A 10,000-year-old white pine forest emerges at Stonewall Beach, Martha's Vineyard, Massachusetts, U.S.A.

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ABSTRACT

Coastal erosion at Stonewall Beach on the island of Martha's Vineyard, Massachusetts, U.S.A., has exposed a thick layer of peaty sediments rich in botanical remains, including well-preserved tree trunks. We identified the species of the tree trunks based on wood anatomy, analyzed pollen and macrofossils in the sediments, and determined the ages of the tree trunks and peat with ^{14}C dating. The tree trunks were identified as *Pinus strobus* (white pine), and pollen assemblages featured high percentages of *P. strobus* in sediments associated with the trunks. The tree trunks and peat dated to ~10,700–9800 calibrated ^{14}C years before present. These findings confirm that Martha's Vineyard, like other parts of southern New England, was dominated by *P. strobus* forest during the early Holocene. At that time, regional climate was drier than today and Martha's Vineyard was not yet isolated from the mainland by postglacial sea-level rise.

Key words: Holocene, New England, paleoecology, *Pinus strobus*, pollen

INTRODUCTION

The postglacial sequence of vegetation changes in New England was first described by Deevey (1939) and later dated by Davis (1969): the late-glacial interval (~14,000–12,000 calibrated ^{14}C years before present; cal yr BP) featured tundra ecosystems (Deevey's zone T) followed by boreal forest dominated by *Picea* A. Dietr. (zone A, with subzones 1–4); *Pinus strobus* L. was regionally dominant during the early Holocene (~12,000–10,000 cal yr BP; zone B); and in the middle Holocene (after ~10,000–8000 cal yr BP) *Tsuga canadensis* (L.) Carrière, *Fagus grandifolia* Ehrh., and *Betula* L. expanded in northern New England, while *Quercus* L. became dominant in southern New England (zone C, with subzones 1–3). Numerous subsequent studies have refined our understanding of the drivers, spatiotemporal patterns, and taxonomic details of vegetation change across the region over the last 14,000 years (e.g., Emery et al. 1967; Foster et al. 2006; Gaudreau 1986; Maenza-Gmelch 1997; Menking et al. 2012; Newby et al. 2014; Oswald et al. 2007, 2018; Peteet et al. 1990, 1993; Shuman et al. 2004; Spear et al. 1994; Whitehead 1979; Winkler 1985).

As sea-level rise and coastal storms erode the coastline of southern New England, the

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surfacing of botanical remains from long-buried soils and peats can yield further insights into the geomorphic and ecological history of the region (e.g., Gontz et al. 2013; Maio et al. 2014; Ogden 1963). At Stonewall Beach, located on the island of Martha's Vineyard (Figures 1–2), several intact tree trunks protrude from a ~1 m thick layer of peaty sediments, indicating a rich repository of botanical remains (Figure 3). We analyzed various aspects of the organic sediments and wood samples, allowing us to reconstruct the landscape and forest that occurred at the site during the early Holocene.

MATERIALS AND METHODS

Stonewall Beach, named for the persistent thick accumulation of rounded cobbles that distinguishes this ~2 km long stretch of the coast, sits on the southwest shore of the island of Martha's Vineyard, just south of Stonewall, Nashaquitsa, and Menemsha Ponds in the town of Chilmark. The site is located within a morainal section of the island and the cobbles were produced in glacial streams and eroded further through wave action on the beach. The southern shore of the island experiences some of the highest rates of erosion on the coastline of the northeastern United States, retreating at a pace ranging from 0.5 to 3.0 m annually (Foster 2017; Kaye 1973; Ogden 1974). The current location of Stonewall Beach would have been hundreds of meters from the coast when Martha's Vineyard was sighted by Bartholomew Gosnold and his crew in 1607 as they explored the area. The eroded shoreline along Stonewall Beach is predominantly heterogeneous morainal deposits that contribute the fabric of the beach, but an exposed layer of peaty material extends for ~50 m along a low stretch in the western half of the beach, ~500 m to the southwest of Stonewall Pond (41.321025° N, 70.762465° W; Figure 3). The low area above the study site supports an extensive (~2.5 ha) sedge and shrub marsh, beyond which the land slopes upward into an area of shrubland, scattered trees, and summer homes.

The peat deposit extends from near the surface ~1 m down the 3 m erosional face. The heterogeneous composition includes peat layers, considerable amounts of wood and roots, and scattered large and occasionally intact tree branches and trunks (~25–30 cm in diameter). In December 2017, representative samples were removed from the largest two tree trunks, ~50 cm below the surface. In addition, three ~5 cm^3 samples were collected from the adjoining peat, just above the tree trunks (sample A), at the level of the trunks (sample B), and just below the trunks (sample C).

