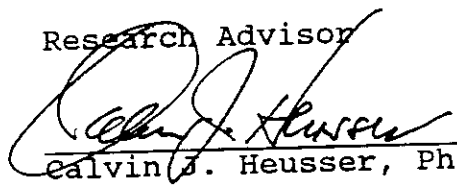
HIGH-RESOLUTION LATE-QUATERNARY BIOSTRATIGRAPHIC RECORDS FROM SOUTHEASTERN NEW YORK STATE, USA: PALEOENVIRONMENTAL IMPLICATIONS

by

Terryanne Elizabeth Maenza-Gmelch

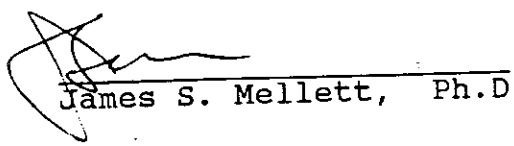
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This dissertation is dedicated

to Jeffrey Gmelch

whose scholarship and kindness

have been

an inspiration.

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ABSTRACT

AMS-dated pollen, plant macrofossil, and charcoal records from Sutherland (41°23'29"N, 74°02'16"W) and Spruce (41°14'22"N, 74°12'15"W) Ponds reveal late-glacial and Holocene vegetation, climate, and fire histories of the Hudson Highlands, southeastern New York. Pollen assemblages (>12,500 yr B.P.) are dominated by herbaceous and shrub types (*Salix, Betula, Alnus,* Ericaceae, Cyperaceae, Gramineae, and Tubuliflorae) and include trees (*Pinus* and *Picea*), possibly representing park tundra. A mixed assemblage of boreal and temperate taxa (*Picea, Abies, Betula papyrifera, Quercus, Ostrya/Carpinus,* and *Fraxinus*) is evident from 12,500 to 11,000 yr B.P. Onset of organic deposition, first occurrence of macrofossils, and large increases in pollen influx suggest dramatic environmental change at 12,500 yr B.P. A *Picea/Abies* assemblage, registering a cool climatic episode, dominates between 11,000 and 10,000 yr B.P. The times of onset and termination of this interval occurred rapidly, each within 150 years. Warm conditions, similar to present, are established by 10,175 yr B.P. as inferred from expanding *Quercus*-dominated forests and invasion by *Pinus strobus,* followed by *Tsuga canadensis* at 9645 yr B.P. and replacement *of Betula papyrifera* by *Betula populifolia* at approximately 9575 yr B.P. *Fagus grandifolia* immigrated at 8100, *Carya* at 6200, and *Castanea dentata* at 3600 yr B.P.

Charcoal in the record indicates that fire was more important during the Holocene than between 12,500 and 10,000 yr B.P. Early Holocene expansion of *Quercus* forests likely occurred in a setting of frequent fire. About 9500 yr B.P., decrease in fire apparently was a factor enabling expansion of *Tsuga canadensis*; however, centuries later, increase of fire appears to have restricted *Tsuga* and permitted expansion of *Quercus*. Consistently high values of *Quercus* in association with high charcoal densities for some nine millennia suggest that fire played an important role in the development and maintenance of *Quercus* forest.

Euroamerican settlement (approximately 1700 A.D.) is well-documented in the pollen record by dramatic rises in *Ambrosia*, Gramineae, and Tubuliflorae. Harvest of *Quercus*, *Pinus*, and *Tsuga canadensis* is recorded as decreased percentages of these taxa. Increased post-settlement charcoal densities 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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PART 1

Late-glacial - early Holocene vegetation and climate at Sutherland Pond, Hudson Highlands, southeastern New York, USA.

ABSTRACT

Close-interval analyses of AMS-dated pollen and plant macrofossil records from Sutherland Pond (41°23'29"N, 74°02'16"W) located in the Black Rock Forest, provide a detailed account of vegetational changes spanning the late-glacial - Holocene transition in the Hudson Highlands, lower Hudson Valley, southeastern New York. Pollen assemblages dating >12,600 yr B.P. are dominated by herbaceous and shrub types (*Salix, Betula, Alnus,* Ericaceae, Cyperaceae, Gramineae, and Tubuliflorae) and included trees (*Pinus* and *Picea*), possibly representing park tundra. A mixed assemblage of boreal and temperate taxa (*Picea, Abies, Betula papyrifera, Quercus, Ostrya/Carpinus,* and *Fraxinus*) is evident from 12,600 to 11,200 yr B.P. Onset of organic deposition, first occurrence of macrofossils, and large increases in pollen influx suggest dramatic environmental change at 12,600 yr B.P. A *Picea/Abies* assemblage, believed to register a cool climatic episode, dominates between 11,200 and 10,120 yr B.P., with rapid onset and termination each occurring within 150 years. Warmer conditions, re-established by 10,120 yr B.P., are inferred from expansion of *Pinus strobus* and increasing

Quercus and *Ostrya/Carpinus*, followed by replacement of *Betula papyrifera* by *Betula populifolia*. Macrofossils indicate the first presence of *Picea* at 12,600, *Pinus strobus* at 10,120, and *Tsuga canadensis* at 9540 yr B.P.

INTRODUCTION

Much shifting in the ranges of arboreal species occurred as climate changed during the late-glacial - Holocene transition. Davis (1976, 1981) estimated arrival times of major tree taxa, as migration occurred northward in eastern North America, by noting the radiocarbon age of the first sharp increase in pollen influx/percentage values. She pointed out the utility of macrofossils in corroborating pollen evidence for local presence of a taxon. As an example, plant macrofossil and pollen influx records from northern New Jersey and southern Connecticut (Peteet *et al.*, 1990; 1993) have helped to clarify the minimum times of arrival (MTA) of *Picea* and *Pinus strobus* in the Northeast. Information of this kind is essential for the refinement of migration patterns and for interpretation of late-glacial, southern New England pollen assemblage zones; for example, recognition of the Younger Dryas cooling event (YD).

AMS-dated pollen and plant macrofossil records presented in this paper from a sediment core of Sutherland Pond, located in the Black Rock Forest, a 1548 ha preserve in the Hudson Highlands of southeastern New York, span the late-glacial to

Holocene transition. The Sutherland Pond record, the first in a pair of studies of the Hudson Highlands, is an attempt to develop a fine resolution paleoenvironmental characterization of the glaciated portion of the mid-Atlantic states and southern New England.

This study addresses the following: what type of vegetation existed in the Hudson Highlands prior to 12,600 yr B.P.?; when did *Picea, Pinus strobus,* and *Tsuga canadensis* migrate to the Hudson Highlands?; what were the vegetational changes during the late-glacial - Holocene transition?; and did vegetation respond and how rapidly to the YD cooling, Holocene warming?

HUDSON HIGHLANDS

Physical features and deglaciation

The Hudson Highlands, cut by the Hudson River between Newburgh and Peekskill, rise >180 m above the adjacent lowlands and reach a maximum elevation of 400 m (Fig. 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, rolling-rocky slopes, and low hills separated by swamps and ponds.

The Highlands were glaciated by the Laurentide ice sheet; however, the glacial geology of the Hudson Highlands is largely unstudied. Denny (1938) determined that Wisconsinan

till deposited on the upland was altered by intense freeze/thaw cycles and solifluction resulting from a cold periglacial climate following deglaciation. From studies of the deglacial history of the Great Valley, west of the Hudson Highlands, the onset of deglaciation is estimated at 17,500 yr B.P., but is based on assumed sedimentation rates (Connally *et al.*, 1989). Muller and Calkin (1993), in their review of age data for Pleistocene glacial events in New York state, point out that the chronostratigraphic framework is weakly supported and there is a great need for AMS dating.

Climate and vegetation

Southeastern New York state is under the influence of cold and dry air from the northern continental interior, warm and humid air from the Gulf of Mexico and adjacent subtropical waters, and maritime air originating over the North Atlantic ocean (Ruffner, 1980). Climate data representative of the Hudson Highlands from West Point, New York (Fig. 1), recorded over a 30 year period (1918-1948), indicate 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).

Black Rock Forest is included in the *Quercus-Castanea* region of the eastern deciduous forest by Braun (1964), while Küchler (1964) describes certain areas as ecotonal between the *Quercus* forest to the south and the *Tsuga-Pinus strobus*-northern hardwoods forest to the north. Topographical

variation and disturbance history have generated a mosaic of plant communities. Hill-tops 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. Valleys, ravines, and north-facing slopes below 335 m include *Tsuga canadensis*, *Liriodendron tulipifera*, *Fraxinus americana*, *Tilia americana*, *Acer saccharum*, *Betula lutea*, and *Fagus grandifolia* (Raup, 1938). On disturbed sites, secondary communities of sprout origin include *Quercus* spp., *Castanea dentata*, *Betula populifolia*, and *Populus grandidentata*.

METHODS

Field

Sutherland Pond (41°23'29"N, 74°02'16"W), 4.05 ha in surface area at 380 m altitude, is situated 2.4 km west of the Hudson River at Cornwall, Orange County, New York (Fig. 1). The coring location within the pond's basin, that is, the point with thickest sediments with no obstructions, was determined with the aid of ground-penetrating radar (Mellett, 1993). Coring was carried out using a square rod piston sampler of 5-cm diameter (Wright *et al.*, 1984) operated from a floating platform at a water depth of 2.57 m. Core segments, totalling 10.6 m, were retrieved in meter lengths,

wrapped in plastic and foil and stored at 4°C until laboratory study.

Laboratory

Cores were initially sampled for pollen at intervals of 5-cm, except in the clay-rich portion, which was at 10-cm, and processed following Heusser and Stock (1984). After preliminary pollen analysis, the core segment spanning the late-glacial - Holocene transition was sampled at 2.5 cm intervals. Identification of pollen and spores are based on descriptive keys (Kapp, 1969; McAndrews *et al.*, 1973; and Faegri and Iversen, 1989), as well as a pollen and spore reference collection. Light microscopy was used to identify and count pollen; routine counting was done at 400X magnification, while critical identifications were made at 1000X. At least 300 upland pollen grains were counted per sample, except where pollen concentrations were low, 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, 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). Organic matter content of sediment is measured by loss-on-ignition at

550°C (Bengtsson and Enell, 1986). Pollen percentage and influx diagrams are constructed using Tilia-graph© software developed by E.C. Grimm. Designation of pollen assemblage zones was by visual inspection for peaks of ecologically indicative taxa. Nomenclature follows Fernald (1950).

Plant macrofossils were isolated from 50 cm^3 of sediment at 5-cm intervals. Isolation included gentle disaggregation of the sediment matrix in 5% potassium hydroxide at 4°C for at least 24 hrs and washing through 150 micron sieves. All particles >150 microns were inspected, and recognizable plant remains were hand-picked and identified using a dissection microscope at 40X magnification. Identification of specimens is made from 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). Ecologically significant conifer needles, seeds, or small sediment samples (1 cm^3) were air-dried and sent for AMS radiocarbon age determination.

RESULTS

Fossil pollen and plant macrofossil zonation

Pollen stratigraphy of the Sutherland Pond (SUP) core is divided into the standard southern New England pollen assemblage zones (Leopold, 1956; Deevey, 1958). Five AMS radiocarbon age determinations establish the chronology for the late-glacial to Holocene transition (Table 1). Complete pollen and macrofossil diagrams are presented in Figures 2 and 3, and a summary diagram of both pollen and plant macrofossils of selected taxa is presented in Figure 4. Sediment lithology is described in Table 2.

Zone SUP-T: *Pinus*-Cyperaceae (>12,600 yr B.P.; 1070-835 cm).

Herb taxa, particularly Cyperaceae, along with shrubs and considerable amounts of *Pinus* (65%), characterize the >12,600 yr B.P. record. Distinctive is the Cyperaceae maximum (60%), which is sustained throughout this zone. Gramineae, Tubuliflorae, and *Artemisia* reach maxima early in the record and decrease upward, while *Salix* and *Alnus* increase later. Assorted minor but significant nonarboreal taxa (Liguliflorae, Umbelliferae, Caryophyllaceae, Chenopodiineae, *Sanguisorba, Thalictrum, Selaginella selaginoides,* and *Lycopodium selago*) and *Picea, Abies, Betula,* and *Quercus* are also present. Pollen influx (PI) and loss-on-ignition (LOI) are low (Fig. 5). No macrofossils were found in this zone.

Zone SUP-A1-2-3: *Pinus-Picea-Abies-Ostrya/Carpinus-Fraxinus-Quercus* (12,600 to 11,200 yr B.P.; 835-814 cm).

This zone features a combination of pollen of both boreal and temperate taxa. Boreal types, *Picea* (12%) and *Abies* (20%), are consistently present throughout with peaks at 830 cm, after which both decrease; sharp increases in PI of *Picea* and *Abies* first occur at 832.5 and 835 cm, respectively. Frequency and PI values of temperate *Quercus* (24%), *Fraxinus* (12%), and *Ostrya/Carpinus* (11%) expand, while *Alnus* frequency is much less than in zone SUP-T. Total PI rises from 835 to 1800 grains per cm^2 per yr at 12,600 yr B.P. Also featured is the onset of increased organic deposition with mean LOI values of 21% compared to 2.5% in zone SUP-T. A needle and seed of *Picea* and an *Alnus* seed occur between 830 and 835 cm, indicating their initial local presence; first *Abies* needles occur between 810 and 815 cm.

Zone SUP-A4: *Picea-Abies-Alnus-Betula papyrifera* (11,200 to 10,120 yr B.P.; 814-796 cm).

An abrupt drop in PI and percentages of *Quercus* (16% to 7%), *Fraxinus* (3% to 1%), and *Ostrya/Carpinus* (10% to 6%) between 815 and 812.5 cm and re-expansion of *Alnus* and boreal types are recorded. *Alnus* is the first to expand to a maximum of 40% at 805 cm, followed successively by *Picea* at 9% (802.5 cm) and *Abies* at 15% (800 cm). Later, *Abies* and *Alnus* gradually diminish toward the top of the zone, whereas *Picea* exhibits an abrupt decline from 9% to 1% in 2.5 cm midway in

the zone. *Betula papyrifera* peaks at 25% (795 cm) and then steadily declines, while increases of Quercus and Ostrya/Carpinus from 8% to 23% and from 1% to 23% occur, respectively, between 797.5 and 795 cm, signalling the onset of the B zone. Corresponding changes in PI support the pollen percentage data. Pollen of *Tsuga canadensis* appears in low percentages (< 4.5%) in this zone. Macrofossils of *Abies, Alnus, Picea, Larix,* and *Betula papyrifera* provide evidence of their local occurrence. LOI fluctuates with a small overall increase.

Zone SUP-B: *Pinus strobus-Quercus* (10,120 to >9540 yr B.P.; 796-775 cm).

Zone SUP-B features the expansion of *Pinus strobus* and *Pinus* undifferentiated pollen percentages and PI together with progressively increasing *Quercus*. *Abies* and *Picea* values become negligible.

Pinus strobus needles appear in the record for the first time between 790 and 795 cm, concurrently with a sharp rise in PI, and continue to be present at upper levels. The last *Abies* and *Picea* macrofossils are encountered in this zone; the last *Betula papyrifera* seeds occur between 780 and 785 cm, followed by seeds of *Betula populifolia* between 775 and 780 cm. In the overlying zone SUP-C1, the earliest *Tsuga canadensis* needles are found at 770 cm, associated with the first sharp rise (8% to 18%) in *Tsuga* pollen frequency at 765 cm and a large increase in PI. A large increase in LOI (30 to

55%) occurs between 787.5 and 785 cm.

VEGETATION OF THE LATE-GLACIAL - HOLOCENE TRANSITION

The herb-shrub-*Pinus-Picea* basal pollen assemblage zone SUP-T at Sutherland Pond, because of its substantial non-arboreal pollen(NAP) component, including largely arctic-alpine species (*Selaginella selaginoides, Lycopodium selago*), is interpreted to possibly represent park tundra, with *Pinus/Picea* existing in protected microsites on the landscape. However, no macrofossils were encountered to indicate the local presence of these trees. Based on macrofossil evidence, it appears that *Picea* may not have reached the site until 12,600 yr B.P. (SUP-A1-2-3). The pollen record is variable in zone SUP-T despite low PI, the reason for this is not understood. Climatic amelioration might be inferred from the observed shift from an herb- to shrub-dominated assemblage.

Herb-dominated, late-glacial pollen zones from the Northeast have been variously interpreted as representing tundra or park tundra on the basis of high herb frequencies (10-50% Cyperaceae plus other NAP) with high *Pinus* (10-70%) and *Picea* (10-40%) frequencies (Davis, 1969; Sirkin, 1971; Miller, 1973; Spear and Miller 1976; Watts, 1979; Ibe, 1980; Cotter *et al.*, 1986; Dunwiddie, 1990; Peteet *et al.*, 1990; Foster and Zebryk, 1993; Spear *et al.*, 1994). Where PI has

been determined, the zones are characterized by low PI values. Comparison of pollen spectra in zone SUP-T with modern pollen spectra from the shrub tundra/forest-tundra regions of eastern Canada (Davis and Webb, 1975; King, 1993) and central Canada (Webb and McAndrews, 1976) offers no interpretational insight because of considerable overlap or dissimilarity between the pollen frequencies (Table 3). It is probable that *Picea* was available for immediate colonization of newly deglaciated terrain since *Picea* needle fragments are found in the basal Gramineae-dominated herb zone (12,400 - 12,200 yr B.P.) at Longswamp, PA, a periglacial site located close to the former ice margin (Watts, 1979).

