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RESEARCH ARTICLE

Paleoecological History of Maplecrest Fen, Catskill Mountains (NY, USA) From Deglaciation to the Industrial Age

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ABSTRACT

Aim: To develop the palaeoecological and palaeoclimatic history of Maplecrest Fen, Greene County, NY.

Location: Catskill Mountains, New York.

Time Period: 13,500 calendar years to present (ybp, present = 1950).

Taxon: Angiosperms, gymnosperms and bryophytes.

Methods: We used pollen and spore analysis, macrofossil analysis, loss-on-ignition (LOI) and X-ray fluorescence (XRF) analysis of a 7.8 m sediment core from the Fen along with AMS radiocarbon dates retrieved from the identified terrestrial macrofossils.

Results: Late-glacial and Holocene vegetational change from ice withdrawal reveals the development of a shallow lake and then fen to the present. The boreal spruce (*Picea*), fir (*Abies*) and paper birch (*(Betula papyrifera*) pollen signature near the base of the core (Zone M2) suggest a Younger Dryas (YD) signal overtopping warmer Allerod aged basal sediments. The early Holocene white pine (*Pinus strobus*) is followed by increases in hemlock (*Tsuga*) and beech (*Fagus*), ushering in a moister climate. About 5200 ybp drought is indicated by the well-known hemlock biostratigraphic decline in the Northeast. *Drepanocladus* moss and stonewort (*Chara*) shift to sedges (*Carex*) and violets (*Viola*) locally present. For the next 5000 years, the vegetation will remain relatively stable with lower temperatures suggested by the return of spruce and fir. Ragweed (*Ambrosia*) rise along with other weedy taxa marks European settlement near the top 50 cm of the core, along with a striking increase in anthropogenic lead, as seen using X-ray fluorescence.

Main Conclusions: Deglaciation began in the Catskills at a high elevation about 13,500 years ago and recession of ice from the Laurentide margin proceeded at about 0.1 km/year. Temperature shifts promoted changes in the boreal forest including warming and cooling, and drought and wetter intervals both appear in the Holocene history but do not appear to be easily forecast as climate continues to warm.

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1 | Introduction

The Catskill region, New York, USA is valued for its tremendous hydrological, ecological, economic and recreational values. In particular, New York City's water supply is greatly dependent on the Catskill watershed, which delivers over 1.5 billion gallons of water daily (Blake, Khanbilvardi, and Rosenzweig 2000). Precipitation and streamflow trend analysis within the Catskills (Pradhanang et al. 2013; Schneiderman et al. 2013) describe the potential for shifts in precipitation and streamflow patterns to impact local economies and people as well. Yet the hydroclimate history has not been studied in detail, and the record of past droughts such as that of the 1960s and documented by tree ring records (Pederson et al. 2013; Seager et al. 2012) provides key information for understanding the future risk of drought to the region. The risk of future drought is of critical importance to the management of New York City's resources, and we assess the history of drought at the millennial scale for this region in a close examination of both pollen and macrofossils. As human-induced climate change stresses modern ecosystems, palaeoecology provides a perspective in understanding past responses to climate change. In particular, with global warming and New York's nearby Mohonk average temperature record indicating generally 2°C warmer than in the last century (Mohonk Climate Database 2023), past studies give us a glimpse into some scenarios we might expect at this site. In particular, future warming studies focus concern on moisture (Frei et al. 2004; Seager et al. 2012). Using the Thornthwaite 1948 water balance model, Frei et al. (2004) found that under all scenarios of future climate, rising temperatures will lead to significantly diminished water supplies unless precipitation increases dramatically (Frei et al. 2004). This has implications for New York City as well as other New York and New Jersey municipalities, as the Catskill Mountains supply water to over 10 million people. As Frei et al. (2004) also note, the Catskill watersheds also influence the salinity of the lower Delaware River, which is critical for Philadelphia water supplies. We assess with palaeoecology the history of drought as well as temperature in the Catskills.

The general history of vegetational change in the Atlantic northeastern United States (New York, Conn, NJ) following deglaciation is largely written in the pollen records found in lake and bog sediments and has been broadly outlined (Deevey Jr. 1939; Ibe 1985; Gaudreau and Webb 1985; Peteet et al. 1990, 1993; Maenza-Gmelch 1997a, 1997b, 1997c; Menking, Peteet, and Anderson 2012; Oswald et al. 2018). Nevertheless, gaps still remain, especially for the Catskill Mountain region of New York where Late Quaternary vegetational dynamics are largely unknown except for several pollen stratigraphic investigations of Late Quaternary sediments in the western Catskills (Ibe 1985) and the adjacent lowland (Ibe and Pardi 1985). One major conundrum is the mode of deglaciation which would affect how exactly the vegetation migrated through this region. Did vegetation in the late-glacial expand northward in the valleys from regions to the south, or did vegetation first colonise the upper reaches of the mountains as they became free of ice? In other words, did ice leave the valley systems first or did deglaciation begin first from the summits? Rich (1934) contended that at least some of the higher Catskill peaks stood out as nunataks during the last glacial maximum (LGM) and that evidence of glaciation (e.g., erratics, glacial striae) above 1189 m on Slide Mountain in the Catskills, for example, is entirely lacking. More palaeoecological studies within and adjacent to the Catskill Mountain region would shed light into the important details of the mode of deglaciation and patterns of migration in this important area. Essential for understanding the time of deglaciation is robust AMS C-14 chronology. Unfortunately, bulk sediment has been previously used for radiocarbon dating in most Catskill basal sediments, but bulk dates are well known to be unreliable (Peteet and Mann 1994; Zimmerman and Wahl 2020; Peteet et al. 1990, 1993; Birks 1993; Hajdas et al. 1993; Grimm, Maher, and Nelson 2009; Curry et al. 2010; Gaglioti et al. 2014; Strunk et al. 2020). This unreliability is due not only to 'old carbon' from carbonates but also from fine-grained materials such as reworked soils and lignite, coal and carbonaceous shales that can be over 8000 years too old. Thus, valid chronologies are needed to define both the timing of deglaciation and for delineation of the timing of key shifts in vegetation and climate up to the present.

In this study, we aim to solve the conundrum of the 'top to bottom' or 'bottom to top' puzzle relating to the mode of deglaciation of the Catskill Mountain region of New York State by comparing the AMS C14 chronology of deglaciation in our site to others. We will then document the coupled pollen-macrofossil AMS-dated stratigraphic record from deglaciation to most recent sediments and focus on the hydroclimate of the region throughout.

2 | Materials and Methods

2.1 | Study Site

Maplecrest Fen is located on the Hensonville quadrangle, 7.5 series (42.30071 N, 74.17407 W), at an elevation of 632 m (Figure 1). It encompasses about 2.4 ha, is generally circular, and in 2011, it had a pH of 4 (Adams and Parisio 2013). The Catskill High Peaks sub-ecoregion include the extensively forested hills and mountains. Bedrock of the Catskill region is of Devonian age and consists of relatively flat-lying, structurally simple, siliciclastic-dominated sedimentary rocks, primarily of sandstone and mudrock, but some conglomerates and minor amounts of carbonates (Ver Straeten 2013).

As the Laurentide ice sheet retreated from its margin at about 15–16,000 ybp, it withdrew northward, and local ice that may have been in small lake basins such as Maplecrest also melted. Differential weathering of the bedrock has strong effects on the soils, surface and groundwaters plants and animals of the region, as pH, texture and topography are all controlled by these processes (Ver Straeten 2013). Generally, the mountain peaks are characterised by boreal forest species such as red spruce (*Picea rubens*), balsam fir (*Abies balsamea*) and paper birch and heart-leaved paper birch (*Betula papyrifera and Betula cordifolia*), while upper and middle slopes are comprised of northern hardwoods such as sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*) and beech (*Fagus grandifolia*). On southern slopes and in valleys, oak (*Quercus*) and hickory (*Carya*) are present (McIntosh 1972; Kudish 2000; Kudish, 2013).

For Maplecrest Fen, a plant list was first compiled by the Torrey Botanical Club and then supplemented by subsequent visits to the site by Morton Adams and Steve Parisio (Adams and Parisio 2013) as well as the authors. The bog itself is covered by a

