Effects of Hydrologic Changes and Precipitation on Tree Island Fire Frequency in the Everglades, Florida

by

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ABSTRACT

This thesis documents a 100-year history of fire in Water Conservation Area 2A (WCA-2A) in the Florida Everglades. Natural fire frequency in this area is not fully understood, and because the region has undergone dramatic anthropogenic changes since the early 1900s due to drainage, it is important to understand how fire frequency has been affected by drainage in order to properly plan restoration activities. Sediment cores taken from tree islands in WCA-2A were processed and examined microscopically for the presence of charcoal. Charcoal concentrations were compared to drainage and precipitation data to determine the impact of these factors on historical fires of the Everglades area. Charcoal records showed an increased fire activity since significant drainage began in the early 1900s, supporting the idea that drainage activities throughout the past century had an influence on fire frequency. Charcoal records from the study area failed to provide conclusive evidence that precipitation played a major role in fire activity in WCA-2A. Results of the study indicate that anthropogenic changes has a greater impact on fire within the study area than precipitation.

CHAPTER 1: INTRODUCTION

There are limited records of historical fires in the Florida Everglades (Sklar and van der Valk 2002). This may be attributed to the lack of South Florida fire data prior to the establishment of the Everglades National Park in 1947 (Beckage et al. 2005). Scientists have a better understanding of the current wetland system than they ever had of the pre-drainage Everglades (Sklar et al. 1999). Therefore, there is little information regarding natural fire occurrence prior to the alteration of hydrologic processes during the 20th century in the Everglades (Sklar and van der Valk 2002). Although fires were most likely present in the Everglades prior to drainage, the region was likely not exposed to such frequent and severe fires as it experienced after drainage commenced more than a century ago (McVoy et al. 2011).

A better understanding of the impact of altered water levels on natural processes such as fire is necessary when determining restoration plans (Ohlson and Tryterud 1999). Observing the past fire history of an area and determining how changes in hydrologic regimes may have impacted such events, can assist regulatory agencies in the development of more effective land and water management strategies (Nelson et al. 2008). Therefore, gaining a better understanding of the fire history of the Everglades will assist agencies in restoring the wetland to a more natural state.

This thesis presents an approximate 100-year fire history based on the presence of charcoal from three tree islands located in Water Conservation Area 2A (WCA-2A) in the Florida Everglades. Fire history was compared to precipitation records and hydrologic changes in the study region. The primary objectives of the study were to provide evidence of fires in the Everglades by analyzing microscopic and macroscopic charcoal particles found in short sediment cores and to determine the impact of both drainage and precipitation on fire history of the area. One specific goal of this research was to describe how the fire history of the Everglades has been affected by hydrologic changes in the area in order to improve management of the region's many tree islands. The questions addressed in this thesis are as follows:

- Based on analysis of macroscopic and microscopic charcoal particles in tree island sediments, what are the general trends in fires over the past approximately 100 years?
- Is there a relationship between the region's fire record and recorded drainage activities since the early 1900s?
- Is there a relationship between the occurrence of fire and precipitation in the region since the early 1900s?

Tree Islands

Tree islands are island-like patches of forest located in wetlands around the world, including the Everglades (Lodge 2005). They are topographical highs in the landscape, but are only slightly higher than average water levels (Sklar et al. 1999). Their tear-drop shape is a result of water flow around their perimeter (Lodge 2005). Water rounds off the head of the island and creates a tail via downstream sedimentation. Most of the Everglades tree islands are submerged during an ordinary wet season. Observations made by early explorers in the 1800s claimed that tree islands were wet enough so that space on which to cook or sleep was scarce (McVoy et al. 2011). However, wetland shrubs, trees, and even upland tree species have been known to inhabit tree islands (Lodge 2005). Tree island size can vary from less than one acre to many hundreds of acres. Soils on tree islands typically consist of peat, although there may be mineral soils found at the surface (Willard et al. 2006). Tree islands are one of several ecologically important habitats in the Everglades (Lodge 2005). They provide habitats for a variety of animals including turtles, alligators, deer, otters, and many species of birds.

Fire and water-level fluctuations are the main disturbances experienced by tree islands in the Everglades (Sklar and van der Valk 2002). The existence of tree islands in the Everglades depends on a balance between fire and water levels (Lodge 2005). Since drainage activities began, some tree islands have become drier and have lost their defenses against fires (Sklar and van der Valk 2002). Tree islands are the component of the Everglades considered most sensitive to changes in hydrology (Sklar et al. 1999). Unfortunately, water management decisions in the 20th century have altered natural processes in the Everglades including those associated with persistence and distribution of tree islands (Lodge 2005).

Ghost islands are tree islands that have undergone significant community degradation or have disappeared entirely from the landscape (Ewe 2009). The formation of ghost tree islands is a consequence of changing hydrology in an area (Ewe et al. 2009). Ghost islands have lost woody vegetation and therefore, their elevation relative to the surrounding marsh (Ewe 2009). They can be easily detected in aerial photographs and appear as scars on the landscape because they are covered by water and marsh vegetation (Figure 1). Very little information is available on the physical, chemical, and biological aspects of this type of tree island (Sklar et al. 2011). Since 1940, approximately 60% of tree islands in the Everglades have been reclassified as ghost islands. Accordingly, two of the three tree islands in this study are characterized as ghost islands.

