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3 Title: Paleoecological History of Maplecrest Fen, Catskill Mountains, (NY, USA) from  
4 Deglaciation to the Industrial Age

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6 Short title: Paleoecology of Maplecrest Fen, Catskills

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16  
17 **Abstract**

18 **Aim:** To develop the palaeoecological and paleoclimatic history of Maplecrest Fen, Greene  
19 County, NY.

20 **Location:** Catskill Mountains, New York

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

22 **Taxon:** angiosperms, gymnosperms, bryophytes

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

26 **Results:** Late-glacial and Holocene vegetational change from ice withdrawal reveals the  
27 development of a shallow lake and then fen to the present. The boreal spruce (*Picea*), fir (*Abies*),  
28 paper birch (*Betula papyrifera*) pollen signature near the base of the core (Zone M2) suggests a  
29 Younger Dryas (YD) signal overtopping warmer Allerod aged basal sediments. The early  
30 Holocene white pine (*Pinus strobus*) is followed by increases in hemlock (*Tsuga*) and beech  
31 (*Fagus*), ushering in a moister climate. About 5200 ybp drought is indicated by the well-known  
32 hemlock bio-stratigraphic decline in the Northeast. *Drepanocladus* moss and stonewort (*Chara*)  
33 shift to sedges (*Carex*) and violets (*Viola*) locally present. For the next 5000 years the vegetation  
34 remained relatively stable with lower temperatures suggested by the return of spruce and fir.  
35 Ragweed (*Ambrosia*) rise along with other weedy taxa marks European settlement near the top  
36 50 cm of the core, along with a striking increase in anthropogenic lead as seen using x-ray  
37 fluorescence.

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

43  
44 **Keywords:** Catskills, deglaciation, paleoecology, pollen, Younger Dryas, drought, hemlock  
45 decline, Holocene, Late-glacial, macrofossils, European settlement, industrialization, climate  
46 change

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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 et al. 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 1960’s 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, paleoecology provides 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 paleoecology the history of drought as well as temperature in the Catskills.

32       The general history of vegetational change in the Atlantic northeastern United States (New  
33 York, Conn, NJ) following deglaciation is largely written in the pollen records found in lake and  
34 bog sediments and has been broadly outlined (Deevey, 1939; Ibe, 1985; Gaudreau and Webb  
35 1985; Peteet et al., 1990; 1993; Maenza-Gmelch, 1997a-c; Menking et al., 2012; Oswald et al,  
36 2018). Nevertheless, gaps still remain, especially for the Catskill Mountain region of New York  
37 where Late Quaternary vegetational dynamics are largely unknown except for several pollen  
38 stratigraphic investigations of Late Quaternary sediments in the western Catskills (Ibe, 1985) and  
39 the adjacent lowland (Ibe and Pardi, 1985). One major conundrum is the mode of deglaciation  
40 which would affect how exactly the vegetation migrated through this region. Did vegetation in  
41 the late-glacial expand northward in the valleys from regions to the south, or did vegetation first  
42 colonize the upper reaches of the mountains as they became free of ice? In other words, did ice  
43 leave the valley systems first or did deglaciation begin first from the summits? Rich (1934)  
44 contended that at least some of the higher Catskill peaks stood out as nunataks during the last  
45 glacial maximum (LGM) and that evidence of glaciation (e.g. erratics, glacial striae) above 1189

1 m on Slide Mountain in the Catskills, for example, is entirely lacking. More paleoecological  
2 studies within and adjacent to the Catskill Mountain region would shed light into the important  
3 details of the mode of deglaciation and patterns of migration in this important area. Essential for  
4 understanding the time of deglaciation is robust AMS C-14 chronology. Unfortunately, bulk  
5 sediment has been previously used for radiocarbon dating in most Catskill basal sediments but  
6 bulk dates are well-known to be unreliable (Peteet and Mann, 1994; Zimmerman and Wahl,  
7 2020; Peteet et al., 1990; Peteet et al., 1993; Birks, 1993; Hajdas et al., 1993; Grimm et al., 2009;  
8 Curry et al., 2010; Gaglioti et al., 2014; Strunk et al., 2020). This unreliability is due not only to  
9 “old carbon” from carbonates, but also from fine-grained materials such as reworked soils and  
10 lignite, coal, and carbonaceous shales that can be over 8000 years too old. Thus valid  
11 chronologies are needed to define both the timing of deglaciation and for delineation of the  
12 timing of key shifts in vegetation and climate up to the present.

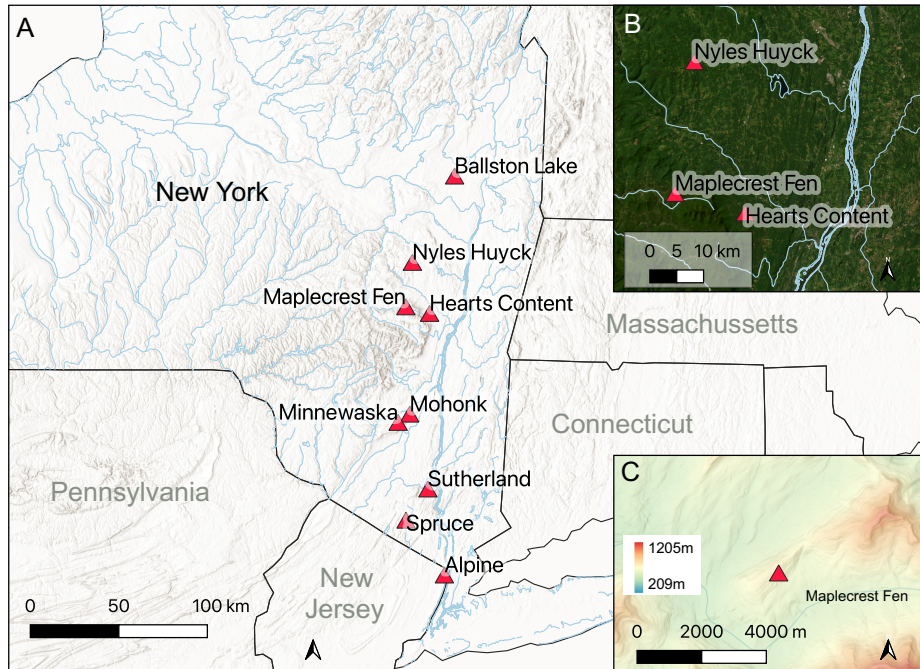
13 In this study we aim to solve the conundrum of the “top to bottom” or “bottom to top” puzzle  
14 relating to the mode of deglaciation of the Catskill Mountain region of New York State by  
15 comparing AMS C14 chronology of deglaciation in our site to others. We will then document the  
16 coupled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