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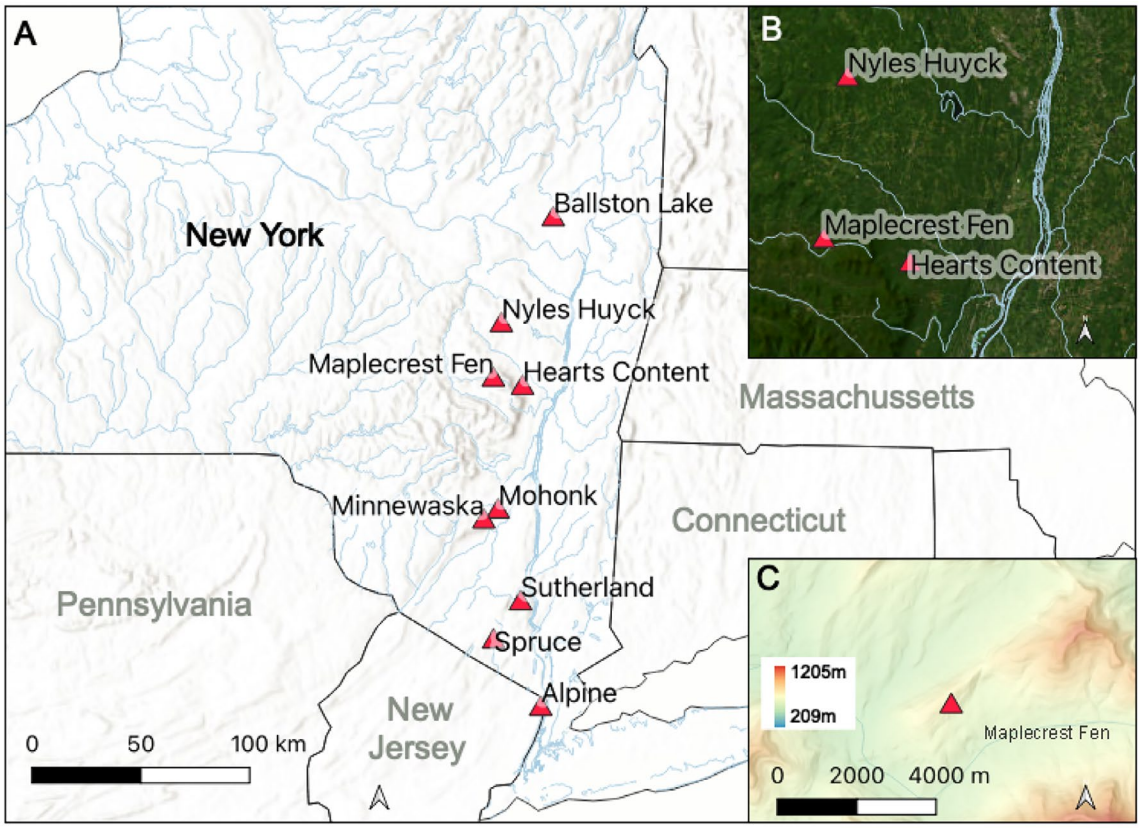


FIGURE 1 | (A) Regional map showing Maplecrest Fen along with other referenced palynological sites in New York. Blue lines are rivers from the National Hydrography dataset; topography is ESRI Hillshade. (B) Satellite imagery from ESRI Sentinel 2 landcover showing Maplecrest Fen and nearby sites. (C) Digital Elevation Map of Maplecrest Fen from USGS.

carpet of *Sphagnum magellanicum* (old name of moss complex) and supports a variety of poor fen or bog vegetation, including *Sarracenia purpurea* and dense stands of *Ilex verticillata*. *Acer rubrum* and invading *Betula alleghaniensis* are common associates. At the bog periphery are found *Abies balsamea*, *Picea rubens*, *Tsuga canadensis*, *Pinus strobus* and *Fraxinus nigra*, with some *Pinus strobus* on the bog mat. Common shrubs seen are *Ilex mucronata*, *Alnus rugosa*, *Aronia melanocarpa*, *Rhododendron roseum*, *R. maximum*, *Kalmia polifolia*, *K. angustifolia*, *Vaccinium corymbosum*, *V. myrtilloides*, *V. oxycoccus*, *Chamaedaphne calyculata*, *Viburnum cassinoides* and *V. alnifolium*. Some of the more abundant herbs throughout the bog included *Oxalis montana*, *Trillium undulatum*, *Eriophorum vaginatum*, *E. virginicum* and *Maianthemum canadense*. *Carex trisperma*, *C. pauciflora*, *Corallorhiza trifida* and *Rhynchospora alba are* also present. The most abundant fern is *Osmunda cinnamomea*. Some bryophytes along with Sphagnum were *Thuidium delacatulum* and *Polytrichum strictum*. The common liverwort found was *Bazzania trifida*.

The climate of the region is marked by a large-temperature seasonal cycle, and the eastern Catskills have the highest mean precipitation in New York State with over 1500 mm/year (Thaler, l996). The mean annual temperature in the eastern watershed from 1964 to 1993 has shifted from about 1° from 6°C to close to 7°C (Frei et al. 2004). Snowfall accounts for approximately 20% of total water equivalent (Thaler 1996; Frei et al. 2004). The moderating influence of the Atlantic Ocean as well as coastal and continental storms and the orography influence the southeast to northwest gradient in both temperature and precipitation (Frei et al. 2004; Seager et al. 2012). In the last few decades, it is clear that the changing climate including the increasing length of the growing season and the frequency of extreme events is affecting the region (De Gaetano and Castellano 2013), particularly in flooding events resulting in storms such as the recent tropical storm Irene of 2011. Risks of the changing climate to the biodiversity in the region warrant further research and monitoring, including sensitive and unique sites such as this Maplecrest Fen (Adams and Parisio 2013).

2.2 | Field and Laboratory Work

In 2015, repeated test borings revealed the deepest part of the bog to be 7.8 m, close to the centre. A Dachnowski Russian corer was used for the first 2 m of extraction, but the recovery was not complete due to a floating mat in the top 1.5 m. A modified Livingstone corer was used to extract the remainder of the core for a total of depth of 7.8 m. In 2018, we returned to the site, and moving 2 m north, we retrieved the top 2 m with the Dachnowski corer. The core was raised in 1-m increments, wrapped in saran and aluminium foil and transferred to the refrigerated Lamont Doherty Earth Observatory core repository. Sampling of the entire core was performed at 5 cm intervals for pollen and macrofossil analysis. Radiocarbon age determinations were performed by UC Irvine on identified macrofossils selected from various samples along the length of the core. These dates provide the basis for the calculation of sediment accumulation (Figure 2)

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expressed as years per centimetre (year/cm) and were derived by dividing a core section (cm) by the number of years spanning its deposition. Dates are listed as calibrated ^{14}C years before present (where present is 1950 CE, hereafter ybp).

2.3 | Pollen and Spore Analysis

Sediment samples of 2 mL were processed every 5 cm following standard procedures (Faegri, Kaland, and Krywinski 1989). This process included KOH, then hydrofloric acid treatment when appreciable sand was present, hydrochloric acid rinse, followed by acetolysis, safranin staining and mounting in liquid glycerin. Large amounts of clay were first treated with 7% sodium pyrophosphate prior to acetolysis (Bates and Gibbard 1978). Pollen was concentrated using 150 and 7 μm screens before being mounted on slides (Cwynar, Burden, and McAndrews 1979). At least 300 pollen grains were tallied from each slide to form the basis for the relative frequency histogram. Relative pollen frequency is based on the pollen sum, and relative spore frequency is based on the pollen and spore sum, and pollen zones were delineated by visual inspection. Both pollen and spores were identified by comparison with a modern reference slide collection and with taxonomic keys provided by McAndrews, Berti, and Norris (1973). Pollen counting was done routinely at a magnification of 400× using an A.O. Spencer binocular microscope. Critical identification of problem types was made under oil immersion at 1000× (n.a.–125). Nomenclature follows Fernald (1970).

2.4 | Macrofossil Analysis

Samples were screened for macrofossils at 5 cm intervals using screens of 0.5 and 0.1 mm, picked from a water slurry at a magnification of 20–60× using a Leitz microscope and identified using the Peteet modern macrofossil collection housed at LDEO. All samples are stored in the LDEO refrigerated repository in water. Identified samples for AMS dating were sent to the University of California Irvine Accelerator Facility (UCIAMS). The selected identified macrofossils from six samples were pretreated with an acid–alkali–acid chemical digestion prior to combustion, graphitisation and measurement by accelerator mass spectrometry. Radiocarbon ages on identified plant macrofossils are presented in Table 1. The ^{14}C ages were calibrated using CALIB 7.1 html (Stuiver and Reimer 1993). Ages are presented in calibrated years BP, ybp hereafter (Before present; 0 year BP = 1950 AD), and uncertainties are shown at the 95% (2-sigma) confidence level. Pollen and spore percentage diagrams as well as the macrofossil diagram were drafted using Tilia and Tiligraph (Grimm 1992). Pollen and macrofossil data are stored in the Neotoma database.

2.5 | Loss-on-Ignition (LOI)

Percent weight loss on ignition (LOI) followed Dean Jr (1974), and after drying, samples were burned at 550°C for 2 h in order to determine the organic matter of the core.

2.6 | X-Ray Fluorescence (XRF)

Samples were dried at 50°C, homogenised and packed into sample containers. They were measured with a Bruker iTracer 5 handheld pXRF unit on 'mudrock' mode. Pb data are selected here for determining chronology. XRF samples were not calibrated with external chemistry because the relative abundance of Pb, rather than absolute concentration, was relevant to this study.

3 | Results

3.1 | Chronology, LOI and Sedimentation Rate (cm/year), Figures 2–3

The age–depth model based on AMS dates (Table 1) is presented in Figure 2.

Sedimentation rates were low during the late-glacial (0.017 cm/year) when loss-on-ignition (LOI) was < 10% (Figures 2 and 3), until the clay sediments became more organic and the LOI reached a brief peak at 40% of about 7 m, during the M2 zone of the Younger Dryas (Figure 4).

Sedimentation rates remain low until about 9000 years ago when rates more than doubled to 0.04 cm/year and then increased to 0.06 cm/year until the late Holocene (2750-1127 ybp) when the rate doubled again to 0.12 cm/year. Much of this sedimentation rate increase occurs as the organic content increases from 40% to 80% LOI between 3500 and 1500 years BP (4.8 m–2 m) and

TABLE 1 | AMS C-14 dates from selected macrofossils, Maplecrest Fen, Catskills, NY.

