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Vegetation, climate, and fire during the late-glacial–Holocene transition at Spruce Pond, Hudson Highlands, southeastern New York, USA

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ABSTRACT: Pollen, plant macrofossil, and charcoal records from Spruce Pond (41°14′22″N, 74°12′15″W), southeastern New York, USA dated by AMS provide details about late-glacial–early Holocene vegetation development in the Hudson Highlands from >12 410 to 9750 ^{14}C yr BP. Prior to 12 410 yr BP, vegetation was apparently open, dominated by herbs and shrubs (Cyperaceae, Gramineae, Tubuliflorae, *Salix, Alnus, Betula*), possibly with scattered trees (*Picea* and *Pinus*). However, *Picea* macrofossils are not found until 12 410 yr BP. Development of a temperature deciduous–boreal-coniferous forest featuring *Quercus, Fraxinus, Ostrya/Carpinus, Pinus, Picea,* and *Abies* occurs between 12 410 and 11 140 yr BP. A return of predominantly boreal forest taxa between 11 140 and 10 230 yr BP is interpreted as an expression of the Younger Dryas cooling event. Holocene warming at 10 230 yr BP is signalled by arrival of *Pinus strobus,* coincident with expansion of *Quercus*-dominated forest. Fire activity, as inferred from charcoal influx, appears to have increased as woodland developed after 12 410 yr BP. Two charcoal influx peaks occur during Younger Dryas time. Early Holocene fire activity was relatively high but decreased for approximately 100 yr prior to the establishment of *Tsuga canadensis* in the forest at 9750 yr BP. © 1997 by John Wiley & Sons, Ltd.

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KEYWORDS: Late-glacial–Holocene transition; pollen and plant macrofossils; fire; AMS radiocarbon dating; New York.

Introduction

Improved reconstruction of the terrestrial environment during the late-glacial to Holocene transition is necessary for comparison of palaeorecords, and depends on finer resolution analyses of fossil pollen and plant-macrofossil records and the use of accelerator-mass-spectrometer (AMS) radiocarbon dating (Lowe *et al.*, 1994). Recent refinement of late-glacial to early Holocene vegetation history in northern New Jersey and southern Connecticut, USA (Peteet *et al.*, 1990, 1993) is the result of such analyses. This more detailed palaeoecological approach to arboreal migration following deglaciation has begun to clarify the timing and pattern of immigration of *Pinus strobus* and *Picea*, among other trees, in the northeastern USA (the Northeast). It has also been instrumental in the recognition of the regional occurrence and duration of the Younger Dryas (YD) age cooling event.

In an effort to expand the geographical area represented by more detailed vegetation records, study of the Hudson Highlands in southeastern New York was undertaken. Pollen and plant macrofossils and AMS radiocarbon dating initially produced a detailed vegetation record from Sutherland Pond, Black Rock Forest, in the lower Hudson River Valley, New York (Maenza-Gmelch, 1996a, b). The paper presented here reports on the late-glacial–Holocene transition at a second site, Spruce Pond, also located in the Hudson Highlands. These papers serve to regionally characterise vegetation, climate, and fire history of the Highlands between >12 500 and 9500 ^{14}C yr BP.

Setting

Physical featues of the core site and deglaciation

Spruce Pond, 2.6 ha in surface area, is situated at 223 m elevation, with maximum water depth of 5 m, and lies within

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Harriman State Park, southeastern New York, at 41°14′22″N, 74°12′15″W (Sloatsburg 7.5′ USGS Quadrangle, 1955). Harriman State Park, a unit of the Palisades Interstate Park, is located in the southwestern corner of the Hudson Highlands (Fig. 1).

The Hudson Highlands, part of the Reading Prong of the New England Physiographic Province (Fenneman, 1938), rise >180 m above the adjacent lowlands, reaching a maximum elevation of 400 m. Bedrock consists of Precambrian gneiss and granite, and topography is characterised by steep slopes, ravines, rolling–rocky slopes, and low hills separated by swamps and ponds (Denny, 1938; McCrone, 1967). The region was glaciated by the Laurentide ice sheet; however, the glacial geology of the Hudson Highlands is largely unstudied. From studies of the Great Valley, west of the Highlands, deglaciation is estimated at 17 500 yr BP, based on assumed late-glacial sedimentation rates (Connally *et al.*, 1989). The chronological setting of regional ice retreat is poorly known (Muller and Calkin, 1993).

Climate

Southeastern New York is under the influence of cold, dry air from the continent's northern interior; warm, humid air from the Gulf of Mexico and adjacent subtropical waters; and maritime air originating over the North Atlantic (Ruffner, 1980). Climate data representative of the Hudson Highlands from West Point, New York (Fig. 1) recorded over a 30-yr period (1918–1948) indicate a mean January temperature of −2.1°C, mean July temperature of 23.7°C, and mean annual precipitation of 1060 mm, uniformly distributed throughout the year (Ross, 1958).