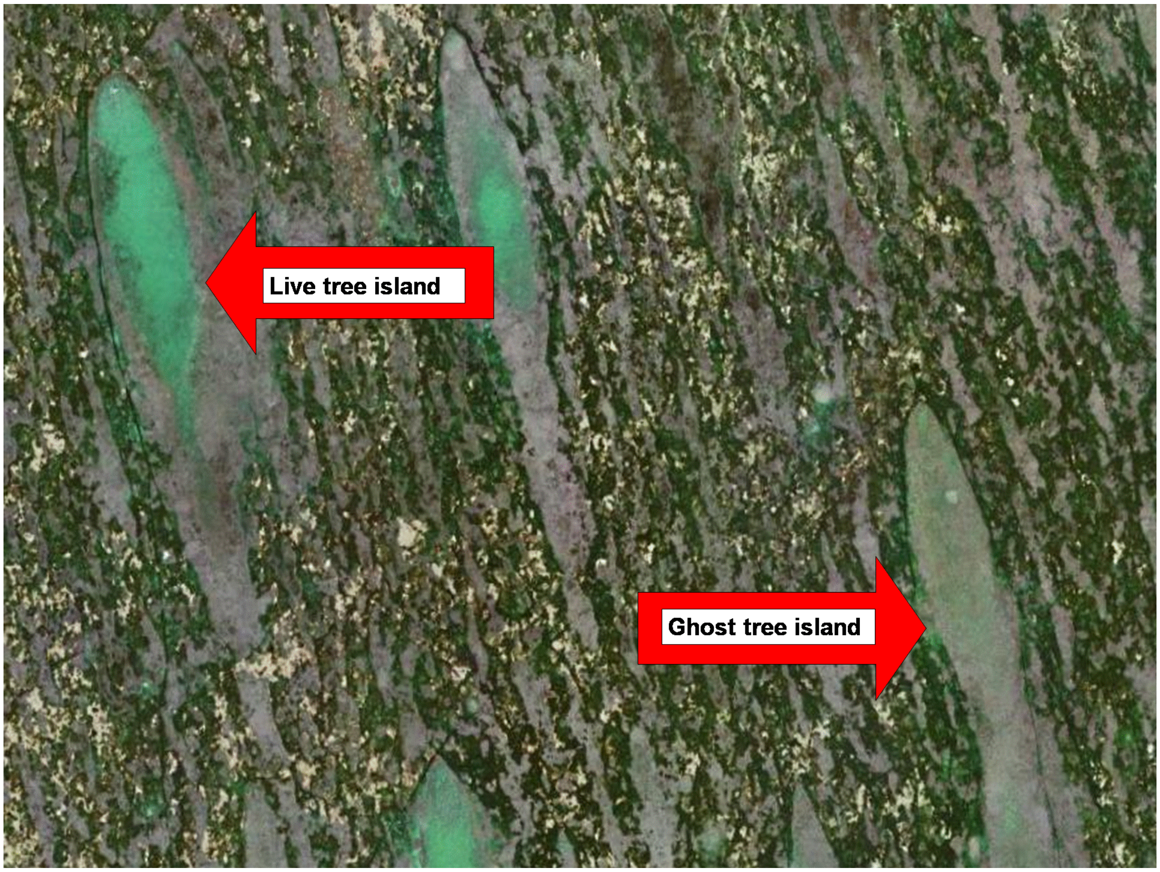
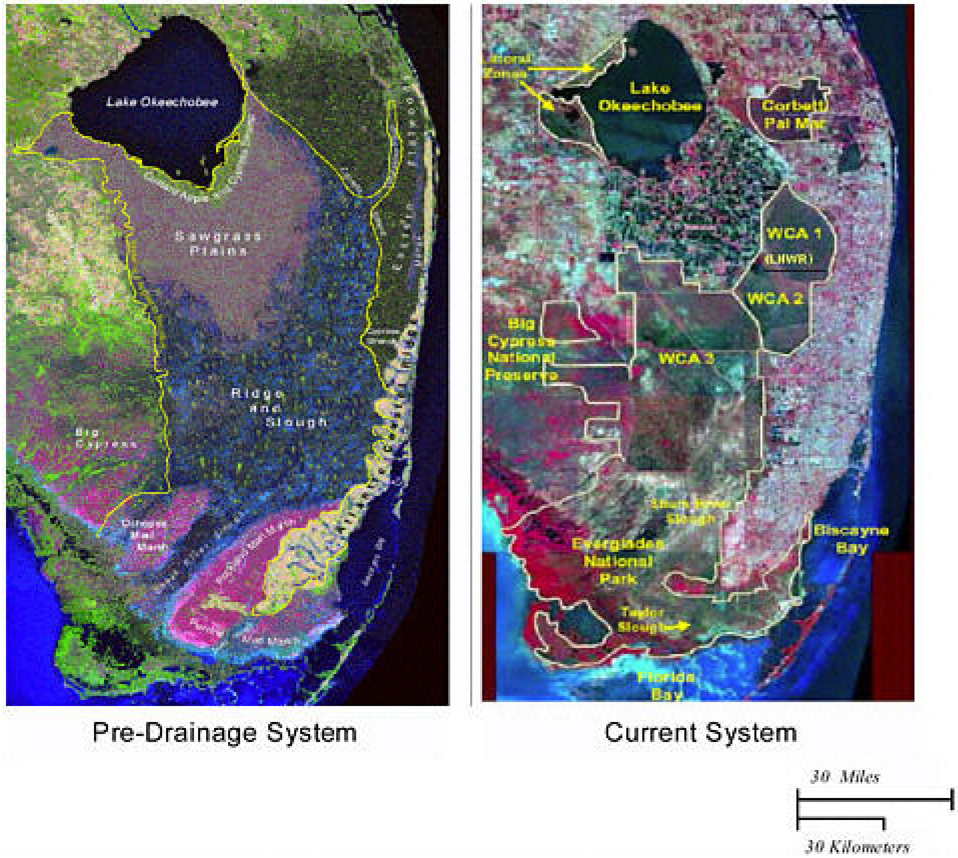


Figure 1: An aerial photograph of live and ghost tree islands (Ewe et al. 2009).

Drainage of the Everglades

The Everglades is approximately 5,000 years old and once comprised 4 million acres of land (Bernhardt et al. 2004), but only half of the region's marshes survive today (Grunwald 2006). Wetland drainage began in the late 1800s for agricultural and urban purposes (Figure 2). Prior to the early 1900s, drainage efforts had little effect on the hydrology of the region (Sklar et al. 1999). The headwaters of the Everglades historically began with the Kissimmee chain of lakes just south of Orlando (Lodge 2005). These lakes drained into the Kissimmee River, which then flowed into Lake Okeechobee. Prior to drainage, water overflowed the southern end of the lake (Bernhardt et al. 2004), marking the beginning of the Everglades (Grunwald 2006). Most water then flowed south from the lake, eventually reaching either Florida Bay or the Gulf of Mexico, although some water flowed to the Atlantic Ocean through low spots in the Atlantic Coastal Ridge (Sklar et al. 2002).



Pre-Drainage System

Current System

Figure 2: The pre-drainage flow of the Everglades and the current post-drainage flow and compartmentalization of the Everglades (National Academies Press 2003).

Even before drainage began, tree islands and other Everglades habitats were impacted by anthropogenic activities (Grunwald 2006). Native Americans lived in the Everglades before the area was settled by Euro-Americans in the late 1800s. Some of these Native Americans made use of the region’s tree islands for living, hunting, and farming (Loveless 1959; Grunwald 2006). Many of the islands were burned to clear the area for planting crops (Grunwald 2006). Overall, the impacts of these activities on the land were small, especially in comparison to drainage and modifications made by the settlers that followed. Completion of the Tamiami Trail in 1928 blocked north-south canoe travel and water flow across the Everglades. Consequently, the Native Americans living on tree islands resettled near roadways.

By 1896, the Florida East Coast Railroad ran along the eastern rim of the Everglades as far south as Miami (Grunwald 2006). Construction resulted in cutting and burning of pine forests and hardwood hammocks along the coastal ridge. Significant alterations of the Everglades commenced in the early 1900s. Drainage began as a way to protect people from flooding and to promote commerce in South Florida (Willard et al. 2006) and also to clear land for agricultural purposes (Grunwald 2006; Waters et al. 2012). Between 1906 and 1920, workers constructed canals in the region to control water movement (Sklar et al. 1999; Grunwald 2006). Excess precipitation in the region was now being removed by a system of canals (Sklar et al. 1999; Waters et al. 2012). Construction of these canals caused water levels to drop in Lake Okeechobee and surrounding areas (Sklar et al. 1999; Sklar and van der Valk 2002). Declining water levels caused the exposure and loss of peat soils through oxidation in the Lake Okeechobee region (Sklar and van der Valk 2002).