Lab number UCIAMS#	Depth (cm)	Macrofossil	C-14 age	Calendar year (BP)
218951	150–155	*Chamaedaphne* seed	1205 ± 20	1127 ± 77
218952	350–355	*Tsuga* twig wood	2605 ± 20	2748 ± 15
218953	495–500	7 Conifer leaf bracts, moss stems, wood	4485 ± 20	5183 ± 126
218954	600–605	7 Conifer leaf bracts, pine needles, *Betula alleg.* seed, *Nuphar* seed fragment	6955 ± 20	7783 ± 65
263885	640–645	*Betula papyrifera* cone scale	7850 ± 25	8684 ± 186
236728	720–730	3 *Picea* needles	11,605 ± 20	13,471 ± 100

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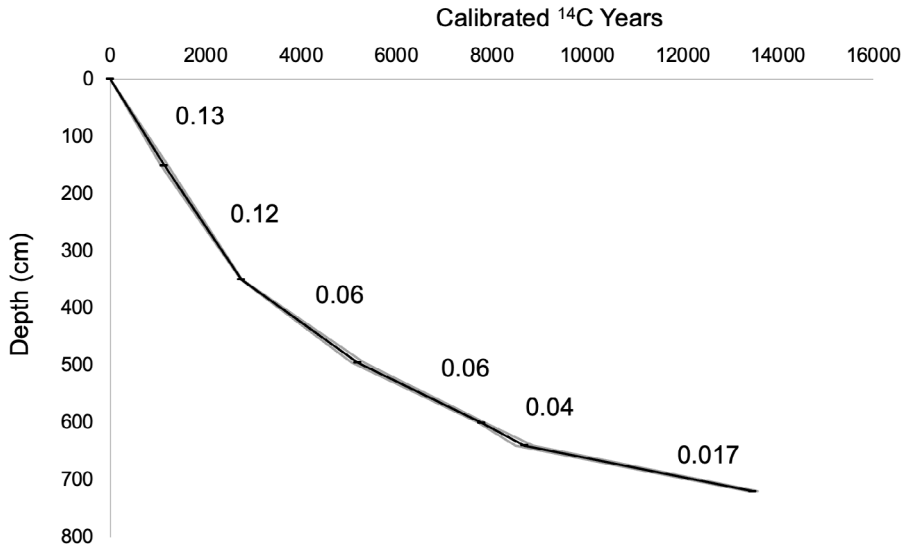


FIGURE 2 | Linear interpolation of sedimentation rates for the Maplecrest Fen core. Calculation of sedimentation rates assumes constant accumulation between dated layers. Grey lines indicate 2 sigma uncertainty.

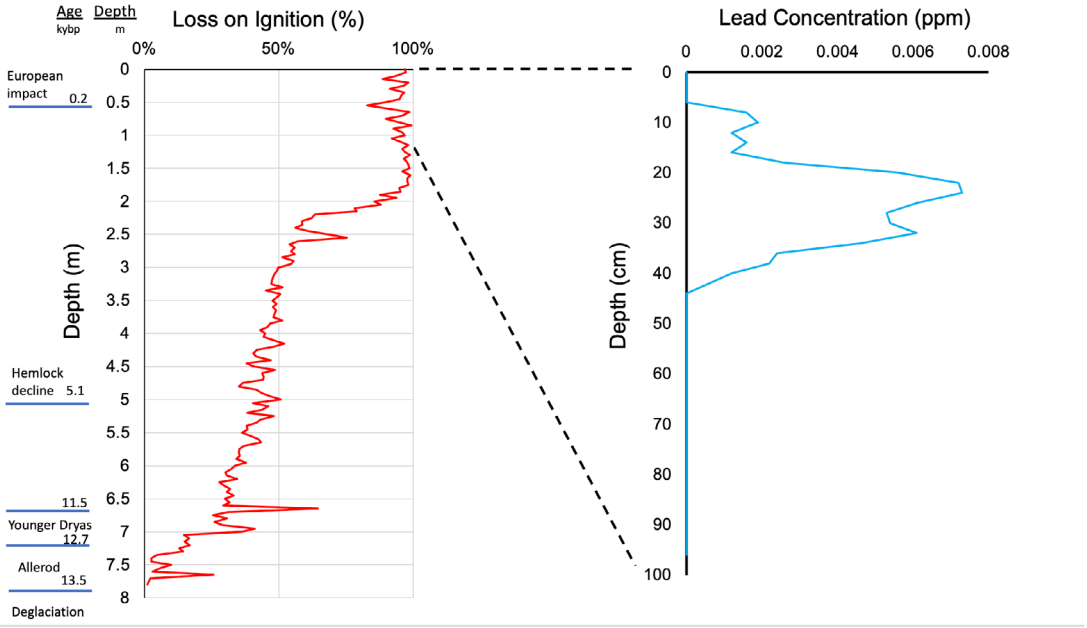


FIGURE 3 | Loss-on-ignition results from the Maplecrest Fen core (left) and lead (Pb) concentrations in the upper meter of Maplecrest Fen core (right) showing Pb contamination with a peak just prior to 20 cm.

finally to over 80%–90% from 1500 years to the present. In these top 2.5 m, the limnic sediments are replaced by peat as the lake became a poor fen. About 200 years ago, the upper 70–0 cm of the core reveals LOI's increasing variability probably due to the disturbance from forest clearance nearby. The Pb increase begins after 45 cm and peaks just below 20 cm and then abruptly declines by a factor of 5 before disappearing in the top 5 cm.

3.2 | Pollen, Spores and Macrofossil Analysis Groupings and Zonation (Figures 4–6)

The relative pollen frequency diagram for Maplecrest Fen (Figure 4) is divided into nine horizontal zones depicting pollen assemblages believed to represent major vegetational shifts in the dominant vegetation. Macrofossils are described along with the pollen zones in Figures 5 and 6.

3.2.1 | Zone M-1 > 13,470–13,000 ybp, 780–720 cm Depth

This zone is distinguished by the presence of very inorganic clay devoid of pollen until 735 cm depth with 80% *Pinus*, 10%–14% *Quercus* and 5% *Betula*. The macrofossil assemblage is dominated by abundant *Drepanocladus* moss, a little *Sphagnum*, *Chara* oogonia, bryozoan statoblasts and numerous cladoceran egg cases, along with some insect remains.

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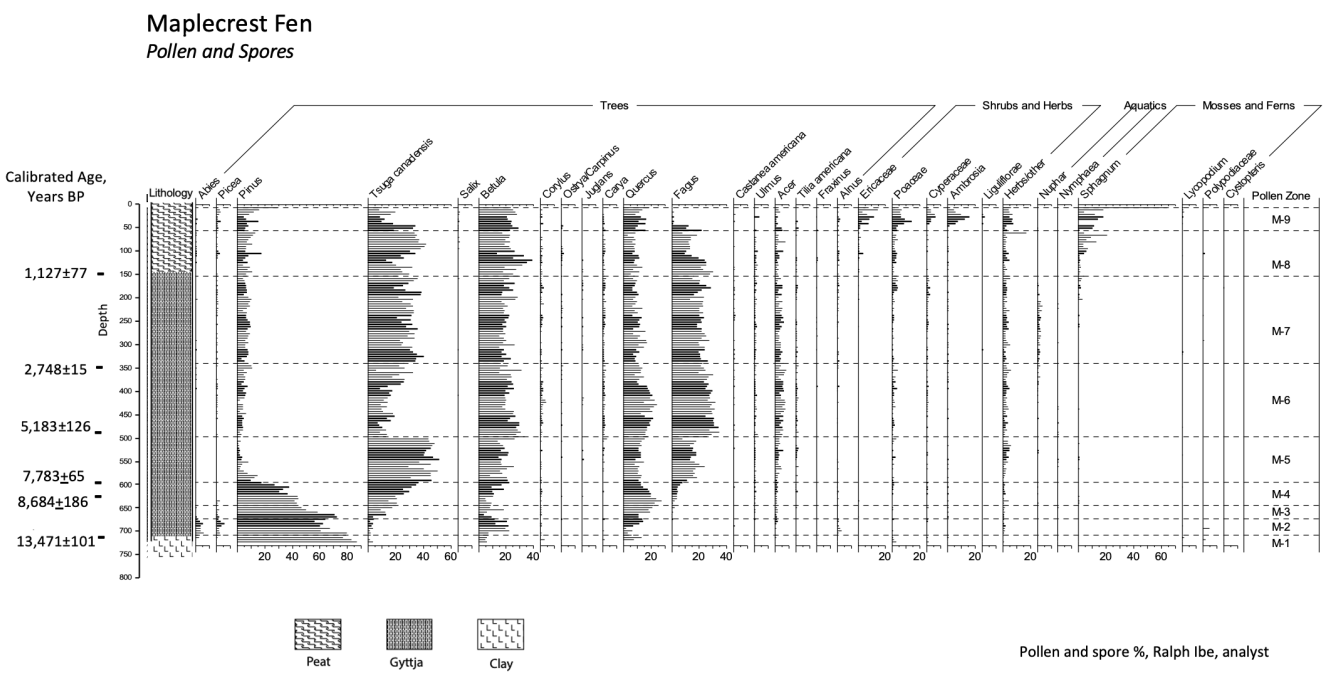


FIGURE 4 | Pollen and spore percentage data for Maplecrest Fen, Catskills.

