A record of Holocene environmental and ecological changes from Wildwood Lake, Long Island, New York

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(Article begins on next page)
A record of Holocene environmental and ecological changes from Wildwood Lake, Long Island, New York

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For resubmission to Journal of Quaternary Science; December 11, 2009

RUNNING HEAD: Holocene lake-sediment record from Long Island, New York

KEYWORDS: charcoal; fire; paleoecology; pitch pine; pollen
ABSTRACT

Analyses of pollen, charcoal, and organic content in a lake-sediment core from Wildwood Lake, Long Island, New York, provide insights into the ecological and environmental history of this region. The early-Holocene interval of the record (~9800-8800 cal. a BP) indicates the presence of Pinus rigida-Quercus ilicifolia woodlands with high fire activity. A layer of sandy sediment dating to 9200 cal. a BP may reflect a brief period of reduced water depth, consistent with widespread evidence for cold, dry conditions at that time. Two other sandy layers, bracketed by \(^{14}\)C dates, represent a sedimentary hiatus from ~8800 to 4500 cal. a BP. This discontinuity may reflect the removal of some sediment during brief periods of reduced water depth at 5300 and 4600 cal. a BP. In the upper portion of the record (<4500 cal. a BP), subtle changes at ~3000 cal. a BP indicate declining prevalence of Quercus-Fagus-Carya forests and increasing abundance of Pinus rigida, perhaps due to reduced summer precipitation. Elevated percentages of herbaceous taxa in the uppermost sediments represent European agricultural activities. However, unlike charcoal records from southern New England, fire activity does not increase dramatically with European settlement. These findings indicate that present-day Pinus rigida-Quercus ilicifolia woodlands on eastern Long Island are not a legacy of recent, anthropogenic disturbances.

INTRODUCTION

Numerous paleoecological and paleoenvironmental records provide a broad view of the post-glacial vegetation and climate history of the northeastern United States (“the Northeast”; e.g., Bernabo and Webb, 1977; Gaudreau and Webb, 1985; Williams et al., 2001; Huang et al., 2002; Shuman et al., 2002a; 2002b; 2004; 2005; 2006). Some parts of the region, however, have
received less recent study and thus aspects of their environmental history are not well
understood. Long Island, New York, is one area where additional information about past
ecological and climatic changes is needed, in particular to improve our understanding of the
following: (1) the long-term history of Pinus rigida (pitch pine) woodlands in central and
eastern Long Island; (2) the distribution of Fagus grandifolia (American beech) along the
Northeast coast during the middle Holocene; and (3) the timing and magnitude of century-scale
variations in climate in this region during the Holocene.

There are various unresolved questions regarding the origin and history of forests
dominated by fire-dependent Pinus rigida and Quercus ilicifolia (scrub oak) on Long Island
(e.g., Backman, 1984; Kurczewski and Boyle, 2000; Jordan et al., 2003), which provide habitat
for a range of rare and endangered species (CPBJPPC, 1995). It is uncertain whether the Pinus
rigida woodlands of eastern Long Island have been maintained for millennia by frequent fire, or
if they have expanded more recently in response to European settlement, forest clearance, and
burning (e.g., Kurczewski and Boyle, 2000). Pinus rigida communities are threatened by
development and fire suppression, and their conservation, management, and restoration should
be guided by information about their past (e.g., CPBJPPC, 1995; Jordan et al., 2003; Parshall et
al., 2003).

Recent paleoecological studies on Cape Cod, Massachusetts, and adjacent islands (Fig. 1)
have documented the widespread occurrence of an unusual coastal vegetation type during the
middle Holocene (Foster et al., 2006). Beginning with the abrupt collapse of Quercus
populations ~5500 calibrated $^{14}$C years before present (cal. a BP), a portion of the coast of
southern New England was dominated by Fagus grandifolia. The geographic extent of coastal
Fagus forests, which persisted until ~3000 cal. a BP, has not been determined for other parts of
the Northeast coast, including Long Island. Several pollen records published some four decades ago (Sirkin, 1967; 1971) suggest that the post-glacial vegetation history of Long Island resembles that of much of southern New England, which can be explained in terms of orbital-scale changes in climate (e.g., Davis, 1969; Suter, 1985; Gaudreau, 1986; Shuman et al., 2001; 2004; Oswald et al., 2007). Late-glacial forests featured cold-tolerant *Picea* (spruce) and *Pinus banksiana* (jack pine), warmer and drier conditions during the early Holocene resulted in dominance by *Pinus strobus* (white pine), and wetter conditions after ~8000 cal. a BP promoted the expansion of various temperate forest taxa, including *Quercus*. There is no indication of a middle-Holocene interval dominated by *Fagus grandifolia* on Long Island (Sirkin, 1967; 1971), but the coarse sampling resolution and very limited chronological control restrict the utility of the existing Long Island records.

