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A Vegetation History from Emerald Pond, Great Abaco Island, The Bahamas, Based on Pollen Analysis

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I am submitting herewith a thesis written by Ian Arthur Slayton entitled "A Vegetation History from Emerald Pond, Great Abaco Island, The Bahamas, Based on Pollen Analysis." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Sally P. Horn, Major Professor

We have read this thesis and recommend its acceptance:

Henri Grissino-Mayer, Ken Orvis

Accepted for the Council:

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Vice Provost and Dean of the Graduate School

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and recommend its acceptance:

Kenneth H. Orvis

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A Vegetation History from Emerald Pond, Great Abaco Island,
The Bahamas, Based on Pollen Analysis

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ian Arthur Slayton

December 2010

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ABSTRACT

Emerald Pond (26° 32' 12" N, 77° 06' 32" W) is a vertical-walled solution hole in the pine rocklands of Great Abaco Island, The Bahamas. In 2006, Sally Horn, Ken Orvis, and students recovered an 8.7 m-long sediment core from the center of the pond using a Colinvaux-Vohnout locking piston corer. AMS radiocarbon dates on macrofossils are in stratigraphic order and indicate that the sequence extends to ca. 8400 cal yr BP. Basal deposits consist of aeolian sands topped by a soil and then pond sediment, suggesting that the site began as a sheltered, dry hole during a Late Pleistocene low sea level stand, and became moister as climate changed and rising sea level pushed up the freshwater table.

The limestone rockland surrounding the site is presently dominated by Bahamian pine (*Pinus caribaea* Morelet var. *bahamensis* (Griseb.) W.H. Barrett & Golfari) with an understory of hardwoods and several palm species. Pollen assemblages in the sediments of Emerald Pond indicate significant environmental change at the site. Pines and palms have dominated for much of the record, with some variation in relative importance. Pine pollen shows a non-uniform, general increase over the record, with highest values reached in a section of the upper meter of the record that contains abundant microscopic charcoal that may be related to anthropogenic activities. Palm pollen is well represented in all but this upper section of the core. The shifts in pollen percentages in the upper meter of the core suggest a generally drier environment during the last two millennia at Emerald Pond.

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CHAPTER ONE

INTRODUCTION

Paleoecological studies based on the analysis of materials preserved in lake sediments are important not only for understanding past conditions of an area, but also for understanding the context of current vegetation and climate, and possible future changes. Pollen, charcoal, plant macrofossils, and other proxy indicators in lake sediments can provide evidence of past vegetation, and even human activity in the area around the site. Relatively few paleoecological studies have been conducted on islands of the Tropical Atlantic and Caribbean region, compared to the surrounding mainland and to other portions of the neotropics. My thesis examines pollen in samples from a sediment core extracted from Emerald Pond on Abaco Island in The Bahamas to reconstruct possible past shifts in vegetation that may indicate past changes in climate as well as human impacts. Radiocarbon dates on macrofossils in the sediment core show that the 8.7 m-long sediment profile spans approximately 8400 calibrated years. The islands of The Bahamas were one of the last places in the region settled by humans, with the Lucayan Taino only arriving as recently as 1350 to 1150 yr BP (Berman and Gnivecki 1995). Much of the record from Emerald Pond will be influenced only by climate and ecological changes, and the arrival of humans may be detectable in the record.

Emerald Pond is a solution hole with vertical rock walls and a water surface about 4 m below the ground surface of the surrounding rockland landscape, which is today dominated by Bahamian pine (*Pinus caribaea Morelet var. bahamensis* (Griseb.) W.H. Barrett & Golfari) (Correll and Correll 1982). A previous study in which I participated (Horn *et al.* in prep.) examined microscopic charcoal in the Emerald Pond sediments as evidence of long-term fire history.

The goal of my master's thesis research is to document pollen assemblages in the Emerald Pond samples to detect possible changes in vegetation from the early Holocene to the present. Based on analysis of samples from 24 levels in the profile, I attempt to discern changes in past vegetation through pollen representation, and any influence climate and human activity may have had on vegetation. I also compare my results with other studies conducted in the tropical Atlantic and Caribbean region. The questions I ask are:

1. How has the vegetation that surrounds Emerald Pond changed over time?
2. Are changes in vegetation associated with changes in fire activity?
3. Is there evidence of human influence on vegetation? If so, when?
4. How does the Emerald Pond pollen record compare with other paleoecological records from The Bahamas?
5. How do inferred changes in vegetation, climate, and disturbance over the Holocene at Emerald Pond relate to regional evidence of paleoclimate and paleoenvironments for this period?

My thesis is divided into seven chapters. I review other paleoenvironmental studies in the Caribbean and Tropical Atlantic in Chapter two. Chapter three describes the vegetation, climate, geology, and human history of Abaco Island. In Chapter four, I describe the Emerald Pond sediment core and the methods I used to study pollen assemblages. The results of the pollen analysis are presented in Chapter five. In Chapter six, I address the research questions I posed above and discuss my results. I summarize my results and present my conclusions in Chapter seven.

CHAPTER TWO

LITERATURE REVIEW

Paleoclimate and paleoecology of the Caribbean and Tropical Atlantic

Within the Caribbean and Atlantic, conditions during the last glaciation were quite different from those of today (Hodell *et al.* 2000). Sea level was up to 126 m lower (Fairbanks 1989) and the region was cooler and drier, according to evidence from lake sediment profiles in the region. Plant distributions were also very different, with savanna grasses and juniper trees in some areas currently dominated by subtropical forests. Evidence from pollen suggests a sudden shift in moisture conditions in the circum-Caribbean and southeast United States as the Pleistocene gave way to the Holocene. An increase in moisture lasted until about 3000 cal yr BP, at which time a general drying trend began that culminated at around 1300 cal yr BP with marked drought events (Hodell *et al.* 2000). These events may have had a large impact on the civilizations of the wider Caribbean region, such as the Maya, by adversely affecting agriculture. Pollen records show that the forests of the Mayan region recovered after the population collapse, providing more stability in the moisture dynamics of the region.

Historical accounts of famine and cold from the Maya and Aztec during the 15th century are reflected in proxy evidence from a lake sediment core taken in northwest Yucatan, Mexico (Hodell *et al.* 2005a, 2005b). Pollen records from the area showed a decline in mesic forest taxa during the same time as oxygen isotope ratios from ostracod and gastropod carbonate showed an increase in lake water salinity. The interpretation of these data is that a drier and cooler climate existed for the Yucatan Peninsula at about the beginning of the Little Ice Age.

Records from Mexico indicate significant changes in climate over the late Pleistocene and Holocene (Metcalfé *et al.* 2000). Sites in Central Mexico record a decline in alder (*Alnus*) and an increase in Chenopodiaceae-Amaranthaceae pollen around 5000 yr BP. This change could be due to a drier climate or to an increase in agricultural activities in the region. A reduction of arboreal taxa and increase in Cheno-Ams in sediments between ca. 5000 and 1500 yr BP may be evidence of the continued presence of humans and agricultural activity. Diatom records from La Piscina de Yuriria show drier than present conditions between about 3700 and 3300 yr BP, 2950 and 2700 yr BP, and 2300 and 800 yr BP, with the driest period between 1570 and 900 yr BP. Records from studies on the Yucatan Peninsula indicate mostly wet conditions from about 7000 to 3000 yr BP, with a possible drier period between 6000 and 5000 yr BP. The driest period of the Holocene at several sites in the region was sometime between 1500 and 900 yr BP, a period that encompasses the demise of the lowland Maya.

An 85,000 year record from Lake Petén Itzá, Guatemala was used to reconstruct hydrologic changes in the northern neotropics during the last glaciations (Hodell *et al.* 2008). Six sediment cores were collected at two different locations, the longest reaching a depth of 75.9 meters. From about 85,000 to 48,000 years before present, sediments with carbonate clay indicating moist conditions predominated (Hodell *et al.* 2008). A gypsum layer deposited about 48,000 years ago indicated a change to a drier climate with cycles of drier and wetter conditions. These cycles correlate with stadial-interstadial stages found in Greenland ice cores and North Atlantic marine sediment cores. Gypsum was deposited during stadials when the Intertropical Convergence Zone was depressed southward and higher clay content was deposited during interstadials from increased precipitation and fine sediment transport. Cold and wet conditions were indicated from 23,000 to 18,000 years ago, in part by the abundance of temperate pollen

types. The moist conditions were likely due to a northward shift of the Intertropical Convergence Zone and possibly increased winter precipitation from more frequent polar outbreaks. Conditions became more arid from 18,000 to 14,700 years ago, but returned to a wetter state from 14,700 to 12,800 years ago. The Younger Dryas marked the reemergence of dry conditions from 12,800 to 10,400 years ago. The authors concluded that these periods of arid conditions were when the Intertropical Convergence Zone had shifted south. Mueller *et al.* (2009) found evidence of tropical forest reduction that coincided with a drop in water level in the lake between about 4500 and 3000 years ago. This reduction in tropical forest likely was related to a drying of the climate. This runs counter to previous suggestions that human activities such as agriculture were responsible for the vegetation changes at the time. The initial reductions in tropical forest likely were not greatly influenced by humans, although humans may have still played a significant role at some point.

Farther south, in Costa Rica and Panama, forests that were once thought to be undisturbed (unaltered by humans) actually experienced a long history of disturbance, stretching back 3000 or more years (Bush and Colinvaux 1994; Horn 2007). Charcoal and pollen evidence in lake sediment cores indicated human occupation, agriculture, and fires. A key indicator of human presence and prehistoric agriculture throughout the American tropics is the presence of maize pollen in sediment cores (Horn 2006). Maize is a domesticated plant that is dependent on humans to survive and perpetuate (Horn 2007). Pollen records of maize predate maize macrofossils in many areas of Central America, with sediment analyses rather than archaeological excavations yielding the earliest evidence for maize cultivation (Horn 2007). The records suggest a rapid and widespread dispersal of maize production, both for the use of its kernels as well as perhaps the stalk in alcohol production (Horn 2006).

Bush and Colinvaux (1994) studied sediment cores from swamps in the Darien region of Panama, an area famous for its remoteness. Pollen samples taken from the bottom of the Lake Wodehouse core had low percentages of taxa associated with disturbance, and high percentages of unknown and diverse taxa, suggesting a mature tropical forest. Large Gramineae pollen that was identified as *Zea* and other pollen associated with agricultural disturbance dated to about 4000 years ago. Evidence of increased fire activity was also present in the record at the same time, as indicated by charcoal fragments in the Lake Wodehouse site profile and in a profile from a neighboring swamp. The authors concluded that the area was heavily modified by humans starting about 4000 years ago up until the depopulation of the region following the Spanish Conquest. Forest succession then brought the vegetation to its current state of appearing pristine. These findings show that the rainforest can be quite resilient, so long as periods of disturbance are kept from causing mass extinctions.

Sediment cores collected off the Venezuelan coast were analyzed for titanium and iron concentration to infer regional hydrologic cycle changes over the last 14,000 years (Haug *et al.* 2001, Peterson and Haug 2006). The Cariaco Basin is on the northern shelf of Venezuela, and its position leads to it receiving both marine and terrestrial sediments. During the summer, the Intertropical Convergence Zone passes over, bringing rainfall that drains the adjacent land mass and flows into the basin. During the winter, runoff from the land is greatly diminished and northeast tradewinds blow over the sea, causing upwelling along the coast. This fuels an increase in biological activity in the surface waters over the basin. Organic matter and microfossils then fall down to the sea floor. These seasonal changes in source and type of sediment create laminations in the Cariaco Basin sediments. Bioturbation does not disturb the sequence, as the basin is anoxic.

The concentrations of titanium and iron in the Cariaco Basin sediment reflect the amount of water running off the land, and thus terrestrial rainfall. Changes in the concentrations of titanium and iron in the sediments between 3800 and 2800 yr BP indicated a southern shift of the ITCZ, causing a decrease in precipitation for northern South America. Haug *et al.* (2001) found that changes in insolation patterns due to the Milankovitch cycle were the most likely driver of the shift. Atlantic sea surface temperatures may also be a factor, and could explain the episodic temporal coincidence of cold high-latitude North Atlantic sea surface temperatures and dry conditions in northern South America, for example during the Little Ice Age and between 3800 and 2800 yr BP.

Black *et al.* (2004) constructed a high resolution record of regional hydrographic variability in Cariaco Basin sediments. A core was sampled at 1 mm intervals in an attempt to achieve the highest resolution possible. Oxygen isotope values from two species of planktic foraminifera revealed past sea surface temperatures and salinity, both linked by the authors to precipitation patterns associated with the Intertropical Convergence Zone. The two species of foraminifera were used because each dominates the local foraminifera assemblage during distinct seasons of the year. *Globigerina bulloides* dominates during the winter months when upwelling from the northeast trade winds occurs, and *Globigerinoides ruber* during the summer months when upwelling is largely absent. A higher amount of the heavier ^{18}O in foraminifera shells indicates cooler conditions. This is because ^{18}O requires more energy to evaporate when part of a water molecule, and releases more energy when it condenses due to the isotope's greater mass. This leads to water molecules with ^{16}O readily evaporating before water molecules with oxygen-18, and thus precipitation tends to be composed of more ^{16}O isotopes. If global temperatures are cooler and more precipitation is stored as snowpack and in glaciers and ice sheets, the ratio of

^{18}O to ^{16}O increases because a disproportional amount of ^{16}O is being stored. The trend of the oxygen isotope values over the 2000-year record suggests a net cooling of the Caribbean and tropical North Atlantic during that time, with a warmer period from 1100–600 BP (Medieval Warm Period) and a cooler period from 500–100 BP (the Little Ice Age). Fluctuations on smaller scales (decadal or century) may be partly controlled by salinity changes resulting from precipitation patterns and thus, indirectly, by solar variability.

Analysis of ocean sediment cores taken off the coast of Puerto Rico revealed a 2000 year record of climate variability in the northeastern Caribbean (Nyberg *et al.* 2001). Higher organic carbon content and organic carbon/total nitrogen ratios around the Little Ice Age indicated increased precipitation and runoff in the northeastern Caribbean Sea. Runoff contributes to the amount of nutrients present in coastal areas, which increases organic carbon values through increases in primary productivity. A moist period at about 1100–950 BP coincided with geochemical and mineral magnetic changes in the record that the authors attributed to a long-term shift in Hadley Cell circulation. Decreased rainfall prior to 1100–950 BP over the Atlantic Ocean favored the transport of dust from North Africa to the eastern Caribbean, leading to higher hematite values in the sediment. Mineral magnetic parameters indicated an oscillatory pattern of wet and dry seasons with a period of about 200 years. Magnetic susceptibility reflected the concentration of magnetic minerals, but also was influenced by diamagnetic and paramagnetic materials. Solar variability that affected the tradewinds and the Hadley circulation is a possible explanation, but the authors did not suggest a particular mechanism.

Ramcharan and McAndrews (2006) used pollen evidence to discern local vegetation changes in a freshwater wetland in Trinidad. Their 980 cm sediment core extends to about 6700 ^{14}C years BP, and *Rhizophora* (red mangrove) pollen dominates the record throughout. This

taxon is likely over-represented, as other local plants do not produce pollen in such large quantities or throughout the year as *Rhizophora* does. Despite the domination of *Rhizophora*, the authors observed some changes in the vegetation. An example of this is periodic occurrences of a larger freshwater wetland with grasses and freshwater plants. A rapid decline in *Rhizophora* at 3000 ¹⁴C years BP and an increase in dicot pollen was coincident with a change in sedimentation, and may signal a disturbance of the vegetation in the area caused by mangrove “dieback.” The authors stated that the presence of *Rhizophora* pollen in the record can indicate relative sea levels, because the presence of *Rhizophora* indicates a marine-shore habitat in the area. The pollen record showed a rise in sea level followed by beach development that removed the habitat for *Rhizophora* and led to a gradual transition to the present herbaceous freshwater wetland dominated by grasses, sedges, *Typha*, and ferns.

