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

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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 (ca. 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 ca. 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 ca. 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. Copyright © 2010 John Wiley & Sons, Ltd.

KEYWORDS: charcoal; fire; palaeoecology; pitch pine; pollen.

Introduction

Numerous palaeoecological and palaeoenvironmental records provide a broad view of the postglacial vegetation and climate history of the northeastern USA ('the Northeast'; e.g. Bernabo and Webb, 1977; Gaudreau and Webb, 1985; Williams *et al.*, 2001; Huang *et al.*, 2002; Shuman *et al.*, 2002a,b; 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 palaeoecological 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 ca. 5500

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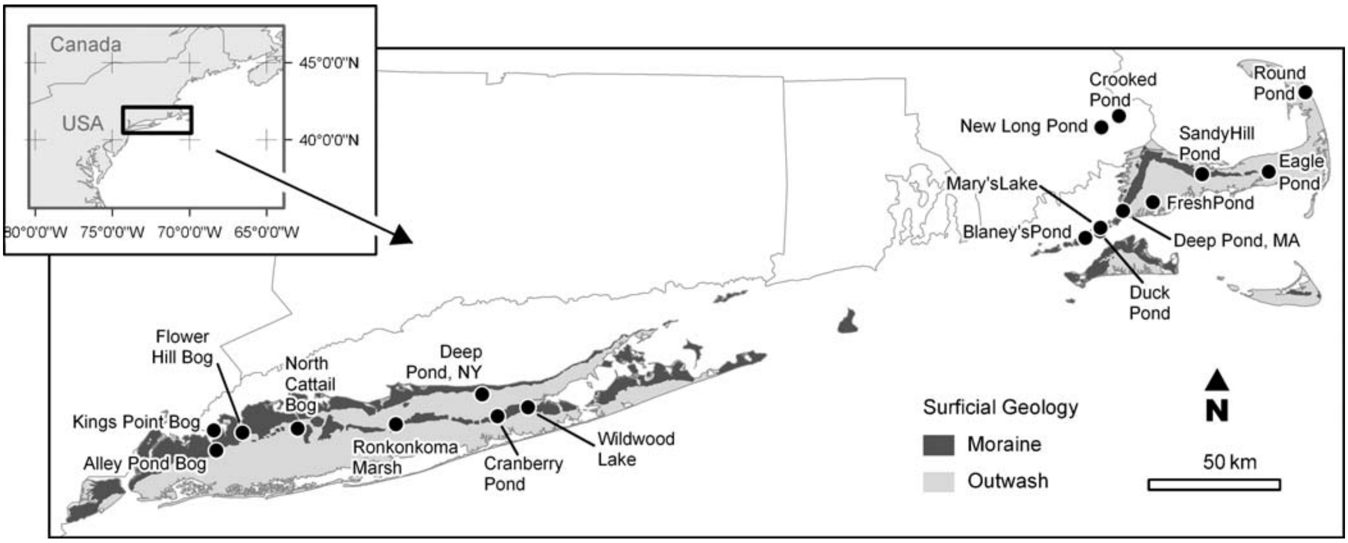

Figure 1 Map of Long Island, New York and Cape Cod, Massachusetts, featuring surficial geology and showing location of Wildwood Lake, other fossil pollen sites on Long Island (Sirkin, 1967, 1971; Backman, 1984), Cape Cod sites used for modern analogue analysis (Parshall *et al*., 2003; W. Oswald and D. Foster, unpublished), and Crooked and New Long Ponds in southeastern Massachusetts (Shuman *et al*., 2001, 2009; Newby *et al*., 2009)

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 ca. 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 postglacial 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 ca. 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 ca. 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 is currently 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

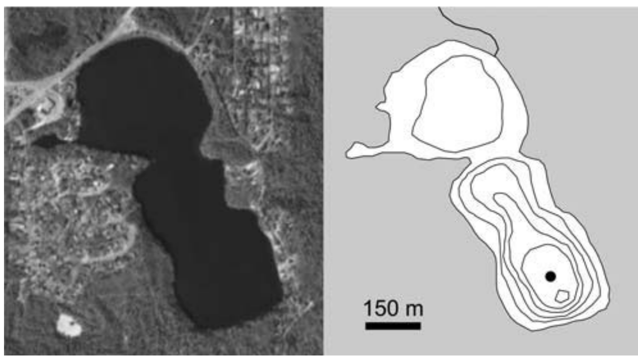

Figure 2 Aerial photo and bathymetric map of Wildwood Lake. Contour interval is 3 m; black circle indicates coring location

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 17th 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 18th and 19th centuries (Kurczewski and Boyle, 2000).

