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

Citation

Oswald, W. Wyatt, David R. Foster, Elaine D. Doughty, and Dana Macdonald. 2010. "A Record of Holocene Environmental and Ecological Changes from Wildwood Lake, Long Island, New York." *Journal of Quaternary Science* 25 (6) (March 1): 967–974. doi:10.1002/jqs.1381.

Published Version

doi:10.1002/jqs.1381

Permanent link

<http://nrs.harvard.edu/urn-3:HUL.InstRepos:33901523>

Terms of Use

This article was downloaded from Harvard University's DASH repository, and is made available under the terms and conditions applicable to Other Posted Material, as set forth at <http://nrs.harvard.edu/urn-3:HUL.InstRepos:dash.current.terms-of-use#LAA>

Share Your Story

The Harvard community has made this article openly available.
Please share how this access benefits you. [Submit a story](#).

[Accessibility](#)

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

W. Wyatt Oswald^{1,2}, David R. Foster², Elaine D. Doughty², and Dana MacDonald³

¹Emerson College, Boston, MA 02116, USA

²Harvard Forest, Harvard University, Petersham, MA 01366, USA

³Department of Geological Sciences, Brown University, Providence, RI 02912, USA

Corresponding author:

W. Wyatt Oswald

Emerson College

Boston, MA 02116, USA

Phone: 617-824-3502

Fax: 617-824-8735

Email: w_wyatt_oswald@emerson.edu

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 ¹⁴C 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

1 the Northeast coast, including Long Island. Several pollen records published some four decades
2 ago (Sirkin, 1967; 1971) suggest that the post-glacial vegetation history of Long Island
3 resembles that of much of southern New England, which can be explained in terms of orbital-
4 scale changes in climate (e.g., Davis, 1969; Suter, 1985; Gaudreau, 1986; Shuman et al., 2001;
5 2004; Oswald et al., 2007). Late-glacial forests featured cold-tolerant *Picea* (spruce) and *Pinus*
6 *banksiana* (jack pine), warmer and drier conditions during the early Holocene resulted in
7 dominance by *Pinus strobus* (white pine), and wetter conditions after ~8000 cal. a BP promoted
8 the expansion of various temperate forest taxa, including *Quercus*. There is no indication of a
9 middle-Holocene interval dominated by *Fagus grandifolia* on Long Island (Sirkin, 1967; 1971),
10 but the coarse sampling resolution and very limited chronological control restrict the utility of
11 the existing Long Island records.

12 Recent studies in southeastern Massachusetts, located northeast of Long Island (Fig. 1),
13 show that lake-sediment records from the Northeast feature not only the orbital-scale changes in
14 climate responsible for the broad sequence of vegetation shifts (e.g., Shuman et al., 2001; 2004),
15 but also century-scale intervals of reduced water depth evidenced by sand layers in near-shore
16 cores (e.g., Newby et al., 2009; Shuman et al., 2009). Relatively brief periods of dry conditions
17 associated with changing ocean conditions appear to have occurred at ~9200, 8300, 5300, 4600,
18 3800, 2900, 2200, and 1500 cal. a BP and may have served as important drivers for some aspects
19 of the vegetation history of the region (Shuman et al., 2004; 2009; Newby et al., 2009).

20 In this paper we discuss a detailed lake-sediment record from Wildwood Lake, located in
21 eastern Long Island (Fig. 1) near the Central Pine Barrens, the largest area of *Pinus rigida*-
22 *Quercus ilicifolia* woodlands on Long Island (CPBJPPC, 1995; Jordan et al., 2003). Preliminary
23 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

1 after European settlement (Backman, 1984). Historical records show that large fires burned
2 across Long Island in the late-eighteenth and nineteenth centuries (Kurczewski and Boyle, 2000).