Recent studies in southeastern Massachusetts, located northeast of Long Island (Fig. 1), show that lake-sediment records from the Northeast feature not only the orbital-scale changes in climate responsible for the broad sequence of vegetation shifts (e.g., Shuman et al., 2001; 2004), but also century-scale intervals of reduced water depth evidenced by sand layers in near-shore cores (e.g., Newby et al., 2009; Shuman et al., 2009). Relatively brief periods of dry conditions associated with changing ocean conditions appear to have occurred at ~9200, 8300, 5300, 4600, 3800, 2900, 2200, and 1500 cal. a BP and may have served as important drivers for some aspects of the vegetation history of the region (Shuman et al., 2004; 2009; Newby et al., 2009).

In this paper we discuss a detailed lake-sediment record from Wildwood Lake, located in eastern Long Island (Fig. 1) near the Central Pine Barrens, the largest area of *Pinus rigida-Quercus ilicifolia* woodlands on Long Island (CPBJPPC, 1995; Jordan et al., 2003). Preliminary data from this record were reported elsewhere (Foster et al., 2006). Our analyses of charcoal,
pollen, and organic content in the Wildwood record provide additional evidence for millennial- to centennial-scale variations in climate and ecosystems in the Northeast (e.g., Newby et al., 2009; Shuman et al., 2009) and contribute to an improved understanding of the origin and dynamics of *Pinus rigida* forests on Long Island.

**STUDY AREA**

Wildwood Lake (40.892°N, 72.673°W) is a 26-ha lake located on eastern Long Island, New York; a single outlet to the north flows into the Peconic River. The lake features two basins separated by a shallow shoal: the northern basin is ~3-m in depth; the southern basin is ~15-m in depth at its deepest point, which is near the southernmost lakeshore (Fig. 2). Much of the lakeshore currently is occupied by residential and commercial development. The lake sits on the Ronkonkoma Moraine (e.g., Fuller, 1914; Sirkin, 1971), which is bordered to the north and south by sandy outwash plains (Fig. 1). The dominant soils of the area are Plymouth loamy sand and Carver and Plymouth sands, both of which have relatively low moisture-holding capacity (USDA, 1972; 1975; Kurczewski and Boyle, 2000). Historical maps and witness-tree data (Kurczewski and Boyle, 2000; Cogbill et al., 2002) suggest that outwash plains featured *Pinus rigida*, *Quercus ilicifolia*, and some tree oaks (e.g., *Q. alba*, *Q. coccinea*, and *Q. velutina*) at the time of European settlement in the mid-seventeenth century; moraines appear to have been dominated by tree oaks (e.g., *Q. rubra*, *Q. prinus*, and *Q. velutina*), with lesser amounts of *Pinus rigida*, *Castanea dentata* (American chestnut), *Carya glabra* (Pignut hickory), and *Fagus grandifolia*. The pollen source area (Sugita, 1994) for this relatively large lake likely includes areas of both moraine and outwash. A charcoal record from nearby Deep Pond (Fig. 1) indicates that fires burned periodically during the late Holocene, increasing in frequency and intensity
after European settlement (Backman, 1984). Historical records show that large fires burned across Long Island in the late-eighteenth and nineteenth centuries (Kurczewski and Boyle, 2000).