Hendry and Digerfeldt (1989) seemed to corroborate this possible fluctuation in sea level, as their research with coastal sediments in Jamaica indicated that sea level was one meter lower 2000 ¹⁴C years ago. They analyzed several peat cores along with stratigraphic measurements, seismic traverses, and echo soundings from the Great Morass at the Negril River, a wetland area in western Jamaica, to construct vegetation and coastline maps of the area at various times in the past (8250–8000 yr BP, 7500–7250 yr BP, 6500–6250 yr BP, 5250–5000 yr BP) as well as at present. The first accumulations of peat in the cores at 8250–8000 yr BP were of freshwater origin, indicating restricted saline intrusion. The wetland had increased in size by 7500–7250 yr BP, and the accumulated peat was of freshwater origin in the central part of the basin, although the authors suspect that there may have been some saltwater intrusion at the outer edge of the wetland due to a rise in sea level to 9 m below present. The wetland greatly expanded to the south by 6500–6250 yr BP. An increase in brackish-marine vegetation in the south indicated

saline intrusion into the wetland, and the growth of mangroves (*Rhizophora*) may have allowed the deposition of clay sediments that can be observed in the basin today. By 5250–5000 yr BP, the wetland area was approximately the same size and shape as the modern Great Morass, with sea level about 3 m lower than it is today. *Rhizophora* dominated all but the central part of the wetland, indicating strong saline influence. The freshwater vegetation at the center of the wetland may have been sustained by karst springs that supplied an inflow of freshwater to that particular part of the wetland. Sea level rise slowed between 5250–5000 yr BP and present. The wetland moved inland further east, but beaches migrated landward as well and the surface area of the wetland remained about the same. A moister climate and increased outflow from neighboring limestone formations pushed saltwater out of much of the area, leading to the predominantly freshwater wetland that makes up the area today.

Higuera-Gundy *et al.* (1999) examined pollen assemblages and oxygen isotope ratios in ostracod shells in a 7.7 m long sediment core from Miragôane Lake in southern Haiti. The modern vegetation around the lake is made up of shrubs, herbs, and fruit trees. The plant taxa represented by the pollen samples indicated a dry climate around 10,300 years BP that increasingly became moist toward modern times, causing forest expansion. The oxygen isotope analysis suggested rising lake levels during the Holocene with only brief reversals. Between 5370 and 2490 ¹⁴C years BP, the oxygen isotope record indicated high but gradually declining lake levels, at the same time that the pollen record indicated moist conditions. These conditions can be explained by a warmer climate, leading to more evaporation from the lake during the dry season. The trends reflected by the Lake Miragôane core are generally consistent with other studies within the circum-Caribbean region. The Miragôane record was one of the first long records obtained from the Caribbean region, and has become a standard to which other records

are compared. When differences with other records are noted in the timing of the onset of climatic changes, these may be due to dating inaccuracies, differences in responses by indicator taxa, or regional climatic differences. Lake Miragôane is on the leeward side of Hispaniola, and has a more seasonal climate than some other sites in the circum-Caribbean. Human activity may also be a complicating factor, as much of the Miragôane record overlaps with the period of human occupancy on Hispaniola, which extends back to at least 6400 cal yr BP (Wilson 2007).

Lane (2009) examined evidence of paleoenvironmental change in lake sediment cores collected from Laguna Castilla and Laguna de Salvador in the Dominican Republic. Pollen analysis indicated a humid montane broadleaf forest around the lakes about 2250–1520 cal yr BP, and microscopic charcoal evidence suggested fires were common in the region. From about 1520–890 cal yr BP, an increase in herbaceous pollen and decline in arboreal taxa occurred. This was interpreted as a period of aridity in the area. Microscopic charcoal concentrations reached some of their highest levels during this period. Pollen evidence indicated prehistoric forest clearance and agriculture from about 890–700 cal yr BP, especially maize agriculture (Lane 2008, Lane 2009). From about 700–350 cal yr BP, an increase in *Pinus* pollen percentages indicated a period of forest recovery, as humans likely abandoned the areas around the lake. *Pinus* readily colonizes poor soils, and likely indicates that the soil quality had deteriorated in the area from human activities. From 350–95 cal yr BP, *Pinus* pollen values decreased in the records and values of broadleaf arboreal taxa slightly increased. This may have been a signal of further forest recovery from the impacts of prehistoric agriculture. A temporal relationship was found between total organic carbon signatures and the inferred scale of maize cultivation (Lane 2008). Data from the cores indicated large shifts in hydrology, vegetation, and disturbance regimes due to climate change and human activity over the last 3,000 years. The

authors interpreted the changes in climate over the record to be associated with shifts in the mean summer position of the ITCZ.

Peros *et al.* (2007) developed a 6000 year record of environmental change from lacustrine sediments in north coastal Cuba. Ten cores were taken from Laguna de la Leche, a shallow coastal lake. Samples were taken from three of the cores at intervals of 3 to 10 cm and were analyzed for pollen, calcareous microfossils, and plant macrofossils. The bottom of the cores had a silicate-rich soil dating to 6500 cal yr BP, at which time the Laguna de la Leche basin was not yet filled. A shallow lake formed within the basin about 6200 cal yr BP, likely because of a rise in elevation of the underlying aquifer due to sea level rise. Water levels continued to rise until about 4200 cal yr BP, at which point sea levels rose above the sill between the lake and the neighboring ocean inlet. Over the next 2000 years, an expansion of mangroves closed off the connection with the sea, leaving Laguna de la Leche a closed brackish lake. The findings suggested a relative sea level rise in the region as the dominant cause of vegetation change in the middle Holocene, and not necessarily climate change. Paleoclimatological signals may be masked by sea level fluctuations, making local sea level history an important aspect when interpreting records from coastal areas.

Several studies of sediment cores from lakes and wetlands in Florida are relevant to Bahamian paleoecological research, because of their proximity and similarities in environments. In south-central Florida, Watts (1975) developed a 37,000 year record of vegetation and climate based on pollen analysis of sediment cores from Lake Annie. Lake Annie is a solution lake at the southern end of the Florida Highlands, an area of sandy upland ridges that extend from the Georgia border to central Florida. The modern vegetation around the lake is dense live-oak scrub with ericaceous shrubs, dwarf palms, shrubby composites, and some pine. Watts divided

the pollen record from this site into three zones. Zone 3, dating from 37,000 to 13,010 BP, had high percentages of pollen from shrub taxa (*Ceratiola* and *Polygonella* spp.) that implied a dry climate. Zone 2 dates from 13,010 to 4715 BP and had high percentages of *Quercus* and *Ambrosia* pollen. This was interpreted by the author to indicate oak scrub and prairie vegetation in the uplands. Zone 1 spanned from 4715 BP to the present and was dominated by pine as well as unusually high percentages of *Myrica*. These changes from zone to zone indicated major shifts in available soil moisture and climate over the period spanned by the Lake Annie record, with drier conditions prevalent at the bottom of the core in Pollen Zone 3, transitioning generally to moister conditions through Zones 2 and 1 into the present day.

Pollen was analyzed in a core collected from Lake Tulane, Florida yielding a 50,000-year record of vegetation (Grimm *et al.* 1993, Watts and Hansen 1994). Shifts in *Pinus* and *Quercus* pollen indicated major changes in vegetation communities in the area. These vegetation changes appear to coincide with Heinrich events found in sediments of the North Atlantic. If events in the North Atlantic and Florida peninsula are related, this synchrony may reflect pulses in hemispheric cooling and the formation of polar ice. The periods with increases in *Pinus* pollen in the Lake Tulane record may also be caused by meltwater from the Laurentide Ice Sheet flowing down the Mississippi River and into the Gulf of Mexico, cooling sea surface temperatures in the gulf and producing a drier climate that favored *Pinus* (Grimm *et al.* 1993). Modern pine forests and wetland communities developed at about 4600 cal yr BP in South Florida.

Microscopic charcoal and pollen analyses were performed on a sediment core from Key Deer Pond on Big Pine Key, Florida (Albritton, 2009). Analysis of the microscopic charcoal indicated an increase in fire in the region around 1200 cal yr BP caused by increased frequency

of drought, overall drier conditions, or both. Pollen analysis indicated a decline in *Pinus* pollen and an increase in buttonwood mangrove (*Conocarpus erectus*) around 357 cal yr BP. Prior to this time, this plant had been almost completely absent from the record. This change may have been related to a change in the water table salinity, as well as sea level rise.

Sediment cores from tree islands in the Florida Everglades were collected to reconstruct tree island development and changes (Willard *et al.* 2006). The initial tree island communities were established as early as 3500 yr BP, with others forming as late as 600 yr BP. Tree islands expanded and merged into larger strand islands during periods of drought such as during the Little Ice Age, from 550–100 yr BP. Many of the periods of tree island development and expansion were found to correspond with late Holocene drought intervals documented in other paleoecological studies in the circum-Caribbean and tropical Atlantic (Willard *et al.* 2006; Hoddell *et al.* 2005, 2005; Haug *et al.* 2003). Hydrologic modification of the Everglades over the last 100 years altered the composition of tree islands recently, with less surface water leading to increased dominance of woody species in the plant community.

Previous paleoecological and paleoenvironmental research in the Bahamas

The first paleoecological record from the Bahamas Archipelago was provided by Kjellmark (1995, 1996). A 2 m long sediment core was taken from Church's Blue Hole on Andros Island, Bahamas. Andros Island is located 100 km east-southeast of the southern tip of Florida, and is the largest of the Bahamian Islands. Church's Blue Hole is a fresh-water-filled sinkhole in the northern part of the island that is 200 m across and 33 m deep. The eastern part of Andros Island is covered with pinewoods with scattered areas of tropical hardwood. Bahamian pine is the dominant tree species. The understory comprises poisonwood, cassada

wood, tetragia, and other tropical hardwoods that are kept from being canopy trees by frequent low-severity surface fires (Kjellmark 1996).

Kjellmark recovered the core from the center of the blue hole with a modified Kullenberg piston coring device that used a 3 m length of 2.5 cm PVC pipe. Pollen counting of core samples was done at 10 cm intervals and at 5 cm intervals where pollen assemblages showed rapid changes. Four hundred grains were counted, unless pine pollen made up more than half of the pollen spectrum. Then the count was continued until at least 200 non-pine pollen grains were found. Charcoal fragments were also counted after the pollen counting, and expressed as charcoal per cubic centimeter using the *Lycopodium* spike.

The seven radiocarbon dates from the core do not show a consistent depth-age relationship, making it difficult to infer patterns of vegetation and environmental change. The dates were obtained from well-washed terrestrial litter fragments extracted from the center of the core. Bulk sediment from the core could not be used because it is partly composed of algae that has incorporated fossil carbon containing bicarbonate from the limestone. Litter fragments in sediment at 98–109 cm depth were dated as younger than litter fragments in the sediment above at 85–89 cm. This may be caused by material that collected in a pocket in the wall of the hole, and later became dislodged and settling on top of younger sediment.

Pollen assemblages in the Church's Blue Hole core indicated a drier than present climate about 2000 years ago, with dry shrub vegetation represented by taxa such as members of the Sapindaceae family, Jamaican dogwood (*Piscidia*), and *Xylosma* dominating the area. About 1500 years ago, a mesic hardwood thicket, represented by higher pollen values of Palmae, *Metopium toxiferum* (poisonwood), and *Salvia bahamensis* (maidenbush), became dominant until it was displaced by the current pinewood vegetation starting about 900 years ago. This

most recent change coincided with an increase in charcoal, which suggested a change in fire disturbance patterns. It may coincide with the arrival of humans, although Kjellmark (1996) cautioned that climate shifts could not be ruled out.

Kjellmark also collected a 249 cm sediment core from Rainbow Blue Hole, dating back to about 1700 yr BP (Kjellmark 1995). The pollen record showed a large amount of pollen from the wetland species *Conocarpus erectus* (buttonwood) and *Achrostichum aureum* (mangrove fern) at the lower end of the core, indicating larger wetlands in the past. Wetland species gave way to more mesic taxa such as *Myrica* and *Exothea paniculata* (butterbough) from about 1500 to 800 years ago. Pine pollen and fern spores then increased along with charcoal concentrations, likely caused by an increase in fire frequency, from possible human-related activities. Pine pollen and charcoal decreased about 500 years ago, which is about the same time that the native humans were removed from the islands by Europeans.

Kjellmark collected a 270 cm sediment core from another site, Stalactite Blue Hole. The core dated to about 2400 yr BP, but did not show the same major pollen fluctuations as the other two sites. The pollen record and charcoal abundance suggested that the area around this site burned fairly often, and had for some time. The bottom part of the profile, from 270 to 80 cm, was dominated by pine, *Myrica*, *Trema*, and *Pteridium*. From 80 cm to 0 cm, *Trema* and *Pteridium* were less abundant, and *Conocarpus* became a dominant taxon. At 0 cm, *Chenopodium/Amaranthus* makes its first appearance in the profile, and *Ambrosia* and Gramineae reach their highest percentages.

Dix *et al.* (1999) recovered two cores from saline ponds formed on limestone bedrock on Lee Stocking Island, The Bahamas, for paleoenvironmental analysis. The ponds' surfaces were both a meter above mean sea level, and the ponds are thought to have been formed from the

enclosing of coastal embayments by long-shore sediment transport. The cores were obtained with a vibrating PVC pipe using compressed air. Samples from the core were taken at irregular intervals corresponding to changing lithology. They were analyzed for carbonate content, particle size composition, macroscopic shells identified to the genus level, and carbonate mineralogy. Energy dispersive spectrometry provided a qualitative assessment of the chemical composition of mud-sized sediment. The changes in biofacies in the cores suggested a trend towards increasingly hypersaline conditions, with abrupt interruptions of either marine water mixing or freshwater influx from changes in rainfall and evaporation conditions. The time of the formation of one of the ponds, ca 740–700 BP, coincided with an increase in precipitation in the northern Bahamas (Dix *et al.* 1999, Kjellmark 1996), indicating that the enclosing of the embayment was triggered by a change in wind and wave regimes (Dix *et al.* 1999).

Sally Horn, Ken Orvis, Allison Stork, and Lisa LaForest collected four overlapping core sections, each ca. 1 m long, for pollen analysis from West Pond, Abaco Island, The Bahamas in 2003 (Stork 2006). Radiocarbon dates showed the profile spans about the last 2100 years. Pollen was adequately preserved within the sediment and Stork (2006) found 24 different pollen taxa with diversity ranging from 2–15 different pollen taxa per level. The lower levels of the sediment profile were dominated by the pollen of broadleaf trees and shrubs. The percentage of *Pinus* pollen increased at 45 cm, and then made up well over two thirds of the pollen in upper levels of the profile. This indicated a distinct change in vegetation at West Pond, beginning about 800 cal yr BP. This shift occurred within an interval with high microscopic charcoal concentrations, as quantified using point counting. These higher charcoal concentrations may reflect the activities of humans. Stork (2006) interpreted an initial peak in charcoal at ca. 1190 cal yr BP to possibly signal the first arrival of humans on Great Abaco Island.

Horn, Orvis, and students also recovered a 280 cm-long sediment core from Split Pond on Abaco Island in 2003 (West 2007). Pollen preservation within the sediment core was generally poor, precluding detailed pollen analysis. Pine pollen was identifiably present within most levels processed from the upper 2.3 m of the profile, although it had suffered significant deterioration. Pine pollen concentrations were highest between 230 and 200 cm, with peaks of 70,000 grains/cm³ and 140,000 grains/cm³. Pine pollen concentrations were between ca. 25,000 and 50,000 grains/cm³ in the upper 200 cm of the core. The sediment core contained concentrations of microscopic charcoal roughly comparable to values at West Pond, and almost no macroscopic charcoal. West (2006) interpreted a peak in microscopic charcoal at ca. 1200 ¹⁴C yr BP to potentially correspond with similar evidence from West Pond (Stork 2006), and to indicate that humans may have arrived on Abaco Island near this time.

West (2007) collected samples of air-fall charcoal from a low-intensity controlled burn conducted in the pine rocklands of Abaco Island to improve interpretations of sedimentary charcoal records (West 2007). No macroscopic charcoal was present in the samples after processing. Microscopic charcoal was found in all of the downwind samples, but was completely absent from traps placed upwind of the burn. This demonstrates that no microscopic charcoal from regional sources contributed to the microscopic charcoal collected in the traps downwind of the burn, at least over the short sampling period. This finding suggested that microscopic charcoal concentrations in Split Pond may reflect local events and not regional ones. It also may help explain the rarity of macroscopic charcoal in sediment cores from Abaco Island. However, the controlled burn studied was a small scale and low-intensity fire, and a fire of different characteristics could lead to different patterns of charcoal deposition.