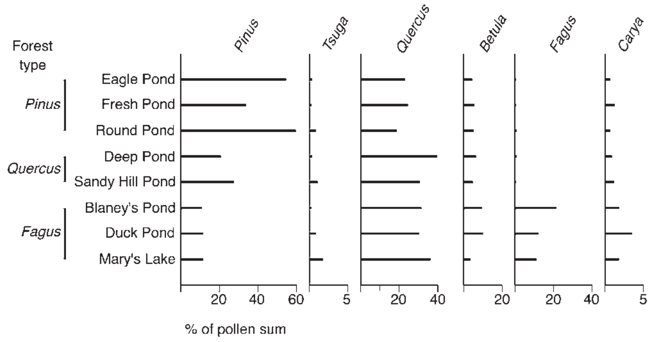

Figure 3 Modern pollen data from sites in southeastern New England: Eagle Pond, Fresh Pond, Round Pond, Deep Pond, Sandy Hill Pond (Parshall *et al.*, 2003), Blaney's Pond, Duck Pond and Mary's Lake (W. Oswald and D. Foster, unpublished)

Methods

We recovered a sediment core from Wildwood Lake in July 2001. The core was collected near the centre 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 aluminium foil.

Sediment organic content was estimated by measuring percent weight loss-on-ignition (LOI); 1 cm^3 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 cm^3 samples in KOH, sieving through a 180 μm screen and counting charcoal pieces >180 μm at 20× magnification (Long *et al.*, 1998). Samples of 1 cm^3 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 analysed at 400× magnification until a minimum of 500 pollen grains and spores of upland taxa were 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}C analysis of bulk sediment samples, each spanning 1 cm core depth (Table 1). ^{14}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}Pb analysis (Table 2; Binford, 1990) and pollen stratigraphy: the rise in agricultural taxa at 130 cm (Figs 4(B) and 5(A)) was assigned an age of 300 cal. a BP (AD 1650; 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. 4(A), (C)). 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 ca. 1000 a) 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. 4(B)). 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 ca. 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. 4(B)). The dates bracketing the sandy layers at ~590 and ~560 cm suggest that these features represent a sedimentary hiatus from ca. 8800 to ca. 4500 cal. a BP. The age model for the upper interval of the core (ca. 4500 cal. a BP to 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 16 ^{210}Pb dates (Tables 1 and 2; Fig. 4(B)).

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

Depth (cm)	^{14}C lab code	$\delta^{13}C$ (‰)	^{14}C date (a BP)	Cal. age range (2σ) (a BP)	Median cal. age (a BP)
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) ± SD (a)
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

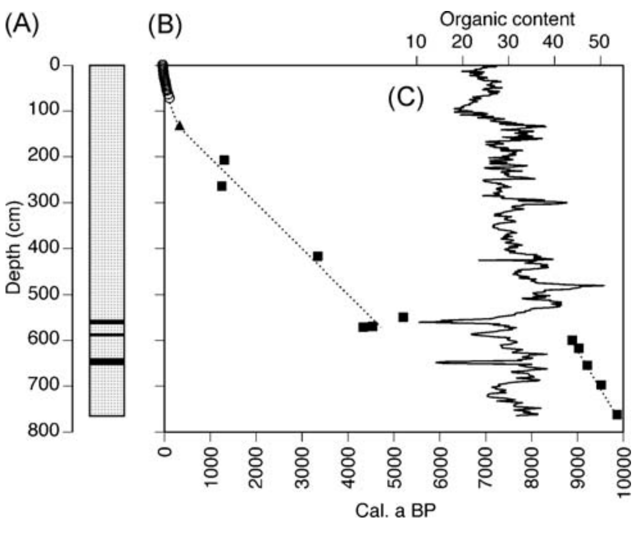

Figure 4 (A) Lithology of the Wildwood Lake sediment core; grey shading indicates lacustrine sediment; black shading indicates sandy layers. (B) Age–depth model; open circles are ^{210}Pb dates, triangle is European settlement and squares are calibrated ^{14}C dates. (C) Organic content estimated by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

Pollen and charcoal records

The lower interval of the Wildwood core (ca. 9800–8800 cal. a BP; Fig. 5(C)) 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. 6(E)) 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} a^{-1}, and *Pediastrum* influx values vary between ∼100 and 2900 algal cell nets cm^{-2} a^{-1} (Fig. 6(D)).

The upper interval of the record (ca. 4500 cal. a BP to present; Fig. 5(B)) features gradually increasing *Pinus* pollen percentages (∼20–40%) and gradually decreasing *Quercus* values (∼50–30%). 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 ca. 4000 and 2000 cal. a BP; *Fagus* and *Carya* pollen percentages decrease slightly during that interval. Poaceae and *Ambrosia* pollen percentages are lower between ca. 4500 cal. a BP and European settlement than they were during ca. 9800–8800 cal. a BP. The fossil assemblages from ca. 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 ca. 2000 cal. a BP (Fig. 6(E)). Charcoal influx values for the middle and late Holocene are ∼5–10 pieces cm^{-2} a^{-1}. Sediment organic content is high between ca. 4400 and 3000 cal. a BP, peaking at 3800 cal. a BP, then peaks again at ca. 2000 cal. a BP (Fig. 6(B)). Influx of *Pediastrum* algal cell nets declines between ca. 4000 and 3000 cal. a BP (Fig. 6(D)).