Subsamples of 100–200 mL from peat samples A–C were washed through a 250 μm sieve; the size fraction > 250 μm was inspected at 40× magnification with a dissecting microscope. Subsamples of the two large pieces of wood from the tree trunks (^{14}C samples 1 and 2) and a wood fragment sieved from peat sample A (^{14}C sample 3) were dated with accelerator mass spectrometry ^{14}C analysis at the National Ocean Sciences AMS Facility (Table 1). ^{14}C dates were calibrated using the IntCal20 calibration curve (Reimer et al. 2020) in CALIB 8.2 (Stuiver and Reimer 1993). To identify the species of the two large pieces of wood, a compound light microscope was used to examine thin sections of the wood along radial and transverse planes. Hand sections of the unmodified wood were taken along those planes from moistened surfaces using a high-carbon surgical steel blade. The sections were then stained using dilute safranin for enhanced lignin

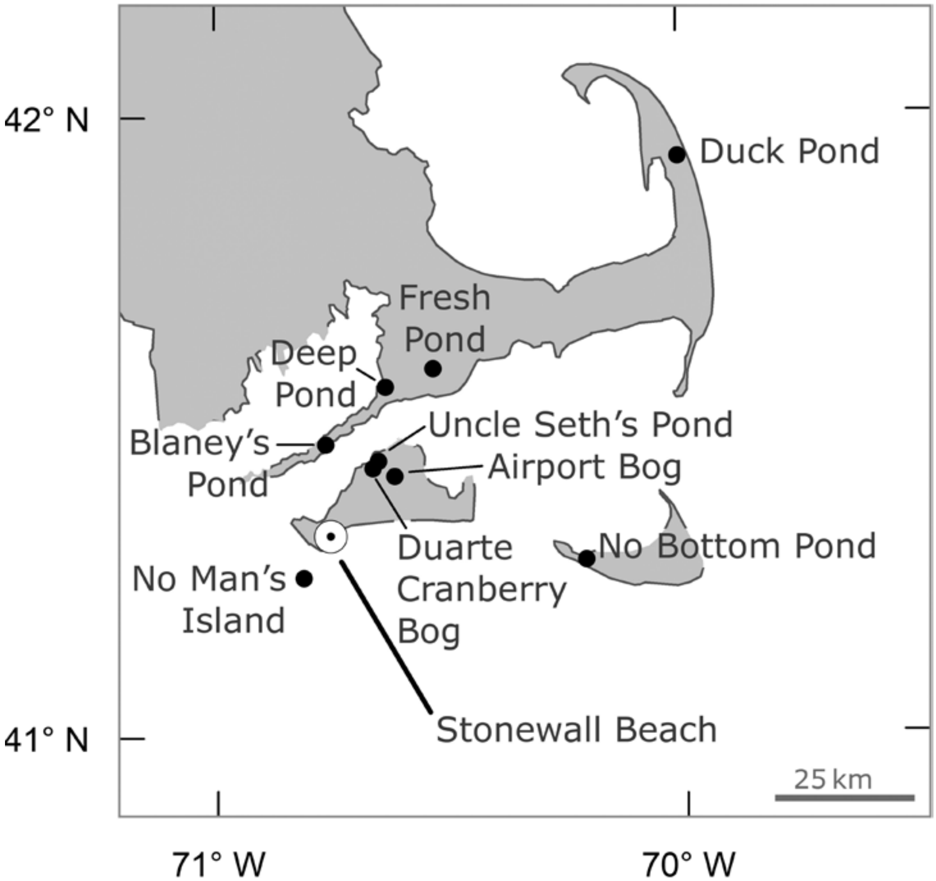

Figure 1. Map of southeastern Massachusetts showing the location of the Stonewall Beach study site on the island of Martha's Vineyard and other locations mentioned in the text.

contrast in imaging wood cell walls and/or with lactophenol aniline blue stain to enhance contrast in imaging of any fungal hyphae. Wood species determination then followed standard wood-identification protocols (Hoadley 1990; Panshin and de Zeeuw 1980), focusing on features such as the presence of resin canals, the pitting type in the rays, and the arrangement of bordered pits in the tracheids.

