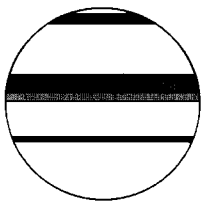
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Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, USA

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Abstract: Holocene vegetation, climate, and fire history of the Hudson Highlands, lower Hudson Valley, southeastern New York, are inferred from AMS radiocarbon-dated pollen, plant-macrofossil and charcoal records from Sutherland (41°23′29″N, 74°02′16″W) and Spruce Ponds (41°14′22″N, 74°12′15″W). Expanding *Quercus*-dominated forests were invaded by *Pinus strobus* at 10 175 radiocarbon years before present (BP), followed by *Tsuga canadensis* at 9645, *Fagus grandifolia* at 8100, *Carya* at 6200, and *Castanea dentata* at 3600 BP; ages are averaged over two sites. Large *Quercus* pollen percentage and influx values are associated with continuous charcoal influx throughout the record, suggesting that fire may have played an important role in the development and maintenance of *Quercus* in the forest. At Sutherland Pond, a temporary decrease in fire at approximately 9500 BP apparently was a factor enabling expansion of *Tsuga canadensis* populations. Onset of Euroamerican agricultural practices in the region (approximately AD 1700) is well documented by rises in pollen of *Ambrosia*, Gramineae and Tubuliflorae and presence of *Rumex* and *Plantago*. Domestic/industrial use of *Quercus*, *Pinus* and *Tsuga canadensis* is also recorded by decreased percentages of these trees. Increased charcoal influx during Euroamerican settlement, particularly at Spruce Pond, may be explained by fire in connection with land clearance, wood-related industries (charcoal, iron and brick manufacturing), and operation of railroads (track fires).

Key words: Holocene, pollen, plant macrofossils, vegetation history, climatic history, fire, AMS radiocarbon dating, New York.

Introduction

Palaeoecological and chronological details of Holocene events in the Hudson Highlands in the lower Hudson Valley of southeastern New York are documented through pollen, plant-macrofossil and charcoal analyses and AMS radiocarbon control of two complete sediment cores from Sutherland and Spruce Ponds (Figure 1, Table 1). I have addressed the following questions. Has fire played a role in the development and maintenance of *Quercus* forest in the Hudson Highlands? What was the invasion sequence of major tree taxa into the Hudson Highlands? Did fire influence any of these invasions? What impact did settlement by Euroamericans have on the vegetation?

Background

The Holocene epoch, characterized by temperatures higher than in the Pleistocene, was the stage for dramatic vegetational change. Following deglaciation, tree populations migrated northward from glacial refuges south of the ice margin, with subsequent development of forests and changes in their disturbance regimes. Studies of plant movement into the deglaciated northeastern USA (the Northeast), based on fossil pollen and in certain instances on plant macrofossils (Bernabo and Webb, 1977; Davis, 1976; 1981a), have revealed differential migration patterns. Trees migrated at different rates from different source areas, forming transient arboreal assemblages that were different from those of today.

The major determinant of increased temperature during the Holocene has most likely been orbitally induced insolation variations (Berger, 1978). For example, at 9000 BP the earth received about 7% more summer solar radiation than today (Kutzbach and Webb, 1991). Moisture balance in the northeast, estimated from pollen response-surfaces, featured low annual precipitation and soil-moisture values at 9000 BP (R.S. Webb *et al.*, 1993). Peak dryness at 9000 BP in the northeast is also evident from low lake levels, as a result of conditions drier than today by 10% or more (T. Webb *et al.*, 1993).

Superimposed on the influence of climate on vegetation are the effects of other factors such as fire (Clark and Robinson, 1993), plant pathogens (Anderson, 1974; Davis, 1981b), and human disturbance (Russell *et al.*, 1993). Fires may have occurred regularly in the *Quercus* forests of eastern North America for thousands of years, promoting *Quercus* dominance (Buell, 1957; Abrams,

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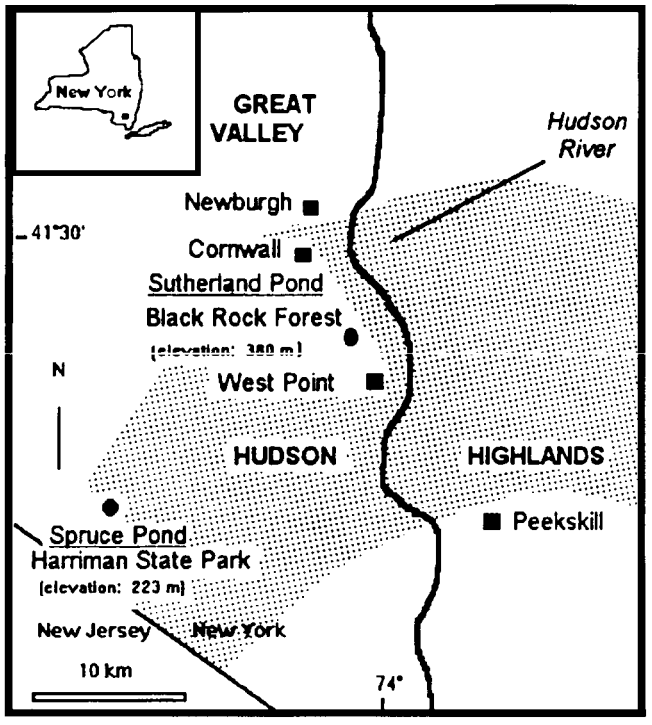


Figure 1 Lower Hudson Valley, southeastern New York, showing the location of Sutherland Pond, Spruce Pond, Hudson Highlands (shaded area), and other places and features mentioned in the text.

Table 1 Location of Hudson Highlands study sites and site information

Core site:	Sutherland Pond	Spruce Pond*
Location:	Black Rock Forest Orange County, New York	Harriman State Park Orange County, New York
Longitude:	74°02′16″W	74°12′15″W
Latitude:	41°23′29″N	41°14′22″N
Altitude:	380 m	223 m
Surface area:	4.05 ha	2.6 ha
Maximum water depth:	2.57 m	5.0 m

*Spruce Pond is 22.5 km southwest of Sutherland Pond

1992; Clark and Robinson, 1993). However, more extensive fossil charcoal data are needed to test this hypothesis (Clark and Robinson, 1993). In some cases fire may have facilitated the establishment of various arboreal taxa as deciduous forest developed after deglaciation. Green (1982) suggests that fire in forests of southwest Nova Scotia promoted the proliferation of invading tree taxa that had previously been excluded by competition.

Hudson Highlands

Physical features and deglaciation

The Hudson Highlands, incised by the Hudson River between Newburgh and Peekskill, rise >180 m above the adjacent lowlands and reach a maximum elevation of 400 m (Figure 1). The highlands, consisting of Precambrian gneiss and granite, are part of the Reading Prong of the New England Physiographic Province (Fenneman, 1938). Topography is characterized by steep slopes, ravines, and rolling-rocky upland, with low hills and ridges separated by lakes and ponds.

The Highlands were glaciated by the Laurentide ice sheet. Wisconsinan till was subsequently altered by periglacial freeze/thaw cycles and solifluction (Denny, 1938). Deglaciation of the Great Valley west of the Hudson Highlands started at 17 500 BP (Connally *et al.*, 1989), but this estimate is based on assumed sedimentation rates. Muller and Calkin (1993) point out that the chronostratigraphic framework for Pleistocene glacial events in New York state is weakly supported.

