans* (Hedw.) Loeske = *Drepanocladus fluitans* (Hedw,) Warnst. The taxonomy for this species was updated using Anderson et al. (1990) rather than Crum and Anderson (1981).

Table 3. Mean pH values of water in the peat of each plant community at Spruce Hole Bog. Standard deviations (sd) and sample sizes (n) appear in parentheses. Data collected during the summer of 1994.

Community	pH
Bog forest	3.63 (sd = 0.21, n = 4)
Tall shrub	3.67 (sd = 0.16, n = 4)
Low shrub	3.85 (sd = 0.20, n = 7)
Sphagnum/sedge lawn	3.91 (sd = 0.33, n = 7)
Lagg	4.26 (sd = 0.50, n = 4)

Table 4. Mean percent cover for dominant species (>5% in at least one community) within each plant community at Spruce Hole Bog.

Plant community

Taxonomy	Cotton grass lagg phase	Leatherleaf-water willow lagg phase	*Carex* lagg phase	Low shrub	Sphagnum/sedge lawn	Tall shrub	Bog forest
Cinnamon fern			8			6	3
Black huckleberry				2		7	9
Highbush blueberry		1	24	7	3	30	41
Three-seeded sedge							9
Mountain holly						2	8
Black spruce							23
Sheep laurel				1		10	4
Sphagnum magellanicum			6	42	6	48	64
Cotton-grass	15			1	9	1	
Water-willow		38	34	24		5	
Sphagnum recurvum	15	22	3	46	93	47	17
Leatherleaf		40	1	27	28	4	
Male-berry	3	2		3	6	2	
Sphagnum cuspidatum	84	78	86	1			
Carex canescens			37		3		

In most bogs, the lagg habitat experiences fluctuating water levels (Buell and Buell 1975), nutrient input from runoff, and higher decay rates during drought or dry periods later in the growing season (Damman and French 1987). Consequently, nutrient levels and Ph values are higher in the lagg than in other bog habitats. At Spruce Hole the lagg was less acidic than the other communities (Table 3).

3.2.6 The low shrub community was uniformly dominated by leatherleaf and water willow (Table 4). Moss cover was composed primarily of *Sphagnum recurvum* and *S. magellanicum*. Subsidiary species included cranberry, male-berry, huckleberry, and round-leaf sundew, but these species only seemed to occupy the sparse drier patches on the edge of the community where it gave way to the tall shrub community. Plants seldom reached heights of over 50 cm in this community. The peat was very wet and hardly stable enough to support the weight of a person. The mat here was least consolidated of all the plant communities except those in the lagg.

Dunlop (1983) reported a leatherleaf-water willow community adjacent to the open water at Mud Pond Bog in Hillsborough. Water willow was not a conspicuously dominant plant at Pequawket bog in Ossipee, however, although it could be found at low percent cover (Fahey 1993).

3.2.7 The *Sphagnum*/sedge lawn community was a small, homogeneous community with plants no more than 50 cm tall, growing on consolidated peat in the eastern part of the bog between the lagg and the black spruce muskeg (Figure 1). Shrub cover was low, and uniform mats of *Sphagnum* mosses with scattered sedges were obvious among the dwarf shrubs. The community was dominated by *Sphagnum recurvum* and leatherleaf (Table 4). Other plants included cotton-grasses, male-berry, a sedge (*Carex canescens*) large-leaf cranberry, and chokeberry.

The *Sphagnum*/sedge lawn community at Spruce Hole Bog was similar to the *Sphagnum capillifolium*-leatherleaf community described as one of five dwarf shrub communities in northeastern peatlands by Dammam and French (1987). Such *Sphagnum* lawns often have many co-dominant species according to Worley (1981). The leatherleaf community at Mud Pond Bog in Hillsborough (Dunlop 1983) is a similar *Sphagnum* lawn community although it is dominated by beak rush and three-seeded sedge rather than cotton-grasses. Sheep laurel was more prominent at Mud Pond Bog (Hillsborough) than at Spruce Hole in this community type.

3.2.8 The tall shrub community surrounded the open pond and extended into the northern reaches of the peatland (Figure 1). Hummock and hollow development was most pronounced in this community, and the dominant vascular plant species was highbush blueberry, with approximately 30% cover and typically about two meters tall. Shorter black huckleberry was also abundant, especially where the tall shrubs gave way to a more open *Sphagnum* mat. Stems of both species were associated with hummocks of *Sphagnum recurvum* and *S. magellanicum* (Table 4). *Sphagnum recurvum* was common in the wet troughs. Small, concentrated patches of *Smilacina trifolia* were found growing between hummocks in the wetter parts of the community that were open to direct sunlight.

Dunlop (1983) identified a huckleberry-highbush blueberry cover type at Mud Pond Bog (Hillsborough), which was very similar to the tall shrub community at Spruce Hole Bog. Highbush blueberry, huckleberry, and sheep laurel were common shrubs in both communities. Damman and French (1987) list tall shrub thickets dominated by highbush blueberry as common in bogs of southern New, England.

Approximately 25 standing dead snags of white pine, approximately 10-35 cm dbh (dbh = diameter at breast height, 1.3 m above the ground) were found in this community. Some large, cut stumps 20-35 cm in diameter were also evident on the bog mat, indicating that some trees had been harvested. A few stems of live white pine were found in this community, but all were less than two meters tall and had sparse and yellow-green foliage.