METHODS

We recovered a sediment core from Wildwood Lake in July 2001. The core was collected near the center of the southern basin of the lake, ~100 m northwest of its deepest point; water depth at the coring location was 14 m (Fig. 2). Coring ceased at 765-cm sediment depth due to mechanical problems. The uppermost sediments (165 cm) were obtained with a 7-cm-diameter plastic tube fitted with a piston. Lower sediments were collected in 1-m drive lengths with a 5-cm-diameter modified Livingstone piston sampler. The surface core was extruded vertically in 1-cm intervals; lower cores were extruded horizontally and wrapped in plastic and aluminum foil.

Sediment organic content was estimated by measuring percent weight loss-on-ignition (LOI); 1-cm³ samples were dried at 90°C and ashed at 550°C (Bengtsson and Enell, 1986). Macroscopic charcoal content of the sediment was determined by soaking 1-cm³ samples in KOH, sieving through a 180-μm screen, and counting charcoal pieces >180-μm at 20X magnification (Long et al., 1998). Samples of 1 cm³ from 116 levels were prepared for pollen analysis following standard procedures (Faegri and Iversen, 1989), and tablets containing Lycopodium spores were added to the samples to estimate concentrations and influx (Stockmarr, 1971). Pollen residues were analyzed at 400X magnification until a minimum of 500 pollen grains and spores of upland taxa was identified for each level. Pollen percentages are expressed relative to the sum of upland tree, shrub, and herb pollen. Only ~30% of Pinus pollen grains were identifiable to the subgenus level, but ~90% of the identified grains were Pinus subgenus
Pinus. We therefore assume that most of the Pinus pollen in the Wildwood record is derived from Pinus rigida.

Fossil-pollen assemblages were compared with modern-pollen spectra from eight sites (Figs. 1 and 3) representing the three primary types of upland forest for Long Island and the coastal area of southern New England (Motzkin et al., 2002). Three sites from Cape Cod are dominated by Pinus rigida (Eagle, Fresh, and Round Ponds; Parshall et al., 2003), two Cape Cod sites are dominated by Quercus species (Deep and Sandy Hill Ponds; Parshall et al., 2003), and three sites from Naushon Island are dominated by Fagus grandifolia (Blaney’s Pond, Duck Pond, and Mary’s Lake; W. Oswald and D. Foster, unpublished). Relationships between fossil and modern assemblages were described by the squared-chord distance index of dissimilarity (SCD; Overpeck et al., 1985). Six taxa were included in this analysis: Pinus, Quercus, Fagus, Carya, Betula, and Tsuga. The majority of identified Pinus grains in these modern samples were Pinus subgenus Pinus. Previous studies have shown that SCD values <0.1 indicate a strong degree of similarity in the composition of the source vegetation (e.g., Overpeck et al., 1985).

Chronological control is provided primarily by accelerator mass spectrometry \(^{14}\text{C}\) analysis of bulk sediment samples, each spanning 1 cm core depth (Table 1). \(^{14}\text{C}\) dates were converted to calibrated years before present (cal. a BP) with CALIB 5.0 (Reimer et al., 2004). The chronology of the upper sediments is based on \(^{210}\text{Pb}\) analysis (Table 2; Binford, 1990) and pollen stratigraphy: the rise in agricultural taxa at 130 cm (Fig. 4B, 5A) was assigned an age of 300 cal. a BP (1650 AD; Kurczewski and Boyle, 2000).

RESULTS

Lithology and chronology
The Wildwood core is lacustrine sediment (LOI ~30%), with the exception of three sandy layers (LOI <25%): 650-646 cm, 592-580 cm, and 562-554 cm (Fig. 4A, 4C). Organic content also declines above 130 cm during the interval of European settlement. The five $^{14}$C ages below 599 cm (Table 1) indicate that the lower interval of the record was deposited quickly (~160 cm in ~1000 years) and a straight line fit to the median calibrated $^{14}$C ages dates the sandy layer at ~650 cm to 9200 cal. a BP (Fig. 4B). A preliminary chronology for this record presented in a regional summary (Foster et al., 2006) assumed that this feature represented the 8200 cal. a BP cold event (e.g., Alley et al., 1997; Alley and Ágústsdóttir, 2005), which appears as an interval of reduced organic content in records from elsewhere in eastern North America (e.g, Spooner et al., 2002; Kurek et al., 2004). However, additional $^{14}$C dating and emerging recognition of a climatic event at ~9200 cal. a BP at many sites worldwide (e.g., Fleitmann et al., 2008), including southeastern Massachusetts (Newby et al., 2009; J. Hou and Y. Huang, unpublished), support the updated age-depth curve presented here (Fig. 4B). The dates bracketing the sandy layers at ~590 and ~560 cm suggest that these features represent a sedimentary hiatus from ~8800 to ~4500 cal. a BP. The age model for the upper interval of the core (~4500 cal. a BP to the present) involves a straight line fit to the European-settlement horizon and the median calibrated ages of the six $^{14}$C dates above 571 cm, and second-order polynomial fit to the European-settlement horizon and the sixteen $^{210}$Pb dates (Tables 1 and 2, Fig. 4B).