The expression in the record (zone SUP-A1-2-3) of a mixed assemblage of boreal - temperate pollen types between 12,600 to 11,200 yr B.P. suggests a mixed conifer-hardwood forest featuring principally *Picea, Abies, Pinus, Quercus, Fraxinus,* and *Ostrya/Carpinus*. Onset of organic deposition, first occurrence of macrofossils, and large increases in PI at 12,600 yr B.P.indicate significant environmental change. The MTA for *Picea* is 12,600 yr B.P., comparable to MTAs at adjacent study sites (Table 4). Needles of *Abies* are abundant in three consecutive samples (815 - 800 cm), suggesting, in conjunction with high pollen percentage values, that *Abies* may have been particularly important at Sutherland Pond. The MTA for *Abies* is estimated to be approximately 11,375 yr B.P. (linearly interpolated age of level 815 cm). It seems that

as the forest closed, *Alnus* was shaded out.

Although no macrofossils were found representing *Quercus, Fraxinus,* and *Ostrya/Carpinus,* their local presence is inferred from comparison with modern pollen-vegetation relationships in eastern and central North America (Davis and Webb, 1975; Webb and McAndrews, 1976). Isopolls of 5%, 0%, and 0% of *Quercus, Fraxinus,* and *Ostrya/Carpinus,* respectively, correspond to their northern distributional limits.

The *Alnus/Picea/Abies* pollen assemblage (zone SUP-A4) is interpreted to represent a rapid reversal in the trend toward development of temperate deciduous forest. After 11,200 yr B.P., reductions in the abundance of *Quercus, Fraxinus,* and *Ostrya/Carpinus* occur in samples across a 2.5 cm interval, as reflected by pollen percentages and PI values. The linear age/depth relationship for this core segment (795 - 812 cm) indicates that this change took place in some 150 years, signifying a rapid cooling. Populations of light-demanding *Alnus* entered into forest openings, followed by shade-tolerant *Picea* and *Abies*. Later, *Picea* and *Abies* decreased in abundance possibly because of an initial phase of climatic amelioration. Fast-growing, shade-intolerant *Betula papyrifera* expanded into the openings left by the boreal conifers, but was short-lived due to recovery of temperate trees at 10,120 yr B.P. when a final, more abrupt warming occurred. Rapid reversal to warmer conditions (again within

150 years) is inferred from the rapid ecesis by temperate trees, comparable to estimates (50 -100 years) made by Peteet *et al.* (1993) for northern New Jersey and southern Connecticut.

The vegetation reversal exhibited in zone SUP-A4 lies within the YD chronozone (11,000-10,000 yr B.P.) and provides additional evidence for a late-glacial cooling event in the Northeast (Peteet *et al.*, 1990; 1993). Numerous sites in Atlantic Canada (Mott *et al.*, 1986) and elsewhere in the Northeast (Peteet, 1987) contain palynological oscillations indicative of the YD cooling. Mayle *et al.* (1993a) in Atlantic Canada and Peteet *et al.* (1990; 1993) in southern New England, have obtained AMS ages for the YD boundaries indicating that the northeastern North American events correlate with the European YD chronozone.

Peak *Alnus* is a common signal for the YD in northeastern North America (Mayle *et al.*, 1993b) with *Alnus rugosa*-type being important in New England. Zone SUP-A4 expresses an undifferentiated *Alnus* peak (40%) associated with elevated PI values, and *Alnus* macrofossils in zone SUP-A1-2-3 indicate the presence of *Alnus* at 12,600 yr B.P. From these data, it seems unlikely that the YD peak at Sutherland Pond represents sudden arrival of *Alnus*. Mayle *et al.* (1993b) suggest that the YD cooling could have created openings in the forest canopy permitting expansion of light-demanding *Alnus*.

The paleoecologic inference for zone SUP-B is of warmth,

perhaps equivalent to that which exists today. After *Pinus strobus* became established in the *Quercus*-dominated forest at 10,120 yr B.P., *Quercus* steadily increased in abundance, *Betula papyrifera* was replaced by *B. populifolia,* and by 9540 yr B.P. *Tsuga canadensis* became established. The large increase in LOI (30 to 55%) occurring midway in the zone possibly indicates enhanced eutrophic conditions of the pond.

From a survey of paleoecological studies made of selected sites in the Northeast (Table 4), a timetable for regional establishment of *Pinus strobus* and *Tsuga canadensis* populations can be inferred. *Pinus strobus* occurs as early as 11,500 at Tannersville Bog, Pennsylvania and 11,000 yr B.P. at Linsley Pond, Connecticut, indicating that climate had probably become as warm as at present. At other sites listed in Table 4, the earliest *Pinus strobus* macrofossils or first sharp increases in PI occur at or after approximately 10,000 yr B.P. The inferred MTA for *Tsuga canadensis* in northeastern Pennsylvania, northeastern New Jersey, southeastern New York, and southern Connecticut is 9,500 yr B.P. It appears that *Tsuga* reached the Adirondack and White Mountains by 7,500 yr B.P. Spear *et al.* (1994) report *Tsuga canadensis* macrofossils at Mirror Lake, New Hampshire at >12,000 yr B.P.; however continuous representation of *Tsuga* needles does not begin until 7500 yr B.P.

CONCLUSIONS

Fine-resolution pollen and plant macrofossil records of the late-glacial - Holocene transition in the Hudson Highlands reveal the following:

1 Prior to 12,600 yr B.P., a tundra-like open vegetation existed, possibly containing arboreal communities of limited extent.

2 Inferred MTAs for *Picea, Pinus strobus,* and *Tsuga canadensis* are, respectively, dated at 12,600, 10,120, and 9540 yr B.P.

3 A mixed assemblage of boreal and temperate taxa, consisting of *Picea, Abies, Betula papyrifera, Quercus, Ostrya/Carpinus,* and *Fraxinus,* is evident between 12,600 and 11,200 yr B.P., under a comparatively mild climate. An *Alnus/Picea/Abies* assemblage is later representative of climatic cooling between 11,200 and 10,120 yr B.P. Warmer conditions were established at 10,120 yr B.P., as suggested by the expansion of *Pinus strobus* and increases in percentages of *Quercus* and *Ostrya/Carpinus,* followed by replacement of *Betula papyrifera* with *Betula populifolia.*

4 Dramatic environmental change occurred at 12,600 yr B.P., as indicated by the increase of organic deposition, first occurrence of macrofossils, and large increases in PI.

5 A clear expression of the YD climatic reversal is present in the pollen and macrofossil records between 11,200 and 10,120 yr B.P.

6 The onset (<11,200 yr B.P.) and termination (10,120 yr B.P.) of the YD occurred rapidly within 150 years.

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TABLE 1

AMS C-14 ages for the late-glacial - Holocene transition, Sutherland Pond, N.Y.

CAMS#	Sample depth(cm)	Sample type	Carbon weight	AMS C-14 Age (yr B.P.)
11441	770	1 cm^3 sediment	--	9540 ± 60
9502	785-790	*Pinus strobus* needle fragments(6)	0.2 mg	9630 ± 70
11442	795	1 cm^3 sediment	--	10,120 ± 60
8393	805	*Abies* seed(1)	60 µg	9660 ± 180 (reject)
11443	812.5	1 cm^3 sediment	--	11,200 ± 60
8392	830-835	*Picea* needle and seed	26 µg	12,600 ± 380

TABLE 2

Lithology of sediments in Sutherland Pond core, New York.

Core segment (cm)	Sediment description	
675 - 787	Reddish black (2.5 YR 2.5/1)*	gyttja
787-835	Dark reddish gray (2.5 YR 3/1)*	clayey gyttja
835-1070	Reddish gray (2.5 YR 6/1)*	clay

*Munsell Soil Color Charts (1992)

TABLE 3

Pollen in surface samples:

Taxon	Eastern Canada*		Central Canada**		Pollen
	shrub tundra	forest-tundra	shrub tundra	forest-tundra	from zone SUP-T
	%	%	%	%	%
Pinus	3.4-8.7	3.5-12.3	19.89	22.84	2.0-65.0
Picea	15.9-26.3	41.5-49.1	10.38	32.66	0.4-7.0
Alnus	5.7-16.7	10.1-17.5	9.51	15.29	1.6-32.0
Betula	22.0-27.7	18.2-18.6	24.03	13.99	0.5-11.0
Cyperaceae	17.4-18.9	6.1-7.9	19.82	5.11	2.4-60.0
Gramineae	1.7-6.0	1.0-1.5	2.98	0.95	0.3-17.0
Quercus	0	0.3	0	0.19	0.9-9.0

*Davis and Webb, 1975; King, 1993
** Webb and McAndrews, 1976

TABLE 4 Selected northeast USA sites indicating minimum arrival times for *Picea*, *Pinus strobus*, and *Tsuga canadensis*. * indicates AMS date

Reference	Site	Fossil type	C-14 age (yr B.P.)
1 Watts (1979)	Tannersville Bog, PA	Picea macrofossils	13,000
		Pinus strobus macrofossils	11,500
		Tsuga canadensis pollen and macrofossils	9700
2 Peteet *et al.* (1990)	Alpine Swamp, NJ	Picea macrofossils	12,300*
		Pinus strobus macrofossils	10,000*
		Tsuga canadensis pollen influx peak	9500*
3 Peteet *et al.*(1993)	Linsley Pond, CT	Picea macrofossils	12,600*
		Pinus strobus macrofossils	11,000*
	Allamuchy Pond, NJ	Picea macrofossils	12,300*
4 Maenza-Gmelch (this paper)	Sutherland Pond, NY	Picea macrofossils	12,600*
		Pinus strobus macrofossils	10,120*
		Tsuga canadensis macrofossils	9540*
5 Davis (1969)	Rogers Lake, CT	Picea pollen influx peak	12,300
		Pinus strobus pollen % and influx maxima	10,000
		Tsuga canadensis pollen influx maximum	9200
6 Spear *et al.* (1994)	Mirror Lake, NH (213 m elevation)	Picea macrofossils	11,400
		Pinus strobus macrofossils	9900
		Tsuga macrofossils	7500
7 Jackson (1989)	Adirondack Mts, NY. (661 m elevation)	Picea macrofossils	>12,000
		Pinus strobus macrofossils	9000
		Tsuga canadensis macrofossils	7400

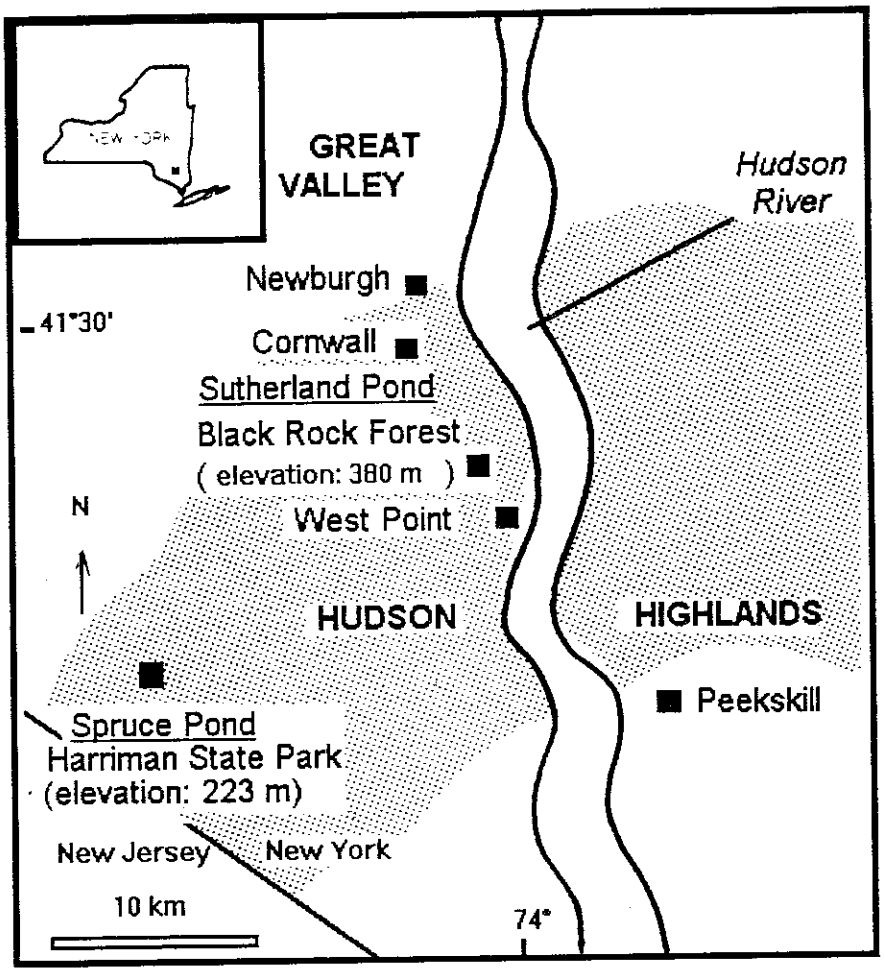


Fig. 1. Lower Hudson Valley, southeastern New York showing locations of Sutherland Pond, Spruce Pond, Hudson Highlands (shaded area), and other places and features mentioned in the text.

Fig. 2. Diagram of pollen and spore frequencies, LOI, and AMS radiocarbon chronology spanning the late-glacial and early Holocene from Sutherland Pond, New York. Closed circles indicate values <1%.

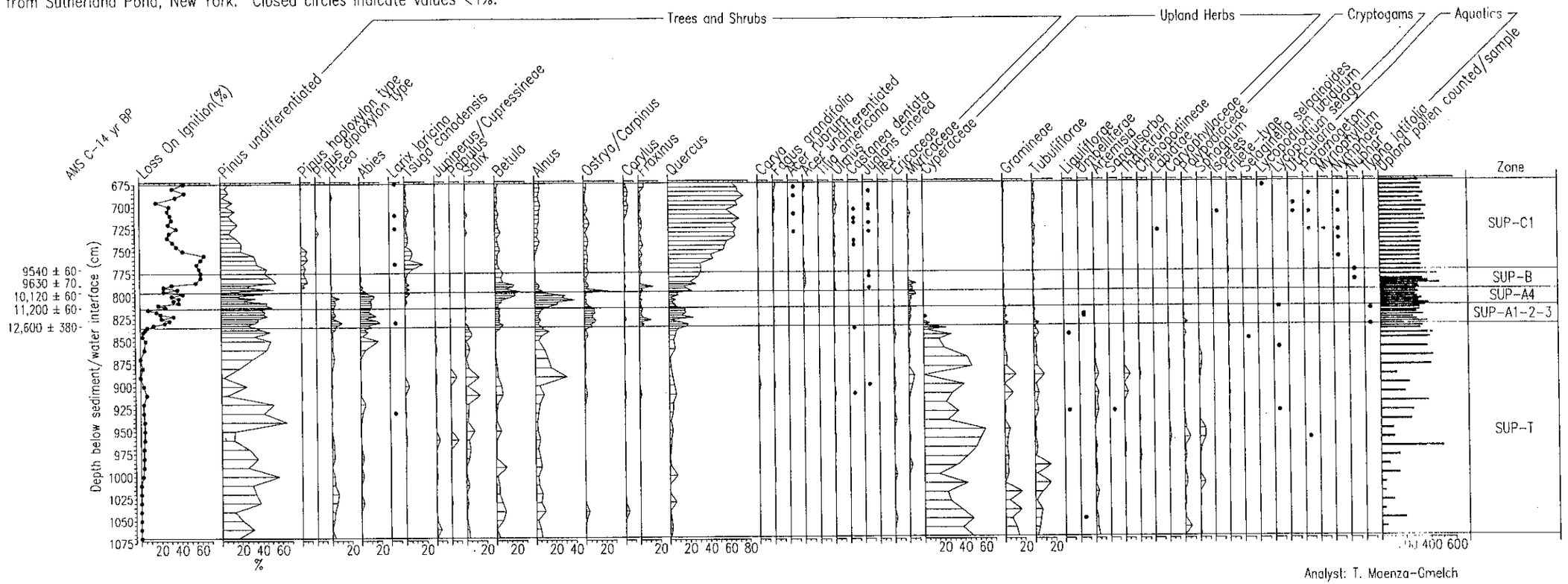
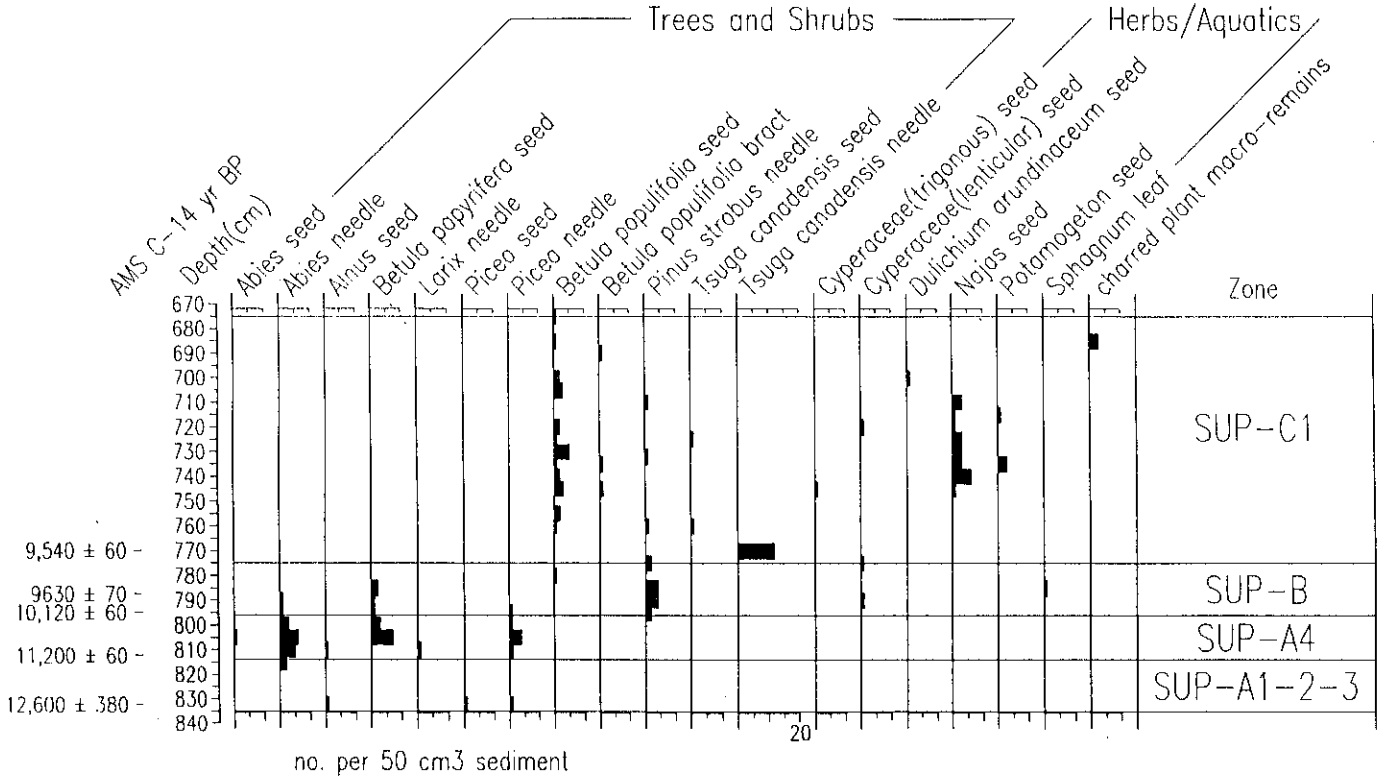


Fig. 3. Diagram of plant macrofossils (no. per 50 cm3 sediment) and AMS radiocarbon chronology spanning the late-glacial and early Holocene from Sutherland Pond, New York.



