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Short Paper

A record of late-Holocene environmental change from southern New England, USA

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ABSTRACT

Analyses of a sediment core from Little Pond, located in the town of Bolton, Massachusetts, provide new insights into the history of environmental and ecological changes in southern New England during the late Holocene. Declines in organic content and peaks in the abundance of *Isoetes* spores indicate reduced water depth at 2900–2600, 2200–1800, and 1200–800 calibrated years before present (cal yr BP), generally consistent with the timing of dry conditions in records from elsewhere in the northeastern United States. The Little Pond pollen record features little change over the last 3000 yr, indicating that the surrounding vegetation was relatively insensitive to these periods of drought. The 1200–800 cal yr BP dry interval, however, coincides with increased abundance of *Castanea* pollen, suggesting that the expansion of *Castanea* in southern New England may have been influenced by late-Holocene climatic variability.

Introduction

Records of late-Holocene environmental change (1) place the climatic variations of recent centuries into long-term context (e.g., Mann et al., 1998; Mann and Jones, 2003; Jones and Mann, 2004; Kaufman et al., 2009), (2) can be used to explore the links between environmental and cultural changes (e.g., Haug et al., 2003; Benson et al., 2007), and (3) help us understand how climatic variability drives century-scale ecological change (e.g., Gavin et al., 2006; Shuman et al., 2009a). Detailed records of climate spanning the past few millennia are relatively abundant in certain regions of eastern North America (Fig. 1), including the Great Lakes region (e.g., Booth and Jackson, 2003; Booth et al., 2004, 2006) and the Chesapeake Bay region (e.g., Cronin et al., 2000, 2003; Willard et al., 2003), but the late-Holocene climatic history of the northeastern USA ("the Northeast") is not as well understood.

Existing paleoenvironmental data from the Northeast provide limited insight into late-Holocene climatic variations. Pollen records from northern New England and southeastern Canada feature increasing abundance of *Picea* (spruce) during the last ~2000 yr (e.g., Webb et al., 1983; Spear, 1989; Shuman et al., 2005), and temperature reconstructions estimated from pollen data from across the region indicate progressive cooling over the last two millennia (Gajewski, 1988). At sites along the Massachusetts coast, higher *Pinus* (pine) abundance and reduced charcoal influx after ~1500 calibrated years before present (cal yr BP) may reflect cooler, moister conditions (Winkler, 1985; Foster et al., 2002; Parshall et al., 2003). On the other hand, sand layers dated to 2500–1800, 1600–1300, and 1200–600 cal yr BP in the sediments of New Long Pond, located in southeastern Massachusetts (Fig. 1), are interpreted as indicating dry conditions (Shuman et al., 2009b; Newby, 2010), as are elevated charcoal and *Pinus* abundance ~1200–600 cal yr BP in a record from Piermont Marsh (Fig. 1) in the lower Hudson Valley, New York (Pederson et al., 2005). Declining abundances of *Fagus* (beech) and *Tsuga* (hemlock) at ~600–500 cal yr BP in pollen records from across the Northeast have been interpreted as a response in forest composition to cooler and/or drier conditions during the Little Ice Age (Gajewski, 1987; Campbell and McAndrews, 1993; Fuller et al., 1998). With the exception of the New Long Pond record (Shuman et al., 2009b; Newby, 2010), few non-pollen proxies have been available to test and refine these interpretations.

In this paper we present a late-Holocene sedimentary record from a small pond located in eastern Massachusetts. The pollen data for the site for the most recent 1000 yr appeared in a previous study (Fuller et al., 1998). New analyses of sediment organic content and pollen, particularly spores derived from aquatic vegetation, yield an improved understanding of climatic shifts in the Northeast since ~3000 cal yr BP. Comparison of the record with evidence from other parts of eastern North America shows how the late-Holocene history of the Northeast relates to that of other regions.