The peat in this community tended to be anchored and did not "quake" when walked on. The pines may have found this substrate amenable to colonization in the past, perhaps because the solid texture of the accumulated peat was drier during an extended period of low water.

3.2.9 The bog forest community was the most distinctive community type in the bog, consisting of a dense, nearly closed stand of black spruce (Figure 1). The canopy of this

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forest was continuous but did not exceed four meters in height. Black spruce stems did not exceed 10 cm dbh. Tall shrubs such as highbush blueberry, black huckleberry, and mountain holly were common (Table 4) especially around the forest margin. Herbaceous cover was scant and consisted mostly of three-seeded sedge and creeping snowberry. There was a diverse bryophyte flora with a variety of fork mosses (Dicranaceae) and liverworts scattered among hummocks of *Sphagnum recurvum* and *S. magellanicum*. Many of these mosses and liverworts were not found elsewhere in the bog.

Damman and French (1987) listed two types of bog forest community found in northeastern bogs: the *Sphagnum magellanicum*/black spruce type and the three-seeded sedge/black spruce type. The S. *magellanicum*/black spruce forest is commonly found on oligotrophic peat in raised peatlands in northern New Hampshire and Maine. The three-seeded sedge-black spruce forest community type is common on peatland borders in both boreal and hardwood (southern) forest zones. The black spruce community at Spruce Hole has affinities to both of these types. In terms of its physical structure and location in the bog it is more similar to the *Sphagnum magellanicum*/black spruce type, but its species composition more closely resembles the three-seeded sedge/black spruce community. Similar black spruce stands do not occur at any of the four New Hampshire peatlands that have been studied quantitatively (Dunlop 1984, Fahey 1993, Hellquist 1994), thus, closed black spruce stands are probably uncommon in southern New Hampshire.

3.2.10 Classification The basin morphology, hydrological conditions, and lack of extensive areas of raised peat (peat elevated well above the water table) qualify Spruce Hole Bog as a primary, or level, peatland (Moore and Bellamy 1974, Johnson 1985). However, the high acidity (pH < 4.2), low species richness (Table 5), and preponderance of *Sphagnum* and other oligotrophic/ombrotrophic indicator species justifies classification of Spruce Hole as a bog rather than a fen (Johnson 1985, p. 28). Thus, the peatland at Spruce Hole is a 'level bog', typical of very oligotrophic peatlands in southern New Hampshire and Vermont, and southern New England.

Spruce Hole Bog is similar to other New Hampshire peatlands that have been intensively studied. This is true both in terms of floristic composition and vegetation. The flora of Spruce Hole is small, however, and is typically a subset of the flora of other peatlands. Specifically, Spruce Hole contains less than half of the species found in any of the four quantitatively studied New Hampshire peatlands (Table 5), and every plant species found there also occurs in at least one of the other four bogs.

Table 5. Number of vascular plant species found in selected New Hampshire peatlands.

Mud Pond Bog (Moultonborough)[1]	124
Pequawket Bog (Ossipee)[3]	109
Mud Pond Bog (Hillsborough)[2]	101
Heath Pond Bog (Ossipee)[3]	70
Spruce Hole Bog (Durham)	37

[1] Hellquist 1994, [2] Dunlop 1983, [3] Fahey 1993

The low species richness at Spruce Hole may be due to a number of factors, among which are its extreme acidity and oligotrophy, its small size, its uniform physical setting, and its great distance from other peatlands. Spruce Hole Bog, judging by the pH measurements and indicator species that occur there, is more oligotrophic than any similar New Hampshire peatland in the literature. It is also the smallest in size (the other four peatlands are at least 10 times the area of Spruce Hole), and it lacks the environmental heterogeneity found in other peatlands in which stream channels, large ponds, and eccentrically configured basins create different habitats, which support different species and communities. The lack of any floating-leaved aquatic assemblage as occurs at Mud Pond Bog (Hillsborough) and Pequawket Bog, for instance, is most likely due to a lack of suitable microhabitat. There are also few peatlands in close proximity to Spruce Hole to provide sources of new species. Pequawket and Heath Pond Bogs, in contrast, have numerous bogs and fens nearby from which plants may readily disperse.

Four of the five plant communities described at Spruce Hole are similar to those of other southern New Hampshire peatlands, varying only slightly in terms of species composition. Communities similar to the black spruce stand at Spruce Hole, however, have not been reported from southern New Hampshire, though they may occur in unstudied peatlands there. Damman and French (1987) report similar conifer forest assemblages in more northern regions of the state, and similar communities can be found at Arcadia Bog in Massachusetts (Motzkin and Patterson (1991) and Victory Basin Bog in Vermont (Bubier 1991). In other New Hampshire peatlands black spruce tends to occur as scattered trees (Dunlop 1983, Fahey 1993, Hellquist 1994).

PART IV. RECENT BOG HISTORY: DYNAMICS Of WHITE PINE

4.1 Introduction

During the vegetational analysis it became apparent that while white pine was a minor component of the bog community at present, it had been more abundant at Spruce Hole a few decades ago. At the time we sampled the bog there was an abundance of large, dead, white pine snags on the mat of the bog as well as around the bog perimeter. When the dead pines on the bog mat were alive and had branches and foliage, parts of the bog would have been covered by a nearly continuous pine canopy. The lack of any living white pine greater than two meters tall today suggests that the white pine population has declined greatly and that past environmental conditions must have been very different.