Pollen and charcoal records

The lower interval of the Wildwood core (~9800-8800 cal. a BP; Fig. 5C) features high percentages of Quercus (~45%) and Pinus pollen (~35%), with lower percentages of Tsuga (hemlock), Betula (birch), Myrica-Comptonia (bayberry-sweetfern), Poaceae (grass), and
Ambrosia (ragweed). These fossil assemblages are similar to modern spectra from the *Quercus* (SCD ~0.08) and *Pinus*-dominated sites (SCD ~0.1; Fig 6E) and dissimilar to those from *Fagus grandifolia*-dominated sites (SCD ~0.2). The highest value for *Pinus* pollen (>50%) falls within the sandy layer at ~650 cm that dates to 9200 cal. a BP. Charcoal influx values fluctuate between ~40 and 80 pieces cm\(^{-2}\) yr\(^{-1}\), and *Pediastrum* influx values vary between ~100 and 2900 algal cell nets cm\(^{-2}\) yr\(^{-1}\) (Fig. 6D).

The upper interval of the record (~4500 cal. a BP to the present; Fig. 5B) features gradually increasing *Pinus* pollen percentages (~20 to 40%) and gradually decreasing *Quercus* values (~50 to 30%). Several taxa have higher pollen percentages in the upper interval than in the early-Holocene part of the record, including *Betula*, *Acer* (maple), *Fagus*, *Carya*, and *Castanea*. *Tsuga* pollen-percentage values increase from ~0 to 5% between ~4000 and 2000 cal. a BP; *Fagus* and *Carya* pollen percentages decrease slightly during that interval. Poaceae and *Ambrosia* pollen percentages are lower between ~4500 cal. a BP and European settlement than they were during ~9800-8800 cal. a BP. The fossil assemblages from ~4500 to 2000 cal. a BP are similar to all three modern-forest types (SCD ~0.06-0.1), but the similarity to the *Fagus grandifolia*-dominated sites declines (SCD ~0.1-0.2) and the similarity to modern *Pinus* samples increases (SCD ~0.05) after ~2000 cal. a BP (Fig. 6E). Charcoal influx values for the middle and late Holocene are ~5-10 pieces cm\(^{-2}\) yr\(^{-1}\). Sediment organic content is high between ~4400 and 3000 cal. a BP, peaking at 3800 cal. a BP, then peaks again at ~2000 cal. a BP (Fig. 6B). Influx of *Pediastrum* algal cell nets declines between ~4000 and 3000 cal. a BP (Fig. 6D).

The changes at 130 cm (300 cal. a BP) represent the era of European settlement and forest clearance (Fig. 5A). A sharp drop in organic content is presumably attributable to increased erosion of mineral material into the lake (Fig. 6B), and a rise in *Pediastrum* influx may
indicate changes in the aquatic ecosystem in response to disturbance in the watershed (Fig. 6D; e.g., Jankovska and Komarek, 2000). *Rumex* (sorrel), Poaceae, and *Ambrosia* increase dramatically, while *Carya, Quercus*, and especially *Pinus* exhibit declining abundances at the beginning of this interval. Decreasing percentages of the herbaceous taxa and increasing *Pinus* pollen percentages (~20 to 50%) in levels dating to ~1950 AD reflect the decline of agricultural activity and reforestation. Charcoal influx values increase from ~5 to 15 pieces cm\(^{-2}\) yr\(^{-1}\) at ~100 cal. a BP (1850 AD), then reach a peak of ~20-35 pieces cm\(^{-2}\) yr\(^{-1}\) in levels dating to ~1920-1970 AD (Fig. 5A).