18

## 19 **2 Materials and Methods**

### 20 **2.1 Study Site**

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



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Figure 1. A. Regional map showing Maplecreek 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 Maplecreek Fen and nearby sites. C, Digital Elevation Map of Maplecreek Fen from USGS.

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 Maplecreek 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 characterized 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).

For Maplecreek 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 carpet of *Sphagnum magellanicum* (old name of moss complex) and supports a variety of poor fen or bog vegetation,

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

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

## 26 **2.2 Field and laboratory work**

27 In 2015, repeated test borings revealed the deepest part of the bog to be 7.8 m, close to the  
28 center. A Dachnowski Russian corer was used for the first two meters of extraction, but the  
29 recovery was not complete due to a floating mat in the top 1.5 m. A modified Livingstone corer  
30 was used to extract the remainder of the core for a total of depth of 7.8 m. In 2018 we returned to  
31 the site and moving 2 meters north we retrieved the top 2 meters with the Dachnowski corer.  
32 The core was raised in 1-meter increments, wrapped in saran and aluminum foil and transferred  
33 to the refrigerated Lamont Doherty Earth Observatory core repository. Sampling of the entire  
34 core was performed at 5 cm intervals for pollen and macrofossil analysis. Radiocarbon age  
35 determinations were performed by UC Irvine on identified macrofossils selected from various  
36 samples along the length of the core. These dates provide the basis for the calculation of  
37 sediment accumulation (Figure 2) expressed as years per centimeter (yr/cm) and were derived by  
38 dividing a core section (cm) by the number of years spanning its deposition. Dates are listed as  
39 calibrated <sup>14</sup>C years before present (where present is 1950 CE, hereafter ybp).  
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## 41 **2.3 Pollen and Spore Analysis**

42  
43 2 ml sediment samples were processed every 5 cm following standard procedures (Faegri et

1 al., 1989). This process included KOH, then hydrofluoric acid treatment when appreciable sand  
2 was present, hydrochloric acid rinse, followed by acetolysis, safranin staining and mounting in  
3 liquid glycerin. Large amounts of clay were first treated with 7% sodium pyrophosphate prior to  
4 acetolysis (Bates et al., 1978). Pollen was concentrated using 150 and 7 micron screens before  
5 being mounted on slides (Cwynar et al., 1979). At least 300 pollen grains were tallied from each  
6 slide to form the basis for the relative frequency histogram. Relative pollen frequency is based on  
7 the pollen sum, and relative spore frequency is based on the pollen and spore sum, and pollen  
8 zones delineated by visual inspection. Both pollen and spores were identified by comparison  
9 with a modern reference slide collection and with taxonomic keys provided by McAndrews et al  
10 (1973). Pollen counting was done routinely at a magnification of 400x using an A.O. Spencer  
11 binocular microscope. Critical identification of problem types was made under oil immersion at  
12 1000x (n.a. - 125). Nomenclature follows Fernald (1970).

## 13 **2.4 Macrofossil Analysis**

14 Samples were screened for macrofossils at 5 cm intervals using screens of 0.5 and 0.1 mm,  
15 picked from a water slurry at a magnification of 20–60X using a Leitz microscope, and identified  
16 using the Peteet modern macrofossil collection housed at LDEO. All samples are stored in the  
17 LDEO refrigerated repository in water. Identified samples for AMS dating were sent to the  
18 University of California Irvine Accelerator Facility (UCIAMS). Selected identified macrofossils  
19 from 6 samples were pre-treated with an acid-alkali-acid chemical digestion prior to combustion,  
20 graphitization, and measurement by accelerator mass spectrometry. Radiocarbon ages on  
21 identified plant macrofossils are presented in **Table 1**. The  $^{14}\text{C}$  ages were calibrated using  
22 CALIB 7.1 html (Stuiver and Reimer, 2013). Ages are presented in calibrated years BP, ybp  
23 hereafter (Before Present; 0 year BP = 1950 AD), and uncertainties are shown at the 95% (2-  
24 sigma) confidence level. Pollen and spore percentage diagrams as well as the macrofossil  
25 diagram were drafted using Tilia and Tiligraph (Grimm, 1992). Pollen and macrofossil data are  
26 stored in the Neotoma database.