For peat samples A–C, subsamples of 1–2 cm^3 were prepared for pollen analysis following standard procedures (Fægri et al. 1989). Pollen residues were mounted in silicone oil and analyzed at 400× magnification using a compound light microscope. Pollen identification was aided by a regional key (McAndrews et al. 1973); *Pinus strobus* was differentiated from *P. banksiana* Lam./*P. rigida* Mill. based on the presence of distal verrucae. Pollen spectra from peat samples A−C were compared with pollen assemblages from Uncle Seth's Pond, a 13,400-year-long record from the north-central

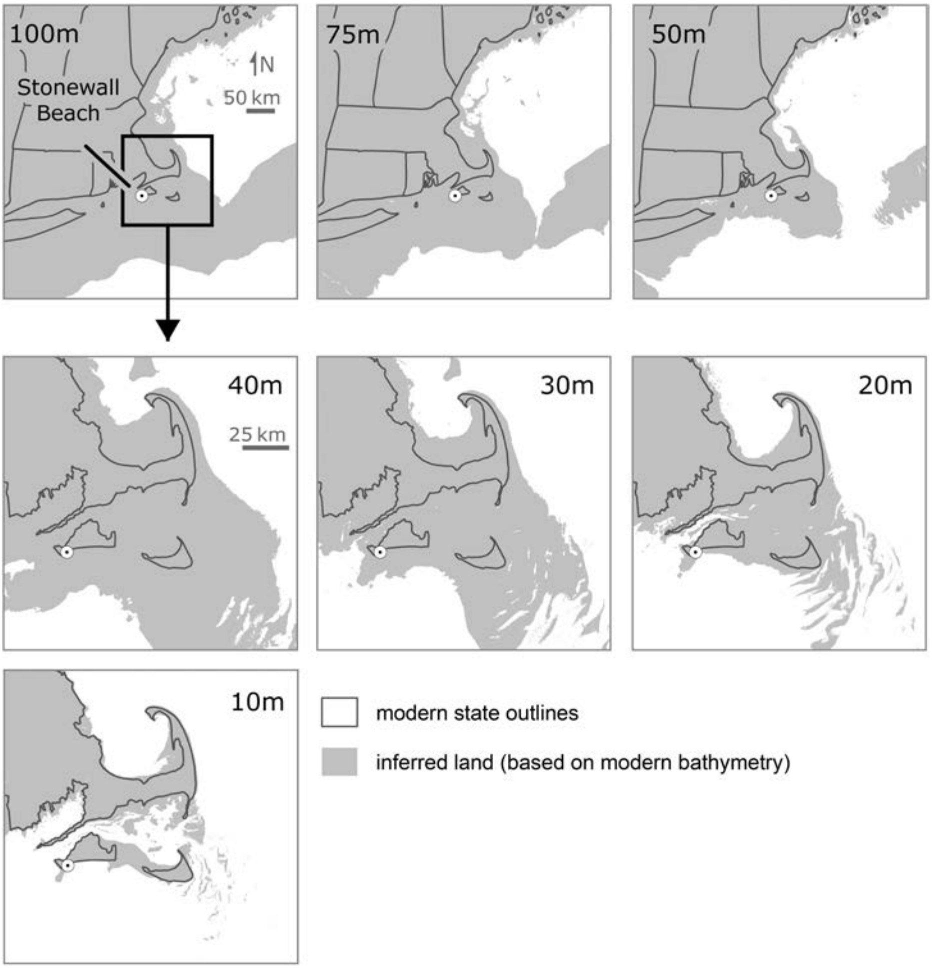

Figure 2. Maps of southern New England (top row) and southeastern Massachusetts (middle and bottom rows) showing the location of the Stonewall Beach study site and representing changes in sea level and geography of the coastline relative to modern bathymetry (i.e., 100–10 m below present-day sea level). These maps do not incorporate isostatic rebound, but they should nonetheless provide a reasonable approximation of the changing coastline of southern New England, including Martha's Vineyard, over the last ~15,000 years (Oakley and Boothroyd 2012). Based on sea-level reconstructions for southern New England (Gutierrez et al. 2003; Oakley and Boothroyd 2012; Oldale and O'Hara 1980; Redfield and Rubin 1962), the maps represent the following times: 100 m = ~15,000 cal yr BP; 75 m = ~14,000–13,000 cal yr BP; 50 m = ~13,000–12,000 cal yr BP; 40 m = ~12,000–11,000 cal yr BP; 30 m = ~10,000 cal yr BP (when *Pinus strobus* grew near the Stonewall Beach study site); 20 m = 9000 cal yr BP; 10 m = ~8000–6000 cal yr BP. Figure modified from Foster (2017).