Analyst: T. Moenza-Gmelch

Fig. 4. Diagram of selected pollen frequencies (%), plant macrofossil concentrations (no./50 cm3 sediment), AMS radiocarbon chronology, and LOI for the late-glacial and early Holocene from Sutherland Pond, N.Y. Macrofossil concentrations are presented as histograms.

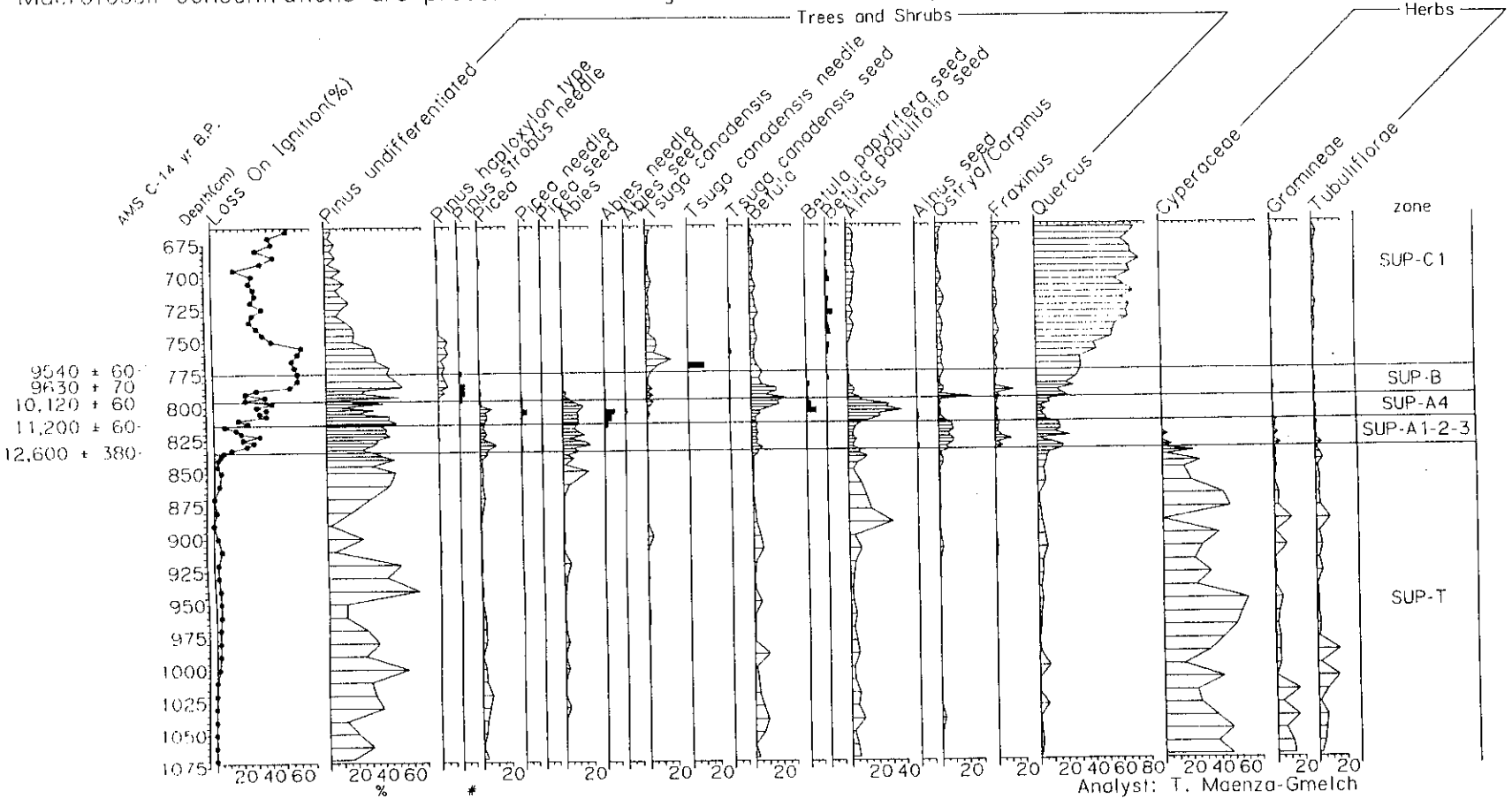
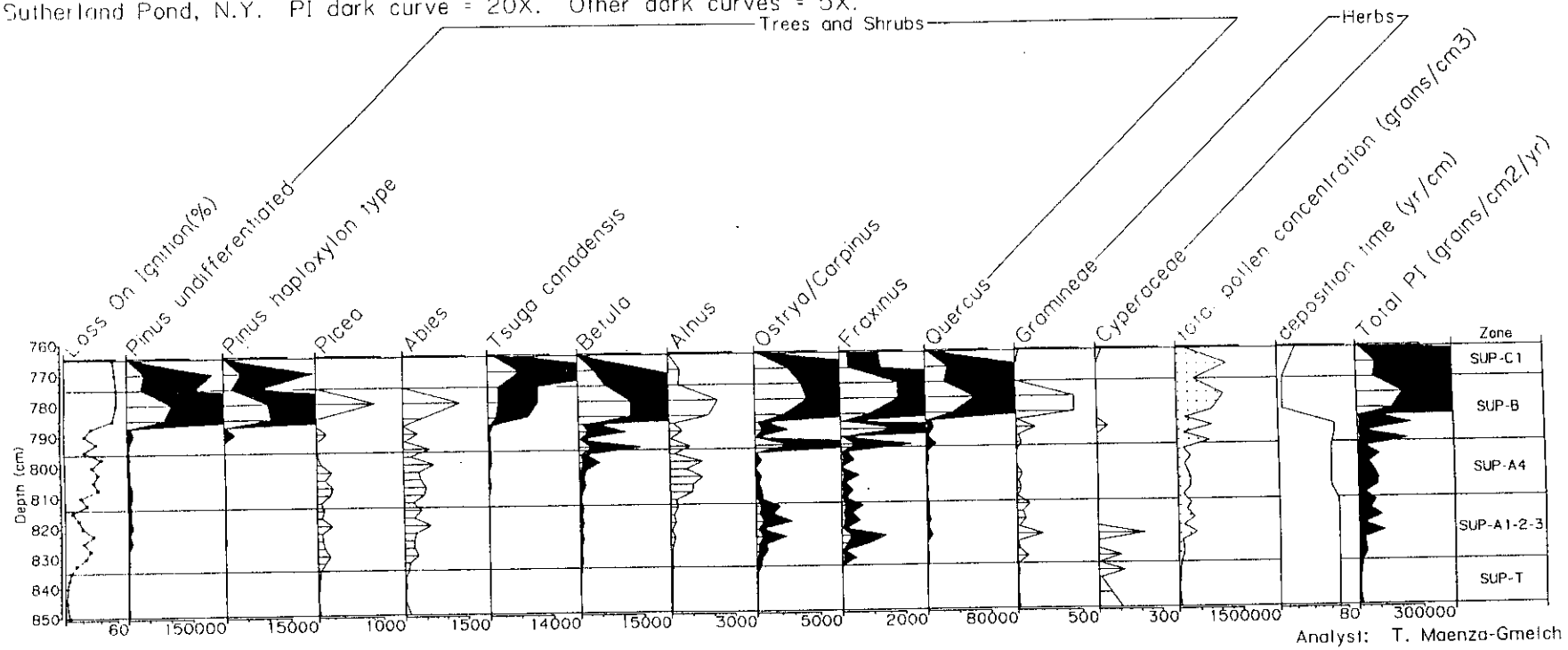


Fig. 5. Diagram of pollen influx (grains/cm2/yr) for selected taxa, LOI, total pollen concentration (grains/cm3), deposition time (yr/cm), and total pollen influx for the late-glacial and early Holocene from Sutherland Pond, N.Y. PI dark curve = 20X. Other dark curves = 5X.



PART 2

Vegetation and climate during the late-glacial - Holocene transition at Spruce Pond, Hudson Highlands, southeastern New York, U.S.A.

ABSTRACT

AMS-dated pollen and plant macrofossil records from Spruce Pond (41°14'22"N, 74°12'15"W), Harriman State Park, southeastern New York, provide further details about late-glacial - early Holocene vegetation development in the Hudson Highlands from >12,410 to 9750 radiocarbon yr B.P. At >12,410 yr B.P., vegetation was apparently open and mostly tundra-like. *Picea* appears to have invaded the landscape at 12,410 yr B.P. followed by development of a temperate deciduous-boreal coniferous forest. A return of predominantly boreal forest between 11,140 and 10,230 yr B.P. is interpreted to represent an expression of the Younger Dryas cooling event. Holocene warming at 10,230 yr B.P. is signaled by arrival of *Pinus strobus*, coincident with expansion of *Quercus*-dominated forest. *Tsuga canadensis* became established at 9750 yr B.P.

INTRODUCTION

Recent refinement of late-glacial - early Holocene vegetation history in northern New Jersey and southern Connecticut (Peteet *et al.*, 1990; 1993) is the result of close-interval pollen stratigraphy augmented by macrofossil analysis and AMS radiocarbon dating. This more detailed paleoecological 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 U.S.A (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 geographic area represented by fine-resolution 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, submitted). 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 characterize vegetation and climate of the Highlands between >12,500 and 9500 radiocarbon yr B.P.

SETTING

Physical features of the core site and deglaciation

Spruce Pond, the core site, 2.6 ha in surface area, situated at 223 m elevation, with maximum water depth of 5 m, lies within 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. The pond drains southeast toward the Ramapo River (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 characterized 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 B.P., based on assumed late-glacial sedimentation rates (Connally *et al.*, 1989). The chronological setting of ice retreat regionally 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-year period (1918-1948) indicate 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).

Vegetation

The forests of southeastern New York are included in the *Quercus-Castanea* region of the eastern deciduous forest by Braun (1964), while 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 basin of Spruce Pond 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-center, in shallower waters. A sediment core, totalling 10.4 m, was retrieved in meter 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). Identification of pollen and spores are based on descriptive keys (Kapp, 1969; McAndrews *et al.*, 1973; and Faegri and Iversen, 1989), as well as a pollen and spore reference collection. Light microscopy was used to identify and count pollen; routine counting was done at 400X magnification and critical identifications at 1000X. 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) are based

on the sum of those groups. Aquatics are based on the sum of all pollen, cryptogams 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). Amounts of organic matter in the core are the results of loss-on-ignition (LOI) measurements at 550°C (Bengtsson and Enell, 1986). Pollen percentage and influx diagrams were constructed using Tilia-graph© software developed by E.C. Grimm. 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 hrs at 4°C and washing through 150 micron sieves. All particles >150 microns were inspected and recognizable plant remains hand-picked and identified using a dissection microscope at 40X 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). Ecologically significant conifer

needles, seeds, and small sediment samples (1 cm^3) were air-dried and sent for AMS radiocarbon age determinations.

RESULTS

Fossil pollen and plant macrofossil zonation

Pollen stratigraphy of the Spruce Pond core is divided into pollen assemblage zones according to the standard southern New England system of zonation (Leopold, 1956; Deevey, 1958). Included are diagrams of all pollen and macrofossils (Figs. 2, 3); selected pollen and plant macrofossils (Fig. 4); and pollen influx (PI) (Fig. 5). In addition, four AMS radiocarbon age determinations establish the chronology for the late-glacial - Holocene transition (Table 1), and the sediment lithology is described (Table 2).

Zone SPP-T: *Pinus*-Cyperaceae (>12,410 yr B.P.; 1010-865 cm).

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, Umbelliferae, *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 PI (< 8000 grains/cm^2/yr) and LOI (6%) are low. No macrofossils were found in this core segment.

Zone SPP-A1-2-3: *Pinus-Picea-Abies-Ostrya/Carpinus-Fraxinus-Quercus* (12,410 to 11,140 (interpolated age) yr B.P.; 865-840 cm).

Zone SPP-A1-2-3 commences with expansion of arboreal types, increase in total PI (12,000 grains/cm²/yr), onset of macrofossil deposition, and a rise in LOI (mean value 18%). A combination of boreal (*Picea, Abies*) and temperate (*Quercus, Fraxinus, Ostrya/Carpinus*) trees characterizes 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* PI (530 grains/cm²/yr) at 850 cm (12,410 yr B.P.). *Picea* needles are found later in the zone as well. Percent and PI of shrubs (*Alnus, Betula, Salix*) and herbs decrease relative to zone SPP-T. Seeds of aquatic plants (*Potamogeton* and *Najas*) are present. Sedimentation rate is relatively slow (1 cm accumulated in approximately 80 years).

Zone SPP-A4: *Picea-Abies-Alnus-Betula papyrifera* (11,140 to 10,230 yr B.P.; 840-805 cm).

Expansion of boreal trees and decline of temperate trees characterize this zone. Pollen percentage and influx values of *Quercus, Fraxinus,* and *Ostrya/Carpinus* decline between 840 and 835 cm, at approximately 11,000 yr B.P. LOI values remain relatively stable. *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*. Increase of temperate

tree pollen coincides with reduction of *Alnus* and *Betula papyrifera* at 805 cm. The first *Tsuga canadensis* pollen (1%) occurs at 810 cm. *B. papyrifera* is present in the macrofossil record. Seeds of aquatic plants are no longer present. Deposition time is rapid (20 - 80 yr/cm) relative to that in zone SPP-A1-2-3 (80 yr/cm).

Zone SPP-B: *Pinus strobus-Quercus* (10,230 to 9750 yr B.P.; 805-785 cm).

The spread of *Pinus strobus* and *Quercus*, as reflected in pollen frequency and influx values, is the feature of zone SPP-B. *Pinus strobus* rises from 0 to 7% and 0 to 7700 grains/cm²/yr between 810 and 805 cm. *Quercus* continually expands (19 to 40%; 3000 to 21,000 grains/cm²/yr). *Fraxinus* and *Ostrya/Carpinus* recover from their SPP-A4 zone low. Frequencies of *Picea* and *Abies* reach zero. *Potamogeton* is the only macrofossil taxon present. LOI increases from 14 to 23%. Deposition time is slightly slower (1 cm accumulated in approximately 20 years) than that in zone SPP-A4. The boundary between zone SPP-B and overlying zone SPP-C1 is defined by an expansion of *Tsuga canadensis* pollen percentage and influx values at 785 cm.

VEGETATION OF THE LATE-GLACIAL - HOLOCENE TRANSITION

Prior to 12,410 yr B.P. open vegetation dominated by herbs and shrubs existed in the vicinity of Spruce Pond. Trees may have been scattered on the landscape; in the absence of macrofossils in zone SPP-T, the presence of trees cannot be confirmed. Tree pollen present (*Pinus, Picea*, plus very low percentages of *Quercus, Fraxinus*, and *Ostrya/Carpinus*) possibly represents long distance transport in a setting of low pollen productivity of the tundra-like vegetation. Cyperaceae, Tubuliflorae, and *Artemisia* dominated early at Spruce Pond but became less important as small trees/shrubs (*Alnus, Betula, Salix*, Ericaceae) expanded in response to climatic warming.

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 a tundra-like environment. These taxa are also found in the eastern Canadian shrub 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 Tubuliforae colonize unstable soils undergoing solifluction.

Pollen of *Pinus* (~3 - 20%) and *Picea* (~2 - 26%) in surface samples from treeless landscapes, for example, alpine-tundra in the White Mountains of New Hampshire and the tundra of eastern and central Canada, has been documented (Davis and Webb, 1975; Webb and McAndrews, 1976; Spear, 1989; King, 1993) and further supports the interpretation of tundra from the pollen record at Spruce Pond despite the presence of some tree pollen.