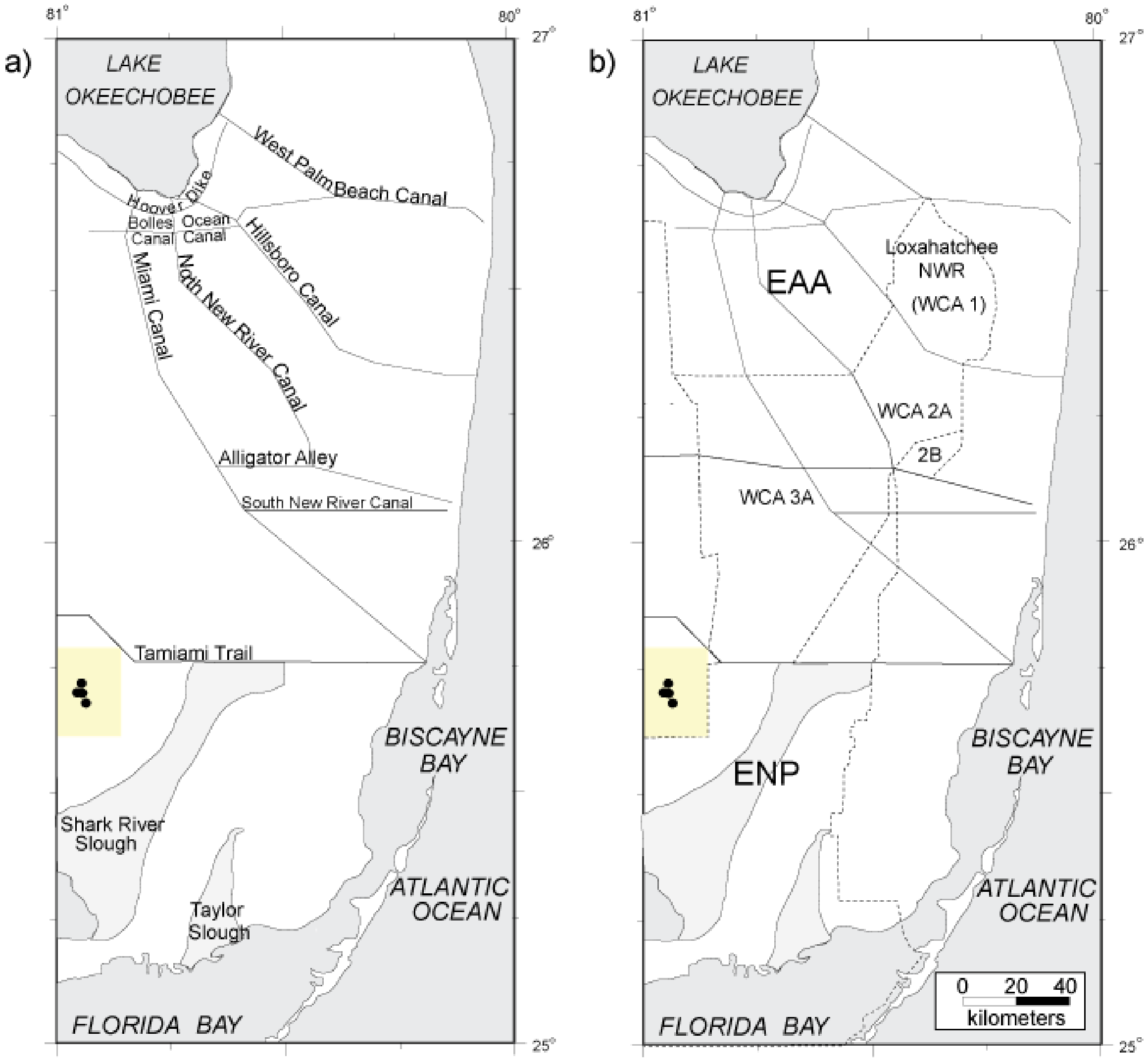


Figure 3: Anthropogenic changes to the Everglades wetland system (Bernhardt and Willard 2006).

Farmland expanded to around 34,000 acres during the 1920s (Grunwald 2006). The water table fell, prompting salt-water intrusion into the Biscayne aquifer and causing fires in the region (Grunwald 2006; McVoy et al. 2011). In 1926 and 1928, hurricanes caused the water in Lake Okeechobee to overflow its southern rim (Grunwald 2006). These events destroyed the lake-front towns of Moore Haven and Belle Glade and killed more than 2,000 people. Destruction from the hurricanes led to the construction of the Hoover Dike (Figure 3a), which prevents the lake from overflowing into the Everglades. The natural overflowing of Lake Okeechobee used to be one of the most important features of the Everglades (Bernhardt et al. 2004). The construction of the dike, additional drainage canals, and years of drought combined to dry out many of the region's wetlands (Bernhardt et al 2004; Grunwald 2006). Consequently, one million acres of former wetland area burned.

Hurricane-related flooding in the 1940s ultimately accelerated drainage in the Everglades (Willard et al. 2006). Devastating floods in 1947 led Congress to pay for a massive flood-control project to control water across South Florida (Grunwald 2006). The Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project) was developed to manage water throughout South Florida, including in the Everglades (Lodge 2005). From the 1940s to the 1970s, the U.S. Army Corps of Engineers (Corps) built extensive systems of levees, canals, and pump stations to protect against floods and to store water during drought periods (Sklar and van der Valk 2002; Willard et al. 2006). The Corps constructed a perimeter levee in the early 1950s on the eastern side of the Everglades in order to block water flow towards the rapidly urbanizing east coast communities between West Palm Beach and Miami (Light and Dineen 1994; Lodge 2005). This levee would become the eastern edge of the Water Conservation Areas (WCAs) (Light and Dineen 1994). The Everglades Agricultural Area (EAA) was developed in the late 1950s (Figure 3b) (Light and Dineen 1994; Lodge 2005) and currently encompasses about 27% of the original Everglades (Lodge 2005). The western and northern boundaries of the WCAs were constructed during this time as well (Light and Dineen 1994). The WCAs were completed during the early 1960s (Figure 3b). Water levels in the WCAs are regulated by large pumps installed in the late 1950s that push water through canals and interconnected water-control structures (Lodge 2005). The creation of the WCAs allowed for more area for agriculture and increased development within the surrounding Everglades (Waters et al. 2012). Between 1965 and 1973, the extension of the canal system into an interconnecting network featuring many pumps and control gates effectively reduced flooding and opened hundreds of thousands of acres to urban development (Light and Dineen 1994; Lodge 2005). Ensuing urban and agricultural development has greatly increased drainage from the Everglades over the last 50 years (Lodge 2005; Bernhardt and Willard 2009).

Anthropogenic changes that occurred as a result of the C&SF Project considerably altered the hydrologic regime of the Everglades (Grunwald 2006). While historic and current water cycles are the same, canals and water control structures have altered the length of hydroperiods, which is the length of time a wetland remains saturated throughout the year (Sklar et al. 1999). Although occasionally inundated with unnaturally high water levels, deliberate reduction of natural water levels has had the greatest impact on the Everglades (Lodge 2005). In 2000, Congress authorized the Comprehensive Everglades Restoration Plan (CERP), which is intended to increase the water supply for all of South Florida and to help rehabilitate badly degraded portions of the Everglades (Bernhardt and Willard 2009).

Fire in the Everglades

Anthropogenic changes to the Everglades hydrology has impacted fire frequency in the region (Loveless 1959; Hallet and Walker 2000). Regional drainage has led to more frequent and intense fires (Gunderson and Snyder 1994; Snyder and Davidson 1994; Sklar et al. 1999; McVoy et al. 2011). Fire frequency generally increases as human population increases, until ultimately habitat fragmentation limits such fires (Nelson et al. 2008). Land is often cleared to make room for development and agriculture by burning, which causes an increase in fire frequency. Once the land is divided, fragmentation limits the spread of fire. Fire frequency can also be influenced by divisions in the natural landscape such as creeks or rivers (Guyette et al. 2002). In much the same manner, canals constructed through the Everglades in the early 1900s created abnormal fire patterns (Sklar et al. 1999). Therefore, fragmentation of the Everglades led to both a decrease in fire frequency in areas that have a higher water level and an increase in destructive fires in drier areas.

Fire has an important impact on the ecology of wetland systems (Gunderson and Snyder 1994) therefore, the composition and structure of the Everglades are sensitive to fire activity (Beckage et al. 2003). During drought conditions, fire can consume marsh and tree island vegetation as well as the peat layers underneath (Loveless 1959; Sklar and van der Valk 2002). Peat, or muck, fires occur when water tables are far enough below ground for the upper peat surface to dry out (McVoy et al. 2011). For peat fires to occur, water tables need to be deeper than the normal dry-season minimum level of 4 to 6 inches below the surface. Since drainage commenced, large areas of the Everglades have burned due to low water levels causing peat fires. Peat fires can cause less frequent, but more intense and longer-lasting disturbances to vegetative communities (Sklar et al. 1999). Peat fires can burn for months, or even years, throughout wet season periods (McVoy et al. 2011). During the 1920s to 1950s, periodic droughts caused extensive peat fires that affected both sawgrass (*Cladium*) and tree islands (Sklar et al. 1999). Areas that were once ridge and slough environments became over-drained, resulting in long-burning peat fires throughout the wetland and on tree islands. Burning peat can potentially lower surface elevations enough to transform the landscape from a drier environment to a pond-like state during wet seasons. Therefore, severe fires and their impact on hydrologic regimes can seriously damage and even destroy tree islands (Sklar and van der Valk 2002). Although peat fires are common now, there is no evidence that the region was ever dry enough for widespread peat fire to occur prior to drainage (McVoy 2011).

The impact of humans on fire activity has been well-documented in other areas of the United States. Nelson et al. (2008) demonstrated that drainage and land development for agriculture from 1909 to 2003 caused an increased fire frequency in Illinois within the Ohio River floodplain. Guyette et al. (2002) demonstrated through dendrochronological studies that human populations have been a major influence on wildfires over the last 320 years in Southern Missouri.