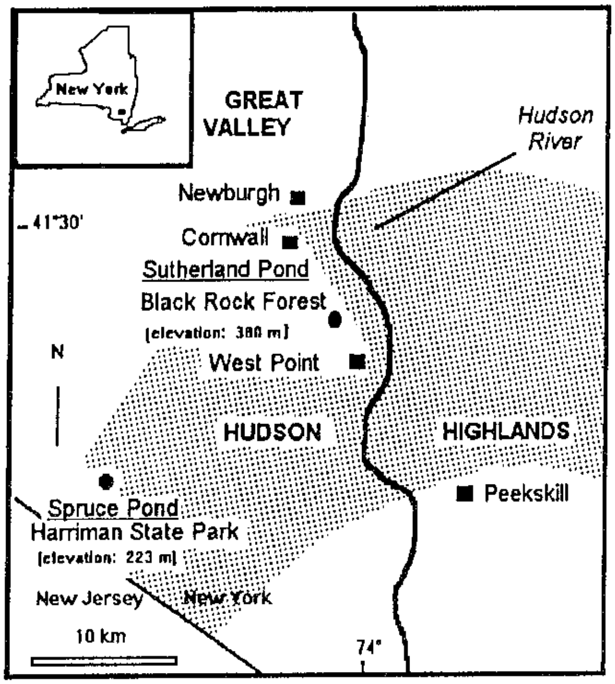

Figure 1 Lower Hudson Valley, southeastern New York, showing the location of Spruce Pond, Hudson Highlands (shaded area), and other places and features mentioned in the text.

Vegetation

The forests of southeastern New York are included in the *Quercus–Castanea* region of the eastern deciduous forest by Braun (1964), whereas Küchler (1964) describes certain areas as ecotonal regions between the *Quercus* forests to the south and the *Tsuga–Pinus strobus*–northern hardwoods forests to the north. Near Spruce Pond, north-facing slopes are dominated by *Quercus rubra, Quercus prinus, Acer saccharum, Betula lenta, Acer rubrum, Fagus grandifolia, Liriodendron tulipifera, Betula lutea,* and *Cornus florida.* South-facing slopes are dominated by abundant *Quercus velutina, Quercus alba,* and *Quercus rubra.* Two-thirds of Spruce Pond's periphery is a low-shrub bog with *Chamaedaphne calyculata, Decodon verticillata, Kalmia angustifolia,* and *Vaccinium corymbosum* dominant (Lynn and Karlin, 1985). The sphagnum mat also supports *Larix laricina* and *Picea mariana.*

Methods

Field

Subsurface characteristics of the Spruce Pond basin were determined with the aid of ground-penetrating radar (Mellett, 1993). Coring was carried out using a 5-cm-diameter square rod piston sampler (Wright *et al.*, 1984) operated from the frozen pond surface in 2.9 m of water. Spruce Pond was cored off-centre to increase the likelihood of recovering plant macrofossils. A sediment core, totalling 10.4 m, was retrieved in metre lengths, wrapped in plastic and foil and stored at 4°C until laboratory study.

Laboratory

Cores were sampled for pollen at 5-cm intervals and processed following Heusser and Stock (1984). Identifications of pollen and spores were based on descriptive keys (Kapp, 1969; McAndrews *et al.*, 1973; Faegri and Iversen, 1989), as well as a pollen and spore reference collection. Species-level determinations within the genus *Betula* were based on macrofossils. Light microscopy was used to identify and count pollen; routine counting was done at 400× magnification and critical identifications at 1000×. At least 300 pollen grains of upland trees, shrubs, and herbs were counted per sample, except where pollen concentrations were too low; slides were subsequently scanned for rare types. Percentages of tree, shrub and upland herb pollen (including Cyperaceae) were based on the sum of those groups. Aquatics were based on the sum of all pollen, cryptograms as a percentage of all pollen and spores. Tablets of *Lycopodium* sp., an exotic marker, of known concentration (Stockmarr, 1971), were added to each sample before processing, so that pollen concentration (grains per cm^3) and influx (grains per cm^2 per year) could be determined (Davis and Deevey, 1964; Davis, 1967; Davis, 1969). The amounts of organic matter in the core were determined by loss-on-ignition (LOI) measurements at 550°C (Bengtsson and Enell, 1986). Pollen percentage and influx diagrams were constructed using Tiliagraph© software (Grimm, 1992). Designation of pollen assemblage zones was by visual inspection for peaks of certain taxa. Nomenclature follows Fernald (1950).

Plant macrofossils were isolated from 50 cm^3 of sediment at 5-cm intervals. Processing included gentle disaggregation of the sediment matrix in 5% potassium hydroxide for at least 24 h at 4°C and washing through 150 μm sieves. All particles >150 μm were inspected and recognisable plant remains hand-picked and identified using a dissection microscope at 40× magnification. Identification of specimens was possible through use of reference collections (Lamont-Doherty Earth Observatory of Columbia University Seed Collection and New York Botanical Garden Herbarium) and literature sources (Montgomery, 1978; Lévesque *et al.*, 1988; Young and Young, 1992).

Small sediment samples (1 cm^3) were air-dried and sent for AMS radiocarbon age determinations at the Center for Accelerator Mass Spectrometry of the Lawrence Livermore National Laboratory. The possibility of contamination of the sediment samples from carbonates is minimal because the surrounding bedrock is granitic. Terrestrial macrofossils could not be used for AMS dating owing to their scarcity in this record. Calculations of sediment accumulation rates (cm yr^{-1}) were based on AMS radiocarbon dates.