Climate and vegetation

Southeastern New York state is under the influence of cold, dry air from the northern continental interior, warm, humid air from the Gulf of Mexico and adjacent subtropical waters, and maritime air originating over the North Atlantic ocean (Ruffner, 1980). Climatic data representative of the Hudson Highlands was recorded at West Point, New York (Figure 1) for AD 1918–1948: mean January temperature −2.1°C, mean July temperature 23.7°C, and mean annual precipitation 1060 mm, uniformly distributed throughout the year (Ross, 1958).

Forests of the Hudson Highlands are part of the *Quercus-Castanea* region of the eastern deciduous forest (Braun, 1964). Certain areas are ecotonal between Appalachian *Quercus* forest to the south and *Tsuga-Pinus strobus*-northern hardwoods forest to the north (Küchler, 1964). Topographic variation and disturbance history have generated a mosaic of plant communities. Hilltops above 370 m in elevation support *Pinus rigida* and *Quercus ilicifolia*, while southwest-facing slopes feature *Quercus alba* and *Carya glabra*. Steep, rocky slopes between 335 and 370 m are characterized by *Quercus prinus* and, less frequently, by *Pinus strobus*; *Quercus rubra* dominates on slopes of lesser gradient. Ravines and north-facing slopes below 335 m include *Quercus rubra, Q. prinus, Acer saccharum, Betula lenta, Acer rubrum, Tsuga canadensis, Liriodendron tulipifera, Fraxinus americana, Tilia americana, Betula lutea, Fagus grandifolia* and *Cornus florida*. South-facing slopes are dominated by *Quercus velutina, Q. alba* and *Q. rubra*. On disturbed sites, secondary communities of sprout origin include *Quercus* spp., *Castanea dentata, Betula populifolia* and *Populus grandidentata*. Some wet areas, for example two-thirds of the periphery of Spruce Pond, support low-shrub bog vegetation featuring *Chamaedaphne calyculata, Decodon verticillata, Kalmia angustifolia* and *Vaccinium corymbosum* (Lynn and Karlin, 1985). The sphagnum mat also supports *Larix laricina* and *Picea mariana*.

Methods

Field

Sediment thickness was determined with ground-penetrating radar (Mellett, 1993). Cores were taken with a square-rod piston sampler of 5-cm diameter (Wright *et al.*, 1984) operated from a floating platform in water 2.57 m deep at Sutherland Pond in August 1991 and from the frozen pond surface (February 1993) in 2.9 m of water at Spruce Pond. Sediment cores, 10.6 m total at Sutherland Pond and 10.4 m total at Spruce Pond, were retrieved in meter lengths, wrapped in plastic and aluminum foil, and stored at 4°C until laboratory study.

Laboratory

Cores were sampled for study at 5-cm intervals (except for the top 2 m at Sutherland Pond, from which samples were taken at 10-cm intervals) and processed following Heusser and Stock (1984). Identification of pollen and spores are based on descriptive keys (Kapp, 1969; McAndrews *et al.*, 1973; Faegri and Iversen, 1989), as well as a pollen and spore reference collection. Routine counting was done at 400× magnification and critical identifications were made at 1000×. At least 300 upland pollen grains were counted per sample; slides were subsequently scanned for rare types. Percentages of tree, shrub and upland herb pollen (including Cyperaceae) are based on the sum of those groups; aquatics are based on the sum of all pollen, and cryptogams on

the sum of all pollen and spores. An exotic marker (*Lycopodium* sp.) of known concentration (Stockmarr, 1971) was 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).

Plant macrofossils from 50 cm^3 of sediment at 5-cm intervals were freed from the sediment matrix by gentle disaggregation in 5% potassium hydroxide at 4°C for at least 24 hrs and washed through 150 μm sieves. Plant remains were identified with a dissection microscope at 40× magnification on the basis of modern 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).

Some levels were selected for AMS radiocarbon age determinations where macrofossils and/or large increases in pollen indicated a taxon's earliest expansion at the site. Other levels were chosen at evenly spaced intervals along each record. Conifer needles, seeds, or small sediment samples (1 cm^3) were air-dried and sent to the Center for Accelerator Mass Spectrometry of the Lawrence Livermore National Laboratory. Calculations of sediment accumulation rates (cm/yr) in each core were based on AMS radiocarbon dates (Table 2). Core tops were estimated to be 0 BP since there was no evidence of surface disturbance.

Charcoal accumulation rates ($mm^2/cm^2/yr$) 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).

Organic-matter content of sediment was measured by loss-on-ignition (LOI) at 550°C (Bengtsson and Enell, 1986). Pollen percentage and influx diagrams were constructed with Tilia-graph© software (Grimm, 1992). Pollen assemblage zones were designated by eye and approximate the zonation terminology used by Deevey (1939). Plant nomenclature follows Fernald (1950).

Results

Pollen percentages, pollen influx, LOI, and charcoal influx are shown in Figures 2, 3, 5, 6. Macrofossil abundance is shown in Figures 4 and 7. Sediment lithology is described in Table 3. Ages marked with an asterisk (*) in the text are estimates based on linear interpolation.

Sutherland Pond (SUP)

Zone SUP-B: Quercus-Pinus *(10,120 to 9540 BP)*

Zone SUP-B features high percentages and influx of *Pinus strobus* and *Pinus* undifferentiated pollen together with as much as 20% *Quercus*. *Betula, Ostrya/Carpinus* and *Fraxinus* are high also. *Pinus strobus* needles appear in the record for the first time at 10 120 BP. *Abies* and *Picea* macrofossils are last encountered in this zone; the last *Betula papyrifera* seeds occur at 9600* BP, followed by seeds of *Betula populifolia* at 9575* BP. Charcoal influx progressively increases from 40 to 1230 $mm^2\ cm^{-2}\ yr^{-1}$.

Zone SUP-C1: Quercus-Tsuga *(9540 to 6180* BP)*

Zone C1 is characterized by rapid increases in *Tsuga canadensis* pollen percentages and influx at 9540 BP, after which percentages decrease and fluctuate around 3–5% for the duration of the zone. *Quercus* and charcoal influx values decrease temporarily during the *Tsuga* peak at 9540 BP. *Quercus* percentages resume expansion, from 40 to 70%, then level off; influx follows suit. *Pinus* pollen notably declines. *Alnus, Salix* and *Ulmus* pollen percentages expand slightly early in the zone concurrent with

Table 2 AMS C14 ages for the Holocene, Hudson Highlands, New York

CAMS No.	Sample depth (cm)	Sample type	Carbon weight (μg)	AMS C14 age (BP)
Sutherland Pond				
9499	200–205	*Betula lenta* seed and unidentified stem fragments	0.9	2020 ± 40
9500	295–300	leaf and twig fragments	1.2	2640 ± 50
11439	400	1 cm^3 sediment	–	3980 ± 60
11440	500	1 cm^3 sediment	–	4650 ± 50
9501	595–600	leaf and twig fragments	0.45	5860 ± 50
8391	765–770	*Tsuga* needles (10)	0.009	6630 ± 220 (reject)
11441	770	1 cm^3 sediment	–	9540 ± 60
9502	785–790	*Pinus strobus* needle fragments (6)	0.2	9630 ± 70
11442	795	1 cm^3 sediment	–	10120 ± 60
Spruce Pond				
16425	175	1 cm^3 sediment	–	2100 ± 70
13241	290	1 cm^3 sediment	–	3540 ± 70
16426	380	1 cm^3 sediment	–	5270 ± 40
16427	480	1 cm^3 sediment	–	6230 ± 60
16428	640	1 cm^3 sediment	–	7860 ± 60
15879	785	1 cm^3 sediment	–	9750 ± 60
15880	805	1 cm^3 sediment	–	10230 ± 60