Miller (2007) studied fire history of the pine rockland forest of Abaco Island using tree-ring analysis. Fire-scarred trees and stumps were visually located and sampled around West Pond and Split Pond. The master chronology of Bahamian pine, originally developed by Lewis *et al.* (unpublished), was extended back to 1935. The fire interval in the study area ranged from 1 to 5 years and fires were likely anthropogenic in origin. The sample size of pines is very good for the period 1965–2003, but few trees older than that were found because of prior widespread logging on the island. The study documented the modern fire-prone ecosystem of Abaco Island. Statistical analyses of the samples revealed low-severity fires occur often and are widespread.

In other recent research that involved sediments and fossils in sinkholes, a variety of vertebrate and plant fossils were recovered from Sawmill Sink, a water-filled sinkhole on Great Abaco Island, located about 40 km from Emerald Pond, the site I studied (Steadman *et al.* 2007). Sawmill sink is a much deeper sink hole than Emerald Pond, with a distinct morphology of a bell-shaped profile and a well developed talus cone. The talus is mostly covered with peat, and is a rich source of micro- as well as macrofossils. The nearly circular opening of the formation has a diameter of 15.5 m. The fossils, discovered by divers, were well-preserved due to an anoxic marine water layer 27 meters below the surface. Plant macrofossils of *Pinus caribaea*, Gramineae, and various ferns and fern allies were found within the debris submerged in the formation. A shift in the assemblage of macrofossils was interpreted as evidence that Abaco Island was dominated by a grassy pineland plant community in the late Pleistocene, with a larger coppice component coming in during the late Holocene, but no dates were obtained on the macrofossils. Pollen analysis was performed on peat collected from an undated tortoise shell found within the sink hole. The pollen taxa identified in the peat are all still present in the modern flora of the island, such as wax myrtle (*Myrica*), many flowering herbs (Asteraceae), and

Bahamian pine. A human tibia and sacrum were found within the debris inside Sawmill Sink, and radiocarbon dating performed on the tibia yielded an age of 1040 ± 40 ^{14}C yr BP (ca. 1050 to 920 cal yr BP). This is the earliest direct evidence of human presence in the Northern Bahamas. The Sawmill Sink finds also included fossil remains of several species of tortoise, lizards, snakes, crocodiles, and birds, many of which are currently not found on Abaco Island, but found instead in Cuba.

CHAPTER THREE

ENVIRONMENTAL AND CULTURAL SETTING

Study area

The Bahamas archipelago is over 1000 km long and is composed of 730 islands and cays, as well as thousands of rock islets with a total land area of 14,365 km² (Britton and Millspaugh 1962; Berman and Gnivecki, 1995; Figures 3.1, 3.2). The Commonwealth of the Bahamas is composed of the northern and central land bodies including 29 islands and over 600 cays. The Turks and Caicos Islands are composed of the southern 40 islands and cays. The majority of the population of the Bahamas lives on the largest of the islands such as Great Bahamas, Andros, and Great Abaco, as they offer the most resources. My study site, Emerald Pond (26° 32' 12" N, 77° 06' 32" W; Figure 3.3), is a solution hole with vertical rock walls and a water surface about 4 m below the ground surface of the surrounding rockland (Figure 3.4) on Great Abaco Island. In January 2006, the water depth was approximately 2.6 m, but showed some diurnal changes driven by the tidal cycle (S. Horn, personal communication). The vertical walls suggest it is a solution/collapse feature similar in origin to a typical blue hole, but blue holes are generally tens of meters deep and extend through the freshwater table and through an acidic aquacline into the seawater table (K. Orvis, personal communication). This is not the case at Emerald Pond. More likely, Emerald Pond is a nascent blue hole in which collapse debris jammed the opening at moderate depth, resulting in a freshwater (albeit slightly tidal) pond only several meters deep, instead of being tens of meters deep (K. Orvis, personal communication).



Figure 3.1: Map of Caribbean Sea and tropical Atlantic ocean showing the location of The Bahamas. (www.cia.gov)



Figure 3.2: Satellite image of portions of The Bahamas, Florida, and Cuba. (NASA)

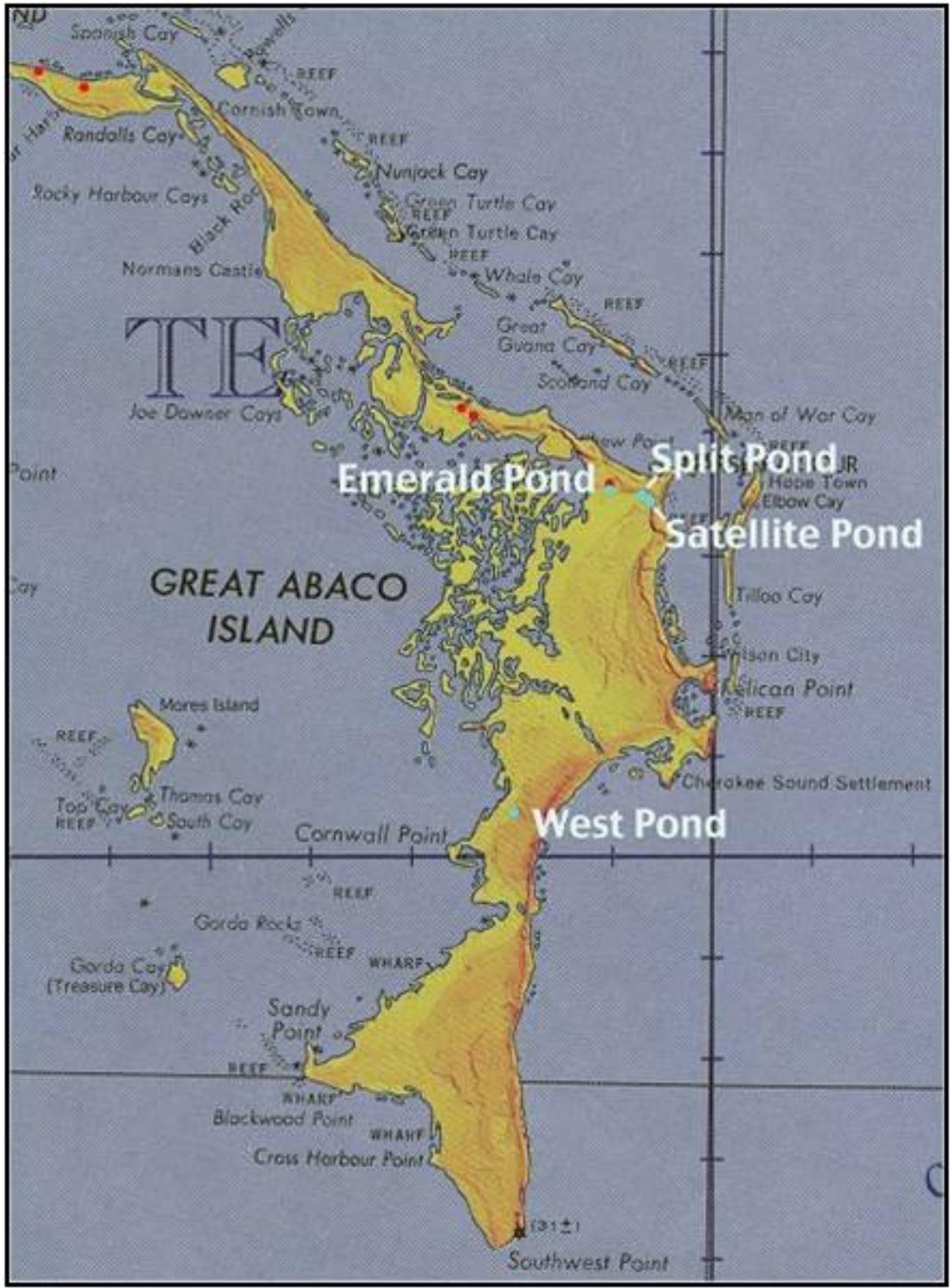


Figure 3.3: Location of Emerald Pond and other sediment coring sites on Great Abaco Island, The Bahamas (light blue dots). Red dots indicate selected tree-ring sampling sites for work led by H. Grissino-Mayer. Map created by K. Orvis.



Figure 3.4: Emerald Pond, Great Abaco Island, The Bahamas, showing the platform positioned for coring. Photograph by S. Horn.

Geological and physiographic setting

The Bahamas are non-volcanic islands composed of oolitic calcium carbonate that accumulated on an underlying platform of limestone (Dodge 1995; Hearty 1998). The landscape has a maximum elevation of no more than 100 m and is dotted with karst features, such as caves and sinkholes (Correll 1979). The limestone bedrock is often exposed and deeply weathered with pits and fissures. No surface streams occur on any of the islands as water quickly drains to the underlying water table (Correll 1979). But marshes, ponds, and solution holes occur where the water table intersects the land surface. These wetlands are of varying salinity. Saline ocean holes also occur offshore.

The underlying stratigraphy of The Bahamas is actually a record of sea level change over the past several hundred thousand years (Hearty 1998). Layers of sandy reddish paleosols represent remnants from a time of lower-than-present sea level when carbonate sand dunes cemented and formed hard crusts (Hearty and Kaufman 2000). The more widespread pitted limestone bedrock is from periods of higher-than-present sea level and formed by either coral or oolitic processes. Sand beaches and dunes were formed when sea level dropped, exposing reefs and the banks. Wind deposited oolitic sand from these structures and the sand collected into dunes. These dunes would sometimes form crusts and cement into ridges (Hearty and Kaufman 2000). During times of lower sea level, many of the islands on the same banks were connected, but no connection ever existed to mainland North America (Correll 1979, Kjellmark 1995).

Climate

The amount of precipitation The Bahamas receive varies by latitude. The northern islands receive the most precipitation, while the southern islands are relatively arid (Correll and

Correll, 1982). Temperatures remain temperate and well above freezing in the winter, and are tropical in the summer. Yearly highs on Abaco Island rarely exceed 34° C and yearly lows rarely fall below 14° C (Dodge 1995). No orographic rainfall occurs on Abaco Island due to the lack of significant elevation, although the difference in meteorological roughness and heat capacity between the sea and the land can lead to the development of convectional systems. Precipitation is higher in summer than winter, caused by convectional storms and tropical systems. Frontal systems do bring occasional rainfall in the winter. Abaco Island receives an average of 1400 cm of rainfall a year (Dodge 1995).

Vegetation

The Bahamian Archipelago is low-lying group of islands and cays with a dry tropical climate, with many similarities to southern Florida in terms of appearance and vegetation communities. The main methods of plant dispersal are strong winds and hurricanes, water, avian fauna, and human activities (Correll and Correll 1982). The lack of physical relief and scarcity of fresh water limits the relative diversity in habitat, but the difficult environment still holds a surprising diversity of plant species. Most of the archipelago's flora originated from Cuba and Florida, with only 9 % of The Bahamas' plant species being endemic. Some of these endemic species, such as pteridophytes (brake fern (*Pteris vittata*) and maiden fern (*Thelypteris augescens*)), require the moist environment of solution pits and banana holes to survive (Correll and Correll 1982). These sinks are the locations with the largest number of species, although no one species necessarily occurs in every one of them.

The Bahamas have a variety of plant communities, including a coastal rock community, coastal hardwood thickets and coppices, pine savannas, pine rockland, and freshwater swamps.

Coastal rock communities exist on rock formations interspersed and exposed to the erosive forces of the sea. The vegetation of this community is characterized by stunted shrubs such as bay marigold (*Borrichia arborescens*) (Correll and Correll 1982). Coastal coppice can be found just beyond the high tide mark, and is composed of a variety of species that may or may not be present in a particular stand, including silver palm (*Coccothrinax argentea*), wild cherry (*Malpighia polytricha*), wild saffron (*Bumelia americana*), and poisonwood (*Metopium toxiferum*), among many others.

The dominant vegetation type on Abaco Island is pine rockland vegetation (Correll and Correll 1982; Kjellmark 1995). The upper canopy is made up of Bahamian pine. The understory is made up of tropical hardwoods, such as poisonwood, chicken toe (*Tabebuia bahamensis*), and cassada wood (*Bumelia salicifolia*), together with saw palmetto (*Serenoa repens*). Savannas are open and flat areas dominated by sawgrass (*Cladium jamaicensis*). Occasional stands of silver palm (*Coccothrinax argentata*) and brier tree (*Bucida spinosa*) are scattered throughout. The transitional communities between the pine rocklands and savannas are the freshwater swamps, where the water table is at the surface. Buttonwood mangrove, myrsine (*Myrsine floridana*), bush iva (*Iva cheranthifolia*) and other shrubs make up the vegetation. Pinelands are maintained by frequent low-intensity ground fires that can occur throughout the year (Kjellmark 1995). These fires can be triggered by winter and summer lightning strikes, or by humans (Myers *et al.* 2001). The fires are sometimes intentionally set for pig hunting, or can escape from agricultural and domestic sources. Bahamian pine is adapted to frequent low-intensity fire, with thick bark, needle clusters, and high open canopies (Miller 2007). Pinelands with an understory dominated by bracken fern (*Pteridium aquilinum*) are thought to have a higher fire frequency than other stands (Myers and Bergh 2004).

Pre-Columbian human history

The Bahamas were first populated by the Lucayan Taino, who were related to the Taino people of the Greater Antilles. The Taino had moved into the Caribbean about 2500 yr BP from the Orinoco River in present-day Venezuela, passing over the Lesser Antilles along the way and settling the larger islands which were already inhabited by the Casimiroid people (Keegan 1992; Berman and Gnivecki 1995). The Bahamas were the last island area in the Circum-Caribbean region to be settled when the Lucayan Taino first began to inhabit the Bahamas about 1350–1150 yr BP (Berman and Gnivecki 1995). These original settlers may have left Hispaniola and Cuba during a period of drought that threatened their subsistence agriculture, and that in combination with possible population pressures made migration to then-uninhabited and exploited lands enticing (Keegan 1992). The migration may have occurred in waves. Return voyages likely occurred, to share information and retrieve more resources that may not have been available in the new land (Berman and Gnivecki 1995). Large crews were likely used to overcome the strength of the Florida Current on return trips, giving them enough paddling power (Seidemann 2001). Despite the relatively arid conditions on many Bahamian islands, it is thought that the undisturbed soil would have been fertile enough to support root-crops such as manioc. The early settlers of the islands brought several crops with them, such as sweet potato, chili pepper, guava, cotton, tobacco, and manioc. While the Taino people living on the Greater Antilles grew maize, there is no evidence of people bringing it to The Bahamas (Keegan 1992).

Land on Bahamian islands was cleared for planting seed and root crops via slash and burn techniques (Berman and Pearsall 2000). The densest populations occurred on the islands best suited for the growing of these non-native crops, which were the more central and northern

islands (Sears and Sullivan 1978). Native land animals, such as the hutia (*Geocapromys ingrahami*), were hunted for food. These small mammals probably existed in fairly high numbers when humans first arrived due to the lack of predators. Land crabs and occasionally birds were also hunted. The drier southerly islands may have been passed up during initial settlement, and only settled later at a time of wetter conditions. The Lucayan typically chose the higher points of a given island to build their settlements. Lithified dune structures on the eastern sides of the islands, especially areas with easy access to protected coves, seem to have been the areas of choice (Keegan 1992). These sites would provide easy access to the beach for foraging and traveling, as the forest and marshy areas of the island were difficult to traverse.

Very little appears to be known about prehistoric occupation on Abaco Island specifically. Keegan (1997) mentioned a burial site found underwater, in a submerged cavern. No remains of the individual were actually found, only the canoe it was sent on. Keegan (1997) also referenced an oar that was found near a sink hole on the island, but did not identify the sink hole. The human remains recovered from Sawmill Sink (Chapter 2) and dated to between 1050 and 920 BP constitute the earliest physical evidence of human presence of Abaco Island.