Charcoal accumulation rates ($mm^2\ cm^{-2}\ yr^{-1}$) were used to estimate past importance of fire. First, charcoal concentration ($mm^2\ cm^{-3}$) per sample was determined from pollen slides using a grid of squares of known area in the eyepiece of the microscope and simultaneous counting of exotic markers. Charcoal particles ranged from 7 to 150 μm^2, although separation of particles into size classes was not attempted. This method is intermediate between those of Waddington (1969) and R. L. Clark (1982). Second, charcoal concentrations were multiplied by sediment accumulation rates to obtain charcoal accumulation rates (charcoal influx).

Erratum: units for charcoal accumulation rates (in both text and figs) should read: ($mm^2/cm^2/year$)/1000

Results

Pollen and plant macrofossil stratigraphy

Pollen stratigraphy of the Spruce Pond (SPP) core is divided into pollen assemblage zones according to the standard southern New England system of zonation (Leopold, 1956; Deevey, 1958). Diagrams of pollen percentages (Fig. 2), macrofossils (Fig. 3) and pollen influx and loss-on-ignition (LOI) (Fig. 4) are presented. Ages of zone boundaries are based on AMS dating (Table 1) except for the age of the SPP-A1-2-3–SPP-A4 boundary (835 cm), which was interpolated. Sediment lithology is described (Table 2).

Zone SPP–T: *Pinus*–Cyperaceae (>12 410 ± 70 yr BP)

Zone SPP–T features 40% Cyperaceae pollen, 40% *Pinus*, and 3% *Picea*. Additional herbaceous types – Gramineae (8%), Tubuliflorae (25%), *Artemisia* (5%), *Thalictrum* (5%) plus ≤1% Caryophyllacae, Chenopodiineae, Umelliferae, *Sanguisorba*, Polypodiaceae, and *Sphagnum* – are present, as well as apparent shrub types – *Salix* (17%), *Betula* (13%), *Alnus* (17%), and Ericaceae (2%). Shrub percentage values are larger in the later part of the zone. Total pollen influx (grains $cm^{-2}\ yr^{-1}$) and LOI (6%) are low. No macrofossils were found in this core segment. Charcoal analysis was not carried out on these minerogenic sediments.

Zone SPP-A1-2-3: *Pinus–Picea–Abies–Ostrya/Carpinus–Fraxinus–Quercus* (12 410 ± 70 to 11 140 yr BP)

Zone SPP-A1-2-3 commences with expansion of arboreal pollen types, consistently higher total pollen influx values, onset of macrofossil deposition, and an increase in LOI at 850 cm. A combination of boreal (*Picea, Abies*) and temperate (*Quercus, Fraxinus, Ostrya/Carpinus*) tree pollen characterises the zone. *Picea* (9%) peaks at 855 cm and later decreases. The *Picea* pollen percentage peak just precedes the first *Picea* seed and elevated *Picea* influx (530 grains $cm^{-2}\ yr^{-1}$) at 850 cm (12 410 yr BP). *Picea* needles are found later in the zone as well. Percentages and influx of shrub pollen (*Alnus, Betula, Salix*) and herb pollen decrease relative to zone SPP-T. Seeds of aquatic plants (*Potamogeton* and *Najas*) are present. Charcoal influx increases from 10 to 70 $mm^2\ cm^{-2}\ yr^{-1}$.

Zone SPP-A4: *Picea–Abies–Alnus–Betula papyrifera* (11 140 to 10 230 ± 60 yr BP)

Expansion of boreal trees and decline of temperate trees characterise this zone. Pollen percentage and influx values of *Ostrya/Carpinus, Fraxinus*, and *Quercus* decline between 830 and 825 cm. *Alnus* expands initially, followed in succession by *Betula papyrifera*, and by *Picea* and *Abies*. *Picea* and *Abies* decline midway in the zone followed by second maxima of *Alnus* and *Betula papyrifera*. Slight increases in *Ostrya/Carpinus, Fraxinus*, and *Quercus* occur at 810 cm, along with the first *Tsuga canadensis* pollen (1%). Reductions in *Alnus* and *Betula papyrifera* occur at 805 cm. *Betula Papyrifera* is present in the macrofossil record. Seeds of aquatic plants are no longer present. Values of LOI remain relatively stable. There are two peaks of charcoal influx in this zone. One broad charcoal peak occurs near the beginning of the zone at 830 to 825 cm, registering 70 to 90 $mm^2\ cm^{-2}\ yr^{-1}$. The second peak is in the middle of the zone at 815 cm and registers 310 $mm^2\ cm^{-2}\ yr^{-1}$ of charcoal.