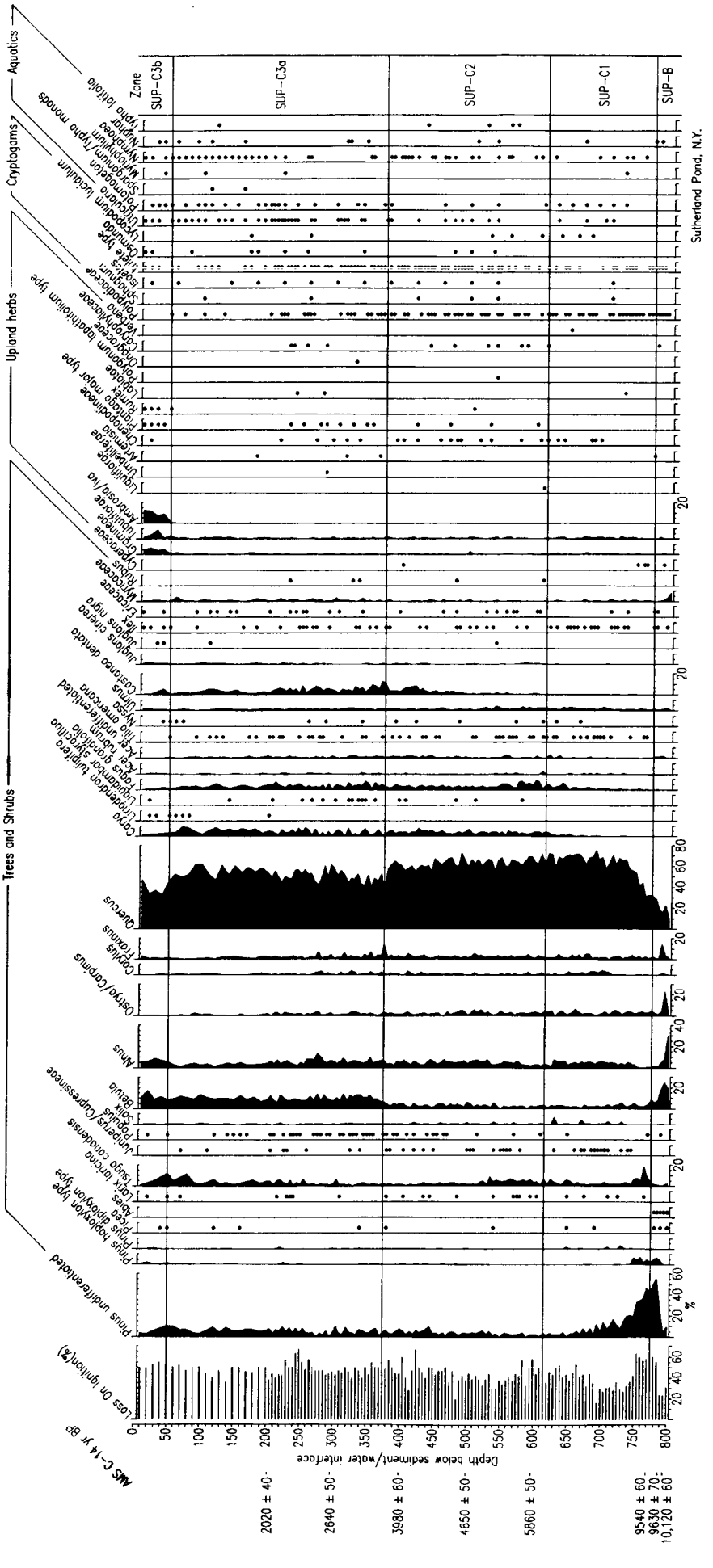


Figure 2 Pollen and spore diagram with loss-on-ignition data and AMS radiocarbon chronology for the Holocene at Sutherland Pond, New York. Closed circles indicate values of <1%.

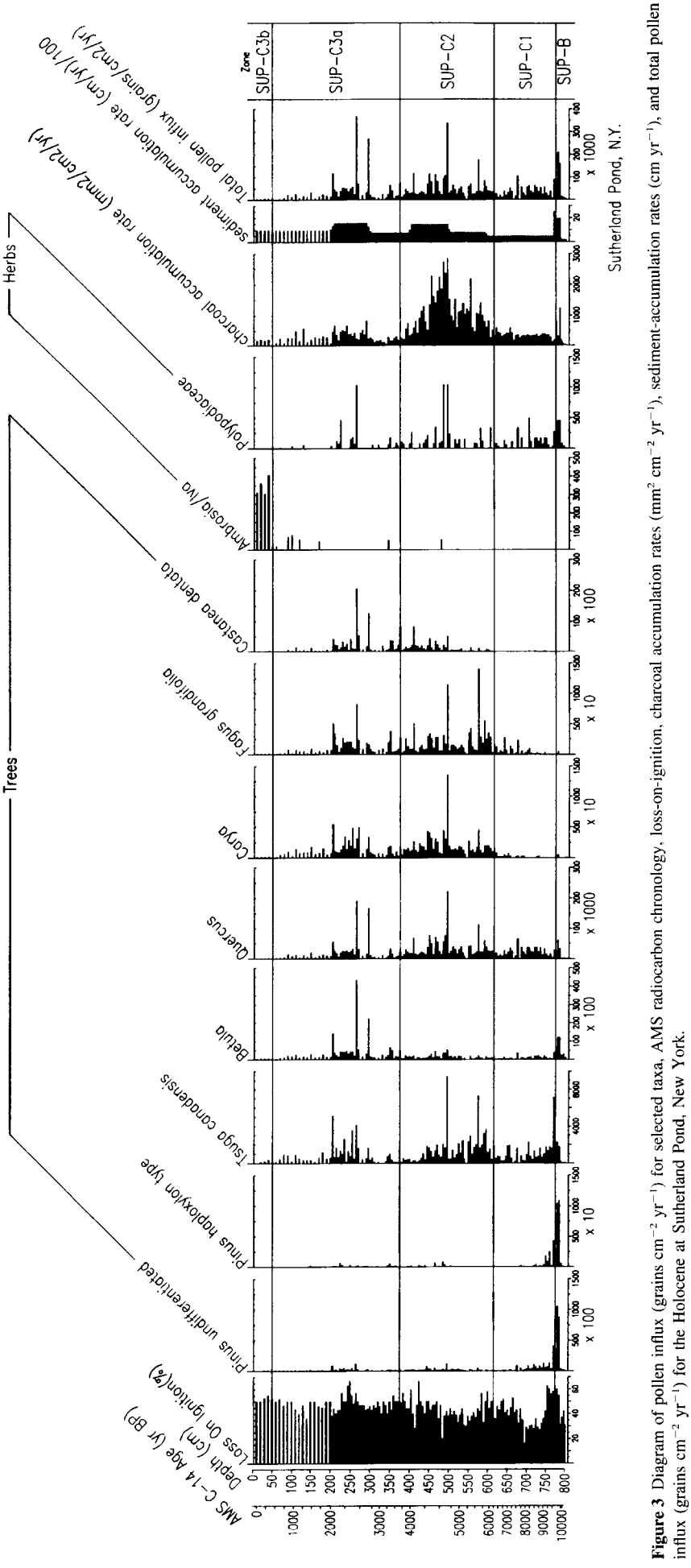


Figure 3 Diagram of pollen influx (grains cm^{-2} yr^{-1}) for selected taxa, AMS radiocarbon chronology, loss-on-ignition, charcoal accumulation rates (mm^2 cm^{-2} yr^{-1}), sediment-accumulation rates (cm yr^{-1}), and total pollen influx (grains cm^{-2} yr^{-1}) for the Holocene at Sutherland Pond, New York.