Denny (1938), studying the glacial geology of the Black Rock Forest in the Hudson Highlands, 22.5 km to the northeast of Spruce Pond, recognized evidence of 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 tundra-like vegetation at Spruce Pond and at Sutherland Pond, New York (Maenza-Gmelch, submitted), 22.5 km northeast of Spruce Pond. Unfortunately, the length of time between deglaciation and the close of the tundra period in the Hudson Highlands is not known due to the absence of datable organic material in the basal clays at each site.

Spores of *Selaginella selaginoides*, a largely circumpolar arctic-alpine species extending south to the Great Lakes region (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 B.P. (Maenza-Gmelch, submitted). Sutherland Pond is situated 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 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. *L. selago,* largely circumpolar arctic-alpine in distribution, extends further southward into sub-boreal regions than does *S. selaginoides* (Fernald, 1950). *L. 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 farther south than the Catskill Mountains, which are approximately 60 km north of the Hudson Highlands (New York Flora Association, 1990.) The presence of spores of *L. selago* and/or *S. selaginoides* in T-zone sediments from Spruce and Sutherland Ponds might indicate that climate in the Hudson Highlands prior to approximately 12,500 yr B.P. was colder than at present.

Dramatic environmental change began at Spruce Pond at 12,410 yr B.P., as indicated by large-scale colonization of the landscape by boreal (*Picea, Abies*) and temperate (*Quercus, Fraxinus, Ostrya/Carpinus*) trees and overall increase in PI and LOI. *Picea* was the first tree to arrive at 12,410 yr

B.P., evidenced by a seed in the macrofossil record. No *Quercus* macrofossils were found, however, and the presence of *Quercus*, as well as of other temperate trees, is only inferred. This inference is based on the occurrence of *Pinus strobus*, an associate, amoung macrofossils at Linsley Pond, southern Connecticut (Peteet *et al.*, 1993) at 11,000 yr B.P. Since *Quercus* and *Pinus strobus* have similar northern distributional limits (Burns and Honkala, 1990), it is conceivable that *Quercus* was in southeastern New York at the same time. The rise in LOI and appearance of macrofossils of aquatics (for example, *Potamogeton* and *Najas*) may indicate an increase of pond productivity.

Beginning at 12,410 yr B.P., rise in the rate of organic deposition, expansion of temperate forest trees, and the eventual decline of *Picea* are considered indicative of a warming trend. Increased organic deposition at about this time is also a feature at Alpine Swamp, New Jersey (12,800 yr B.P.), Allamuchy Pond, New Jersey (12,400 yr B.P.), Linsley Pond, Connecticut (12,400 yr B.P.) (Peteet *et al.*, 1990, 1993), and Sutherland Pond, New York (12,600 yr B.P.) (Maenza-Gmelch, submitted). Peteet considers this an indication of major regional warming in the Northeast correlative with the Bølling/Allerød warming of Europe and Greenland. In northwest Europe during the Bølling chronozone (13,000 - 12,000 yr B.P.), *Juniperus* and *Betula* regionally replaced the earlier heliophilous herbaceous vegetation (Bohncke *et al.*, 1988); in

southwest Europe, at approximately 13,000 yr B.P., herbaceous vegetation was invaded by *Juniperus, Betula,* and *Pinus* (Beaulieu *et al.*, 1994).

The transition from zone SPP-A1-2-3 to SPP-A4, occurring at approximately 11,000 yr B.P., is marked by a reversal in temperate forest development. Boreal tree species displaced temperate species during nearly 1000 years between 11,140 and 10,230 yr B.P. This event falls within the European YD chronozone (approximately 11,000 to 10,000 yr B.P.) 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.

The chronology and vegetation characteristics of this cooling event in the Northeast were initially presented by Peteet *et al.* (1990; 1993) from data at sites in northern New Jersey and southern Connecticut. Mayle *et al.* (1993) has subsequently established the timing of the YD in Atlantic Canada. At Spruce Pond during the cooling trend, it appears that populations of temperate *Quercus, Fraxinus,* and *Ostrya/Carpinus* were reduced at 11,140 yr B.P. Light demanding *Alnus,* then *Betula papyrifera* 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.* Rapid recovery of temperate tree species, principally *Quercus,* at 10,230 yr B.P. resulted in the reduction of *Alnus* and *Betula papyrifera,* most likely by shading.

Vegetation near Spruce Pond appears to have responded quickly to the onset/termination of YD age conditions. In the more closely sampled record from Sutherland Pond (Maenza-Gmelch, submitted), rapid vegetation response (< 150 years) was calculated for the onset and termination of cooling. Peteet *et al.* (1993) estimate that vegetation in northern New Jersey and southern Connecticut responded to warming at 10,000 yr B.P. in 50 to 100 years, suggesting the rapidity of the warming.

Holocene climatic warming at Spruce Pond is registered by the arrival of *Pinus strobus* at 10,230 yr B.P. 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*. At 9750 yr B.P., just after the close of zone SPP-B, *Tsuga canadensis* pollen expanded, suggesting the arrival of *Tsuga canadensis*. 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, which shows comparable amounts of pollen and in addition macrofossils.

Pinus strobus arrived at Sutherland Pond at 10,120 yr B.P. and *Tsuga canadensis* at 9540 (Maenza-Gmelch, submitted). Since 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 geographic positions.) It appears that *Pinus strobus* may have migrated at the rate of 0.2 km/yr while *Tsuga canadensis* migrated more slowly at the rate of 0.1 km/yr.

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 (Fig. 6). 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, submitted) and Alpine Swamp, New Jersey (Peteet *et al.*, 1990). The increased LOI could possibly be indicative of well-developed upland soil that is needed for establishment of *Tsuga canadensis* (Burns 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 B.P. in the vicinity of Spruce Pond, southeastern New York.

2 A mixed deciduous-coniferous forest developed between 12,410 and 11,140 yr B.P., featuring *Picea, Abies, Quercus, Fraxinus*, and *Ostrya/Carpinus* with *Picea* arriving at 12,410 yr B.P. It appears that pond productivity also increased.

3 A reversal in temperate forest development occurred between 11,140 and 10,230 yr B.P., 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 B.P., while climate warmed as evidenced by the arrival of *Pinus strobus* and expansion of *Quercus*. *Tsuga canadensis* arrived at 9750 yr B.P.

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TABLE 1

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

CAMS#	sample depth (cm)	vegetation event dated	carbon weight*	AMS C-14 age (yr B.P.)
15879	785	*Tsuga* arrival	5.1mg	9750 ± 60
15880	805	*Pinus strobus* arrival	5.1mg	10,230 ± 60
11444	830	YD onset	2.3 mg	10,720 ± 80
13243	850	*Picea* arrival	11.9 mg	12,410 ± 70

*after sample pretreatment and graphitization at CAMS

TABLE 2

Lithology of sediments in Spruce Pond core, New York.

Core segment (cm)	Sediment description
750 - 855	dark reddish gray (2.5 YR 3/1)*
	clayey gyttja
855 - 910	reddish gray (2.5 YR 6/1)*
	clay

*Munsell Soil Color Charts (1992)

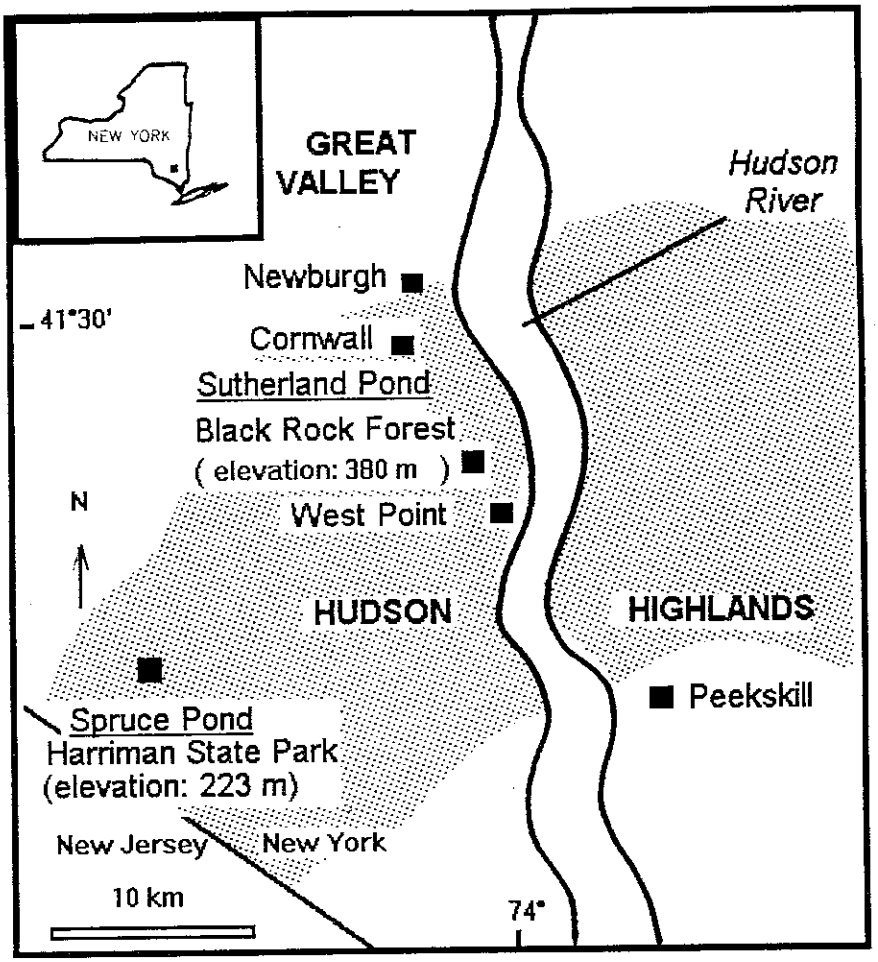


Fig. 1. Lower Hudson Valley, southeastern New York showing locations of Sutherland Pond, Spruce Pond, Hudson Highlands (shaded area), and other places and features mentioned in the text.

FIG. 2. Diagram of pollen and spore frequencies, LOI, and AMS radiocarbon chronology spanning the late-glacial and early Holocene at Spruce Pond, New York. Closed circles indicate values <1%. Analyst: T. Maenza-Gmelch

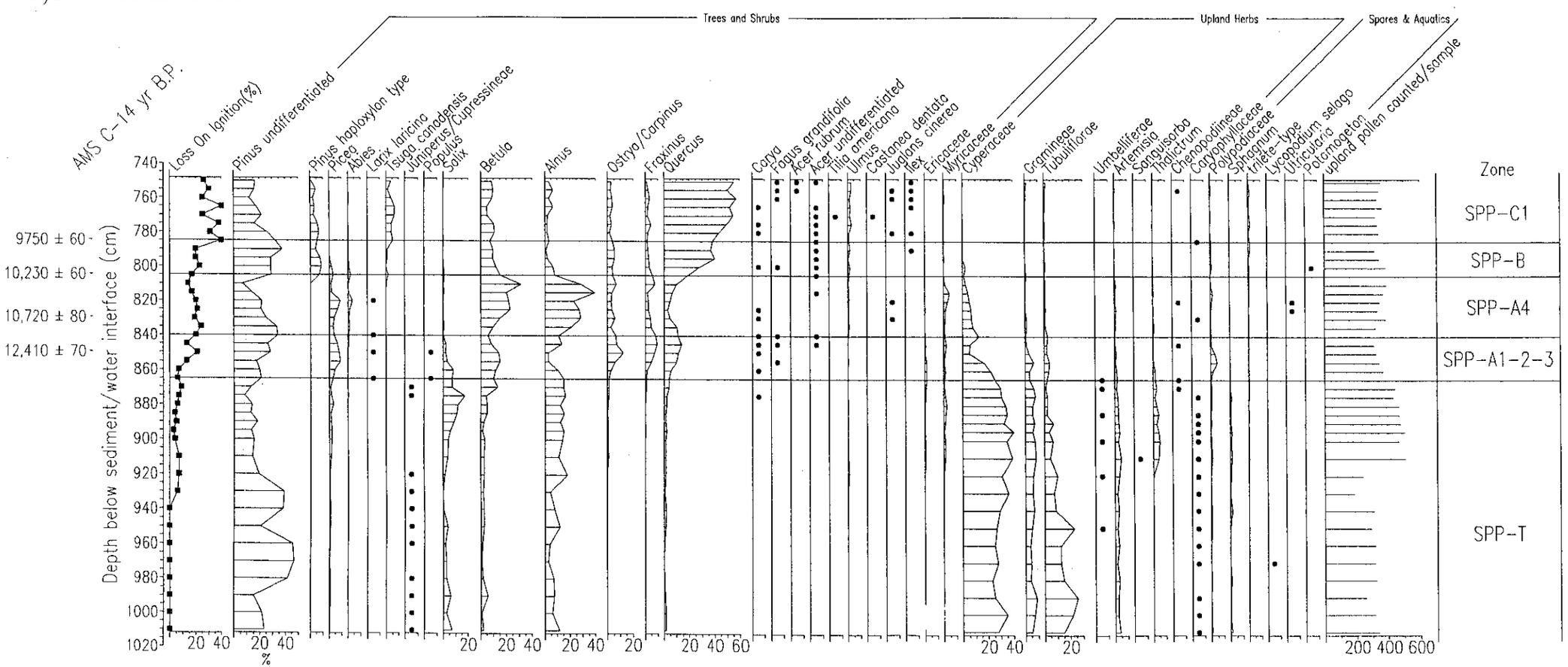
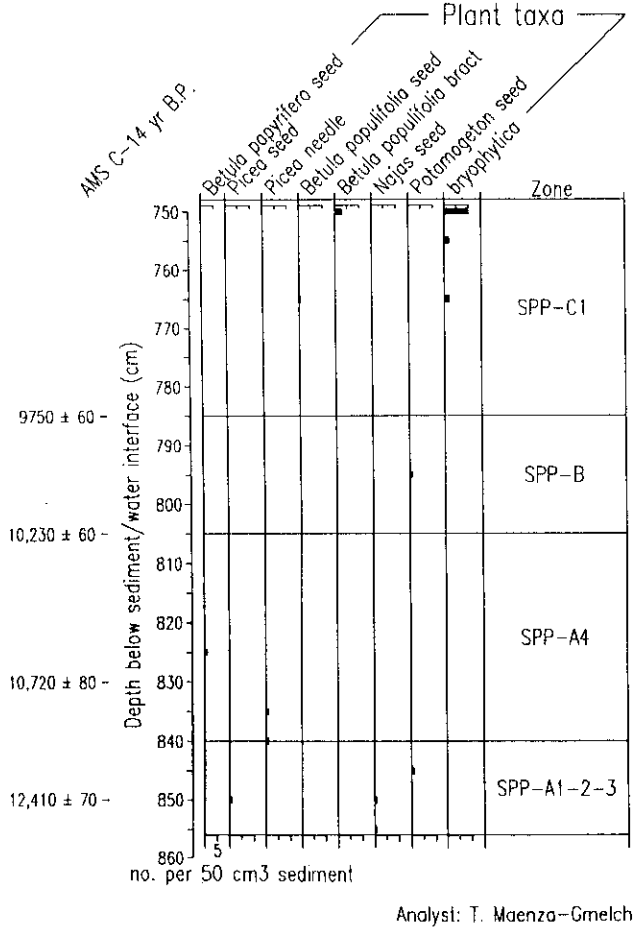


Fig. 3. Diagram of plant macrofossils (no. per 50 cm3 sediment) and AMS radiocarbon chronology spanning the late-glacial and early Holocene at Spruce Pond, N.Y.



Analyst: T. Maenza-Gmelch

Fig. 4. Diagram of selected pollen frequencies (%), plant macrofossil presence (indicated by closed circle), AMS radiocarbon chronology, and LOI for the late-glacial and early Holocene at Spruce Pond, New York.

