VEGETATION AND FIRE HISTORY OF THE DWARF PINE RIDGES, SHAWANGUNK MTS., NEW YORK

FINAL REPORT

by

CHARLES LAING
University of Massachusetts
Department of Forestry and Wildlife Management
Amherst, MA 01003

Submitted to The Nature Conservancy
Eastern New York Regional Office

March 1994

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The objective of this study is to investigate the vegetation and fire history of a portion of the dwarf pitch pine ridge community on Ice Caves Mountain in the Northern Shawangunk Mountains, New York, by means of a paleoecological analysis of a sediment core from within a nearby swamp. With this information it should be possible to estimate the age of the existing pitch pine community and its historical fire regimes and to use these data in support of management and conservation initiatives for this rare community.

The dwarf pine plains [also referred to as the dwarf pine ridge or dwarf pine barrens community (Reschki 1990, Windisch 1990)] of the Northern Shawangunk Mountains are characterized by pitch pine dominating an overstory canopy that is consistently less than two meters high (McIntosh 1959, Olsvig 1980). Similar dwarf pine vegetation is found within the pine barrens of Long Island and New Jersey where it seems to occupy particularly droughty sites which have been termed fire-sheds, these sites having elevated fire frequencies due to their central location within the fire-dominated pine barrens ecosystem. A similar situation does not now exist with the dwarf pine plains that dominate Ice Caves Mountain, because they are bounded on three sides by less flammable, mesic oak forest that covers the slopes of the Shawangunks. The pitch pine of the Shawangunks are a unique example of the dwarf pitch pine community in that they are found at an elevation of 2000 ft (610 m) and are growing on shallow soils with exposed bedrock. The Long Island and New Jersey Barrens occur on deep outwash sand and gravel deposits. The importance of fire in the maintenance of this dwarf pitch pine community is suggested by the prevalence of multiple stemmed individuals and almost complete cone serotiny (Olsvig 1980, Windisch 1990).

The historical record of forest fires in the Northern Shawangunks (Smiley & Huth 1982) documents fires that occurred between 1842 and 1982. Sixty-six forest fires were recorded during this 140-year period; the largest occurring in the vicinity of the dwarf pine plains. This fire burned under severe drought conditions in October 1947, and consumed

7,405 acres (2997 ha.) in the area of Lake Maratanza, the town of Cragsmoor and east of the town of Ellenville. In July 1953, 600 acres (243 ha.) were burned in the area of the Ellenville Ice Caves. Forest fires also burned a large area "toward southern end of ....range" in July 1923. In addition to these documented fires are numerous incidental accounts, often related to the deliberate firing of the pine plain heath vegetation by berry pickers in order to promote good crops (Torrey 1935, Snyder & Beard 1981). Earlier fire occurrence is harder to assess, but the French Huguenot settlers of the New Paltz may have periodically burned the area of the present pine plains to promote berry crops (Olsvig 1980). Prior to European settlement the Esopus Indians, like other tribes in the Northeast (Day 1953, Niering 1953, Patterson and Sassaman 1988), were undoubtedly aware of the benefits of periodic burning to promote browse and berry crops and otherwise manipulate the vegetation . The Indians may have also used fire to assist in their raids over the mountaintop (Smith 1887).

The closest relevant paleoecological investigation is that of the pitch pine-oak community of the Kitattinny Mountains, a southern extension of the Shawangunks in northern New Jersey, by Niering (1953). Niering's pollen analysis suggests that a pollen assemblage similar to that of the present pitch pine-oak forest rose to dominance over the past 1,000 years. In a study of the New Jersey Pine Barrens (Florer 1972), pollen analysis of postglacial bog sediments indicate that pine-oak communities have dominated the vegetation for the past 10,000 years. Neither of these studies include an analysis of microscopic charcoal to estimate prehistoric fire occurrence, and they were outside of areas now occupied by dwarf pitch pine associations. A 12,000-year history of vegetation and climate from Cape Cod, Massachusetts (Winkler 1985) indicates that a *Pinus rigida-Quercus* association dominated the landscape by 9,000 yr B.P. High charcoal frequencies throughout this period suggest that the pine barrens association developed during a period of warmer and drier climate.

A number of paleoecological studies have included analysis of microscopic charcoal in pre- and post-colonial sediments in the Northeast (Patterson & Backman 1988). Average postcolonial Charcoal:Pollen ratios are generally higher than in pre-colonial time, being ascribed to fires resulting from land clearance and timber harvesting activities. A recent paleoecological study from Acadia National Park, Maine (Laing 1993) associated existing jack pine stands with increased fire frequency and severity following European settlement. Sedimentary studies from the pitch pine-oak forests of Cape Cod and Long Island (Patterson & Backman 1988) identified frequent fires in precolonial sediments, but with European settlement destructive wildfires fueled by slash from land clearing activities drastically altered forest composition, favoring the pitch pine component in southeastern Massachusetts near Plymouth.

Although other pitch pine barrens have been the focus of paleoecological investigations (Patterson, Winkler, Florer), these sites are all located on till or outwash deposits. This study is unique in its association with a dwarf pitch pine community growing at high elevation on rock outcrops. The microscopic charcoal analysis associated with this paleoecological investigation will provide additional evidence of fire occurrence in both pre- and post-settlement times and therefore aid in the understanding of the disturbance regime that is associated with the dwarf pine plains community of the Northern Shawangunks.

STUDY AREA

Geology and Soils The Northern Shawangunk ridge is capped by Silurian quartzite conglomerate, commonly termed Shawangunk Grit, which is extremely resistant to erosion. It dissolves rather than erodes and this results in extremely slow soil formation through the gradual accumulation of organic material. In certain areas such as The Badlands (Figure 1), rock outcrops are common, and where soil has formed it is often only a few inches in depth. These soils are termed ombrotrophic, as the relatively low levels of available nutrients are derived primarily from precipitation. The impermeability of the quartzite conglomerate bedrock means that in many areas of poor drainage on Ice Caves Mountain the thin soils can become saturated very easily, and this is reflected in the dominance of wetland shrubs such as *Chamaedaphne calyculata* . However, the shallowness of the soils results in a very limited moisture holding capacity which can lead to intense water stress during periods of severe drought (P. Huth personal comm.).

Climate The Northern Shawangunks have one of the longest sets of continuous climate data in the Northeast with the nearby Mohonk Lake Cooperative Weather station in operation since 1896 (Kiviat 1988). At an elevation of 1250 ft (381 m), this weather station has recorded a mean annual temperature of 47.8° F (mean January temp. 24.9° F; mean July temp. 70.3° F) and a mean annual precipitation of 46.6 inches. The dwarf pitch pine plains on Ice Caves Mountain occupy the highest and most exposed part of the Shawangunk ridge, however, and have a harsher local climate with more extreme temperatures, higher wind speeds and lower average relative humidities. This greater exposure can lead to extremely high surface temperatures in the summer and strong winds and rime ice episodes in the winter which can kill off any growth above the low pitch pine canopy (P. Huth personal comm.).

Vegetation The plant ecology of the Shawangunks dwarf pine plains has been described by a number of authors and comparisons have been made with the related communities on Long Island and New Jersey (McIntosh 1959, Olsvig 1980). In the Shawangunks pine plains of Ice Caves Mountain, *Pinus rigida* is joined by *Betula populifolia* and *Pyrus melanocarpa* in the canopy with *Viburnum cassinoides* common in places (Olsvig 1980). A variety of ericaceous shrubs dominate the understory; *Vaccinium augustifolium*, *V. vacillans*, *Kalmia angustifolia* and *Comptonia peregrina*, with

Chamaedaphnecalyculata prominent on wetter sites. Betula populifolia was present in 75% of the stands sampled by McIntosh (1959) but the species only becomes an important canopy component in the dwarf pine plains association (Olsvig 1980). A detrended correspondence analysis (DCA) of 50 samples from the Shawangunk Mountains gives the highest species scores for Betula populifolia and Pyrus melanocarpa associated with the heathlands. This result may indicate a fire response by the two species since the heathland is known to have recently burned.

Associated with the pine plains are areas of rock barrens where vegetation is confined to rock crevices or shallow accumulations of organic material. On these sites *Quercus prinus* joins *Pinus rigida* in the stunted overstory and *Quercus ilicifolia* and *Gaylussacia baccata* are present in the shrub layer together with *Vaccinium angustifolium* and *Kalmia latifolia*. There are also scattered heaths within the pine plains which are similar to the pine plains floristically except for the absence of *Pinus rigida*.