Study area

This area of southern New England is located in the hardwood-*Pinus strobus*–*Tsuga canadensis* (white pine-eastern hemock) forest

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Figure 1. Map showing locations of Little Pond (this study), New Long Pond (Shuman et al., 2009b; Newby, 2010), Piermont Marsh (Pederson et al., 2005), Chesapeake Bay (e.g., Cronin et al., 2003), Lac Hertel (Muller et al., 2003), Hole Bog, and Minden Bog (Booth et al., 2006).

zone (Spurr, 1956; Westveld, 1956). Important hardwood trees include *Quercus rubra* (northern red oak), *Q. alba* (white oak), *Q. velutina* (black oak), *Acer rubrum* (red maple), *A. saccharum* (sugar maple), *Betula alleghaniensis* (yellow birch), *B. papyrifera* (paper birch), *B. lenta* (black birch), and *Fagus grandifolia* (American beech). *Pinus strobus* and *Tsuga canadensis* are also common. Most of southern New England has reforested since agricultural abandonment in the mid-nineteenth century (Hall et al., 2002). Eastern Massachusetts is characterized by cold winters (mean January temperature is −4°C at Bedford, Massachusetts, for example) and warm summers (mean July temperature is 22°C). Mean annual precipitation is 110 cm, distributed relatively evenly throughout the year (Easterling et al., 1996).

Little Pond (42.4223°N, 71.5877°W, 99 m elevation) is located in the town of Bolton, Massachusetts (Fig. 1). The 5.0-ha, 3.2-m-deep pond has a single outlet that flows south towards the Assabet River. The 32-ha watershed is mainly wooded at present, with some residential development and a summer camp along the shoreline.

Methods

A 1100-cm-long sediment core was collected from Little Pond in September 1994. The upper sediments, including an undisturbed sediment-water interface, were collected with a plastic tube fitted with a piston. The surface core was extruded vertically in the field in 1-cm segments. Lower sediments were raised in 1-m drive lengths using a modified Livingstone piston sediment sampler (Wright et al., 1984). Those core segments were extruded horizontally in the field and wrapped in plastic and aluminum foil. All samples were subsequently refrigerated.

For this study we analyzed the upper ~170 cm of the Little Pond core. The age–depth model is based on ^{210}Pb analysis of recent sediments (Binford, 1990), pollen evidence for European settlement, and accelerator mass spectrometry ^{14}C analysis of bulk-sediment samples (Table 1). ^{14}C dates were converted to calibrated years before present (cal yr BP) using the IntCal09 calibration curve in CALIB 5.0 (Stuiver and Reimer, 1993; Reimer et al., 2009). Sediment organic content was estimated for 1-cm^3 samples at selected depths by percent weight loss-on-ignition (LOI) at 550°C. Sediment samples of 1–2 cm^3 were prepared for pollen analysis following standard procedures (Faegri and Iversen, 1989), and tablets containing *Lycopodium* spores were added to the samples to estimate pollen and spore concentrations (Stockmarr, 1971). Pollen residues were mounted in silicone oil and analyzed at 400× magnification. At least 500 pollen grains and spores of upland plant taxa were counted for each sample, and pollen percentages were calculated relative to that sum.

Table 1
Chronological data for the Little Pond sediment core.

Type	Depth (cm)	^{14}C lab code	δ^{13}C (‰)	^{14}C date ^{14}C (yr BP)	Cal age range (2σ) (cal yr BP)	Age* (cal yr BP)
Surface	0–1					−44
^{210}Pb**	12–13					76
ESH***	52–53					268
^{14}C	58–62	Beta-097596	−28.8	930±80	689–969	843
	74–78	Beta-097597	−29.1	920±60	699–935	838
	88–92	Beta-097598	−28.2	1300±60	1074–1306	1224
	167–168	AA-57236	−26.3	2880±30	2887–3141	3009

*Median calibrated age for ^{14}C dates; **Oldest of 11 ^{210}Pb age assignments; ***ESH = European settlement horizon; ^{14}C date for 58–62 cm not used in age–depth model.