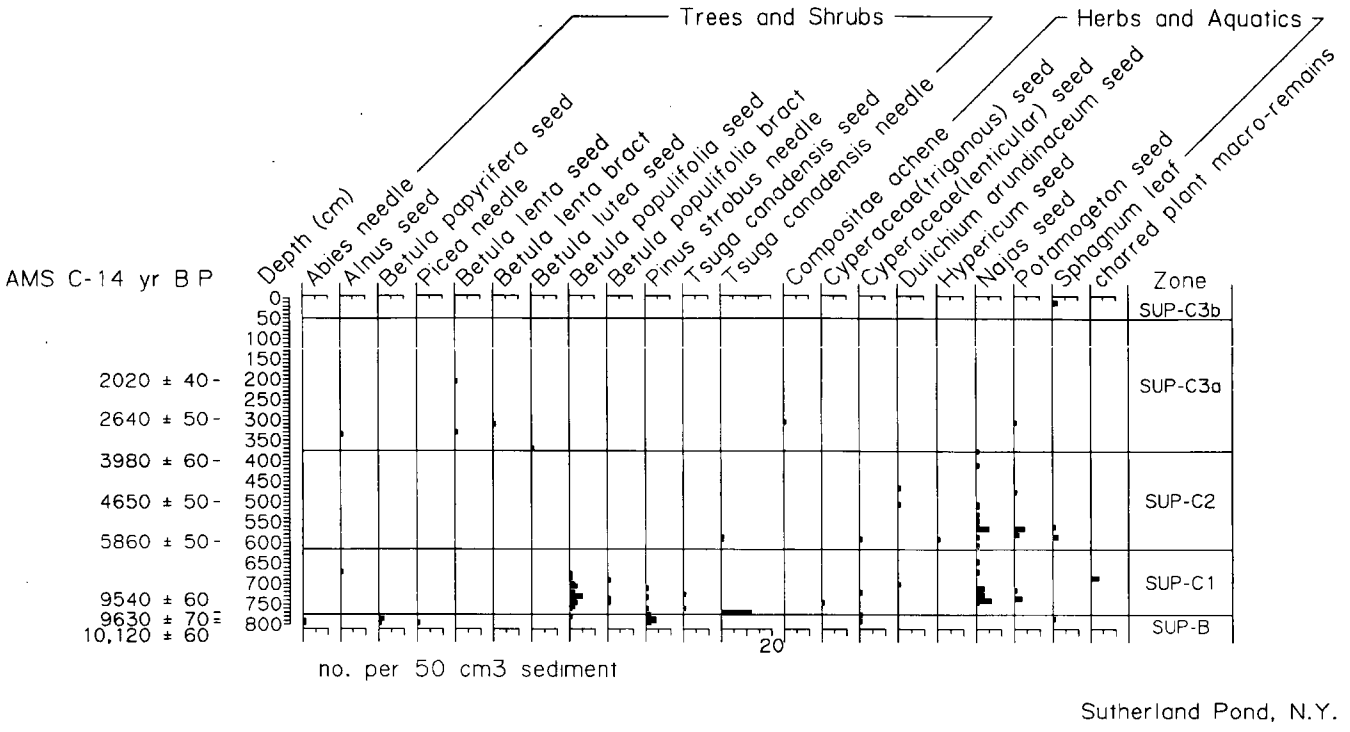


Figure 4 Diagram of plant macrofossils (number per 50 cm^3 sediment) and AMS radiocarbon chronology for the Holocene at Sutherland Pond, New York.

Table 3 Lithology of Holocene sediments from Hudson Highlands, New York

Site	Depth (cm)	Sediment description
Sutherland Pond	0–787	reddish black (2.5 YR/1)* gyttja
	787–795	dark reddish grey (2.5 YR 3/1) clayey gyttja
Spruce Pond	0–655	very dark brown (10 YR 2/2) gyttja
	655–805	dark reddish grey (2.5 YR 3/1) clayey gyttja

*Munsell Soil Color Charts (1992)

development of an aquatic pollen assemblage including *Utricularia, Potamogeton, Myriophyllum, Nymphaea* and *Nuphar. Fagus grandifolia* pollen percentage and influx values increase at 8150* BP. Charcoal influx increases after 9500 BP and remains relatively constant. Large LOI values (60%) are recorded at the beginning of the zone, decline midway at about 8500 BP and rise again. Macrofossils include *Alnus, Betula populifolia, Pinus strobus, Tsuga canadensis*, Cyperaceae, *Dulichium, Najas* and *Potamogeton.*

Zone SUP-C2: Quercus-Carya *(6180* to 3650* BP)*

Elevated percentage and influx values of *Carya* (5%) distinguish zone SUP-C2, beginning at 6180* BP. *Quercus* percentages are stable, but influx is slightly larger than that in SUP-C1. Charcoal influx is considerably higher over the duration of the zone. *Castanea dentata* pollen influx values increase at 4610* BP. *Tsuga* pollen influx values are reduced 50% at 4180* BP. LOI is stable. The aquatic pollen assemblage from zone SUP-C1 persists with the addition of *Typha latifolia.* Macrofossils include *Tsuga*, Cyperaceae, *Najas, Potamogeton, Sphagnum, Hypericum* and *Dulichium.*

Zone SUP-C3a: Quercus-Castanea *(3650* BP to AD 1700)*

Peak pollen percentage values of *Castanea dentata* define the beginning of the zone at 3650* BP. *Quercus* percentages decrease slightly compared to the previous zone. Charcoal influx is much less than that in SUP-C2 and further decreases at the top of the zone. Increased *Tsuga* influx values begin again at 2460* BP. LOI is stable. Macrofossils include *Alnus, Betula lenta, Betula lutea*, Compositae, *Najas* and *Potamogeton.*

Zone SUP-C3b: Ambrosia-*Gramineae-Tubuliflorae (AD 1700 to present)*

Large increases in the percentage and influx values of *Ambrosia*, Gramineae and Tubuliflorae distinguish zone SUP-C3b from SUP-C3a. *Rumex* and *Plantago* are also present. *Pinus, Tsuga, Fagus* and *Quercus* values decrease. *Acer rubrum* is slightly increased. *Castanea* values, large at the zone onset, reach zero later on, followed by increases in *Betula* and *Quercus*. Charcoal influx increases slightly. *Sphagnum* is the only taxon represented in the macrofossil record.

Spruce Pond (SPP)

Zone SPP-B: Quercus-Pinus *(10 230 to 9750 BP)*

High pollen percentage and influx values of *Pinus strobus* and *Pinus* undifferentiated are the signature of zone SPP-B, along with expanding *Quercus. Pinus strobus* rises from 0 to 7% at 10 230 BP. *Quercus* continually expands (19 to 40%). *Betula* registers up to 15%, *Ostrya/Carpinus* and *Fraxinus* approximately 5%. *Potamogeton* is the only macrofossil taxon present. LOI increases from 14 to 23%. Charcoal influx decreases from 190 to 60 mm^2 cm^{-2} yr^{-1}.