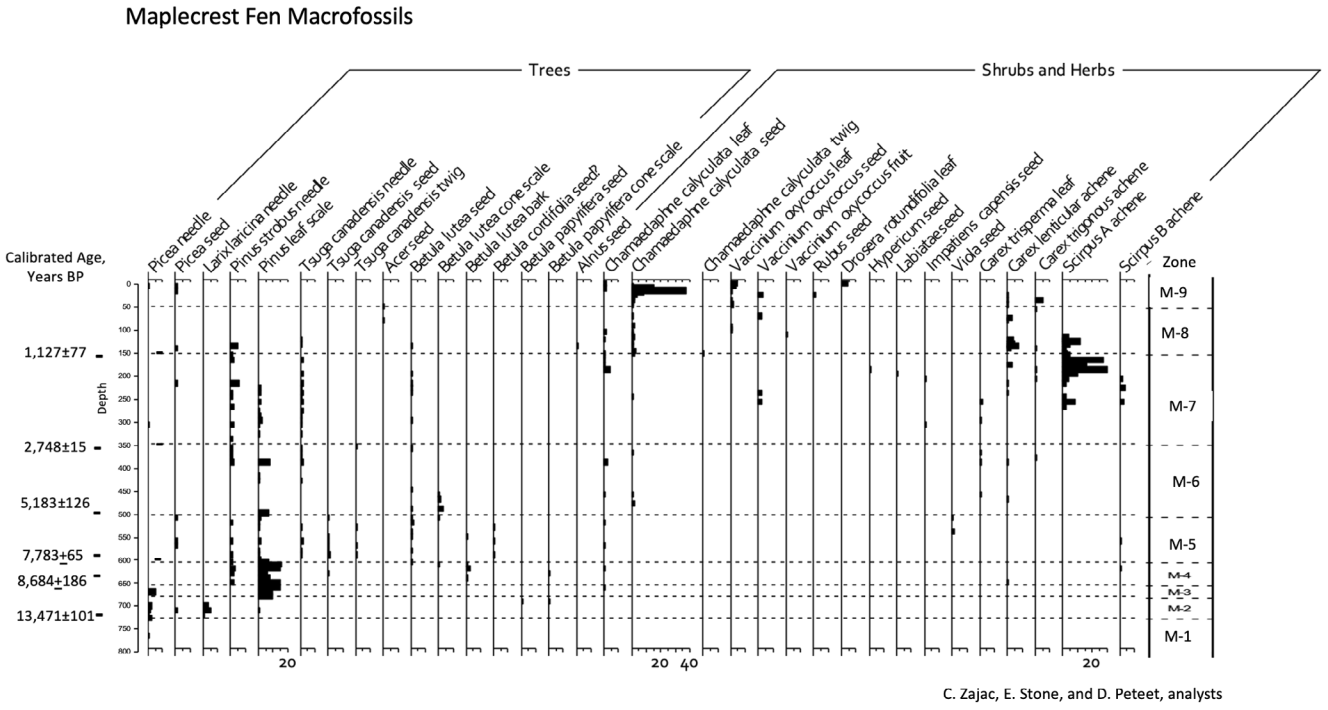


FIGURE 5 | Macrofossil diagram for Maplecrest Fen, Catskills showing trees, shrubs and herbs, using same pollen zones. Data presented as macrofossils/20 cc sample.

3.2.2 | Zone M-2 13,000–11,500 ybp, 720–670 cm Depth

This zone is composed of gyttja and LOI increase from about 17% to 30%, but the sedimentation rate is very low (0.017). A slight but distinctive increase of both *Abies* and *Picea* is accompanied by a very minor but distinct presence of *Alnus* accompanied by a significant increase of *Betula* to 20% along with a decline in oak and pine. Macrofossils present include *Picea* needles and a seed, *Larix* needles, a few conifer leaf scales and a *Betula papyrifera* seed and cone scale. Cladoceran egg cases and insects are scarce, but charcoal is present.

3.2.3 | Zone M-3, ll,500–8700 ybp, 670–650 cm Depth

While the LOI remains close to 30% in this zone, the sedimentation rate remains very low at 0.017 cm/year. *Abies* and *Picea* decline almost to 0% while *Pinus* first increases about

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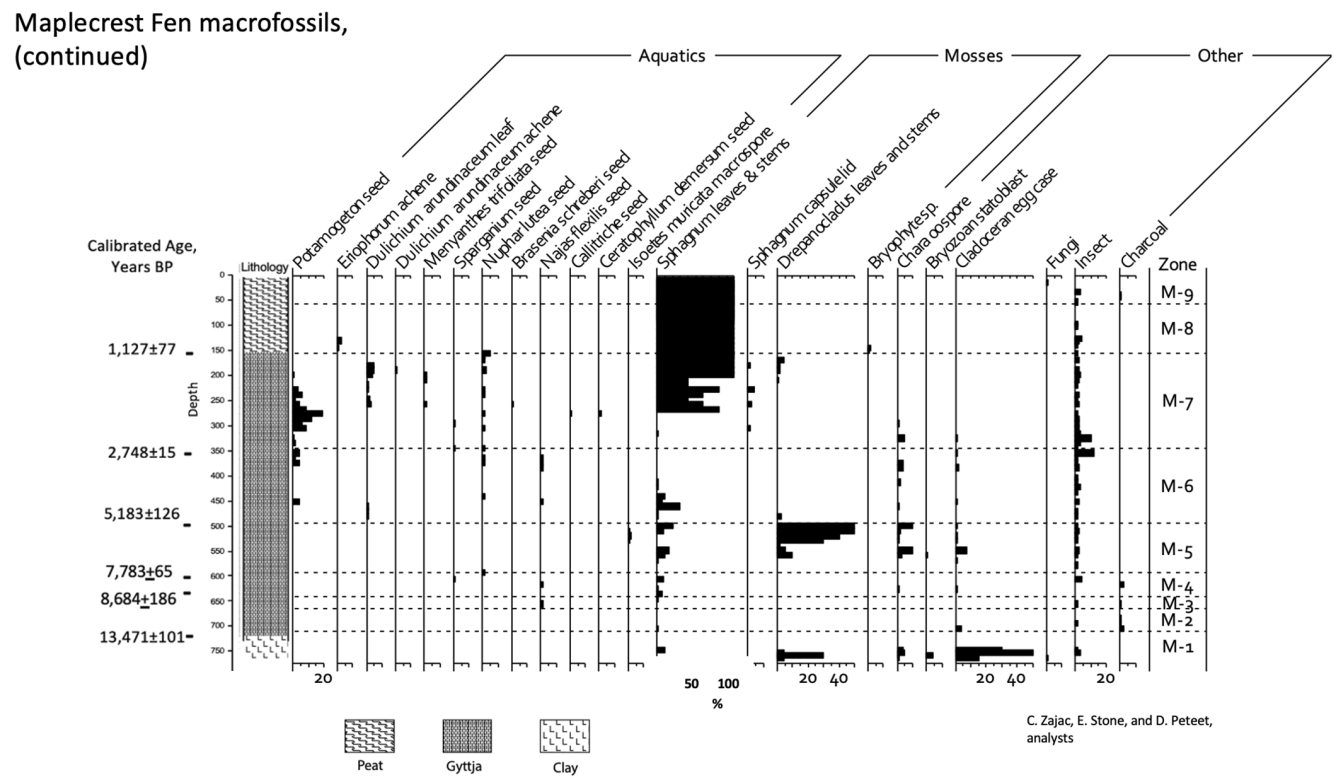


FIGURE 6 | Macrofossil diagram for Maplecrest Fen, Catskills showing aquatics, mosses and various other fossils, using same pollen zones. Data presented as macrofossils/20 cc sample, excepting *Sphagnum* which is presented as the percentage of the sediment.

60%–70% but then declines to 50%. Concurrently, *Quercus* increases from 10% to 20%, as does *Tsuga canadensis*, and *Acer* pollen maintains a small presence. *Picea* needles are still present in the zone, but it is characterised primarily by conifer cone scales, probably from *Pinus strobus*. A single *Chamaedaphne* leaf and *Najas* seed are present. *Sphagnum* re-appears at the top of the zone.

3.2.4 | Zone M-4, 8700–7800 ybp, 650–600 cm Depth

As sedimentation rates more than double to 0.04 cm/year and LOI fluctuates around 30%–35%, *Pinus* pollen continues to decline while *Tsuga* reaches values over 35% and *Quercus* increases up to maximum values around 25%. *Picea* pollen declines to zero, and *Fagus* arrives and then is continuously present at 5%. *Pinus strobus* needles, conifer leaf scales and *Tsuga* seeds are present. *Betula papyrifera* cone scales and then *B. lutea* cone scales are present. *Chamaedaphne* leaves appear, and an aquatic seed of *Najas* is present along with a *Sparganium* seed and increased *Sphagnum* leaves. *Chara*, some insect remains and charcoal are also present.

3.2.5 | Zone M-5, 7800–5200 ybp, 600–500 cm Depth

Organic content in the core continues to rise to 50%, and sedimentation rates increase from 0.04 to 0.06 cm/year. Pine drops to nearly 0%, while *Tsuga* reaches nearly its maximum value throughout the core at almost 50%. *Fagus* and *Betula* rise to 20%, while *Quercus* declines to about 15%, and *Acer* and *Tilia* increase slightly but remain low. Shrub/herb pollen increases to almost 10%. The top of zone 5 at nearly 500 cm marks the dramatic *Tsuga* decline from 40% to 10% seen throughout the northeastern forests. Conifer leaf scales decline sharply (mostly *Pinus strobus*), and while several *Picea* seeds are present in the zone, the abundant *Tsuga* needles, seeds and twigs along with *Betula lutea* and possibly *B. cordifolia* seeds dominate the macrofossil component. *Chamaedaphne* leaves are present, along with *Viola* seeds, *Isoetes* macrospores, *Sphagnum* leaves, abundant *Drepanocladus* moss, *Chara*, cladoceran egg cases and insects, with an absence of charcoal.