Along the plateau of the Shawangunks to the northeast, the pine plains generally grade into pine barrens vegetation where *Pinus rigida* increases in stature and is joined by *Acer rubrum, Nyssa sylvatica, Amelanchier canadensis* and *Quercus prinus* in the canopy. *Sassafras albidum* also becomes common on moister, sheltered areas on the slopes. *Gaylussacia baccata* and *Kalmia angustifolia* dominate the dense shrub layer. On the slopes of Ice Caves Mountain, where the quartzite conglomerate gives way to a shale substrate, a more typical oak forest predominates with hemlock forest in more mesic ravines sites.

Core Site The site selected for this paleoecological investigation is a spruce swamp (hereafter termed The Shawangunk Spruce Swamp) which lies along the southwestern boundary of Minnewaska State Park (Figure 1). The swamp lies within a fault that bisects the main axis of the Northern Shawangunks and cuts across the northern portion of the dwarf pitch pine community. This section of the community is termed "dwarf pine plains

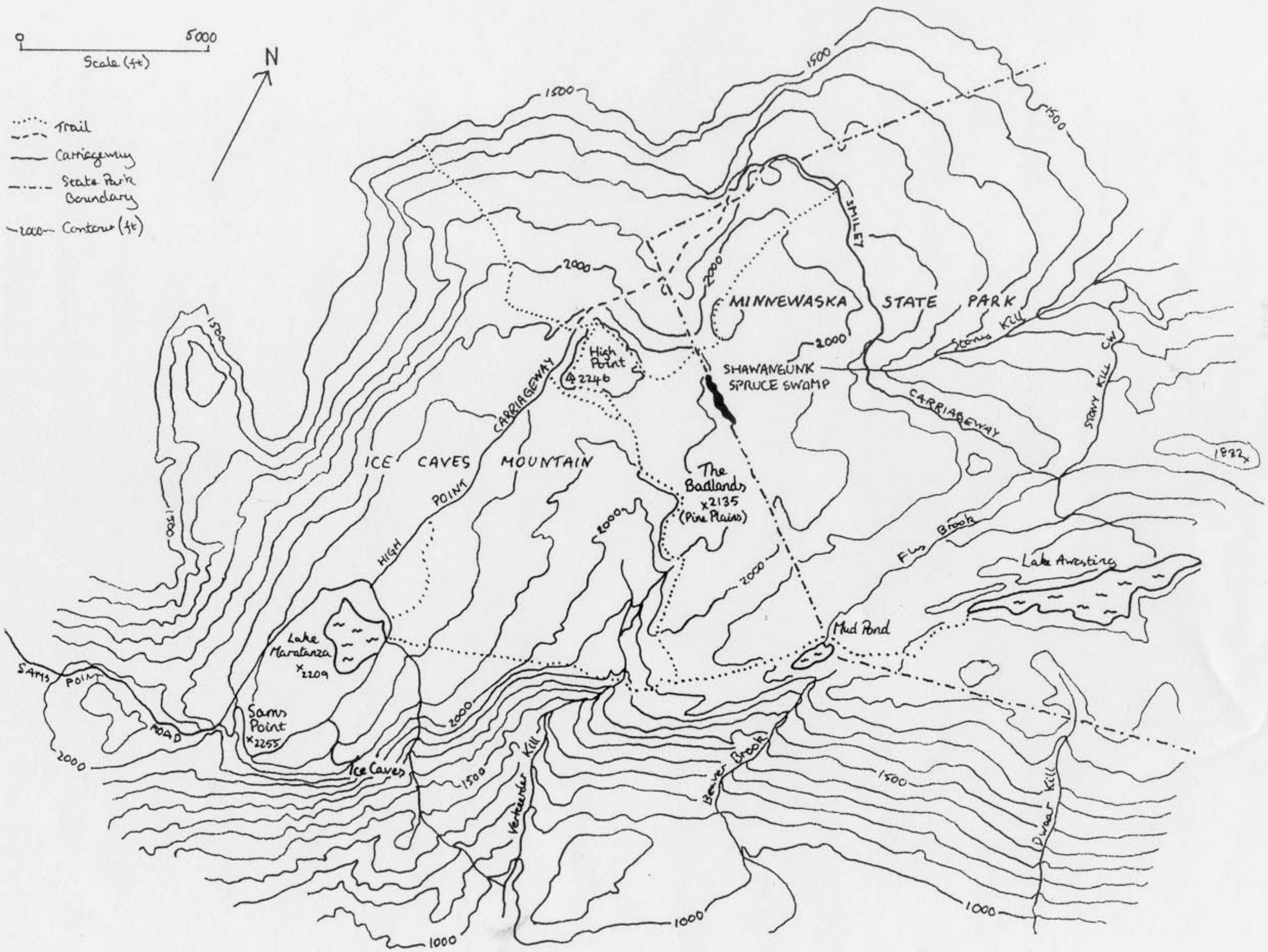

Figure 1. Map of the location of Shawangunk Spruce Swamp on Ice Caves Mountain, Northern Shawangunks, Ulster County, New York.

with rocky gaps" by Windisch (1990) due to the presence of exposed bedrock scattered within a matrix of flammable dwarf pine vegetation. At an elevation of 2,020 ft, (616 m) Shawangunk Spruce Swamp extends for approximately 230 ft (70 m) along the fault, and ranges from 10 to 45 ft (3 to 14 m) in width. The elevated slab rock on either side of the fault is dominated by dwarf pitch pine, but the swamp itself is dominated by large, mature hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), white pine (*Pinus strobus*) and black gum (*Nyssa sylvatica*). Other tree species present include red maple (*Acer rubrum*), grey birch (*Betula populifolia*) and pitch pine. Shrubs include mountain holly (*Nemopanthus mucronata*), mountain laurel (*Kalmia latifolia*) and highbush blueberry (*Vaccinium corymbosum*), while mosses and ferns dominate the herbaceous layer. The area chosen for coring is a small opening in the canopy and is dominated by cinnamon fern (*Osmunda cinnamomea*) and sphagnum moss.

METHODS

Fossil Pollen and Microscopic Charcoal Analyses

Two cores - the study core and one back-up - were recovered from the Shawangunk Spruce Swamp using a piston corer, 9cm in diameter. In both cores, 66cm of organic material were taken before coring was obstructed by embedded wood.

Sediment samples were taken every 2cm in the study core with finer scale sampling (at 1cm intervals) around levels of particular interest. Sub-samples of $0.5cm^3$ were prepared according to procedures described by Faegri and Iversen (1975). A known quantity (102,100 grains/cc) of *Eucalyptus* pollen was added to each sample prior to preparation, which included treatment with hot 10% KOH to dissolve humic substances, 10% HCl to remove colloidal SiO_2, silicoflourides and $CaCO_3$, 48% HF to remove siliceous matter and acetolysis to remove organic remains. Samples were acetolysed for 1 minute in a water bath kept just below boiling point. Samples were stained with one drop of 1.0% safranin, dehydrated with TBA, and suspended in silicone oil. Slides of the resulting material were analyzed under a compound microscope using 400x magnification for pollen grain identification. A minimum of 500 grains were counted for each sample, and an accompanying tally of *Eucalyptus* grains allowed the calculation of both pollen concentrations in addition to pollen percentages.

The material prepared for fossil pollen analysis was also analyzed for microscopic charcoal. The point count method (Clark 1982) was used for estimating the projected area of charcoal for each sample. The ratio of fossil pollen and *Eucalyptus* (P:E ratio) was used in the calculation of microscopic charcoal, which is expressed as the ratio of charcoal area (measured in square microns) to fossil pollen (Ch:P). In order to place emphasis on the fire history of the surrounding pine plains rather than the swamp itself, and to remove the influence of large quantities of locally produced wetland pollen on the P:E ratio, only the upland pollen sum (see Figure 3) was used in these calculations.

Fossil pollen percentages and microscopic charcoal data were summarized in diagramatic form using the program TILIA developed by Eric Grimm, Illinois State Museum.