Post-Columbian history

European contact first occurred in 1492, when Christopher Columbus reached the island of San Salvador in the Bahamas (Berman and Gnivecki 1995). No colonies were built by the Spanish. Over the next 30 years, the natives were taken as slaves to mines on Hispaniola or to Spain, in a process that eventually completely removed the native population. The islands were used only by pirates and smugglers for a period of time, until the English permanently colonized the islands in the 1700s (Dodge 1995). Some of the loyalists to the British monarchy from the

North American English colonies traveled to The Bahamas to escape persecution after the American Revolution, and to remain subjects of the King.

Small-scale agriculture was reasonably successful on the islands, but the growth of settlements and the shipbuilding industry led to an increase in the need for timber. Bahamian pine was often used to build ship masts. Export timber and paper industries also eventually developed, causing subsequent deforestation in large areas of the larger islands. The Bahamas Timber Company began to export Bahamian pine from Great Abaco Island in the early 1900s (Dodge 1995). The company employed 12% of the population of Abaco Island by 1912. The distance from the stands being cut and the mill grew as more trees were removed, and by 1916 the mill closed due to the rising cost of transporting the timber over land. Despite a large portion of Great Abaco Island being deforested from these previous operations, two other smaller logging companies began operating just a few years later. Widespread logging on the island began again near the middle of the 20th century under the Owens-Illinois Corporation. Owens-Illinois also operated sugar plantations on Abaco, and caused other large impacts on the landscape of Abaco Island by building an airport and dredging a channel for a shipping terminal. In their logging operations, the company left five seed-bearing trees per an acre, in an effort to allow stands to recover after harvesting them. Much of the stands of Bahamian pine on the island today are even-aged and relatively young, the result of natural regeneration from seeds of these seed trees left after logging.

CHAPTER FOUR

THE EMERALD POND CORE AND METHODS OF POLLEN ANALYSIS

An 8.7 m long sediment core was recovered from Emerald Pond in January 2006 by a coring team consisting of Dr. Sally Horn, Dr. Ken Orvis, Allison Stork, and Sarah Deane. The core was collected from a floating platform positioned near the center of the lake, with anchor lines attached to eyebolts wedged into the rock wall at water level. The watery, uppermost sediments from 0–73 cm in the profile were collected with a mud-water interface (MWI) corer fabricated by Jason Curtis, using a design modified from Fisher *et al.* (1992). The MWI core was extruded on the platform in 1-cm intervals, with samples placed in zipper-top plastic bags for return to the University of Tennessee. The deeper sediments were recovered with a Colinvaux-Vohnout (C-V) locking piston corer (Colinvaux *et al.* 1999), in nine successive sections starting at 50 cm in the profile. The C-V core sections were returned to the lab in their original aluminum tubes.

The aluminum core tubes were opened in the Laboratory of Paleoenvironmental Research by S. Horn and K. Orvis. The tubes were sliced longitudinally in half, using a specialized router, and the sediment core section in each tube was sliced longitudinally using a thin wire. Core sections were photographed by S. Horn and described on core logs by K. Orvis. The core logs noted sediment type, texture, and Munsell colors (Table 4.1). One half was held in reserve for archival purposes. The other half of each core section was sampled for pollen analysis and loss-on-ignition (LOI) (Dean 1974) analysis at 8 to 16 cm intervals. Ten levels from the MWI core were also sampled for pollen and LOI analysis.

Table 4.1: Stratigraphy of the Emerald Pond core (based on core logs by K. Orvis)

Depth in Profile (cm)	Sediment Description	Munsell Color
<i>Mud-water interface core (excluding overlap with first C-V core section)¹</i>		
0–1	Pale brown, very loose sediment	10 YR 2/4 to 8/4
1–3.5	Variably greenish sediment showing chlorophyll	
3.5–14	Brown or greyish brown watery sediment.	10YR5/2, 10YR 6/2
14–41	Slightly firmer sediment with carbonate sand (especially from 17–18 cm) and abundant macrofossils including pine needles, a pine cone, and bark and twigs from pines or other trees	10YR5/2, 10YR 6/2
41–50		10YR 4/2 to 10YR 2/2
<i>C-V core sections</i>		
50–58	Sandy, organic-rich marl with mottles, interbedded macrofossils, and some laminae	10YR2/1 to 10YR8/4
58–63	As above but without visible layering	10YR2/1 to 10YR8/4
63–65.5	Thin laminae	10YR1/1 to 10YR4/3 10YR6/2 to 10 YR8/3
65.5–74	Mixed organic-rich material with sparse sand and shells	10YR1/1 to 10YR4/3, 10YR6/2 to 10YR8/3
74–150	Banded marl, rare sand and shell fragments	10YR6/1 to 10YR8/1, 10YR6/3 to 10YR8/3
150–159	Black organic debris with vaguely laminated marl	10YR6/2, 10YR4/2, 10YR7/3
159–192	Tightly laminated marl with rare sand and occasional organic macrofossils	7.5YR4/2 to 10YR7/2
192–194.5	Marl with sparse sand, no laminae	7.5YR6/3

Table 4.1 continued

Depth in Profile (cm)	Sediment Description	Munsell Color
194.5–250	Tightly laminated marl with rare sand and occasional microfossils	5YR3/2 to 10YR8/2
250–315	Loose marl with few organic macrofossils and sparse sand	10YR6/2, 7.5YR6/3 10YR5/2 to 10YR8/2
315–331	Slightly firmer marl with few organics	10YR6/2
331–350	Loose marl with some organic components	7.5YR5/2, 10YR7/2
350–444	Soft marl with mostly silt-sized particles, possibly gypsic	10YR6/3 to 7.5YR6/3 to 2.5Y7/3
444–448	Marl with distinct laminae	
448–450	Soft silty marl	10YR6/3 to 7.5YR6/3 to 2.5Y7/3
450–459	Sticky clay-silt marl with no laminations	10YR4/2 to 10YR7/3
459–546.5	Tightly laminated marl with coarse silt, organic macrofossils present	10YR6/2 to 10YR7/2, 7.5YR6/6, 7.5YR6/2, 7.5YR6/3
546.5–631.5	Silty soft marl with alternating zones of yellow and green colors, weakly laminated in some intervals, with some organics and shells	10YR7/2, 5GY7/1, 10YR3/2, 10YR3/1, 10YR5/1,
631.5–633.5	Gap	
633.5–646.5	Silt-sized marl with sparse sand-sized clasts, colors fade slowly between shades	2.5Y7/3, 5Y6/3, 10YR7/3, 5GY6/1
646.5–680.5	Silty marl with sparse sand-sized clasts, mottled coloring	5Y7/2, 10YR8/3, 2.5Y7/2 to 5G5/1

Table 4.1 continued

Depth in Profile (cm)	Sediment Description	Munsell Color
680.5–724.5	Silty marl with coarsely banded colors, occasional lines of black organics and fragile shells	2.5Y7/2, 10YR7/4, 2.5Y5/3, 10YR6/4 to 10YR7/4
724.5–733.5	Silt-sized dense marl with sparse sand-sized clasts	2.5Y6/3, 10YR6/3
733.5–756	Firm silty marl with few shell fragments and macrofossils, transitioning to sandy marl and then to soft fine-silt marl	10YR7/3, 2.5Y4/2 to 5G6/1
756–790.5	Soft silty marl banded in greens and yellows, some freshwater gastropods and other macrofossils present	5G6/1 to 5GY8/1
800–803.5	Fiber-rich banded organic marl	2.5Y5/3 to 10YR3/4
803.5–805.5	Void	
805.5–812	Pink carbonate marl with rare organics transitioning to firm sandy marl	7.5YR7/2, 5Y5/3 to 10YR7/3
812–814	Fibrous marly organics	10YR6/2 to 10YR4/1, 10YR2/2
814–819	Gap	
819–829	Fibrous organics and fibrous marl	10YR6/2 to 10YR 4/1 5Y4/1, 5Y5/2
829–840	Stiff marl with shells	10Y4/1 to 5GY6/1 to 5Y7/3
840–860	Marl with organics and shells	10YR2/1, 5YR2.5/3
860–868	Sandy soil with carbonate pebbles	10Y3/1

¹Munsell colors for the mud-water interface core were recorded by S. Horn in July 2010 based on field notes and inspection of bagged sediment and are less precise than colors recorded for the C-V core sections immediately upon opening the core tubes.

The loss-on-ignition values corresponded well with the core stratigraphy (Figure 4.1). The marl at the top of the core is organic-rich, with LOI values greater than 50% at 49 cm below the top of the mud-water interface. From about 53 cm in the profile to the lower end of the core at 800 cm, organic matter content is low, mainly between 2% and 5% in these generally silty marls, with peaks of 11% at 253 cm and 7% at 416 cm of depth. The peak at 253 cm corresponds to a loose marl with distinct organic components. Below 800 cm, the stratigraphy suggests shallow-water to seasonally-flooded to largely dry soil at the very bottom of the core. The LOI values in this section are high, with peaks of 55% at 822 cm and 85% at 853 cm. Some sections of the upper 800 cm of the Emerald Pond core show laminations that may be annual, but I did not make use of these laminations in my pollen study.

S. Horn selected ten macrofossils from the MWI and C-V core sections for radiocarbon determinations. The macrofossils were dated using Accelerator Mass Spectrometry (AMS) dating by Beta Analytic Laboratory in Miami, Florida. Results show a normal stratigraphic order, with one modern date on pine needles at 38.5 cm in the profile that we reject. We interpret the presence of modern pine needles at this depth in the profile as due to the intrusion of a branch with needles on a pine trees that fell into the lake (Horn *et al.* in prep.). The record as a whole spans 8400 calibrated years (Table 4.2, Figure 4.2). The prior study of microscopic charcoal in the Emerald Pond core (Horn *et al.* in prep.) revealed that charcoal concentrations were variable but in general higher by a factor of 2 than values in the West and Split Pond profiles. The highest charcoal concentrations (ca. 300–400 mm²/cm³) occur from 48–58 cm in the profile, corresponding to the period from about 610 to 820 cal yr BP.

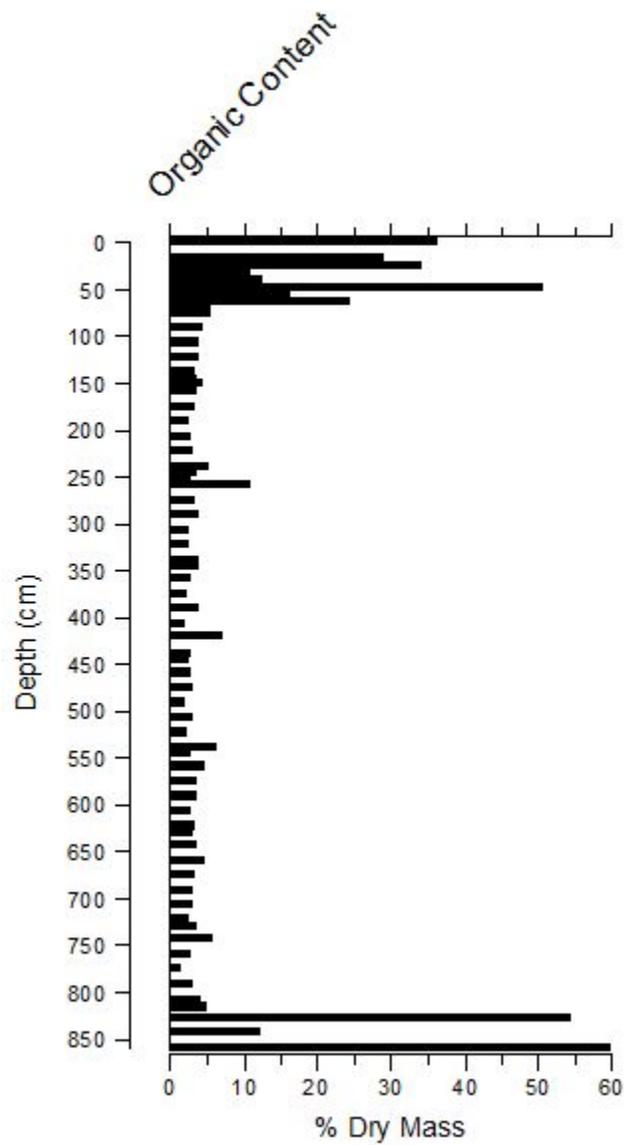


Figure 4.1: Organic content for sediments in the Emerald Pond profile, as estimated from loss-on-ignition at 550 °C. The uppermost value is that of a surface grab sample collected by diving in 2003, prior to lake coring. The bars is truncated for the basal sample, which has an organic content of 85.2% calculated on a dry mass basis (Horn *et al.* in prep.)

Table 4.2: AMS radiocarbon determinations and calibrations for the Emerald Pond core sections
(Horn *et al.* in prep.)

Lab number ^a	Depth (cm)	Material dated	$\delta^{13}\text{C}$ (‰)	^{14}C yr BP	Calibrated age range ^b $\pm 2\sigma$ (cal yr BP)	Area under probability curve	Wt mean ^c
B-228996	38.5	Pine needles	-30.2	114.6 \pm 0.4 pMC			
B-274755	54.5	Leaf fragments	-28.5	760 \pm 40	743–656 761–753	0.873 0.009	697
B-274754	64	Leaf fragments	-29.6	1120 \pm 40	1095–936 1140–1103 1168–1161	0.921 0.068 0.011	1028
B-214532	71.5	Wood (stick)	-26.1	1920 \pm 40	1763–1736 1949–1769 1967–1963	0.037 0.957 0.006	1863
B-239089	111	Plant fragments	-27.9	2110 \pm 40	1958–1953 2158–1987 2175–2174 2299–2251	0.004 0.924 0.001 0.071	2089
B-233108	222.5	Pine needles	-21.5	2820 \pm 40	2818–2803 3064–2844	0.016 0.984	2926
B-227840	423	Wood (stick)	-26.3	4590 \pm 40	5187–5055 5223–5215 5242–5237 5331–5263 5460–5375	0.280 0.006 0.004 0.393 0.316	5289

Table 4.2 continued

Lab number ^a	Depth (cm)	Material dated	$\delta^{13}\text{C}$ (‰)	^{14}C yr BP	Calibrated age range ^b $\pm 2\sigma$ (cal yr BP)	Area under probability curve	Wt mean ^c
B-227841	496.5	Leaf	-25.4	5100 \pm 40	5921–5746	1.000	5829
B-227842	742	Wood (charred)	-25.4	6910 \pm 40	7833–7671	1.000	7742
B-217276	860	Wood (stick)	-28.7	7630 \pm 50	8540–8369	1.000	8436

^aAnalyses were performed by Beta Analytic Laboratory in Miami, Florida.

^bCalibrations were calculated using CALIB 5.0.1 (Stuiver and Reimer, 1993) and the dataset of Reimer *et al.* (2004).

^cWeighted mean of the 2σ calibrated radiocarbon probability distribution.