3.2.6 | Zone M-6, 5200–2700 ybp, 500–350 cm Depth

Sedimentation rates remain at 0.06 cm/year, and LOI fluctuates between 40% and 50%. The initiation of zone 6 witnesses the low values of *Tsuga* along with a maximum of *Betula* and *Fagus*, with an increase in *Quercus* to about 15%. *Acer* pollen is at the top of this zone, both *Pinus* (to 10%, with *P. strobus* needles at the top of the zone) and *Tsuga* (to 30%) double their pollen contribution, as *Quercus* declines to 10%. Poaceae are more abundant in this zone but remain around 2%. Macrofossils include *Betula lutea* cone scales, seeds and *Chamaedaphne* seeds and leaves, along with *Carex trisperma* leaves and lenticular *Carex* achenes, and the zone shows first a decline in *Sphagnum* leaves with increases in *Potamogeton*, *Nuphar* and *Najas* seeds along with *Chara* at the top of the zone. With this rise, *Pinus strobus* and *Tsuga* needles reappear, paralleling their recovery in the pollen record.

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3.2.7 | Zone M-7, 2700–1100 ybp, 350–150 cm Depth

Sedimentation rate doubles in this zone from 0.06 to 0.12 cm/year, and LOI increases from 50% to over 90%. *Tsuga*, *Fagus* and *Betula* are abundant, while *Quercus* again declines to 10%. *Pinus* remains < 15% while *Nuphar* pollen increases, then disappears at the top of the zone, and is replaced by Ericaceae pollen and *Sphagnum* spores. Both *Pinus strobus* and *Tsuga* needles are consistently present, with the reappearance of *Picea* with both a seed and needle. While *Chamaedaphne* leaves and a seed are still present, *Vaccinium oxycoccus* seeds along with *Hypericum* and *Impatiens capensis* seeds are also present for the first time, along with both lenticular and trigonous *Carex* achenes and abundant *Scirpus* achenes of two types. Abundant *Potamogeton* along with *Sparganium*, *Nuphar*, *Brasenia* and *Callitriche* seeds all replace *Chara*, with *Dulichium* and *Menyanthes trifoliata* seeds and *Sphagnum* leaves forming much of the organic material.

3.2.8 | Zone M-8, 1100–200 ybp (1750 CE), 150–50 cm Depth

Sedimentation rates increase to 0.13 cm/year, and LOI is generally over 90%. *Tsuga* pollen fluctuates between 20% and 40%, while *Betula* first increases to over 30% and then declines back to 20%. *Pinus* pollen slightly increases to > 10% *as Fagus* declines from 20% to close to 10% about halfway up in the zone. *Chamaedaphne* and *Vaccinium oxycoccus* seeds and leaves are present, along with lenticular *Carex* and a few declining *Scirpus* achenes. *Sphagnum* spores show a distinct increase.

3.2.9 | Zone M-9, 200 ybp (1750 CE)-Present, 50–0 cm Depth

Sedimentation rate remains at 0.13 cm/year, and organic matter fluctuates between about 80% and 90%. The upper 45 cm of the record (Figure 3) shows the Pb rise from the industrial era, isotopically identified and dated to the early 1800's in regional records (Lima et al. 2005; Peteet et al. 2018). Dramatic declines in *Tsuga* and *Fagus* pollen, along with increases in *Ambrosia* and Ericaceae as well as Poaceae and Cyperaceae, mark the beginning of European settlement. A single *Picea* seed confirms its presence, but *Picea* pollen is < 5%. Continued increases in *Sphagnum* spores mark the closure of the open water, and macrofossils of *Chamaedaphne*, *Andromeda*, *Vaccinium oxycoccus* and *Drosera* along with *Carex* achenes and abundant *Sphagnum* leaves and stems are present.

4 | Discussion

4.1 | Late-Glacial—Allerod and Younger Dryas (YD). Zones M-1 and M-2 (>13,470-11,500 ybp)

At the base of the Maplecrest core as ice melted out of the shallow lake basin during the Allerod warming sometime greater than 13,400 ybp, the environment is limnic (Table 2). Present are abundant cladoceran egg cases, several bryozoan statoblasts, several *Chara* oospores and abundant *Drepanocladus*, a bryophyte abundant in mineral- and nutrient-rich lakes as deep as 6 m (Rintannin 1977). *Chara* is a green alga that signals mineral-rich waters as well, and they grow in the photic zone. Dominated by pine pollen with very little *Quercus* and *Betula*, it appears equivalent to the A1–A3 New England pollen zones of Deevey Jr. (1939) and Davis (1969) that reflect cool late-glacial conditions recognised as the warming of deglaciation (Bolling-Allerød) which was followed by the Younger Dryas cooling.

The timing of our pollen stratigraphic zone agrees well with the warming signal of almost 15% *Quercus* pollen and significant pine. We found *Picea* needle remains, demonstrating the presence of boreal forest, while pine may have been blowing throughout the landscape from the sites to the south. The overlying zone M2 reveals a clear Younger Dryas (YD) in the pollen with a decline in *Quercus* and demonstrates a cooler boreal forest composed of *Abies*, *Picea* and *Larix*, as the *Larix* macrofossils add to the coniferous diversity. The assemblage is typical of the Younger Dryas in other locations to the south near the Laurentide margin including Alpine, NJ, Allamuchy Pond, NJ and Linsley Pond, CT (Peteet et al. 1990, 1993) and Spruce Pond and Sutherland Pond (Maenza-Gmelch 1997a, 1997b) as well as those closer to the Catskills, including Lake Minnewaska and Mohonk Lake (Menking, Peteet, and Anderson 2012). We find *Betula papyrifera* seeds and cone scales, as well as the signature YD *Alnus* pollen (Mayle, Levesque, and Cwynar 1993; Peteet et al. 1993). Interestingly, the LOI shows an increase at this point, similar to the record in Lake Minnewaska, possibly signalling a higher input to the lake. The climatic estimates from the sites to the south suggest a 4°C–6°C cooling (Peteet et al. 1993; Shemesh and Peteet 1998). To the north, we see a very clear palynological YD signal at Heart Content's Bog as well as in Niles Huyck Bog, and even the termination of the YD at Ballston Lake with its initial formation (Toney, Rodbell, and Miller 2003).

Maplecrest Fen, at an elevation of 690 m, yields a basal date of 13,471 ybp and is the highest elevation site in the Catskills where cores for palaeoecology have been extracted. It is difficult to compare regional basal dates because our date is AMS radiocarbon dating of terrestrial macrofossils, while all previous sediment core dates from lakes are bulk dates on 10 cm samples of sediment and considerably unreliable and older, as would be expected (Grimm, Maher, and Nelson 2009; Strunk et al. 2020). For example, Meadowdale bog, to the northeast near Voorheeseville, NY, around 112 m elevation, yields a bulk radiocarbon date of around 16,650 ybp for basal sediments while basal sediments from Great Bear Swamp, close to Alcore Reservoir, at an elevation of 208 m yield a bulk radiocarbon date of 15,060 ybp (Dineen 1986). These old bulk ages are much older than sites AMS-dated further south, such as those in Black Rock Forest and near the glacial margin (Peteet et al. 2012). Other sites such as Niles Huyck Bog in Rensselaerville, N/Y (Ibe 2017) at an elevation of 560 m are undated; Balsam Lake in the western Catskill's is undated at the base; and Heart's Content Bog, Catskills, at elevation 107 m with a very similar late-glacial pollen stratigraphy is undated (Ibe and Pardi 1985). A pollen diagram for South Lake Bog to the west at an elevation of 652 m (Ibe, l985) is also a similar profile to this site. These sites are similar in their

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TABLE 2 | Chronological sequence of regional and local vegetation and climate; *indicates macrofossils.