Pitch pine is the only member of the hard pine group (subgenus *diploxylon*) presently occurring in the Northern Shawangunks [a single individual of jack pine (*Pinus banksiana*) has been identified near the Ellenville Ice Caves (P. Huth, personal communication)]. However, it is possible that other members of this subgenus, notably red pine (*Pinus resinosa*) and jack pine, have been important components of the ridge-top community in the past. Therefore, at selected levels in the core, an attempt was made to identify to type these morphologically similar pollen grains. Similar distinctions have been made in other studies using either simple size criteria (Winkler 1982, Whitehead 1964, Laing 1993), multiple morphological character analyses (Hansen & Cushing 1973, Ammaan 1977), or a combination of pollen and macrofossil analyses (Watts 1970). In this study simple size criteria were used based on measurements of the total length (including bladders) of as many whole, undamaged, *diploxylon* type pollen grains as possible.

Core Chronology

Stratigraphic control for the core was provided by a combination of radiocarbon dates and fossil pollen markers in sediments. Two radiocarbon dates were obtained from Beta Analyticals, Coral Gables, Florida. The samples chosen from the core were from levels where peaks in microscopic charcoal abundance had identified increases in fire occurrence. There was little evidence of root penetration throughout the core and large pieces of woody material were removed from the samples in the event that they had been displaced during the coring process. Other levels in the core were dated by stratigraphic markers - abrupt changes in the pollen percentages of certain species that could be assigned a known age. Increases in ragweed (*Ambrosia*), sorrel (*Rumex*), plantain (*Plantago*) and grass (*Gramineae*) pollen reflect the land-clearing activities associated with European settlement (Davis et al. 1980). The abrupt decline of hemlock throughout the Northeast *ca.* 4800 B.P. (Davis 1981, Gaudreau 1988), is also used as a stratigraphic marker. Changes in arboreal pollen percentages were compared with fossil pollen diagrams of dated lake-sediment cores from nearby sites. These analyses provided a regional context within which the more localized Shawangunk Spruce Swamp vegetation history could be placed.

RESULTS

Identification of Diploxylon Pollen

The results of the diploxylon pollen grain width measurements are shown in Figure 2. Six levels were analyzed, four towards the base of the core where diploxylon pollen percentages increase (46cm, 50cm, 60cm, 62cm) another at 20cm and one at the level closest to the bog surface at 1cm. The 1cm sample may be taken to represent the present

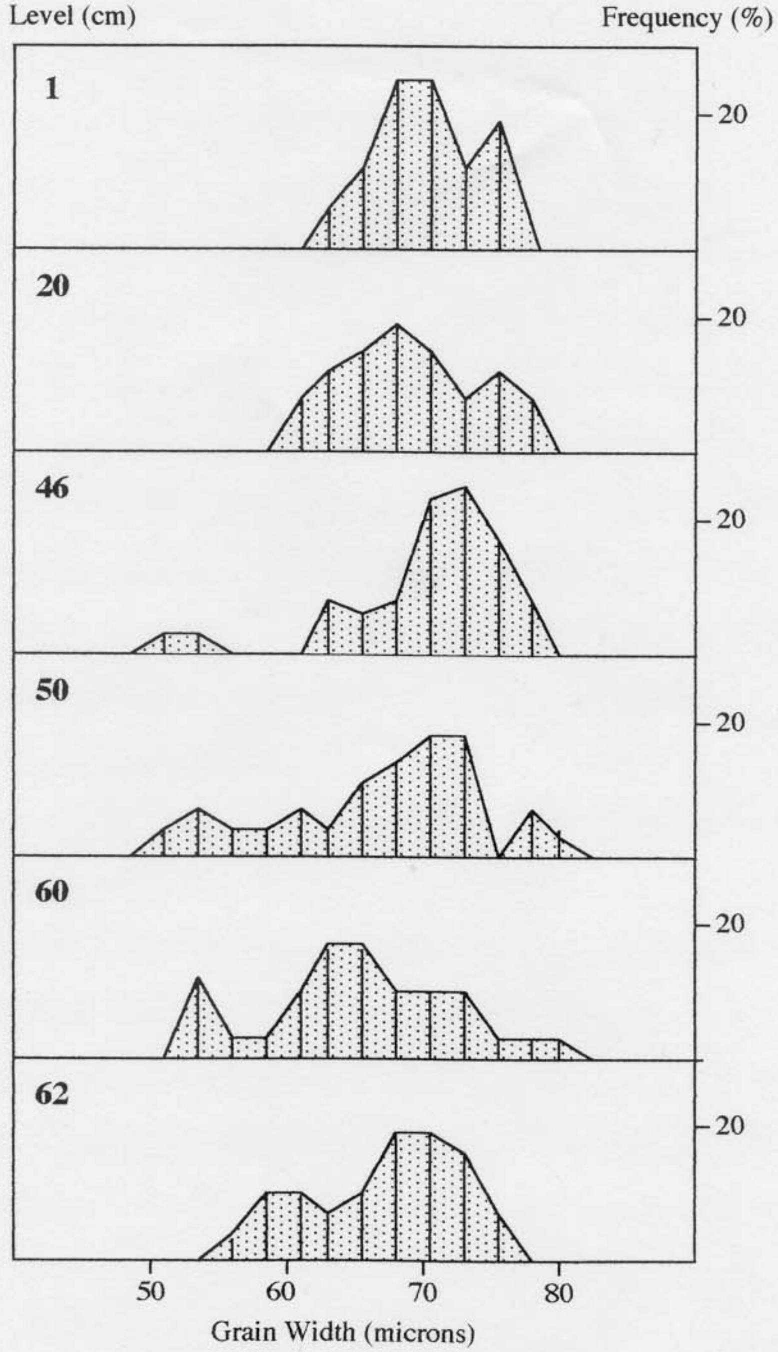

Figure 2. Frequency Distribution of fossil diploxylon pine pollen grains from selected levels in the Shawangunk Spruce Swamp peat core.

plant community which is dominated by pitch pine. An almost unimodal distribution of grain widths (between 60 and 80 μm) confirms pitch pine as the only diploxylon pollen type present. Pollen grain widths within this range dominate all the sample levels indicating pitch pine as the most important contributor. However, levels 46cm, 50cm, 60cm and 62cm have lesser numbers of smaller grains which may indicate a small representation of red and/or jack pine during these periods.

Core Chronology

The Shawangunk Spruce Swamp core represents approximately the last 9000 years (Figure 3). The level 42-45cm was dated by radiocarbon analysis at 5760 +/- 70 years BP (Beta-66668) and the level 24-27cm dates to 1920 +/- 50 years BP (Beta-66667). There are no visible charcoal layers in the core that would be evidence of fires burning into this portion of the swamp and consequently consuming peat. Fire scars on nearby tree stumps indicate, however, that other sections of the swamp have burned during historic time. The radiocarbon dates indicate extremely low sediment accumulation rates; 33.3cm/10^3 years between 0 - 10cm, 9.9cm/10^3 years from 10 - 26cm and 4.7cm/10^3 years from 26 - 44cm. Extrapolation from the lower radiocarbon date combined with a comparison of arboreal pollen percentages in the basal levels with those from other sites of a similar latitude provide an estimated basal age of ~9000 years BP at 62 cm. These sediment accumulation rates are at the bottom end of the average range of values calculated for the Holocene at mid-latitudes which is 16 - 257 cm/10^3 years (Webb & Webb 1988). However, one might expect this from the extremely slow weathering and soil formation that is characteristic of the ridge-top of the Northern Shawangunks.