Zone SPP-C1: Quercus-Tsuga *(9750 to 6230 BP)*

Tsuga canadensis percentage values are large (8%) at the zone onset (9750 BP) and then oscillate around 5% for the remainder of the zone. *Tsuga* influx values increase 10 times at the zone onset as well. Percentages of undifferentiated *Pinus* pollen

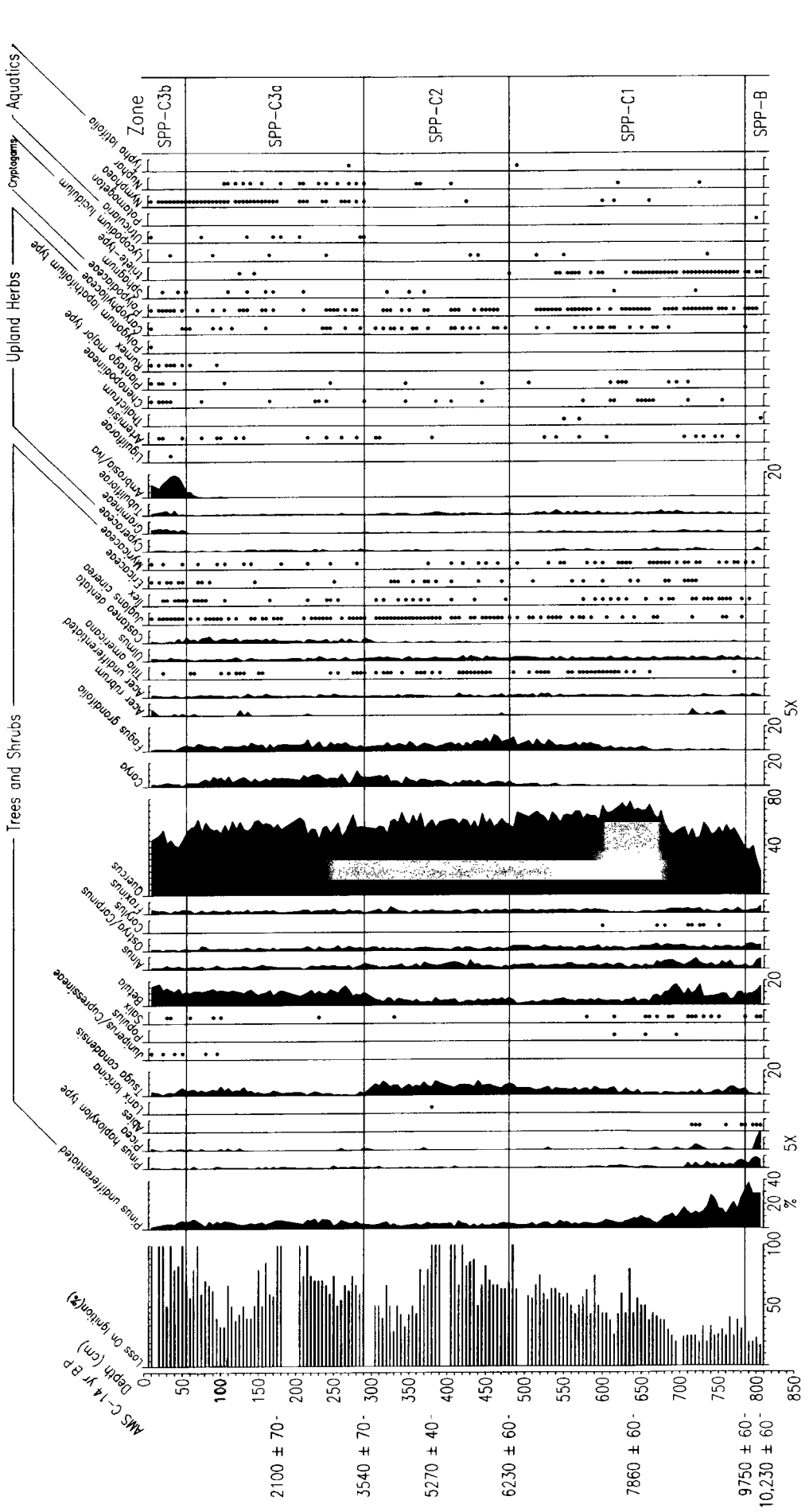


Figure 5 Pollen and spore diagram with loss-on-ignition data and AMS radiocarbon chronology for the Holocene at Spruce Pond, New York. Closed circles indicate values of <1%.

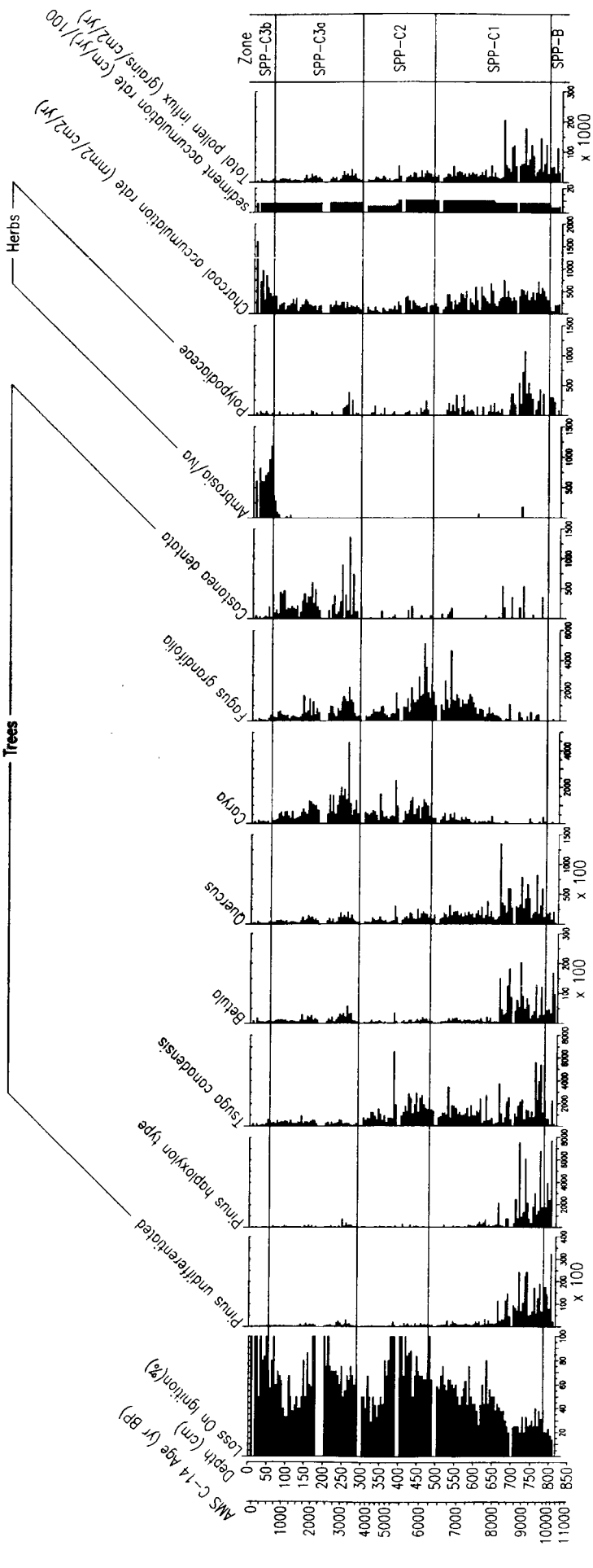


Figure 6 Diagram of pollen influx (grains cm^{-2} yr^{-1}) for selected taxa, AMS radiocarbon chronology, loss-on-ignition, charcoal-accumulation rates (mm^2 cm^{-2} yr^{-1}), sediment-accumulation rates (cm yr^{-1}), and total pollen influx (grains cm^{-2} yr^{-1}) for the Holocene at Spruce Pond, New York.

