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Sensitivity of wetland hydrology to external climate forcing in central Florida

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ABSTRACT

Available proxy records from the Florida peninsula give a varying view on hydrological changes during the late Holocene. Here we evaluate the consistency and sensitivity of local wetland records in relation to hydrological changes over the past ~5 ka based on pollen and diatom proxies from peat cores in Highlands Hammock State Park, central Florida. Around 5 cal ka BP, a dynamic floodplain environment is present. Subsequently, a wetland forest establishes, followed by a change to persistent wet conditions between ~2.5 and 2.0 ka. Long hydroperiods remain despite gradual succession and basin infilling with maximum wet conditions between ~1.3 and 1.0 ka. The wet phase and subsequent strong drying over the last millennium, as indicated by shifts in both pollen and diatom assemblages, can be linked to the early Medieval Warm Period and Little Ice Age, respectively, driven by regionally higher sea-surface temperatures and a temporary northward migration of the Intertropical Convergence Zone. Changes during the 20th century are the result of constructions intended to protect the Highlands Hammock State Park from wildfires. The multiple cores and proxies allow distinguishing local and regional hydrological changes. The peat records reflect relatively subtle climatic changes that are not evident from regional pollen records from lakes.

Introduction

Hydrologic variability is inherent to the Florida peninsula over glacial to interglacial timescales due to the surrounding water masses that transport heat northward as part of the Atlantic meridional overturning circulation (AMOC). Major long-term hydrological changes have been reported in Quaternary pollen records from central Florida lake deposits, where the alteration between oak-ragweed and pine-dominated vegetation prominently reflects drier and wetter periods over the last glacial–interglacial cycle (Watts, 1969, 1971, 1975, 1980; Grimm et al., 1993, 2006; Watts and Hansen, 1994; Willard et al., 2007), and which are likely forced by changes in AMOC intensity (Donders et al., 2011). During the Holocene, regional vegetation again shifted from dry oak to wetter pine vegetation cover across the peninsula starting around 6.5 ± 1 cal ka BP (Watts and Hansen, 1994; Grimm et al., 2006), whereby the humidity increase was more prominent farther south, suggesting forcing though intensification of the El Niño Southern Oscillation (Donders, 2014). Florida estuarine deposits show that this vegetation change co-occurs with an increase in runoff, pointing to increased precipitation in combination with sea-level rise as important driver (Van Soelen et al., 2012). Further humidity increase is evident in the southernmost lakes and local wetland records between 2 and 3 ka in central Florida Watts and Hansen, 1994; Donders et al., 2005a; Willard and Bernhardt, 2011). This change is rather variable in expression and in some sections shows an opposite trend (Glaser et al., 2013).

Sensitivity of proxy records

While they are very relevant for estimating sensitivities in future fresh water availability, higher order humidity changes are difficult to detect for various reasons. The available lake records show little expression of sub-millennial climatic changes due to the averaging effect of regional pollen rain (see Donders, 2014 and references therein) and are therefore not suitable for deducing more detailed evidence of changes in precipitation on sub-millennial timescales. Local wetland sites are potentially more sensitive to small-scale humidity changes but highly variable in their expression due to high spatial variability, local succession, and influence of sea-level change (Donders et al., 2005b; Willard et al., 2006; Willard and Bernhardt, 2011; Dekker et

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al., 2015). Here we test the sensitivity and consistency of such wetland records for hydrology reconstructions in a multi-proxy and multi-site approach.

Available palynological evidence for late Holocene centennial-scale hydrological variability in Florida comes primarily from wetland environments in the southern part of the peninsula (Gleason and Stone, 1994; Willard et al., 2001a; Donders et al., 2005a; Willard and Bernhardt, 2011). Peat-based pollen records from the Everglades indicate two dry intervals around 1.0 ka and 0.4 ka, reflected by transition from long hydroperiod slough vegetation to moderate hydroperiod sawgrasses (Bernhardt and Willard, 2009; Willard et al., 2001a; Sanchez et al., 2013). Additional evidence for precipitation-linked hydrological changes are available from speleothem growth rate analysis (Van Beynen et al., 2007, 2008), otoliths, and shell stable isotopes ratios from coastal archaeological mounts (Wang et al., 2011), and on ostracod assemblages and stable isotope ratios from lake deposits (Alvarez Zarikian et al., 2005). In particular, the latter study provides a full Holocene record, but the strong influence of other (ground- and sea-water) sources also strongly affects the isotopic composition at these sites, potentially masking precipitation-related changes. Overall, the variety in environments studied and proxies used so far hamper the construction of detailed late Holocene hydrological changes for Florida, since few sensitivity tests and little multi-proxy data from well-dated wetland sections are available. Moreover, the low elevation of the coastal sites might induce an overprint of the signal of precipitation change by the Holocene relative sea-level (RSL) rise (Donders, 2014).