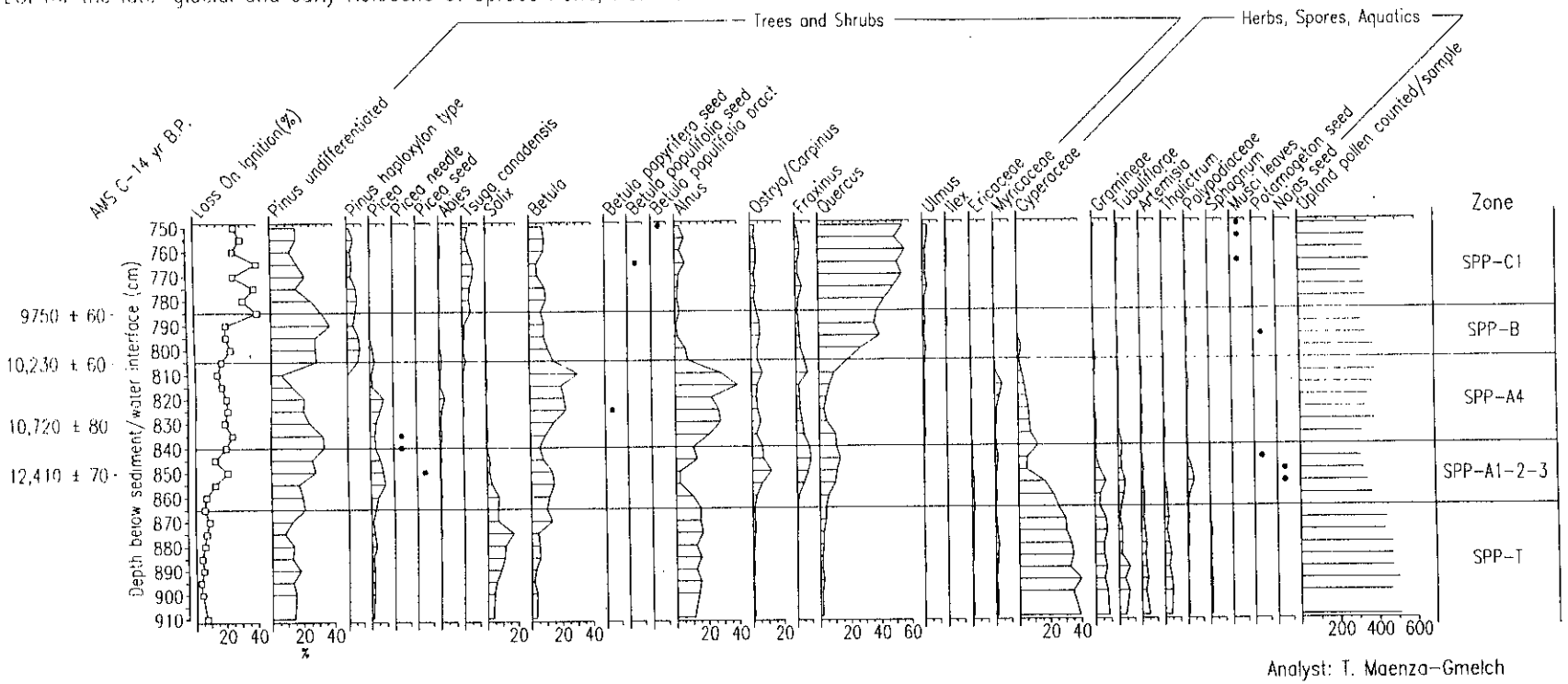
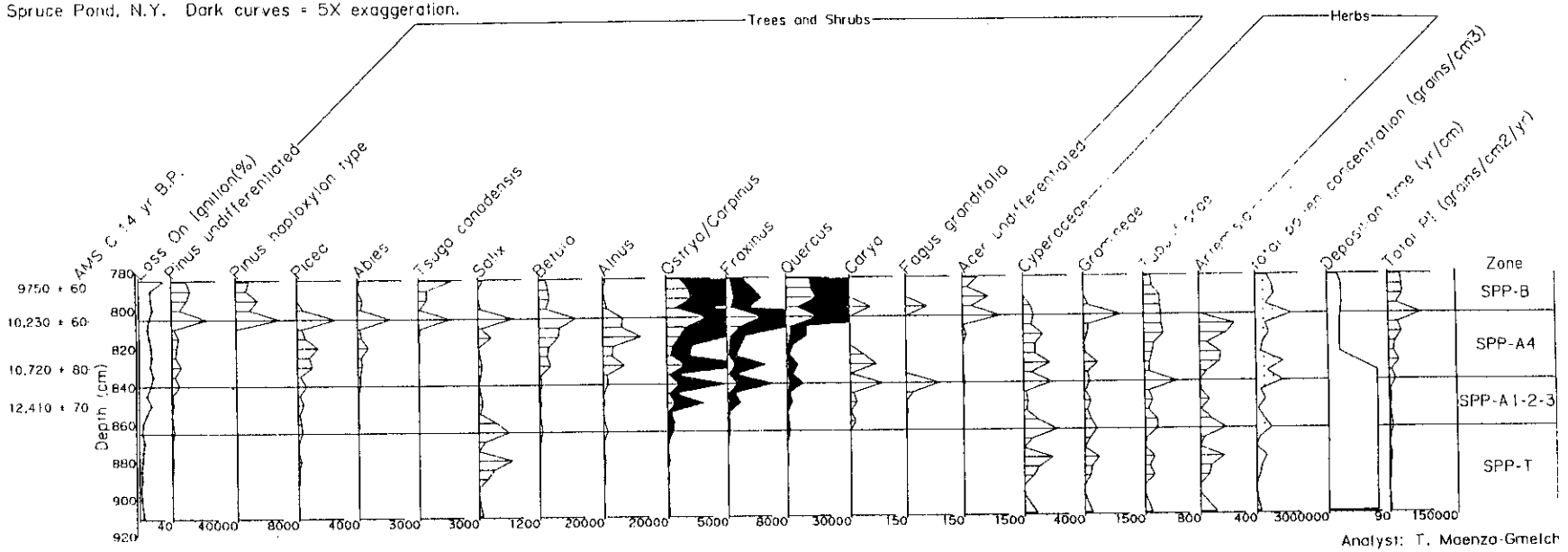


Fig. 5. Diagram of pollen influx (grains/cm2/yr) for selected taxa, LOI, total pollen concentration (grains/cm3), deposition time (yr/cm), and total pollen influx for the late-glacial and early Holocene from Spruce Pond, N.Y. Dark curves = 5X exaggeration.



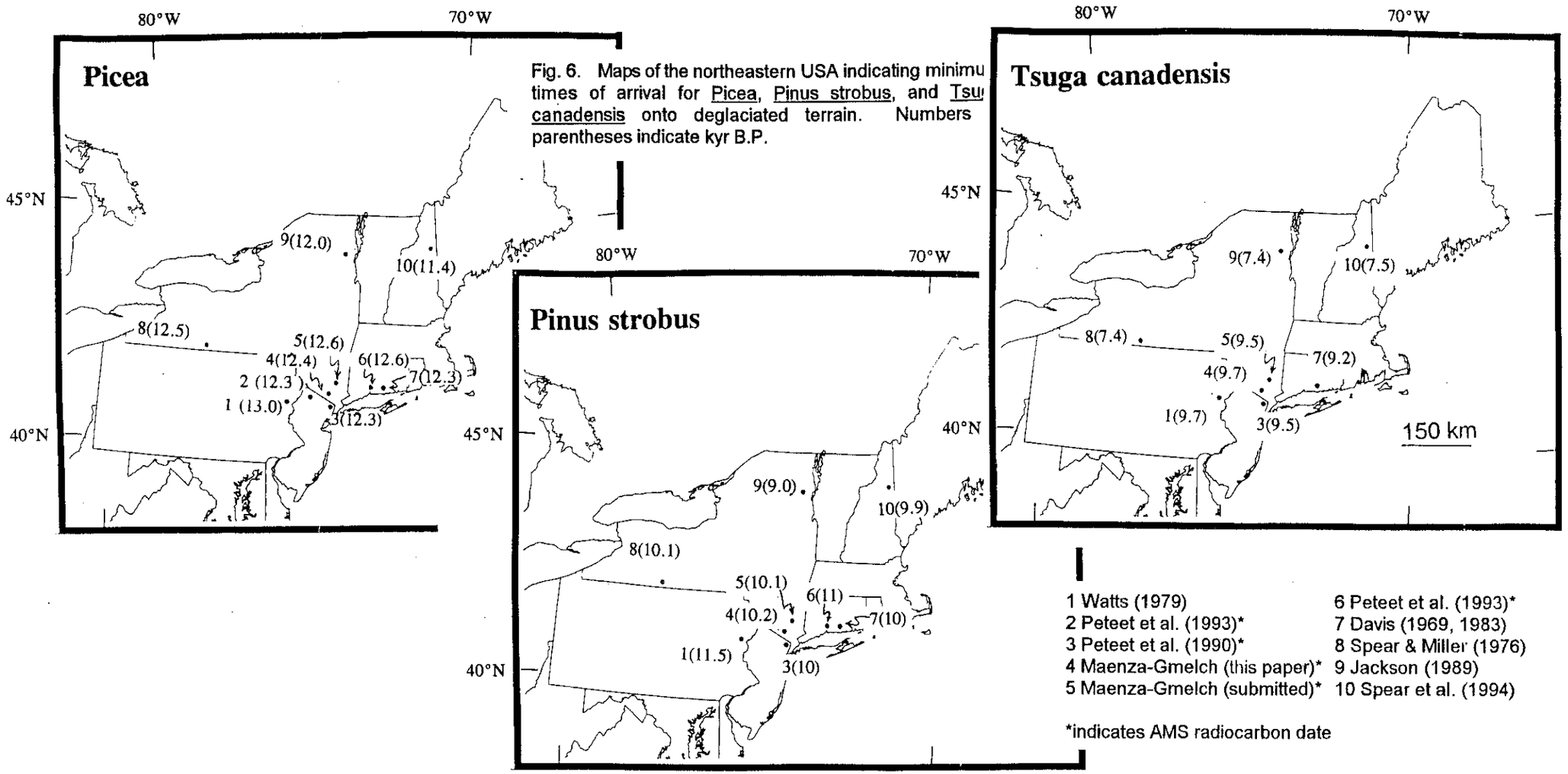


Fig. 6. Maps of the northeastern USA indicating minimu times of arrival for Picea, Pinus strobus, and Tsu canadensis onto deglaciated terrain. Numbers parentheses indicate kyr B.P.

1 Watts (1979)
2 Peteet et al. (1993)*
3 Peteet et al. (1990)*
4 Maenza-Gmelch (this paper)*
5 Maenza-Gmelch (submitted)*
6 Peteet et al. (1993)*
7 Davis (1969, 1983)
8 Spear & Miller (1976)
9 Jackson (1989)
10 Spear et al. (1994)

*indicates AMS radiocarbon date

PART 3

Holocene vegetation, climate, and fire history of the Hudson Highlands, southeastern New York, U.S.A.

ABSTRACT

AMS radiocarbon-dated pollen, plant macrofossil, and charcoal records from Sutherland Pond (41°23'29"N, 74°02'16"W) and Spruce Pond (41°14'22"N, 74°12'15"W) provide insight into the Holocene vegetation, climate, and fire histories of the Hudson Highlands, lower Hudson Valley, southeastern New York. Rapidly expanding *Quercus*-dominated forests were invaded by *Pinus strobus* at 10,175 yr B.P., followed by *Tsuga canadensis* at 9645, *Fagus grandifolia* at 8100, *Carya* at 6200, and *Castanea dentata* at 3600 yr B.P. *Quercus* remained consistently high from approximately 8600 yr B.P. until 1700 A.D. Large charcoal densities are associated with *Quercus* for the same period, suggesting that fire may have played an important role in the development and maintenance of *Quercus* in the forest. Onset of Euroamerican agricultural practices in the region (approximately 1700 A.D.) is well-documented by rises in pollen of *Ambrosia*, Gramineae, and Tubuliflorae and presence of *Rumex* and *Plantago*. Settlement and industrial use of *Quercus*, *Pinus*, and *Tsuga canadensis* is also recorded by

decreased percentages of these trees. Large charcoal densities at both sites during Euroamerican settlement may be explained by fire in connection with land-clearance, wood-related industries (charcoal, iron, and brick manufacturing), and operation of railroads (track fires).

INTRODUCTION

Holocene pollen stratigraphy of southern New England, first described by Deevey (1939), features four pollen assemblage zones: *Pinus* (B), *Quercus-Tsuga* (C-1), *Quercus-Carya* (C-2), and *Quercus-Castanea* (C-3). Subsequent investigations applied this scheme widely in the Northeast. These include southern Connecticut (Leopold, 1956), west-central Massachusetts (Davis, 1958), northeastern New Jersey (Heusser, 1963), Long Island, New York (Sirkin, 1971), lower Hudson Valley, New York (Weiss, 1974), Allegheny Plateau area of New York (Spear and Miller, 1976), northern New Hampshire (Davis *et al.*, 1980), Cape Cod, Massachusetts (Winkler, 1985), the coastal islands of southeastern New England (Dunwiddie, 1990), and the Adirondack Mountain region of New York (Whitehead and Jackson, 1990).

The Holocene epoch, characterized by temperatures higher than in the Pleistocene, was the stage for dramatic vegetational change as exemplified by these pollen assemblage zones. Following deglaciation, trees 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 United States (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 quite different from those of today.

The major determinant of increased temperature during the Holocene has been orbitally-induced insolation variations (Berger, 1978). Earth-sun geometry at 9,000 yr B.P., for example, shows perihelion in July and maximum axial tilt, placing earth's northern hemisphere closest to the sun and greater maximum seasonality of solar radiation at approximately 7% more 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 9,000 yr B.P. (R. S. Webb *et al.*, 1993). Peak dryness at 9,000 yr B.P. in the Northeast is also evident from low lake levels, as a result of conditions drier than today by 10% or more (Webb *et al.*, 1993).

Davis *et al.* (1980) inferred the interval of maximum warmth during the Holocene from altitudinal range extensions (300 to 400 m) of *Pinus strobus* and *Tsuga canadensis* in the White Mountains of New Hampshire. They estimate a 2°C increase in temperature and 400 mm decrease in precipitation compared to today during 9,000 to 5,000 yr B.P. Jackson (1989), using the same principle, inferred a 1.6°C temperature increase and 66 to 100 mm decrease in precipitation for the Adirondack Mountains.

Superimposed on the influence of climate on vegetation are the effects of other factors, which include plant pathogen outbreaks, for example, the mid-Holocene *Tsuga* decline (Davis, 1981b) and the early twentieth century *Castanea* decline (Anderson, 1974). Additional important factors are fire (Clark and Robinson, 1993) and human disturbance (Russell *et al.*, 1993). Thus, interpretation of vegetation change inferred from the fossil record requires identification and isolation of a multitude of potential causal factors.

Investigation of the possible past influence of fire on an ecosystem typically involves charcoal particle analysis in association with pollen analysis. Charcoal particles preserve well and are abundant in pond and lake sediments (Patterson *et al.*, 1987). It has been demonstrated that, for small basins (2-3 ha), stratigraphic charcoal can accurately reflect fire activity within a watershed (Patterson and Backman, 1988). Swain (1973) has also shown the reliability with which basins record charcoal from local fires by comparing stratigraphic charcoal peaks from varved lake sediments with fire-scarred tree ring data and historical records. However, data from Swain (1973) and Cwynar (1978) indicate that the estimate of fire frequency from stratigraphic charcoal analysis is probably conservative.

Most methods of charcoal analysis employ light microscopy to quantify charcoal present on pollen slides. For example, Waddington (1969) used a grid of squares of known area in the

microscope eyepiece in order to measure charcoal particle area in size classes. R.L. Clark (1982) introduced a point count method to estimate charcoal area, without separation of particles into size classes. Patterson *et al.* (1987) point out that charcoal particle size is not a reliable parameter with which to estimate charcoal particle source area because taphonomic and laboratory processes alter particle size. J.S. Clark (1988) introduced a petrographic thin-section method in order to observe stratigraphic charcoal in its original form and orientation within the sediment matrix. While this method eliminates unwanted modifications of particle size during laboratory procedure, it is labor intensive and requires abundant core material.

Observation of current fire regimes and analysis of historic documents suggest that fires may have occurred regularly in *Quercus* forests for thousands of years (Abrams, 1992; Clark and Robinson, 1993). However, current fire regimes cannot be readily extrapolated to presettlement time due to changes in climate; also, historic records might have been biased (Russell, 1983; Clark and Robinson, 1993). Additional stratigraphic charcoal data are needed to determine if fire has been a factor promoting *Quercus* dominance (Abrams, 1992).

Stratigraphic charcoal measurements obtained from lake sediments provide the most useful method for understanding the role of fire in particular ecosystems because charcoal from

lake sediments enables a long-term perspective (Clark and Robinson, 1993). More detailed analyses of changes in charcoal abundance during times of rapid climate change, the late-glacial to Holocene transition, for example, would be useful since fire regimes prevailing within a vegetation type could be potentially different from those contributing to the establishment of that vegetation type (Clark and Robinson, 1993).

In this paper, data are presented and discussed from two continuous AMS-dated Holocene records of pollen, plant macrofossils, and charcoal from Sutherland Pond and Spruce Pond in the Hudson Highlands, lower Hudson Valley, southeastern New York. Sutherland Pond, Black Rock Forest (41°23'29"N, 74°02'16"W), 4.05 ha in surface area at 380 m altitude, is situated 2.4 km west of the Hudson River at Cornwall, Orange County, New York (Fig. 1). Spruce Pond, Harriman State Park (41°14'22"N, 74°12'15"W), 2.6 ha in surface area at 223 m altitude, is located 22.5 km to the southwest of Sutherland Pond, approximately 24 km west of the Hudson River (Fig. 1). Thus far, these are the only AMS-dated Holocene records available in the Northeast and the only stratigraphic charcoal records continuously spanning the last 12,500 years in New York state.

The purpose of the paper is to contribute regional chronological and paleoecological details of Holocene events through use of AMS radiocarbon control and macrofossil and

charcoal analyses. The following questions are addressed: Has fire played a role in the development and maintenance of *Quercus* in the forests of the Hudson Highlands? What are the possible causes of variation in charcoal abundance during the Holocene? What was the invasion sequence of major tree species into the Hudson Highlands? Can plant macrofossil analysis improve the taxonomic resolution of the pollen record? Does AMS-dating reveal any chronological differences compared to previously published Holocene records that used conventional bulk radiocarbon methods? Is there evidence of late-Holocene Neoglacial cooling in the Hudson Highlands?

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 (Fig. 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; however, the glacial geology of the Hudson Highlands is largely unstudied. Denny (1938) determined that Wisconsinan

till deposited in the forest was subsequently altered by periglacial freeze/thaw cycles and solifluction. From studies of the deglacial history of the Great Valley, west of the Hudson Highlands, the onset of deglaciation is estimated at 17,500 yr B.P. (Connally *et al.*, 1989), but this estimate is based on assumed sedimentation rates. Muller and Calkin (1993), in their review of age data for Pleistocene glacial events in New York state, point out that the chronostratigraphic framework is weakly supported and that there is a need for AMS dating.