## 27 **2.5 Loss-on-ignition (LOI)**

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

## 30 **2.6 X-ray fluorescence (XRF)**

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

## 35 **3 Results**

### 36 **3.1 Chronology, LOI and Sedimentation rate (cm/yr), Figures 2-3**

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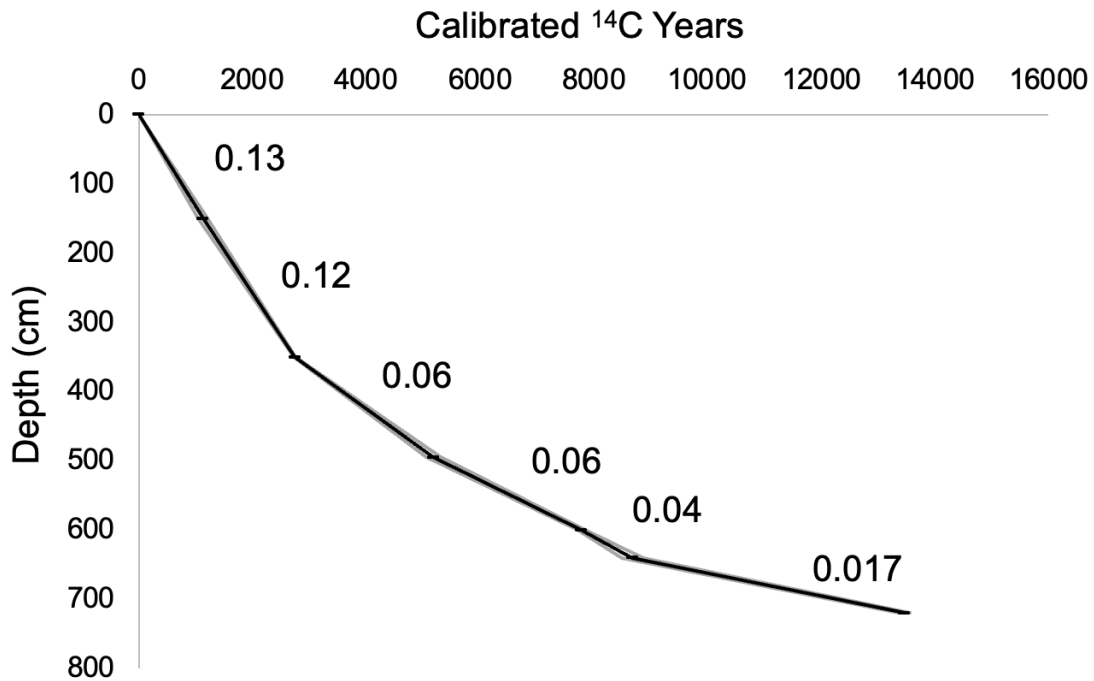
39 The age-depth model based on AMS dates (**Table 1**) is presented in **Figure 2**.

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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	<u>Chamaedaphne</u> seed	1205±20	1127±77
218952	350-355	<i>Tsuga</i> 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, <i>Betula</i> <u>alleg.</u> seed, <u>Nuphar</u> seed fragment	6955±20	7783±65
263885	640-645	<i>Betula</i> <u>papyrifera</u> cone scale	7850±25	8684±186
236728	720-730	3 <u>Picea</u> needles	11605±20	13471±100

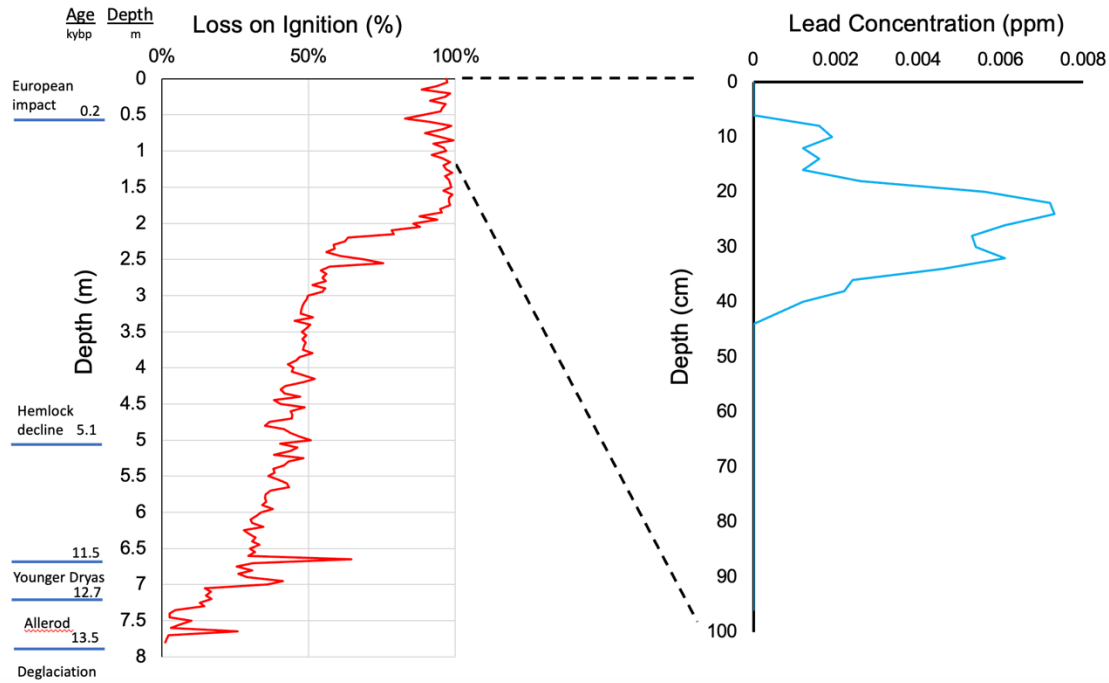
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2 Figure 2. Linear interpolation of sedimentation rates for the Maplecrest Fen core. Calculation of  
 3 sedimentation rates assumes constant accumulation between dated layers. Gray lines indicate 2  
 4 sigma uncertainty.

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



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

5 Sedimentation rates remain low until about 9000 years ago when rates more than doubled to 0.04  
 6 cm/yr, and then increased to 0.06 cm/year until the late Holocene (2750-1127 ybp) when the rate  
 7 doubled again to 0.12 cm/yr. Much of this sedimentation rate increase occurs as the organic  
 8 content increases from 40-80% LOI between 3500 and 1500 yr BP (4.8 m-2 m) and finally to  
 9 over 80-90% from 1500 yr to the present. In these top 2.5 meters the limnic sediments are  
 10 replaced by peat as the lake became a poor fen. About 200 years ago the upper 70-0 cm of the  
 11 core reveals LOI increasing variability probably due to disturbance from forest clearance nearby.  
 12 The Pb increase begins after 45 cm and peaks just below 20 cm, then abruptly declines by a  
 13 factor of 5 before disappearing in the top 5 cm.