Results

The upper ~170 cm of the Little Pond sediment core spans ~3000 yr (Table 1; Fig. 2). The age–depth model differs slightly from that presented by Fuller et al. (1998) but maintains an increase in the rate of sedimentation at the depth of European settlement. Sediment organic content varies between ~25% and 45%, with low values dating to 2900–2600, 2200–1800, and 1200–800 cal yr BP (Fig. 3). Pre-settlement pollen assemblages are dominated by *Quercus* (40–50%), with lower percentages of *Fagus*, *Betula*, *Tsuga*, *Pinus*, *Ulmus* (elm), *Carya* (hickory), *Fraxinus* (ash), *Acer*, and *Alnus* (alder; Fig. 3). The pollen record features little change, with the exception of an increase in *Castanea* (chestnut) pollen percentages to >3% at ~1000 cal yr BP. European forest clearance and agricultural activities of the eighteenth and nineteenth centuries are marked by declining organic content, reduced abundance of tree pollen, and elevated percentages of Poaceae (grass) and *Ambrosia* (ragweed). Spore concentrations of *Isoetes* (quillwort), an emergent aquatic plant, exhibit pronounced fluctuations, with major peaks at ~2000 and 1000 cal yr BP coinciding with two of the intervals of low organic content (Fig. 3).

Discussion

Late-Holocene environmental changes in the northeastern USA

The sedimentary record from Little Pond provides new insight into climatic variations in the Northeast over the last few millennia. The

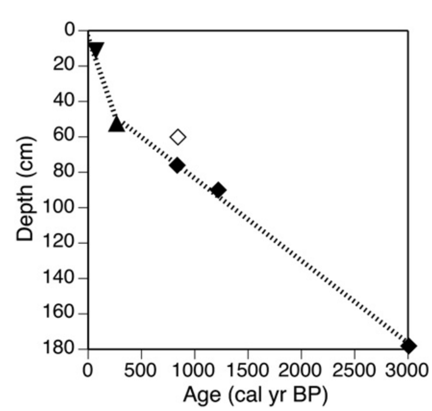

Figure 2. Age–depth relationship for the sediment core from Little Pond. Inverted triangle = oldest of 11 ^{210}Pb age assignments; triangle = European settlement horizon; diamonds = ^{14}C dates; open diamond (60 cm) not used in age–depth model.

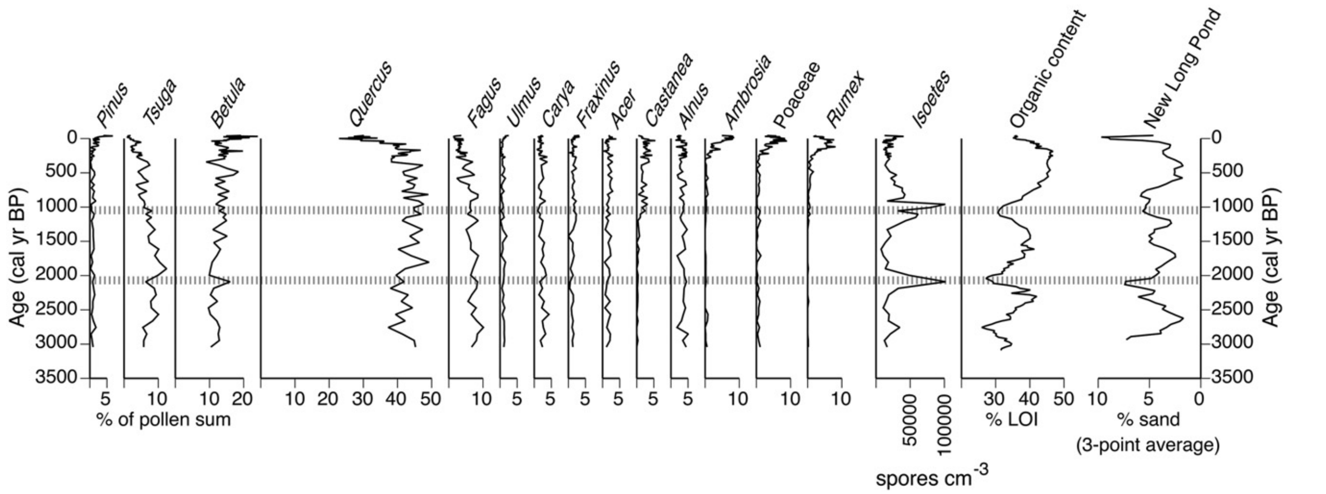

Figure 3. Pollen percentage diagram for selected taxa in the Little Pond record. Also shown are concentrations (spores cm^{-3}) for *Isoetes*, organic content (percent loss-on-ignition; %LOI), and % sand in the New Long Pond record from southeastern Massachusetts (Fig. 1; Shuman et al., 2009b; Newby, 2010).