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). Climate data representative of the Hudson Highlands from West Point, New York (Fig. 1), recorded over a 30 year period (1918-1948), indicate 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).

Forests of the Hudson Highlands are considered part of the *Quercus-Castanea* region of the eastern deciduous forest by Braun (1964), while Küchler (1964) describes certain areas as ecotonal between *Quercus* forest to the south and *Tsuga-Pinus strobus*-northern hardwoods forest to the north. Topographic

variation and disturbance history have generated a mosaic of plant communities. Hill-tops 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. Valleys, ravines, and north-facing slopes below 335 m include *Tsuga canadensis*, *Liriodendron tulipifera*, *Fraxinus americana*, *Tilia americana*, *Acer saccharum*, *Betula lutea*, and *Fagus grandifolia* (Raup, 1938). On disturbed sites, secondary communities of sprout origin include *Quercus* spp., *Castanea dentata*, *Betula populifolia*, and *Populus grandidentata*. 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*. 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

Coring location within each basin, that is, the point with thickest sediments with no obstructions, was determined by the use of ground-penetrating radar (Mellett, 1993). Coring was carried out using 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 and from the frozen pond surface in 2.9 m of water at Spruce Pond, not its deepest part which is 5 m. 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 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, 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; and Faegri and Iversen, 1989), as well as a pollen and spore reference collection. A light microscope was used to identify and count pollen; routine counting was done at 400X magnification, while critical identifications were made at 1000X. 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 were isolated from 50 cm^3 of sediment at 5- cm intervals. Isolation was by gentle disaggregation of the sediment matrix in 5% potassium hydroxide at 4°C for at least 24 hrs and washing through 150 μm sieves. All particles >150 μm were inspected, and recognizable plant remains were hand-picked and identified using a dissection microscope at 40X magnification. Identifications are based on 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). AMS radiocarbon age determinations (eight at Sutherland Pond and seven at Spruce Pond) establish the chronologies (Table 1). Some levels were selected for dating if 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. Refer to Table 1 for sample types.

A measure of the total charcoal particle area per slide ($\mu m^2/cm^3$) was determined by utilizing a grid of squares of known area in the eyepiece of the microscope. By simultaneous counting of the exotic marker, density of the particulates was determined. Amounts of charcoal were from the same slides that were used for pollen analysis, therefore, charcoal particle size ranged between 7 and 150 μm, although separation of particles into size classes was not attempted. This method is intermediate between those of Waddington (1969) and R.L. Clark (1982).

Organic matter content of sediment is measured by loss-on-ignition (LOI) at 550°C (Bengtsson and Enell, 1986). Pollen frequency (%) and influx (PI) diagrams are constructed using Tilia-graph© software developed by E.C. Grimm. Pollen assemblage zones are designated on the basis of zonation terminology adhering to the scheme used by Deevey (1939). Plant nomenclature follows Fernald (1950).

RESULTS

Sutherland Pond (SUP)

Reference is made to diagrams of pollen frequency and pollen influx (Figs. 2-4), macrofossil abundance (Fig. 5), and loss-on-ignition and charcoal density (Figs. 2 and 3). Sediment lithology is described in Table 2. Ages marked with an asterisk (*) in the text are estimates based on linear interpolation.

Zone SUP-B: *Quercus-Pinus* (10,120 to 9540 yr B.P.).

Zone SUP-B features the increase of *Pinus strobus* and *Pinus* undifferentiated frequency and influx together with progressively increasing Quercus frequency and influx. *Pinus strobus* needles appear in the record for the first time at 10,120 yr B.P., concurrently with a sharp rise in PI, and continue to be present. *Abies* and *Picea* macrofossils are ultimately encountered in this zone; the last *Betula papyrifera* seeds occur at 9600* yr B.P., followed by seeds of *Betula populifolia* at 9575* yr B.P. Charcoal densities higher at the onset decrease upward in the zone.

Zone SUP-C1: *Quercus-Tsuga* (9540 to 6180* yr B.P.).

Zone C1 is characterized by a dramatic and rapid increase in the PI and pollen percentages of *Tsuga canadensis* at 9540 yr B.P., after which percentages decrease and modulate around 5% for the duration of the zone. *Quercus* expands from 30 to 70% then levels off, PI follows suit. PI and frequencies (45

to 5%) of undifferentiated *Pinus* pollen steadily decline. *Pinus strobus* declines as well. *Alnus, Salix,* and *Ulmus* pollen expand slightly early in the zone concurrent with development of an aquatic pollen assemblage including *Utricularia, Potamogeton, Myriophyllum, Nymphaea,* and *Nuphar.* Percentages of *Fagus grandifolia* pollen show small expansions at 8130* yr B.P.

Charcoal density values are low at the zone beginning, associated with maximum *Tsuga* values. Next, charcoal expands when *Tsuga* percentages decrease and *Quercus* increases. Large LOI values (60%) are recorded at the beginning of the zone, decline midway and rise again. Macrofossils include *Alnus, Betula populifolia, Pinus strobus, Tsuga canadensis,* Cyperaceae, *Dulichium, Najas* and *Potamogeton.*

Zone SUP-C2: *Quercus-Carya* (6180* to 3645* yr B.P.).

Elevated PI and percentage values of *Carya* (5%) distinguish zone SUP-C2, beginning at 6180* yr B.P. *Quercus* percentages are stable but PI is slightly larger than that in SUP-C1. *Tsuga* pollen percentage and PI values decrease at 4180* yr B.P. followed by increase in Betula percentage values. LOI is stable.

Charcoal densities are considerably higher over the duration of the zone, in association with consistently high *Quercus* percentages. 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* (3645* yr B.P. to 1700 A.D.).

Increased frequency and PI values of *Castanea dentata* beginning at 3645* yr B.P. are featured in this zone. *Quercus* frequencies decrease slightly after about 3700* yr B.P. *Tsuga* values recover at 2380 yr B.P. LOI is stable.

Charcoal density values are less than those in SUP-C2 and decrease at the top of the zone. Macrofossils include *Alnus*, *Betula lenta*, *Betula lutea*, Compositae, *Najas*, and *Potamogeton*.

Zone SUP-C3b: *Ambrosia*-Gramineae-Tubuliflorae (1700 A.D. to present).

Large increases in the percentage and PI values of *Ambrosia*, Gramineae, and Tubulifloreae 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* then *Quercus*. Charcoal density values increase. *Sphagnum* is the only taxon represented in the macrofossil record.

Spruce Pond (SPP)

Reference is made to diagrams of pollen frequency and influx (Figs. 6-8), macrofossil abundance (Fig. 9), and loss-on-ignition and charcoal density (Figs. 6 and 7). See Table 2 for sediment lithology.

Zone SPP-B: *Quercus-Pinus* (10,230 to 9750 yr B.P.).

Proliferation of *Pinus stobus* amoung expanding *Quercus,* as reflected in pollen frequency and influx values, is the signature of zone SPP-B. *Pinus strobus* rises from 0 to 7% at 10,230 yr B.P. *Quercus* continually expands (19 to 40%). *Fraxinus* and *Ostrya/Carpinus* expand. Frequencies of *Picea* and *Abies* reach zero. *Potamogeton* is the only macrofossil taxon present. LOI increases from 14 to 23%. Charcoal density values are initially high and then decrease.

Zone SPP-C1: *Quercus-Tsuga* (9750 to 6230 yr B.P.).

Tsuga canadensis percentage values peak at 8% at the zone onset (9750 yr B.P.) and then oscillate around 5% for the remainder of the zone. *Tsuga* PI values increase 10 times at the zone onset as well. *Pinus* percentages decrease from 30 to 5%, *Pinus strobus* pollen decreases too. PI values for *Pinus* show similar declines. *Quercus* pollen increases from 40 to 70% and then levels off at 70%. *Betula* values are large (15 to 20%) the first half of the zone and then decrease to and remain at 5%. *Fagus* expands at 8050* yr B.P. *Picea* is sporadically present (trace amounts) throughout the zone.

Charcoal densities are low at the zone beginning

concurrent with high *Tsuga*. Charcoal subsequently expands in association with decreased *Tsuga* and increased *Quercus* pollen percentages. LOI increases. Aquatic assemblage includes *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 yr B.P.).

This zone is marked by expansion of *Carya* percentage and PI values at 6230 yr B.P. Single grain occurrences of *Picea* appear less frequently than in zone SPP-C1. *Tsuga* pollen percentage and PI values decrease at 3925* yr B.P. followed by increased *Betula* percentage and PI values.

Charcoal is consistently present but at slightly less concentrations than in previous zone. LOI continues to increase from previous zone but decreases midway.

Zone SPP-C3a: *Quercus-Castanea* (3540 yr B.P. to 1700 A.D.).

Castanea frequency and PI values expand at 3540 yr B.P. *Tsuga* values recover at 2035* yr B.P. *Picea* pollen begins to register more consistently (<1%) beginning at 1470* yr B.P. Charcoal is consistently present, slightly more than that in zone SPP-C2. LOI exhibits the same oscillations as in previous zone. *Betula lenta* is present as a macrofossil.

Zone SPP-C3b: *Ambrosia*-Gramineae-Tubuliflorae (1700 A.D. to the present).

Ambrosia, Tubuliforae, and Gramineae pollen expands

dramatically and *Plantago* and *Rumex* are present at the zone beginning. *Quercus, Pinus, Tsuga, Tilia,* and *Fagus* are decreased. *Acer rubrum* is more frequent. *Castanea* decreases toward the top of the zone followed by increases in *Betula* and *Quercus*. Charcoal expands dramatically as well. LOI is consistently high.

DISCUSSION

Expansion and development of *Quercus* forest

Early Holocene forests of the Hudson Highlands were characterized by rapidly expanding *Quercus* populations and by successive immigration of other arboreal components. *Pinus strobus* appears to have arrived between 10,120 and 10,230 yr B.P., followed by *Tsuga canadensis* between 9540 and 9750, *Fagus grandifolia* between 8050* and 8130*, *Carya* between 6180* and 6230, and *Castanea dentata* between 3540 and 3645* yr B.P. Davis (1983) decribes a similar invasion sequence for southern Connecticut, but it is chronologically modified; for example, *Carya* arrives at 5000 and *Castanea* at 2000 yr B.P.

It is likely that these differences in chronology stem from differences in the radiocarbon techniques used, that is, AMS vs bulk radiocarbon methods. The mid-Holocene *Tsuga* decline (Davis, 1981b), recorded throughout the Northeast between 4800 and 2800 yr B.P., occurs in the Hudson Highlands sites between 4050* and 2200* yr B.P.

Forest dominated by *Quercus* with *Castanea* and *Carya* as sub-dominants is apparent in the pollen record by 3600* yr B.P. and lasted until disturbance by Euroamericans. Witness tree records in survey reports from southeastern New York show that communities contained *Quercus rubra, Q. velutina,* and *Q. alba* with *Castanea* and *Carya* common in pre-settlement time (Loeb, 1987).

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 populationscontained *B. papyrifera,* which was replaced at about 9575* yr B.P. by *B. populifolia* at Sutherland Pond; mid- and late-Holocene *Betula* populations included a mixture of *B. populifolia, B. lenta,* and *B. lutea*.

Neoglacial cooling in the late-Holocene appears to be evident at both sites from increase in mesic types, for example, *Betula* and *Tsuga* after approximately 4000* and 2000* yr B.P., respectively. Alternatively, the rise of *Betula* might be a successional response to openings created by reduced *Tsuga* populations, following pathogen outbreak, and the subsequent *Tsuga* rise might represent population recovery. Slight decrease in comparitively less-mesic *Quercus* at Sutherland Pond beginning at around 3700* yr B.P. and an increase in *Picea* at Spruce Pond at around 1500* yr B.P. may be less ambiguous signals indicative of cool/moist conditions.

Davis (1983) points out that boreal elements began to increase at various sites in the Northeast between 5000 and 1000 yr B.P. *Picea* expanded at all elevations in the White Mountains of New Hampshire at 2000 yr B.P., 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 of *Nyphaea* and *Nuphar*, both floating aquatic taxa, become adundant 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 be indicative of 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 wasteplaces where soils have been disturbed (Niering, 1988). Keatinge (1967) examined historical documents on the Hudson Highlands and reported that Europeans settled villages, including Cornwall, in 1685 A.D., and in 1702 A.D., the English purchased 20,000 acres of forest from the Iroquois. Thus, an age of 1700 A.D is an estimate for the *Ambrosia* rise found at Sutherland and Spruce Ponds.

Contemporaneously, large decreases in *Quercus, Tsuga,* and *Pinus* characterize the recent sediments. Forest-related industries, in progress between approximately 1750 and 1850 A.D., included iron, brick, and charcoal production. The manufacturing processes for each required enormous amounts of low quality wood, resulting in much clearcutting at 25 to 30 year intervals (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 likely 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 opportunustic, light-demanding, early successional tree species (Burns and Honkala, 1990). Decreases in *Quercus, Tsuga, Fagus, 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).

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

Fire history

Charcoal concentration data obtained from Sutherland and Spruce Ponds indicate that fire has been an important influence on vegetation development in the Hudson Highlands throughout the Holocene. The last 12,500 years of stratigraphic charcoal abundance (Fig. 10) indicate that fire was more important after 10,000 yr B.P. (See Maenza-Gmelch (submitted) and Maenza-Gmelch (in prep.) for discussion of late-glacial vegetation at these sites.) It appears that charcoal densities, gradually building up after 12,500 yr B.P., dropped between roughly 11,000 and 10,000 yr B.P. (Younger Dryas age), then expanded after 10,000. A temporary decrease in charcoal values after about 9500 yr B.P. was followed by elevated values which persisted until just before Euroamerican disturbance at approximantely 1700 A.D. These fluctuations in charcoal density and percentages of *Quercus*

and *Tsuga* during transition from late-glacial to Holocene indicate that *Quercus* varied positively with fire and *Tsuga*, negatively (Fig. 10.).

It appears that early Holocene expansion of *Quercus* forests occurred in a setting that included fire. At about 9500* yr B.P., decreases in fire may have allowed areas of *Tsuga* to expand. A few hundred years later, fire activity increased, possibly a factor in restricting *Tsuga* and permitting expansion of *Quercus*. Consistently high values of *Quercus* in association with high charcoal densities for some nine millennia afterward suggest that fire played an important role in the development and maintenance of *Quercus* forest. In post-settlement times, relationships are more difficult to interpret because Euroamericans used excessive fire and cut large amounts of *Pinus*, *Quercus*, and *Tsuga* simultaneously.

The ecophysiologies of *Quercus* and *Tsuga* indicate mechanisms by which fire controls their abundance. *Quercus* species may be increased after fire since injury stimulates sprouting. Thick bark, resistance to rotting after scarring, and suitablilty of fire-created seed beds for acorn germination are additional factors (Abrams, 1992). *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). 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).

Quercus species have been dominant in the forests of the Hudson Highlands for some 9000 years. Since most *Quercus* species are considered to represent early- to mid-successional stages (Burns and Honkala, 1990), ecological factors are 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 Hudson Highlands and can therefore outcompete northern hardwoods on such sites. Synergism between fire and soils in the Hudson Highlands, that is, less mesic soils would permit fire and fire would prevent better soil development, is likely.

Causes of Fire: Climate

Warmer/drier atmospheric conditions that developed in response to insolation changes may account for the increase in fire in the Holocene. Studies in the Northeast have considered charcoal records indicative of fire extending back to the early Holocene. In New England, Anderson *et al.* (1986) found elevated charcoal levels between 9800 to 7500 yr B.P. in lake sediment from northern Maine; Davis (1985) noted an

abundance of charcoal associated with dominance of *Pinus* and *Quercus* pollen in New Hampshire between 9000 and 7000 yr B.P.; and Winkler (1985) and Dunwiddie (1990) reported abundant charcoal associated with *Pinus* pollen-dominated sediments between 9000 and 5000 yr B.P. from Cape Cod, Massachusetts and Nantucket, Massachusetts, respectively. In northeastern New Jersey, Watts (1979) and Peteet *et al.* (1990) also present data that indicate charcoal in association with abundant *Pinus* and *Quercus* pollen during this same interval. These studies suggest that the increase of charcoal found in sediments dated between approximately 9000 and 5000 yr B.P. may be a consequence of suitable conditions for burning, which are reflected by the warmer/drier climate of the early-mid Holocene (Deevey and Flint, 1957; Wright, 1992).

Causes of Fire: Native Americans

Climatic control of burning may be masked by the use of fire by native Americans. Day (1953) reminds us that native Americans regularly burned areas of the Northeast for farming, hunting, and travel, as reported in historical documents. Russell (1983), in her examination of historical documents from throughout the Northeast, concluded that native American use of fire increased fire frequency above levels caused by lighting. However, Patterson and Sassaman (1988) note that there is little agreement on the extent to which humans used fire. The presence of native Americans in Orange County since > 10,000 years B.P. has been documented, although how

extensively they used fire has not been determined. Evidence for Paleo-Indian occupation is found at Dutchess Quarry Cave in the Great Valley and is placed at 10,600 yr B.P. (Funk, 1976). A large number of rockshelters, excavated in the Bear Mountain region of the Hudson Highlands, contained materials from the Archaic to Woodland Periods, 8000 yr B.P. to 1600 A.D. (Funk, 1976).