Age (ybp)	Forest	*Shrubs, *herbs, *aquatics	Zone	Interval	Climate
Present-200	Yellow birch–pine–oak–hemlock (*B. lutea*, *P. strobus*, *Quercus*, *Tsuga*, **Picea*)	Ragweed (*Ambrosia* *Chamaedaphne*, *Carex*, *Vaccinium*, *Sphagnum*	M-9	European impact	Cool, wet
200–1100	Hemlock–yellow birch–beech–oak (**Tsuga*, **B. lutea*, *Quercus*, **Pinus*, **Picea*)	*Chamaedaphne* *Carex*	M-8	Late Holocene	Cool, wet
1100–2700	Hemlock–yellow birch–beech–oak (**Tsuga*, **B. lutea*, *Fagus*, *Quercus*, **Pinus*, **Picea*)	*Scirpus*, *Carex*, herbs, *Chamaedaphne*, *Potamogeton*, *Dulichium*, *Menyanthes*, *Nuphar*, *Sphagnum*	M-7	Late Holocene	Cooler, wet
2700–5200	Beech–yellow birch–oak (*Fagus*, **B. lutea*, *Quercus*)	*Chamaedaphne*, *Carex*, *Dulichium*, *Najas*, *Potamogeton*, *Nuphar*, *Chara*	M-6	Mid-late Holocene	Warm, oscillating wetter
5200–7800	Hemlock–yellow birch–oak–beech (**Tsuga*, *Quercus*, **B. lutea*, *Fagus*, **P. strobus*, **Picea* **Hemlock decline**	*Chamaedaphne*, *Viola*, *Isoetes*, *Drepanocladus*, *Sphagnum*, *Chara*	M-5	Early-Mid Holocene	Warm, oscillating moist then drier
7800–8900	White pine–oak–hemlock–beech (**P. strobus*, **Tsuga*, *Quercus*, **B. lutea*, *Fagus*)	*Chamaedaphne*, *Carex*, *Scirpus*, *Najas*	M-4	Early Holocene	Warm, wetter
8900-11,500	White pine–oak–hemlock (**P. strobus*, *Quercus*, *Tsuga*)	*Najas*	M-3	Early Holocene	Warm, dry
11,500-13,000	Boreal forest (**Picea*, *Abies*, **Larix*, **Pinus*, **B. papyrifera*, *Alnus*)	*Sphagnum*	M-2	Younger Dryas	Cold, wet
13,000-13,470	Boreal forest with oak (**Picea*, *Abies*, *Quercus*)	*Drepanocladus*, *Sphagnum*, *Chara*	M-1	Allerod	Cool, dry

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earliest vegetation of boreal forest, but the lower elevation Heart's Content Bog nearby includes a lower meter of clay sediment with spruce and up to 20% sedge, suggesting a slightly earlier deglaciation prior to the Allerod with cold conditions. Thus, our data and the Heart Contents Bog data suggest that lower elevations may have been deglaciated first as climate first warmed. The 12,870 ybp-dated bottom sediments in the higher reaches of the White Mountains of New Hampshire at Lost Pond at 600 m elevation (Spear, Davis, and Shane 1994) place younger dates for basal sediments at higher elevations and older dates for corresponding basal sediments at low relief positions, similar to our findings. Similarly, palaeoecological sites in the Adirondacks on an elevational gradient are older at lower altitudes (Whitehead and Jackson 1990). Future sites with AMS chronology are needed to clearly define the timing of deglaciation with respect to elevation.

4.2 | Early–Mid Holocene, Zones M-3 and M-4 (11,500–7800 ybp)

At the initiation of the Holocene, the resurgence in pine in Maplecrest Fen, probably white pine, is typical of other sites throughout the northeast (Peteet et al. 1990; Peteet et al. 1993; Maenza-Gmelch 1997a, 1997b; Menking, Peteet, and Anderson 2012). Low sedimentation rates suggest a drier climate leading to a higher oxidation of organic remains. A drier climate favours *Pinus strobus* growth, and warmer temperatures also favour the decline of *Abies* and *Larix*. Light-demanding *Larix* also may have been outshaded as *Quercus*, *Tsuga and Acer* moved into the landscape (Table 2).

Our *Pinus* pollen zone supported *Tsuga* and *Fagus as Quercus declined*, leading to a more diverse forest in M-4 with the boreal forest replacement *of Betula papyrifera* by *Betula lutea*. The hardwoods play a much larger role, and sedimentation rates are higher than previous rates due to more input from the moister hardwood complex and/or increased productivity in the lake with a warmer, moister climate. The presence of *Najas* indicates warmer/shallower water as well (Haas and McAndrews 2000), and some charcoal is present, indicating fires. At sites to the south such as Linsley Pond, CT, a study of black carbon shows a higher black carbon soot content during the early Holocene when fires were hotter (Han et al. 2016). Organic content of the lake continues to increase, probably with higher productivity on the landscape.

4.3 | Mid Holocene, Zone M-5 (7800–5200 ybp)

A diverse *Tsuga*-hardwood forest characterises this zone locally, primarily interpreted as moist with the dominance of *Tsuga* and *Fagus* with low *Pinus* and a higher sedimentation rate in the lake. The local environment may have also been more diverse with various *Betula* species and shaded, as *Chamaedaphne* increased and *Viola* and *Sphagnum* as well as *Isoetes* were present. *Chara* is abundant, suggesting increases in mineral groundwater from below (Siegel et al. 1995), and *Drepanocladus* moss becomes extremely abundant as well. Nearby sites such as Mohonk and Minnewaska show similar regional pollen stratigraphy, but the sedimentation rate in these lakes is much lower, limiting the ability to make good assessments of moisture fluctuations in this mid-Holocene interval (Menking, Peteet, and Anderson 2012). In New England, this zone is characterised by lower water levels and drought (Thorson and Webb 1991), but the high percentage of *Tsuga* and *Fagus* at this site suggest available moisture, along with the increased sedimentation rate (Table 2).

4.4 | Mid-Late Holocene, Zone M-6 (5200–2700 ybp)

By 5200 ybp, *Tsuga* declined precipitously at Maplecrest, reaching the well-known biostratigraphic hemlock decline, and *Fagus* replaced *Tsuga* in the canopy. The Maplecrest surrounding forest continued to increase in hardwood abundance with the rise in *Fagus* and *Betula*. In contrast, Minnewaska reveals a large increase in *Castanea* (Menking, Peteet, and Anderson 2012) which may reflect the more southerly location and shallower soils. Some recent studies of modern pollen rain relationships in both the Catskill and the Adirondack Mountains of New York (Ibe 1984; Ibe and Sperling 1986) and in New Jersey (Ibe, Loeb, and Sperling 1990) demonstrate that *Acer* is grossly underrepresented in the pollen rain. *Acer* can play a subdominant role in the forest locally. LOI fluctuates and declines by 10%, suggesting drier conditions. The presence of *Betula lutea* confirms relatively warm temperatures and its presence at the site, and *Carex* and shallow aquatics along with *Chara* are indicative of declines in moisture with increases in mineral groundwater. A rebound in *Tsuga* concurrent with the decline in *Quercus* towards 3000 ybp suggests cooler and moister temperatures ensued (Table 2).

Sites that show this classic *Tsuga* decline include Mohonk, Minnewaska (Menking, Peteet, and Anderson 2012) around 5420 ybp, close to 5300 ybp at Ballston Lake, and a little later at Sutherland Pond around 4700 ybp (Maenza-Gmelch 1997a). While the *Tsuga* decline is abrupt at 5200 ybp at Maplecrest, it is abrupt at Balsam Lake (bulk date of 5000 ybp); in contrast; the decline is more gradual at Niles Huyck Bog to the north, where the lowest pollen percentage dates to 4788 ± 317 ybp. At Grinnell Lake in northern New Jersey, the decline occurs at 5300 ybp (Zhao, Yu, and Zhao 2010) and is synchronous with an oxygen isotope shift that is interpreted as an atmospheric circulation shift resulting in a cooler, drier climate. Part of the difference in timing of the decline may be the differential dating of the onset of decline versus the lowpoint. In a transect of five sites in New England from Vermont to Connecticut, Oswald and Foster (2011) note the decline begins close to 5500 ybp, and the decline appears abrupt.

4.5 | Late Holocene, Zone M-7 (2700–1100 ybp)

The diverse forest with abundant *Tsuga* and *Fagus* and less *Quercus* suggests a return to a moist, cooler climate, and the higher sedimentation rate is consistent with this interpretation. The presence of *Picea* nearby also suggests cooling, The shift from shallow aquatic flora (*Potamogeton*, *Nuphar* and *Callitriche*) to emergent taxa such as *Menyanthes* and *Dulichium* as well as *Sphagnum* and several *Carex* and *Scirpus* achenes indicate the pond was filling in and becoming a fen, which is also indicated by the presence of *Vaccinium oxycoccus* (Table 2)

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4.6 | Late Holocene Prior to European Impact, Zone M-8 (1100–200 ybp) (1750 CE)

Tsuga pollen fluctuates along with *Betula* in this zone, while *Pinus* slightly increases and *Fagus* declines. The *Betula* increase suggests the disturbance of the forest, and the *Betula lutea* seed confirms its presence at the site. Sedimentation rates continue to be high (0.12 cm/year), and as the pond transitions to a bog with a *Sphagnum* matrix, fewer forest macrofossils are present. *Chamaedaphne* and *Vaccinium oxycoccus* are present again, along with sedge achenes. *Sphagnum* spores show a distinct increase and mark the beginning of closure of open water at Maplecrest (Table 2).

4.7 | European Impact, Zone M-9 (200 ybp) (1750 CE—Present)

The impact of European forest clearance is evident in the upper 50 cm of the profile with sharp declines in *Tsuga* and *Fagus* pollen, along with *Pinu*s, although *Pinus* then recovers in the most recent 100 years with reforestation typical of the northeastern US (Pederson et al. 2013). The nature of the fen environment is evident with typical poor fen species such as *Chamaedaphne*, *Vaccinium oxycoccus* and *Drosera*, as well as the *Sphagnum*. Our Pb profile from X-ray fluorescence also shows the rise in Pb, beginning at about 45 cm depth (Figure 3), and peaking about 23 cm, which we interpret as the peak prior to the Pb decline in l975 due to the declines in leaded gasoline targeted by the Clean Air Act (https://www.epa.gov/clean-air-act-overview/evolution-clean-air-act). This profile is similar to our Pb profiles in Tivoli Bay (Sritrairat et al. 2012) and Piermont Marsh (Peteet et al. 2020) in the Hudson River as well as other regional sites such as Jamaica Bay in NYC (Peteet et al. 2018) and Nell's Island, Conn (Copple et al. 2023) in Long Island Sound. The same profile from this relatively pristine Catskills Mountain region and the Hudson River locations to the south signals the northeastern US pollution from the industrial era up into the late 1970's, with a return to cleaner conditions today due to political action (Table 2).