Zone SPP-B: *Pinus strobus–Quercus* (10 230 ± 60 to 9750 ± 60 yr BP)

Pollen of *Pinus strobus* rises from 0 to 7% and 0 to 7700 grains $cm^{-2}\ yr^{-1}$ between 810 and 805 cm. *Quercus* pollen increases in abundance (19 to 40%; 3000 to 21 000 grains $cm^{-2}\ yr^{-1}$). *Fraxinus* and *Ostrya/Carpinus* pollen percentage values remain relatively constant but influx values for these taxa, and most of the other pollen types in the record, exhibit peaks at 805 cm. Frequencies of *Picea* and *Abies* reach zero. *Potamogeton* is the only macrofossil taxon present. Values of LOI increase from 14 to 23%. The boundary between zone SPP-B and the overlying zone is defined by an expansion of *Tsuga canadensis* pollen percentage and influx values at 785 cm. Charcoal influx declines from 190 to 60 $mm^2\ cm^{-2}\ yr^{-1}$ and then rises to 170 $mm^2\ cm^{-2}\ yr^{-1}$.

Vegetation of the late-glacial–Holocene transition at Spruce Pond

Prior to 12 410 yr BP (zone SPP-T) open vegetation dominated by herbs and shrubs existed in the vicinity of Spruce

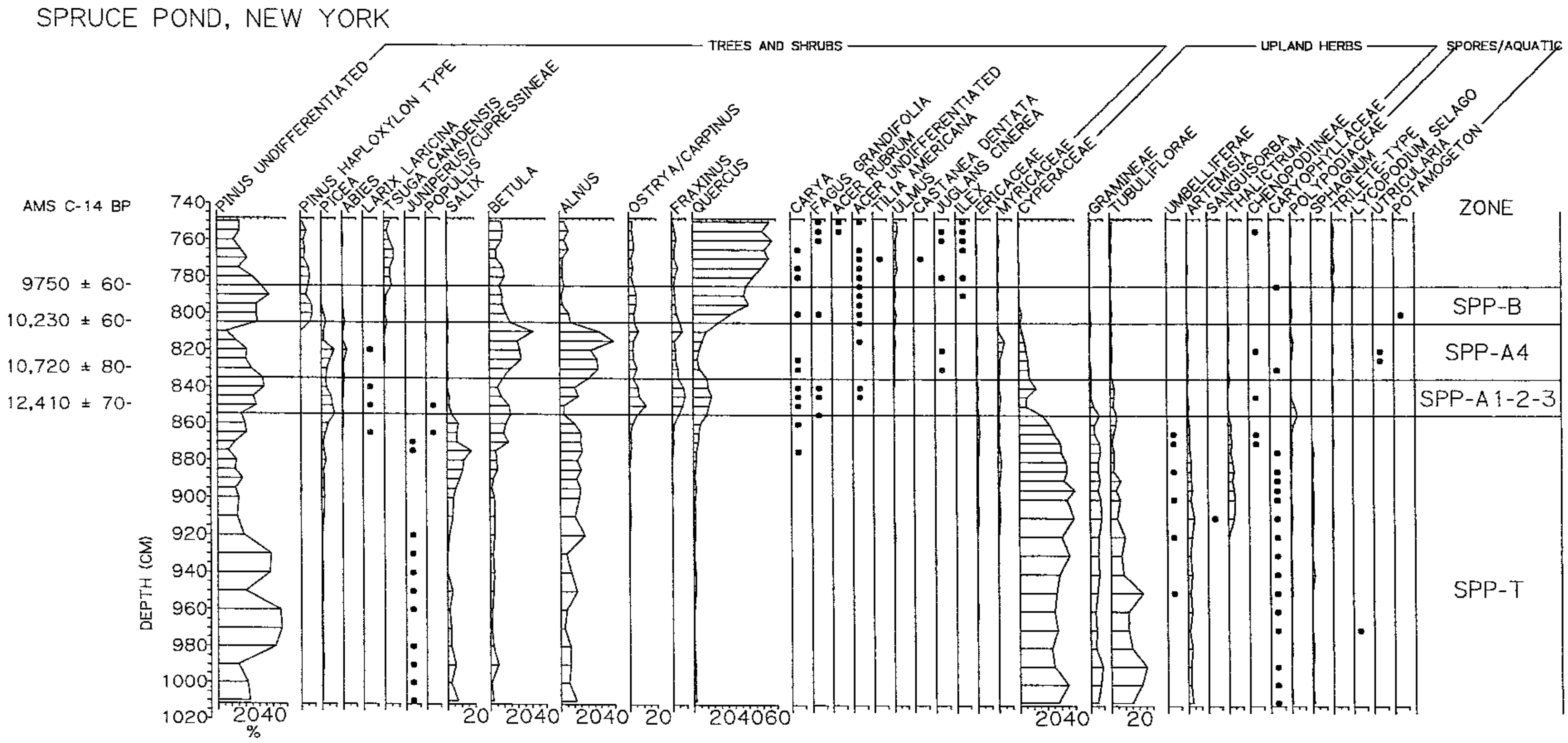

Figure 2 Pollen and spore diagram with AMS radiocarbon chronology for the late-glacial and early Holocene at Spruce Pond, New York. Closed circles indicate values of <1%.