Although little is known about how individual tree islands have been affected by fire resulting from changes in hydrology (Sklar and van der Valk

2002), fire has been identified as an important factor in tree island growth under normal conditions (Sklar et al. 1999). It is assumed that some tree islands burned as a result of lower water levels, which could have led to long-term or permanent loss of the islands (Sklar and van der Valk 2002). In some cases, shorter intervals between fires resulted in a loss of smaller tree islands, while in other cases, longer intervals between fires resulted in an increase of woody species on selected islands (Sklar and van der Valk 2002). In still other cases, tree islands may have increased in area as drainage exposed areas of peat and contributed to colonization of trees and shrubs. Therefore, further studies on drainage and tree islands in the Everglades are needed to determine exactly how they were affected by water management.

Precipitation in South Florida

Warm and dry climatic conditions, like those present in South Florida during the winter and spring, generally promote an increase in fire activity (Hallet and Walker 2000). South Florida has a wet season that lasts from June through October and a dry season that lasts from November to May (Beckage et al. 2003). The region periodically experiences drought as part of an exceptionally arid dry season (Hallet and Walker 2000). Drought can lead to reduced surface water and a lowered water table (Obeysekera et al. 1999), which can increase the potential for fires to occur (Abtew et al. 2011). Historic droughts occurred during 1932, 1955–1957, 1961–1963, 1971–1972, 1973–1974, 1980–1982, 1985, 1988–1989, 1990, and 2000–2001 (Abtew and Huebner 2001). Lightning from storms can cause severe fires in the region; however, this is more likely to happen during the transition period from the dry winter season to the wetter summer season (Beckage and Platt 2003).

The influence of climate on fire activity in an area has been documented by numerous paleoecological studies. For example, Veblen (2003) showed that the presence of charcoal in an area can indicate a drier climate and, therefore, more fires. Furthermore, information contained in long-term fire and pollen records has shown the impact of temperature and rainfall changes on fire frequency (Hallet and Walker 2000). Therefore, as previous studies have demonstrated, fire frequency may be altered due to rainfall variability.

Climate can be influenced by changes in land cover (Willard et al. 2006). Changes in land cover on Florida throughout the 20th century have been correlated with reduced summer precipitation and increased daytime temperature (Marshall et al. 2004). Such conditions have the potential to magnify drier conditions. During a study by Marshall et al. (2004), possible impacts of the transformation of the Florida landscape on warm season climate were examined using simulations carried out by the Regional Atmospheric Modeling System. Sea breezes are driven by thermal interactions occurring between the land and the ocean; therefore, wetland drainage and urbanization can alter the flow of rain-bearing sea breezes and can contribute to changes in physical impacts of weather circulations. Marshall et al. (2004) found that when natural vegetation is replaced with areas of urban development and agricultural land, it is possible for maximum temperatures to increase and rainfall to decrease.

Use of Fossil Charcoal to Establish Historical Fire Records

A common and effective method used to interpret fire histories is to analyze charcoal particles contained in sediments of lakes and wetlands (Hallet and Walker 2000; Brunelle and Whitlock 2003; Tinner and Sheng Hu 2003; Beaty and Taylor 2009). Charcoal is created when fire incompletely combusts organic material (Whitlock and Larsen 2001). Charcoal records are especially useful in constructing fire histories because charcoal particles from fires can remain in sediments for thousands of years (Brunelle and Whitlock 2003; Beaty and Taylor 2009; Schlachter and Horn 2009) and can provide information about variations in fire frequency and intensity (Brunelle and Whitlock 2003). Charcoal can be introduced into wetland soils or sediments when the surrounding upland plants burn and when wetland soils get dry enough to burn.

The size of charcoal particles (microscopic versus macroscopic) provides information about the distance of fire from the deposition site of charcoal particles (Ohlson and Tryterud 2000; Carcaillet et al. 2001; Whitlock and Anderson 2003). Macroscopic charcoal (particles 125 µm and larger) signal the presence of local fires (Ohlson and Tryterud 2000; Carcaillet et al. 2001; Brunelle and Whitlock 2003; Whitlock and Anderson 2003; Stahli et al. 2006; Beaty and Taylor 2009). In more general terms, the larger the particle of charcoal, the closer the fire occurred to where charcoal was deposited. Accordingly, soil samples dominated by large charcoal particles are indicative of fires that occurred locally, because large particles are not likely to have traveled very far (Rhodes 1998; Anderson 2001; Brunelle and Whitlock 2003).

Microscopic charcoal (particles smaller than 125 µm) also provides information about local fire history, but unlike their macroscopic counterpart, they can travel long distances from the original fire site (Carcaillet et al. 2001). Microscopic charcoal particles can travel far beyond 100 m (Whitlock and Larsen 2001). Previous studies have shown these smaller particles to have traveled between 6 and 7 km away from the site of the fire (Whitlock and Larsen 2001; Whitlock and Anderson 2003). This is because it is easier for smaller, lighter particles to be dispersed by wind and water. Therefore, microscopic charcoal is used to construct a regional fire history (Carcaillet et al. 2001; Tinner and Sheng Hu 2003; Whitlock and Anderson 2003).

The size of charcoal particles can also give information about fire intensity (Whitlock and Larsen 2001). High-intensity fires can produce larger particles than low-intensity fires. These low-intensity fires have low combustion efficiency so they may produce a higher amount of particulate matter.

Finally, charcoal abundance also contributes to the characterization of fire history in a given area (Enache and Cumming 2007). Usually, when a greater amount of charcoal is present, a higher number of fires have occurred in an area. Conversely, the less charcoal that is present, the lower the number of fires that have occurred in an area.

Processing macroscopic and microscopic charcoal particles from sediments typically involves the use of different laboratory methods. Macroscopic charcoal is typically processed by disaggregating charcoal from sediments (Hallet and Walker 2000; Carcaillet et al. 2001; Enache and Cumming

2007; Long et al. 2007; Black et al. 2008; Beaty and Taylor 2009). Processing of microscopic charcoal is typically done in conjunction with preparation of pollen slides using different, harsher chemicals than used during macroscopic charcoal processing (Carcaillet et al. 2001; Tinner and Sheng Hu 2003; Whitlock and Anderson 2003; Kennedy et al. 2006). Pollen analysis is a paleoecological technique that can be used to study vegetation changes over time (Willard et al. 2006). These analyses require the creation of fossil pollen slides in order to view the pollen assemblages microscopically.

There are a variety of ways to disaggregate samples to separate macroscopic charcoal from sediments. Long et al. (2007) soaked sediment samples in 5% sodium hexametaphosphate for 24 hours to deflocculate charcoal from the sediments. Black et al. (2008) used 8% sodium hypochlorite to soak samples for 24 hours. This was done to remove pigment from organic matter to better identify charcoal particles. Enache and Cumming (2007) soaked their samples overnight in 10% potassium hydroxide and then soaked them in 5% sodium hypochlorite for 48 hours to oxidize the organic matter. Beaty and Taylor (2009) used the same combination of chemicals, but chose a hot 5% potassium hydroxide solution to disaggregate their samples, and then a 10% sodium hypochlorite solution heated to 50–60 degrees Celsius for 8–10 minutes. Carcaillet et al. (2001) used a tetra-sodium diphosphate solution to soak samples for a minimum of two days in order to deflocculate the sediments, and then disaggregated samples with a manual water spray. Hallet and Walker (2000) used a cold 10% hydrochloric acid solution for one hour to deflocculate all the carbonates in their samples.

Microscopic charcoal is most often processed during pollen slide preparation (Carcaillet et al. 2001; Tinner and Sheng Hu 2003; Whitlock and Anderson 2003; Kennedy et al. 2006) because sample preparation and counting time can be reduced by doing both activities at the same time (Rhodes 1998). However, microscopic charcoal can be fragmented during pollen preparation due to harsh chemicals used during the process. This can result in an increase in the amount of charcoal particles and leads to an overestimation of the amount of charcoal present in the samples (Carcaillet et al. 2001; Whitlock and Anderson 2003), yet researchers have found ways to mitigate this problem.