14

15 **3.2 Pollen, Spores, and Macrofossil Analysis Groupings and Zonation (Figure 4,5,6)**

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17 The relative pollen frequency diagram for Maplecrest Fen (Figure 4) is divided into 9 horizontal  
 18 zones depicting pollen assemblages believed to represent major vegetational shifts in the  
 19 dominant vegetation. Macrofossils are described along with the pollen zones in Figure 5 and 6.

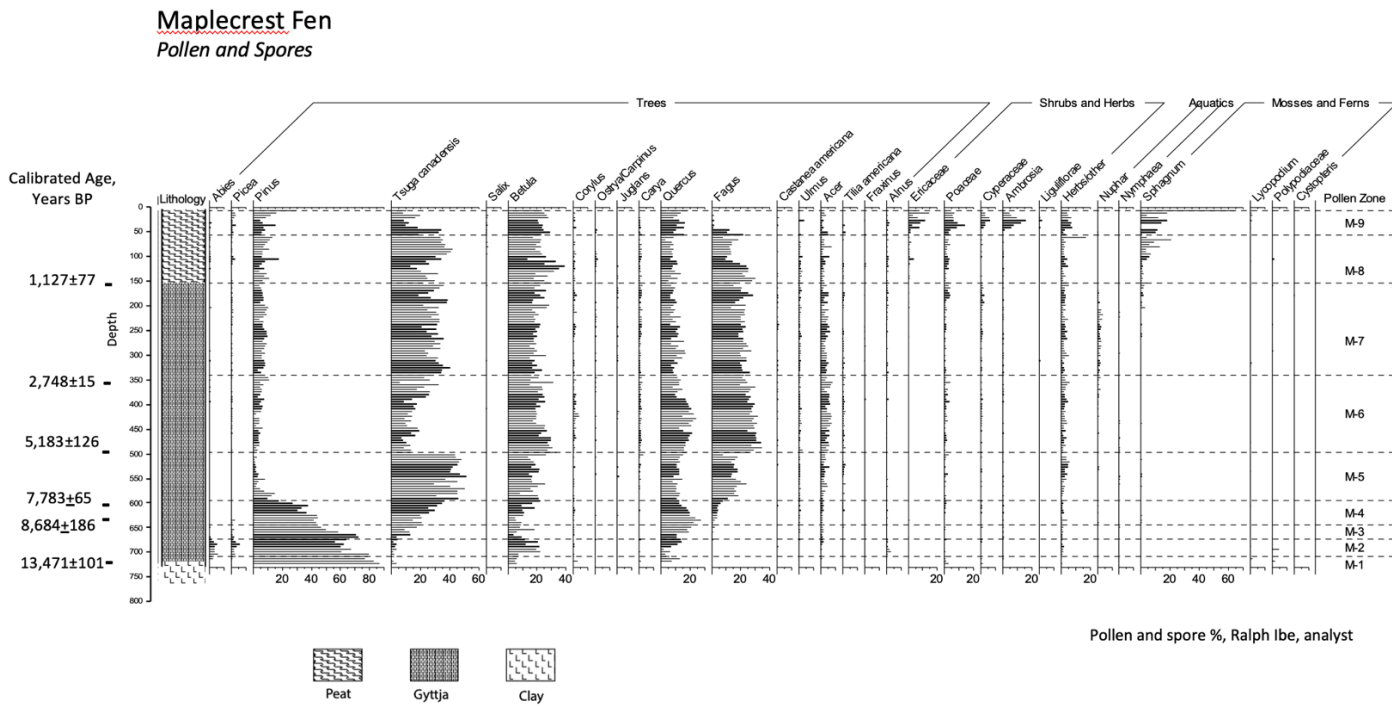
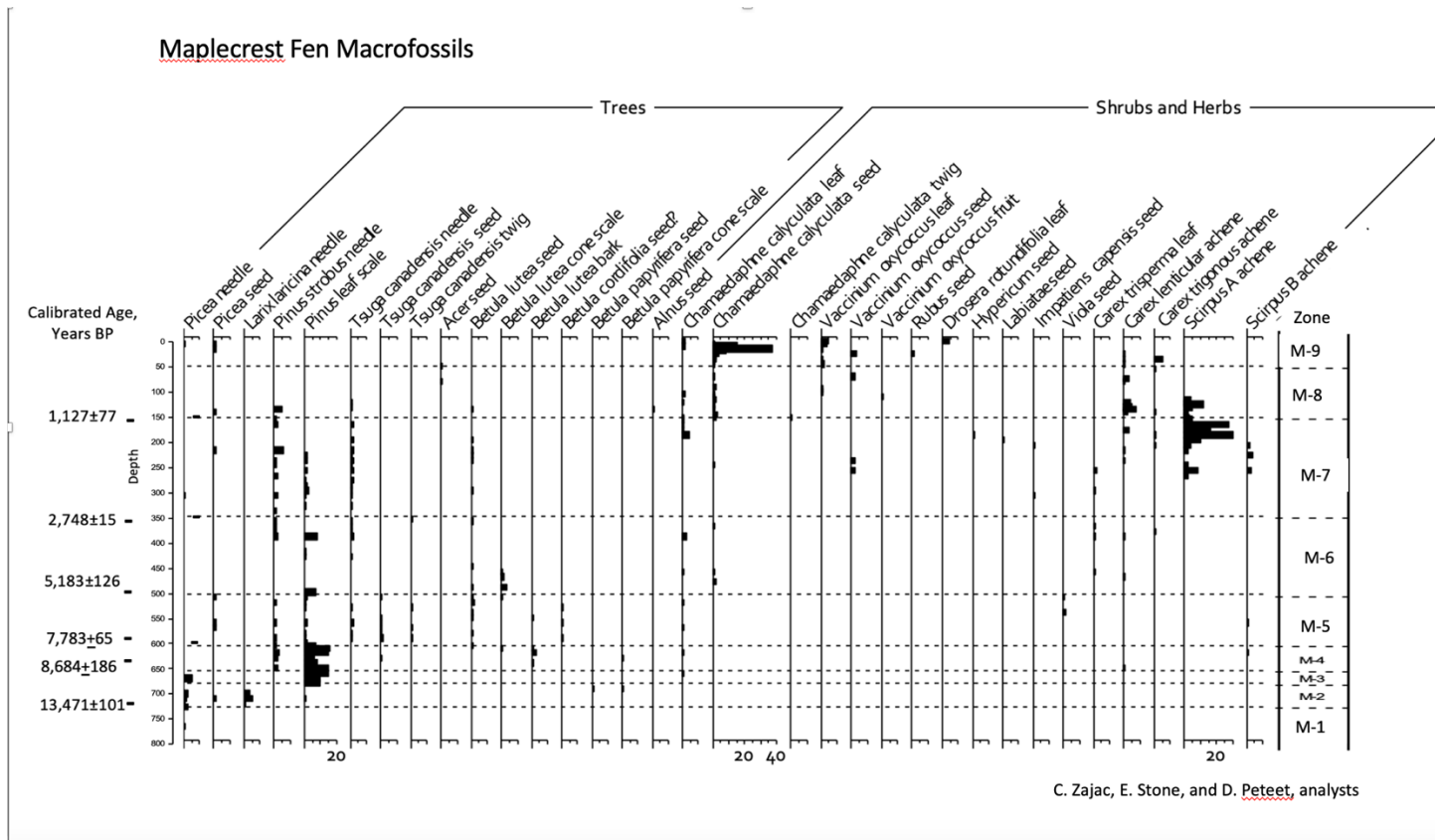