organic content of sediments of New England ponds similar in size to the study site has been shown to vary in response to water depth: shallow, littoral sediments are likely to be lower in organic content than those in the deeper, central areas of lake basins (Shuman, 2003). Given that relationship, we interpret the intervals of low organic content dating to 2900–2600, 2200–1800, and 1200–800 cal yr BP as most likely to represent periods of reduced water depth associated with dry climatic conditions. The abundance of *Isoetes* spores in sediments has been interpreted in various ways (e.g., van der Hammen and Cleef, 1986; Horn, 1993; Sifeddine et al., 1996), but the close correspondence of *Isoetes* with organic content suggests that, in the Little Pond record, it also reflects changes in water depth. It is likely that as the lake became shallower, *Isoetes* was able to colonize exposed lakeshores and shallow littoral zones, and its larger populations were in closer proximity to the coring site in the center of the pond (Horn, 1993). The shift to higher organic content at ~800–600 cal yr BP probably represents higher effective moisture at the beginning of the Little Ice Age.

The evidence for dry conditions at 1200–800 cal yr BP at Little Pond is consistent with other records from New England and elsewhere in North America. 1200–800 cal yr BP is well known as an interval of widespread drought, with evidence for dry conditions in the Northeast (Pederson et al., 2005; Shuman et al., 2009b; Newby, 2010), the Great Lakes region (Booth et al., 2006), Chesapeake Bay (e.g., Brush, 1986; Cronin et al., 2003; Willard et al., 2003), the southeastern USA (e.g., Stahle et al., 1988), the Great Plains (Dean, 1997; Forman et al., 2001; Yu et al., 2002; Goble et al., 2004; Mason et al., 2004; Shapley et al., 2005), and the western USA (e.g., Cook et al., 2004). The inferred dry conditions at 2900–2600 and 2200–1800 cal yr BP, on the other hand, are less consistent with droughts observed in records from other parts of eastern North America. The Little Pond drought events span intervals of lowered lake level at New Long Pond in southeastern Massachusetts (2500–1800 cal yr BP; Shuman et al., 2009b; Newby, 2010) and Lac Hertel (Fig. 1) in the St. Lawrence lowlands, southern Quebec (2600–1800 cal yr BP; Muller et al., 2003), but do not match dry conditions at 1600–1300 cal yr BP at New Long Pond and 1850–1650 cal yr BP at Hole Bog and Minden Bog (Fig. 1) in the western Great Lakes region (Booth et al., 2006).

Over the last century, drought across the continental USA has been associated with cool sea-surface temperatures (SSTs) in the tropical and eastern Pacific Ocean and warm SSTs in the North Atlantic (Enfield et al., 2001; McCabe et al., 2004, 2008; Booth et al., 2006), with a restricted area of cool SSTs off the east coast of North America from Virginia northward (Booth et al., 2006). Cool SSTs along the Northeast have been linked to an intense drought that occurred in New England during AD 1962–1965 (Namias, 1966), and the dry intervals of the late Holocene may have been associated with those types of conditions in the North Atlantic.

Forest responses to late-Holocene climatic variations

The postglacial history of the Northeast is characterized by several major shifts in vegetation composition in response to changes in climate (e.g., Shuman et al., 2009b), but despite evidence for intervals of dry conditions at 2900–2600, 2200–1800, and 1200–800 cal yr BP, there do not appear to be pronounced changes in the Little Pond pollen record for the past ~3000 yr. This may be attributable to the insensitivity of this vegetation assemblage to a few centuries of dry conditions, and to the fact that these late-Holocene climatic variations were not as dramatic as those that occurred in New England during the early and middle Holocene (e.g., Shuman et al., 2009b; Newby, 2010). On the other hand, the increased abundance of *Castanea* in the Little Pond pollen record at ~1000 cal yr BP appears to coincide with the most recent period of dry climate (Fig. 3). The expansion of *Castanea* across southern New England was time-transgressive (e.g., Shuman et al., 2009b), and it is unclear whether dry conditions aided its increase at Little Pond or simply happened to occur as *Castanea* arrived in this area of eastern Massachusetts. In either case, our findings are inconsistent with those of Shuman et al. (2009b), who attributed gaps in chestnut establishment, including at 2500–1100 cal yr BP, to periods of dry conditions. In the Little Pond record, where we can compare climate and vegetation proxies in the same core, it appears that *Castanea* was able to expand during an interval of drought.