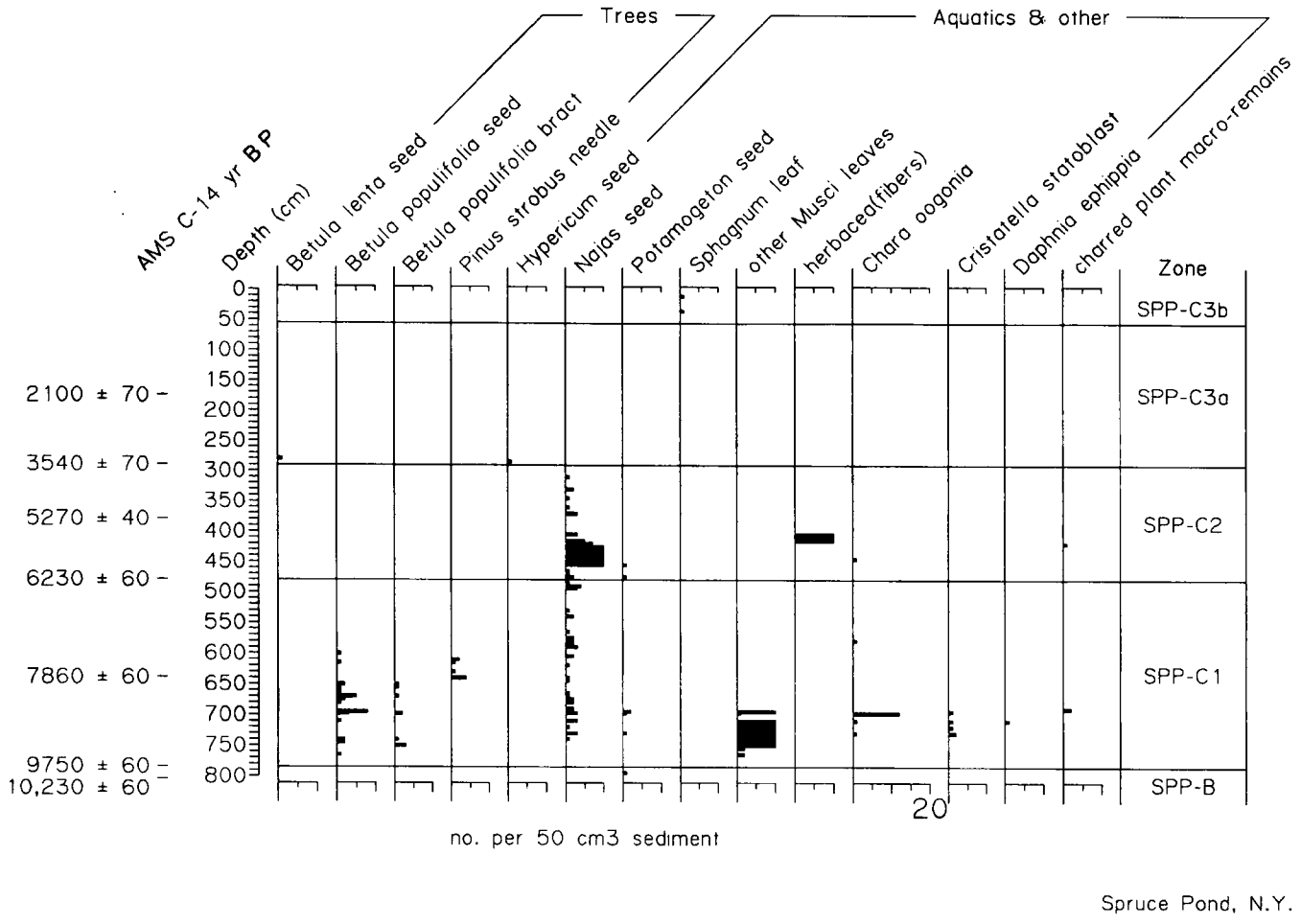


Figure 7 Diagram of plant macrofossils (number per 50 cm^3 sediment) and AMS radiocarbon chronology for the Holocene at Spruce Pond, New York.

decrease from 30 to 5%; *Pinus strobus* decreases too. Influx values for *Pinus* show similar declines. *Quercus* pollen increases from 40 to 70% and then levels off. *Betula* values are large (up to 20%) the first half of the zone and then decrease. *Fagus* expands at 8120* BP. *Picea* is sporadically present (trace amounts) throughout the zone. Charcoal influx increases from 170 m^2 cm^{-2} yr^{-1} to as high at 750 mm^2 cm^{-2} yr^{-1}. LOI values generally increase except for a decline at about 8500 BP. Aquatic assemblages include *Typha, Nuphar* and *Nymphaea* pollen and *Najas, Potamogeton*, moss, *Chara, Cristatella* and *Daphnia* macrofossils. *Betula populifolia* and *Pinus strobus* are the only trees represented by macrofossils.

Zone SPP-C2: Quercus-Carya *(6230 to 3540 BP)*

This zone is marked by expansion of *Carya* pollen percentages and influx at 6230 BP. Single grain occurrences of *Picea* appear less frequently than in zone SPP-C1. *Tsuga* pollen percentage and influx values decrease at 3540 BP, followed by increased *Betula* percentages and influx. Charcoal influx is slightly less than in previous zone. LOI increases in the first half of the zone and then decreases.

Zone SPP-C3a: Quercus-Castanea *(3540 BP to* AD *1700)*

Castanea pollen percentages expand at 3540 BP, but influx expands slightly later at 3160* BP. *Tsuga* values increase at 1650* BP. *Picea* pollen begins to register more consistently (<1%) beginning at 1470* BP. Charcoal influx is slightly more than that in zone SPP-C2. LOI is variable. *Betula lenta* is present as a macrofossil.

Zone SPP-C3b: Ambrosia-*Gramineae-Tubuliflorae (*AD *1700 to the present)*

Ambrosia, Tubuliforae and Gramineae pollen expands dramatically, and *Plantago* and *Rumex* are present. *Quercus, Pinus, Tsuga, Tilia* and *Fagus* decrease. *Acer rubrum* is more frequent. *Castanea* decreases toward the top of the zone, followed by increases in *Betula* and *Quercus*. Charcoal influx increases dramatically. LOI is consistently high.

Discussion

Early and middle Holocene forest change

Early-Holocene forests of the Hudson Highlands were characterized by expanding *Quercus* populations and by successive immigration of other arboreal components. I have considered the first large increases in a taxon's pollen percentage and influx values and, where possible, earliest occurrence of macrofossils as signals for each taxon's arrival. In some cases, for example *Pinus strobus* and *Tsuga canadensis*, the precise core level at which the arrival signal occurs was AMS-dated (Table 1). Late glacial pollen and macrofossil data from Sutherland and Spruce Ponds have been analyzed (Maenza-Gmelch, unpublished data); no evidence for earlier occurrence of the following taxa has been found: *Pinus strobus* appears to have arrived between 10 120 and 10 230 BP, followed by *Tsuga canadensis* between 9540 and 9750 (possibly earlier), *Fagus grandifolia* between 8120* and 8150*, *Carya* at 6230, and *Castanea dentata* between 3540 and 3645* BP. Davis (1983) describes a similar invasion sequence for southern Connecticut, with *Castanea* arriving considerably later at about 2700

BP. A reasonable estimate of the arrival time for *Castanea* in the Hudson Highlands is 3600 BP. This age is intermediate between the inferred arrival times of *Castanea* in southern Connecticut and northeastern Pennsylvania (Watts, 1979).

The mid-Holocene *Tsuga* decline (Davis, 1981b), recorded throughout the northeast between 4800 and 2800 BP (Davis, 1983), is apparent in the Hudson Highlands records but at varying times. The decline begins at Sutherland Pond at 4180* and lasts for about 1700 years. At Spruce Pond the decline starts at 3540 BP and lasts for approximately 1900 years.