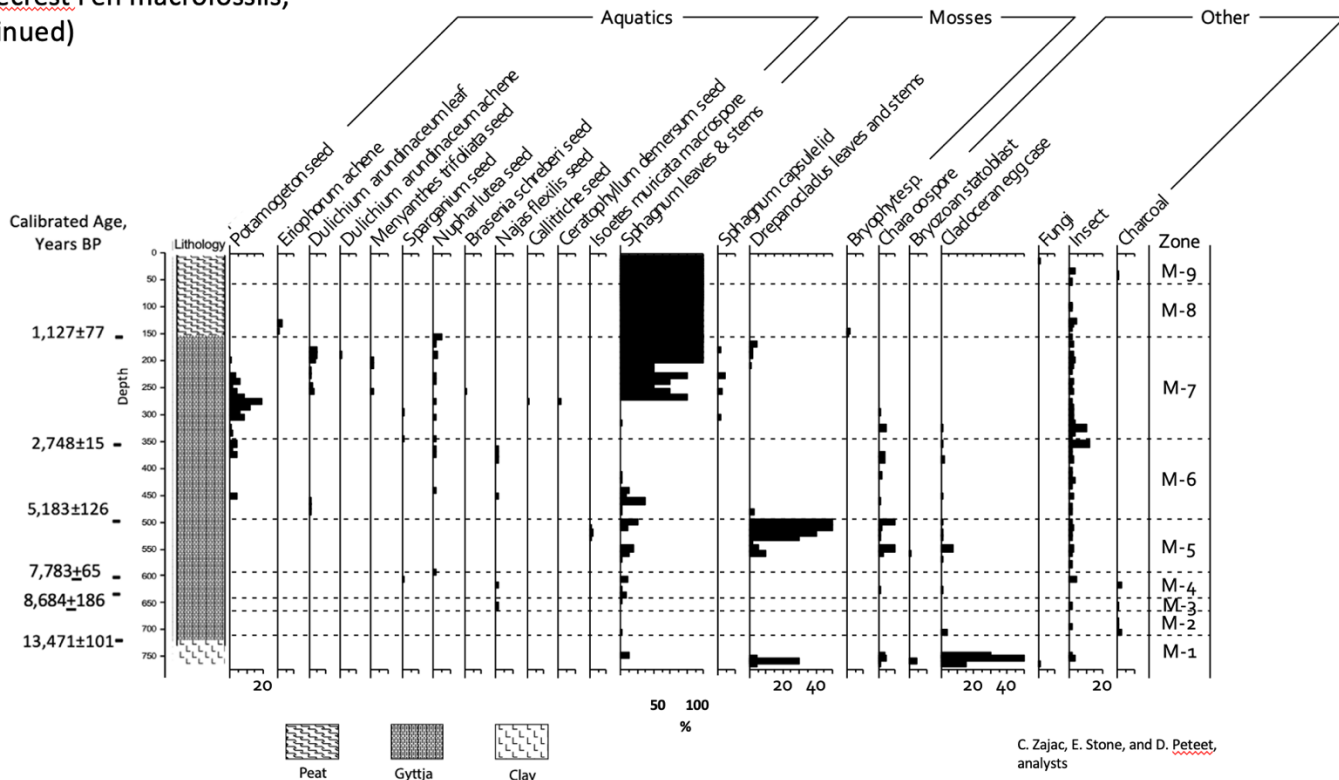
Figure 4. Pollen and spore percentage data for Maplecrest Fen, Catskills.

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1  
 2 Figure 5. Macrofossil diagram for Maplecrest Fen, Catskills showing trees, shrubs, and herbs,  
 3 using same pollen zones. Data presented as macrofossils/20cc sample.  
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Maplecrest Fen macrofossils,  
(continued)



C. Zajac, E. Stone, and D. Peteet,  
analysts

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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 the *Sphagnum* which is presented as percentage of the sediment.

**3.2.1 Zone M-1 >13,470-13,000 ybp, 780-720 cm depth** 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.

**3.2.2 Zone M-2 13,000-11,500 ybp, 720-670 cm depth.** This zone is comprised of gyttja and LOI increase from about 17% - 30%, but 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% to 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.