The dramatic increase in agricultural indicator pollen percentages, most notably *Ambrosia* and *Gramineae*, at 8 cm represents European settlement and subsequent land-clearing and agriculture in the surrounding lowlands. The town of New Paltz, 13 miles to the east, was settled in c.a. 1677 (Olsvig 1980), and therefore an age of ~300 years BP is

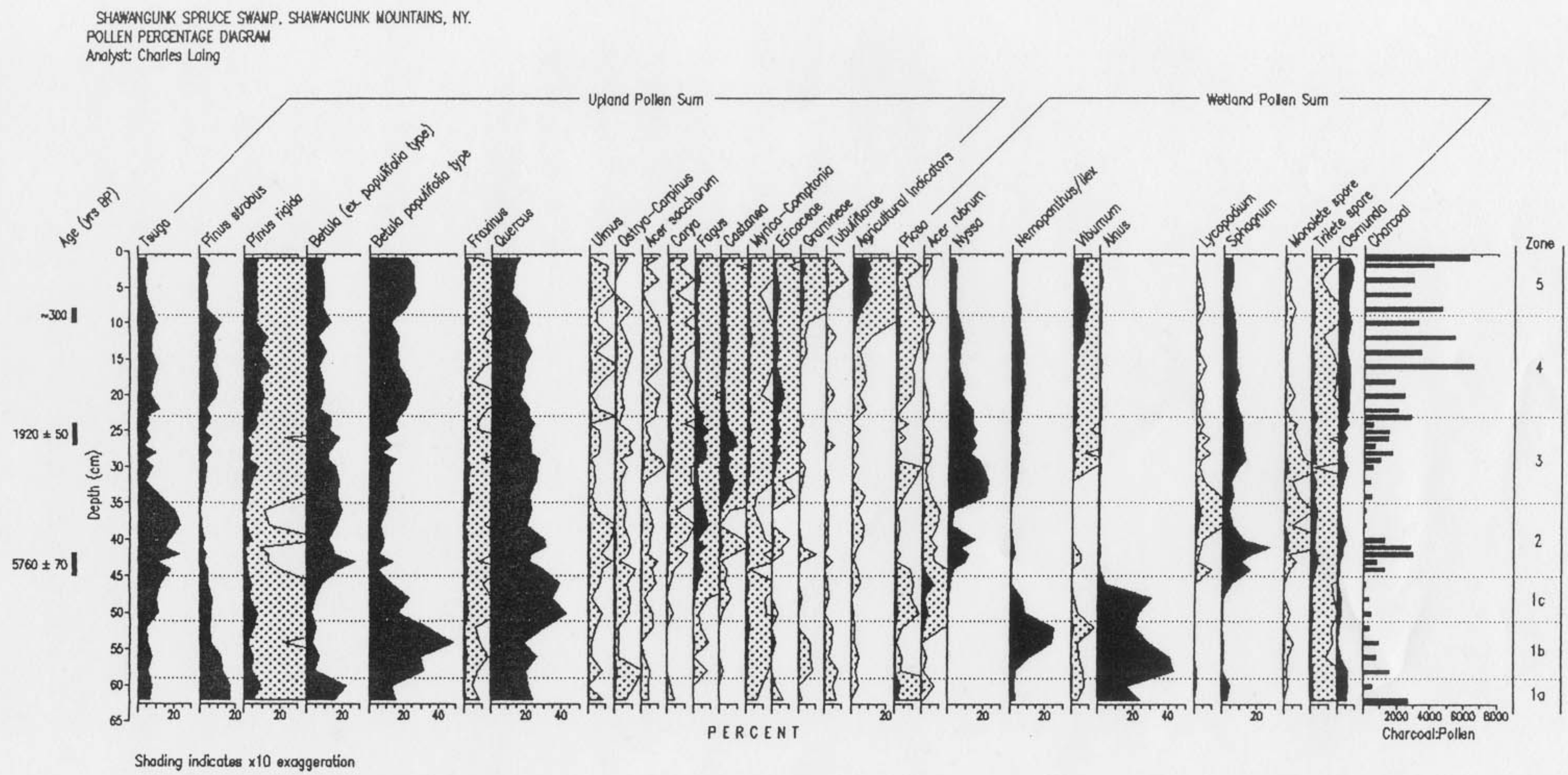

Figure 3. Pollen diagram from Shawangunk Spruce Swamp identifying fossil pollen percentages and microscopic charcoal:pollen ratios.

assigned to this level of 8-10 cm. The sharp decline in *Tsuga* pollen percentages at 36cm appear to date the hemlock decline which occurred at ca. 4800 yrs B.P. throughout the Northeast. This date is consistent with the bracketing radiocarbon dates.

Vegetation History

The results of the Shawangunk Spruce Swamp fossil pollen analysis are presented as a pollen percentage diagram (Figure 3). Separate pollen sums were used for the upland taxa and wetland taxa in order to accentuate changes in relative pollen percentages within each group and reduce the effect of large quantities of wetland pollen and spores on the relative proportion of pollen from other taxa. The pollen diagram has been divided into five pollen assemblage zones as well as three subzones based on the major groupings of plots identified using a FORTRAN program for stratigraphically constrained cluster analysis (CONISS, E.C. Grimm, University of Minnesota). Percentages of all pollen types including those not represented in the pollen diagram and charcoal:pollen ratios are listed in tables in Appendix A.

Zone SSS-1: (62 - 45 cm; ~9,000 to ~6000 yr B.P.). *Betula populifolia* and *Quercus* pollen dominate this zone while *Pinus strobus* and *P. rigida* pollen decreases from 17% and 10% to 6% and 4% respectively. High percentages of the wetland shrub taxa *Alnus* and *Nemopanthus/Ilex* pollen probably indicate their dominance of swamp vegetation cover.

Subzone 1a: In this subzone *Pinus rigida* remains relatively high, reaching 10%, while *Pinus strobus* and *Picea* pollen percentages are at their highest for the core, ~17% and 5% respectively. *Betula* (ex. *populifolia*-type) percentages (~20%) exceed those of *Betula populifolia*-type (15%), while *Quercus* values remain between 20% and 25%. *Tsuga* pollen increases from 5% to 6%. *Alnus* pollen dominates the wetland shrub component decreasing from 28% to 20%, while *Nemopanthus/Ilex* and *Viburnum* remain low at 5% and 1% respectively. *Osmunda* spores remain relatively high at 7% and *Sphagnum* increases to 5%. High *Pinus* and *Picea* values suggest that this subzone represents the end of the B (pine) pollen zone of Deevey/Davis terminology (Deevey 1939, Davis 1969).

Subzone 1b: *Pinus rigida* pollen percentages decrease gradually before rebounding to 7%, while *Pinus Strobus* values drop more sharply from 15% to 6%. *Betula populifolia* type pollen dominates this subzone, peaking first at 30% then again at 50%. At the same time *Betula* (ex. *populifolia*-type) decreases to 5% and remains low. *Quercus* increases to 30% at the top of this subzone while *Picea* decreases to <1%. *Tsuga* and *Fraxinus* percentages remain at 5% and 1% respectively, and *Fagus* pollen first appears at around 1%. *Alnus* initially dominates the wetland shrubs peaking at 48%, but it then decreases to 22% while *Nemopanthus /Ilex* increases from 5% to 25%, its highest value for the core. Other wetland shrub taxa remain at or below 1%. *Gramineae* pollen percentages increase slightly throughout much of this subzone reaching 2% while *Sphagnum* and *Osmunda* spores decrease to around 1%.

Subzone 1c: This subzone together with Zone-2 correspond with pollen zone C1 (oak, hemlock) of the Deevey/Davis terminology. *Pinus rigida* decreases from 7% to 4% and *Pinus strobus* decreases from 6% to 5%. *Betula populifolia*-type pollen peaks at 20% then decreases to 10%. *Betula* (ex. *populifolia*-type) increases to 10% at the top of the subzone. *Quercus* increases to its highest values for the core, fluctuating between 35% and 40%. *Tsuga* and *Picea* also show increases, reaching 10% and 2% respectively. *Acer rubrum* peaks at 6% and 7%, their highest values for the core, and *Castanea*, *Carya* and *Nyssa* pollen appears consistently for the first time, the latter reaching 3% at the top of the subzone. *Fagus* also increases to 3% by the top of the subzone. Previously important wetland shrub taxa - *Alnus*, *Nemopanthus/Ilex* and *Viburnum* - all decrease to <5%, and *Alnus* remains below 3% for the rest of the core. *Sphagnum* spores increase to 10% by the top of the subzone, whereas *Osmunda* remains at or below 4%.

Zone SSS-2: (45-35 cm; ~6,000 to ~4,800 yr B.P.). In this zone *Pinus rigida* pollen percentages decrease to their lowest levels in the core, <5%, while *Pinus strobus* decreases gradually to 1%. *Tsuga* increases to a maximum of 23% before declining at the top of the zone. *Betula populifolia*-type remains low at ~10% while *Betula* (ex. *populifolia*-type) peaks at 25% and then decreases to about 20% near the top of the zone. *Quercus* decreases from 30% to fluctuate around 22% and *Picea* drops to below 1%. *Ulmus* and *Carya* increase to 2%, *Fagus* continues to increase to a maximum value of 10% near the top of the zone; and *Nyssa* peaks at 15% before dropping to less than 5%. Wetland shrub taxa remain at <5% throughout the zone, while trilete spores reach their highest values for the core (4%). *Sphagnum* spore percentages also peak in this zone reaching 27%, but *Osmunda* remains at or below 6%.