Arboreal macrofossils recovered from Sutherland and Spruce Ponds provide increased taxonomic resolution of the vegetation records, particularly within the genus *Betula*. *Betula* seed and bract fossils indicate that earliest Holocene populations contained *B. papyrifera*, which was replaced at about 9575* BP by *B. populifolia* at Sutherland Pond; mid- and late-Holocene *Betula* populations included a mixture of *B. populifolia, B. lenta* and *B. lutea*.

Slight decreases in pollen influx of *Quercus* at Sutherland and Spruce Pond beginning at around 3600* BP and an increase in *Picea* at Spruce Pond at around 1500* BP may be indicative of neoglacial cooling (Porter and Denton, 1967). Neoglacial cooling in the late Holocene is believed to be represented at various sites in the northeast between 5000 and 1000 BP by an increase in boreal elements (Davis, 1983). *Picea* expanded at all elevations in the White Mountains of New Hampshire at 2000 BP, suggesting a cooler, moister climate (Spear *et al.*, 1994).

Aquatic macrophytes

Changes in pollen and macrofossils of aquatics, generally comparable between Sutherland and Spruce Ponds, follow the trend of hydrarch succession. *Najas* seeds are abundant in zones C1 and C2 at both sites, with small amounts of *Potamogeton* seeds associated. Both taxa are submerged aquatics and are sensitive to changes in water level and/or shading out by floating aquatics (Lynn, 1983; Likens, 1985). Pollen grains of *Nymphaea* and *Nuphar*, both floating aquatic taxa, become abundant in zone C3 at both sites, while *Najas* and *Potamogeton* are infrequent. Associated larger LOI values in zones C2 and C3 at Spruce Pond and in zone C3 at Sutherland Pond may indicate pond shallowing.

Post-settlement vegetation change

The topmost pollen assemblage zones in the records from Sutherland and Spruce Ponds, marked by increases in *Ambrosia*, Gramineae and Tubuliflorae and presence of *Rumex* and *Plantago*, record the onset of Euroamerican disturbance of the landscape. The *Ambrosia* rise is a common event found in many pollen records in the northeast (Davis, 1965; Russell *et al.*, 1993). *Ambrosia, Rumex* and *Plantago* are often found in cultivated and old fields, roadsides, and waste places where soils have been disturbed (Niering, 1988). Europeans settled villages, including in Cornwall, in AD 1685, and in AD 1702 the English purchased 20 000 acres of forest from the Iroquois (Keatinge, 1967). Thus, an age of AD 1700 is a reasonable estimate for the *Ambrosia* rise found at Sutherland and Spruce Ponds.

Decreases in *Quercus, Tsuga* and *Pinus* characterize the recent sediments as well. Forest-related industries operating between approximately AD 1750 and 1850, included iron, brick and charcoal production. The manufacturing processes for each required enormous amounts of wood (Moon, 1909; Raup, 1938; Keatinge, 1967). Stripping of *Tsuga* for its bark in use by the tanning industry was also widespread (Russell *et al.*, 1993). These industries and domestic needs for wood probably account for the decrease of *Quercus, Tsuga* and *Pinus* in the pollen record. Increases in *Betula* and *Acer rubrum* accompanying this decline represent expansion by opportunistic, light-demanding, early-successional tree species (Burns and Honkala, 1990). Decreases in *Quercus, Tsuga, Fagus* and *Castanea* and increases in *Betula* and *Acer rubrum* are common post-settlement signals in the pollen records from other sites in the *Quercus* forest region (Russell *et al.*, 1993).

Decreases in *Castanea dentata* pollen succeeded by increases in *Betula* and *Quercus* reflect the demise and replacement of *Castanea* due to a fungal pathogen introduced at New York City in AD 1904 (Anderson, 1974). Prior to the blight, *Castanea* represented 35% of the trees in the forest with as much as 70% on mid-elevation slopes (Moon, 1909). In AD 1909, only 1 to 2% of *Castanea* was affected by the pathogen; by AD 1915, most *Castanea* were killed (Moon, 1909). Today, *Castanea* is almost entirely a sprout-growth population, only rarely maturing to produce pollen.

Fire history

Role of fire in the development and maintenance of Quercus *forest*

Continuous accumulations of charcoal in Sutherland and Spruce Ponds during the Holocene indicate that fire has been a factor influencing vegetation development in the Hudson Highlands. The warmer/drier climate of the early and middle Holocene (Deevey and Flint, 1957; Wright, 1992) may have provided the appropriate conditions for burning. Increased charcoal between 9000 and 5000 BP has been noted at other sites in the northeast and Great Lakes regions (Watts, 1979; Davis, 1985; Winkler, 1985; Anderson *et al.*, 1986; Winkler *et al.*, 1986; Dunwiddie, 1990; Peteet *et al.*, 1990; Laing, 1994).

Development and maintenance of the large *Quercus* component in forests of the Hudson Highlands, since 9000 BP, may be due to frequent fire. *Quercus* is increased after fire because injury stimulates sprouting. Thick bark, resistance to rotting after scarring, and suitability of fire-created seed beds for acorn germination are additional factors (Abrams, 1992). Comparison of arboreal compositions of previously burned and unburned areas in Rhode Island, southeastern Connecticut, and south-central New York indicates that fire promotes dominance of *Quercus* species and suppresses northern hardwoods and *Tsuga* (Brown, 1960; Niering and Goodwin, 1962; Swan, 1970).

Since most *Quercus* species are considered to represent early- to mid-successional stages (Burns and Honkala, 1990), disturbance is suspected of promoting *Quercus* dominance and preventing replacement by later-successional northern hardwoods. It seems likely that fire has maintained *Quercus* forest as a pyroclimax and is therefore responsible for its long-term stability. Soils must play a synergistic role in the maintenance of *Quercus* forest. *Quercus* species can tolerate the generally dry, shallow and rocky soils of the Highlands and can therefore outcompete northern hardwoods on such sites. Synergism is likely between fire and soils, that is less mesic soils would permit fire, and fire would prevent better soil development.

Reduced fire at 9500 BP facilitated expansion of Tsuga *populations*

Establishment of small populations of *Tsuga canadensis* might have occurred at Sutherland and Spruce Ponds as early as approximately 10 600 BP, indicated by 2% *Tsuga* pollen (Maenza-Gmelch, unpublished data). Roughly 2% *Tsuga* pollen occurs at sites in northern New Jersey and southern Connecticut at this time as well (Peteet *et al.*, 1990; 1993). In central North America, *Tsuga* pollen is not usually found outside the modern range of *Tsuga* trees (Webb and McAndrews, 1976). Accordingly, 2% *Tsuga* pollen in the fossil record might indicate the trees past presence. However, 2% *Tsuga* pollen can be found outside the range of trees at some eastern North American sites (Davis and Webb, 1975).

In the Hudson Highlands, presence of fire may have delayed

expansion of *Tsuga* populations until 9500 BP, as is apparent at Sutherland Pond where a reduction of charcoal influx is contemporaneous with large increases in *Tsuga* pollen percentage and influx values and earliest occurrence of *Tsuga* macrofossils (Figure 8). An analog for this hypothesis can be found where modern *Tsuga* populations are expanding in areas protected from fire (Charney, 1980; Brown, 1982; Hemond *et al.*, 1983; Farr and Tyndall, 1992). The ecophysiology of *Tsuga* provides a mechanism by which fire controls its abundance. *Tsuga* is reduced by fire because of thin bark (in young trees), shallow root systems, and sensitivity of seeds, seedlings and small trees to desiccation (Burns and Honkala, 1990).