1 **3.2.3 Zone M-3, 11,500- 8,700 ybp, 670-650 cm depth.** While the LOI remains close to 30% in  
2 this zone, the sedimentation rate remains very low at 0.017 cm/yr. *Abies* and *Picea* decline  
3 almost to 0% while *Pinus* first increases about 60 to 70%, but then declines to 50%.  
4 Concurrently, *Quercus* increases from 10-20%, as does *Tsuga canadensis*, and *Acer* pollen  
5 maintains a small presence. *Picea* needles are still present in the zone, but it is characterized  
6 primarily by conifer cone scales, probably from *Pinus strobus*. A single *Chamaedaphne* leaf and  
7 *Najas* seed is present. *Sphagnum* re-appears at the top of the zone.

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9 **3.2.4 Zone M-4, 8700-7,800 ybp, 650-600 cm depth.** As sedimentation rates more than double  
10 to 0.04 cm/yr and LOI fluctuates around 30-35 %, *Pinus* pollen continues to decline while *Tsuga*  
11 reaches values over 35% and *Quercus* increases up to maximum values around 25%. *Picea*  
12 pollen declines to zero, and *Fagus* arrives and then is continuously present at 5%. *Pinus strobus*  
13 needles, conifer leaf scales, and *Tsuga* seeds are present. *Betula papyrifera* cone scales and then  
14 *B. lutea* cone scales are present. *Chamaedaphne* leaves appear, and an aquatic seed of *Najas* is  
15 present along with a *Sparganium* seed and increased *Sphagnum* leaves. *Chara*, some insect  
16 remains, and charcoal are also present.

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18 **3.2.5 Zone M-5, 7,800-5200 ybp, 600-500 cm depth.** Organic content in the core continues to  
19 rise to 50%, and sedimentation rates increase from .04 to 0.06 cm/yr. Pine drops to nearly 0%  
20 while *Tsuga* reaches nearly its maximum value throughout the core at almost 50%. *Fagus* and  
21 *Betula* rise to 20%, while *Quercus* declines to about 15%, and *Acer* and *Tilia* increase slightly  
22 but remain low. Shrub/herb pollen increases to almost 10%. The top of zone 5 at nearly 500 cm  
23 marks the dramatic *Tsuga* decline from 40% to 10% seen throughout the northeastern forests.  
24 Conifer leaf scales decline sharply (mostly *Pinus strobus*) and while several *Picea* seeds are  
25 present in the zone, the abundant *Tsuga* needles, seeds, and twigs along with *Betula lutea* and  
26 possibly *B. cordifolia* seeds dominate the macrofossil component. *Chamaedaphne* leaves are  
27 present, along with *Viola* seeds, *Isoetes* macrospores, *Sphagnum* leaves, and abundant  
28 *Drepanocladus* moss, *Chara*, cladoceran egg cases and insects, with an absence of charcoal.

29  
30 **3.2.6 Zone M-6, 5200-2,700 ybp, 500-350 cm depth.** Sedimentation rates remain at 0.06 cm/yr.  
31 and LOI fluctuates between 40-50%. The initiation of zone 6 witnesses the *Tsuga* low values  
32 along with a maximum of *Betula* and *Fagus*, with an increase in *Quercus* to about 15%. *Acer*  
33 pollen top of this zone, both *Pinus* (to 10%, with *P. strobus* needles at the top of the zone) and  
34 *Tsuga* (to 30%) double their pollen contribution, as *Quercus* declines to 10%. Poaceae are more  
35 abundant in this zone, but remain around 2%. Macrofossils include *Betula lutea* cone scales,  
36 seeds, and *Chamaedaphne* seeds and leaves, along with *Carex trisperma* leaves and lenticular  
37 *Carex* achenes, and the zone shows first a decline in *Sphagnum* leaves with increases in  
38 *Potamogeton*, *Nuphar*, *Najas* seeds along with *Chara* at the top of the zone, With this rise, *Pinus*  
39 *strobus* and *Tsuga* needles reappear, paralleling their recovery in the pollen record.

40  
41 **3.2.7 Zone M-7, 2700-1,100 ybp, 350-150 cm depth.** Sedimentation rate doubles in this zone  
42 from .06 cm/yr to 0.12 cm/yr, and LOI increases from 50% to over 90%. *Tsuga*, *Fagus*, and  
43 *Betula* are abundant, while *Quercus* again declines to 10%. *Pinus* remains less than 15% while  
44 *Nuphar* pollen increases, then disappears at the top of the zone and is replaced by Ericaceae  
45 pollen and *Sphagnum* spores. Both *Pinus strobus* and *Tsuga* needles are consistently present, and  
46 the re-appearance of *Picea* with both a seed and needle. While *Chamaedaphne* leaves and a seed

1 is still present, *Vaccinium oxycoccus* seeds along with *Hypericum* and *Impatiens capensis* seeds  
2 are also present for the first time, along with both lenticular and trigonous *Carex* achenes and  
3 abundant *Scirpus* achenes of two types. Abundant *Potamogeton* along with *Sparganium*,  
4 *Nuphar*, *Brasenia*, *Callitriche* seeds all replace *Chara*, with *Dulichium* and *Menyanthes trifoliata*  
5 seeds and *Sphagnum* leaves forming much of the organic material.  
6

7 **3.2.8 Zone M-8, 1,100 ybp – 200 ybp (1750 CE), 150 - 50 cm depth.** Sedimentation rates  
8 increase to 0.13 cm/yr and LOI is generally over 90%. *Tsuga* pollen fluctuates between 20 and  
9 40%, while *Betula* first increases to over 30% and then declines back to 20%. *Pinus* pollen  
10 slightly increases to greater than 10% as *Fagus* declines from 20% to close to 10% about  
11 halfway up in the zone. *Chamaedaphne* and *Vaccinium oxycoccus* seeds and leaves are present,  
12 along with lenticular *Carex* and a few declining *Scirpus* achenes. *Sphagnum* spores show a  
13 distinct increase.  
14