**DISCUSSION**

The Wildwood Lake record provides new insights into past environmental and ecological changes on Long Island, New York, including century-scale variations in climate and the long-term history of vegetation and fire.

This sediment core from Wildwood Lake contains only a ~1000 year interval of the early Holocene, but nonetheless does contribute to our understanding of Long Island ecosystems between ~9800 and 8800 cal. a BP. The prevalence of *Pinus* and *Quercus*, paucity of mesic-forest taxa such as *Fagus grandifolia* and *Carya*, relatively high abundance of *Ambrosia*, and very high charcoal influx values suggest open *Pinus-Quercus* woodlands with frequent fire on the Ronkonkoma moraine and adjacent areas of outwash. Similar pollen assemblages in early-Holocene samples from other sites on Long Island (Sirkin, 1967; 1971) indicate that this type of vegetation was widespread. High fire activity and open forest structure, as evidenced by
abundant *Ambrosia* (Faison et al., 2006), are consistent with evidence suggesting that regional climate was relatively dry during this interval (Fig. 6A; Shuman et al., 2001; 2004; 2009; Newby et al., 2009).

**Evidence for century-scale climatic events**

The decline in organic content that is dated securely to 9200 cal. a BP likely represents an interval of particularly dry climate and reduced water levels at Wildwood Lake. A similar feature occurs in the sediments of New Long Pond in southeastern Massachusetts (Newby et al., 2009) and geochemical data from Blood Pond in south-central Massachusetts indicate a ~4°C temperature decline at that time (J. Hou and Y. Huang, unpublished). Emerging evidence suggests that a widespread climatic event took place at ~9200 cal. a BP, presumably caused by a weakening of Atlantic meridional overturning circulation (e.g., Fleitmann et al., 2008). The peak in *Pinus* pollen abundance at 9200 cal. a BP in the Wildwood Lake record may represent a change in vegetation in response to cold, dry conditions. This finding is consistent with other evidence for century-scale ecological changes associated with early-Holocene variations in climate (e.g., Shuman et al., 2004).

The organic-content and ^14^C data demonstrate that the Wildwood core features a >4000 year hiatus between ~8800 and ~4500 cal. a BP. One interpretation of this finding is that climate was dry and water levels were low throughout this entire period. Webb et al. (1993) offered a similar interpretation based on lake-sediment data from other sites in southern New England. More-recent reconstructions of lake-level changes for sites across the Northeast (e.g., Lavoie and Richard 2000; Newby et al., 2000; Dieffenbacher-Krall and Nurse 2005; Shuman et al. 2005), including Crooked Pond in southeastern Massachusetts (Fig. 6A; Shuman et al., 2001), however,
indicate that the period from ~8000 to 5500 cal. a BP was relatively wet, suggesting that the sedimentary hiatus may not simply represent a continuous interval of dry conditions. Instead, we hypothesize that the pronounced dry events recorded at New Long Pond at ~5300 and 4600 cal. a BP (Shuman et al., 2009) occurred across the region and also caused major water-level reductions at Wildwood Lake. If the portion of the lake bottom cored for this study were substantially shallower than at present, perhaps by >10 m, older sediments could have been re-deposited to the deeper part of the lake, resulting in the loss of that interval of the record from ~8800 cal. a BP to the time when deeper water levels once again reached this site. The sandy layers at ~590 and ~560 cm presumably were re-deposited from the exposed lakeshore and shoal; the $^{14}$C dates indicate that those sediments were mixed. Our data suggest that the accumulation of lake sediment resumed ~4500 cal. a BP, a date consistent with the lake-level reconstructions for Crooked Pond (Shuman et al., 2001) and New Long Pond (Shuman et al., 2009).