Subtle increases in the pollen of mesic taxa, including *Tsuga*, *Fagus*, and *Picea*, in the Piermont Marsh pollen record from the lower Hudson Valley, New York, have been interpreted as indicating cooler, moister conditions during the Little Ice Age (Pederson et al., 2005). In pollen records from north-central Massachusetts, however, *Tsuga* and *Fagus* decline at ~600–500 cal yr BP, leading Fuller et al. (1998) to suggest that conditions became drier at that time. The rise in organic content and corresponding decline in *Isoetes* in the Little Pond record at the onset of the Little Ice Age are indicative of rising water levels, but we are unable to differentiate between increasing precipitation and decreasing evaporation. Taken together, the various lines of evidence may indicate a shift in the seasonality of precipitation, with drier conditions during the growing season, to the detriment of the mesic tree taxa, and with wetter winters and/or cooler mean annual temperatures accounting for the deeper lake levels.

Conclusions

The sedimentary record from Little Pond reveals late-Holocene environmental changes in eastern Massachusetts generally consistent with those observed elsewhere in the Northeast (e.g., Pederson et al., 2005; Shuman et al., 2009b; Newby, 2010) and matches some, but not all, features of late-Holocene climate in other regions of eastern North America (e.g., Muller et al., 2003; Booth et al., 2006). Declines in organic content and peaks in the abundance of *Isoetes* spores indicate dry conditions at 2900–2600, 2200–1800, and 1200–800 cal yr BP. The surrounding vegetation was relatively insensitive to these intervals of drought, although the expansion of *Castanea* in the vicinity of Little Pond coincided with the dry conditions at 1200–800 cal yr BP. Future studies of the late-Holocene climate history of the Northeast could build upon this work by exploring even finer-scale environmental changes (e.g., Booth et al., 2006), and by further investigating human and ecological responses to the climatic variations of the last few millennia.

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References

Benson, L.V., Berry, M.S., Jolie, E.A., Spangler, J.D., Stahle, D.W., Hattori, E.M., 2007. Possible impacts of early-11th-, middle-12th-, and late-13th-century droughts on western Native Americans and the Mississippian Cahokians. Quaternary Science Reviews 26, 336–350.

Binford, M.W., 1990. Calculation and uncertainty analysis of ^{210}Pb dates for PIRLA project cores. Journal of Paleolimnology 3, 253–267.

Booth, R.K., Jackson, S.T., 2003. A high-resolution record of late-Holocene moisture variability from a Michigan raised bog, USA. The Holocene 13, 863–876.

Booth, R.K., Jackson, S.T., Gray, C.E.D., 2004. Paleoecology and high-resolution paleohydrology of a kettle peatland in upper Michigan. Quaternary Research 61, 1–13.

Booth, R.K., Notaro, M., Jackson, S.T., Kutzbach, J.E., 2006. Widespread drought episodes in the western Great Lakes region during the past 2000 years: geographic extent and potential mechanisms. Earth and Planetary Science Letters 242, 415–427.

Brush, G.S., 1986. Patterns of recent sediment accumulation in Chesapeake Bay (Virginia–Maryland U.S.A.) tributaries. Chemical Geology 44, 227–242.

Campbell, I.D., McAndrews, J.H., 1993. Forest disequilibrium caused by rapid Little Ice Age cooling. Nature 366, 336–338.

Cook, E.R., Woodhouse, C., Meko, D.M., Stahle, D.W., 2004. Long-term aridity changes in the western United States. Science 306, 1015–1018.

Cronin, T., Willard, D., Karlsen, A., Ishman, S., Verardo, S., McGeehin, J., Kerhin, R., Holmes, C., Colman, S., Zimmerman, A., 2000. Climatic variability in the eastern United States over the past millennium from Chesapeake Bay sediments. Geology 28, 3–6.