Any baseline investigation of a natural community should consider the dynamics of the system and the dead white pine stems provided an opportunity for us to assess the magnitude and rate of recent change in the plant community at Spruce Hole. Such information may be useful in gauging the significance of future changes in the bog community. To determine the rate and magnitude of change in white pine abundance in the bog, the following were performed: (1) reconstructed the past distribution of the white pine population on the bog mat by mapping the locations of stumps and fallen and standing snags; (2) described the present distribution of white pine in the bog by mapping all live pine stems, (3) used tree ring analysis to date the mortality of pine stems on the bog mat and around the margin of the bog.

4.2 Methods

The distribution of all live and dead white pine on the mat of the bog were mapped. Locations of dead pines were established using a compass and SONIN 150 ultrasonic distance-meter. The present and past distribution of white pine was then superimposed on a map of the present vegetation in order to infer the former extent of the pine population in relation to current plant communities.

Two or more increment cores were taken from dead trees in two areas: (1) the bog mat, mainly in the tall shrub, bog forest, and low shrub communities; and (2) at the perimeter of the bog, both in the moat and at the border between the moat and adjacent upland. Cores were taken from 16 trees on the mat and 10 at the bog perimeter, all greater than 10 cm dbh. In addition, cores were taken from 13 mature, living, upland trees. Increment cores are small cylinders of wood, approximately 4 mm in diameter, that are extracted radially from the tree. The cores were dried, mounted on wood blocks, and sanded to a fine polish until individual cells could be seen when viewed under a dissecting microscope. Tree rings were measured to the nearest micrometer and analyzed using standard dendrochronological techniques (Fritts 1976, Schweingruber 1988).

Growth patterns in tree rings are similar across many trees in a habitat. It is thus possible to date rings from a dead piece of wood in which the last year of growth is unknown by comparing the patterns of growth with wood samples for which absolute dates of ring production are known. This process is known as crossdating (Wigley et al. 1987). Cores from the live upland pine trees were used to establish a master chronology in which average ring widths were known for each year. Tree ring widths from the dead trees were then compared, where the relation between ring width and year was not known, to the master chronology. Crossdating each of the dead stems allowed identification of the year in which its mortality occurred. Crossdating was accomplished using the program COFECHA (Holmes 1983).

4.3 Results

Over 80 dead white pine stems were mapped on the bog mat. Over 30 of these exceeded 20 cm dbh (about 8 inches) and some approached 40 cm dbh. The distribution of dead pine stems (Figure 3) suggested that a white pine population once extended in a ring around the pond following what is today (and probably was then) the most consolidated areas of peat. The distribution of these dead trees corresponded well to the distribution of the tall shrub community, the fringes of the bog forest, and the relatively more consolidated portions of the *Sphagnum*/sedge lawn (Figure 3). The population of live, white pine, in contrast, was restricted to two small areas in the tall shrub and bog forest communities (Figure 4) and consisted entirely of seedlings and saplings, none of which exceeded three meters in height or 10 cm dbh.

Crossdating of the dead trees was successful, allowing estimation of the year of death for each tree. White pine trees growing on the peat mat of the bog died between 1939 and 1962 (Figure 5a,b). The mortality of trees at or near the bog perimeter began in 1967 but occurred mostly in the late 1980s and early 1990s (Figure .5b). 'The two perimeter trees that died first (1967 and 1982) were situated farther from the upland border (in deeper water) than those trees dying after 1985.

Tree growth, measured as the increase in cross-sectional wood area per year, was plotted over time for each tree from the mat, perimeter, and upland (Figure5a). In trees from the bog mat, a sharp decline in growth beginning in 1948 just preceded the period of greatest mortality in the 1950s ('A' in Figure 5a). All 13 perimeter trees showed greatly reduced growth in 1982-83 ('D' in Figure 5a), although most individuals regained high growth rates ('F' in Figure 5a) before dying in the late 80s or early 90s. Growth of upland trees, alive in 1995 when they were cored, showed very low values in the late 1940s and early 1980s ('F' in Figure 5a), corresponding to periods of reduced growth in the dead trees from the mat and perimeter.

4.4 Discussion

White pine often occurs in peatlands along with other conifers such as black spruce and larch (Johnson 1985). Due to the low oxygen levels and other stresses, however, white pine often fails to reach reproductive maturity in peatlands and most newly established trees are probably the result of seeds transported from outside the community to favorable sites on the peat surface.

Dead snags of white pine are often found in wetlands where establishment and rapid growth of pine during time of low water levels is followed by flooding and consequent oxygen deprivation of roots for an extended period. Such flooding occurs commonly in marshes and fens after damming of streams by humans or beavers (e.g., Schwintzer and Williams 1974, Schwintzer 1979, Mitchell and Niering 1993). White pine mortality is less easy to explain in kettlehole peatlands, such as Spruce Hole, which have no inlet or outlet and typically receive water only from precipitation, runoff, or ground water.