Middle- and late-Holocene vegetation and fire

The similarity of middle-Holocene pollen spectra to modern samples from three different types of vegetation ($Pinus$, $Quercus$, and $Fagus$) may be attributable to the large pollen source area of Wildwood Lake. Presumably, the lake receives some pollen from the local vegetation on the Ronkonkoma moraine, as well as some pollen from vegetation on the nearby outwash plains. The similarity of middle-Holocene pollen assemblages to modern $Pinus$ samples suggests that areas of sandy soil were dominated by $Pinus\ rigida$, as seems to have been the case during the early Holocene. The forests of the moraine itself, on the other hand, appear to have featured $Quercus$ with some $Carya$ and $Fagus\ grandifolia$. The abundance of $Fagus$, however, is
substantially lower for this interval than in records from Cape Cod and nearby islands, where its pollen percentages reach 30-40% during ~5500-3000 cal. a BP (Foster et al., 2006). Climate appears to have become cooler and wetter between ~4000 and 2000 cal. a BP, as evidenced by rising water levels at Crooked Pond (Shuman et al., 2001), for example. This change may be manifest in the Wildwood Lake record by the declines in *Pediastrum* influx and organic content at that same time. Several tree taxa exhibit subtle changes in abundance between ~4000 and 2000 cal. a BP. Most importantly, *Quercus*, *Carya*, and *Fagus* become somewhat less common, whereas *Pinus* increases in abundance. We interpret this gradual change as a decline in the prevalence of *Quercus*-dominated hardwood forests and the coincident expansion of some *Pinus rigida* on the Ronkonkoma moraine. The declining abundance of *Fagus* in response to cooler, wetter conditions is counterintuitive given its prevalence in northern parts of New England (e.g., Thompson et al., 1999; Cogbill et al., 2002). Shuman and Donnelly (2006) hypothesize that the seasonality of precipitation may have shifted between the middle and late Holocene, so that even though annual precipitation increased after ~3000 cal. a BP, the summer months were drier. Reduced summer rainfall might explain the decline of *Fagus* and rise of drought-tolerant *Pinus rigida* in the Wildwood record. Relatively stable charcoal influx values after ~4000 cal. a BP suggest that fire activity was not altered by these changes in climate and vegetation. This finding contrasts with other fire-history data from eastern North America, which indicate an increase in burning during since ~3000 cal. a BP (e.g., Carcailliet and Richard, 2000; Power et al., 2008).

**Recent changes in fire and *Pinus rigida* abundance**

Fire activity, as evidenced by charcoal influx, does not appear to increase at the time of European settlement. This stands in contrast to fire-history data from Deep Pond, located ~15
km northwest of Wildwood (Fig. 1; Backman, 1984), and elsewhere in southern New England (Parshall and Foster, 2002), which show a rise in burning. Historical accounts suggest that large fires burned across eastern Long Island in the late-eighteenth and nineteenth centuries (e.g., Kurczewski and Boyle, 2000), but the Wildwood charcoal record indicates that those fires were typical for the last few millennia. Indeed, they were probably smaller and less intense than fires of the early Holocene; fire activity on Long Island was very high ~9800-8800 cal. a BP when climate was relatively dry. Historical records suggest that fire frequency and intensity increased when the Long Island Railroad reached eastern Long Island in the mid-nineteenth century (Kurczewski and Boyle, 2000). This change may be reflected in the Wildwood charcoal record by the elevated influx values from ~100-0 cal. a BP (~1850 to 1950 AD).

The increase in *Pinus* and *Quercus* pollen percentages in the uppermost sediments of Wildwood Lake reflect the establishment of *Pinus rigida-Quercus ilicifolia* woodlands following the abandonment of agriculture over the last century. *Pinus* abundance at present appears to be slightly higher than it has been over the last millennium, perhaps indicating that *Pinus rigida* benefited modestly from the disturbances associate with European settlement, deforestation, and agriculture (Kurczewski and Boyle, 2000). This interpretation is consistent with the ability of *Pinus rigida* to establish under early-successional conditions (e.g., Motzkin et al., 1996; Windisch, 1999). However, *Pinus rigida* does not appear to be dramatically more abundant than it was prior to European settlement, suggesting that this vegetation type is not necessarily a legacy of recent anthropogenic disturbances.