Figure 3. Photos from Stonewall Beach, Martha's Vineyard, Massachusetts. **A.** Photo of study site (white arrow) on Stonewall Beach. **B.** Photo of study site showing the peat deposit with protruding tree trunks. **C.** Close-up photo of one of the tree trunks. **D.** Close-up photo of two of the tree trunks. Photos by David R. Foster.

part of Martha's Vineyard (Oswald et al. 2018), using the squared chord distance dissimilarity index (SCD) (Overpeck et al. 1985). Fourteen taxa were included in this analysis: *Picea*, *Pinus banksiana*/*Pinus rigida*, *Pinus strobus*, *Tsuga* (Endl.) Carrière, *Betula*, *Fagus* L., *Quercus*, *Carya* Nutt., *Acer* L., *Alnus* Mill., *Ilex* L., Myricaceae, Ericaceae, and Poaceae.

RESULTS AND DISCUSSION

The > 250 μm size fraction of the peat samples featured woody and herbaceous plant macrofossils, as well as remains of several aquatic organisms, including *Daphnia* O.F. Müll. ephippia (sample A), *Potamogeton* L. seeds (samples A and C), and *Chara* L. oogonia (sample C). The large pieces of wood were determined to be *Pinus strobus* based on characteristic softwood properties, including the gradual transition of the wood's growth rings and large and regular resin canals. Under the microscope, fenestriform pitting in the ray crossfields and uniseriate bordered pits on the radial tracheid walls also confirmed that the wood was *P. strobus*. The wood dated to 9802 cal yr BP and 10,679 cal yr BP (Table 1; Figure 4).

The pollen assemblages from peat samples A and B were dominated by *Pinus strobus* (~60%), with smaller abundances of various taxa, including *Betula*, *Quercus*, *Ilex*,

Table 1. ^{14}C dating results for Stonewall Beach, Martha's Vineyard, Massachusetts. Samples were analyzed at the National Ocean Sciences AMS (NOSAMS) Facility. $\delta^{13}C$ indicates the isotopic fractionation of ^{13}C to ^{12}C. ^{14}C dates are given with standard deviation. ^{14}C dates were calibrated (cal) with CALIB 8.2 (Stuiver and Reimer 1993).

^{14}C sample	Material dated	NOSAMS lab number	$\delta^{13}C$	^{14}C date ± 1σ error	Median cal age (2σ range)
1	Wood from tree trunk	OS-124842	−24.15	9450 ± 25	10,679 (10,581–10,757)
2	Wood from tree trunk	OS-124843	−24.34	8790 ± 25	9802 (9679–10,110)
3	Wood from peat sample A	OS-124844	−29.64	9170 ± 30	10,320 (10,241–10,483)

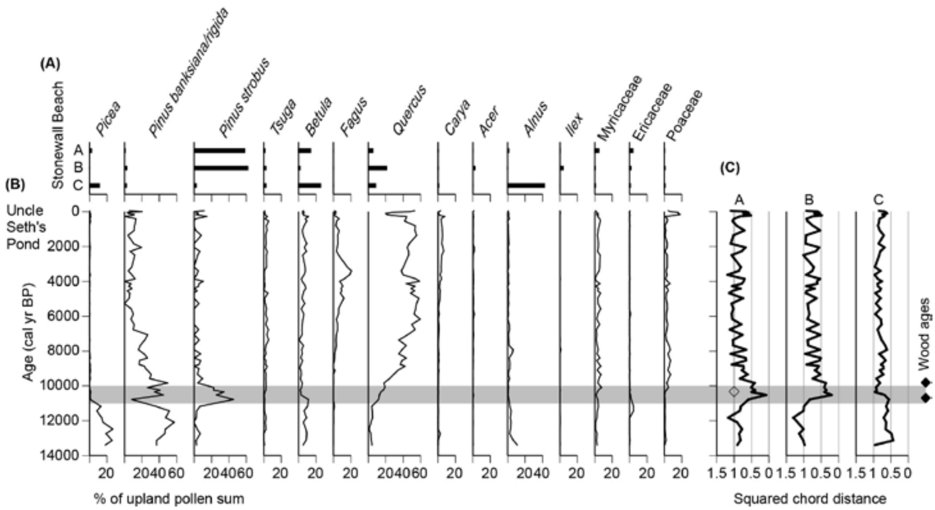

Figure 4. Paleoecological data from Martha's Vineyard, Massachusetts. **A.** Pollen assemblages from three peat samples (A, B, and C) from Stonewall Beach. **B.** Postglacial pollen record from Uncle Seth's Pond (Oswald et al. 2018). **C.** Comparison of the Stonewall Beach pollen assemblages (A, B, and C) and Uncle Seth's Pond pollen record (see y-axis in panel B for sample ages) with the squared chord distance dissimilarity index (Overpeck et al. 1985). Low values (i.e., right side of x-axis) reflect a high degree of similarity between the Stonewall Beach and Uncle Seth's Pond pollen assemblages. Open diamond shows the age of a wood fragment sieved from peat sample A (^{14}C sample 3); closed diamonds show the ages of wood samples from the tree trunks (^{14}C samples 1 and 2). The horizontal gray shading highlights the 11,000–10,000 cal yr BP interval dominated by *Pinus strobus* L.