Causes of Fire: Euroamericans

Settlement by Euroamericans, beginning at approximately 1700 A.D., drastically increased fire frequency in the vicinity of Spruce Pond but to a much lesser extent at Sutherland Pond. Forestry practices in the Hudson Highlands included clearcutting every 25 to 30 years followed by uncontrolled burning (Moon, 1909). This method tended to deplete the soil of nutrients and moisture-holding capacity, reduce the amount of northern hardwoods, *Tsuga,* and *Pinus strobus,* and increase sprout-hardwoods. In 1909, a 35,000 acre Hudson Highlands preserve was set up which included regulations for improved forestry methods and strict fire prevention, thus initiating a period of forest recovery. However, some wildfires persisted as a result of the numerous track fires from locomotives in use on the railroads (Pyne, 1988). Greater post-settlement charcoal densities at Spruce Pond may be due to its 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.

CONCLUSIONS

1 Consistently high values of *Quercus* in association with high charcoal densities for some nine millennia suggest that fire played an important role in the development and maintenance of *Quercus* forest.

2 Warmer/drier atmospheric conditions that developed in response to insolation changes may account for the increase in fire in the Holocene.

3 Settlement by Euroamericans, beginning at approximately 1700 A.D., 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).

4 Holocene invasion of *Quercus* forest in the Hudson Highlands featured the following sequence: *Pinus strobus* at 10,175 yr B.P., *Tsuga canadensis* at 9645, *Fagus grandifolia* at 8100, *Carya* at 6200, and *Castanea dentata* at 3600 yr B.P.

5 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 yr B.P. by *B. populifolia*. Mid- and late-Holocene *Betula populations* included a mixture of *B. populifolia, B. lenta,* and *B. lutea*.

6 Some of the AMS-dated vegetation events at Sutherland and Spruce Ponds, for example, arrival of *Carya* and *Castanea,* and occurrence of the *Tsuga* decline, are of different ages than those in older studies using bulk dates.

7 Neoglacial cooling may be represented by a slight decrease in *Quercus* at Sutherland Pond beginning at around 3700 yr B.P. and an increase in *Picea* at Spruce Pond at around 1500 yr B.P.

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TABLE 1

AMS C-14 ages for the Holocene, Hudson Highlands, New York.

CAMS #	Sample depth (cm)	Sample type	Carbon weight	AMS C-14 age (yr B.P.)
SUTHERLAND POND:				
9499	200-205	*Betula lenta* seed and unidentified stem fragments	0.9 milligrams	2020 ± 40
9500	295-300	leaf and twig fragments	1.2 milligrams	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 milligrams	5860 ± 50
8391	765-770	*Tsuga* needles (10)	9.0 micrograms	6630 ± 220 (reject)
11441	770	1 cm^3 sediment	--	9540 ± 60
9502	785-790	*Pinus strobus* needle fragments (6)	0.2 milligrams	9630 ± 70
11442	795	1 cm^3 sediment	--	10120 ± 60

TABLE 1 (continued)

CAMS #	Sample depth (cm)	Sample type	Carbon weight	AMS C-14 age (yr B.P.)
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	--	10,230 ± 60

TABLE 2

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 gray (2.5 YR 3/1) clayey gyttja
Spruce Pond	0 - 655	very dark brown (10 YR 2/2) gyttja
	655 - 805	dark reddish gray (2.5 YR 3/1) clayey gyttja

*Munsell Soil Color Charts (1992)

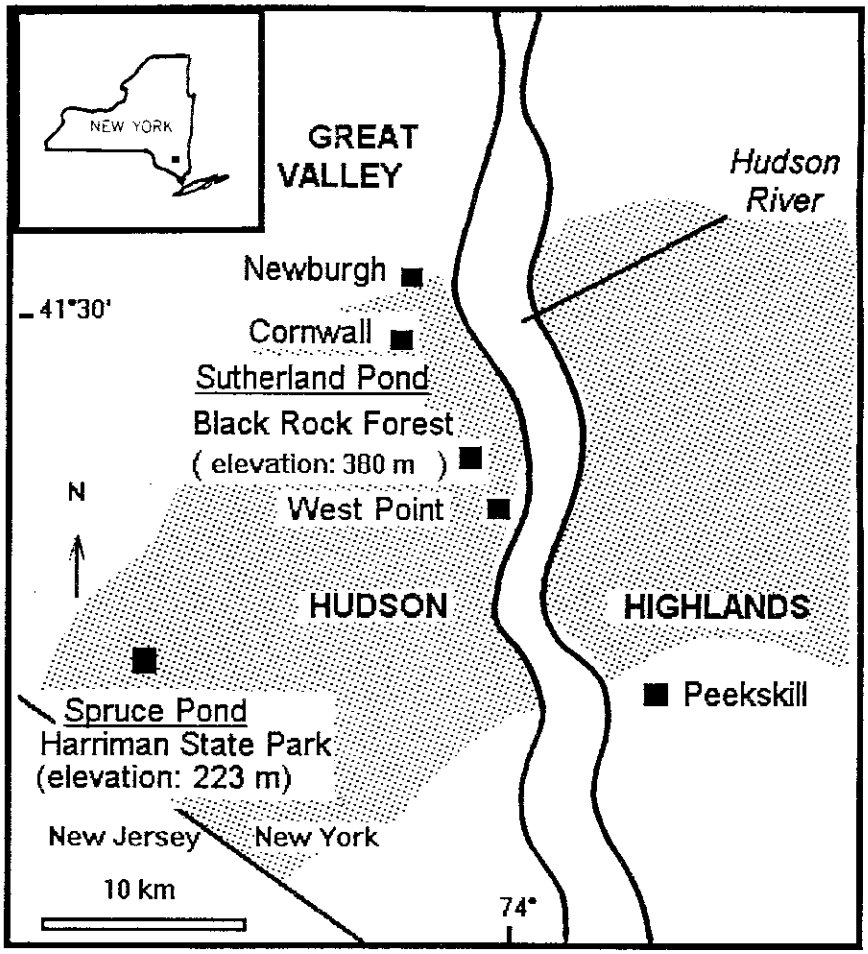


Fig. 1. Lower Hudson Valley, southeastern New York showing locations of Sutherland Pond, Spruce Pond, Hudson Highlands (shaded area), and other places and features mentioned in the text.

Fig. 2. Diagram of pollen and spore frequencies, loss-on-ignition, and AMS radiocarbon chronology for the Holocene at Sutherland Pond, New York. Closed circles indicate values of <1%.
Analyst: T. Maenza-Gmelch

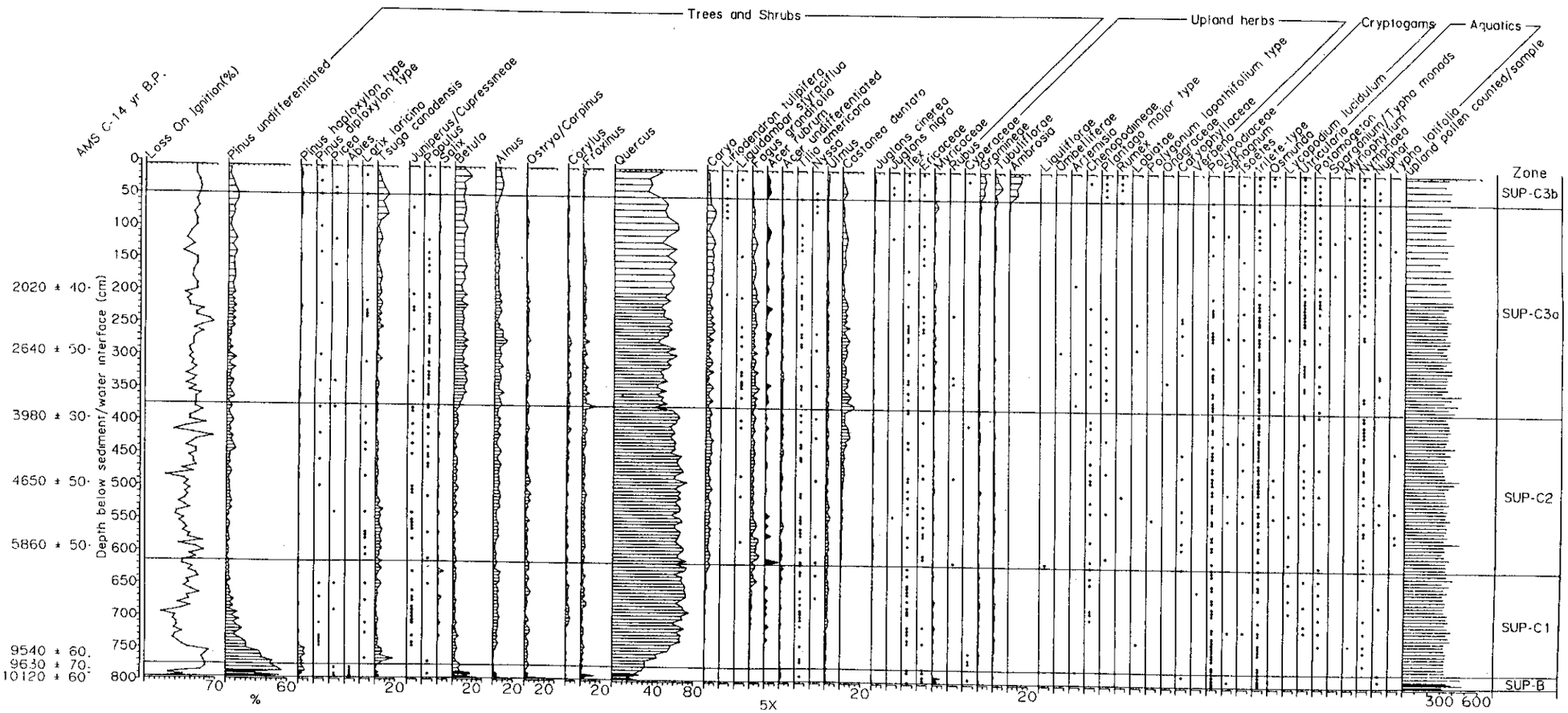


Fig. 3. Diagram of selected pollen frequencies(%), plant macrofossils (no./50 cm3 sediment), AMS radiocarbon chronology, LOI, and charcoal density values (um2/cm3) for the Holocene at Sutherland Pond, N.Y. Closed circles indicate values of <1%. Macrofossils as histograms.

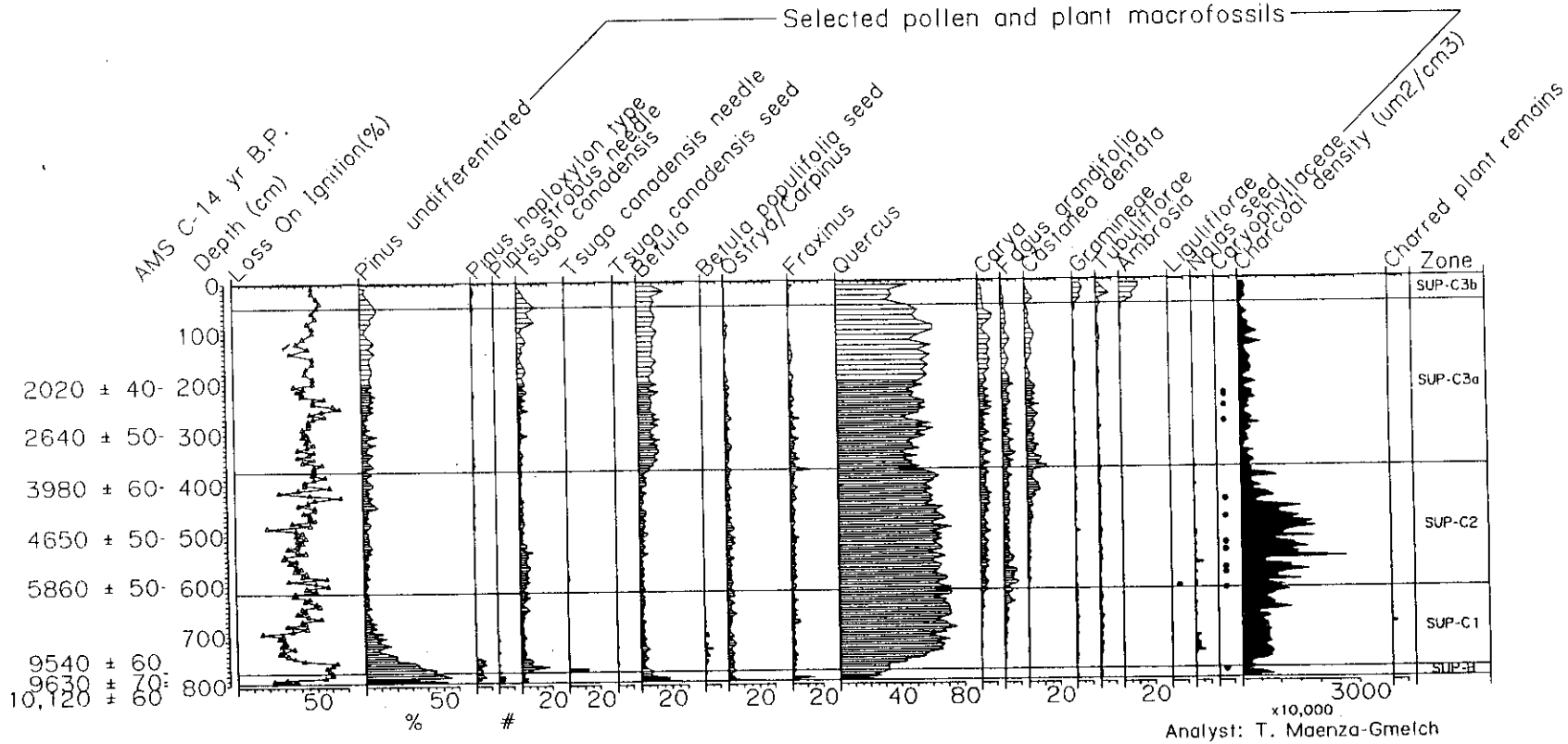
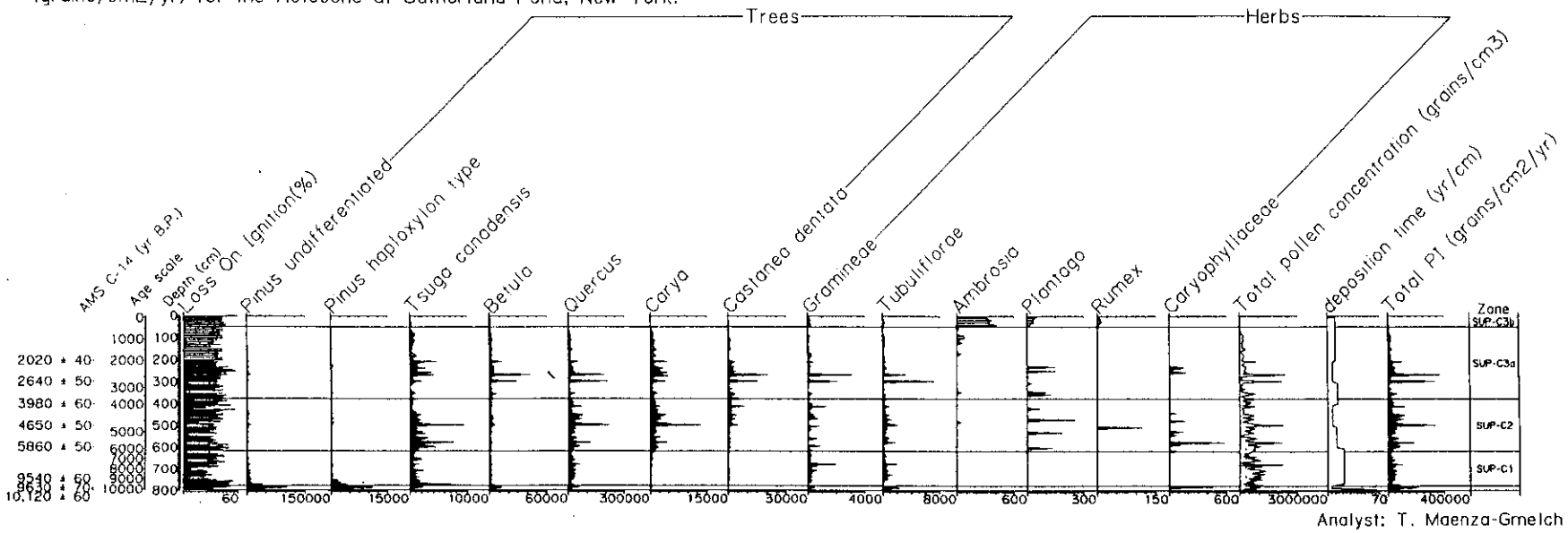


Fig. 4. Diagram of pollen influx (grains/cm2/yr) for selected taxa, AMS radiocarbon chronology, LOI, total pollen concentration (grains/cm3), deposition time (yr/cm), and total pollen influx (grains/cm2/yr) for the Holocene at Sutherland Pond, New York.