It is evident that white pine has declined in abundance at Spruce Hole Bog in the last fifty years and several lines of evidence point to rising water levels as a likely cause. First, the present conditions in the bog appear to be poor for white pine growth and establishment. The few living pines in the bog exhibit symptoms (sparse foliage and chlorosis) typical of plants whose roots suffer from oxygen deprivation. Second, the area of the bog in which pines can establish appears to have contracted, with establishment occurring in communities with more consolidated peat (Figure 4). Third, the sequence of mortality, with trees on the mat dying first, followed by margin trees in the deeper water of the moat, and then by those nearer the upland is what one would expect where rising water levels are responsible. Fourth, the butts of many of the dead margin trees were covered by water most of the year. It is highly unlikely that white pine could establish at these sites today.

In addition to white pine, black spruce and red maple may also have declined in recent decades. Hodgdon's (1962) report states that the black spruce formed an "irregular and interrupted fringing border" around the pond in the center of the bog. At present, small (< 2 m tall) dead black spruce stems can be found around the pond, mostly on the south perimeter, but very few live trees exist outside of the bog forest community south of the pond (Figure 1). There are numerous dead red maple stems throughout the bog, some 4-5 meters tall, but very few live ones (S. Miller and T. Lee, personal observation). Tree ring analysis was not used to age mortality of red maple, as tree rings are difficult to discern in this species. The relative numbers and sizes of dead and live maples suggest, however, that the species has declined in recent years. Hodgdon (1962) also noted a declining maple population and implied that rising water levels were responsible. Cummings (1969), in a paper resulting from a student research project at UNH, suggested that rising water levels had reduced populations of both white pine and black spruce at Spruce Hole.

Several alternative hypotheses may be offered to explain the decline of white pine at Spruce Hole. Such hypotheses must take into account the local nature of the decline. While white pine has declined in the bog, it grows vigorously on the slopes surrounding the bog and throughout the adjacent upland. Thus, regional factors such as changes in temperature or growing season length are unlikely explanations. Insects and disease can cause local tree decline. There were gypsy moth outbreaks in Durham in 1946 and 1981, and these coincide with periods of reduced tree growth in the bog mat, perimeter, and upland trees that we cored. While red oak is the preferred forage of gypsy moths, these herbivores will switch to other species, including white pine, when preferred forage is depleted. Review of air photos taken in 1981 indicates a high level of defoliation in the vicinity of Spruce Hole. Air photos were unavailable for 1946. It is possible that the gypsy moth caterpillars defoliated the bog pines to such an extent that high mortality ensued. It is also possible that insect damage interacted with water stress; a gypsy moth outbreak could have exacerbated the deleterious effects of gradual flooding and could have started a general decline in forest growth that culminated in high mortality. Another alternative to rising water levels is deposition of pollutants, especially sulfur and nitrogen oxides, which could affect chemistry of the poorly buffered bog water more than that of the upland soils. Most of the evidence, however, points to rising water as the cause of tree decline at Spruce Hole.

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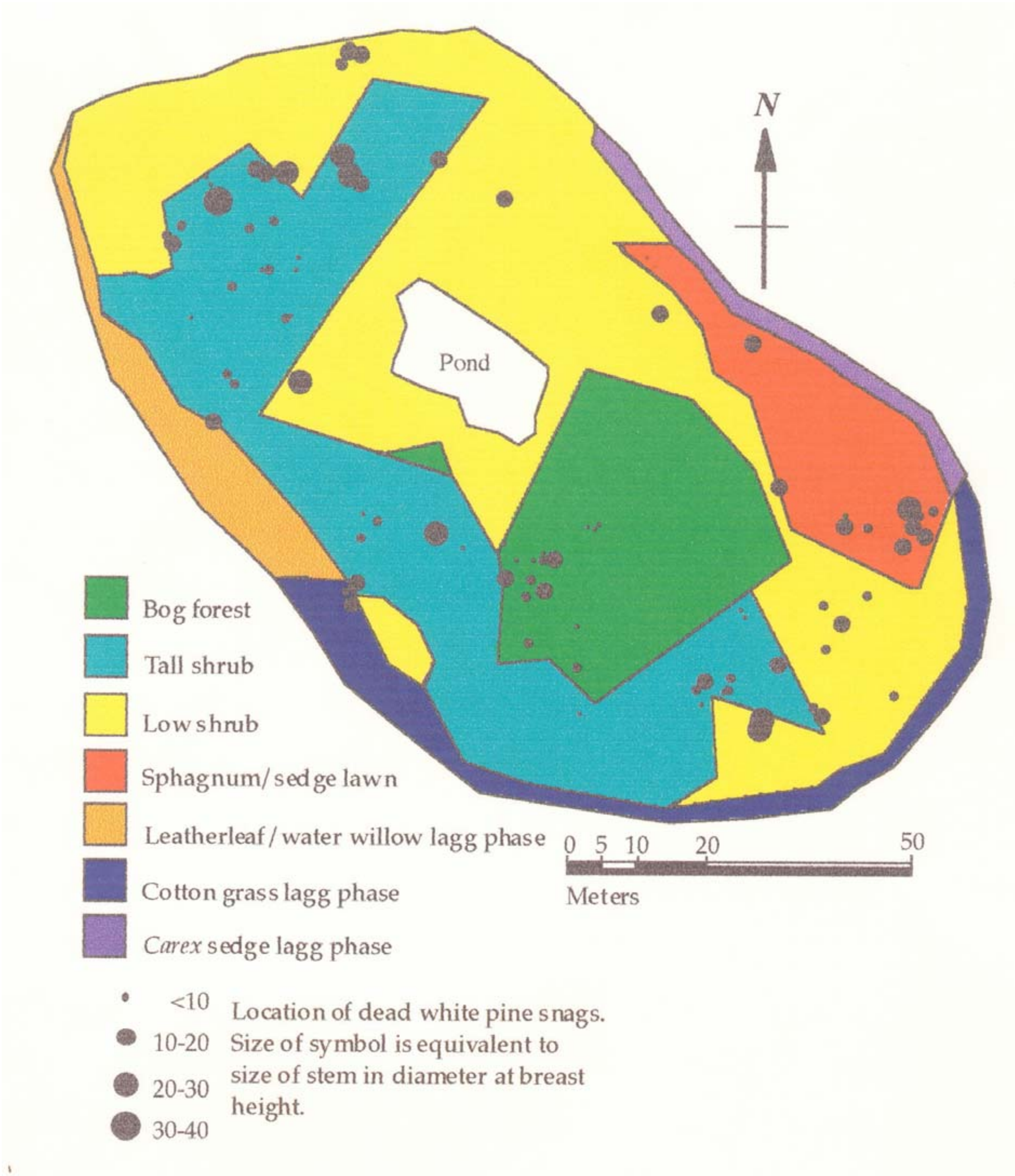