Zone SSS-3: (35-23 cm; ~4,800 to ~1,600 yr B.P., equivalent to pollen zone C2 [oak, hickory] in Deevey/Davis terminology). Both *Pinus rigida* and *Pinus strobus* increase slightly in this zone, reaching 8% and 7% respectively. The lower zone boundary is marked by the *Tsuga* decline, its pollen percentages decreasing to 5% and remaining at about this level throughout the zone. *Nyssa* percentages recover sharply and peak at 22%, then decrease to 15% after having dropped to <5% at the top of Zone SSS-2. *Castanea* also reaches its maximum values during this zone, reaching 10% before decreasing slightly. *Betula* (ex. *populifolia*-type) pollen percentages continue to exceed those of *Betula populifolia*-type at first but decrease from 20% to 15% while the smaller *B. populifolia*-type grains increase from 10% to 15%. *Fagus* decreases to 2% but returns to 8%, and *Carya* increases to its highest percentages for the core (3%). The wetland shrubs *Nemopanthus/Ilex* and *Viburnum* regain some importance in this zone, the former increasing to 5% and the latter increasing later to 2%. Other shrubs also increase in this zone, *Myrica-Comptonia* and *Ericaceae*, increasing to 3% and 4% respectively. *Sphagnum* spores increase to 13% by the middle of the zone while trilete spores drop to <1% and *Osmunda* fluctuates around 5%.

Zone SSS-4: (23-9 cm; ~1,600 to ~300 yr B.P., equivalent to pollen zone C3a [oak,chestnut; presettlement] in Deevey/Davis terminology). In this zone *Pinus rigida* pollen increases to its highest percentages, reaching 15% before decreasing to 7%. *Pinus strobus* also has elevated pollen percentages throughout much of this zone, fluctuating around 10%. At the same time *Betula populifolia*-type pollen increases to 24% then gradually decreases to 13%, while *Betula* (ex. *populifolia*-type) remains at around 10%. *Tsuga* and *Picea* also increase during this zone to around 10% and 2% respectively. *Quercus* remains relatively constant between 15% and 20% and *Carya*, *Fagus* and *Castanea* are all below 5%. *Nyssa* pollen percentages decline throughout the zone from 15% to 5% at the top. *Nemopanthus/Ilex* continues to increase reaching 8% before declining again, and *Viburnum* increases to 8% but only in the latter portion of the zone. *Myrica-Comptonia* pollen percentages remain around 2%, while *Ericaceae* peaks at 6% before dropping to 3% for the rest of the zone. Pollen types indicative of disturbance and, when they appear in large quantities in recent sediments, as agricultural indicators (*Ambrosia*, *Rumex*, *Plantago lanceolata*) appear consistently for the first time and increase to 5% at the top of the zone, while *Sphagnum* and *Osmunda* spores remain relatively unchanged at 7% and 6% respectively.

Zone SSS-5: (9-0 cm; ~300 yr B.P. to present, equivalent to pollen zone C3b [oak,chestnut; postsettlement] in Deevey/Davis terminology). *Pinus rigida* pollen percentages are consistantly below their Zone SSS-4 values remaining at 7%. *Pinus strobus* percentages are also lower, decreasing to 5% and then 2% at the top of the core. *Tsuga* percentages decrease to 5%, and *Quercus* falls to 12% before recovering to 16% at the top of the core. *Betula populifolia*-type is the only arboreal taxa that increases in this zone, rising from 10% to 25%. *Betula* (ex. *populifolia*-type) remains at around 10%, and *Picea* decreases slightly to 1%. *Nyssa* continues to decline, with percentages dropping from 5% to 3% at the top of the core while other arboreal genera, including *Carya*, *Fagus* and *Castanea*, decrease slightly then recover in the uppermost level. Of the wetland shrub taxa, *Nemopanthus/Ilex* fluctuates around 5% while *Viburnum* pollen percentages reach their maximum core values of 11% before decreasing to 7%. *Myrica-Comptonia* and *Ericaceae* percentages remain at Zone SSS-4 levels of around 2% and 3% respectively. This zone is characterized by an increase in *Gramineae* pollen percentages to 3%. Other agricultural indicator types (*Ambrosia*, *Rumex*, *Plantago lanceolata*) reach 10%. *Sphagnum* and *Osmunda* spores remain relatively unchanged, fluctuating around 5% and 6% respectively.

Charcoal Analysis

The extremely condensed nature of the Shawangunk Spruce Swamp sediment core, with ~9,000 yrs represented in only 62 cm, makes the production of a detailed fire history very difficult. Each 1-cm sample represents from 30 to 190 yrs depending on its depth within the core, so individual high Ch:P values may represent more than one fire. Levels between those I sampled may also contain evidence of one or more fires. However, fine-resolution sampling between 40-45 cm and 22-30 cm tended to emphasize the charcoal peaks already identified at the coarser resolution. Because charcoal peaks that appear to individual fires or a relatively short period of increased fire activity span more than one level, it is reasonable to assume that the routine sampling at 2-cm intervals accurately identifies gross changes in the local fire regime.

Microscopic charcoal (Figure 3) provides evidence of fire occurence throughout the period of time represented by the sediment core. Charcoal:Pollen (Ch:P) ratios range from 6553 to 92. This range of values is comparable with Ch:P ratios calculated for other bog sites in the Northeast (Laing 1993, Motzkin et al. 1993). are relatively low throughout the core and this is probably a function of the extremely high pollen concentrations. Variations in Ch:P ratios and sharp peaks associated with changes in the relative pollen percentages of certain taxa (*Sphagnum*, *Nyssa*, *Pinus rigida*) seem to identify individual fires and periods of increased fire activity within this range of Ch:P values.

A peak in Ch:P ratios at the base of the core is followed by consistently lower values for the rest of Pollen Assemblage Zone SSS-1. The large peak in *Betula populifolia*-type pollen percentages during subzone-1b may be associated with two small charcoal peaks, but the long period spanned by the increased percentages suggests the increase is associated with successionary changes occurring both within the local swamp vegetation (highlighted by the increased abundances of *Nemopanthus/Ilex* and *Alnus* pollen) and in the surrounding area.

Abrupt changes in the percentages of several pollen types coincide with two charcoal peaks, one at 44 cm and the other at 41-42 cm. Fluctuations in both the arboreal taxa (*Tsuga*, *Betula*, *Quercus*) and local wetland taxa (*Nyssa*, *Sphagnum*)suggest that these fires affected the swamp itself. Radiocarbon dating of the sediment from 42 to 45 cm provided an estimated age of 5,760 +/- 70 yrs B.P. (Beta-66668). There follows a period of very low charcoal values which, though only spanning 13 cm in the core, represents approximately 3,000 years centered around the time of the hemlock decline. The upper half of the core sees a dramatic change in charcoal sedimentation with higher Ch:P values and more frequent peaks. Small peaks in Ch:P ratios occur at 28 cm and 25 cm and are associated with numerous changes in the associated pollen assemblage. The Ch:P peak at 22 to 23 cm also seems to represent an individual fire event based on changes in the fossil pollen spectrum but above this level Ch:P ratios remain high making the identification of separate fires impossible. Ch:P ratios reach their maxima at 16 cm and in the uppermost level, reaching 6553 and 6273 respectively. Between these peaks values remain above 2500.

DISCUSSION

Paleoecology of the Dwarf Pine Plains

Fossil pollen and microscopic charcoal analyses from The Shawangunk Spruce Swamp provide insights into the vegetation and fire history of the dwarf pine plains over the last ~9000 years. Radiocarbon dating in conjunction with pollen indicators are used to identify the chronology of vegetation change within the sediment core. In order to understand the relationship between the pollen collected from the core and its representation of the surrounding vegetation one must try to assess the pollen source area of the deposition basin.

The analysis of peat sediment from a relatively small swamp, as opposed to lake sediments, should in this study emphasize pollen produced locally rather than regionally (Jacobson & Bradshaw 1981, Heidi & Bradshaw 1982, Prentice 1984, Bradshaw & Miller 1988, Jackson 1990). The pollen identified in the Shawangunk Spruce Swamp sediments can be roughly divided into three categories: pollen produced by plants associated with the swamp, pollen from the surrounding dwarf pitch pine community, and pollen from more remote sources (these may include the oak forest of the slopes and the cultivated lowlands). An examination of the surface pollen from the core should identify the present pollen source area of this deposition basin and therefore provide an estimate of the proportions of these different pollen sources reaching the swamp surface.

