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Late Holocene climate-induced forest transformation and peatland establishment in the central Appalachians

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ABSTRACT

Understanding the potential for ecosystem transformation and community change in response to climate variability is central to anticipating future ecological changes, and long-term records provide a primary source of information on these dynamics. We investigated the late Holocene history of upland forest and peatland development at Cranesville Swamp, a peatland located along the West Virginia–Maryland border in the USA. Our primary goal was to determine whether establishment of peatland was triggered by moisture variability, similar to recent developmental models derived from depressional peatlands in glaciated regions. Results indicate that the peatland established at about 1200 cal yr BP, and was associated with a dramatic and persistent change in upland forest composition. Furthermore, timing of these upland and wetland ecological changes corresponded with evidence for multidecadal drought and enhanced moisture variability from nearby tree-ring and speleothem climatic reconstructions. Our results add to a growing body of research highlighting the sensitivity of both peatland development and upland forest communities to transient drought and enhanced moisture variability, and suggest that enhanced moisture variability in the future could increase the probability of similarly abrupt and persistent ecological change, even in humid regions like eastern North America.

Introduction

Concerns over potential ecosystem responses to ongoing and future climate change have motivated recent efforts to better understand climate–ecosystem interactions (e.g., Jackson and Hobbs, 2009; Dawson et al., 2011; Dietl and Flessa, 2011). These efforts have renewed interest in paleoecology as an approach to empirically test hypotheses about long-term ecological responses to climate variability and provide information on ecosystem responses to climatic events lacking modern analogues. Such retrospective studies can be especially useful in understanding the likelihood and dynamics of rapid, ecosystem transformations, which are particularly hard to forecast and may occur in response to rare, but extreme forcing events, such as multi-decadal droughts (Scheffer et al., 2001; Foley et al., 2003; Scheffer et al., 2009; Shuman et al., 2009; Dodds et al., 2010; Ireland and Booth, 2011; Ireland et al., 2012). Understanding the likelihood of such events in response to climatic extremes and variability can provide important context for ecosystem management, climate-change preparedness, and adaptation (Folke et al., 2004; Groffman et al., 2006; Dodds et al., 2010; Gillson and Marchant, 2014).

Paleoecological studies provide a primary source of information on climate–ecosystem dynamics, and have significantly advanced our understanding of the climate sensitivity of a range of community and ecosystem types (Gray et al., 2006; Jackson et al., 2009; Shuman et al., 2009; Booth et al., 2012; Clifford and Booth, 2015). For example, until recently, population- and community-level changes within the eastern deciduous forest of North America were thought to result primarily from the cumulative effects of fine-scale, individual tree mortality events with stochastic timing (Runkle, 1982). However, paleoecological studies indicate that climate variability and climate-induced disturbance played an important role in shaping forest structure and species composition during the Holocene (Jackson and Booth, 2002; Shuman et al., 2004; Gray et al., 2006; Shuman et al., 2009; Booth et al., 2012; Clifford and Booth, 2015). Tree ring records from the last several centuries further support this view (Pederson et al., 2014) and can potentially increase the precision of timing estimates for changes observed in sediment-based paleoecological records. Similar observations have also been made in peatland ecosystems, where paleoecological studies have revealed linkages between climatic variability and step-wise peatland establishment and expansion patterns. Evidence for abrupt and rapid episodes of peatland expansion in response to transient climatic events is causing a reevaluation of classic models of hydroseral succession as it is commonly portrayed in textbooks (Ireland et al., 2012; Ricklefs and Relyea, 2014).

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Peatlands are well suited to studying historic ecosystem responses to climate variability because they record their own developmental history as well as changes in community composition of the surrounding terrestrial forest within their stratigraphy. Furthermore, peatlands provide valuable ecosystem services, including maintenance of regional biodiversity, natural water filtration and flood abatement, and, importantly, long-term carbon sequestration (Zedler and Kercher, 2005). *Sphagnum*-dominated peatlands are especially important sources of biodiversity because the nutrient-poor conditions provide unique habitat for many locally rare plant species, especially when these peatlands occur in relative isolation from more northerly peat-rich regions (Francl, 2003). Traditionally, peatland development in landscape depressions has been viewed as a gradual, climate-independent process whereby peatland vegetation colonizes lake margins and gradually extends inward across an open-water body over many millennia (e.g., Tallis, 1973; Kratz and DeWitt, 1986; Wilcox and Simonin, 1988; Anderson et al., 2003; Ireland et al., 2012). However, this autogenic developmental model has been questioned for lacking strong empirical support and recent research in glaciated landscapes of North America has revealed that peatland establishment and expansion in these systems is an episodic, non-linear process, likely driven by hydrological variability (Ireland and Booth, 2011; Ireland et al., 2012, 2013). Under this allogenic model, drought events lead to shallow water or exposed, moist sediments that are available for colonization by peatland plants. Subsequent rises in water level lead to floatation of buoyant peat mats. Ireland et al. (2013) noted the importance of moisture variably, including both drought and pluvial conditions in driving the process and pattern of peatland establishment within basins of glaciated landscapes. However, it is unclear whether similar mechanisms and dynamics characterize peatland development in depressional ecosystems in unglaciated regions. Understanding linkages between climatic processes and peatland development are particularly important in southerly locations along the margin of more continuous peatland distribution, because peatlands may be more vulnerable to ongoing and future climate changes in these areas.

