Marl Prairie Vegetation Response to 20th Century Hydrologic Change

Christopher E. Bernhardt and Debra A. Willard

U.S. Geological Survey, Eastern Earth Surface Processes Team,
926A National Center, Reston, VA 20192

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Abstract

We conducted geochronologic and pollen analyses from sediment cores collected in solution holes within marl prairies of Big Cypress National Preserve to reconstruct vegetation patterns of the last few centuries and evaluate the stability and longevity of marl prairies within the greater Everglades ecosystem. Based on radiocarbon dating and pollen biostratigraphy, these cores contain sediments deposited during the last ~300 years and provide evidence for plant community composition before and after 20th century water management practices altered flow patterns throughout the Everglades. Pollen evidence indicates that pre-20th century vegetation at the sites consisted of sawgrass marshes in a peat-accumulating environment; these assemblages indicate moderate hydroperiods and water depths, comparable to those in modern sawgrass marshes of Everglades National Park. During the 20th century, vegetation changed to grass-dominated marl prairies, and calcitic sediments were deposited, indicating shortening of hydroperiods and occurrence of extended dry periods at the site. These data suggest that the presence of marl prairies at these sites is a 20th century phenomenon, resulting from hydrologic changes associated with water management practices.

Introduction

During the 20th century, the hydrology of the greater Everglades ecosystem was altered to accommodate agricultural and urban needs, significantly altering the distribution and composition of plant and animal communities throughout the wetland (Davis and others, 1994; Light and Dineen, 1994; Lodge, 2005). Changes in both the timing and amount of water flowing through the extensive wetland system have been correlated with reduced numbers of tree islands and altered distribution and community composition of tree islands, sawgrass ridges, sloughs, and other marsh types throughout the system (Bernhardt and others, 2004; Willard and others, 2001a, 2006). Marl prairies occupy higher-elevation sites on either side of Shark River Slough (Fig. 1) and differ from most Everglades wetlands in occurrence of a calcitic substrate and short hydroperiods; these sites typically are dry for an average of nine months per year (Davis and others, 2005). The unique hydrologic and ecologic character of this habitat allows it to have the greatest plant species diversity of the Everglades, well-developed periphyton mats, and unique faunal assemblages. Concern about negative impacts of anthropogenic stressors has led to development of conceptual models to restore marl prairie habitats within an adaptive management framework (Davis and others, 2005). Central to restoration planning is determination of the pre-drainage distribution of marl prairies to predict their likely response to anticipated restoration strategies. Although marl prairie response to changes associated with the Central and South Florida Project (C&SF Project) in the mid-20th century have been documented by field studies, little is known about impacts of hydrologic changes earlier in the century, which include construction of the Tamiami Trail, Hoover Dike, and other water control structures. We designed this pilot study to determine whether proxy evidence preserved in solution holes from marl prairies yields adequate data to evaluate temporal and spatial changes in marl prairie communities, to reconstruct pre-drainage (pre-20th century) and post-drainage plant communities, and to determine whether observed ecosystem changes are correlated with hydrologic alteration of the wetland ecosystem.

Marl Prairie Habitat and Community

Within the ~6,000 km^2 of wetlands comprising the greater Everglades ecosystem lies a mosaic of vegetation types, including tree-islands, mangrove forests, cypress swamps, marl prairies, sawgrass marshes, and sloughs (Fig. 1a) (Davis, 1943; Loveless, 1959; Davis and others, 1994). Marl prairie landscapes occupy ~1,990 km^2 of higher-elevation sites within this mosaic (Fig. 1b), consisting of a mixture of wet prairie, sawgrass, tree islands, and tropical hammock communities (Olmstead and Loope, 1984). Marl prairies have the shortest hydroperiods of the Everglades (2-9 months) (Lodge, 2005); under present conditions, many sites east of Shark River Slough are dry for an average of 9 months per year (Van Lent and others, 1993; Fennema and others, 1994). The short hydroperiods and shallow water depths that characterize marl prairies result in accumulation of a calcitic mud substrate (Fig. 2) rather than a peat substrate, and periphyton assemblages are dominated by calcite-encrusting, filamentous cyanobacteria such as *Scytonema* and *Schizothrix* (Browder and others, 1994; Davis and others, 2005). Marl prairies have high plant diversity, with approximately 100 different species (Lodge 2005). Of those, approximately half are grasses and sedges (Porter, 1967), and the dominant species depends on hydroperiod: sites with 1-2 month hydroperiods are dominated by *Schizachyrium rhizomatum* (Florida little bluestem), those with 3-5 month hydroperiods are dominated by *Muhlenbergia* (muhly grass), and those with 6-8 month hydroperiods are dominated by *Cladium* (sawgrass) (Olmstead and Loope, 1984; Davis and others, 2005). The combination of low-stature herbaceous ground cover and extended dry periods has fostered development of specialized faunal assemblages that are closely tied to the habitat, including the Cape Sable Seaside Sparrow, macroinvertebrates, herpetofauna, and wading birds.