Figure 3. Distribution of dead white pine trees in relation to present plant communities. Stem diameter values in cm.

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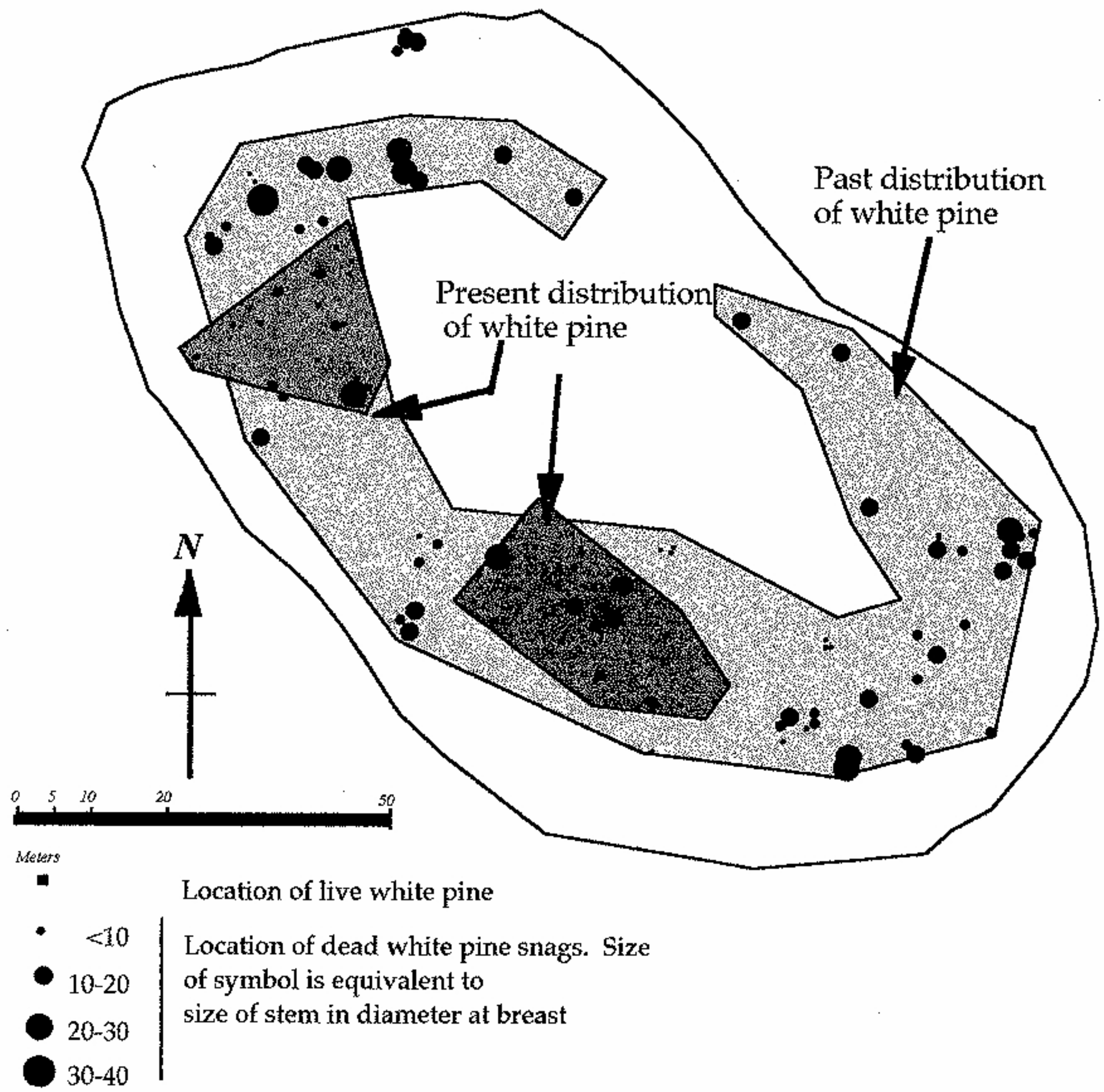

Figure 4. Past and present distribution of white pine at Spruce Hole Bog.