Reconstruction approach in wetlands

Ideally, a relatively upland wetland basin independent of RSL would be used for reconstructions of other hydrologic forcings, investigated through multiple sections and independent proxies to separate local effects from more regional humidity trends. The abundant wetlands and lakes of the elevated central Lakes Wales Ridge of Florida are known to have hydrology largely dependent on precipitation, or precipitation-induced seepage from the surface aquifers (Gaiser et al., 2009a,b). The plant associations in Florida wetlands are directly related to surface- water depth and ponding duration (hydroperiod) (Kushlan, 1990; Givnish et al., 2008), and the palynological signal reflects this variation as well (Willard et al., 2001b; Donders et al., 2005b; Bernhardt and Willard, 2009; Sanchez et al., 2013). Besides pollen-based vegetation reconstructions, diatoms (siliceous algae) have proven to be a highly useful tool for determining aquatic environmental change in such wetland settings (Gaiser et al., 1998, 2001, 2004; Gaiser and Johansen, 2000; Pearce et al., 2011; Quillen et al., 2013). Due to their short reproductive cycle and sensitivity to environmental conditions as water depth, acidity, and hydroperiod (Battarbee et al., 1986; Gaiser et al., 2001; Smol and Stoermer, 2010), changes in their assemblages can be applied for reconstructing local changes in freshwater environments.

Here we present sub-centennial-scale resolution pollen and diatom records from two nearby peat sections from Highlands Hammock State Park in central Florida to test the consistency and sensitivity of local wetland proxy records to centennial-scale wetland changes. Interpretation of the records is aided by comparison with a large surface sample dataset from the Southeastern USA, allowing reconstruction of wetland type and associated hydroperiod. Regional precipitation forcing through sea-surface temperature (SST) changes of the water masses surrounding Florida indicate increased temperatures around 2.5 ka and 1.1 ka (Keigwin, 1996; Richey et al., 2007), and higher order variability coupled to the solar irradiance minima during the Little Ice Age (Poore et al., 2004). Such SST changes cause precipitation anomalies in Florida (Donders et al., 2011) and, if large enough, are expected to produce a wetland humidity increase that is consistent between both sites and proxies.

Regional setting

Geomorphology and climate

Highlands Hammock State Park (HHSP) is located near Sebring in the broad, gently sloping DeSoto Plain along the western edge of the Lake Wales Ridge in Highlands County, central Florida (Fig. 1A). This area is characterized by a series of north-south-oriented relict shorelines and dunes formed during Pleistocene sea-level highstands. These sandy deposits overlay a karstic Eocene to Miocene limestone bedrock (Scott et al., 2001). Generally, central Florida contains many basins in the sand hills and ridges, where rainfall easily percolates the permeable sands, favoring groundwater flow over surface-water drainage (Sacks et al., 1998). In this setting, the HHSP is exceptional as it includes a low-energy riparian wetland with a peaty soil located in a basin between two sandy beach ridges. Elevation ranges within the park between ~45 and 24 m above sea level (m asl). The Lake Wales Ridge forms the surface-water divide between the Kissimmee River basin to the east, the Peace River basin to the west, and the tributaries to the south that flow into Lake Okeechobee.

The investigated section is part of the surficial aquifer, which is confined by a sequence of low-porosity carbonates and clay lenses (part of the Hawthorn Group), restricting the flow of water between the surficial aquifer and the underlying Upper Florida aquifer (Spechler, 2010; Gates, 2012). Groundwater in the surficial aquifer is recharged primarily by precipitation, but also by septic tanks, irrigation from wells, seepage from lakes and streams, and the lateral groundwater inflow from adjacent areas (FDEP, 2007). Rain water percolates through the sandy ridges and seeps out at the slopes and base of low-lying sites like HHSP, resulting in two seasonal creeks (Haw Branch and Tiger Branch) that enter the park from the sandy paleoshore ridge to the east. Before drainage canals were dug around AD 1930, water moved overland as sheet flow through several broad marshes with stable wet conditions. Typical seepage slope communities with grass or fern understories and open pine/palm canopy with occasional hardwood species where present, requiring frequent burning and uninterrupted lateral ground-water flow (FDEP, 2007). Flow through HHSP is south to north into Little Charley Bowlegs Creek and eventually into the Peace River, which discharges into the northeastern part of Charlotte Harbor. Presently, the water depth and discharge of this system are subject to highly seasonal fluctuations, resulting in water level ranging from about 0.3 to 1.5 m (Spechler, 2010).

Central Florida has a subtropical summer wet climate with day temperatures ranging between 23 and 33°C. The 30-year mean annual precipitation measured at Archbold Biological station (1978–2007) is 1325 mm, of which most is received between June and September during summer storms (Spechler, 2010). This weather pattern is strongly determined by the annual movement of the North Atlantic Subtropical (or Bermuda) High (BH) (Davis et al., 1997). On multi-decadal scale, enhanced summer precipitation over the Florida peninsula has been linked to warm phases of the Atlantic Multidecadal Oscillation (AMO) (Enfield et al., 2001), whereas anomalously high winter precipitation is related to the El Niño mode of the Pacific El Niño Southern Oscillation (Ropelewski and Halpert, 1987; Donders et al., 2013).

Present-day vegetation

Hydrological conditions are the main control on the composition of wetland vegetation communities in HHSP. Pine flatwoods are present on the elevated well-drained sandy ridges east and west of the park, characterized by longleaf pine (*Pinus palustris*) and slash pine (*P. elliottii*), accompanied by live oak (*Quercus virginiana*), with a palmetto (*Serenoa repens*) and wiregrass (*Aristida stricta*) ground cover. The central feature of the park is the hydric hammock located on the limestone hill, dominated by a variety of hardwood species like live oak, sweet gum (*Liquidambar styraciflua*), pignut hickory (*Carya glabra*),