4.8 | Conclusions

1. Our AMS-dated basal record at Maplecrest Fen provides a northward and altitudinal migration path for boreal forest as it moved northward from the Laurentide margin. Earliest dates near the glacial moraine from New Jersey to Staten Island and Conn. are close to 15–16,000 ybp (Peteet et al. 2012) from many sites, while in Maplecrest at 690 m elevation and about 200 km north, ice melt is about 2500 years later at 13,500 ybp, suggesting ice retreat and migration rate of roughly 0.1 km/year. The sediment record reveals increasing organic matter deposition with warming and a late-glacial shift from a spruce–fir–larch boreal forest to a deciduous one, along with a record of shifting moisture and temperature throughout the Holocene up to the present.
2. Classical features of the northeastern palaeoclimate defined decades ago by Deevey Jr. (1939) are visible in the pollen record, including the late-glacial Allerod and Younger Dryas. Subsequently, these include the early Holocene white pine zone, mixed deciduous forest with hemlock, abrupt hemlock decline indicating drier conditions, which return to cooler, moister conditions at the close of the Holocene. These patterns are similar to the oscillations in moisture recognised throughout southern New England, and we note the presence of charcoal in the early Holocene white pine zone which could be an analogue for future climate as warming continues. Similarly, the *Tsuga* decline due to drought and disease may be a portent of warmer future conditions. However, the 20% increase in rainfall since the 1970's in the region (Pederson et al. 2013) has certainly helped to alleviate moisture deficits that characterised the 1960's. This variability is thought to be due to internal atmospheric dynamics and thus not easily predicted (Seager et al. 2012). Future warming with higher evaporation may signal droughts in the Catskills future, threatening water supplies as well as particular moisture-loving species.
3. The macrofossil record from Maplecrest Fen provides greater understanding of local conditions, especially moisture. The presence of larch is important during the late-glacial, as it shows the openness and diversity of the boreal forest and the *Betula papyrifera* and *Alnus* seeds typical of the Younger Dryas. The discovery of aquatics and emergent in the fen which are not present today (*Chara*, *Callitriche*, *Isoetes*, *Menyanthes* and *Dulichium*) enrich our understanding of the Maplecrest local vegetation and its changes through time due to climate.
4. European settlement in the area is visible with classical *Ambrosia* and Poaceae increases, indicative of disturbance as well as decline in trees due to forest clearance. The XRF data reveal that the lead pollution stratigraphy matches records from more populated regions in the Hudson Valley collected from marsh sediments (Pederson et al. 2013; Sritrairat et al. 2012; Peteet et al. 2018, 2020). This suggests that industrial era lead pollution is not a localised signature from New York City but rather a result of widespread atmospheric pollution across the Northeastern United States.

Author Contributions

D.M.P. and R.I. designed the study, and R.I. counted pollen while C.Z., E.S., and D.M.P. identified macrofossils and C.C. led the XRF analysis. D.M.P. led the data analysis and writing with input from all authors.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Data Availability Statement

All palaeoecological data will be available in the Neotoma palaeoecology database.

References

Adams, M. S., and S. J. Parisio. 2013. "Biodiversity Elements Vulnerable to Climate Change in the Catskill High Peaks Subecoregion (Ulster, Delaware, Sullivan, and Green Counties, New York State)." *Annals of the NY Academy of Sciences* 1298: 86–94.

Bates, C. D. P. C., and P. L. Gibbard. 1978. "A New Method for the Preparation of Clay Rich Sediment Samples for Palynologic Investigations." *New Phytologist* 81: 459–463.

Birks, H. H. 1993. "The Importance of Plant Macrofossils in Late-Glacial Climatic Reconstructions: An Example From Western Norway." *Quaternary Science Reviews* 12: 719–726.

Blake, R., R. Khanbilvardi, and C. Rosenzweig. 2000. "Climate Change Impacts on New York City's Water Supply System." *Journal of the American Water Resources Association* 36: 279–292. https://doi.org/10.1111/j.1752-1688.2000.tb04267.x.

Copple, S. P., D. M. Peteet, D. Balk, C. Chang, B. Jones, and M. Tzortziou. 2023. "Marsh Archive Reveals Human Population History and Future Implications for Estuarine Health in Long Island Sound." *Science of the Total Environment* 895: 164885. https://doi.org/10.1016/j.scitotenv.2023.164885.

Curry, B., M. Konen, T. Larson, et al. 2010. "The DeKalb Mounds of Northeastern Illinois as Archives of Deglacial History and Postglacial Environments." *Quaternary Research* 74: 82–90.

Cwynar, L. C., E. Burden, and J. H. McAndrews. 1979. "An Inexpensive Method for Concentrating Pollen and Spores From Fine-Grained Sediments." *Canadian Journal of Earth Sciences* 16: 1115–1120.

Davis, M. B. 1969. "Climatic Changes in Southern Connecticut Recorded by Pollen Deposition at Rogers Lake." *Ecology* 50: 409–422.

De Gaetano, A., and C. M. Castellano. 2013. "Recent and Future Changes in Extreme Rainfall in the Catskills Region of New York." *Annals. New York Academy of Sciences* 1298: 43–51.

Dean, W. E., Jr. 1974. "Determination of Carbonate and Organic Matter in Calcareous Sediments and Sedimentary Rocks by Loss on Ignition: Comparison With Other Methods: SEPM." *Journal of Sedimentary Research* 44: 242–248. https://doi.org/10.1306/74D729D2-2B21-11D7-8648000102C1865D.

Deevey, E. S., Jr. 1939. "Studies on Connecticut Lake Sediments. I. A Postglacial Climate Chronology for Southern New England." *American Journal of Science* 237: 691–724.

Dineen, R. J. 1986. "Deglaciation of the Hudson Valley Between Hyde Park and Albany, New York." In *The Wisconsinan Stage of the First Geological. District, Eastern New York*, edited by D. H. Caldwell, 89, 192–108. Albany, New York: New York State Museum Bulletin 455.

Faegri, K., P. E. Kaland, and K. Krywinski. 1989. *Textbook of Pollen Analysis*. Chichester: Wiley and Sons.

Fernald, M. L. 1970. *Gray's Manual of Botany*. New York: Van Nostrand.

Frei, A., R. L. Armstrong, M. P. Clark, and M. C. Serreze. 2004. "Catskill Mountain Water Resources: Vulnerability, Hydroclimatology, and Climate Change Sensitivity." *Annals of the Association of American Geographers* 92, no. 2: 203–224.

Gaglioti, B. V., D. H. Mann, B. M. Jones, J. W. Pohlman, M. L. Kunz, and M. J. Wooller. 2014. "Radiocarbon Age-Offsets in an Arctic Lake Reveal the Long-Term Response of Permafrost Carbon to Climate Change." *Journal of Goephysical Research: Biogeosciences* 119: 1630–1651.

Gaudreau, D. C., and T. Webb. 1985. "Late Quaternary Pollen Stratigraphy and Isochrone Maps for the Northeastern United States." In *Pollen Records of Late Quaternary North Amercian Sediments*, edited by V. M. Bryant Jr. and R. G. Holoway, 247, 423–280. Dallas, Taxas: Published by the American Association of Stratigraphic Palynologists Foundation.

Grimm, E. 1992. *Tilia and Tilia-Graph Software, Version 2.0*. Springfield, illinois: Illinois State University.

Grimm, E. C., L. J. Maher, and D. M. Nelson. 2009. "The Magnitude of Error in Conventional Bulk-Sediment Radiocarbon Dates From Central North America." *Quaternary Research* 72: 301–308.

Haas, J. N., and J. H. McAndrews. 2000. "The Summer Drought Related Hemlock (*Tsuga canadensis*) Decline in Eastern North America 5700–5100 Years Ago." In *Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America*, edited by K. McManus, 81–88. Newtown Square, PA: USDA Forest Service General Technical Report NE-267.

Hajdas, I., S. D. Ivy, J. Beer, et al. 1993. "AMS Radiocarbon Dating and Varve Chronology of Lake Sopppenseee From 6000-12000 14C Years BP." *Climate Dynamics* 9: 107–116.

Han, Y. M., D. M. Peteet, R. Arimoto, et al. 2016. "Climate and Fuel Controls on North American Paleofires: Smoldering to Flaming in the Late-Glacial-Holocene Transition." *Scientific Reports* 6: 20719. https://doi.org/10.1038/srep20719.

Ibe, R. A. 1984. "Modern Pollen Rain Vegetation Relations at Four Different Elevations of Slide Mountain, Catskill Mountains New York." *Bulletin of the Torrey Botanical Club* 111: 96–102.

Ibe, R. A. 1985. "Postglacial Montane Vegetational History Around Balsam Lake, Catskill Mountains, New York." *Bulletin of the Torrey Botanical Club* 12: 176–186.

Ibe, R. A. 2017. "Late Glacial Vegetational History of the Niles Huyck Bog, Rensselaerville, New York." *Northeastern Naturalist* 24, no. 1: 25–36.

Ibe, R. A., R. Loeb, and J. A. Sperling. 1990. "Tree-Pollen Relations at the Greenbrook Sanctuary, Alpine New Jersey." *Bulletin of the New Jersey Academy of Science* 35: 1–15.