Everglades Hydrologic History

In the natural Everglades system, seasonal rainfall and overflow of water from Lake Okeechobee dictated the hydrologic patterns. Water flowed southward from Lake Okeechobee along a gentle slope of 3 cm km^{-1} (Kushlan, 1990), eventually reaching Florida Bay and the Gulf of Mexico through Shark River Slough and Taylor Slough (Fig. 1). The late 19th to early 20th century marked the first phase of intensive drainage efforts to render parts of the Everglades usable for agricultural and urban development (Light and Dineen, 1994). By 1930, four drainage canals (the North New River, Hillsboro, Miami, and West Palm Beach) were constructed, the Hoover Dike encircled Lake Okeechobee, and the Tamiami Trail was constructed, consisting of a combination of raised roads and culverts (Fig. 3a) (Deuver and others, 1986; Light and Dineen, 1994; Sklar and van der Valk, 2002). Even more extensive compartmentalization began in the 1950's with the construction of three Water Conservation Areas (WCA), which incorporate a series of canals, levees, and other water-control structures to control flooding within the northern Everglades (Fig. 3b) (Light and Dineen, 1994). By the late 20th century, it was recognized that the health of the Everglades ecosystem and the quality and quantity of available water affected the economic and cultural health of south Florida, and the U.S. Federal and Florida State governments enacted the Comprehensive Everglades Restoration Plan (CERP). The CERP aims to achieve flow patterns similar to the historic hydrologic regime through modification and removal of existing water-control structures. It is assumed that the natural resilience of the wetland will allow its recovery to a more natural state.

One key to successful wetland restoration is an understanding of the natural processes that govern wetland development. We collected sediment cores from solution holes in marl prairies west of Shark River Slough to address several questions. Is the sedimentary record long enough to provide data on pre- and post-drainage vegetation? If pollen is preserved in these sediments, can marl prairie vegetation be distinguished from other wetland types? If plant community changes occurred, is the timing correlated with specific climatic or anthopogenic events? Do these data indicate changes in the spatial distribution of marl prairies through time? It is important to address these questions to accurately predict responses of marl prairie plant and animal communities to planned changes in water delivery associated with restoration efforts.

Methods

Using a 10 cm diameter piston-coring device, we collected five cores in the Rattlesnake Ridge area of Big Cypress National Preserve (Fig. 4, Table 1). Because only a thin veneer of calcitic sediment (<5 cm) covers most of the marl prairie, we collected a series of sediment cores from solution holes in the limestone bedrock. These solution holes ranged up to 73 cm in depth and provided sufficiently wet sites for accumulation and preservation of organic and calcitic sediments with minimal loss due to drying and oxidation. Four of the five cores consisted of a basal peat overlain by marl; the fifth core (core 03-9-16-3), which penetrated 73 cm of sediment, consisted entirely of peat. We hypothesize that the latter solution hole was sufficiently deep to maintain permanent standing water, facilitating preservation of peat throughout. Cores were sampled in 1 cm increments, and samples were dried and subsampled for radiocarbon dating and pollen analysis. This report focuses on pollen records from two sediment cores (03-9-16-3 and 03-9-16-6).

Chronology of the cores is based on a combination of radiocarbon dating on bulk sediment from core 03-9-16-6 (Table 2) and occurrence of the biostratigraphic indicator *Casuarina equisetifolia* (Australian pine) in both cores. *Casuarina equisetifolia* was introduced to South Florida ~1900 AD; calibration of its pollen with ^{210}Pb geochronologies in a series of cores from Florida and Biscayne Bays indicates that *C. equisetifolia* pollen first occurred in south Florida sediments at 1910 +/- 15 years, becoming common after 1940 (Duever and others 1986, Langeland, 1990; Wingard and others, 2003). An additional biostratigraphic indicator is the decrease in *Pinus* pollen. We interpret this as the pollen signature of *Pinus* logging during the late 1930's based partly on historical records (Duever and others 1986) and patterns exhibited in sediment cores with excellent ^{210}Pb dating (Wingard and others, 2003).