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

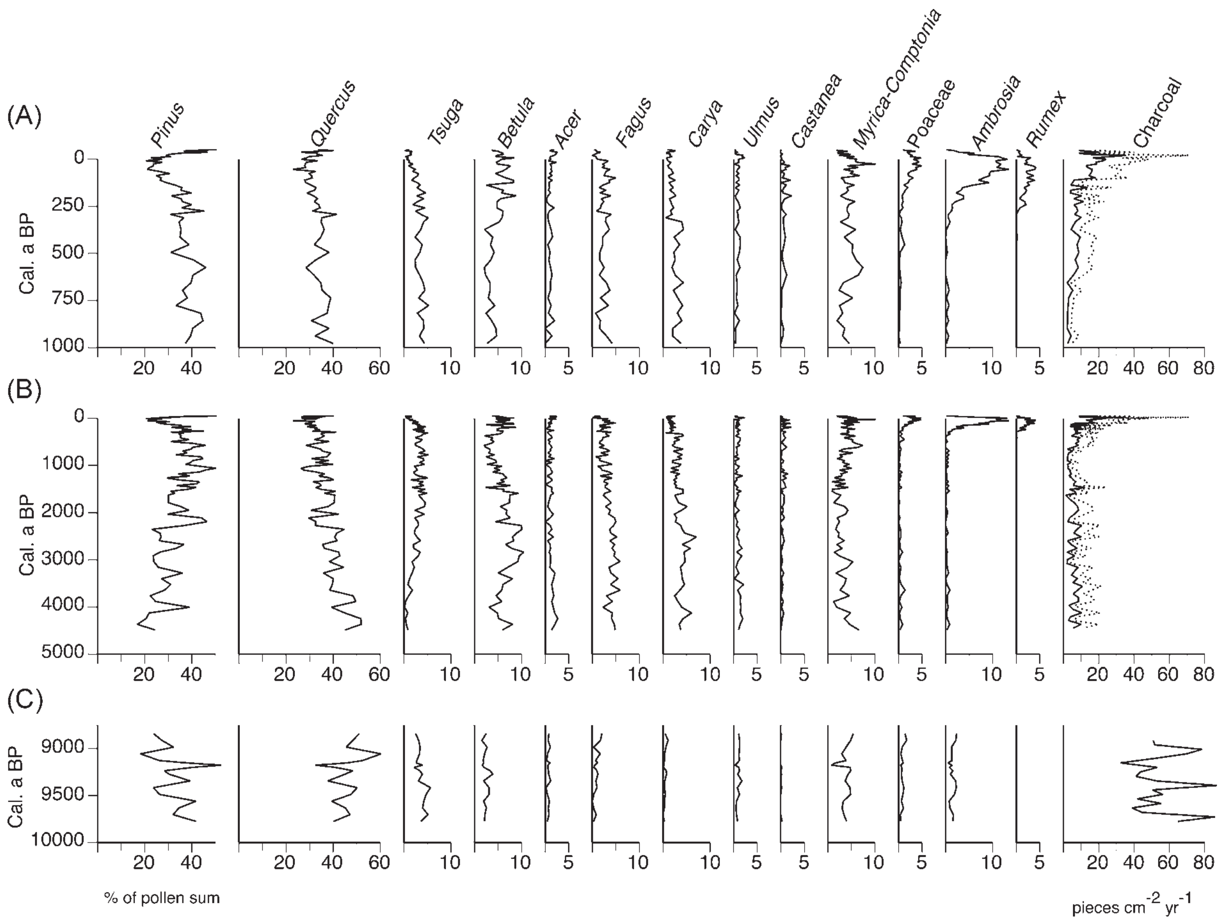

Figure 5 Pollen percentages diagram for selected taxa and charcoal influx values. Separate diagrams are shown for: (A) 1000 cal. a BP to present; (B) ca. 4500 cal. a BP to present; (C) ca. 9800–8800 cal. a BP. Dashed charcoal influx lines in (A) and (B) represent 2× exaggeration. Estimated age for European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

($\sim$20–50%) in levels dating to ca. AD 1950 reflect the decline of agricultural activity and reforestation. Charcoal influx values increase from $\sim$5 to 15 pieces cm^{-2} a^{-1} at ca. 100 cal. a BP (AD 1850), then reach a peak of $\sim$20–35 pieces cm^{-2} a^{-1} in levels dating to ca. AD 1920–1970 (Fig. 5(A)).