In the uppermost level of the pollen diagram, the percentages of *Tsuga*, *Nyssa*, *Picea* and *Acer rubrum* probably represent the presence of these trees on the swamp itself, given that all are consistently underrepresented in fossil pollen studies (Heidi & Bradshaw 1982). The percentages of *Sphagnum* and *Osmunda* spores also reflect their dominance of the ground cover immediately surrounding the core site. Some pollen types may be from both local and regional sources, but their association with other pollen producers from the same plant community should make source identification possible. *Pinus strobus* pollen may be derived from the trees associated with the swamp or from components of the downslope oak forest community, because pine pollen can be transported long distances. The provenance of the *Pinus rigida* pollen has potential sources both on the swamp, from the dwarf pine plains, and from the less stunted pine barrens vegetation that occurs along the ridge to the northeast. The relative scarcity of *Pinus rigida* on the swamp compared to its dominance in the surrounding vegetation supports extralocal sources for most of this pollen, however. Additional support for an extralocal source for *Pinus rigida* is found in the representation of other components of the existing dwarf pitch pine community in the pollen record. *Betula populifolia*-type pollen, *Viburnum* and *Comptonia* are all well-represented in the uppermost level and they are all important components of the present vegetation of the uplands. The only important canopy species of the pine plains community that is not present is *Pyrus melanocarpa*, a member of the Rosaceae family that is insect pollinated (entimophilous) and therefore consistently underrepresented in fossil pollen studies. Although ericaceous shrubs dominate the understory of the dwarf pine plains and are well represented on the swamp itself, their low pollen production is clearly reflected in the pollen percentage diagram.

Another extralocal source of pollen to Shawangunk Spruce Swamp is the oak-dominated forested slopes below the plains. These are represented by large quantities of *Quercus* pollen and lesser proportions of *Fraxinus, Ulmus, Carya, Fagus, Betula* (ex. *populifolia* type) and *Castanea* - species which are all present on these richer sites. The presence of large numbers of *Ambrosia* pollen grains (the main component of the Agricultural Indicator group) in the uppermost samples emphasizes the existence of a regional pollen component to influx to this small deposition basin. The ragweed pollen must be transported from the cultivated lowlands lying east and west of the Shawangunk ridge. The increase in *Gramineae* pollen that occurs with increases in agricultural indicators suggests that this type is also derived from agricultural sources.

The pollen diagram for the Shawangunk Spruce Swamp illustrates the sequence of vegetation and fire history that has preceded the existence of the present dwarf pitch pine community and the existing swamp community. Prior to 5760 +/- 70 yrs B.P. (42-45 cm), both pine pollen types show gradual decreases from high values at the base of the core. A large peak in *Betula populifolia*-type pollen percentages at 54 cm suggests there may have been a period of increased disturbance during this time but the associated peaks in microscopic charcoal are small and do not seem to indicate major periods of increased fire activity. It is possible that sampling at 50 yrs missed additional microscopic charcoal evidence of fire although it seems more likely that the broad *Betula populifolia*-type peak is associated with changes in the local wetland community. The swamp vegetation was very different during this period with a dense shrub canopy of *Nemopanthus/Ilex* and *Alnus* and sparser ground cover. The dominance of *Alnus* (a nitrogen-fixer) in Shawangunk Spruce Swamp throughout Zone SSS-1 suggests that higher sedimentation rates might be expected in this portion of the core.

At least two distinct fires, which apparently affected both the swamp and surrounding vegetation, occurred around 5760 +/- 70 yrs B.P.. The evidence in the pollen assemblage comes from twin peaks in both the *Nyssa* and *Sphagnum* profiles and short-term fluctuations in the percentages of many arboreal pollen types. There is only a slight and temporary increase in *Pinus rigida* following these disturbances, as the period between the two radiocarbon dates is dominated by more mesic species; *Tsuga, Betula* (ex. *populifolia*-type) and *Nyssa*. The upper date of 1920 +/- 50 yrs B.P. is associated with another period of increased fire activity, and charcoal values remain high throughout the upper portion of the core. Associated with the increase in fire frequency is an increase in the percentages of all the components of the dwarf pine plains community represented in the fossil pollen assemblage (*Pinus rigida*, *Betula populifolia*-type, *Ericaceae*, *Viburnum*). The increase in agricultural indicator pollen between 8 and 10 cm identifies the period of European settlement. The decreases in abundance of a number of arboreal taxa - *Tsuga*, *Pinus strobus* and *Quercus* - following European settlement is probably a function of timber-harvesting and land-clearing activities associated with increasing European occupation and utilization of the area. In addition to intensive woodcutting through the late 1800's, charcoal production was an important industry in the Shawangunks from the late 1700's to the early 1900's, and tanbark peeling of the hemlocks in the early and mid 1800's lead to their virtual elimination from the area (Kiviat 1988). The slash left from this harvesting lead to fires that are considered to have been the most intense in local history (Snyder & Beard 1981). It is possible that the severity of these post-settlement fires favored the *Betula populifolia* component of the dwarf pine plains. This pioneer species increases in the upper portion of the pollen diagram.

The shift in vegetation towards a fire-dominated pitch pine community, perhaps similar to the dwarf pine plains that now occupy a portion of the area surrounding Shawangunk Spruce Swamp is displayed in the results of detrended correspondence analysis (DCA) of the upland pollen from the sediment core (Figure 4). This diagram plots sample levels from the 62-cm-long core against changes in pollen percentages of selected pollen taxa. The taxa used in the DCA - *Tsuga, Pinus strobus, P. rigida, Betula populifolia* type, *Betula* (ex. *populifolia* type), *Castanea, Carya, Fagus, Ericaceae* - are plotted in Figure 4A. Only upland pollen types, the pollen being derived largely from sources outside the wetland, are used in this analysis in order to accentuate the importance of vegetation history on the surrounding uplands. An interesting feature highlighted by the diagram is the relative similarity of the upper-most and bottom-most levels despite the long time period and vegetation change in between. This similarity is probably a function of these two portions of the core having the highest *Betula populifolia* and *Pinus strobus* percentages and does not necessarily suggest that the representive communities are analogous. The lower samples show considerable level-to-level variation, however, with a general trend away from the disturbance-associated species *Pinus rigida* and *Betula populifolia* towards more mesic genera such as *Quercus*, *Betula* (ex. *populifolia* type) and *Tsuga* . There are three distinct groupings of plots, one comprising 7 samples (levels 44 to 36cm, group III), another with 10 samples (levels 34 to 23 cm, group II) and one