Hydrogen peroxide has been used to prepare samples for both macroscopic and microscopic charcoal analysis. Rhodes (1998) outlined a procedure for preparing microscopic charcoal from lacustrine and terrestrial samples using 6% hydrogen peroxide. This method was developed to address the issue of charcoal particle fragmentation associated with processing charcoal and pollen at the same time using harsh chemicals. In this method, organic matter that is not charred is bleached and partially digested by the hydrogen peroxide. The samples are then identified and counted under a dissecting microscope. In order to process macroscopic charcoal particles from sediments, Schlachter and Horn (2009) experimented by soaking samples for 24 hours in various concentrations of hydrogen peroxide (1, 3, 6, and 9%). They concluded that 3% hydrogen peroxide was a strong enough concentration to sufficiently bleach the organic material without altering the number or size of charcoal particles through fragmentation.

CHAPTER 2: STUDY AREA

The Water Conservation Areas (WCAs) located in South Florida comprise 1,337 square miles of land (U.S. Army Corps of Engineers 2008). They are an important habitat for fish and wildlife and they provide recreational areas for Florida residents and visitors. A regulation schedule provides a minimum water level suitable for sustaining native fish and wildlife and other natural values. The WCAs' main purpose is to serve as reservoirs for water supply to urban areas.

WCA-2 was developed to allow for growth of emergent vegetation: wetland plants that are rooted in marsh soil but protrude above the water surface (Light and Dineen 1994). It is divided by a levee into WCA-2A and WCA-2B. WCA-2A was completed in 1961 (Rutchey et al. 2008), is totally enclosed by levees, and accounts for 80% of WCA-2's total area (Light and Dineen 1994). WCA-2A receives most of its water via drainage from the Everglades Agricultural Area (EAA) and outflows from WCA-1 during the wet season (Sklar et al. 2002). Water can be directed to the driest parts of the WCA with WCA-2A outputs going to either WCA-3 or WCA-2B (Light and Dineen 1994).

WCA-2A experienced tree island loss due to high water levels as far back as the 1940s (Lodge 2005). Since then, lowered water levels resulting from drainage and drought conditions have altered peat accretion and oxidation processes (Sklar et al. 1999). Such conditions have combined to decrease wetland elevation by way of increased microbial oxidation and a higher frequency of peat fires and this has led to a decrease in wetland elevation. The loss of elevation made the WCAs more susceptible to ponding. As water levels rose again in the 1960s, tree islands that had experienced elevation loss became susceptible to drowning (Sklar et al. 2002). With the exception of drought years, the area was continuously flooded from 1961 until 1980 (Willard et al. 2006) and eventually converted to a deep-water slough (USGS 2003). As a result, an increased abundance of weedy species in marsh areas and ferns on tree islands appeared (Willard et al. 2006). Cattails (*Typha*) began to replace native sawgrass (*Cladium*) and more than a decade of increased hydroperiods and water depths (Wu et al. 1997) essentially led to the disappearance of many tree islands in WCA-2A (Sklar et al. 2002; Ewe et al. 2009). Higher water levels have drowned up to 95% of the original tree islands in the area (Ewe 2009) so that WCA-2A has only three remaining living tree islands (Ewe et al. 2009). Drowned tree islands are degraded to the point where they are properly classified as ghost islands. WCA-2A has a higher number of ghost tree islands than any other area in the Everglades.

Beginning in 1980, authorities initiated efforts to return water levels in WCA-2A to their pre-drainage state (Rutchey et al. 2008). Drawdowns were attempted prior to 1980 (Light and Dineen 1994) after which time a new water regulation scheme was put in place, which included a permanent drawdown schedule. Lowered water levels allowed for periodic exposure of marsh sediments (Light and Dineen 1994; Rutchey et al 2008).

The three tree islands used in the present study were designated 2A-14-2, 2A-15-6, and 2A-22-18 by the South Florida Water Management District (SFWMD). Figure 4 shows the locations of the three tree islands. Two of the tree islands (2A-14-2 and 2A-15-6) are classified as ghost islands and the third tree island (2A-22-18) is a live island.

2A-14-2

Tree island 2A-14-2 is located in the central part of WCA-2A, and is situated at 26.29787 N, -80.44041 W (Ewe et al. 2009). A previous paleoecological study determined that the tree island formed between 1050 to 150 BC (Willard et al. 2006). This ghost tree island is now surrounded mostly by open water and slough areas (Ewe et al. 2009). Sawgrass (*Cladium*) covers the entire island. Pollen analysis of sediment cores examined by Willard et al. (2006) showed an increase in water lilies (*Nymphaea)* from 1960 to 1980, which indicated wetter conditions. This is consistent with the interval during which tree islands in WCA-2A began to disappear and wet prairies were converted to sloughs. After 1980, an increase in sawgrass (*Cladium)* and Asteracae pollen was consistent with a period of more water drawdowns and periodic exposure of marsh soils.

2A-15-6

Tree island 2A-15-6 is located in the eastern part of WCA-2A at 26.27528 N, -80.31951 W (Ewe et al. 2009). This ghost tree island is located in a slough area but is close to the eastern edge of WCA-2A, near the urbanized coastal ridge. This tree island has been observed since 1940 by scientists for boundary and vegetation changes. The eastern edge of 2A-15-6 has proven to be the most dynamic. In 1940, the island supported woody plants and trees. By 1973, however, it was dominated by cattails (*Typha*). This change in flora corresponded with higher water levels in WCA-2A during the 1960s and 1970s (Sklar et al. 1999). Presently, the island is dominated by sawgrass (*Cladium*) and there are no large trees present on the island (Ewe et al. 2009).

2A-22-18

Tree island 2A-22-18 is located in the northern part of WCA-2A at 26.41981 N, -80.45062 W, close to the EAA (Ewe et al. 2009). At the time of core collection, there was sparse sawgrass (*Cladium*) along with many recently burned trees and plants. Tree coverage on the island was sufficient enough to form a canopy.

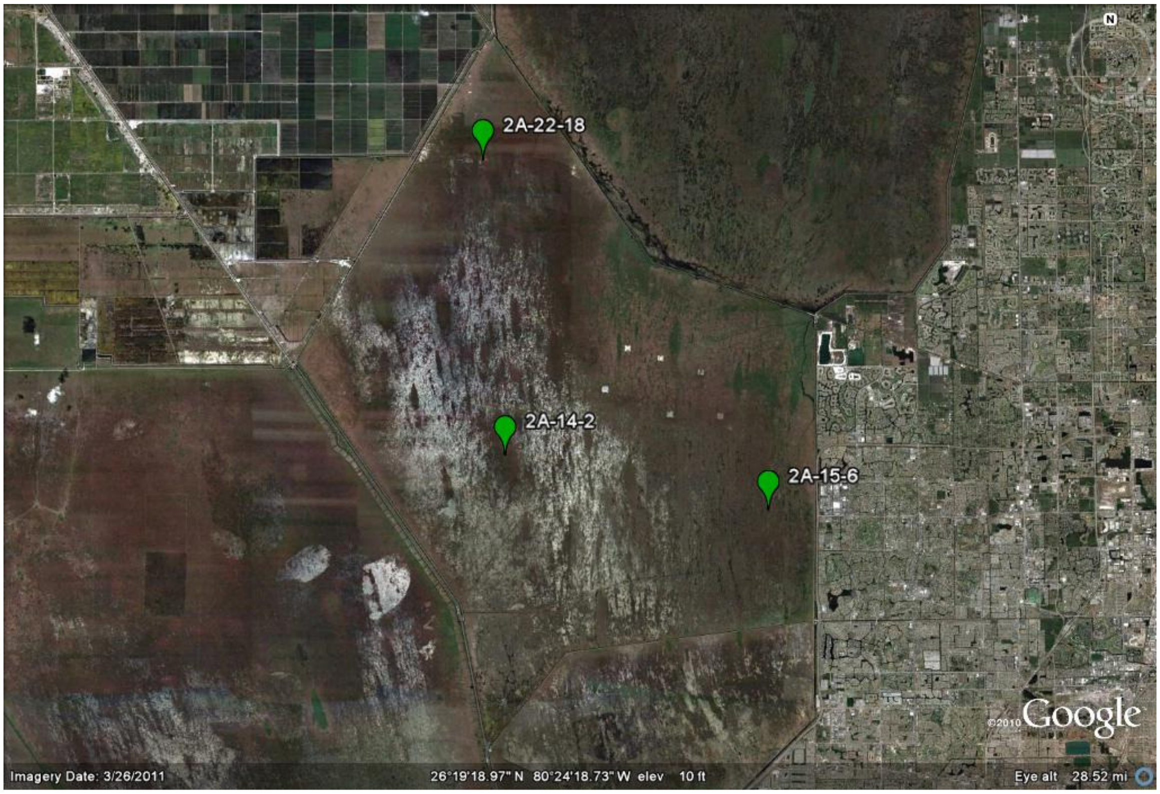


Figure 4: Locations of tree islands used in this study (Google Earth 2011).