3 4 METHODS

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

13 Sediment organic content was estimated by measuring percent weight loss-on-ignition
14 (LOI); 1-cm³ samples were dried at 90°C and ashed at 550°C (Bengtsson and Enell, 1986).
15 Macroscopic charcoal content of the sediment was determined by soaking 1-cm³ samples in
16 KOH, sieving through a 180-µm screen, and counting charcoal pieces >180-µm at 20X
17 magnification (Long et al., 1998). Samples of 1 cm³ from 116 levels were prepared for pollen
18 analysis following standard procedures (Faegri and Iversen, 1989), and tablets containing
19 *Lycopodium* spores were added to the samples to estimate concentrations and influx (Stockmarr,
20 1971). Pollen residues were analyzed at 400X magnification until a minimum of 500 pollen
21 grains and spores of upland taxa was identified for each level. Pollen percentages are expressed
22 relative to the sum of upland tree, shrub, and herb pollen. Only ~30% of *Pinus* pollen grains
23 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 ¹⁴C analysis of bulk sediment samples, each spanning 1 cm core depth (Table 1). ¹⁴C 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 ²¹⁰Pb 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

1 *Ambrosia* (ragweed). These fossil assemblages are similar to modern spectra from the *Quercus*-
2 (SCD ~0.08) and *Pinus*-dominated sites (SCD ~0.1; Fig 6E) and dissimilar to those from *Fagus*
3 *grandifolia*-dominated sites (SCD ~0.2). The highest value for *Pinus* pollen (>50%) falls within
4 the sandy layer at ~650 cm that dates to 9200 cal. a BP. Charcoal influx values fluctuate
5 between ~40 and 80 pieces cm⁻² yr⁻¹, and *Pediastrum* influx values vary between ~100 and 2900
6 algal cell nets cm⁻² yr⁻¹ (Fig. 6D).

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

21 The changes at 130 cm (300 cal. a BP) represent the era of European settlement and
22 forest clearance (Fig. 5A). A sharp drop in organic content is presumably attributable to
23 increased erosion of mineral material into the lake (Fig. 6B), and a rise in *Pediastrum* influx may

1 indicate changes in the aquatic ecosystem in response to disturbance in the watershed (Fig. 6D;
2 e.g., Jankovska and Komarek, 2000). *Rumex* (sorrel), Poaceae, and *Ambrosia* increase
3 dramatically, while *Carya*, *Quercus*, and especially *Pinus* exhibit declining abundances at the
4 beginning of this interval. Decreasing percentages of the herbaceous taxa and increasing *Pinus*
5 pollen percentages (~20 to 50%) in levels dating to ~1950 AD reflect the decline of agricultural
6 activity and reforestation. Charcoal influx values increase from ~5 to 15 pieces cm⁻² yr⁻¹ at ~100
7 cal. a BP (1850 AD), then reach a peak of ~20-35 pieces cm⁻² yr⁻¹ in levels dating to ~1920-1970
8 AD (Fig. 5A).

10 DISCUSSION

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

15 Early-Holocene vegetation and fire

16 This sediment core from Wildwood Lake contains only a ~1000 year interval of the early
17 Holocene, but nonetheless does contribute to our understanding of Long Island ecosystems
18 between ~9800 and 8800 cal. a BP. The prevalence of *Pinus* and *Quercus*, paucity of mesic-
19 forest taxa such as *Fagus grandifolia* and *Carya*, relatively high abundance of *Ambrosia*, and
20 very high charcoal influx values suggest open *Pinus-Quercus* woodlands with frequent fire on
21 the Ronkonkoma moraine and adjacent areas of outwash. Similar pollen assemblages in early-
22 Holocene samples from other sites on Long Island (Sirkin, 1967; 1971) indicate that this type of
23 vegetation was widespread. High fire activity and open forest structure, as evidenced by

1 abundant *Ambrosia* (Faison et al., 2006), are consistent with evidence suggesting that regional
2 climate was relatively dry during this interval (Fig. 6A; Shuman et al., 2001; 2004; 2009; Newby
3 et al., 2009).