Myricaceae, and/or Ericaceae (Figure 4). SCD values with the Uncle Seth's Pond pollen record were smallest (i.e., the assemblages were most similar) at ~10,500–9800 cal yr BP. The small piece of wood sieved from peat sample A (^{14}C sample 3) dated to 10,320 cal yr BP (Figure 4). The pollen assemblage from peat sample C had high abundances of *Alnus* (~40%), *Betula* (~25%), and *Picea* (~10%). Minimal SCD values for that sample occurred at ~13,100–12,700 cal yr BP (Figure 4).

The deposits exposed at Stonewall Beach appear to be a sequence of wetland sediments, with the basal materials dating to the late-glacial interval. The high abundance of *Alnus* pollen in sample C is consistent with high percentages of *Alnus* in pollen zone A4 (*sensu* Deevey 1939) in the nearby Squibnocket Cliff peat record, located ~2 km southwest of our study site (Ogden 1963), and with elevated *Alnus* across the region during the Younger Dryas interval (e.g., Levesque et al. 1993; Oswald et al. 2007; Peteet et al. 1993). Higher in the sequence, pollen data and ^{14}C results date the sediments to the early Holocene. During ~10,700–9800 cal yr BP, the site was dominated by *Pinus strobus*, but the forest also included *Quercus* and *Betula*, with an understory of *Ilex* and members of Myricaceae and Ericaceae. The trunks of the *P. strobus* trees featured some fungal deterioration and weathering on the surface, but the limited degree of decay suggests that the wood was protected from fungal degradation by rapid submergence in a shallow pond or wetland.

The percentages of *Pinus strobus* pollen in Stonewall Beach samples A and B (~60%) were higher than in the early-Holocene intervals of most other pollen records from the southern New England coast. For other Martha's Vineyard sites (Figure 1), *P. strobus* percentages were ~40% at Uncle Seth's Pond (Oswald et al. 2018), and total *Pinus* L. percentages were ~60% in both the Airport Bog and Duarte Cranberry Bog records (Ogden 1958, 1959); *Pinus* pollen was not identified to the species level at the latter two sites. Across the coastal area (Figure 1), early-Holocene *P. strobus* pollen percentages were ~30% at Duck Pond on outer Cape Cod (Winkler 1985), ~40% at Deep Pond and ~20% at Fresh Pond on inner Cape Cod (Oswald et al. 2018), ~20% at Blaney's Pond on Naushon Island (Oswald et al. 2018), and ~30% at No Bottom Pond on Nantucket (Dunwiddie 1990). Although *Pinus* pollen was not identified at the species level in a pollen record from No Man's Island (Benninghoff 1948), total *Pinus* pollen percentages were ~20% for the early Holocene. This variability in pollen records across the coastal region may reflect heterogeneity in the abundance of *P. strobus* on the landscape during the early Holocene. It may also be attributable to differences in basin sizes and thus pollen source areas of the study sites, as pollen records from small basins are dominated by nearby vegetation (e.g., Sugita 1994). *Pinus strobus* was locally present at the Stonewall Beach site, and therefore we should expect the sediments of a relatively small wetland to have high abundances of *P. strobus* pollen.

Our analyses date the *Pinus strobus* stand at Stonewall Beach to ~10,700–9800 cal yr BP, and a ^{14}C-dated cone from nearby Aquinnah suggests that *P. strobus* was present on this part of Martha's Vineyard until ~9000 cal yr BP (Ogden and Hay 1964). At the time of this *P. strobus* forest on Martha's Vineyard, sea levels were substantially lower than today, the island was still part of the mainland, and Stonewall Beach was an inland site, located several kilometers from the coast (Figure 2). *Pinus strobus*-dominated forest occurred across the entire region (Oswald et al. 2018), and climate was like that of present-day Minnesota, substantially drier than today (Deevey 1939; Shuman and Marsicek 2016). Climate became wetter during ~10,000–8000 cal yr BP, resulting in a shift in dominance from *P. strobus* to *Quercus* across southern New England (Oswald et al. 2018). *Pinus strobus* was apparently absent from Martha's Vineyard throughout the middle and late Holocene, and it occurs on the island today thanks to its purposeful re-introduction during the last few centuries.

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