CHAPTER 3: METHODS

Core Collection and Charcoal Processing

The consulting firm Ecology and the Environment (E & E) collected the three sediment cores used in this study from tree islands in Water Conservation Area 2A (WCA-2A) during 2009 as part of a larger study for the South Florida Water Management District (SFWMD) intended to assess island microtopography, soil bulk density, and vegetation patterns (Figure 4) (Ewe 2009). As part of core collection, sediment composition was described and noted (Ewe et al. 2009). Investigation of the Everglades increased during the 1940s and aerial photographs were taken of the study area during this time (McVoy et al. 2011). Even though the Everglades had been altered prior to this time, many pre-drainage landscapes are visible in the pictures. The consulting scientists compared these aerial photographs from 1940 with those from 2009 (Ewe 2009). Tree islands were identified and then transected perpendicular to original directions of the islands based on locations of their historical head, middle, and tail positions. Sixty-cm-long sediment cores were collected by manually driving a polycarbonate piston coring tube into the central portion of the middle transect on each island. The cores were then sectioned into 1-cm slices and sub-samples for charcoal analysis were placed into screw-top vials and sent to the University of South Florida St. Petersburg for processing. Sub-samples were refrigerated until processed to slow decomposition of organic matter.

Microscopic and macroscopic charcoal particles were processed together at the same time using 3% hydrogen peroxide. To process macroscopic charcoal, the methods developed by Schlachter and Horn (2009) were used. A 1-cm^3 portion of each sample was measured out and the wet weight was recorded. A sub-sample of this size has proven sufficient in reconstructing fire histories (Hallet and Walker 2000; Carcaillet et al. 2001). Samples were soaked for 48 hours in 20 mL of 3% hydrogen peroxide solution to bleach the organic matter and allow better visibility of charcoal particles. Samples were gently rinsed, using deionized water, through a set of nested sieves with mesh sizes of 125, 250, 500, and 1,000 µm. Different mesh sizes were used to determine the distribution of macroscopic charcoal in the individual size classes. Carcaillet et al. (2001) used this sieving technique successfully in local fire-history reconstruction. Charcoal particles that remained on sieves were rinsed into four different Petri dishes depending on their size class (Schlachter and Horn 2009). Remaining sediment not caught by the sieves, along with water used to rinse samples through the sieves, was collected in a bowl and the volume of the liquid was measured. After the volume was measured, the liquid was mixed thoroughly and 30 mL was removed and placed in a Petri dish. The remaining liquid was discarded. The amount of microscopic charcoal (less than 125 µm) found in 30 mL of liquid was used to estimate the amount of microscopic charcoal found in the total volume of liquid collected. At approximately 10-cm intervals throughout the length of the sediment core, three Petri dishes were prepared for measurement of the microscopic size charcoal particles. This procedure ensured that a consistent amount of microscopic charcoal was represented in the smaller volume of liquid chosen for inspection. All size classes were dried at 60 degrees Celsius in a drying oven for approximately one day before counting.

Resulting macroscopic and microscopic charcoal particles were counted on Petri dishes with a dissecting microscope. The sediment was viewed at 20X magnification for size classes larger than 125 µm and at 40X magnification for particles smaller than 125 µm, as it has been shown that using a microscope magnifying at a minimum of 30X magnification is needed to identify most microscopic charcoal particles (Rhodes 1998). Charcoal can be identified by its color and texture, normally appearing black, angular, shiny, and opaque when viewed under a microscope (Rhodes 1998; Anderson 2001; Whitlock and Larsen 2001; Tinner and Sheng Hu 2003; Kennedy et al. 2006). Only black, shiny, and opaque particles were counted in this study. Occasionally before counting, the Petri dishes were moistened using a spray bottle of deionized water to more readily identify charcoal particles because this helped differentiate between opaque charcoal and translucent bleached sediment. If the sediment was bleached enough to readily identify charcoal without remoistening, the moistening step was not taken. Clear plastic grids were placed under the Petri dishes during counting to keep track of which areas of the Petri dish had been examined for the presence of charcoal. To calculate the number of charcoal particles/cm^3 for the microscopic size class, the following equation was used:

mL of liquid measured/total volume of water = number of
charcoal particles counted/total number of charcoal particles

The sample size used was always 30 mL.

Precipitation Data

Precipitation information since 1900 was obtained from the Southeast Regional Climate Center's (SRCC) website. Several stations surrounding the study area were examined to determine the length of their precipitation record. Five stations in South Florida (Ft. Lauderdale, Ft. Myers, Ft. Pierce, Belle Glade, and Canal Point) were chosen based on the historical precipitation data available. Stations were chosen based on their proximity to the study area and the number of years of precipitation data available for each station. Some stations closer to the study area did not have data available from the early 1900s so they could not be used. If information was available from more than one station, the average of the data were calculated and used.

Pb-210 Dating

Pb-210 dates of the cores taken from tree islands 2A-14-2 and 2A-15-6 were provided by SFWMD. Dates were not provided for the core from 2A-22-18 because it was not dateable. Pb-210 dating is a common method for dating sediments less than 150 years old (Schelske 1994; Schlotter and Engstrom 2006). Pb-210 was used to date the sediment cores to examine anthropogenic impacts on the Everglades during the last century. Previous studies have used Pb-210 dating in areas where sediment types and sources have changed during the last 150 years (Appleby et al. 1986). Pb-210 has been used effectively in a previous study for determining sedimentation rates in peat soils from WCA-2A (Cohen et al. 1999). Another study using Pb-210 by Willard et al. (2006) found that the approximate age of 20-22 cm deep sediments on Everglades tree island 2A-14-2 was 140 years.

Pb-210 is a radioactive isotope of lead (Appleby 2001). It has a half-life of 22.3 years which makes it useful in dating sediments that are approximately 150 years old (Schelske 1994). C-14 is also used to date sediments but it has a long half-life of 5568 years and the possibility of bomb fallout contamination does not allow it to be used in dating sediments deposited during the 1900s (Appleby 2001).

Pb-210 occurs naturally as part of the U-238 decay series (Appleby 2001). Pb-210 has two components: supported Pb-210 which derives from the decay of Ra-226 in sediments and unsupported Pb-210 which derives from the atmosphere. A high level of Pb-210 at the soil surface is a result of being recently deposited from the atmosphere. In deeper soil layers, the total Pb-210 concentration will be lower as the Pb-210 decays. Rn-222 (which is a gaseous decay product of Ra-226) diffuses from soil into the atmosphere (Schelske et al. 1994; Appleby 2001). Rn-222 decays through several short-lived radionuclides into Pb-210 (Appleby 2001). This unsupported Pb-210 is removed from the atmosphere by precipitation or dry deposition and is deposited on the surface of the Earth (Schelske et al 1994; Appleby 2001). Pb-210 that falls directly on bodies of water is transported through the water column and deposited in sediments (Appleby 2001). The amount of unsupported Pb-210 is determined by subtracting the amount of supported Pb-210 from the total amount present in sediments. The unsupported Pb-210 decay in sediments provides a basis for estimating sediment ages.

Pb-210 in sediments is measured using either alpha or gamma spectrometry (Appleby 2001). The option used is usually determined by what method is available; in this study, gamma spectrometry was used. Alpha spectrometry is more sensitive than gamma spectrometry but only determines the total Pb-210 present and requires destruction of samples during chemical preparation (Appleby et al. 1986; Appleby 2001). This method measures the Pb-210 emitted by Po-210 (a granddaughter product of Pb-210 decay) using alpha radiation (Appleby 2001).