4 5 Evidence for century-scale climatic events

6 The decline in organic content that is dated securely to 9200 cal. a BP likely represents an
7 interval of particularly dry climate and reduced water levels at Wildwood Lake. A similar
8 feature occurs in the sediments of New Long Pond in southeastern Massachusetts (Newby et al.,
9 2009) and geochemical data from Blood Pond in south-central Massachusetts indicate a ~4°C
10 temperature decline at that time (J. Hou and Y. Huang, unpublished). Emerging evidence
11 suggests that a widespread climatic event took place at ~9200 cal. a BP, presumably caused by a
12 weakening of Atlantic meridional overturning circulation (e.g., Fleitmann et al., 2008). The peak
13 in *Pinus* pollen abundance at 9200 cal. a BP in the Wildwood Lake record may represent a
14 change in vegetation in response to cold, dry conditions. This finding is consistent with other
15 evidence for century-scale ecological changes associated with early-Holocene variations in
16 climate (e.g., Shuman et al., 2004).

17 The organic-content and ¹⁴C data demonstrate that the Wildwood core features a >4000
18 year hiatus between ~8800 and ~4500 cal. a BP. One interpretation of this finding is that climate
19 was dry and water levels were low throughout this entire period. Webb et al. (1993) offered a
20 similar interpretation based on lake-sediment data from other sites in southern New England.
21 More-recent reconstructions of lake-level changes for sites across the Northeast (e.g., Lavoie and
22 Richard 2000; Newby et al., 2000; Dieffenbacher-Krall and Nurse 2005; Shuman et al. 2005),
23 including Crooked Pond in southeastern Massachusetts (Fig. 6A; Shuman et al., 2001), however,

1 indicate that the period from ~8000 to 5500 cal. a BP was relatively wet, suggesting that the
2 sedimentary hiatus may not simply represent a continuous interval of dry conditions. Instead, we
3 hypothesize that the pronounced dry events recorded at New Long Pond at ~5300 and 4600 cal. a
4 BP (Shuman et al., 2009) occurred across the region and also caused major water-level
5 reductions at Wildwood Lake. If the portion of the lake bottom cored for this study were
6 substantially shallower than at present, perhaps by >10 m, older sediments could have been re-
7 deposited to the deeper part of the lake, resulting in the loss of that interval of the record from
8 ~8800 cal. a BP to the time when deeper water levels once again reached this site. The sandy
9 layers at ~590 and ~560 cm presumably were re-deposited from the exposed lakeshore and
10 shoal; the ^{14}C dates indicate that those sediments were mixed. Our data suggest that the
11 accumulation of lake sediment resumed ~4500 cal. a BP, a date consistent with the lake-level
12 reconstructions for Crooked Pond (Shuman et al., 2001) and New Long Pond (Shuman et al.,
13 2009).

14 15 Middle- and late-Holocene vegetation and fire

16 The similarity of middle-Holocene pollen spectra to modern samples from three different
17 types of vegetation (*Pinus*, *Quercus*, and *Fagus*) may be attributable to the large pollen source
18 area of Wildwood Lake. Presumably, the lake receives some pollen from the local vegetation on
19 the Ronkonkoma moraine, as well as some pollen from vegetation on the nearby outwash plains.
20 The similarity of middle-Holocene pollen assemblages to modern *Pinus* samples suggests that
21 areas of sandy soil were dominated by *Pinus rigida*, as seems to have been the case during the
22 early Holocene. The forests of the moraine itself, on the other hand, appear to have featured
23 *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., Carcaillet 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

1 km northwest of Wildwood (Fig. 1; Backman, 1984), and elsewhere in southern New England
2 (Parshall and Foster, 2002), which show a rise in burning. Historical accounts suggest that large
3 fires burned across eastern Long Island in the late-eighteenth and nineteenth centuries (e.g.,
4 Kurczewski and Boyle, 2000), but the Wildwood charcoal record indicates that those fires were
5 typical for the last few millennia. Indeed, they were probably smaller and less intense than fires
6 of the early Holocene; fire activity on Long Island was very high ~9800-8800 cal. a BP when
7 climate was relatively dry. Historical records suggest that fire frequency and intensity increased
8 when the Long Island Railroad reached eastern Long Island in the mid-nineteenth century
9 (Kurczewski and Boyle, 2000). This change may be reflected in the Wildwood charcoal record
10 by the elevated influx values from ~100-0 cal. a BP (~1850 to 1950 AD).