We isolated pollen from the sediment cores and surface samples using standard palynological preparation techniques (Traverse, 1988; Willard and others, 2001a). For each sample, one tablet of *Lycopodium* spores was added to between 0.5 grams to 1.5 grams of sediment. Samples were processed with HCl and HF to remove carbonates and silicates respectively, acetolyzed (1 part sulfuric acid: 9 parts acetic anhydride) in a boiling water bath for 10 minutes, neutralized, and treated with 10% KOH for 10 minutes in a water bath at 70˚ C. After neutralization, residues were sieved with 149 µm and 10 µm nylon mesh to remove the coarse and clay fractions, respectively. When necessary, samples were swirled in a watch glass to remove mineral matter. After staining with Bismarck Brown, palynomorph residues were mounted on microscope slides in glycerin jelly. At least 300 pollen grains were counted from each sample to determine percent abundance and concentration of palynomorphs (Tables 3, 4). Identifications were made using reference material at the US Geological Survey and descriptions contained in Willard et al. (2004). Abundance data are available through the USGS SOFIA website (http://sofia.usgs.gov) and the North American Pollen Database (NAPD) at the World Data Center for Paleoclimatology in Boulder, CO (http://www.ngdc.noaa.gov/paleo/pollen.html).

Reconstruction of past plant communities is based on statistical comparison of fossil and modern assemblages from different wetland communities throughout the Everglades (Willard and others, 2001b). Using the modern analog technique (Overpeck and others, 1985), we statistically compared modern and fossil assemblages to those that share similar vegetation and environmental parameters. We calculated squared chord distance (SCD) between down-core pollen assemblages and a suite of 197 surface samples collected throughout southern Florida in the early 1960s and 1995-2002 (Willard et al., 2001b, 2006) to define the similarity between each fossil and modern pollen assemblage. Internal comparison among surface samples from ten vegetation types indicates that samples with SCD values < 0.15 may be considered close analogs (Willard et al., 2001b). If analogs were present for a fossil assemblage, we identified the source vegetation for the fossil assemblage as one of the twelve types represented in the modern database.

Results

Geochronology

Radiocarbon dates from the upper 8 cm of core 03-9-16-6 yield >110 pMC (percent modern carbon). This indicates that the analyzed material is less than 50 years old and has more ^{14}C than the 1950 AD reference standard; thermonuclear testing during the 1950s generated ^{14}C, and organisms that lived after that time incorporated the "extra" ^{14}C in their biomass, yielding results with >100 pMC. *Casuarina* pollen first occurs at 7.5 cm in cores 03-9-16-3 and 03-9-16-6; this is consistent with radiocarbon dates from 03-9-16-6 that indicate deposition of the upper 8 cm during the 20th century. Radiocarbon dating of the sample at 10.5 cm in core 03-9-16-6 indicates a calibrated age of 300 yrBP; the one sigma ranges for this calibrated date are 310-290 yrBP, indicating deposition well before hydrologic changes of the 20th century. However, the two sigma ranges for the calibrated date are much broader (430-0 yrBP), making accurate calculation of pre-drainage sediment accumulation rates tenuous.

Pollen Assemblages

Pollen is abundantly preserved in sediments throughout both cores, typically comprising >10,000 grains g^{-1}. Two assemblage zones were identified in both core 03-9-16-3 and 03-9-16-6, based on visual inspection of pollen diagrams and downcore changes in modern analogs (Figs. 5, 6). Raw counts of pollen from each sample are provided in Tables 3 and 4. Pollen Assemblage Zone I is dominated strongly by *Pinus* pollen (>65%). *Quercus* pollen comprises <1% of assemblages, and the bulk of the remaining assemblage consists of marsh taxa including *Cladium* and *Sagittaria* (Figs. 5, 6).

In Pollen Assemblage Zone II, *Pinus* pollen is less abundant than in zone I (<60%); *Quercus* and *Myrica* pollen are more abundant, and pollen of the Poaceae, Cyperaceae, Asteraceae, and Amaranthaceae are more than twice as abundant as in zone I (Figs. 5, 6). *Casuarina* pollen is present throughout most of Zone II, and *Quercus* pollen reaches peak abundance in the uppermost samples.

Discussion

Sediment cores collected in the present marl prairie west of Shark River Slough contain records of distinct lithologic, hydrologic, and vegetation change during the 20th century. The presence of peat in the lower part of the cores indicates sufficiently deep water for preservation of organic sediments before 1900 AD; moderate hydroperiods and water depths did not favor growth of carbonate-secreting periphyton. The upper 7-10 cm of each core consisted either of marl or marly peat, indicating the existence of shallower water and shorter hydroperiods that favored marl production and accumulation.

Peats deposited below ~10 cm in both cores represent pre-drainage assemblages, based on the radiocarbon date of 300 cal yrBP in core 03-9-16-6 and similarities in pollen assemblages from the two cores. These pre-20th century assemblages (Pollen Assemblage Zone I) are analogous to sawgrass marshes and wet prairies present in the modern Everglades National Park, which possess sufficiently long hydroperiods to maintain sparse *Cladium* stands and accumulate organic sediments.