Gamma spectrometry is simple, nondestructive (meaning that the samples can be used for further analyses), and provides data for a range of radionuclides simultaneously (Schelske et al. 1994; Appleby 2001). However, it is not as precise as alpha spectrometry, requires large samples, and has a low counting efficiency (Schelske et al. 1994). This method determines Pb-210 concentration based on its gamma ray emission (Appleby 2001). Because gamma spectrometry can give results for several radionuclides at one time, the Ra-226 measured during the process can give provide a direct measure of supported Pb-210 concentration in sediments (Schelske et al. 1994).

There are two commonly-used models in Pb-210 dating: the Constant Rate of Supply (CRS) model and the Constant Initial Concentration (CIC) model

(Appleby 2001). The CRS model was used in this study. The CIC model is based on the assumption that sediments have a constant initial Pb-210 concentration regardless of accumulation rates. Therefore, the supply of Pb-210 in sediments is assumed to vary directly in proportion to the sedimentation rate.

The CRS model is more widely used and was developed for use in sites where sedimentation is not uniform (Appleby 2001). The CRS model is valid in sites where changes in the sedimentation rate over time result in changes in the unsupported Pb-210 concentration. Dates of older sediments are calculated based on the amount of Pb-210 present. The CRS model is based on several assumptions. The first assumption is that there is a constant supply of unsupported Pb-210 produced in the atmosphere and deposited in sediments (Appleby and Oldfield 1978; Appleby 2001). The second assumption is that Pb-210 in fresh water is removed from solution quickly by attaching to particulate matter so the majority of Pb-210 in sediments is assumed to be a result of fallout from the atmosphere (Appleby 2001). Finally, the last assumption is that the initial unsupported Pb-210 activity in sediments is not redistributed in sediments and decays exponentially over time. The CRS model has proved reliable in the majority of cases but it will not result in accurate dates if there are gaps in the sedimentation record.

Pb-210 concentration in sediments might not solely be related to atmospheric flux (Appleby 2001). This might call into question the assumptions of the CRS model, however, some evidence supports that atmospheric flux is the dominant influence on Pb-210 concentration in sediments. Therefore, the CRS model is found to be reliable in most cases. The CRS model is likely to be more reliable in sites that have not undergone major hydrological changes that have gaps in the sediment record or have resulted in altered sediment focusing. The CIC model might provide a good alternative as long as sedimentation has remained constant over time. In circumstances where both sedimentation and Pb-210 supply rates have changed over time, neither model would be appropriate to use.

Pb-210 dating can be affected by the distribution of sediments or changes in the rate of Pb-210 deposition to the core site (Schottler and Engstrom 2006). Loss of surface material during sampling can cause inaccuracies as well (MacKenzie et al. 2012). It is possible for material containing Pb-210 to wash in to the environment and affect the outcomes of the model (Appleby and Oldfield 1978; Appleby 2001). Given these potential sources of error, approximate dates will be referred to throughout the remainder of this paper.

Calculation of Charcoal Concentrations

Concentrations of microscopic and macroscopic charcoal were determined for each sample in terms of particles/cm^3 and also particles/g of dry weight. Concentration of particles/g of dry weight was calculated for each core depth for both microscopic and macroscopic size classes. Concentration of particles/g of dry weight allowed for a more accurate representation of charcoal in the samples than the particles/cm^3. Water was present in many of the samples and the conversion of concentration of particles/cm^3 to particles/g of dry weight allowed for correction for the presence of water (Gardner and Whitlock 2001). These concentrations were estimated by dividing the total number of charcoal particles/cm^3 in each size class by bulk density values (g of dry sediment/cm^3 wet) using data available from Ewe et al. (2009).

Charcoal Accumulation Rates (CHAR) (the number of charcoal particles/cm^2/year) were estimated for cores from tree islands 2A-14-2 and 2A-15-6. CHAR values were calculated to determine how much charcoal had accumulated over the span of years represented by individual samples. CHAR values were calculated using the number of charcoal particles/g dry weight of the samples. The particles/g of dry sediment was divided by 1000 mg. This value was multiplied by the mass sedimentation rates (in mg/cm^2/year) (Tables A1 and A2 in Appendix I) of each depth interval to obtain the CHAR values. Accumulation rates can only be calculated for depth intervals that have Pb-210 dates associated with them (Whitlock and Anderson 2003). Therefore, CHAR values were only calculated for cores taken from 2A-14-2 and 2A-15-6. All data used for the calculations can be found in Tables A1, A2, and A3 in Appendix I.

Charcoal concentrations in particles/cm^3, particles/g of dry weight, and CHAR values were plotted using the program C2. If no data were available for a particular charcoal size class or core, data were not plotted. Charcoal concentration data were plotted using the mid-point of the depths. Years that represent the ages of the sediments are on the right side of the figures. Due to space constraints on the figure, not all Pb-210 dates available for a core were included.

CHAPTER 4: RESULTS

Summary of Sediment Core Descriptions

2A-14-2

Peat depth at the time of sampling was 131 cm at the head of the island and was noted to have increased from north to south (Ewe et al. 2009). Many depth intervals in the upper portion of the core taken from this tree island had high water content. This is probably due to the fact that 2A-14-2 is a ghost tree island and has been mostly covered by water from the surrounding marsh since the 1960s (Willard et al. 2006). The sediment core collected on this island and used in the present study contained fine roots (both living and dead) found in the majority of depths and dark brown (almost black at some depths) peat and muck soils throughout the core (Ewe et al. 2009).

2A-15-6

Peat depth at the time of sampling was 134 cm at the head of the island (Ewe et al. 2009). Peat depth was noted to have increased from south to north. The sediment core from this site contained organic, peaty soils and fine roots throughout. Peat was dark brown to black in color.

2A-22-18

At the time of sampling, peat depth at the head of the island was 200 cm, deeper than the other two islands in the study (Ewe et al. 2009). Peat depth on this island increased from south to north. The core taken from this island contained wet, mucky soils with fine to medium roots. A large amount of organic litter such as leaves and sticks was found throughout the core.

Pb-210 Dates for Tree Island Cores and Age versus Depth Profile

Pb-210 dates of the cores taken from tree islands 2A-14-2 (Figure 5) and 2A-15-6 (Figure 6) were provided by the South Florida Water Management District (SFWMD). The core from tree island 2A-22-18 could not be dated because the Pb-210 profile ended abruptly in the upper portion of the core (Joseph M. Smoak, pers. comm.). This was likely due to a physical disturbance that caused movement of the sediments. It is likely that the top 6 cm of the core represented approximately the last 120 years, with deeper soils being much older. Pb-210 dating is an effective method for dating sediments less than 200 years old (Schlotter and Engstrom 2006). Therefore, the sediments from the cores taken from 2A-14-2 and 2A-15-6 are only dated to the middle 1800s.

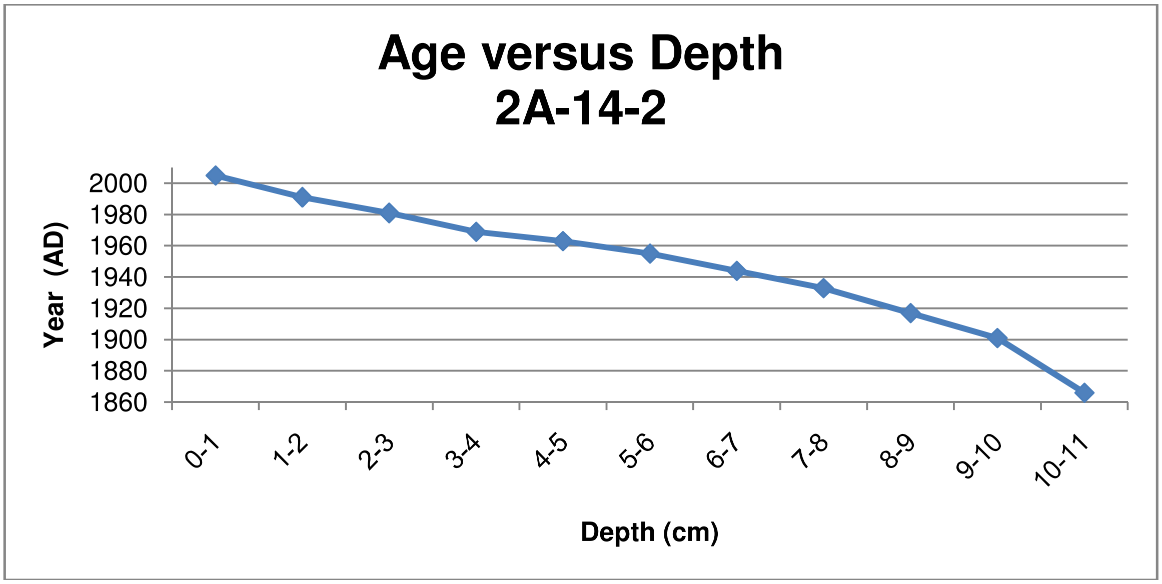


Figure 5: Age versus depth profile for the 2A-14-2 core. Depth (cm) is from the top of the core and ages are estimated based on Pb-210 dating.