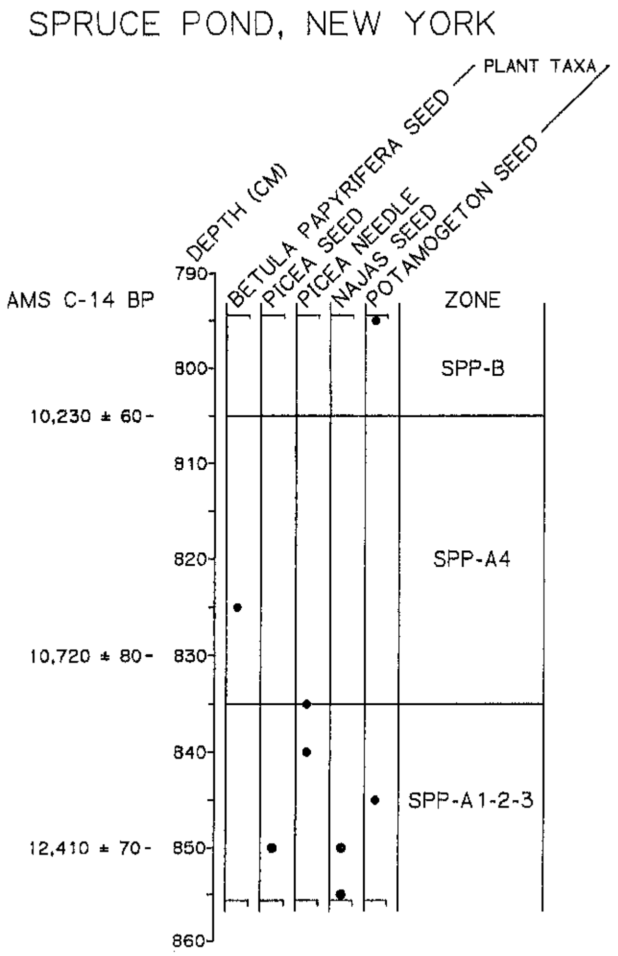

Figure 3 Diagram of plant-macrofossils and AMS radiocarbon chronology for the late-glacial and early Holocene at Spruce Pond, New York. Closed circles represent one macrofossil per 50 cm^3 sediment.

Pond. Trees may have been scattered on the landscape, as in forest tundra. However, the presence of trees cannot be confirmed, nor can the species of *Betula* be determined, owing to the absence of macrofossils. Tree pollen present (*Pinus, Picea,* plus very low percentages of *Quercus, Fraxinus,* and *Ostrya/Carpinus*) may be a result of long-distance transport in a setting of low pollen productivity. As an analogue, pollen of *Pinus* (ca. 3–20%) and *Picea* (ca. 2–26%) is found in surface samples from treeless landscapes, such as alpine-tundra in the White Mountains of New Hampshire and the tundra of eastern and central Canada (Davis and Webb, 1975; Webb and McAndrews, 1976; Spear, 1989; King, 1993).

In pollen surface samples along elevational transects in New Hampshire's White Mountains, percentages of Ericaceae, Gramineae, Cyperaceae, and Caryophyllaceae are highest above treeline (Spear, 1989; Spear *et al.,* 1994), lending support to the interpretation that the herb- and shrub-dominated zone SPP-T represents an open environment. These taxa are also found in the eastern Canadian shrub tundra and forest tundra (King, 1993). Spear (1989) notes that *Arenaria groenlandica* (Caryophyllaceae) is an important pioneer species on disturbed soils in several alpine communities in the White Mountains. Also noted is that *Artemisia,* Gramineae, Cyperaceae, and Tubuliflorae colonise unstable soils undergoing solifluction.

Denny (1938), studying the glacial geology of the Black Rock Forest in the Hudson Highlands, 22.5 km to the northeast of Spruce Pond, recognised evidence for intense frost action and solifluction, which led him to conclude that a periglacial climate prevailed for some time after local deglaciation. Denny's climatic inference might explain the presence of an open landscape at Spruce Pond and at Sutherland Pond (Black Rock Forest), New York (Maenza-Gmelch, 1996b). Whether tundra or forest tundra existed in the Hudson Highlands immediately following deglaciation remains unclear.

The presence of spores of *Selaginella selaginoides* and/or *Lycopodium selago* in T-zone sediments might indicate that climate in the Hudson Highlands prior to approximately 12 500 yr BP was colder than at present. Spores of *S. selaginoides,* largely a boreal species that extends south to mixed forests (Fernald, 1950), were not found at Spruce Pond, possibly indicating less harsh conditions than at Sutherland Pond where the spores were found in sediments >12 600 yr BP (Maenza-Gmelch, 1996b). Sutherland Pond is at a higher elevation (380 m) and close to the Hudson River Valley (2.4 km), whereas Spruce Pond is in a more protected location, 24 km west of the Hudson River, at only 223 m elevation. (Their relative elevations are assumed to have remained constant.) Spores of *S. selaginoides* have also been found in late-glacial sediments of Allenberg Bog, western New York (Miller, 1973). *Lycopodium selago* spores were found in T-zone sediments at both Spruce and Sutherland Ponds. *Lycopodium selago,* largely boreal in distribution, extends further southward into sub-boreal regions than does *S. selaginoides* (Fernald, 1950). *Lycopodium selago* spores have been found in late-glacial sediment from Lake-of-the-Clouds (1542 m elevation) on Mount Washington (Davis, 1985). The current distribution of *L. selago* in New York State may not extend further south than the Catskill Mountains, which are approximately 60 km north of the Hudson Highlands (New York Flora Association, 1990.)