Sediments containing Pollen Assemblage Zone II were deposited during the 20th century, based on modern radiocarbon dates from core 03-9-16-6 and the presence of *Casuarina* pollen in both cores. In this zone, pollen of Poaceae, Cyperaceae, Amaranthaceae, and Asteraceae doubled in abundance, and lithologic changes occurred. These assemblages are analogous to those from modern marl prairies. This evidence indicates the onset of shorter hydroperiods and shallower water than the sawgrass marshes that previously occupied the sites. Although paired ^{210}Pb and pollen analyses would be necessary to determine precisely when these changes occurred, these data clearly indicate that modern marl prairies west of Shark River Slough developed after 20th century hydrologic modification of the system reduced flow to the region. These data stand in contrast to hypotheses that marl prairies west of Shark River slough were affected by extended flooding from flows through the S12A and S12B gates from WCA 3A. Rather, reconstructed vegetation patterns from these sites indicate initiation of drier conditions during the 20th century.

Although marl prairie communities may have existed at other sites within the greater Everglades ecosystem prior to the 20th century, plant communities at the sites analyzed in this pilot study consisted of sawgrass marshes before drainage of the system. These data indicate that the current spatial distribution and community composition of marl prairies are a response to water management and land cover changes of the 20th century. Further sampling of modern marl prairie communities and adjacent communities is necessary to document the pre- and post-drainage distribution of marl prairie and associate faunal communities and to predict likely responses of marl prairie communities to anticipated changes in Everglades water management.

Conclusions

1) Prior to the 20th century, sawgrass marshes occupied these sites west of the Shark River Slough; the existence of longer hydroperiods than today allowed accumulation of a peat substrate.
2) Sediments deposited during the 20th century are marls or marly peats; grass and sedge pollen abundance was roughly double its pre-drainage abundance, indicating the presence of grass-dominated marl prairie vegetation.
3) Pollen assemblages and lithologic patterns indicate that post-drainage hydroperiods in these sites were significantly shorter than those before the 20th century.

Hydrologic modifications associated with water management altered the predrainage sawgrass marshes to the marl prairies that occupy the sites today. The present distribution of marl prairies west of Shark River Slough appears to be a direct result of water management practices begun in the 20th century, rather than a natural feature of the Everglades landscape. Further sampling and analyses are necessary to reconstruct the pre-drainage distribution of the marl prairie ecosystem.

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Figure Captions

Figure 1. A) Distribution of vegetation types in the greater Everglades ecosystem (from Willard and others, 2004. B) Plot of DEM (digital elevation model) data produced at 30 m grid spacing in southern Everglades (from Desmond, G., High Accuracy Elevation Data Collection: http://sofia.usgs.gov/exchange/desmond/desmondelev.html). Highest elevations (2.0-1.7 m) represent areas favorable for marl prairie habitats.

Figure 2. a) Sediment core collected from solution hole in marl prairie habitat. Note marl layer at top of core. b) Photograph of periphyton and marl sediment that makes up surface sediments in Everglades marl prairies.

Figure 3. Map of water control structures in place in greater Everglades ecosystem. a) ~1930 AD b) ~1970 AD (post C&SF Project) (from Willard and others, 2006). Study area is highlighted in yellow. Core sites are indicated by black dots.

Figure 4. Map of core localities in Big Cypress National Preserve. See Table 1 for information on core location and sediment depth. Sites analyzed in this study are indicated by yellow dots.

Figure 5. Percent abundance of pollen of major plant taxa in sediment core 03-9-16-3. Closest modern analogs were identified through comparison with modern samples using the modern analog technique and squared chord distance (SCD) as the dissimilarity measure. Samples with SCD≤0.15 are considered to be close analogs. Double asterisks mark the first occurrence of *Casuarina* at 7.5 cm.

Figure 6. Percent abundance of pollen of major plant taxa in sediment core 03-9-16-6. Closest modern analogs were identified through comparison with modern samples using the modern analog technique and squared chord distance (SCD) as the dissimilarity measure. Samples with SCD≤0.15 are considered to be close analogs. Double asterisks mark the first occurrence of *Casuarina* at 7.5 cm. Radiocarbon dates are reported either as calibrated years before present (cal yrBP) or pMC (percent modern carbon). Samples with >100 pMC are less than 50 years old and have more ^{14}C than the 1950 AD reference standard; thermonuclear testing during the 1950s generated ^{14}C, and organisms that lived after that time incorporated the "extra" ^{14}C in their biomass, yielding results with >100 pMC.