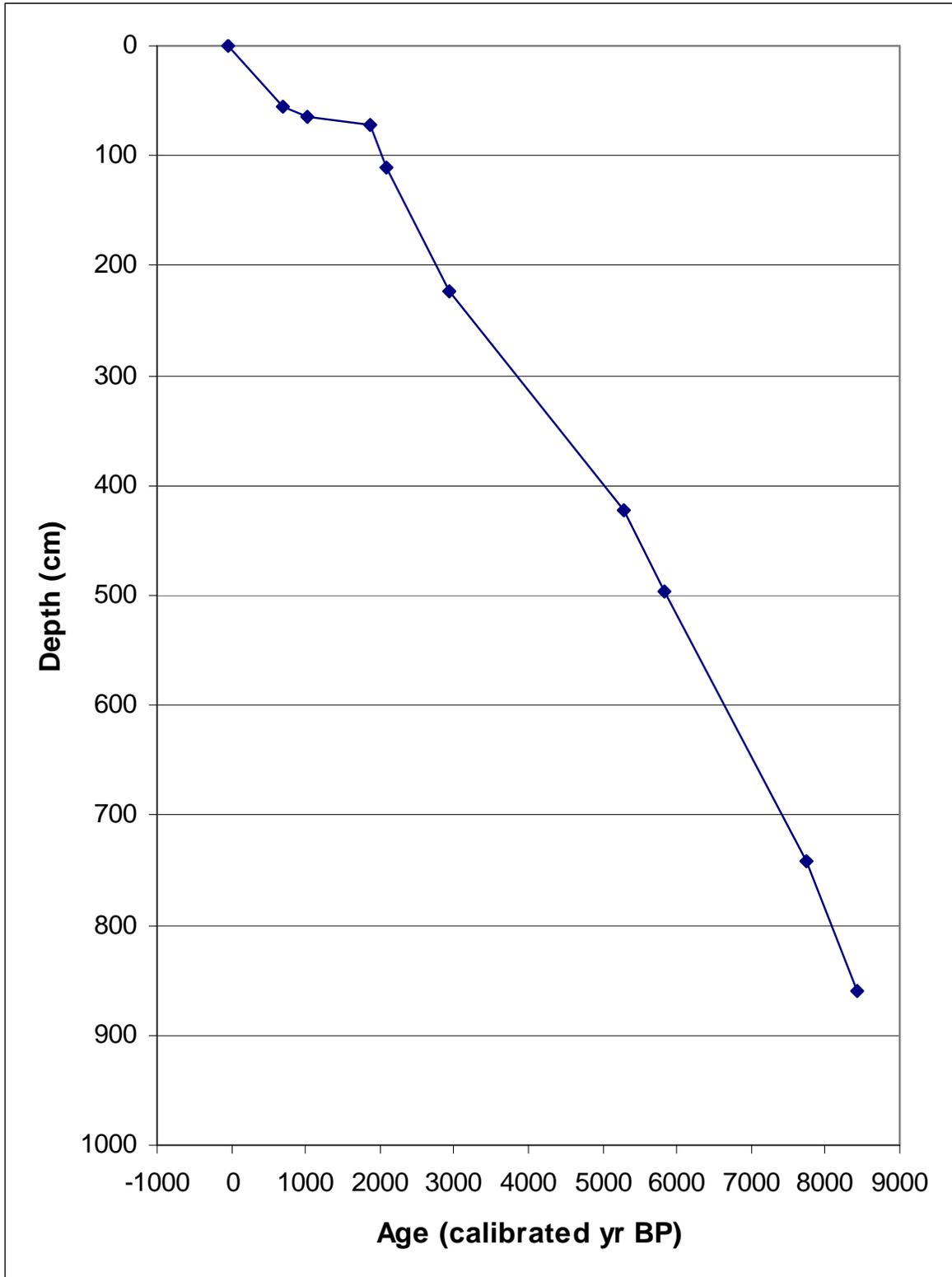


Figure 4.2: Age/depth diagram for the Emerald Pond sediment profile.

Pollen Analysis

Working under the direction of S. Horn, A. Stork processed 68 samples from the Emerald Pond core for pollen analysis. Several batches were processed using the method most commonly used for tropical sediments in our Laboratory of Paleoenvironmental Research (Appendix A), but later the decision was made to use a modified version of this method that included a nitric acid step (Appendix B). This decision was made to try to produce “cleaner” pollen samples that would have less obscuring organic matter and therefore be easier to count. For my study of vegetation history based on pollen analysis, I identified and counted pollen on slides from 24 levels in the Emerald Pond profile. Some of the levels did not have adequate pollen on the slides to be counted, so I only included the slides with more abundant pollen. Of the levels counted and included in the pollen diagram, nine were processed without the nitric acid step and 15 were processed using the nitric acid step. Based on unpublished experiments conducted in our lab by M. Caffrey, the added nitric step is unlikely to have affected the pollen percentage data (Caffrey, unpublished data). These differences in processing could affect microscopic charcoal concentrations, but for the prior study of microscopic charcoal we only used slides with residues processed identically using the nitric acid step.

I counted grains at 400x magnification to a minimum of 250 pollen grains, exclusive of indeterminate pollen grains and fern spores. I identified pollen grains to the lowest taxonomic level possible using pollen reference slides in our lab collection, the online *Key to Pollen of the Bahamas* (Snyder *et al.* 2007), and the *Atlas of Pollen and Spores of the Florida Everglades* (Willard *et al.* 2004). Taxonomy follows Correll and Correll (1982). Indeterminate pollen grains were classified as either physically corroded or damaged so as to lack definitive diagnostic features, or concealed by detritus. Indeterminate pollen grains made up a very small percentage

of the total pollen sum. I sketched and described all unknown pollen grains for later examination. Fern spores were classified by morphology.

To help interpret the pollen spectra in the Emerald Pond core, I examined descriptions of plants whose pollen I found, in floras and other books on Bahamian vegetation, including *Bahama Flora* (Britton and Millspaugh 1962) and *Flora of the Bahama Archipelago* (Correll and Correll 1982). A general description for each of the taxa identified in the pollen record was made at the appropriate taxonomic level (Appendix C). I compiled all pollen and LOI data into spreadsheets and constructed pollen diagrams using the C² software designed for ecological and paleoecological data analysis (Juggins 2003). Pollen concentrations were estimated based on counts of *Lycopodium* control spores added during pollen processing (Stockmarr 1971), using this formula:

$$\frac{\text{Total pollen counted}}{\text{Volume of pollen sample}} \times \frac{\text{Lycopodium spores added}}{\text{Lycopodium spores counted}} = \text{Pollen concentration (grains/cm}^3\text{)}$$

To provide a rough estimate of pollen concentrations for the levels of the core from which prepared pollen slides contained too few pollen grains for practical counting, I did quick counts of pollen, fern spores, and control spores on 44 slides. On these slides I counted pollen on transects near the middle of the cover slips until I reached a count of 10 *Lycopodium* control spores. Pollen concentrations were calculated using the formula above.

CHAPTER FIVE

RESULTS

Pollen concentration and preservation

Pollen preservation varied through the profile. Microscope slides for the levels not included in my thesis had few pollen grains and the grains that were present looked tattered and torn. On the 44 slides for which I did quick counts to assess pollen concentrations, the average roughly estimated concentration was about 10,000 pollen grains/cm³. The more securely estimated concentrations for the levels for which I did full pollen counts averaged just over 24,000 pollen grains/cm³ (range 10,000 to 75,000 grains/cm³ (Table 5.1)). On these counted slides, pollen was fairly well preserved. Indeterminate pollen grains made up less than 2% of the total pollen including indeterminates, with most grains classified as indeterminate because they were broken.

Pollen and spore types and diversity

I identified 63 different pollen types in the sediment profile from Emerald Pond. Ferns spores were rare, accounting on average for less than 0.5% of the total pollen and spores in the levels counted. Pollen diversity ranged from five to 23 identified pollen types in each level (Table 5.2). The upper middle of the profile (358–106 cm depth) had the lowest pollen diversity, while the bottom sample of the core had the largest number of identified pollen taxa. However, these data have not been subjected to rarefaction analysis to adjust for the differing pollen sums, and do not include unknown pollen types. Hence, they are only a very approximate indication of the pollen diversity in the Emerald Pond samples.

Table 5.1: Pollen concentrations (grains/cm³) for the Emerald Pond profile.

Depth (cm)	Pollen Concentration
0	41,031
16	22,759
32	15,144
40	19,185
56	25,201
58	23,215
64	44,321
70	24,874
106	14,240
150	26,745
158	10,153
238	14,258
250	27,718
274	17,821
358	15,105
390	21,433
458	21,736
490	17,840
538	32,927
557.5	21,537
573.5	21,330
605.5	12,892
641.5	11,378
843	75,488

Table 5.2: Pollen diversity for the Emerald Pond profile. The pollen sums ranged from 250–369 pollen grains in each sample. Unknown pollen types are excluded from the diversity value.

Depth (cm)	Number of different pollen types
0	12
16	7
32	8
40	15
56	11
58	17
64	9
70	13
106	17
150	7
158	11
238	13
250	8
274	10
358	5
390	9
458	16
490	15
538	11
557.5	11
573.5	16
605.5	14
641.5	14
843	23

Pollen stratigraphy

Large changes in pollen percentages occur over the Emerald Pond record (Figures 5.1, 5.2). For purposes of discussion, I divided the record into two zones based on major pollen shifts. I describe the zones below. Ages are based on linear interpolations using the weighted means of the probability distributions of the calibrated ages (Table 4.2).

Zone 2 (843–106 cm) 8336–2060 cal yr BP

The lower part of Zone 2 includes a sampling gap of just over one meter between the lowest level counted (843 cm, interpolated age 8336 cal yr BP) and a sample at 641.5 cm (ca. 6959 cal yr BP). Slides prepared for pollen analysis from this part of the core contained too few pollen grains or too much obscuring debris for practical counting. Rough estimates of pollen concentrations on these otherwise uncounted slides showed pollen concentrations between 2700 and 9700 grains/cm³ (Figure 5.2). The pollen assemblage in the bottom sample of the core has the highest pollen diversity and highest percentages of *Myrica* and *Rhizophora* pollen in the record, but both decline above the gap to low percentages by the middle of Zone 2. Rubiaceae pollen also declines upward in Zone 2. Cyperaceae pollen is prominent throughout the zone. *Pinus* and Palmae percentages are at their lowest in the profile at the bottom of the core. *Pinus* generally increases from 22% at the lowest level to 68% at 150 cm, before a decline to 36% at the Zone 2/1 boundary. Above the gap between 843 and 641.5 cm, Palmae consistently accounts for about 25% of the pollen sum. The aquatic plants Polygalaceae and *Typha* show small peaks in Zone 2 and at the Zone 2/1 boundary.

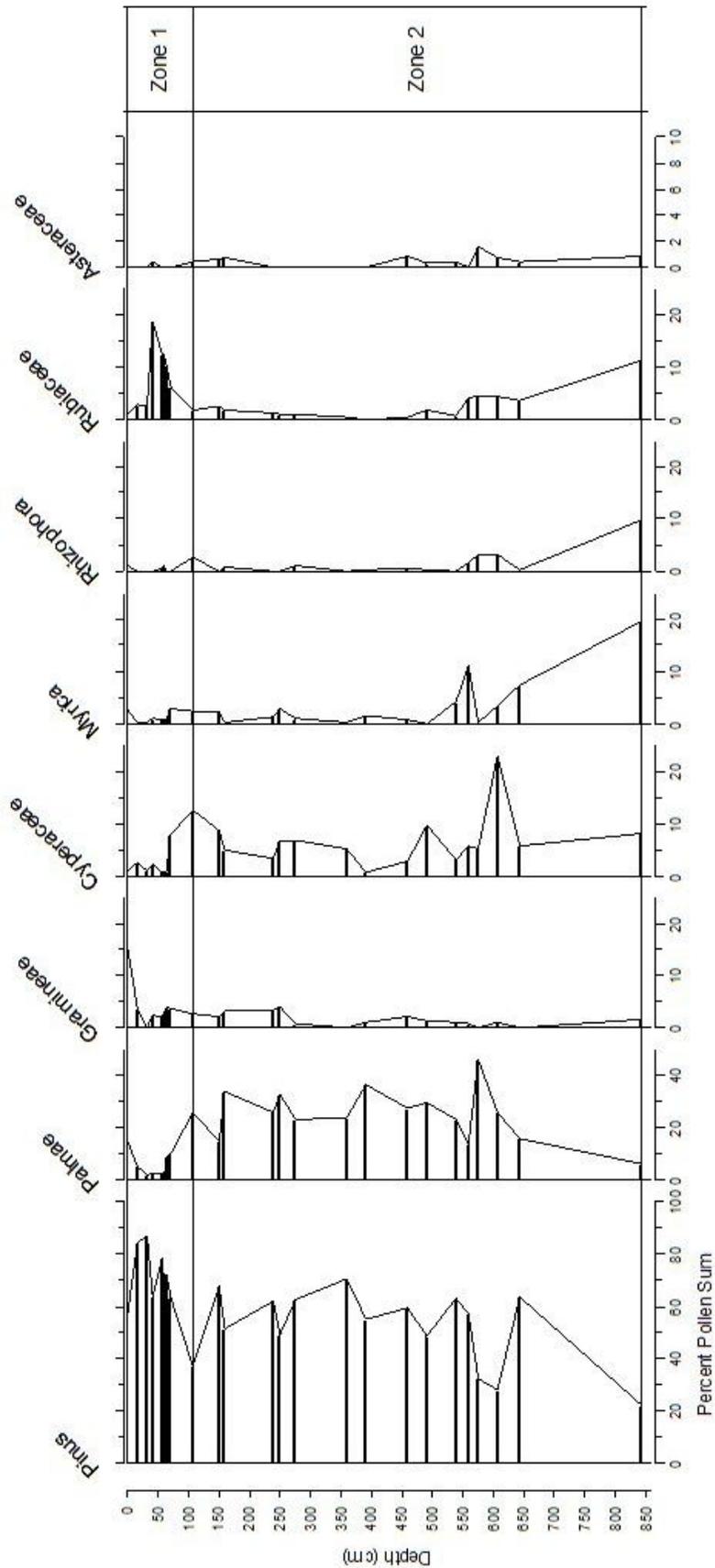


Figure 5.1: Pollen diagram for the Emerald Pond sediment profile. Bars show counted pollen samples. Zones were delineated for discussion purposes. Zone 2 is from 843–106 cm and Zone 1 is from 106–0 cm. No samples were counted between 641.5 and 843 cm because pollen slides had very few grains on them or were difficult to count because of obscuring debris. The pollen sum for all taxa in this figure excludes indeterminates and fern spores.

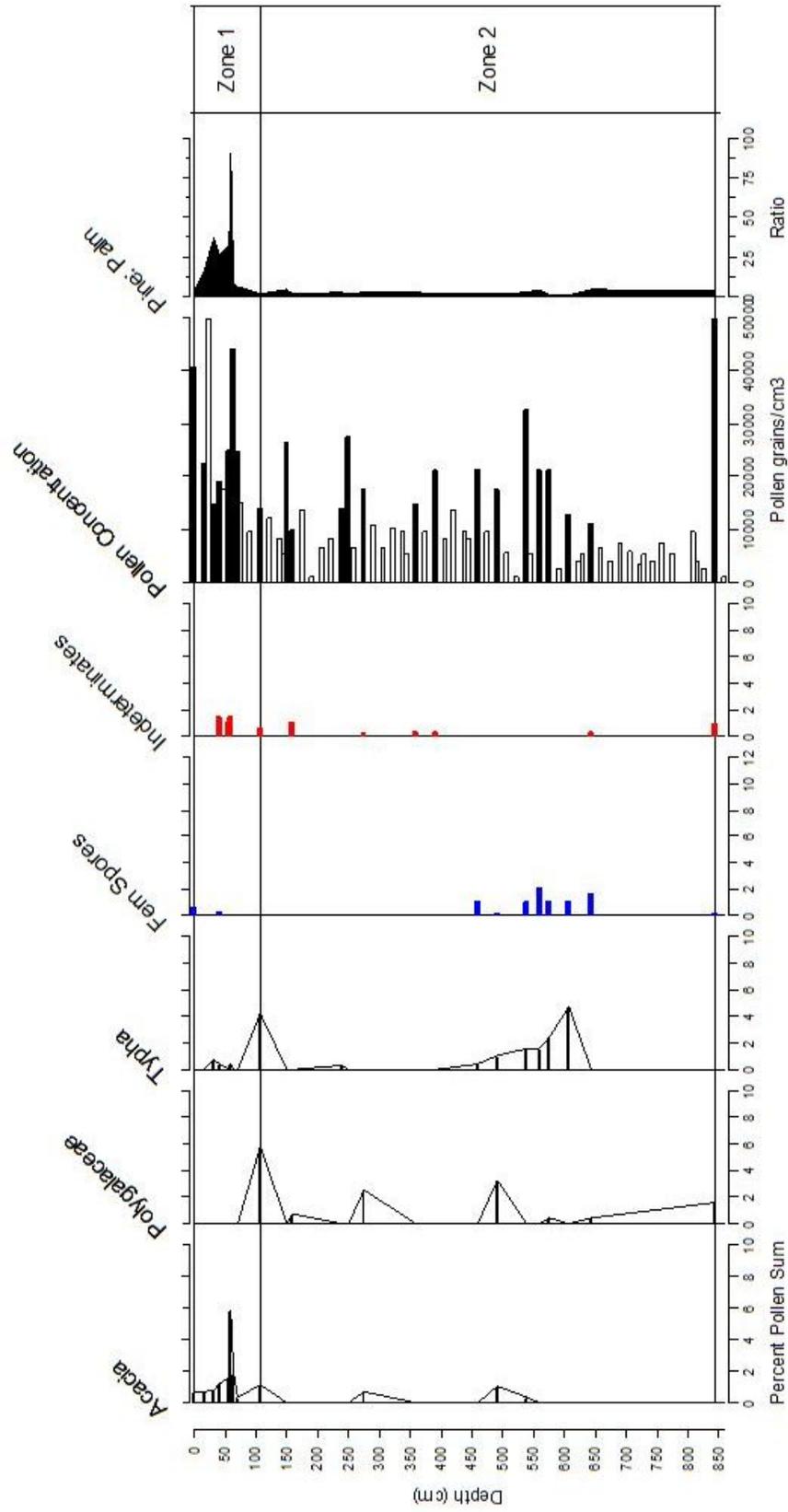


Figure 5.2: Pollen diagram for the Emerald Pond sediment profile (continued.) Pollen counts for *Acacia*, *Polygalaceae*, and *Typha* are graphed as percent total pollen excluding indeterminates and fern spores. Fern spores are plotted as a percent of total pollen plus spores. Indeterminate pollen is plotted as a percent of total pollen including indeterminates. The pollen concentration profile includes the rough estimates for samples not included in the pollen analysis as open bars; solid bars show concentrations for the counted levels.