In this study, we reconstructed the late Holocene developmental history of Cranesville Peatland in West Virginia, USA as well as the vegetation history of the surrounding upland forest. Our primary goal was to determine whether establishment of peatland in the basin was triggered by moisture variability, similar to recently documented patterns in the western and central Great Lakes region (Ireland and Booth, 2011; Ireland et al., 2013). To do this, we compared (1) the timing and characteristics of pollen-inferred upland forest changes with the timing of sediment and plant-macrofossil indicators of peatland establishment and (2) the timing of peatland establishment and forest changes in our records to nearby paleoclimate records of moisture variability derived from both speleothems and tree rings.

Methods

Study site

This study was conducted at Cranesville Peatland (39.535°N, 79.481° W), commonly referred to as Cranesville Swamp, a 225-ha, peatland complex located along the West Virginia–Maryland border (Venable, 1991; Francl, 2003). From 1895 to 2012, regional January and July air temperatures averaged −0.5 and 22.9°C, respectively, while annual precipitation averaged 900 mm (U.S. Climate Division WV 6; http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl). The peatland surface is at an elevation of 778 m above sea level, roughly 100 m below the surrounding uplands (Venable, 1991). The underlying geology is composed of sedimentary rocks of the Greenbrier Group, which consists of mixed sandstone, shale, and limestone, and the basin containing the peatland is not of glacial origin (Francl, 2003). A previous palynological investigation of an undated 3.5-m long core from the area suggested preservation of a continuous stratigraphic record covering as much as the last 15,000 yr (Cox, 1968).

Within this broader wetland complex, we studied an oligotrophic, *Sphagnum*-dominated section in the southwestern portion of the basin (Fig. 1). Surface waters in this area were acidic (pH = 4.2, Francl, 2003), and the site was dominated by plants common in nutrient-poor peatlands including widely scattered *Picea rubens*, *Larix larcina*, and *Pinus strobus* trees, ericaceous shrubs and sedges, and a groundcover dominated by *Sphagnum* spp. (Venable, 1991; Francl, 2003). Much of the peatland was logged in 1893 (Venable, 1991). Prior to the logging, dense stands of *P. rubens* dominated much of Cranesville Swamp (up to 75% of the trees), with smaller amounts of *P. strobus*, *Tsuga canadensis*, and *Larix laricina* (Schreve et al., 1910; Francl, 2003). Since 1960, Cranesville Swamp has been owned by the Nature Conservancy and active management of the wetland complex occurs today.

Field methods

In the fall of 2011, a 10-cm-diameter piston corer with a serrated cutting edge, well-suited to the collection of fibric surface peats, was used to collect the upper 63 cm of peat from the northeast-central portion of the peatland (Fig. 1). A Russian-style peat corer (5-cm-diameter) was used to collect the less fibric material spanning 50 to 100 cm in depth. The Russian-style core was collected within 30 horizontal cm of the piston coring location to ensure stratigraphic continuity between the cores. A second Russian-style core was collected from a location on the peatland about ~200 m to the south (Fig. 1), to capture the contact between limnetic sediments and peat at a second location. Cores were extruded and described in the field, wrapped in plastic and aluminum foil, and transported to the laboratory in rigid PVC tubes. Cores were kept in cold storage at ~4°C until sampling.

Organic content, plant macrofossils, and pollen

Quantitative paleoecological analyses were performed on Core 1. Estimated organic matter content and plant macrofossils were used to delineate stratigraphic changes and reconstruct wetland development (cf. Ireland and Booth, 2011). The core was sliced into contiguous, 1-cm intervals with an electric carving knife and volumetric subsamples were collected for analysis of (1) loss-on-ignition (LOI), (2) plant macrofossils, and (3) pollen. Standard procedures were followed for all of these

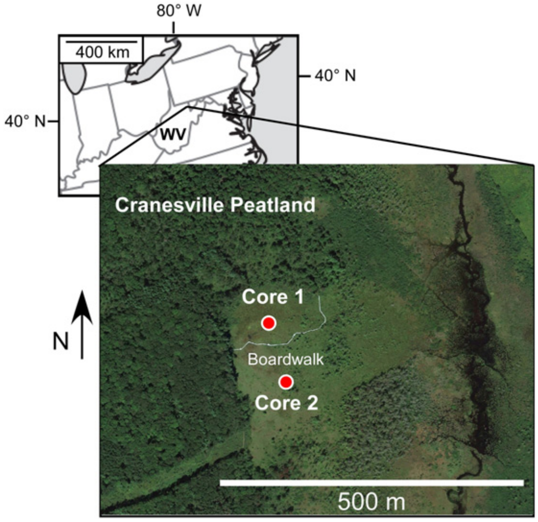

Figure 1. Map of study location and core sites (Core 1: 39.535270°N, 79.482782°W; Core 2: 39.534434°N, 79.48176°W).