Native American use of fire

Native Americans regularly burned areas of the northeast for farming, hunting and travel, as reported in historical documents (Day, 1953). Historical documents from throughout the northeast also indicate that native American use of fire increased fire frequency above levels caused by lightning (Russell, 1983). Increased charcoal accumulation during a period of Iroquois occupation at Crawford Lake, Ontario, Canada, in association with palynological changes, suggests that native Americans could have influenced fire regimes and forest vegetation (Clark and Royall, 1995a). The continuous presence of native Americans in the lower Hudson Valley, New York, since 10 000 BP (Funk, 1976) facilitates their potential influence on the vegetation during the same period. However, there is little agreement on the extent to which humans used fire (Patterson and Sassaman, 1988).

Euroamerican use of fire

Euroamerican settlement in the Hudson Highlands beginning at approximately AD 1700 increased fire frequency in the vicinity of Spruce Pond but to a much lesser extent at Sutherland Pond. Increased charcoal accumulation after settlement has been documented at other sites in the northeast (Russell *et al.*, 1993; Clark and Royall, 1995b). Forestry practices in the Highlands included clearcutting every 25 to 30 years followed by uncontrolled burning (Moon, 1909; Raup, 1938; Keatinge, 1967). Additional causes of increased post-settlement charcoal influx would be use of fire in connection with land-clearance, wood-related industries (charcoal, iron and brick manufacturing), and operation of railroads (track fires) (Pyne, 1988).

Comparison of charcoal records from Sutherland and Spruce Ponds

In order to explain the similarities and differences between charcoal records from Sutherland and Spruce Ponds, the landscape-source of charcoal must be considered. 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). Empirical studies have shown that charcoal in small basins can accurately reflect fire activity within a watershed (Clark, 1988; Patterson and Backman, 1988).

At Sutherland and Spruce Ponds, similarities between charcoal records may represent regional fire events such as the increased charcoal influx during the Holocene as compared to the Late-glacial (Maenza-Gmelch, unpublished data) and increased charcoal influx after settlement. Differences between the charcoal records may represent local fire events. For example, Spruce Pond records a greater increase in charcoal influx during post-settlement time than does Sutherland Pond. This may be explained by Spruce Pond's proximity to the Erie Rail Road, furnaces in the Sterling Forest area, Ramapo River Valley (a major avenue of commerce), and more settlers in general.

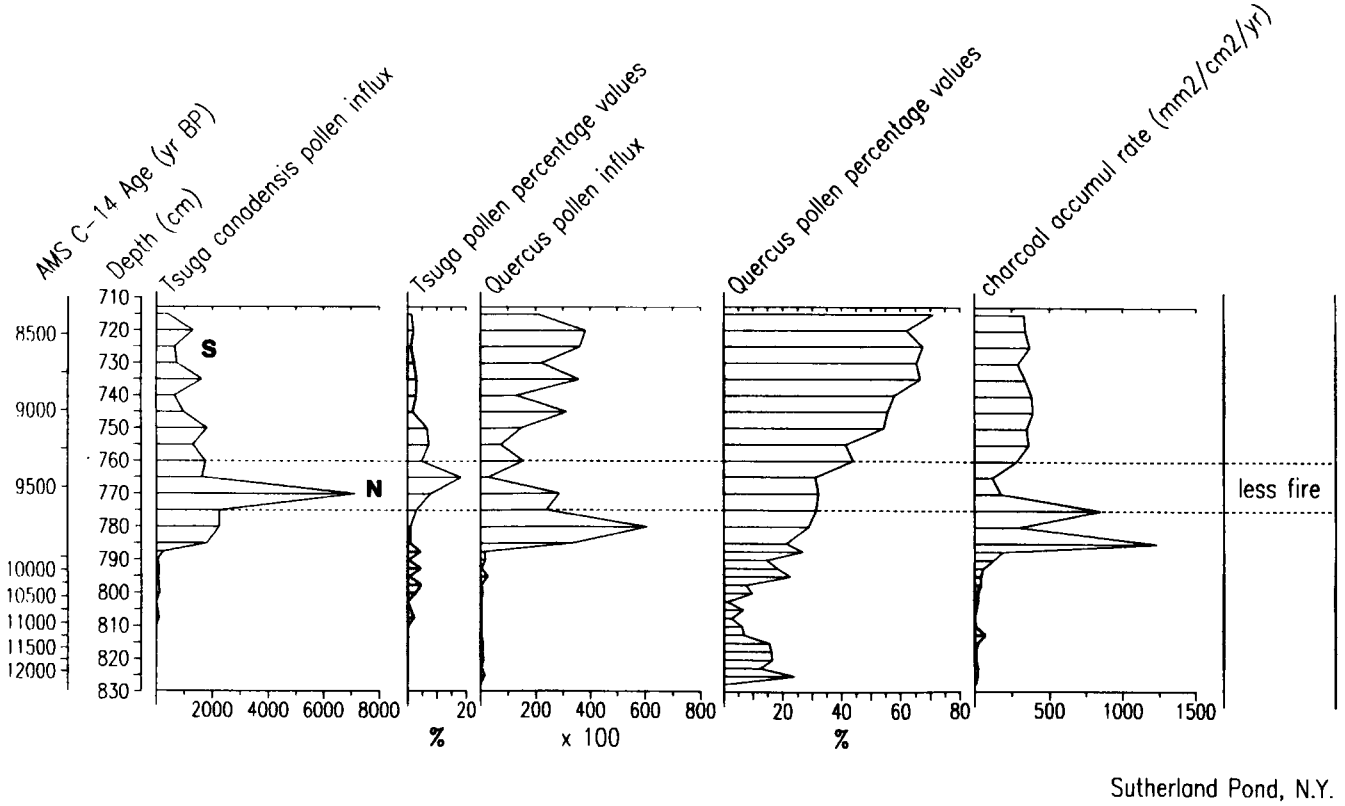


Figure 8 Diagram of pollen percentage and influx values for *Tsuga canadensis* and *Quercus* for comparison with charcoal-accumulation rates for the early Holocene at Sutherland Pond, New York. N = 12 *Tsuga* needles. S = 1 *Tsuga* seed.

Conclusions

1) Holocene invasion of *Quercus* forest in the Hudson Highlands featured the following sequence: *Pinus strobus* at 10 175 BP, *Tsuga canadensis* at 9645, *Betula populifolia* at 9575, *Fagus grandifolia* at 8100, *Carya* at 6200, and *Castanea dentata* at 3600 BP.
2) Fire may have played an important role in the development and maintenance of *Quercus* forests of the Hudson Highlands, as suggested by large *Quercus* pollen percentage and influx values in association with continuous charcoal influx throughout the Holocene.
3) A temporary decrease in fire at approximately 9500 BP apparently was a factor enabling expansion of *Tsuga canadensis* populations in the vicinity of Sutherland Pond.
4) Arboreal macrofossils recovered from Sutherland and Spruce Ponds increased the taxonomic resolution of the vegetation records, particularly within the genus *Betula*. At Sutherland Pond *B. papyrifera* was replaced at about 9575 BP by *B. populifolia*. Mid- and late-Holocene *Betula* populations included a mixture of *B. populifolia, B. lenta* and *B. lutea*.
5) Neoglacial cooling may be represented by slight decreases in *Quercus* beginning at around 3600 BP and an increase in *Picea* at Spruce Pond at around 1500 BP.
6) Settlement by Euroamericans, beginning at approximately AD 1700, increased fire frequency, which may be explained by use of fire in connection with land-clearance, wood-related industries (charcoal, iron and brick manufacturing), and operation of railroads (track fires).

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