Zone 1 (106–0 cm) 2060–756 cal yr BP (AD 2006)

Pinus peaks in Zone 1, reaching its highest percentages in the profile, 86% at 32 cm. Gramineae, Rubiaceae, and *Acacia* also show sharp peaks. Gramineae peaks at the top of Zone 1, accounting for 20% of the assemblage. Rubiaceae has a peak of over 20% in the middle of Zone 1, before declining to the same percentage levels as in Zone 2. Percentages of *Typha*, Polygalaceae, Cyperaceae, and *Rhizophora* decline at the Zone 2/1 boundary, and are low throughout the zone. Palmae declines to its lowest percentages in the profile in the middle of Zone 1, but shows a slight recovery at the top of the zone. The ratio of pine to palm pollen shows highest values in Zone 1. Pollen concentration values are somewhat higher than in zone 2, discounting the basal sample of that zone.

CHAPTER SIX

DISCUSSION

How has the vegetation that surrounds Emerald Pond changed over time?

That pine pollen accounts for over 30% of total pollen in all but two levels of the Emerald Pond profile indicates that the Bahamian pines that currently dominate the rockland surrounding the pond have been present locally since the early part of the middle Holocene. Their importance in the vegetation has, however, varied over time, as has the importance of associated taxa. The pollen assemblages in the basal sample (843 cm) at the bottom of Zone 2 and in the first three samples above the gap (641.5 cm, 605.5 cm, and 573.5 cm) suggest more mesic vegetation than present around Emerald Pond at this time. The portion of this period above the gap is from ca. 6959 to 6429 cal yr BP. The slightly higher diversity in pollen types in this part of the record may indicate a more diverse plant community in general or perhaps a wider variety of communities around Emerald Pond. The peaks in *Rhizophora*, *Typha*, and Cyperaceae percentages in this lower part of Zone 2 may be an indication of increased wetland habitats at this time, when lower sea level may have created larger low-lying areas on the western side of Abaco Island. They may also be representative of a time of lower water levels within the hole itself. Lower sea levels could also be an influence on the pollen values, as shallow banks on the western side of Abaco could have been heavily vegetated wetlands at a time of moderately lower sea level.

The middle part of Zone 2, from 557.5 cm to 250 cm (ca. 6304 to 3250 cal yr BP), may reflect a vegetation makeup in transition to modern conditions, with *Pinus*-dominated plant communities and understories of shrubs and tropical hardwoods, as well as members of the

Palmae and Cyperaceae families and pteridophytes. However, palms were much more important in the pineland community at this time than at present. *Rhizophora*, *Myrica*, and Rubiaceae all decline in importance, but are still present in the profile. The top of Zone 2, from 250 cm to 106 cm (3250 to 2060 cal yr BP), shows a shift towards a more open-canopied pineland, with increased grasses in the understory.

The Zone 2/1 boundary (ca. 2060 cal yr BP) marks a major shift in vegetation toward increased pine dominance. The pollen assemblage and pine to palm pollen ratio in Zone 1 indicates a vegetation community more dominated by pine and grass than at any other time in the last several thousand years. Peaks in pollen of Rubiaceae and *Acacia* suggest possibly drier conditions than in the rest of Zone 2. Many species of Rubiaceae and *Acacia* native to The Bahamas are somewhat xeric, growing on rocky flats and in scrublands (Appendix C).

The changes in vegetation suggested by shifts in pollen assemblages through the Emerald Pond core are likely caused in part by changes in relative moisture. The bottom of Zone 2 may indicate a period of wetter conditions than present, and the shifts at the Zone 2/1 boundary (2060 cal yr BP) and within Zone 1 above 64 cm (1028 cal yr BP) may indicate increased frequency of droughts or overall drier conditions. The significant slowing of sedimentation in this part of the profile (Figure 4.2) is consistent with the interpretation of drier conditions and possibly even with some missing time in the record owing to dessication of the sediments, affecting pollen preservation. It is also possible that rather than an overall drying, the shifts may indicate an increase in the seasonality of moisture in this part of the profile. Drier summers or longer summer dry seasons may have a similar effect on the pollen assemblages, and the possibility would still exist of missing time due to dessication of the sediments within the pond.

Are changes in vegetation associated with changes in fire activity?

That the section of the profile with highest pine dominance is also the section with highest microscopic charcoal concentrations (Horn *et al.* in prep.) suggests that increased fire incidence, as well as drier climate, has characterized the last two millennia at Emerald Pond. Although some palms are able to survive fire, the steep decline in palm pollen percentages at the Zone 2/1 boundary suggests that changes in climate and fire at Emerald Pond gave a strong advantage to Bahamian pine, which is strongly fire adapted with thick bark, open crowns, and open needles, as well as the ability to quickly regenerate after fires (Meyers 2004). The several small peaks of herbaceous taxa in Zone 1 may indicate post-fire herb flushes.

Is there evidence of human influence on vegetation? If so, when?

The more variable nature of pollen percentages in Zone 1, together with peaks in charcoal between 48 and 58 cm (Horn *et al.* in prep.), suggest that this zone may be a time of human disturbance. The estimated date for the Zone 2/1 boundary at 106 cm of ca. 2060 cal yr BP predates the consensus time frame of 1350 to 1150 yr BP for the arrival and settlement of The Bahamas by the Lucayan Tainos (Keegan 1992, Berman and Gnivecki 1995). But it is not until later in Zone 1, at 64 cm (ca. 1028 cal yr BP), that pine percentages reach over 70%, surpassing all previous values. The interval of highest microscopic charcoal concentrations begins 6 cm higher in the profile, and is estimated to correspond to the period from ca. 819 to 607 cal yr BP. Thus, in general, the pine pollen and charcoal evidence appear to fit with a possible scenario of human settlement, and to fit with the indications of human settlement in the charcoal and pollen records from West and Split Ponds in The Bahamas.

The fires, increased pines, and more variable pollen spectra in the upper part of Zone 1 may reflect land use changes accompanying Lucayan settlement and agriculture on Abaco Island. The Lucayans practiced “slash-and-burn” agriculture (Keegan 1997). The Spanish reported them growing manioc, sweet potato, cocoyam, maize, beans, gourds and squashes, chili pepper, fruit trees, tobacco, cotton, and fish poisons in gardens. No archaeological evidence has been found of the Lucayans growing maize, and no *Zea* pollen was found in the Emerald Pond profile. The Lucayan Taino would clear and burn plots, rotating to a new area every few years to allow the previous plot to fallow and recover (Keegan 1997). The settlement sites would also move after a period of time had passed and local resources had been relatively depleted. Once set, these land-clearing fires could have spread beyond the intended area. The variability in pollen values for so many taxa in the top 80 cm of the record may be due to irregular intervals of disturbance associated with forest clearance in various areas, as well as both natural and human-ignited fires.

How does the Emerald Pond pollen record compare with other paleoecological records from The Bahamas?

The vegetation changes found in other studies within The Bahamas are reasonably similar to those recorded in the sediment of Emerald Pond. Kjellmark’s study of Church’s Blue Hole from Andros Island indicated drier conditions from 3200 to 1500 cal yr BP, findings corroborated by work done on Hispaniola (Kjellmark 1996; Hodell *et al.* 1991). The Emerald Pond record may indicate a drier environment at this time as well. Graminae pollen levels from about 220 cm to 80 cm are somewhat elevated, along with Cyperaceae and *Myrica*. This may represent a more open canopy with less arboreal species, and more herbaceous and hardy shrub taxa growing around them. The resolution of this study of the Emerald Pond record makes it

difficult to compare Kjellmark's finding of a possibly moister environment from ~1500 cal yr BP to ~900 cal yr BP based on the higher values of aquatic taxa in the assemblages, as the interval for sampling coupled with the slow sedimentation rate in this portion of the core compresses this time in the record. If anything, the Emerald Pond record seems to indicate drier climate at this time. It may be possible that this increase in aquatic taxa at Church's Blue Hole was not due to a wetter climate, but to a drop in the water level of Church's Blue Hole, which could have created shallow areas on rock shelves that could have increased aquatic plants locally.

Kjellmark's sites of Church's Blue Hole and Rainbow Blue Hole on Andros Island both show a late Holocene spike in pine:palm pollen ratios similar to the spike at Emerald Pond (Figure 6.1). At all three sites this may reflect a shift to a more "pyrogenic" vegetation assemblage. At Emerald Pond the shift occurred after ca. 1028 cal yr BP. Kjellmark (1996) described the window of time that this shift occurred in the Church's Blue Hole record as 1500 to 740 ¹⁴C yr BP, and noted that this time frame was consistent with the arrival of the Lucayans to the archipelago. Based on a radiocarbon date of 800 ¹⁴C yr BP over a wide (8 cm) interval that spans the shift in the Rainbow Blue Hole core (Kjellmark 1995), the timing at this site may have been similar. The Stalactite Blue Hole record developed by Kjellmark (1995) on Andros Island does not show the same steep increase in pine:palm ratios. However, this record does show increased percentages of herbaceous taxa in the upper sediments, similar to the Emerald Pond profile. At both sites these shifts may indicate human disturbance in the last few centuries.

The increase in pine pollen at the top of the Emerald Pond profile is similar to results from West Pond on Abaco Island. Both records indicate an increase in *Pinus* and other pyrogenic or disturbance taxa over the last ~700 cal yr BP. The lack of strong representation of *Rhizophora* in the Emerald Pond record except in the lowest part of the profile is similar to the

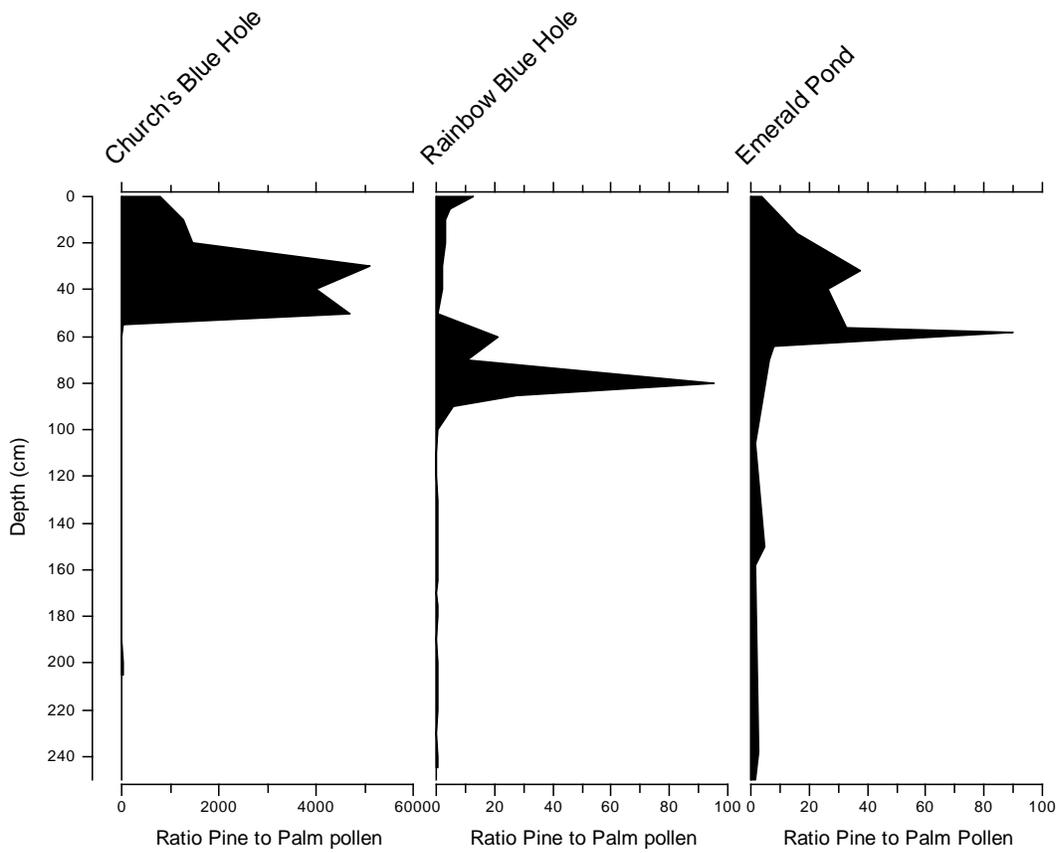


Figure 6.1: Ratios of pine to palm pollen in the upper 2.5 m of sediment profiles from Church's Blue Hole and Rainbow Blue Hole on Andros Island, The Bahamas (data from Kjellmark 1995) and from Emerald Pond (this study). A count for Palm pollen of zero at 80 cm in the Rainbow Blue Hole record was changed to a 1 to make it possible to graph the ratio of pine to palm pollen.

West Pond record, which only had a brief episode of *Rhizophora* being present. It is likely that *Rhizophora* was not growing locally at either site, but rather its pollen was transported to the core sites by wind.

The evidence for slightly lower pine dominance through Zone 2 is broadly consistent with the macrofossil evidence found at Sawmill Sink (Steadman *et al.* 2007), which indicated a heavier component of tropical coppice earlier in the Holocene, as compared to present. The macrofossil and pollen taxa recovered and identified from Sawmill Sink include Wax Myrtle (*Myrica*), Poisonwood (*Metopium toxiferum*), Cassada-wood (*Bumelia*), many flowering herbs (Asteraceae), and Bahamian pine (*Pinus*), all of which were also identified in the Emerald Pond profile. The age of the human skeleton remains found within Sawmill Sink (ca. 1050–920 cal yr BP) also fits with the inferred timing of the human activity and increased fire at Emerald Pond.

How do inferred changes in vegetation, climate, and disturbance over the Holocene at Emerald Pond relate to regional evidence of paleoclimate and paleoenvironments for this time period?

The inferred dry period at ca. 1028 cal yr BP in the Emerald Pond record coincides with indicated fire frequency increases at about 1200 cal yr BP in the Key Deer Pond record from Big Pine Key, Florida (Albritton 2009). The changes indicated at similar times in cores from the Bahamas may also be influenced by a regional change in climate, as well as by humans. Possible times of drier conditions in the Emerald Pond record around 3250–2382 cal yr BP (250 to 150 cm) and 2060 cal yr BP (106 cm) correspond to periods of tree island expansion in the Florida Everglades that Willard (2006) linked with climate changes documented in Central American climate records.