Ibe, R. A., and R. Pardi. 1985. "A Radiocarbon Dated Pollen Diagram for Heart's Content Bog, Green County, New York." *Northeastern Geology* 7: 201–208.

Ibe, R. A., and J. A. Sperling. 1986. "Vegetation-Modern Pollen Rain Relations on Whiteface Mountain, Adirondack Mountains mew York." *Northeastern Geology* 8: 23–31.

Kudish, M. 2000. *The Catskill Forest—A History, Fleischmanns*, 218. New York: Purple Mountain Press.

Kudish, M. 2013. "History of the Spruce-Fir Forest in the Catskill Mountains of New York." *Annals of the New York Academy of Sciences* 1298: 78–85. https://doi.org/10.1111/nyas.1227.

Lima, A. L., B. A. Bergquist, E. A. Boyle, et al. 2005. "High-Resolution Historical Records From Pettaquamscutt River Basin Sediments: 2. Pb Isotopes Reveal a Potential New Stratigraphic Marker." *Geochimica et Cosmochimica Acta* 69: 1813–1824.

Maenza-Gmelch, T. E. 1997a. "Vegetation, Climate, and Fire During the Late-Glacial-Holocene Transition at Spruce Pond, Hudson Highlands, Southeastern New York, USA." *Journal of Quaternary Science* 12: 15–24.

Maenza-Gmelch, T. E. 1997b. "Late-Glacial–Early Holocene Vegetation, Climate, and Fire at Sutherland Pond, Hudson Highlands, Southeastern New York, U.S.A." *Canadian Journal of Botany* 75: 431–439.

Maenza-Gmelch, T. E. 1997c. "Holocene Vegetation, Climate, and Fire History of the Hudson Highlands, Southeastern New York, USA." *Holocene* 7: 25–37.

Mayle, F. E., A. J. Levesque, and L. C. Cwynar. 1993. "*Alnus* as an Indicator Taxon of the Younger Dryas Cooling in Eastern North America." *Quaternary Science Reviews* 12: 295–305.

13652699, 2025, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jbi.15052 by Columbia University Libraries, Wiley Online Library on [26/09/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

McAndrews, J. H., A. A. Berti, and G. Norris. 1973. *Key to the Quaternary Pollen and Spores of the Great Lakes Region*, 61. Ontario Canada: University of Toronto Press Toronto.

McIntosh, R. P. 1972. "Forests of the Catskill Mountains, New York." *Ecological Monographs* 45: 143–161.

Menking, K. M., D. M. Peteet, and R. Y. Anderson. 2012. "Late-Glacial and Holocene Vegetation and Climate Variability, Including Major Droughts, in the Sky Lakes Region of Southeastern New York State." *Palaeogeography Palaeoclimatology Palaeoecology* 353-355: 45–59. https://doi.org/10.1016/j.palaeo.2012.06.033.

Mohonk, NY. 2023. "Climate Database." https://www.mohonkpreserve.org/what-we-do/conservation-programs/conservation-science/weather-data/.

Oswald, W., and D. Foster. 2011. "Mid-Holocene Dynamics of *Tsuga canadensis* (Eastern Hemlock) in Northern New England, USA." *Holocene* 22, no. 1: 71–78.

Oswald, W., D. Foster, B. Shuman, et al. 2018. "Subregional Variability in the Response of New England Vegetation to Postglacial Climate Change." *Journal of Biogeography* 45: 2375–2388.

Pederson, N., A. R. Bell, E. R. Cook, et al. 2013. "Is an Epic Pluvial Masking the Water Insecurity of the Greater New York City Region?" *Journal of Climate* 26: 1339–1354.

Peteet, D., J. Nichols, D. Pederson, et al. 2020. "Climate and Anthropogenic Controls on Blue Carbon Sequestration in Hudson River Tidal Marsh, Piermont, New York." *Environmental Research Letters* 15, no. 6: 1–11. https://doi.org/10.1088/1748-9326/ab7a56.

Peteet, D. M., M. Beh, C. Orr, D. Kurdyla, J. Nichols, and T. Guilderson. 2012. "Delayed Deglaciation of Extreme Arctic Conditions 21-16 cal kyr at the Southeastern Laurentide Ice Sheet Margin?" *Geophysical Research Letters* 39: 1–6. https://doi.org/10.1029/2012GL051884.

Peteet, D. M., R. A. Daniels, L. E. Heusser, J. S. Vogel, J. R. Southon, and D. E. Nelson. 1993. "Late-Glacial Pollen, Macrofossils and Fish Remains in Northeastern, USA: The Younger Dryas Oscillation." *Quaternary Science Reviews* 12: 597–612. https://doi.org/10.1016/0277-3791(93)90002-4.

Peteet, D. M., and D. H. Mann. 1994. "Late-Glacial Vegetational, Tephra, and Climatic History of Southwestern Kodiak Island, Alaska." *Ecoscience* 1: 255–267.

Peteet, D. M., J. Nichols, T. Kenna, et al. 2018. "Sediment Starvation Destroys New York City marshes' Resistance to Sea Level Rise." *Proceedings of the National Academy of Sciences* 115, no. 41: 10281–10286. https://doi.org/10.1073/pnas.1715392115.

Peteet, D. M., J. S. Vogel, D. E. Nelson, J. R. Southon, R. J. Nickmann, and L. E. Heusser. 1990. "Younger Dryas Climatic Reversal in Northeastern USA? AMS Ages for an Old Problem." *Quaternary Research* 33: 219–230. https://doi.org/10.1016/0033-5894(90)90020-L.1989.

Pradhanang, S., R. Mukundan, E. Schneiderman, et al. 2013. "Streamflow Responses to Climate Change: Analysis of Hydrologic Indicators in a new York City Water Supply Watershed." *Journal of the American Water Resources* 49: 1308–1326.

Rich, J. I. 1934. *Glacial Geology of the Catskills*, 180. Albany, NY: Bulletin. 229. New York State Museum.

Rintannin, T. 1977. "Lake Studies in Eastern Finnish Lapland. II. Aquatic Flora: Musci and Hepaticae." *Annales Botanici Fennici* 14: 149–152.

Schneiderman, E., A. Matonse, M. Zion, et al. 2013. "Comparison of Approaches for Snowpack Estimation in new York City Watersheds." *Hydrological Processes* 27, no. 21: 3050–3060.

Seager, R., N. Pederson, Y. Kushnir, and J. Nakamura. 2012. "The 1960s Drought and the Subsequent Shift to a Wetter Climate in the Catskill Mountains Region of the new York City Watershed." *Journal of Climate* 25, no. 19: 6721–6742.

Shemesh, A., and D. Peteet. 1998. "Oxygen Isotopes in Fresh Water Biogenic Opal–Northeastern US Allerod-Younger Dryas Temperature Shift." *Geophysical Research Letters* 25, no. 11: 1935–1938.

Siegel, D. I., A. S. Reeve, P. H. Glaser, and E. A. Romanowicz. 1995. "Climate-Driven Flushing of Pore Water in Peatlands." *Nature* 374: 531–533.

Spear, R. W., M. B. Davis, and L. C. K. Shane. 1994. "Late Quaternary History of Low- and Mid-Elevation Vegetation in the White Mountains of New Hampshire." *Ecological Monographs* 64: 85–109.

Sritrairat, S., D. M. Peteet, T. C. Kenna, R. Sambrotto, D. Kurdyla, and T. Guilderson. 2012. "A History of Vegetation, Sediment and Nutrient Dynamics at Tivoli North Bay, Hudson Estuary, New York." *Estuarine, Coastal and Shelf Science* 102: 24–35. https://doi.org/10.1016/j.ecss.2012.03.003.

Strunk, A., J. Olsen, H. Sanei, A. Rudra, and N. K. Larsen. 2020. "Improving the Reliability of Bulk Sediment Radiocarbon Dating." *Quaternary Science Reviews* 242: 106442.

Stuiver, M., and P. J. Reimer. 1993. "Extended14C Data Base and Revised CALIB 3.014C Age Calibration Program." *Radiocarbon* 35: 215–230.

Thaler, J. S. 1996. *Catskill Weather*. Fleischmanns, NY: Purple Mountain Press.

Thorson, R. M., and R. S. Webb. 1991. "Postglacial History of a Cedar Swamp in Connecticut." *Journal of Paleolimnology* 6: 17–35.

Toney, J. L., D. T. Rodbell, and N. G. Miller. 2003. "Sedimentologic and Palynologic Records of the Last Deglaciation and Holocene From Ballston Lake, New York." *Quaternary Research* 60: 189–199.

Ver Straeten, C. 2013. "Beneath It all: Bedrock Geology of the Catskill Mountains and Implications of Its Weathering." *Annals of the New York Academy of Sciences* 1298: 1–29.

Whitehead, D. R., and S. T. Jackson. 1990. "New York State Museum Bulletin." In *The regional vegetational history of the High Peaks (Adirondack Mountains) New York*, vol. 478, 27. Albany, NY: New York State Museum.

Zhao, Y., Z. Yu, and C. Zhao. 2010. "Hemlock (*Tsuga canadensis*) Declines at 9800 and 5300 Cal. Yr BP Caused by Holocene Climatic Shifts in Northeastern North America." *Holocene* 20, no. 6: 877–886.

Zimmerman, S., and D. Wahl. 2020. "Holocene Paleoclimatic Change in the Western U.S. the Importance of Chronology in Discerning Patterns and Drivers." *Quaternary Science Reviews* 246: 106487. https://doi.org/10.1016/j.quascirev.2020.106487.

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