Cronin, T.M., Dwyer, G.S., Kamiya, T., Schwede, S., Willard, D.A., 2003. Medieval Warm Period, Little Ice Age and 20th century temperature variability from Chesapeake Bay. Global and Planetary Change 36, 17–29.

Dean, W.E., 1997. Rates, timing, and cyclicity of Holocene eolian activity in north-central United States: evidence from varved lake sediments. Geology 25, 331–334.

Easterling, D.R., Karl, T.R., Mason, E.H., Hughes, P.Y., Bowman, D.P., 1996. United States Historical Climatology Network (US HCN) Monthly Temperature and Precipitation Data, ORNL/CDIAC-87. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge.

Enfield, D.B., Mestas-Nunez, A.M., Trimble, P.J., 2001. The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental U.S. Geophysical Research Letters 28, 2077–2080.

Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis, Fourth edition. John Wiley and Sons, Chichester.

Forman, S.L., Oglesby, R., Webb, R.S., 2001. Temporal and spatial patterns of Holocene dune activity on the Great Plains of North America: megadroughts and climate links. Global and Planetary Change 29, 1–29.

Foster, D.R., Hall, B., Barry, S., Clayden, S., Parshall, T., 2002. Cultural, environmental, and historical controls of vegetation patterns and the modern conservation setting on the island of Martha's Vineyard, USA. Journal of Biogeography 29, 1381–1400.

Fuller, J.L., Foster, D.R., McLachlan, J.S., Drake, N., 1998. Impact of human activity on regional forest composition in central New England. Ecosystems 1, 76–95.

Gajewski, K., 1987. Climatic impacts on the vegetation of eastern North America for the past 2000 years. Vegetatio 68, 179–190.

Gajewski, K., 1988. Late Holocene climate changes in eastern North America estimated from pollen data. Quaternary Research 29, 255–262.

Gavin, D.G., Hu, F.S., Lertzman, K.P., Corbett, P., 2006. Weak climatic control of forest fire history during the late Holocene. Ecology 87, 1722–1732.

Goble, R.J., Mason, J.A., Loope, D.B., Swinehart, J.B., 2004. Optical and radiocarbon ages of stacked paleosols and dune sands in the Nebraska Sand Hills, USA. Quaternary Science Reviews 23, 1173–1182.

Hall, B., Motzkin, G., Foster, D.R., Syfert, M., Burk, J., 2002. Three hundred years of forest and land-use change in Massachusetts, USA. Journal of Biogeography 29, 1319–1335.

Haug, G.H., Gunther, D., Peterson, L.C., Sigman, D.M., Hughen, K.A., Aeschlimann, B., 2003. Climate and the collapse of Maya civilization. Science 299, 1731–1735.

Horn, S.P., 1993. Postglacial vegetation and fire history in the Chirripo Paramo of Costa Rica. Quaternary Research 40, 107–116.

Jones, P.D., Mann, M.E., 2004. Climate over past millennia. Review of Geophysics 42 (RG2002).

Kaufman, D.S., Schneider, D.P., McKay, N.P., Ammann, C.M., Bradley, R.S., Briffa, K.R., Miller, G.H., Otto-Bliesner, B.L., Overpeck, J.T., Vinther, B.M., Arctic Lakes 2k Project Members, 2009. Recent warming reverses long-term Arctic cooling. Science 325, 1236–1239.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1998. Global-scale temperature patterns and climate forcing over the past six centuries. Nature 392, 779–787.

Mann, M.E., Jones, P.D., 2003. Global surface temperatures over the past two millennia. Geophysical Research Letters 30, 1820.

Mason, J.A., Swinehart, J.B., Goble, R.J., Loop, D.B., 2004. Late-Holocene dune activity linked to hydrological drought, Nebraska Sand Hills, USA. The Holocene 14, 209–217.

McCabe, G.J., Palecki, M., Betancourt, J.L., 2004. Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. Proceedings of the National Academy of Sciences 101, 4136–4141.

McCabe, G.J., Betancourt, J.L., Gray, S.T., Palecki, M.A., Hidalgo, H.G., 2008. Associations of multi-decadal sea-surface temperature variability with US drought. Quaternary International 188, 31–40.