These analyses of the sedimentary record from Wildwood Lake improve our understanding of Holocene environmental and ecological changes on Long Island, New York, but some questions deserve additional study. Detailed reconstructions of lake-level history (e.g.,
Shuman et al., 2001; Newby et al., 2009) for this and other sites are needed to test our hypotheses about past changes in climate and water depth, and the analysis of pollen and charcoal data from other sites on Long Island would provide further insights into past spatial patterns of vegetation and fire.

ACKNOWLEDGEMENTS

We thank Brian Hall, Tim Parshall, Glenn Motzkin, and Sarah Truebe for field and laboratory assistance. The manuscript was greatly improved by suggestions from Konrad Gajewski, Marilyn Jordan, and two anonymous reviewers. This project was funded by the National Science Foundation, the A. W. Mellon Foundation, the Nature Conservancy, the National Ocean Sciences Accelerator Mass Spectrometry Facility, and a Huret Faculty Development Award.
REFERENCES CITED


Table 1: $^{14}$C results for the Wildwood Lake sediment core

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Table 2: $^{210}$Pb results for the Wildwood Lake sediment core

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<td>-33.5 ± 0.6</td>
</tr>
<tr>
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<tr>
<td>28</td>
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<tr>
<td>32</td>
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<tr>
<td>36</td>
<td>3.4 ± 0.7</td>
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<tr>
<td>40</td>
<td>11.0 ± 0.7</td>
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<tr>
<td>44</td>
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<tr>
<td>48</td>
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<tr>
<td>52</td>
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<tr>
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<td>41.7 ± 1.2</td>
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<tr>
<td>64</td>
<td>66.5 ± 2.2</td>
</tr>
<tr>
<td>72</td>
<td>95.5 ± 10.6</td>
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FIGURE CAPTIONS

Figure 1: Map of Long Island, New York and Cape Cod, Massachusetts featuring surficial geology and showing location of Wildwood Lake, other fossil-pollen sites on Long Island (Sirkin, 1967; 1971; Backman, 1984), Cape Cod sites used for modern-analogue analysis (Parshall et al., 2003; W. Oswald and D. Foster, unpublished), and Crooked and New Long Ponds in southeastern Massachusetts (Shuman et al., 2001; 2009; Newby et al., 2009).

Figure 2: Aerial photo and bathymetric map of Wildwood Lake. Contour interval is 3 m; black circle indicates coring location.

Figure 3: Modern-pollen data from sites in southeastern New England: Eagle Pond, Fresh Pond, Round Pond, Deep Pond, Sandy Hill Pond (Parshall et al., 2003), Blaney’s Pond, Duck Pond, and Mary’s Lake (W. Oswald and D. Foster, unpublished).

Figure 4: (A) Lithology of the Wildwood Lake sediment core; gray shading indicates lacustrine sediment; black shading indicates sandy layers. (B) Age-depth model; open circles are $^{210}$Pb dates, triangle is European settlement; squares are calibrated $^{14}$C dates. (C) Organic content estimated by percent weight loss-on-ignition.

Figure 5: Pollen percentages diagram for selected taxa and charcoal influx values. Separate diagrams are shown for: (A) 1000 cal. a BP to present; (B) ~4500 cal. a BP to present; (C) ~9800-8800 cal. a BP. Dashed charcoal-influx lines in (A) and (B) represent 2X exaggeration. Estimated age for European settlement is 300 cal. a BP.

Figure 6: (A) Lake-level reconstructions for sites in southeastern Massachusetts; water-depth estimates for Crooked Pond (Shuman et al., 2001); triangles are dry events evidenced by sand layers in sediments of New Long Pond (Newby et al., 2009; Shuman et al., 2009). (B) Wildwood Lake organic content, estimated by percent weight loss-on-ignition. (C) Influx of macroscopic charcoal for Wildwood Lake. (D) Influx of *Pediastrum* algal cell nets in the Wildwood record. (E) Mean squared chord distance (SCD) values for comparison of Wildwood
Lake fossil pollen assemblages with modern pollen spectra from sites dominated by *Fagus* (n=3; W. Oswald and D. Foster, unpublished), *Quercus* (n=2; Parshall et al., 2003), and *Pinus* (n=3; Parshall et al., 2003). SCD values <0.1 indicate similar vegetation composition.