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

21 These analyses of the sedimentary record from Wildwood Lake improve our
22 understanding of Holocene environmental and ecological changes on Long Island, New York,
23 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.

1 REFERENCES CITED

- 2
3 Alley RB, Mayewski PA, Sowers T, Stuiver M, Taylor KC, Clark PU. 1997. Holocene climatic
4 instability: a prominent, widespread event 8200 years ago. *Geology* **25**: 483-486.
5
6 Alley RB, Ágústssdóttir AM. 2005. The 8k event: cause and consequences of a major Holocene
7 abrupt climate change. *Quaternary Science Reviews* **24**: 1123-1149.
8
9 Backman AE. 1984. 1000-year record of fire-vegetation interactions in the northeastern United
10 States: a comparison between coastal and inland regions. M.Sc. thesis, University of
11 Massachusetts, Amherst.
12
13 Bengtsson L, Enell M. 1986. Chemical analysis. In *Handbook of Holocene Palaeoecology and*
14 *Palaeohydrology*, Berglund BE (ed). John Wiley and Sons: Chichester, UK; 423-454.
15
16 Bernabo JC, Webb T, III. 1977. Changing patterns in the Holocene pollen record of northeastern
17 North America: a mapped summary. *Quaternary Research* **8**: 64-96.
18
19 Binford MW. 1990. Calculation and uncertainty analysis of ²¹⁰Pb dates for PIRLA project cores.
20 *Journal of Paleolimnology* **3**: 253-267.
21
22 Carcaillet C, Richard PJH. 2000. Holocene changes in seasonal precipitation highlighted by fire
23 incidence in eastern Canada. *Climate Dynamics* **16**: 549-559.
24
25 Central Pine Barrens Joint Planning and Policy Commission (CPBJPPC). 1995. Central Pine
26 Barrens Comprehensive Land Use Plan, Vol. 1-2, <http://www.pb.state.ny.us>.
27
28 Cogbill CV, Burk J, Motzkin J. 2002. The forests of presettlement New England, USA: spatial
29 and compositional patterns based on town proprietor surveys. *Journal of Biogeography* **29**:
30 1279-1304.
31
32 Davis MB. 1969. Climatic changes in southern Connecticut recorded by pollen deposition at
33 Rogers Lake. *Ecology* **50**: 409-422.
34
35 Dieffenbacher-Krall AC, Nurse AM. 2005. Late-glacial and Holocene record of lake levels of
36 Mathews Pond and Whitehead Lake, northern Maine, USA. *Journal of Paleolimnology* **34**: 283-
37 310.
38
39 Faegri K, Iversen J. 1989. Textbook of Pollen Analysis. Fourth edition. John Wiley and Sons,
40 Chichester, UK.
41
42 Faison EK, Foster DR, Oswald WW, Doughty ED, Hansen BCS. 2006. Early-Holocene
43 openlands in southern New England. *Ecology* **87**: 2537-2547.
44
45 Fleitmann D, Mudelsee M, Burns SJ, Bradley RS, Kramers J, Matter A. 2008. Evidence for a
46 widespread climatic anomaly at around 9.2 ka before present. *Paleoceanography* **23**: PA1102.