Muller, S.D., Richard, P.J.H., Guiot, J., de Beaulieu, J.-L., Fortin, D., 2003. Postglacial climate in the St. Lawrence lowlands, southern Quebec: pollen and lake-level evidence. Palaeogeography, Palaeoclimatology, Palaeoecology 193, 51–72.

Namias, J., 1966. Nature and possible causes of the northeastern United States drought during 1962–1965. Monthly Weather Reviews 94, 543–554.

Newby, P.E., 2010. Evidence of Late Pleistocene and Holocene Centennial-Scale Drought from Southeastern Massachusetts. PhD thesis, Brown University, Providence.

Parshall, T., Foster, D.R., Faison, E., MacDonald, D., Hansen, B.C.S., 2003. Long-term history of vegetation and fire in pitch pine-oak forests on Cape Cod, Massachusetts. Ecology 84, 736–748.

Pederson, D.C., Peteet, D.M., Kurdyla, D., Guilderson, T., 2005. Medieval Warming, Little Ice Age, and European impact on the environment during the last millennium in the lower Hudson Valley, New York, USA. Quaternary Research 63, 238–249.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk, Ramsey C., Buck, C.E., Burr, G., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J., Turney, C.S.M., van der Plicht, J., Weyhenmeyer, C., 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51, 1111–1150.

Shapley, M.D., Johnson, W.C., Engstrom, D.R., Osterkamp, W.R., 2005. Late-Holocene flooding and drought in the northern Great Plains, USA, reconstructed from tree rings, lake sediments and ancient shorelines. The Holocene 15, 29–41.

Shuman, B., 2003. Controls on loss-on-ignition variation in cores from two shallow lakes in the northeastern United States. Journal of Paleolimnology 30, 371–385.

Shuman, B., Newby, P., Donnelly, J.P., Tarbox, A., Webb III, T., 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., Henderson, A.K., Plank, C., Stefanova, I., Ziegler, S.S., 2009a. Woodland-to-forest transition during prolonged drought in Minnesota after ca. AD 1300. Ecology 90, 2792–2807.

Shuman, B.N., Newby, P., Donnelly, J.P., 2009b. 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.

Sifeddine, A., Bertrand, P., Lallier-Verges, E., Patience, A.J., 1996. Lacustrine organic fluxes and palaeoclimatic variations during the last 15 ka: Lac du Bouchet (Massif Central, France). Quaternary Science Reviews 15, 203–211.

Spear, R.W., 1989. The late Quaternary history of high-elevation vegetation in the White Mountains of New Hampshire. Ecological Monographs 59, 125–151.

Spurr, S.H., 1956. Forest associations in the Harvard Forest. Ecological Monographs 26, 245–262.

Stahle, D.W., Cleveland, M.K., Hehr, J.G., 1988. North Carolina climate change reconstructed from tree rings: A.D. 372 to 1985. Science 240, 1517–1519.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13, 615–621.

Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon 35, 215–230.
van der Hammen, T., Cleef, A.M., 1986. Development of the high Andean paramo flora and vegetation. In: Vuilleumier, F., Monasterio, M. (Eds.), High Altitude Biogeography. Oxford University Press, New York, pp. 153–201.
Webb III, T., Richard, P., Mott, R.J., 1983. A mapped history of Holocene vegetation in southern Quebec. Syllogeus 49, 273–336.
Westveld, M., 1956. Natural forest vegetation zones of New England. Journal of Forestry 54, 332–338.
Willard, D.A., Cronin, T.M., Verardo, S., 2003. Late-Holocene climate and ecosystem history from Chesapeake Bay sediment cores, USA. The Holocene 13, 201–214.
Winkler, M.G., 1985. A 12,000-year history of vegetation and climate for Cape Cod, Massachusetts. Quaternary Research 23, 301–312.
Wright Jr., H.E., Mann, D.H., Glaser, P.H., 1984. Piston corers for peat and lake sediments. Ecology 65, 657–659.
Yu, Z., Ito, E., Engstrom, D.R., Fritz, S.C., 2002. A 2100-year decadal-resolution trace-element and stable-isotope record from Rice Lake in the northern Great Plains, USA. The Holocene 12, 605–617.