Cyperaceae, Tubuliflorae, and *Artemisia* dominated early at Spruce Pond but became less important as small trees and/or shrubs *(Alnus, Betula, Salix,* Ericaceae) expanded in response to climatic warming. Unfortunately, the length of time between deglaciation and the establishment of forest at about 12 410 yr BP is not known owing to the absence of datable organic material in the basal clays.

Dramatic environmental change began at Spruce Pond at 12 410 yr BP (zone SPP-A1-2-3), as indicated by colonisation of the landscape by boreal (*Picea, Abies*) and temperate (*Quercus, Fraxinus, Ostrya/Carpinus*) trees, overall increase in pollen influx and input of organic matter to the pond (Fig. 4), appearance of macrofossils of aquatics (for example, *Potamogeton* and *Najas*) possibly indicating an increase of pond productivity, and a rise in charcoal influx suggesting that fire was a component of woodland development.

Picea may have been the first tree to arrive, at 12 410 yr BP, evidenced by a seed in the macrofossil record. This age is comparable to estimated arrival times for *Picea* in northern Pennsylvania (Watts, 1979), northern New Jersey (Peteet *et al.,* 1990, 1993), southern Connecticut (Davis, 1969; Peteet *et al.,* 1993), and southeastern New York (Maenza-Gmelch, 1996b).

No *Quercus* macrofossils were found, however, the presence of *Quercus,* as well as other temperate trees, is inferred. This inference is based on comparison of modern *Quercus* pollen percentage and concentration (grains cm^{-3}) values in relation to the modern distribution of *Quercus* trees. Today, about 6–10% *Quercus* pollen can be found in the conifer/hardwoods forest region and 5% *Quercus* pollen can be found at the northern limit of *Quercus* trees in eastern