- 1
2 Foster DR, Oswald WW, Faison EK, Doughty ED, Hansen BCS. 2006. A climatic driver for
3 abrupt mid-Holocene vegetation dynamics and the hemlock decline in New England. *Ecology*
4 **87**: 2959-2966.
5
6 Fuller ML. 1914. The Geology of Long Island. United States Geological Survey Professional
7 Paper 82, Washington, DC.
8
9 Gaudreau DC. 1986. Late-Quaternary vegetational history of the Northeast: paleoecological
10 implications of topographic patterns in pollen distributions. Ph.D. thesis, Yale University, New
11 Haven.
12
13 Gaudreau DC, Webb T, III. 1985. Late-Quaternary pollen stratigraphy and isochrone maps for
14 the northeastern United States. In *Pollen Records of Late Quaternary North American Sediments*,
15 Bryant J, Holloway J (eds). American Association of Stratigraphic Palynologists: Dallas; 247-
16 280.
17
18 Huang Y, Shuman B, Wang Y, Webb T, III. 2002. Hydrogen isotope ratios of palmitic acid in
19 lacustrine sediments record late-Quaternary climate variations. *Geology* **30**: 1103-1106.
20
21 Jankovska V, Komarek J. 2000. Indicative value of *Pediastrum* and other coccal green algae in
22 palaeoecology. *Folia Geobotanica* **35**: 59-82.
23
24 Jordan MJ, Patterson WA, III, Windisch AG. 2003. Conceptual ecological models for the Long
25 Island pitch pine barrens: implications for managing rare plant communities. *Forest Ecology and*
26 *Management* **185**: 151-168.
27
28 Kurek J, Cwynar LC, Spear RW. 2004. The 8200 cal. a BP cooling event in eastern North
29 America and the utility of midge analysis for Holocene temperature reconstructions. *Quaternary*
30 *Science Reviews* **23**: 627-639.
31
32 Kurczewski FE, Boyle HF. 2000. Historical changes in the pine barrens of central Suffolk
33 County, New York. *Northeastern Naturalist* **7**: 95-112.
34
35 Lavoie M, Richard PJH. 2000. Postglacial water-level changes of a small lake in southern
36 Quebec, Canada. *The Holocene* **10**: 621-634.
37
38 Long CJ, Whitlock C, Bartlein PJ, Millspaugh SH. 1998. A 9000-year fire history from the
39 Oregon Coast Range, based on a high-resolution charcoal study. *Canadian Journal of Forest*
40 *Research* **28**: 774-787.
41
42 Motzkin G, Eberhardt R, Hall B, Foster DR, Harrod JC, MacDonald D. 2002. Vegetation
43 variation across Cape Cod, Massachusetts: environmental and historical determinants. *Journal of*
44 *Biogeography* **29**: 1439-1454.
45