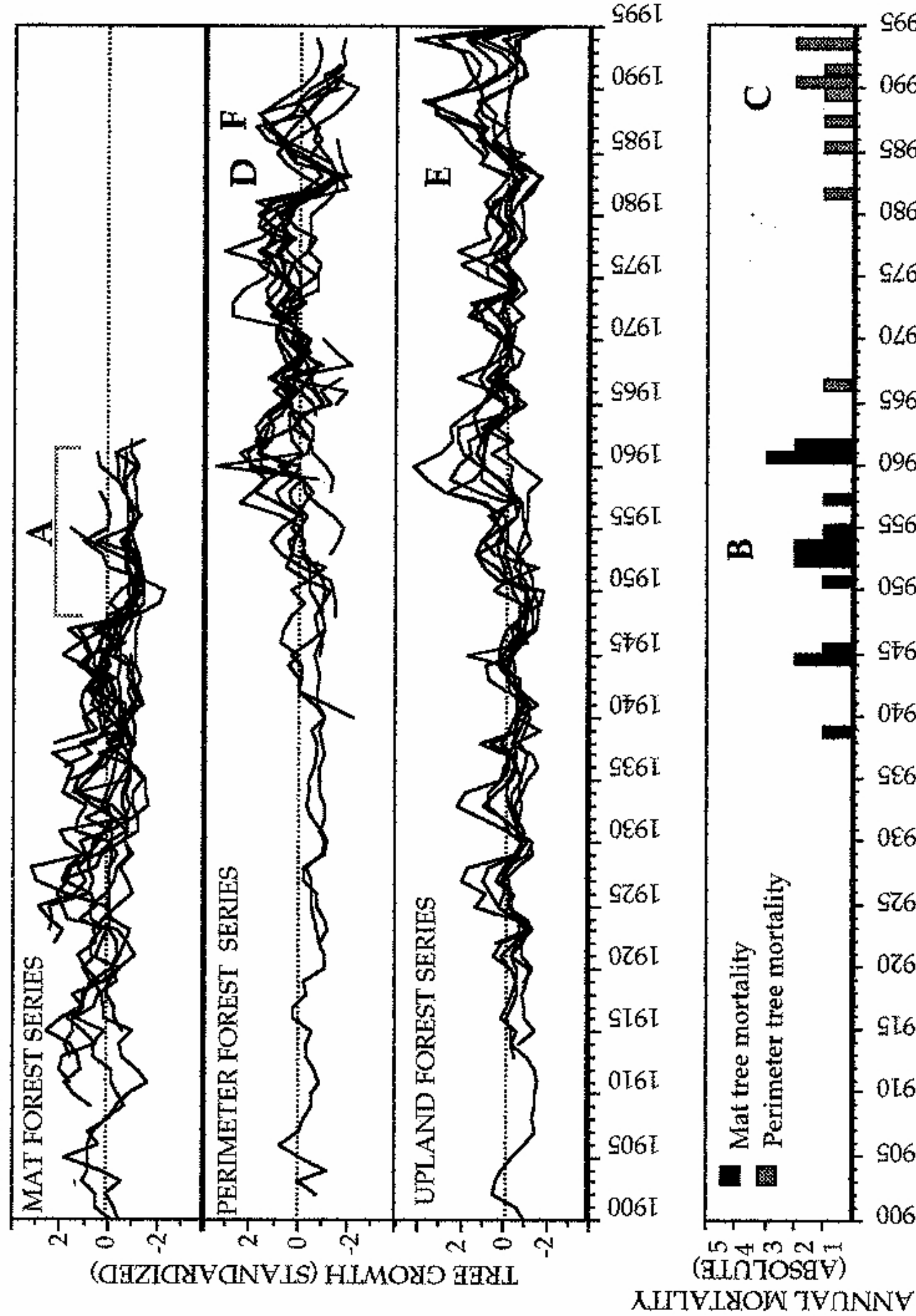

Figure 5a (top). Tree growth (standardized basal area increments) per year for each tree from the bog mat, bog perimeter, and upland forest. Figure 5b (bottom). Absolute annual mortality (number of trees dying per year) versus time for the mat and perimeter habitats.

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If rising water level is the cause of tree decline at Spruce Hole, the next question to answer is: what is the cause of rising water levels? An obvious answer is increased levels of precipitation, but climate records for Durham show no such pattern. Both Hodgdon (1962) and Cummings (1969) suggested that logging of large pines in the bog prior to 1960 caused the Spruce Hole water table to rise, presumably due to reduced transpiration. Conifer forests can transpire more water than comparable deciduous forests or shrub vegetation (Bosch and Hewlett 1982); thus tree removal would result in a higher water table. Logging occurred in the uplands west and south the bog in the late 1980's and could be responsible for continued water level increases. Water table rise may also be due to the natural development of an impermeable layer of organic material beneath the bog surface (see hydrology portion of this report).

Tree mortality and the apparent loss of at least one orchid species, grass pink (see section on Flora and Vegetation), over the past 50 years indicate that vegetation change does occur at Spruce Hole. Thus, present communities should not be viewed as static associations, but rather as entities subject to the vagaries of environmental cycles, hydrological changes, disturbance, or autogenic community dynamics.