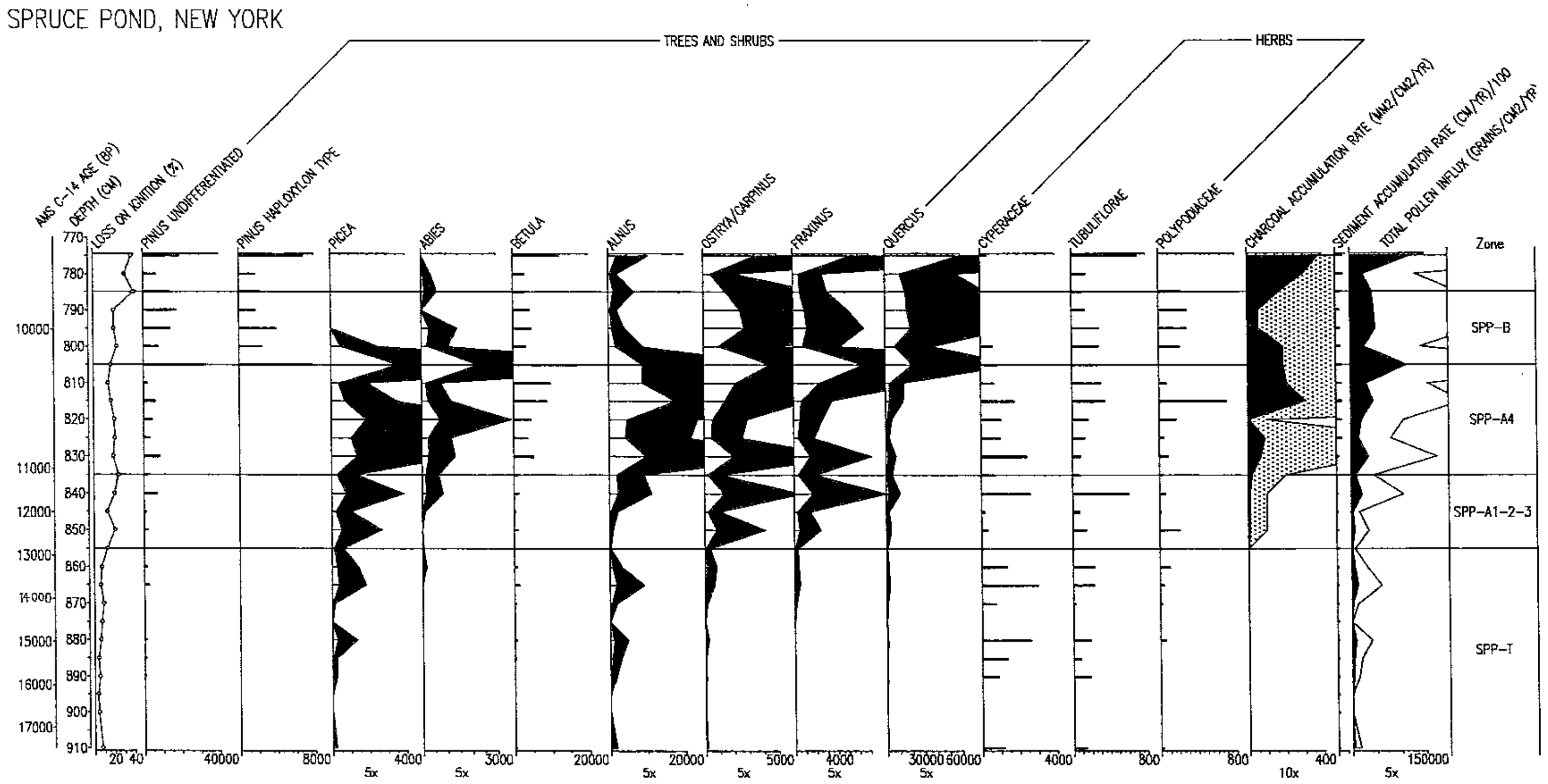

Figure 4 Diagram of pollen influx (grains cm^{-2} yr^{-1}) for selected taxa, AMS radiocarbon chronology, loss-on-ignition, charcoal accumulation rates (mm^2 cm^{-2} yr^{-1}), sediment accumulation rates (cm yr^{-1}), and total pollen influx (grains cm^{-2} yr^{-1}) for the late-glacial and early Holocene at Spruce Pond, New York.

Table 1 AMS Carbon-14 ages for the late-glacial–Holocene transition, Spruce Pond, New York. All samples were 1 cm^3 of sediment

Centre for Accelerator Mass Spectrometry reference number	Sample depth (cm)	Vegetation event dated	Carbon weight[a] (mg)	AMS ^{14}C age (yr BP)
15879	785	*Tsuga* arrival	5.1	9750 ± 60
15880	805	*Pinus strobus* arrival	5.1	10230 ± 60
11444	830	–	2.3	10720 ± 80
13243	850	*Picea* arrival	11.9	12410 ± 70

[a]After sample pre-treatment and graphitisation at the Centre for Accelerator Mass Spectrometry

Table 2 Lithology of sediments in Spruce Pond core, New York

Core segment (cm)	Sediment description
750–855	Dark reddish grey (2.5 YR 3/1)[a] Clayey gyttja
855–910	Reddish grey (2.5 YR 6/1)[a] Clay

[a]Munsell Soil Color Charts (1992).

and central North America (Davis and Webb, 1975; Webb and McAndrews, 1976). *Quercus* pollen percentages at Spruce Pond between 12410 and 11140 yr BP ranged between 10 and 14%. In addition, *Quercus* pollen concentrations at Spruce Pond for the same period are considerably higher than modern concentrations in samples from the conifer/hardwoods and deciduous forests (Davis and Webb, 1975).

Beginning at 12410 yr BP, a rise in the rate of organic deposition and the expansion of woodland are considered indicative of a warming trend. Increased organic deposition at about this time is also a feature at Alpine Swamp, New Jersey (12800 yr BP), Allamuchy Pond, New Jersey (12400 yr BP), Linsley Pond, Connecticut (12400 yr BP) (Peteet *et al.*, 1990, 1993), and Sutherland Pond, New York (12600 yr BP) (Maenza-Gmelch, 1996b). Peteet *et al.* (1993) consider this an indication of major regional warming in the Northeast correlative with the Bølling/Allerød warming of Europe and Greenland. In northwest and southwest Europe, the Swiss Plateau, southern Sweden and Denmark, replacement of heliophilous herbaceous vegetation by woodland or shrubs, featuring *Betula* and/or *Juniperus*, occurred at approximately 12500 yr BP (Bohncke *et al.*, 1988; Ammann *et al.*, 1994; de Beaulieu *et al.*, 1994; Berglund *et al.*, 1994; Walker *et al.*, 1994).

The transition from zone SPP-A1-2-3 to SPP-A4, occurring at approximately 11140 yr BP, is marked by a reversal in temperate forest development. Boreal tree species displaced temperate species for about 900 yr between 11140 and 10230 yr BP. This event falls within the European YD chronozone (approximately 11000 to 10000 yr BP) (Mangerud *et al.*, 1974) and is interpreted to represent a climatic cooling. Earlier pollen analysis in the Hudson Highlands (Nicholas, 1968) also indicates a *Picea* peak in the A4 zone, suggesting a cooling.

At Spruce Pond during this cooling trend, it appears that populations of temperate *Quercus, Fraxinus* and *Ostrya/Carpinus* were reduced after about 11140 yr BP. Light demanding *Alnus*, then *Betula papyrifera* (and possibly other species of *Betula*) filled in the gaps. *Picea* and *Abies* expanded next but afterward declined midway in the zone, succeeded by a second maximum of *Alnus* and *Betula papyrifera*. Recovery of temperate tree species, principally *Quercus*, at 10230 yr BP resulted in the reduction of *Alnus* and *Betula papyrifera*, most likely by shading. All arboreal pollen types show influx peaks at 10230 yr BP. These pollen influx peaks might be an artefact of changes in sediment focusing.

A similar chronology and sequence of vegetation events for this cooling in the Northeast were presented initially by Peteet *et al.* (1990, 1993) from data at sites in northern New Jersey and southern Connecticut. During the YD in Atlantic Canada (approximately 10800 to 10000 yr BP) boreal forest changed to shrub tundra, and herb tundra replaced shrub tundra in other areas (Mayle *et al.*, 1993a; Mayle and Cwynar, 1995).