The more recent dry period in the Emerald Pond record may correspond with the dry period found in diatom records from La Piscina de Yuriria that occurred between 1570 and 900

yr BP (Metcalfé *et al.* 2000). The shift to relatively drier conditions from the bottom of Zone 2 in the Emerald Pond record towards the top of Zone 2 seems to match evidence of a drier climate at ca. 5000 to 1500 yr BP found in Central Mexican sediment records (Metcalfé *et al.* 2000). These corresponding shifts in climate may indicate a larger regional change in moisture, due to shifts in large-scale circulation patterns, including potential shifts in the mean seasonal positions of the Intertropical Convergence Zone.

CHAPTER SEVEN

CONCLUSIONS

The paleoecological record from Emerald Pond provides a ca. 8400 cal yr record of vegetation change, and some evidence about the timing of the arrival of humans to The Bahamas Archipelago. The vegetation surrounding Emerald Pond shifted from a somewhat mesic vegetation community to a community transitioning to modern assemblages heavily composed of pines and palms beginning ca. 6304 cal yr BP, probably due to a relatively drier climate and increase in fire frequency. A shift in assemblage may indicate a period of drought at ca. 2060 cal yr BP, which corresponds to findings by Kjellmark on Andros Island (1996). The arrival of humans to the Bahamian archipelago sometime between 1350 and 1150 yr BP (Berman and Gnivecki 1995) and their subsequent arrival to Abaco Island, may be represented in the Emerald Pond record by an increase in *Pinus* pollen values at ca. 1360 cal yr BP and high charcoal concentrations beginning at about 820 cal yr BP. Human arrival within this time range is consistent with archaeological evidence on Abaco Island (Steadman *et al.* 2007). A great increase in Gramineae pollen values during the last few hundred years may correspond to higher levels of disturbance through human activities. It is likely that the vegetation of the area was greatly influenced by humans almost as soon as they arrived through the setting of agricultural fires and manual clearing of land, but no direct evidence of local agricultural activity such as maize pollen was found in this study.

The Emerald Pond record adds to a growing body of work on the paleoenvironment of the past 2,000 to 4,000 years of the Bahamian Archipelago, and extends the vegetation history of the area beyond that by several thousand years. Future higher resolution pollen analysis on the

record may confirm the larger trends revealed in this study and others, and also give a more detailed picture of fire history and periods of drought within the region. The vegetation changes found in other studies in The Bahamas are reasonably similar to those recorded from the sediment of Emerald Pond. The time frame of the arrival of humans may be more precisely estimated. Research on microscopic charcoal that is ongoing may also corroborate some of the interpretations made in this study, or allow them to be modified and strengthened to account for the added data.

The vegetation changes in the Emerald Pond record, particularly over the last 300 to 400 years, seem to be strongly linked to a change in fire frequency. Taxa of fire-adapted Bahamian pine increase to their highest levels in the record along with disturbance taxa such as Gramineae, while previously dominant Palmae decline. These changes combine to suggest an increase in fire frequency that favored Bahamian pine. Fire frequency during that time was probably greatly influenced by human activities and has helped shape the vegetation community of modern Abaco Island, as more fire and disturbance tolerant plants dominate the modern pine rockland community. Future research at this site would benefit from trapping and examining modern pollen rain compositions, and how they reflect modern vegetation communities found on the island. The laminations found within the Emerald Pond sediments could be used to create a higher resolution record, and perhaps provide an opportunity to employ other proxies.

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APPENDICES

APPENDIX A: Pollen Processing Procedure A

The following procedure, known as the JR2-HCl procedure in the Laboratory of Paleoenvironmental Research, was used to process sediment samples from Emerald Pond for pollen analysis. Samples were processed in 15 ml Nalgene® polypropylene centrifuge tubes. The centrifuge used was an IEC model CL bench top centrifuge with a 6 x 15 ml swinging bucket rotor. All centrifugations were carried out at the highest speed.

1. Add 1 *Lycopodium* tablet to each centrifuge tube (n = 13,911).
2. Add 10 ml 10% HCl, and let reaction proceed; slowly fill tubes until there is 10 ml in each tube. Stir well, and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.
3. Add hot distilled water, stir, centrifuge for 2 minutes, and decant. Repeat for a total of two washes.
4. Add 10 ml 5% KOH, stir, and place in boiling bath for 10 minutes, stirring after 5 minutes. Remove from bath. Centrifuge 2 minutes and decant.
6. Wash 4 times with hot distilled water. Centrifuge for 2 minutes each time.
7. Fill tubes about 1/2 way with distilled water, stir, and pour through 125 µm mesh screen, collecting liquid in a labeled beaker underneath. Use distilled water to wash the screen, and to wash out any material remaining in the centrifuge tube.
8. Centrifuge material from beaker by repeatedly pouring beaker contents into correct tube, centrifuging for 2 minutes, and decanting.
9. Add 10 ml of 49% HF and stir. Place tubes in bath for 20 minutes, stirring after 10 minutes. Centrifuge 2 minutes and decant.
10. Add 10 ml 10% HCl. Stir well, and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.
11. Add 10 ml hot Alconox® solution, made by dissolving 4.9 cm³ dry commercial Alconox® powder in 1000 ml distilled water. Stir well and let sit for 5 minutes. Then centrifuge and decant.
12. Add more than 10 ml hot distilled water to each tube. Stir, centrifuge for 2 minutes, and decant. Assuming that no samples need retreatment with HF, continue washing with hot distilled water as above for a total of 3 water washes.
13. Add 10 ml of glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

14. Make acetolysis mixture by mixing together 9 parts acetic anhydride and 1 part concentrated sulfuric acid. Add about 8 ml to each tube and stir. Remove stirring sticks and place in boiling bath for 5 minutes. Stir after 2.5 minutes. Centrifuge for 2 minutes and decant.
15. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes and decant.
16. Wash with hot distilled water, centrifuge and decant.
17. Add 10 ml 5% KOH, stir, remove sticks, and heat in vigorously boiling bath for 5 minutes. Stir after 2.5 minutes. After 5 minutes, centrifuge for 2 minutes and decant.
18. Add 10 ml hot distilled water, centrifuge for 2 minutes, and decant for a total of 3 washes.
19. After decanting last water wash, use the vortex genie for 20 seconds to mix sediment in tube.
20. Add one drop safranin stain to each tube. Use vortex genie for 10 seconds. Add distilled water to make 10 ml. Stir, centrifuge for 2 minutes, and decant.
21. Add a few ml TBA, use vortex genie for 20 seconds. Fill to 10 ml with TBA, stir, centrifuge for 2 minutes, and decant.
22. Add 10 ml TBA, stir, centrifuge 2 minutes and decant.
23. Vibrate samples using the vortex genie to mix the small amount of TBA left in the tubes with the microfossils. Centrifuge down vials.
24. Add several drops of 2000 cs silicone oil to each vial. Stir with a clean toothpick.
25. Place uncorked samples in the dust free cabinet to let the TBA evaporate. Stir again after one hour, adding more silicone oil if necessary.
26. Check samples the following day; if there is no alcohol smell, cap the samples. If the alcohol smell persists, give them more time to evaporate.

APPENDIX B: Pollen Processing Procedure B

The following procedure was used to process sediment samples from Emerald Pond for pollen and microscopic charcoal analysis. It differs from the JR2-HCl procedure in having a nitric acid step, and is known in the Laboratory of Paleoenvironmental Research as the JR2-Nitric procedure. Samples were processed in 15 ml Nalgene® polypropylene centrifuge tubes. The centrifuge used was an IEC model CL bench top centrifuge with a 6 x 15 ml swinging bucket rotor. All centrifugations were carried out at the highest speed.

1. Add 1 *Lycopodium* tablet to each centrifuge tube (n = 13,911).
2. Add 10 ml 10% HCl, and let reaction proceed; slowly fill tubes until there is 10 ml in each tube. Stir well, and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.
3. Add hot distilled water, stir, centrifuge for 2 minutes, and decant. Repeat for a total of two washes.
4. Add 10 ml 5% KOH, stir, and place in boiling bath for 10 minutes, stirring after 5 minutes. Remove from bath. Centrifuge 2 minutes and decant.
6. Wash 4 times with hot distilled water. Centrifuge for 2 minutes each time.
7. Fill tubes about 1/2 way with distilled water, stir, and pour through 125 µm mesh screen, collecting liquid in a labeled beaker underneath. Use distilled water to wash the screen, and to wash out any material remaining in the centrifuge tube.
8. Centrifuge material from beaker by repeatedly pouring beaker contents into correct tube, centrifuging for 2 minutes, and decanting.
9. Add 10 ml of 49% HF and stir. Place tubes in bath for 20 minutes, stirring after 10 minutes. Centrifuge 2 minutes and decant.
10. Add 10 ml 10% HCl. Stir well, and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.
11. Add 10 ml 35% HNO₃. Stir well and let sit for 5 minutes. Centrifuge for two minutes and decant.
12. Add 10 ml hot Alconox® solution, made by dissolving 4.9 cm³ dry commercial Alconox® powder in 1000 ml distilled water. Stir well and let sit for 5 minutes. Then centrifuge and decant.

13. Add more than 10 ml hot distilled water to each tube. Stir, centrifuge for 2 minutes, and decant. Assuming that no samples need retreatment with HF, continue washing with hot distilled water as above for a total of 3 water washes.
14. Add 10 ml of glacial acetic acid, stir, centrifuge for 2 minutes, and decant.
15. Make acetolysis mixture by mixing together 9 parts acetic anhydride and 1 part concentrated sulfuric acid. Add about 8 ml to each tube and stir. Remove stirring sticks and place in boiling bath for 5 minutes. Stir after 2.5 minutes. Centrifuge for 2 minutes and decant.
16. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes and decant.
17. Wash with hot distilled water, centrifuge and decant.
18. Add 10 ml 5% KOH, stir, remove sticks, and heat in vigorously boiling bath for 5 minutes. Stir after 2.5 minutes. After 5 minutes, centrifuge for 2 minutes and decant.
19. Add 10 ml hot distilled water, centrifuge for 2 minutes, and decant for a total of 3 washes.
20. After decanting last water wash, use the vortex genie for 20 seconds to mix sediment in tube.
21. Add one drop safranin stain to each tube. Use vortex genie for 10 seconds. Add distilled water to make 10 ml. Stir, centrifuge for 2 minutes, and decant.
22. Add a few ml TBA, use vortex genie for 20 seconds. Fill to 10 ml with TBA, stir, centrifuge for 2 minutes, and decant.
23. Add 10 ml TBA, stir, centrifuge 2 minutes and decant.
24. Vibrate samples using the vortex genie to mix the small amount of TBA left in the tubes with the microfossils. Centrifuge down vials.
25. Add several drops of 2000 cs silicone oil to each vial. Stir with a clean toothpick.
26. Place uncorked samples in the dust free cabinet to let the TBA evaporate. Stir again after one hour, adding more silicone oil if necessary.
27. Check samples the following day; if there is no alcohol smell, cap the samples. If the alcohol smell persists, give them more time to evaporate.

APPENDIX C: Annotated List of Pollen and Spore Types found in the Emerald Pond Sediments profile

Taxonomy follows Correll and Correll (1982), which is also the source of the descriptions of plant taxa. Descriptions of the pollen and spores of taxa were gathered from *Key to Pollen of the Bahamas* (Snyder *et al.* 2007), and the *Atlas of Pollen and Spores of the Florida Everglades* (Willard *et al.* 2004).

Pteridophyta

POLYPODIACEAE

Terrestrial or epiphytic plants with creeping to suberect rhizomes. This is the largest family of ferns and contains several thousand species. They are found worldwide, from arctic to tropical regions, in both rain forests and arid regions.

Polypodium

Epiphytic, sometimes terrestrial or rock-inhabiting ferns. Genus comprises hundreds of species, found mainly in tropical and subtropical regions throughout the world. Spore is oval and monolete, with slight to moderate verrucate sculpturing.

Thelypteridaceae

Sparsely scaly terrestrial or rock-inhabiting ferns. Can be found in coppices, sink holes, and rock faces. World-wide genus of nearly a thousand species. Spore is oval and monolete, with psilate to slightly rugulate sculpturing.

Gymnosperms

PINACEAE

Resinous mostly evergreen trees or shrubs with needle-like or scale-like leaves, and woody cones. The family is composed of over 250 species in 10 genera, widely distributed in the Northern Hemisphere.

Pinus

Tree growing up to 30 m with thick bark splitting into irregular plates, and narrow cones. The only native species found in The Bahamas is *Pinus caribaea* var. *bahamensis*. It can be found

throughout the Bahamian and Caicos islands, in large stands. Pollen has two reticulate air sacs attached to the body of the grain.

Angiosperms

ANACARDIACEAE

Vines, shrubs, or trees with resin ducts in the bark and herbage, and a poisonous resinous juice. This juice can cause severe dermatitis on contact. The family is composed of about 600 species, mostly found in the tropics.

Metopium

Tall shrub or tree with thin bark that splits into scales and spreading branches. Commonly found in pinelands and coppices throughout the year. Pollen spheroidal and tricolporate, with fine reticulate, as well as slight clavate, sculpturing.

ANNONACEAE

Commonly known as the custard-apple family, typically trees, shrubs or woody climbers with aromatic wood and leaves. The family is composed of over 2000 species in more than 100 genera found mostly in the tropics.

Annona

Mostly trees with leathery or papery leaves. Often has sweet smooth-skinned fruit. Found mostly in the warmer regions of America, and has been introduced to the tropics of the Eastern Hemisphere. Pollen is irregular in shape and very large, often appearing to be folded in a roughly triangular shape. Its tectum is perforate, with closely spaced pits.

APOCYNACEAE

Trees, shrubs, vines, or herbs with regular five-petaled flowers and often milky juice. The family is composed of over 1500 species occurring throughout the world, including many ornamental and poisonous members.

Angadenia

Slender woody vine, usually less than 1 m long. Found in scrublands, coppices, and pinelands throughout the year. Pollen is stephanoporate with four pores slightly unaligned on an equatorial plane. Surface structure is psilate to scabrate.

Echites

Shrubby climber, grows on shrubs in coppices, pinelands and scrublands throughout the year. Pollen is stephanoporate with five slightly recessed pores.

AQUIFOLIACEAE

Commonly known as the holly family, typically evergreen polygamodioecious shrubs or trees composed of three genera and over 500 species widely distributed over temperate and tropical regions.

Ilex

Shrubs or trees that can be deciduous or evergreen. There are three species native to the Bahamas, growing in marshy and swampy conditions, or in coppices, pinelands, and scrublands depending on the species. Pollen is spheroidal and tricolpate, with prominent gemmae.

ARACEAE

A large and diverse family of terrestrial, epiphytic or aquatic plants. They can be herbs or climbers, often with acrid or pungent juices and berries. Pollen is inaperturate, ovular, and psilate.

ASTERACEAE

Herbs, vines, or shrubs with dense involucrate flowering heads. One of the largest families of vascular plants in the world with over 15,000 species, frequently found in open or disturbed spaces. Pollen is echinate and tricolporate with a subspheroidal to prolate shape.

Gundlachia

Shrubby leafy plants native to the West Indian islands. Can be found in The Bahamas on coppiced saline flats, marshes, dune sands, pinelands, edge of coppices, and disturbed areas. Pollen is tricolpate, echinate, and mostly spheroidal, but colpi clearly distinguishable.

BORAGINACEAE

Herbaceous or shrubby bristly plants, often with small fruit that can break into four single-seeded parts, or remain intact and become drupaceous.

Bourreria

A shrub or small tree that can grow to about 10 m tall with reddish bark. It can be found in scrublands and coppices throughout The Bahamas. Pollen is prolate, tricolporate, and psilate with defined rims running around the inside equator of the grain.

Note: The two genera below produce pollen that is difficult to distinguish. I attempted to separate the types.

Heliotropum

Herbaceous to somewhat shrubby plant that can be perennial or annual. Species can be found throughout the tropics and subtropics, in thickets, exposed land, wasteland, pastures, or open coppices and scrublands. Pollen is tricolporate and psilate, with narrow slitted furrows giving it a 6-lobed appearance in polar view. Endoaperture is an elongated oval.

Mallotonia

Stout shrubs reaching about 3 m tall, growing in dense clumps on open sandy beach areas or rock shelves above water throughout the year. Pollen is tricolporate and psilate, with narrow slitted furrows giving it a 6-lobbed appearance in polar view. Endoaperture is a round pore.