PART V. PERMANENT PLOTS

5.1 Purpose

Permanent monitoring plots were installed to allow quantitative assessment of future changes in species composition and abundance in the bog,

5.2 Location of plots

Three permanent plots were located in each of three plant communities: tall shrub, low shrub, and bog forest. In the lagg community peat was too unstable to permit establishment of permanent plots without seriously damaging the area being studied. The *Sphagnum*/sedge lawn community was too small to allow establishment of permanent plots. Permanent plots were located (and can be relocated) using compass bearings from reference tree trunks on the mat of the bog

5.3 Plot description

Each permanent plot (1.5 m X 4.0 m) was marked by two oak stakes (Figure 6). Stapled to the top of each stake was an aluminum tag bearing the plot number. The stakes were 1.5 m apart oriented along an east-west azimuth. Each stake marked the midpoint of one of the two long (4.0 m) sides of the plot. The long axis of the plot was oriented north-south. The stakes were used to locate two subplots (1.5 m X 2.0 m) and to anchor the subplot frame (Figure 6). The two subplots were designated as "north" or "south."

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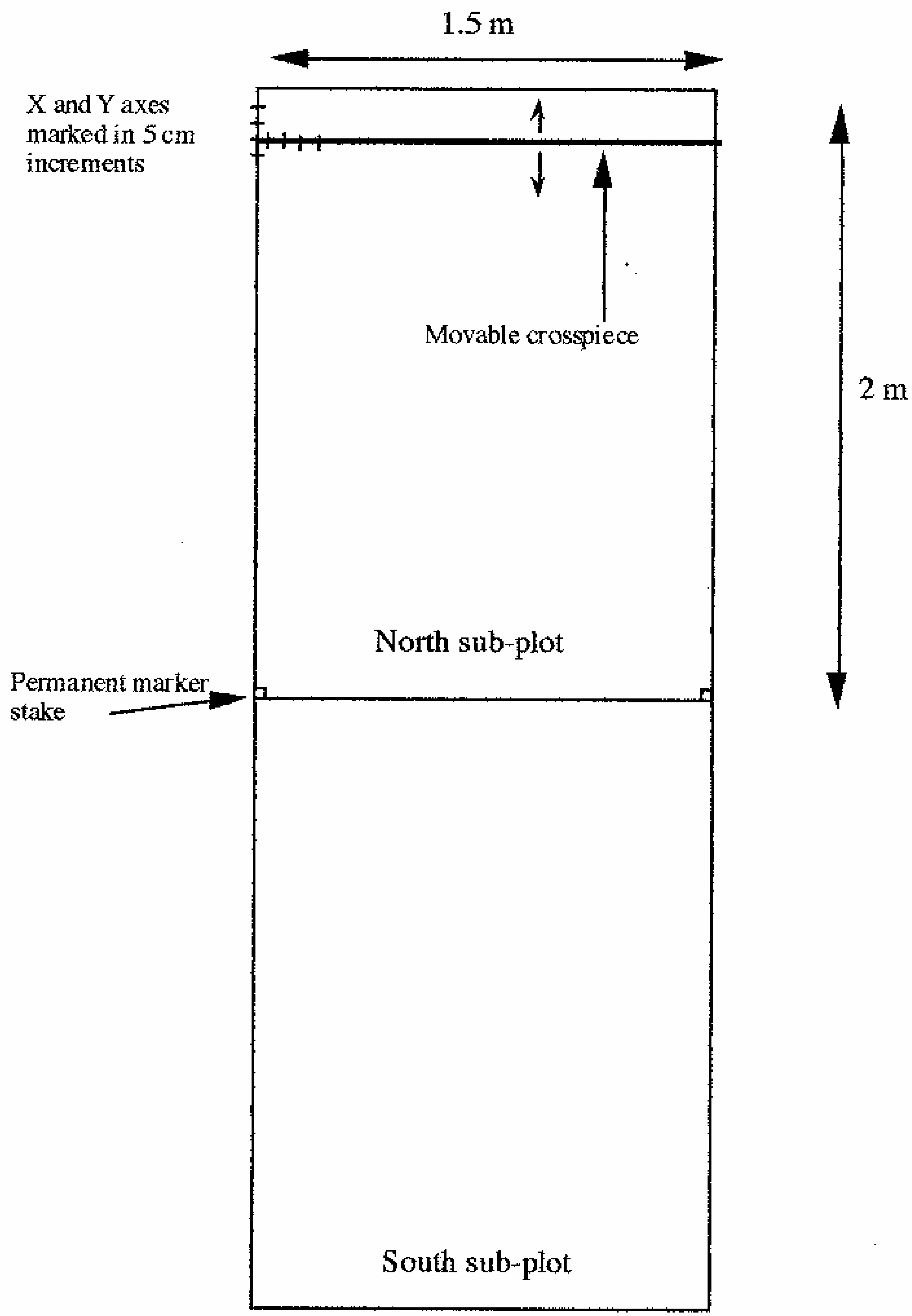

Figure 6. Diagram of permanent plot design.

Each subplot was sampled using a rectangular frame made from 0.5 inch diameter PVC pipe. The two longest sides (2.0 m) of the frame as well as a movable crosspiece were marked at 5 cm increments in order to create an X-Y coordinate system for sampling. The movable crosspiece could be adjusted vertically (Y - axis) using the increment markings on the sides of the subplot frame, and then sampling points could be located horizontally (X - axis) using the increment markings on the crosspiece.