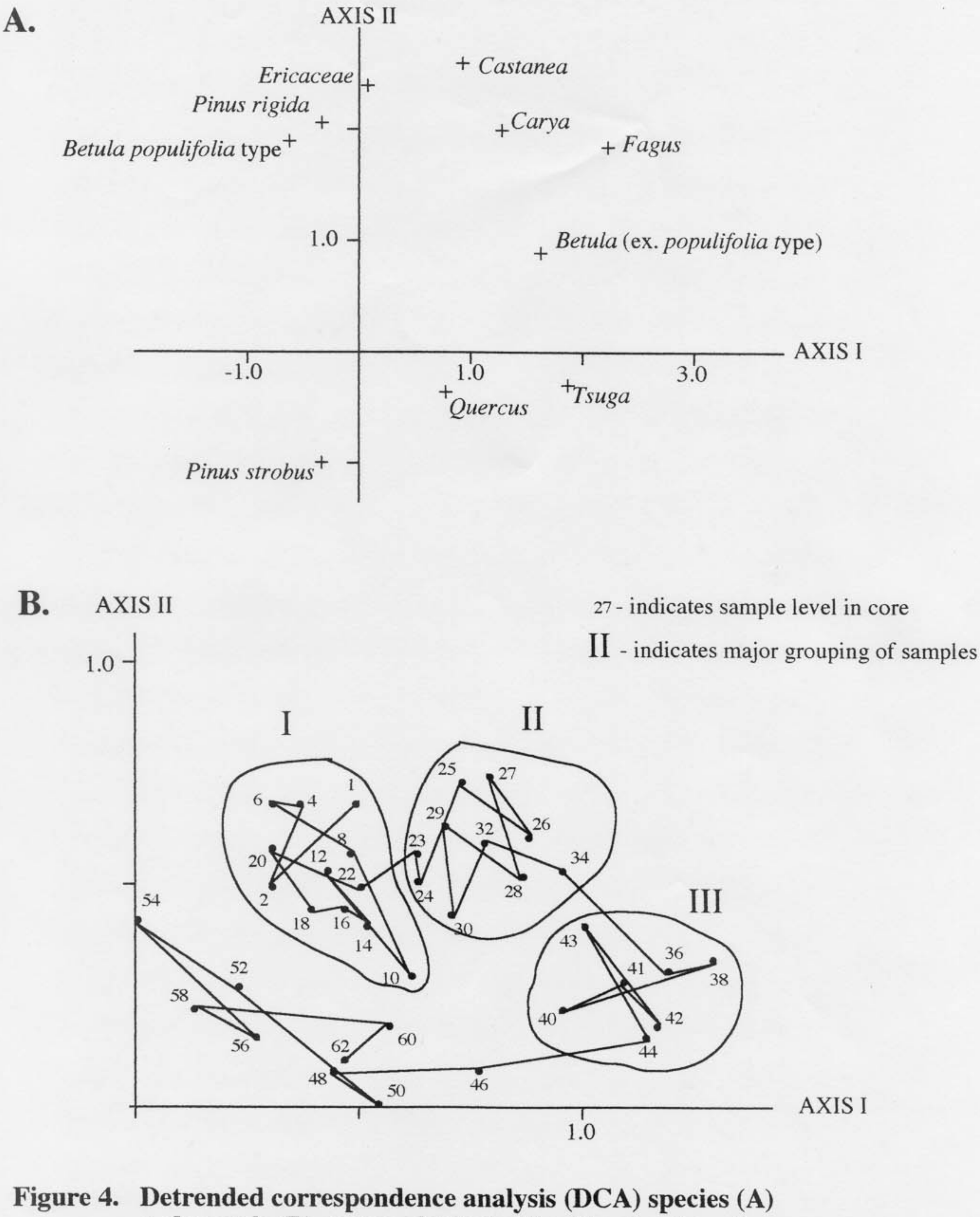

Figure 4. Detrended correspondence analysis (DCA) species (A) and sample (B) scores of selected fossil pollen taxa from Shawangunk Spruce Swamp (Numbers indicate level of sample)

comprising the uppermost 12 samples (levels 22 to 1 cm, group I). Groups III and II both show minimal level-to-level change in vegetation composition. They span approximately 2000 and 3000 years respectively, during which time different assemblages of more mesic genera such as *Betula* (ex. *populifolia*-type), *Tsuga* and *Fagus*, increased in importance. *Pinus rigida* and other disturbance-related pollen types were less prevalent than at present . After a series of fires towards the end of this relatively stable period, the composition of the vegetation community changed with increased proportions of *Pinus rigida*, *Betula populifolia* type and *Pinus strobus*. This change is identified by the shift to the left on DCA axis I in the position of group I, which includes samples from the period of European settlement.

Within the 12 upper-most samples there is relatively little level-to-level variation, with both presettlement and postsettlement plots lying close together. The position of the surface sample level at the center of this group suggests that a fire-dominated pitch pine community, perhaps similar to the dwarf plains that now occupy a portion of the area, has existed throughout this period. This stable pitch pine community is associated with increased fire occurrence and, perhaps, severity based on the elevated Ch:P ratios that characterize these levels. Fire severity may have been increased by more frequent or prolonged droughts and/or more flammable fuels due to increased pitch pine importance. Ignitions associated with Indian occupation may also have increased during this period, and following European settlement, slash from wood cutting may have lead to increased fire severity.

The fossil pollen and microscopic charcoal analyses from Shawangunk Spruce Swamp indicate that *Pinus rigida* has been present since at least approximately 9,000 years ago. However the fossil pollen and DCA suggest that *Pinus rigida* was initially a component of a community that bore little resemblance to the present dwarf pine plains. This assemblage changed throughout the first few thousand years represented by the core as the proportions of more mesic species - some of which only arrive in the area around

6,000 B.P (*Carya, Fagus,* and *Castanea*) - increased. It is difficult to determine the exact origin of the pollen from some of these more mesic components, but the low relative proportion of *Pinus rigida* pollen suggests a community like the present pine plains vegetation was more limited in extent. Alternatively the dominance of more mesic genera both leading up to and immediately following the *Tsuga* decline may represent an absence of dwarf pine plains vegetation and a richer pine barrens community in its place. This richer forest community may have covered much of the Ice Caves Mountain area, growing on deeper organic soils that had accumulated in the absence of frequent fires.

The microscopic charcoal analysis identifies an increase in fire frequency and, perhaps, severity over the past 2000 years in the vicinity of Shawangunk Spruce Swamp but does not identify the mechanism behind this change. Other fossil pollen analyses from sites throughout the Northeast have identified a period of climate change beginning between 2,500 and 1,500 years ago and leading to changes in forest composition (Davis et al. 1980, Green 1982, Anderson et al. 1985, Gaudreau 1986). Computer modelling has demonstrated that climate change may result in increases in disturbance frequency (Overpeck et al. 1990). Gajewski (1986) associates the neoglacial expansion of the boreal forest with a change in frequency of arctic air masses in the area. Evidence of fire accompanying the establishment of the present day forest type around 1450 yrs B.P. was found in studies from the Acadian Forest (Wein et al. 1986) and around 1900 yrs B.P. on Mount Desert Island, Maine (N. Drake unpublished data, Laing 1993). Therefore, it is possible that the peaks in Ch:P which appear around the radiocarbon-dated levels 24 to 27 cm (1920 +/- 50 yrs B.P.) represent a series of fires associated with a change in climate or one, dramatic drought event that caused wide-spread fires throughout northeast North America. Associated with these relatively small charcoal peaks is an expansion of the shrub components of the dwarf pine plains, *Viburnum* and *Ericaceae*, and subsequently the canopy components, *Pinus rigida* and *Betula populifolia*-type. From ~2,000 B.P. to the present, charcoal values remain high, presumably as a result of the expansion of the highly flammable dwarf pitch pine association. There could be both climatic and anthropogenic ignition sources during this period. The high elevation and drought susceptibility of the dwarf pine plains could increase the probability of lightning ignitions. Alternatively the increased importance of huckleberry and blueberry on the ridgetop may have prompted increased Indian ignitions to promote berry crops.

Comparative studies of other Northeast Pine Barrens

Paleoecological studies have been conducted in other pine barrens in the Northeast at Deep Pond on Long Island (Backman 1984), Charge and Wigeon Ponds near Plymouth, Massachusetts (Patterson & Backman 1988) and most recently at Newfield Bog in the Waterboro Pine Barrens, Maine (Patterson 1994). These barrens are all located on till or outwash deposits whereas the pitch pine in the Shawangunk Spruce Swamp study are growing at high elevation on rock outcrops. The pollen and charcoal profiles from Charge and Widgeon Ponds in Myles Standish State Forest (Patterson & Backman 1988) identify an abrupt change in forest composition associated with wood cutting and repeated, destructive fires during the 1800's. During this period the pitch pine component of the pine-oak forests surrounding the two sites increased substantially leading to the present dominance of pine barrens vegetation in the area. In the Waterboro Barrens (Patterson 1994) less frequent presettlement fires allowed pitch pine to exist as part of a more mesic forest community. However, increases in charcoal abundances and in the proportions of pollen indicators of frequent fire and open conditions (grey birch and heathland species) following European settlement indicate the expanse of the present pitch pine barrens vegetation. The charcoal and pollen record from Deep Pond, Long Island (Backman 1984) which spans ~2200 yrs, reveals that fires were as frequent in presettlement as in postsettlement forests. Throughout this period oak and pitch pine have fluctuated in relative abundance but following settlement the pitch pine increases, possibly reflecting the decrease in oak due to logging activities. The Shawangunk Spruce Swamp vegetation and fire history span a considerably longer time period than the aforementioned studies and identify when this particular pine barrens ecosystem evolved. The Shawangunk charcoal and pollen record seems most similar to the Deep Pond chronology in that both identify high fire frequency throughout the past 2000 yrs associated with a pitch pine dominated community. The Long Island, Plymouth and Waterboro studies all suggest increases in the importance of pitch pine following European settlement, whereas the Shawangunk core indicates that possible changes in fire frequency and/or severity have reduced pitch pine importance during this period.