CACTACEAE

A family of succulent plants with prominent areoles and spines, with over a thousand species in the Western Hemisphere. In The Bahamas, they are typically found on rocky hillsides, in coppices and thickets, and scrublands. Pollen is large and tricolpate with dense clavate surface structures.

CARICACEAE

Short-lived and soft-wooded trees or large shrubs, with only rare branching. The plant has large alternating leaves and milky sap, and a large berry with numerous seeds. The species found in The Bahamas are widely cultivated for their edible fruit.

Carica

Dioecious tree that can grow to about 8 m tall, with a branchless trunk that splits into two or more heads of leaves. The plant produces oblong yellow or orange fruit (papayas) with thick yellow flesh enclosing a cluster of many black seeds. It can be found throughout the tropical regions of the New World, and through all but the most northern Bahamian islands. The pollen grain's exine is psilate with tiny even pitting across the surface. The grain is tricolpate with a rounded 3-lobed appearance.

CONVOLVULACEAE

Herbs, vines, lianas, shrubs, or trees with occasionally milky sap. Commonly known as the Morning Glory family, the family Convolvulaceae contains over 1600 species in tropical and temperate regions throughout the world.

Ipomoea

Twining vines, shrubs, or trees with purple, pink, white, or yellow flowers. Examples of species within the genus are *Ipomoea indica* (Morning Glory), *Ipomoea batatas* (Sweet-potato), and *Ipomoea violacea* (moon-vine). Most species commonly occur in disturbed or cultivated areas, and occasionally thickets. Pollen is echinate and periporate, with spear-like spines that have parallel sides and end in a conical or rounded tip.

Merremia

Pantropical twining vines with herbaceous or woody bases and solitary flowers or few-flowered. The genus commonly occurs in disturbed sites and on the edge of coppices. Pollen is large and tricolpate. It has a perforate tectum, and the colpus is open, giving the grain a somewhat triangular "three leafed clover" appearance in polar view.

CYPERACEAE

Commonly known as the Sedge family, the family Cyperaceae includes grass-like or rush-like herbs with long linear leaf blades usually growing in wet or damp environments. Species of this family occur in subtropical and tropical locations throughout both the New and Old World. Pollen appears inaperturate and is irregular in shape. Grains are usually psilate and pear-shaped, and very thin.

ERYTHOXYLACEAE

Smooth-barked trees or shrubs, commonly known as the Coca family. Only the genus *Erythroxylum* occurs in the New World, and in The Bahamas it can be found growing in coppices, pinelands, and scrublands. Pollen is spheroidal, tricolporate, and finely but clearly scabrate, with colpi that extend towards the poles in a “V” shape.

EUPHORBIACEAE

Trees, shrubs, or herbs often with sticky sap. Commonly known as the Spurge family, it is a diverse and large group containing over 200 genera and thousands of species, many poisonous. Examples of genera within this family are *Manihot* (cassava), *Hevea* (Brazilian rubber tree), and *Ricinus* (castor bean). Pollen is tricolporate, and has a reticulate structure. It is often prolate in equatorial view, and triangularly rounded in polar view. The endo-aperture is elongated transversely to the colpi (e.g. transverse furrow).

Argythamnia

Herbaceous perennials or shrubs with a woody base and herbaceous stems. The stems and leaves are covered in malpighiaceus hairs. Members can be found in sandy loam or rocky soils in and on the edge of coppices, and on rock and salt flats throughout the Bahamas. Pollen is spheroidal and stephanocolpate with four apertures. The grains are finely reticulated with obvious lumens.

Hippomane

Trees with acrid milky juice and silvery to dark gray fissured bark. Members of the genus can be found in scrublands, open coppices, and near salt flats, throughout the Bahamas. The pollen grain is psilate with minute clavate structures across the surface. The grain is tricolporate with a rounded 3-lobed appearance.

Margaritaria

Viny dioecious shrub that can grow to about 3 m tall and 8 m wide, but rarely gets so large. It can be found in coppices, scrublands, and pinelands during the wetter time of the year. Pollen is tricolporate and has defined reticulation with deep but very small lumens. Colpi are long and narrow, and the grain is prolate, and “football shaped.”

Phylanthus

Trees, shrubs, or herbs. Members of the genus in The Bahamas can be found in coppices, thickets, and disturbed areas. Pollen is inaperturate with irregular lines of gemmate structures. Grains have a striate-reticulate pattern.

FLACOURTIACEAE

Trees or shrubs, often with small and inconspicuous flowers. Species are widely distributed in the tropical and subtropical regions of the world. Pollen is spheroidal to subspheroidal, and tricolporate. The surface is reticulate, with luminae smaller near the apertures.

GRAMINEAE

Plants with herbaceous culms, with some species becoming woody vines or reed-like, commonly known as the Grass family. It contains 10000 species in 602 genera from all over the world. Members can be found in virtually all environments in The Bahamas. Pollen is monoporate with a distinct annulus.

LAURACACEAE

Mostly tropical and subtropical aromatic trees or occasionally shrubs with persistent or deciduous leaves, or sometimes parasitic vines with small scale-like leaves. Flowers are small and clustered, without petals.

Cassytha

Parasitic slender vine with yellowish or pale green wiry stems and branches that is attached to a host plant by haustoria. It can be found parasitically growing on various herbaceous and woody plants in dense tangles, smothering supporting vegetation. Pollen is subprolate, barrel-shaped, and stephanocolpate with meridional apertures.

LEGUMINOSAE

Trees, shrubs, vines or herbs with alternate branching and compound leaves. This family has a “pod” for fruit, dry structures that often break up into single-seed sealed units, or split lengthwise. They can be found anywhere where seed plants can be found.

Acacia

Shrubs, small trees, or rarely perennial herbs, often with stipular spines or prickles. Members of this genus can be found in The Bahamas in coppices and pinelands. Pollen is a polyad, made up of 16 grains tightly aggregated, with scabrate to almost psilate surface structure.

Caesalpinia

Armed or unarmed trees, shrubs, or perennial herbs, with over 200 species found in tropical and warm regions throughout the world. Found in the Bahamas in coppices and scrublands. Pollen is large and tricolporate with rough reticulation and distinctly wide muri.

Calliandra

Shrubs, small trees, or rhizomatous perennial shrubs with persistent flat pods. Species in this genus can be found in the warmer regions of the Western Hemisphere, and in The Bahamas can be found in pinelands, coppices, and thickets. Pollen is a polyad of eight grains in a teardrop shape with a scabrate surface structure.

Lysiloma

Unarmed shrubs or trees with alternating leaves and straight, very flat pods. The genus is composed of over 35 species in the southern United States and tropical America. Pollen is a large polyad of 16 inaperturate and psilate grains closely clustered together.

LILIACEAE

Mostly perennial herbs with erect or climbing stems. The family has worldwide distribution. Types found in The Bahamas typically grow in open areas and thickets. Pollen is monocolpate, with the colpus extending from end to end of the grain, with scabrate to reticulate surface structure.

MALPIGHIACEAE

Shrubs or trees, sometimes climbing, with simple hairs that are sometimes stinging and with nut-like fruit. Most of the over 850 species in the family are native to the American tropics and subtropics.

Malpighia

Shrub that reaches about 3 m tall, usually multi-branched. The genus is made up of 35 species, including various kinds of wild cherries. In The Bahamas, it can be found in rocky open coppices, scrublands, and rocky flats. Pollen is poriporate with thick walls, with rounded and thick areas around pores.

Triopteris

Slender glabrous twining vine, with opposite leaves. It can be found in The Bahamas climbing on shrubs and small trees on the edge of coppices and in open rocky areas. Pollen is periporate with thick walls and eight pores, psilate, without thickened areas around pores. Grains are significantly smaller than *Malpighia* pollen grains.

MYRICACEAE

Commonly known as the Bayberry or Wax-myrtle family, the family Myricaceae is composed of monoecious or dioecious shrubs or small trees.

Myrica

Shrubs or small trees with smooth grey bark and yellowish-green leaves with resinous dots. The plants can be found growing in sandy or rocky thickets, coppices, and pinelands with year-round water available. Pollen is triporate with thick walls and no obvious columellae, and protruding pores.

MYRTACEAE

Shrubs or trees with simple leaves and berries or many-seeded capsules, found throughout the tropics.

Myrcianthes

Shrub or small tree found throughout the West Indies, Florida, Mexico, Central America, and northern South America. It can be found growing in The Bahamas on rocky slopes, flats in coppices, and sometimes on coastal coppices. Pollen is small, tricolporate, and triangular, with the pores at the ends of the vertices.

NYMPHACEAE

The family Nymphaeaceae is commonly known as the Water Lily family, and has a worldwide distribution. Species in The Bahamas can be found in calm pools of freshwater. Pollen is monosulcate, echinate, and ovular. Spines are conical and thorn-like.

ONAGRACACEAE

Herbs, sometimes woody at the base, are found within the Onagraceae family, commonly known as the Evening Primrose family. The family is composed of over 650 species in 19 genera found worldwide, but mostly outside the tropics and in subarid western North America.

Ludwigia

Herbs preferring wet locations with minutely toothed leaves. In the Bahamas, the genus can be found in moist soil around ponds, freshwater marshes, ditches, or anywhere else where wet conditions prevail. Pollen is tricolporate and oblate, with deep vestibula, and a surface with fine verrucae.

PALMAE

The palm family comprises trees, shrubs, or perennial vines with persistent leaves. The family contains over 2500 species in over 200 genera. Members of this family can be found throughout the warm regions of the world, and in The Bahamas they can occur conceivably anywhere. Pollen is bilaterally symmetrical with a single sulcus running most of the length of the grain, and surface texture varying from psilate to scabrate.

PASSIFLORACEAE

Herbaceous or woody plants that climb by axillary tendrils, with capsular berries. The family is found in tropical and warm temperate zones in both hemispheres.

Passiflora

Characteristic of the family, with lobed leaves and an edible pulpy fruit. It can be found in The Bahamas climbing on small shrubs in pinelands, savannas, coppices, and thickets. Pollen is stephanocolpate, reticulate or with irregular surface structures, with intercolpium at apertures.

POLYGALACEAE

Herbs, shrubs, or trees with worldwide distribution, characterized by the ovary being 2-celled. Species native to The Bahamas can be found in coppices, scrublands, and moist swampy areas. Pollen is polycolporate, oblate, and flaring at the equator.

PONTEDERIACEAE

Perennial aquatic and bog plants with floating or creeping roots. Species native to The Bahamas can be found in ponds, lakes, canals, and ditches. Pollen is monocolpate and psilate, with the single colpus not extending all the way to the poles.

PHYTOLACCACEAE

Herbs, shrubs vines and rarely trees, the Pokeweed family comprises over 120 species that are found mainly in the American subtropics and tropics. Species native to The Bahamas grow in disturbed areas and at the edges of coppices.

Rivinia

A plant that has erect stems that become vine-like with spreading branches as it grows. It can be found in low coppices, sinkholes, vacant lots, open slopes, and scrublands. Pollen is stephanoporate, spheroidal, and scabrate to psilate.

RHIZOPHORACEAE

Evergreen shrubs or trees, often with knee roots and leathery leaves. Members of the family can be found throughout the tropical and subtropical regions of the world.

Rhizophora

Salt-tolerant shrub or tree with prop roots that forms dense thickets. It can be found along muddy shores and in coastal swamps, and occasionally inland throughout the Bahamian islands. Pollen is tricolporate, psilate, and spheroidal, with a thick exine and intercolpium flattened and turning in to a furrow.

RUBIACEAE

The Rubiaceae family includes trees, shrubs, or herbs. Commonly known as the Madder family, it contains over 6000 species in over 500 genera from all over the world. Many types in The Bahamas can be found in scrublands and coppices, as well as pine rocklands.

Psychotria

Shrubs or small trees, rarely perennial herbs, commonly known as coffee. Species native to The Bahamas can be found in coppices, hammocks, swampy areas, sink holes, and scrublands. Pollen is tricolporate, spheroidal, and clavate.

Strumphia

A shrub native to the West Indies. It can be found on coastal rocks and rocky flats, throughout The Bahamas. Pollen is tricolpate and scabrate, with furrows with equatorial constriction.

SAPOTACEAE

Shrubs or trees, often spiny with milky juice, mostly found in the tropics.

Bumelia

Mostly tropical evergreen shrubs or trees with hard wood. Species of this genus can be found in any environment in The Bahamas. Pollen is tetracolporate, psilate, and prolate.

SCROPHULARIACEAE

Mainly herbs, commonly known as the Figwort family.

Capraria

An herbaceous multiple-branched plant found throughout subtropical and tropical America, growing along roads, in fields, open coppices, and thickets. Pollen is tricolpate, subprolate, and thick-walled with wide colpi.

SOLANACEAE

The potato or Nightshade family includes herbs, shrubs, and trees. Species native to The Bahamas can often be found growing at the edges of thickets and coppices, or along road sides. Pollen is tricolporate, small, psilate, and subprolate.

STERCULIACEAE

The Sterculiaceae or Cacao family includes 70 genera and over 1000 species of trees, shrubs, and herbs, found mostly in the tropics.

Melochia

Shrub or herb, native to The Bahamas and found in waste areas, open thickets, open pinelands, and coppices. Pollen is tricolpate, intectate, large, and scabrate. The grain often appears collapsed.

THEOPHRASTACEAE

Trees or shrubs, made up of over 100 species in four genera. Native to the American tropics and subtropics.

Jacquinea

Evergreen shrubs or small trees with small white or yellow flowers, found in the warmer regions of the Western Hemisphere. Species native to The Bahamas are found in coppices and scrublands. Pollen is tricolporate, scabrate with clavate elements, and the endopore is not distinct from a surface view. The colpi are narrow.

TILIACEAE

Trees, shrubs, or rarely herbs, the Linden family is made up of 450 species in 50 genera found mostly in southeastern Asia and South America.

Corchorus

Mostly low shrubs with alternate serrated leaves. The genus has over 100 species in tropical and warm temperate regions of both hemispheres. It can be found throughout The Bahamas, in cleared lands, open fields, and scrublands.

TYPHACEAE

Aquatic perennial herbs with a creeping rhizome and erect leaves. There is only one genus, *Typha*, in the family. The plants have worldwide distribution, and in The Bahamas, native species can be found in brackish or freshwater marshes and ponds. Pollen is monoporate and scabrate, with closely spaced pits giving the appearance of being finely reticulate.

UMBELLIFERAE

Primarily herbaceous plants, commonly with hollow stems and with member species found worldwide. Pollen is tricolporate, prolate, and reticulate. Colpi run the length of the grain.

ULMACEAE

Trees or rarely shrubs with watery sap, commonly known as the Elm family.

Trema

A tree up to 8 m tall, found in Florida and the West Indies. In The Bahamas, it can be found in coppices and scrublands. Pollen is diporate, psilate, small, and suboblate, with pores slightly protruding.

VERBENACEAE

Shrubs, small trees, or occasionally herbs. The family is composed of more than 3300 species in 76 genera distributed throughout the world.

Duranta

Extremely variable and polymorphic shrub or small tree, with slender drooping branches. It can be found in The Bahamas in coppices, pinelands, and fields. Pollen is tricolpate, psilate, and subprolate. The furrows have equatorial constrictions.

Pseudocarpidium

Shrub or small tree with light bark, up to 5 m tall. In The Bahamas, members of the genus can be found in coppices and scrublands. Pollen is tricolpate, scabrate, subprolate, and small. Grains tapered towards ends with narrow colpi.

VITA

Ian Arthur Slayton was born on Mountain Home Air Force Base, southern Idaho, in 1984. He attended Union County High School in Maynardville, Tennessee, graduating valedictorian of his class. Ian received a B.A. in Geography from the University of Tennessee in Knoxville before entering the graduate program in Geography in 2006. He served as a graduate teaching assistant and head teaching assistant for introductory physical geography courses while a graduate student. Upon completing his M.S. degree, Ian will enter the Ph.D. program in Geography at the University of Denver, where he hopes to continue to study lake sediments, including their characterization using ground-penetrating radar.