5.4 Cover data collection

The origin of each sub-plot was located in the northeast corner of the sub-plot. The point-intercept method was used to quantify plant cover in each plot. Eighty points were sampled in each subplot by sampling 10 lines, each parallel to the Y axis. Eight points were examined per line. This method yielded a total of 160 sample points per plot. Lines were sampled beginning with 10 cm on the Y-axis and every 20 cm afterward (10 cm, 30 cm, 50 can ... etc ... 190 cm). X-axis points were designated along the crosspiece beginning at 5 cm and progressing in 20 cm intervals (5 cm, 25 cm, 45 cm ... etc ... 145 cm).

A point was sampled by placing a 30 cm piece of stiff wire (1 mm diameter) vertically against the X-axis crosspiece at the appropriate distance from the plot frame and recording one "tick" for each species of plant against which it came into contact. If one plant overtopped another a tick was assigned to both plants, and thus the total number of ticks per sub-plot often exceeded 80. Ticks for tall vegetation were approximate because the wire was not long enough to accurately contact tall vegetation. Percent cover was determined for each species in each subplot by dividing the number of ticks for that species by 80. A complete species list for each subplot was made to include species that may have been present, but were too rare to be sampled by the point-intercept technique.

Lastly, the number of stems of each woody shrub species and their estimated heights were recorded as either 1-2 meters tall or 2+ meters tall. Trunks of *P. mariana*, however, were mapped to the nearest centimeter using the subplot grid and their estimated heights were recorded.

5.5 Results and Discussion

Data from the permanent monitoring plots now exist. These are intended for use in assessing vegetation change in the bog over time. Change can be determined by re-sampling these plots at 5-10 year intervals and comparing the percent cover values obtained with those from previous samples.

PART VI. RECOMMENDATIONS

To maintain the biological qualities that make Spruce Hole Bog a National Natural Landmark the bog should be managed so as to minimize two kinds of impact.

First, actions that would dramatically affect water levels in the bog should be avoided. Some variation in water level occurs naturally and, in fact, this data suggests a gradual rise in water table. However, if water level increased at a faster rate than peat accumulates, plant species associated with wetter areas of the bog will increase in abundance while species of the bog forest, such as black spruce, will decrease and perhaps even disappear. Lowering water levels would have the opposite effect, with likely invasion of the drier communities by certain tree species, including white pine and red maple.

Second, damage to the bog mat (the layer of peat in which living plants are rooted) should be minimized. Repeated trampling by humans can displace and compact the bog mat, reducing the area available for plants and other organisms that require a bog mat and making conditions more favorable for organisms that do well in open water. The bog should be checked occasionally for evidence of trampling. Should trampling become a problem, it may be worthwhile for the Town to consider some action. This might be as simple as requesting UNH faculty to reduce the number of class field trips taken to the bog, or as complex as constructing a small boardwalk over the bog mat, A boardwalk would allow visitors to view the salient features of the bog without damaging them. At present, we do not believe trampling is a serious problem at Spruce Hole.

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Final Report for Hydrogeologic Studies of the Spruce Hole Bog Sand and Gravel Formation

by

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13 November 2000

Executive Summary

The sand and gravel formation that contains the Spruce Hole Bog was studied in order to more clearly delineate the hydrogeology of the system and the ecology of the bog. Numerous monitoring wells and one production well were installed in the formation. Ground water and surface water levels were monitored over a five-year period. In addition, precipitation and streamflows were also monitored. A pumping test was performed on the production well with attendant analyses of well water quality.

The sand and gravel formation is considered and aquifer and is capable of yielding upwards of 350,000 gallons of water per day. More realistically, one production well, centrally located in the formation, can yield approximately 300,000 gallons per day. The production well installed as part of this study is considered a test well. It is physically located in the Town of Lee. This well can be used as a water supply well, however it needs to be developed (purge fine materials away from the gravel pack around the well screen) before it can be used in this capacity. The quality of this ground water is excellent. In a water sample taken at the end of the pumping test, all tested water quality parameters were better than US EPA primary and secondary drinking water standards.

The formation can be used as a ‘storage reservoir’ for applied surface water (artificial recharge and subsequent recovery). In this case, water from the Lamprey or Oyster Rivers could be pumped to a recharge basin, for infiltration purposes. Depending on the location of the recharge basin, most of the pumped/infiltrated water could have a residence time in the formation of greater than one year. If the formation were not used for groundwater supply, any artificially recharged water would follow the natural groundwater flowpath to streams that discharge into the Oyster River.

The Spruce Hole Bog appears to be insulated from the groundwater below by all of the dead and decomposed peat at its base. The water level of the bog seems to have risen over time, as evidenced by core samples from the standing dead trees in and around the bog.

Recommendations for future efforts for this formation include:

1. Continue monitoring stream flows, well water levels, and bog characteristics, on at least a monthly frequency.
2. Continue the very close scrutiny of development proposals for private property on the formation. The best scenario is for the Town to own this property, in lieu of this; incentives may be necessary to convince private property owners to maintain the formation in a more or less undeveloped state.
3. Activities at the Town gravel pit in the formation should be carefully selected in order to minimize the potential for soil and groundwater contamination.
4. If artificial recharge is to be seriously considered, a field scale study should be performed in order to verify the estimates made by the computer simulations performed during this study.