- 1 Motzkin G, Foster DR, Allen AE, Harrod JC, Boone RD. 1996. Controlling site to evaluate
2 history: vegetation patterns of a New England sand plain. *Ecological Monographs* **66**: 345-365.
3
- 4 Newby PE, Killoran P, Waldorf M, Shuman B, Webb T, III, Webb RS. 2000. 14,000 years of
5 sediment, vegetation, and water level changes at Makepeace Cedar Swamp, southeastern
6 Massachusetts. *Quaternary Research* **53**: 352-368.
7
- 8 Newby PE, Donnelly JP, Shuman BN, MacDonald D. 2009. Evidence of centennial-scale
9 drought from southeastern Massachusetts during the Pleistocene/Holocene transition.
10 *Quaternary Science Reviews* **28**: 1675-1692.
11
- 12 Oswald WW, Faison EK, Foster DR, Doughty ED, Hall BR, Hansen BCS. 2007. Post-glacial
13 changes in spatial patterns of vegetation across southern New England. *Journal of Biogeography*
14 **34**: 900-913.
15
- 16 Overpeck JT, Webb T, III, Prentice IC. 1985. Quantitative interpretation of fossil pollen spectra:
17 dissimilarity coefficients and the method of modern analogs. *Quaternary Research* **23**: 87-108.
18
- 19 Parshall T, Foster DR. 2002. Fire on the New England landscape: regional and temporal
20 variation, cultural and environmental controls. *Journal of Biogeography* **29**: 1305-1317.
21
- 22 Parshall T, Foster DR, Faison E, MacDonald D, Hansen BCS. 2003. Long-term history of
23 vegetation and fire in pitch pine-oak forests on Cape Cod, Massachusetts. *Ecology* **84**: 736-738.
24
- 25 Power MJ, Marlon J, Ortiz N, Bartlein PJ, Harrison SP, Mayle FE, Ballouche A, Bradshaw
26 RHW, Carcaillet C, Cordova C, Mooney S, Moreno PI, Prentice IC, Thonicke K, Tinner W,
27 Whitlock C, Zhang Y, Zhao Y, Ali AA, Anderson RS, Beer R, Behling H, Briles C, Brown KJ,
28 Brunelle A, Bush M, Camill P, Chu GQ, Clark J, Colombaroli D, Connor S, Daniau A-L,
29 Daniels M, Dodson J, Doughty E, Edwards ME, Finsinger W, Foster D, Frechette J, Gaillard M-
30 J, Gavin DG, Gobet E, Haberle S, Hallett DJ, Higuera P, Hope G, Horn S, Inoue J, Kaltenrieder
31 P, Kennedy L, Kong ZC, Larsen C, Long CJ, Lynch J, Lynch EA, McGlone M, Meeks S,
32 Mensing S, Meyer G, Minckley T, Mohr J, Nelson DM, New J, Newnham R, Noti R, Oswald W,
33 Pierce J, Richard PJH, Rowe C, Sanchez Goñi MF, Shuman BN, Takahara H, Toney J, Turney
34 C, Urrego-Sanchez DH, Umbanhowar C, Vandergoes M, Vanniere B, Vescovi E, Walsh M,
35 Wang X, Williams N, Wilmschurst J, Zhan JH. 2008. Changes in fire regimes since the Last
36 Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data.
37 *Climate Dynamics* **30**: 887-907.
38
- 39 Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE,
40 Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hogg
41 AG, Hughen KA, Kromer B, McCormac FG, Manning SW, Ramsey CB, Reimer RW, Remmele
42 S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004.
43 IntCal04 Terrestrial radiocarbon age calibration, 26 - 0 ka BP. *Radiocarbon* **46**: 1029-1058.
44

- Shuman B, Bravo J, Kaye J, Lynch JA, Newby P, Webb T, III, 2001. Late-Quaternary water-level variations and vegetation history at Crooked Pond, southeastern Massachusetts. *Quaternary Research* **56**: 401-410.
- Shuman B, Bartlein P, Logar N, Newby P, Webb T, III. 2002a. Parallel climate and vegetation responses to the early Holocene collapse of the Laurentide Ice Sheet. *Quaternary Science Reviews* **21**: 1793-1805.
- Shuman B, Webb T, III, Bartlein P, Williams JW. 2002b. The anatomy of a climatic oscillation: vegetation change in eastern North America during the Younger Dryas chronozone. *Quaternary Science Reviews* **21**: 1763-1916.
- Shuman B, Newby P, Huang Y, Webb T, III. 2004. Evidence for the close climate control of New England vegetation history. *Ecology* **85**: 1297-1310.
- Shuman B, Newby P, Donnelly JP, Tarbox A, Webb T, III. 2005. A record of late-Quaternary moisture-balance change and vegetation response from the White Mountains, New Hampshire. *Annals of the Association of American Geographers* **95**: 237-248.
- Shuman B, Donnelly JP. 2006. The influence of seasonal precipitation and temperature regimes on lake levels in the northeastern United States during the Holocene. *Quaternary Research* **65**: 44-56.
- Shuman B, Huang Y, Newby P, Wang Y. 2006. Compound-specific isotopic analyses track changes in the seasonality of precipitation regimes in the northeastern United States at ca. 8200 cal. a BP. *Quaternary Science Reviews* **25**: 2992-3002.
- Shuman BN, Newby P, Donnelly, JP. 2009. Abrupt climate change as an important agent of ecological change in the Northeast U.S. throughout the past 15,000 years. *Quaternary Science Reviews* **28**: 1693-1709
- Sirkin LA. 1967. Late-Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, New York. In *Quaternary Paleocology*, Cushing EJ, Wright HE, Jr. (eds). Yale University Press: New Haven; 248-274.
- Sirkin LA. 1971. Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. *Pollen et Spores* **13**: 93-100.
- Spooner I, Douglas MSV, Terrusi L. 2002. Multiproxy evidence of an early Holocene (8.2 kyr) climate oscillation in central Nova Scotia, Canada. *Journal of Quaternary Science* **17**: 639-645.
- Stockmarr J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* **13**: 615-621.
- Sugita S. 1994. Pollen representation of vegetation in Quaternary sediments—theory and method in patchy vegetation. *Journal of Ecology* **82**: 881-897.