15 **3.2.9 Zone M-9, 200 ybp (1750 CE) -present, 50-0 cm depth.** Sedimentation rate remains at  
16 0.13 cm/yr, and organic matter fluctuates between about 80-90%. The upper 45 cm of the record  
17 (Fig.3) shows the Pb rise from the industrial era, isotopically identified and dated to the early  
18 1800's in regional records (Lima et al., 2005; Peteet et al. 2018). Dramatic declines in *Tsuga* and  
19 *Fagus* pollen, along with increases in *Ambrosia* and Ericaceae as well as Poaceae and  
20 Cyperaceae marks the beginning of European settlement. A single *Picea* seed confirms its  
21 presence, but *Picea* pollen is less than 5%. Continued increases in *Sphagnum* spores mark the  
22 closure of the open water, and macrofossils of *Chamaedaphne*, *Andromeda*, *Vaccinium*  
23 *oxycoccus* and *Drosera* along with *Carex* achenes and abundant *Sphagnum* leaves and stems are  
24 present.  
25

## 26 **4. Discussion**

### 27 **4.1 Late-glacial – Allerød and Younger Dryas (YD). Zones M-1 and M-2 (>13,470-11,500** 28 **ybp)** 29

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

39 The timing of our pollen stratigraphic zone agrees well with the warming signal of almost 15%  
40 *Quercus* pollen, and significant pine. We found *Picea* needle remains, demonstrating the  
41 presence of boreal forest, while pine may have been blowing throughout the landscape from sites  
42 to the south. The overlying zone M2 reveals a clear Younger Dryas (YD) in the pollen with a  
43 decline in *Quercus*, and demonstrates a cooler boreal forest comprised of *Abies*, *Picea*, and  
44 *Larix*, as the *Larix* macrofossils add to the coniferous diversity. The assemblage is typical of the

1 Younger Dryas in other locations to the south near the Laurentide margin including Alpine, NY,  
2 Allamuchy Pond, NJ, and Linsley Pond, CT (Peteet et al., 1990; 1993) and Spruce Pond and  
3 Sutherland Pond (Maenza-Gmelch, 1997a, b) as well as those closer to the Catskills, including  
4 Lake Minnewaska and Mohonk Lake (Menking et al., 2012). We find *Betula papyrifera* seeds  
5 and cone scales, as well as the signature YD *Alnus* pollen (Mayle et al. 1993; Peteet et al., 1993).  
6 Interestingly, the LOI shows an increase at this point, similar to the record in Lake Minnewaska,  
7 possibly signaling higher input to the lake. The climatic estimates from sites to the south suggest  
8 a 4-6°C cooling (Peteet et al.1993, Shemesh and Peteet, 1998). To the north, we see a very clear  
9 palynological YD signal at Heart Content’s Bog as well as in Niles Huyck Bog, and even the  
10 termination of the YD at Ballston Lake with its initial formation (Toney et al., 2003).

11 Maplecrest Fen, at an elevation of 690 m, yields a basal date of 13,471 ybp and is the highest  
12 elevation site in the Catskills where cores for paleoecology have been extracted. It is difficult to  
13 compare regional basal dates because our date is AMS radiocarbon dating of terrestrial  
14 macrofossils, while all previous sediment core dates from lakes are bulk dates on 10 cm samples  
15 of sediment, and considerably unreliable and older, as would be expected (Grimm et al.,2009;  
16 Strunk et al., 2020). For example, Meadowdale bog, to the northeast near Voorheesville, NY,  
17 around 112 m elevation, yields a bulk radiocarbon date of around 16,650 ybp for basal sediments  
18 while basal sediments from Great Bear Swamp, close to Alcore Reservoir, at an elevation of 208  
19 m yields a bulk radiocarbon date of 15,060 ybp. (Dineen, 1986). These old bulk ages are much  
20 older than sites AMS-dated further south, such as those in Black Rock Forest and near the glacial  
21 margin (Peteet et al., 2012). Other sites such as Niles Huyck Bog in Rensselaerville, N/Y (Ibe,  
22 2017) at an elevation of 560 m are undated, Balsam Lake in the western Catskill’s is undated at  
23 the base, and Heart's Content Bog, Catskills at elevation 107 m with a very similar late-glacial  
24 pollen stratigraphy is undated (Ibe and Pardi, 1985). A pollen diagram for South Lake Bog to the  
25 west at an elevation of 652 m (Ibe, 1985) is also similar profile to this site. These sites are similar  
26 in their earliest vegetation of boreal forest, but the lower elevation Heart’s Content Bog nearby  
27 includes a lower meter of clay sediment with spruce and up to 20% sedge, suggesting a slightly  
28 earlier deglaciation prior to the Allerod with cold conditions. Thus our data and the Heart  
29 Contents Bog data suggests that lower elevations may have been deglaciated first as climate first  
30 warmed. The 12,870 ybp dated bottom sediments in the higher reaches of the White Mountains  
31 of New Hampshire at Lost Pond at 600 m elevation (Spear et al., 1994) places younger dates for  
32 basal sediments at higher elevations and older dates for corresponding basal sediments at low  
33 relief positions, similar to our findings. Similarly, paleoecological sites in the Adirondacks on an  
34 elevational gradient are older at lower altitudes (Whitehead and Jackson, 1990). Future sites  
35 with AMS chronology are needed to clearly define the timing of deglaciation with respect to  
36 elevation.

37

#### 38 **4.2 Early – Mid Holocene, Zones M-3 and M-4 (11,500-7800 ybp)**

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

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

#### 10 **4.3 Mid Holocene, Zone M-5 (7800-5200 ybp)**

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

#### 22 **4.4 Mid-Late Holocene, Zone M-6 (5200-2700 ybp)**

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

36 Sites that show this classic *Tsuga* decline include Mohonk, Minnewaska (Menking et al. 2012)  
37 around 5420 ybp, close to 5300 ybp at Ballston Lake, and a little later at Sutherland Pond around  
38 4700 ybp (Maenza-Gmelch, 1997a). While the *Tsuga* decline is abrupt at 5200 ybp at  
39 Maplecrest, abrupt at Balsam Lake (bulk date of 5000 ybp) in contrast the decline is more  
40 gradual at Niles Huyck Bog to the north, where the lowest pollen percentage dates to 4788±317  
41 ybp. At Grinnell Lake in northern New Jersey, the decline occurs at 5300 ybp (Zhao et al., 2010)  
42 and is synchronous with an oxygen isotope shift they interpret as an atmospheric circulation shift  
43 resulting in a cooler, drier climate. Part of the difference in timing of the decline may be the  
44 differential dating of the onset of decline vs. the lowpoint. In a transect of five sites in New

1 England from Vermont to Connecticut, Oswald and Foster (2011) note the decline begins close to  
2 5500 ybp, and the decline appears abrupt.