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.

Early Holocene vegetation and fire

This sediment core from Wildwood Lake contains only a ca. 1000 a interval of the early Holocene, but nonetheless does contribute to our understanding of Long Island ecosystems between ca. 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. 6(A); 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 $\sim$4°C temperature decline at that time (J. Hou and Y. Huang, unpublished). Emerging evidence suggests that a widespread climatic event took place at ca. 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 a hiatus between ca. 8800 and $\sim$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

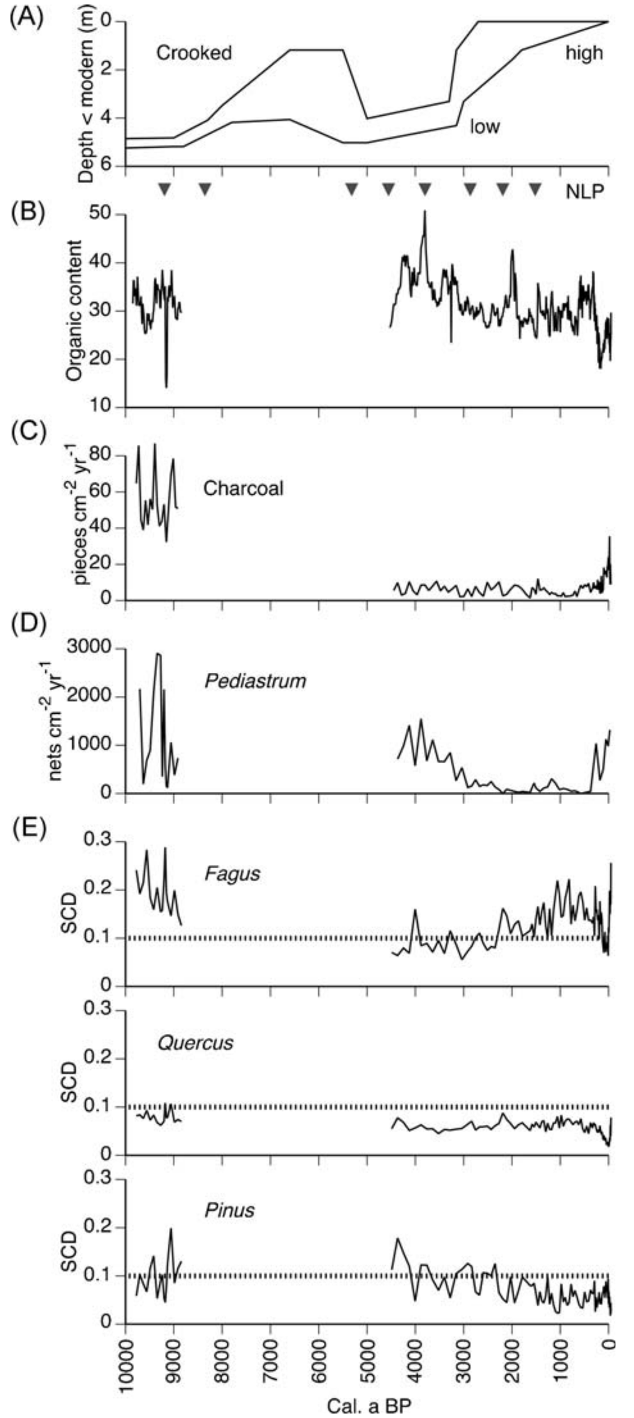

Figure 6 (A) Lake-level reconstructions for sites in southeastern Massachusetts; water-depth estimates for Crooked Pond (Shuman *et al.*, 2001); triangles are dry events evidenced by sand layers in sediments of New Long Pond (Newby *et al.*, 2009; Shuman *et al.*, 2009). (B) Wildwood Lake organic content, 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

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. 6(A); Shuman *et al.*, 2001), however, indicate that the period from ca. 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 hypothesise that the pronounced dry events recorded at New Long Pond at ca. 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 redeposited to the deeper part of the lake, resulting in the loss of that interval of the record from ca. 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 redeposited 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 ca. 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 ca. 5500–3000 cal. a BP (Foster *et al.*, 2006). Climate appears to have become cooler and wetter between ca. 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 ca. 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) hypothesise that the seasonality of precipitation may have shifted between the middle and late Holocene, so that even though annual precipitation increased after ca. 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 ca. 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 ca. 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 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 18th and 19th 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 ca. 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 19th century (Kurczewski and Boyle, 2000). This change may be reflected in the Wildwood charcoal record by the elevated influx values from ca. 100 to 0 cal. a BP (ca. AD 1850–1950).

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 associated 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.

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