Whatever the cause of increased fire frequency prior to European settlement, it seems to be closely linked with the appearance of a fire-dominated pitch pine community, perhaps similar to the dwarf plains that now occupy a portion of this area. Higher *Pinus rigida* pollen percentages immediately preceding European settlement suggest that the dwarf pine plains may have been even more extensive then than now. More destructive wildfires following European settlement may have favored the *Betula populifolia* component of the dwarf pine plains in more recent times. Given the fire-adapted nature of this community, prolonged fire suppression would undoubtedly be detrimental to its continuing dominance of the Ice Caves Mountain ridge-top. However, the extreme edaphic stresses associated with the harsh microclimate and poor soils are probably an important factor in maintaining the pine plains ecosystem and may promote its existence for some time in the absence of fire.

ACKNOWLEDGEMENTS

This study was supported by a grant from the Eastern New York Regional Office of The Nature Conservancy. Sample preparation and analyses were conducted using the pollen laboratory facilities of the Department of Forestry and Wildlife Management at the University of Massachusetts, Amherst. I would like to thank William A. Patterson III for his association with this research and review of this report. I also thank Paul Huth for providing information on the ecology of the Shawangunks and for his enthusiasm in all studies related to them. Kate Hubbs in her initial capacity as Director of Preserve Design and who, together with Andrea Stevens, provided the necessary assistance in coring the site. John Bradley and Mr. & Mrs. Fred Grau made access to the area possible and provided useful local information.

LITERATURE CITED

Ammaan, B.R. 1977. A pollen morphological distinction between *Pinus banksiana* Lamb. and *P. resinosa* Ait. Pollen et Spores 19: 521-529.

Anderson, R.S., Davis, R.B., Miller, N.G. & R. Stuckenrath. 1985. History of late- and post-glacial vegetation and disturbance around Upper South Branch Pond, northern Maine. Can. J. Bot. 64: 1977-1986.

Backman, A.E. 1984. 1000-year record of fire-vegetation interactions in the Northeastern United States: a comparison between coastal and inland regions. M.S. Thesis, University of Massachusetts, Amherst.

Bradshaw, R.H.W. & N.G. Miller. 1988. Recent successional processes investigated by pollen analysis of closed canopy forest sites. Vegetatio 76: 45-54.

Clark, R.L. 1982. Point count estimation of charcoal in pollen preparations and thin sections of sediments. Pollen et Spores 24: 523-535.

Clark, J.S. 1988. Effects of climate change on fire regimes in northwestern Minnesota. Nature 334: 233-235.

Davis, M.B. 1969. Climatic changes in southern Connecticut recorded by pollen deposition of Rogers Lake. Ecology 50: 409-422.

Davis, M.B., Spear, R.W. & L.C.K. Shane. 1980. Holocene climate of New England. Quat. Res. 14: 240-250.

Davis, M.B. 1981. Quaternary history and the stability of forest communities. pp *In* D.C. West, H.H. Shugart & D.B. Botkin (eds), Forest succession: concepts and application. Springer-Verlag, New York.

Davis, R.B. & G.L. Jacobsen, Jr. 1985. Late glacial and early Holocene landscapes in northern New England and adjacent areas of Canada. Quat. Res. 23: 341-368.

Day, G.M. 1953. The Indian as an ecological factor in the northeastern forest. Ecology 34: 329-346.

Deevey, E.S.Jr. 1939. Studies on Connecticut lake sediments. I. A post-glacial climatic chronology for southern New England. Amer. J. Sci. 237: 691-724.

Faegri, K. & J. Iversen. 1975. Textbook of Pollen Analysis, Third Revised edition. Hafner Press, New York.

Florer, L.E. 1972. Palynology of a postglacial bog in the New Jersey Pine Barrens. Bull. Torr. Bot. Club 99: 135-138.

Gajewski, K. 1986. Climatic impacts on the vegetation of eastern North America during the past 2000 years. Vegetatio 68:

Gaudreau, D.C. 1986. Late-Quaternary vegetational history of the northeast: paleoecological implications of topographic patterns in pollen distributions. Ph.D. Thesis, Yale University, New Haven, CT.

Green, D.G. 1982. Fire and stability in the postglacial forests of southwest Nova Scotia. J. Biogeog. 9: 29-40.

Hansen, B.S. & E.J. Cushing. 1973. Identification of pine pollen of Late Quaternary age from the Chuska Mountains, New Mexico. Geol. Soc. Am. Bull. 84: 1181-1200.

Heidi, K.M. & R.H.W. Bradshaw. 1982. The pollen-tree relationship within forests of Wisconsin and Upper Michigan, U.S.A. Rev. Palaeobot. Palynol. 36: 1-23.

Jackson, S.T. 1990. Pollen source area and representation in small lakes of the northeastern United States. Rev. Palaeobot. Palynol. 63: 53-76.

Jacobson, G.L.Jr. & R.H.W. Bradshaw. 1981. The selection of sites for paleovegetational studies. Quat Res. 16: 80-96.

Kiviat, E. 1988. The Northern Shawangunks, An Ecological Survey. Mohonk Preserve, Inc., New Paltz, NY

Laing, C.P. 1993. The importance of fire in the maintenance of jack pine at its southeastern range limit in Acadia National Park, Maine. M.S. Thesis, University of Massachusetts, Amherst, MA.

McIntosh, R.P. 1959. Presence and cover in pitch pine-oak stands of the Shawangunk Mtns. Ecology 40: 482-485.

Motzkin, G., Patterson, W.A.III. & N.E.R. Drake. 1993. Fire history and vegetation dynamics of a Chamaecyparis thyoides wetland on Cape Cod, Massachusetts. J. Ecol. 81: 391-402.

Niering, W.A. 1953. The past and present vegetation of High Point State Park, N.J. Ecol. Monog. 23: 127-148.

Olsvig, L.S. 1980. A comparative study of Northeastern Pine Barrens vegetation. University Microfilm International, Ann Arbor, MI.

Overpeck, J.T., Rind, D. & R. Goldberg. 1990. Climate-induced changes in forest disturbance and vegetation. Nature 343: 51-53.

Patterson, W.A.III & A.E. Backman. 1988. Fire and disease history of forests. pp. 107-135 *In* B. Huntley & T. Webb III. (eds), Vegetation History, Kluwer Academic Publishers, New York.

Patterson, W.A.III & K.E. Sassaman. 1988. Indian fires in the prehistory of New England. pp. *In* G.P. Nicholas (ed). Holocene Human Ecology in Northeastern North America, Plenum Publishing Corporation, New York.

Patterson, W.A.III. 1994. The Waterboro Barrens: fire and vegetation history as a basis for the ecological management of Maine's unique scrub oak-pitch pine barrens ecosystem. Report submitted to Maine Chapter, The Nature Conservancy.

Prentice, I.C. 1984. Pollen representation, source area, and basin size: toward a unified theory of pollen analysis. Quat. Res. 23: 76-86.

Reschki, C. 1990. Ecological communities of New York State. New York Natural Heritage Program. N.Y.S. Department of Environmental Conservation, Latham, NY.

Smiley, D. & P.C. Huth. 1982. Shawangunk forest fires: 1842 to 1982. Mohonk Preserve Inc., Mohonk Lake, New Paltz, New York.

Smith, P.H. 1887. Legends of the Shawangunk. Pauling, New York.

Snyder, B. & K. Beard. 1981. The Shawangunk Mountains: a history of nature and man. Mohonk Preserve Inc., Mohonk Lake, New Paltz, New York.

Torrey, R.H. 1935. Trip of September 21-22 in the Shawangunks. Torreya 35: 153-155.

Watts, W.A. 1970. The full-glacial vegetation of northwestern Georgia. Ecology 51: 17-30.

Webb, R.S. & T. Webb. III. 1988. Rates of sediment accumulation in pollen cores from small lakes and mires of eastern North America. Quat. Res. 30: 284-297.

Wein, R.W., Burzynski, M.P., Sreenivasa, B.A. & K. Tolonen. 1986. Bog profile evidence of fire and vegetation dynamics since 3000 years BP in the Acadian Forest. Can. J. Bot. 65: 1180-1186.

Whitehead, D.R. 1964. Fossil pine pollen and full-glacial vegetation in southeastern North Carolina. Ecology 45: 767-777.

Windisch, A. 1990. Draft Dwarf Pine Barrens Element Stewardship Abstract. Unpublished report to The Nature Conservancy.

Winkler, M.J. 1985. A 12,000-year history of vegetation and climate for Cape Cod, Massachusetts. Quat. Res. **23:** 301-312.