#### 3 **4.5 Late Holocene, Zone M-7 (2700-1,100 ybp)**

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

#### 10 **4.6 Late Holocene prior to European Impact, Zone M-8 (1,100 ybp - 200 ybp (1750 CE)**

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

18  
19

#### 20 **4.7 European Impact, Zone M-9 (200 ybp (1750 CE – present)**

21 The impact of European forest clearance is evident in the upper 50 cm of the profile with sharp  
22 declines in *Tsuga* and *Fagus* pollen, along with *Pinus*, although *Pinus* then recovers in the most  
23 recent 100 years with reforestation typical of the northeastern US (Pederson et al., 2005). The  
24 nature of the fen environment is evident with typical poor fen species such as *Chamaedaphne*,  
25 *Vaccinium oxycoccus*, and *Drosera*, as well as the *Sphagnum*. Our Pb profile from X-ray  
26 fluorescence also shows the rise in Pb beginning about 45 cm depth (Figure 3), and peaking  
27 about 23 cm which we interpret as the peak prior to the Pb decline in 1975 due to the declines in  
28 leaded gasoline targeted by the Clean Air Act ([https://www.epa.gov/clean-air-act-  
29 overview/evolution-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  
30 (Sritrairat et al., 2012) and Piermont Marsh (Peteet et al., 2020) in the Hudson River as well as  
31 other regional sites such as Jamaica Bay in NYC (Peteet et al., 2018) and Nell's Island, Conn  
32 (Copple et al., 2023) in Long Island Sound. The same profile from this relatively pristine  
33 Catskills Mountain region and the Hudson River locations to the south signals the northeastern  
34 US pollution from the industrial era up into the late 1970's, with a return to cleaner conditions  
35 today due to political action.

36

#### 37 **4.8 Conclusions**

38 1) Our AMS-dated basal record at Maplecrest Fen provides a northward and altitudinal  
39 migration path for boreal forest as it moved northward from the Laurentide margin. Earliest  
40 dates near the glacial moraine from New Jersey to Staten Island and Conn. are close to 15-  
41 16,000 ybp (Peteet et al. 2012) from many sites, while Maplecrest at 690 m elevation and  
42 about 200 km north, ice melt is about 2500 years later at 13,500 ybp, suggesting ice retreat  
43 and migration rate of roughly 0.1 km/yr. The sediment record reveals increasing organic

1 matter deposition with warming and a late-glacial shift from a spruce-fir-larch boreal forest  
 2 to a deciduous one, along with a record of shifting moisture and temperature throughout the  
 3 Holocene up to the present.

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

4  
5

- 6 2) Classical features of the northeastern paleoclimate defined decades ago by Deevey (1939) are  
 7 visible in the pollen record, including the late-glacial Allerod and Younger Dryas.  
 8 Subsequently, these include the early Holocene white pine zone, mixed deciduous forest with  
 9 hemlock, abrupt hemlock decline indicating drier conditions, and return to cooler, moister  
 10 conditions at the close of the Holocene. These patterns are similar to the oscillations in  
 11 moisture recognized throughout southern New England, and we note the presence of charcoal  
 12 in the early Holocene white pine zone which could be an analog for future climate as  
 13 warming continues. Similarly, the *Tsuga* decline due to drought and disease may be a portent  
 14 of warmer future conditions. However, the 20% increase in rainfall since the 1970's in the  
 15 region (Pederson et al. 2012) has certainly helped to alleviate moisture deficits such as  
 16 characterized the 1960's. This variability is thought to be due to internal atmospheric  
 17 dynamics, and thus not easily predicted (Seager et al., 2012). Future warming with higher  
 18 evaporation may signal droughts in the Catskills future, threatening water supplies as well as  
 19 particular moisture-loving species.
- 20 3) The macrofossil record from Maplecrest Fen provides greater understanding of local  
 21 conditions, especially moisture. The presence of larch is important during the late-glacial, as  
 22 it shows the openness and diversity of the boreal forest, and the *Betula papyrifera* and *Alnus*  
 23 seeds typical of the Younger Dryas. The discovery of aquatics and emergent in the fen which

1 are not present today (*Chara*, *Callitriche*, *Isoetes*, *Menyanthes*, *Dulichium*) enrich our  
2 understanding of the Maplecrest local vegetation and its changes through time due to climate.

- 3  
4 4) European settlement in the area is visible with classical *Ambrosia* and Poaceae increases  
5 indicative of disturbance, as well as decline in trees due to forest clearance. The XRF data  
6 reveal that the lead pollution stratigraphy matches records from more populated regions in  
7 the Hudson Valley collected from marsh sediments (Pederson et al., 2005, Sritrairat et al.,  
8 2012; Peteet et al., 2018; Peteet et al., 2020). This suggests that industrial era lead pollution  
9 is not a localized signature from New York City, but rather a result of widespread  
10 atmospheric pollution across the Northeastern United States.  
11

## 12 **Data Availability**

13 All paleoecological data will be available in the Neotoma paleoecology database.  
14

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17 **Biosketch**

18 Dorothy Peteet is interested in the timing of deglaciation and the paleoecological history of the  
19 eastern US since the Laurentide ice retreated, as well as Alaskan deglaciation. She focuses on  
20 wetlands of many types including tidal marshes, and studies blue carbon in the northeastern US.  
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