An alternative explanation of the zone SPP-A4 pollen sequence is that local fires opened areas for expansion of *Alnus* and *Betula* with *Picea* and *Abies* following in succession. In this zone, two charcoal influx peaks are associated with such pollen influx sequences after each peak. Sedimentary records from the *Picea–Betula* coastal forests of Maine reveal this pattern of fire and succession, each cycle lasting approximately 80 to 100 yr (Patterson and Backman, 1988). The weakness of this hypothesis lies in the possibility that the source areas of charcoal and pollen are not comparable. This pattern of fire during the YD is not evident at Sutherland Pond (Maenza-Gmelch, 1996b). Differences in the charcoal profiles at each site may represent local fire events as opposed to regional fires. Small sedimentary basins (<5 ha), such as Sutherland and Spruce Ponds, have important inputs of pollen from the surrounding few hundred metres of forest in addition to the regional input of pollen (Jacobson and Bradshaw, 1981; Bradshaw and Webb, 1985; Prentice, 1985, 1988; Jackson, 1990; Sugita, 1994). This may be the case for charcoal input as well (Patterson *et al.*, 1987). It is more likely that the SPP-A4 *Alnus* peak is a response to a regional forcing because peak *Alnus* is a common signal for the YD throughout northeastern North America (Mayle *et al.*, 1993b) with *Alnus rugosa* type being important in New England.

Holocene warming in the Hudson Highlands beginning at approximately 10200 yr BP is in agreement with the synchronous warming occurring in the North Atlantic region at around 10000 yr BP (Lowe *et al.*, 1994). Warming at Spruce Pond is registered by the arrival of *Pinus strobus* at 10230 yr BP and expansion of *Quercus, Fraxinus,* and *Ostrya/Carpinus*. Pond productivity appears also to have increased, as suggested by a rise in organic matter content and presence of *Potamogeton*. Early Holocene fire activity was relatively high but decreased for approximately 100 yr prior to the establishment of *Tsuga canadensis* in the forest at 9750 yr BP (see Maenza-Gmelch (1996a) for full discussion of Holocene vegetation, climate, and fire in the Hudson Highlands). Although no *Pinus strobus* or *Tsuga canadensis* macrofossils were found at Spruce Pond, simultaneous with the earliest expansion of pollen of these species, their local presence is implied by data from Sutherland Pond (Maenza-Gmelch, 1996b), which show comparable amounts of pollen and, in addition, macrofossils.

Pinus strobus arrived at Sutherland Pond at 10 120 yr BP and *Tsuga canadensis* at 9540 yr BP. As Sutherland Pond is 22.5 km northeast of Spruce Pond, preliminary estimates of migration rates of these taxa in the Hudson Highlands can be calculated. (It is assumed that Spruce Pond was deglaciated before Sutherland Pond based on their geographical positions.) It appears that *Pinus strobus* may have migrated at the rate of 0.2 km yr^{-1} whereas *Tusga canadensis* migrated more slowly at the rate of 0.1 km yr^{-1}. For comparison, the estimated rate of migration for *Tsuga canadensis* through the Northeast is 0.2–0.3 km/yr (Davis, 1976).

Arrival times for *Pinus strobus, Tsuga canadensis* and *Picea* at Spruce and Sutherland Ponds are comparable to times recorded in the glaciated mid-Atlantic and southern New England regions of the Northeast, as determined by recent AMS-dated studies and selected previous studies (Davis, 1969, 1983; Spear and Miller, 1976; Watts, 1979; Jackson, 1989; Peteet *et al.*, 1990, 1993; Spear *et al.*, 1994). These data help refine the initial migration framework provided by Davis (1976, 1981).

At Spruce Pond a large LOI value (40%) is associated with expansion of *Tsuga canadensis.* Similarly large LOI values occur at Sutherland Pond (Maenza-Gmelch, 1996a) and Alpine Swamp, New Jersey (Peteet *et al.*, 1990). The increased LOI could possibly be indicative of well-developed upland soil, which is needed for establishment of *Tsuga canadensis* (Burnes and Honkala, 1990), as well as enhanced eutrophic conditions in the pond.

Conclusions

1. An open herb- and shrub-dominated vegetation with possible scattered trees existed prior to 12 410 yr BP in the vicinity of Spruce Pond, southeastern New York.
2. A mixed deciduous–coniferous forest developed between 12 410 and 11 140 yr BP, featuring *Picea, Abies, Quercus, Fraxinus,* and *Ostrya/Carpinus,* with *Picea* arriving at 12 410 yr BP. It appears that pond productivity also increased.
3. A reversal in temperate forest development occurred between approximately 11 140 and 10 230 yr BP, as *Quercus, Fraxinus,* and *Ostrya/Carpinus* declined and *Picea, Abies, Betula papyrifera,* and *Alnus* expanded. This event within the time frame of the Younger Dryas chronozone is believed to represent a climatic cooling.
4. Temperate forest development resumed at 10 230 yr BP, while climate warmed as indicated by the arrival of *Pinus strobus* and expansion of *Quercus.*
5. Fire activity appears to have increased as woodland developed after 12 410 yr BP. Two charcoal influx peaks occur during Younger Dryas time. Early Holocene fire activity was relatively high but decreased for approximately 100 yr prior to the establishment of *Tusga canadensis* in the forest at 9750 yr BP.

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