- 1
2 Suter SM. 1985. Late-glacial and Holocene vegetation history in southeastern Massachusetts: a
3 14,000-year pollen record. *Current Research in the Pleistocene* **2**: 87-89.
4
5 Thompson RS, Anderson KH, Bartlein PJ. 1999. Atlas of relations between climatic parameters
6 and distributions of important trees and shrubs in North America. U. S. Geological Survey
7 Professional Paper 1650, <http://pubs.usgs.gov/pp/p1650-a>.
8
9 United States Department of Agriculture (USDA). 1972. General Soil Map, Suffolk County,
10 New York.
11
12 United States Department of Agriculture (USDA). 1975. Soil Survey of Suffolk County, New
13 York.
14
15 Webb RS, Anderson KA, Webb T, III. 1993. Pollen response-surface estimates of Late-
16 Quaternary changes in the moisture balance of the northeastern United States. *Quaternary*
17 *Research* **40**: 213-227.
18
19 Williams JW, Shuman BN, Webb T, III. 2001. Dissimilarity analyses of late-Quaternary
20 vegetation and climate in eastern North America. *Ecology* **82**: 3346-3362.
21
22 Windisch AG. 1999. Fire Ecology of the New Jersey Pine Plains and Vicinity. Ph.D. thesis,
23 Rutgers University, New Brunswick.

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

Depth (cm)	^{14}C lab code	$\delta^{13}\text{C}$	^{14}C date	Cal age range (2σ)	Median cal age
207	AA-58100	-27.98	1300 ± 40	1143-1301	1237
264	AA-58101	-27.70	1240 ± 40	1068-1270	1179
417	OS-47543	-25.48	3080 ± 40	3171-3383	3301
549	OS-72387	-25.43	4510 ± 40	5039-5310	5163
569	OS-72388	-26.14	4030 ± 40	4417-4784	4497
571	OS-56478	-25.80	3860 ± 35	4156-4412	4290
599	OS-72389	-23.81	7980 ± 60	8645-9004	8844
617	OS-47544	-24.49	8070 ± 60	8720-9240	8987
654	OS-56479	-25.25	8210 ± 45	9021-9302	9175
697	OS-56480	-24.87	8440 ± 40	9333-9531	9474
762	OS-47545	-24.28	8790 ± 60	9563-10,151	9822

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

Depth (cm)	Age (relative to AD 1950) $\pm$ S.D.
0	-50.0 ± 0.6
4	-46.9 ± 0.6
8	-42.6 ± 0.6
12	-38.4 ± 0.6
16	-33.5 ± 0.6
20	-29.3 ± 0.6
24	-24.5 ± 0.6
28	-18.8 ± 0.6
32	-10.5 ± 0.6
36	3.4 ± 0.7
40	11.0 ± 0.7
44	18.5 ± 0.8
48	26.2 ± 0.9
52	33.9 ± 1.0
56	41.7 ± 1.2
64	66.5 ± 2.2
72	95.5 ± 10.6

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.