Analyst: T. Maenza-Gmelch

Fig. 5. Diagram of plant macrofossils (no. per 50 cm3 sediment) and AMS radiocarbon chronology for the Holocene at Sutherland Pond, N.Y. Analyst: T. Maenza-Gmelch

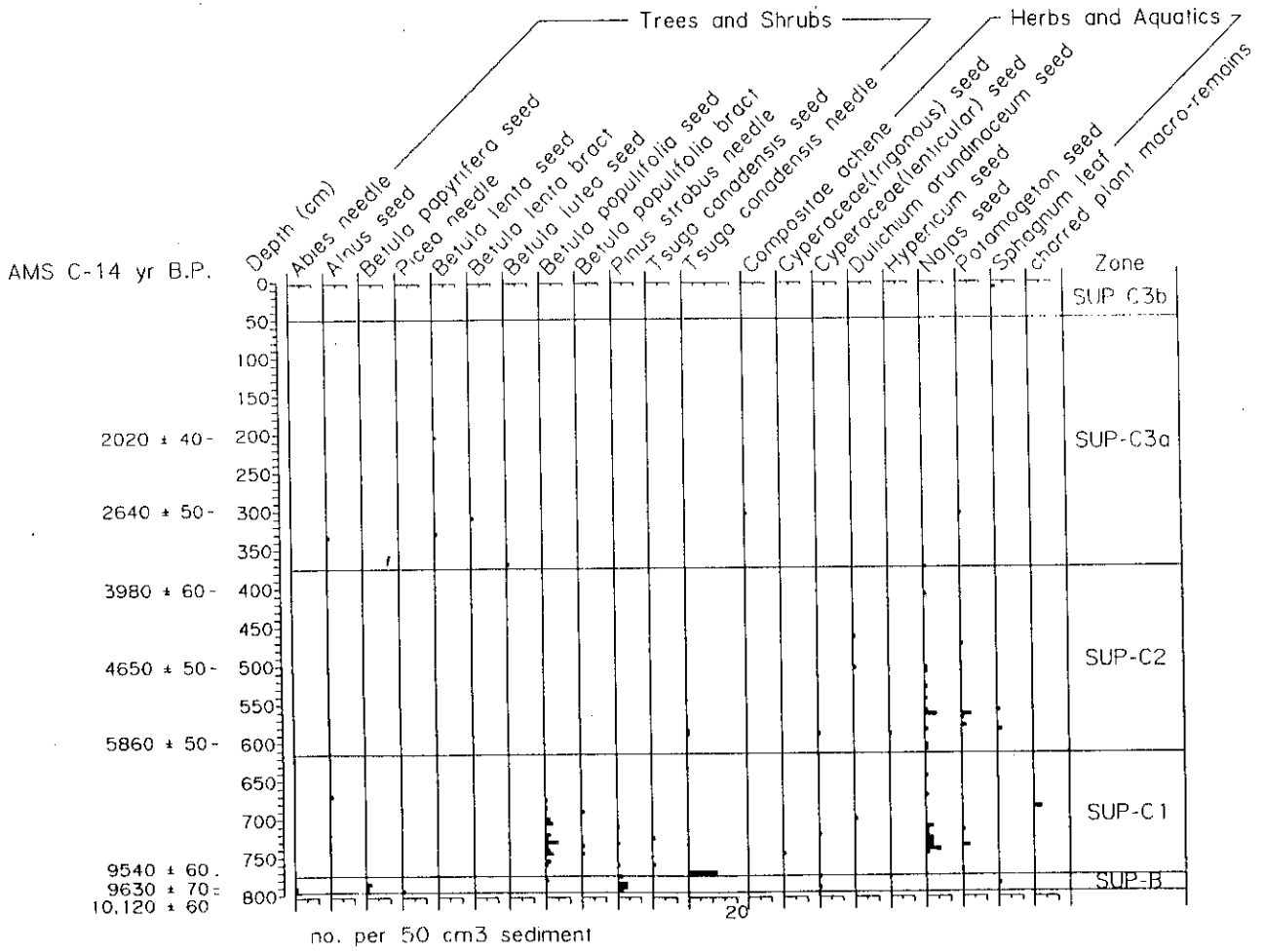
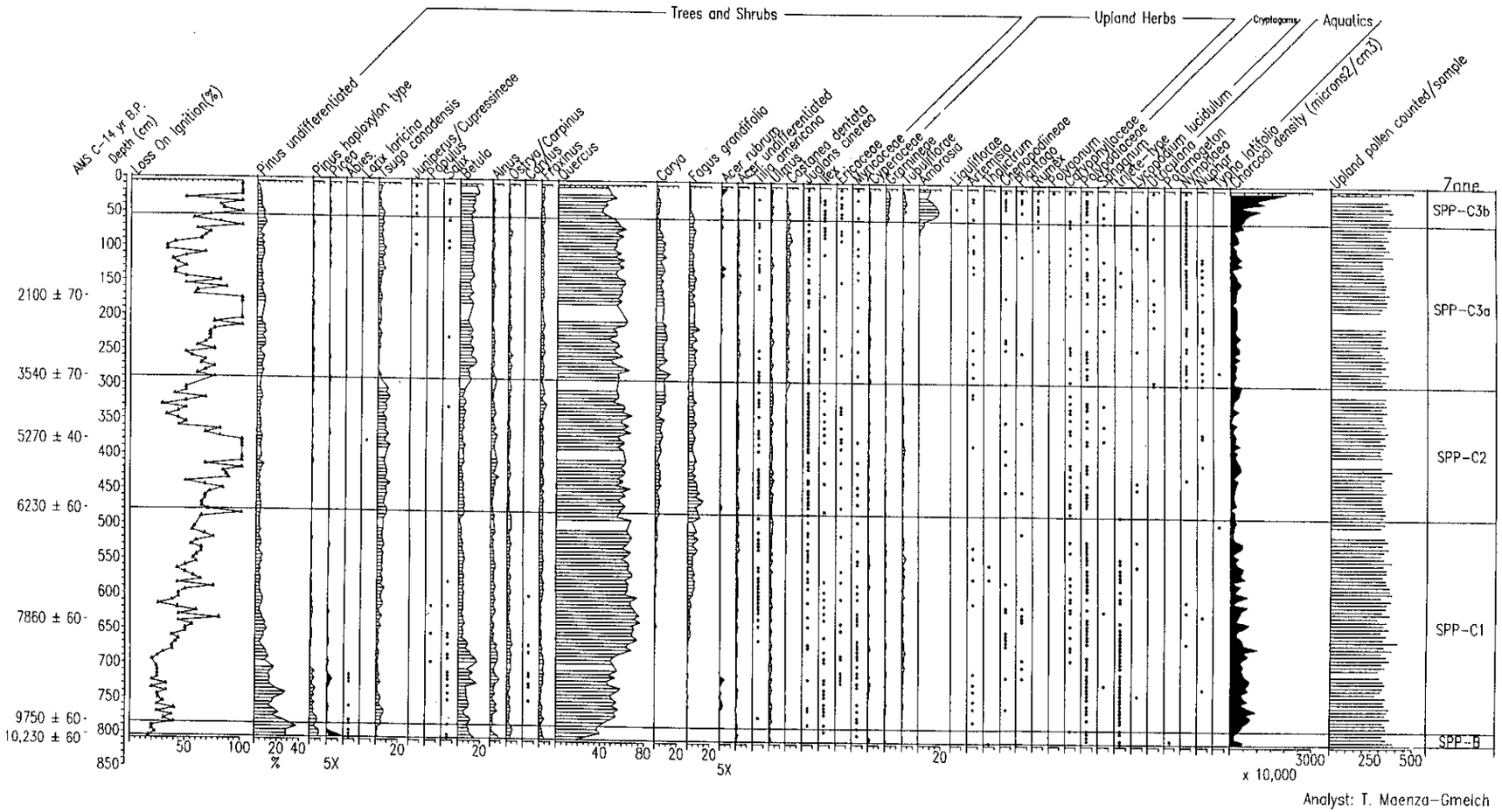
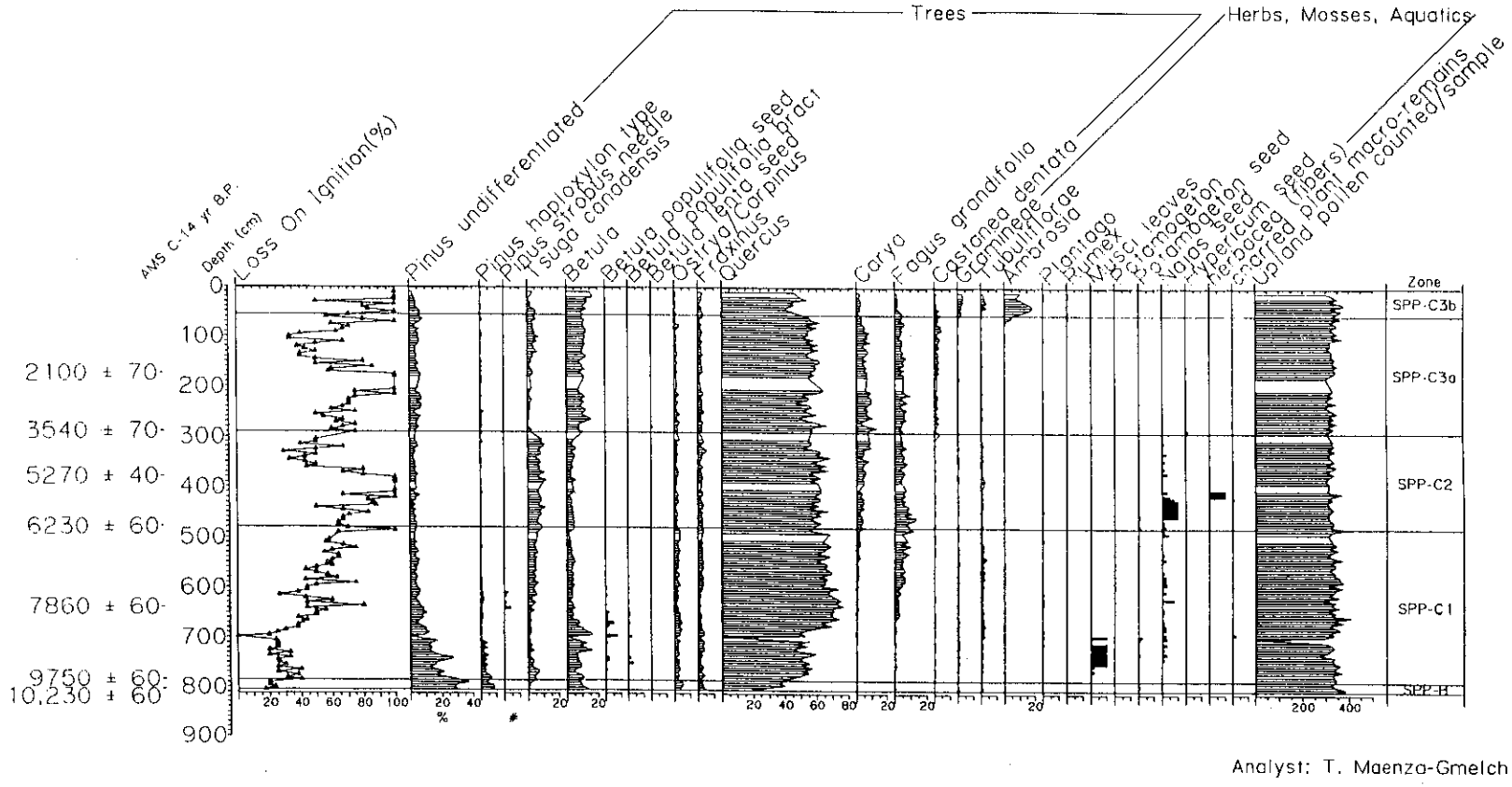


Fig. 6. Diagram of pollen and spore frequencies, loss-on-ignition, AMS radiocarbon chronology, and charcoal density values (um2/cm3) for the Holocene at Spruce Pond, New York.
Closed circles indicate values of <1%.



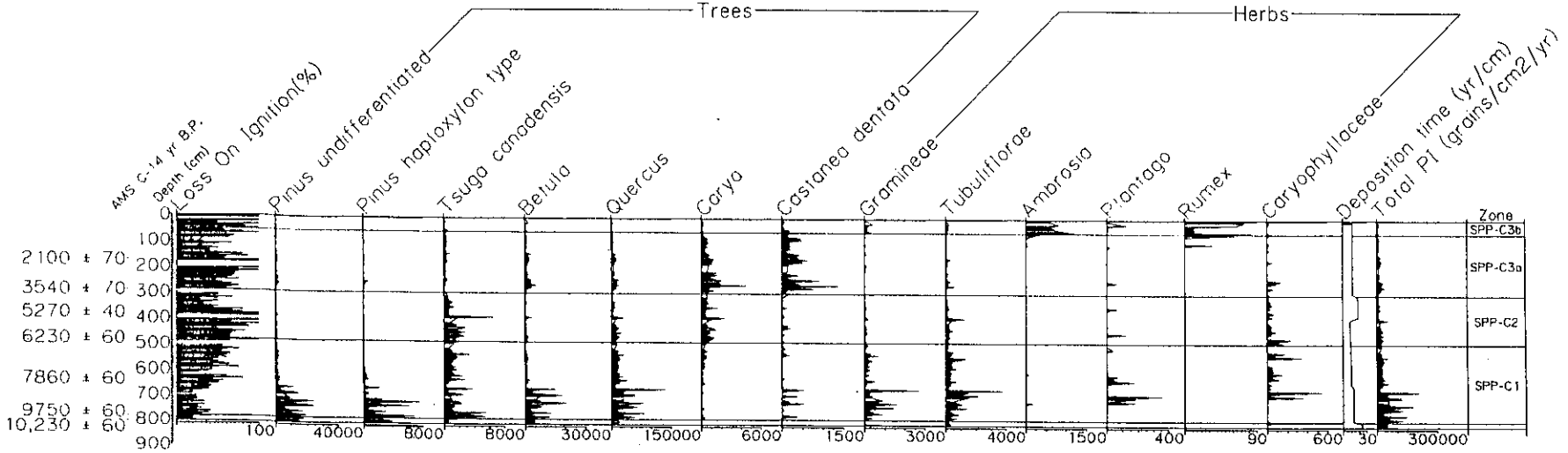
Analyst: T. Maenza-Gmelch

Fig. 7. Diagram of selected pollen frequencies (%), plant macrofossils (no. per 50 cm3 sediment), AMS radiocarbon chronology, and LOI for the Holocene at Spruce Pond. Macrofossil graphs are represented in histogram-style.



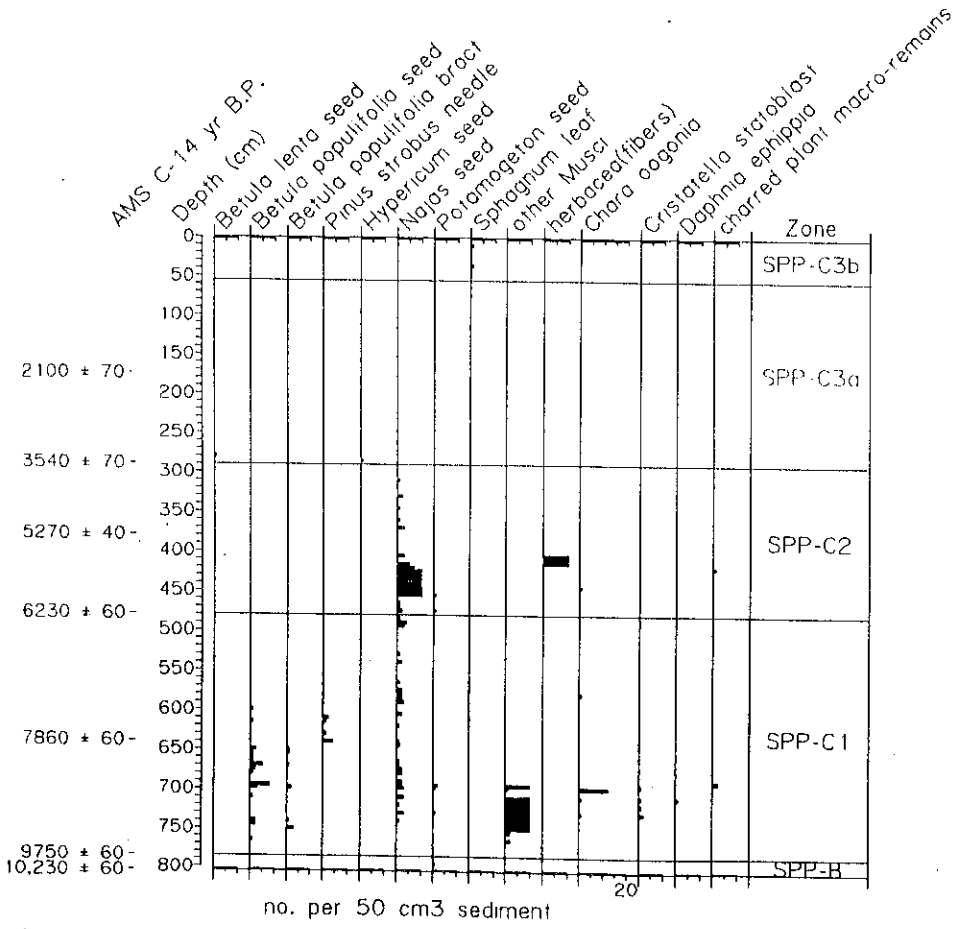
Analyst: T. Maenza-Gmelch

Fig. 8. Diagram of pollen influx (grains/cm2/yr) for selected taxa, AMS radiocarbon chronology, LOI, total pollen concentration (grains/cm3), deposition time (yr/cm), and total pollen influx (grains/cm2/yr) for the Holocene at Spruce Pond, New York.



Analyst: T. Maenza-Gmelch

Fig. 9. Diagram of macrofossils (no. per 50 cm3 sediment) and AMS radiocarbon chronology for the Holocene at Spruce Pond, N.Y.



Analyst: T. Maenza-Gmelch

Fig. 10. Diagram of pollen frequencies (%) of Tsuga and Quercus in relation to charcoal density values spanning the last 12,500 years at Sutherland and Spruce Ponds, New York.

Analyst: T. Maenza-Gmelch