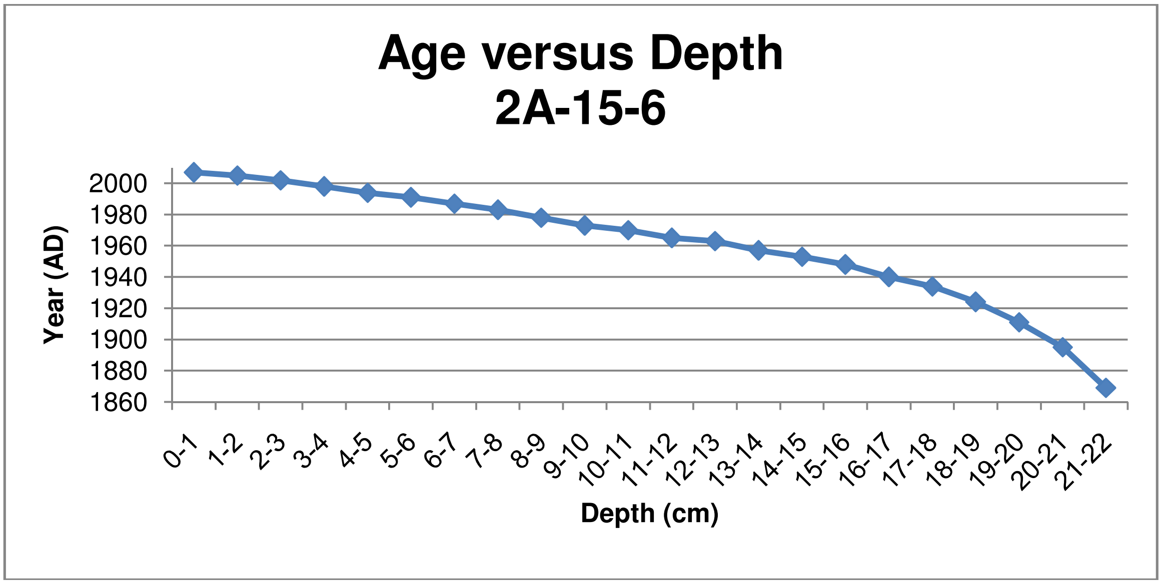


Figure 6: Age versus depth profile for the 2A-15-6 core. Depth (cm) is from the top of the core and ages are estimated based on Pb-210 dating.

Ghost Tree Island 2A-14-2 Charcoal Record

Microscopic charcoal concentrations ranged from 0 to 2,457 particles/cm^3 from the core at ghost island 2A-14-2 and were found in 24 different depth intervals throughout the core (Figure 7). The greatest concentration of microscopic charcoal particles was present in the upper 8 cm of the sediment core, representing approximately 1930 to the present. Therefore, charcoal was present in sediments that were deposited during the middle 1930s, the middle 1950s, the late 1960s, and the early 2000s. Microscopic charcoal particles were also present at seven other depths that reflect pre-1900 time intervals.

Total macroscopic charcoal concentrations (greater than 125 µm) ranged from 0 to 17 particles/cm^3 in the 2A-14-2 core (Figure 7). Macroscopic charcoal particles were not abundant in this core and were present in only 13 depth intervals. Most of the larger charcoal particles in this core were located in the top 11 cm, with an occasional particle also found below 14 cm. Sediments that contained charcoal were deposited during the middle 1860s, the late 1910s, the early 1930s, the middle 1950s, the 1960s, the early 1980s, and the early 1990s to the present time. Charcoal concentrations from the 125–249-µm size class ranged from 0 to 16 particles/cm^3. Charcoal concentrations in the 250–499-µm size class ranged from 0 to 5 particles/cm^3. The greatest concentration of charcoal particles from both of these size classes was from 17 cm to the top of the core. There were no charcoal particles greater than 500 µm in the 2A-14-2 core so graphs depicting information from this size class are not included.

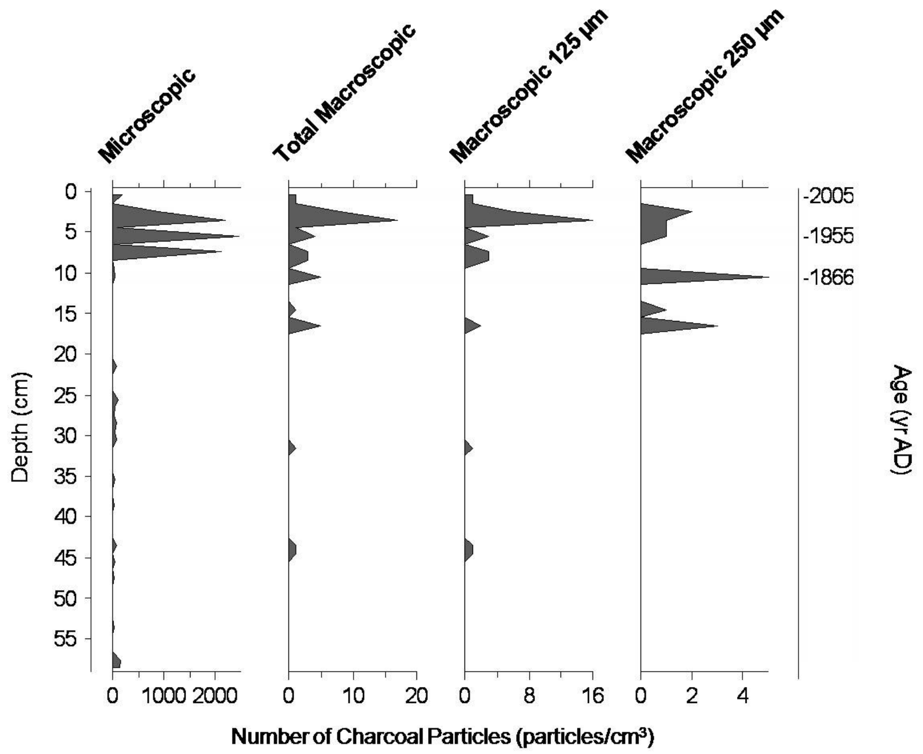


Figure 7: Charcoal concentration in particles/cm^3 for all size classes for the 2A-14-2 core. The 500–999-µm and greater than 1,000-µm size classes are not represented because there was no charcoal found greater than 500 µm.

Microscopic charcoal concentrations ranged from 0–22,121 particles/g dry weight in the 2A-14-2 core (Figure 8). The greatest microscopic charcoal concentration was present in the top 11 cm of the core (or since the middle 1860s). The bottom 2 cm of the core also contained higher charcoal concentrations.

Total macroscopic charcoal concentrations ranged from 0 to 171 particles/g dry weight in the 2A-14-2 core (Figure 8). The greatest amount of charcoal particles was found in the top 17 cm of the core, with the largest concentration at 4–5 cm depth (or during the middle 1960s). Aside from the top 17 cm, only a few other depth intervals had any charcoal present (32–33 cm and 43–45 cm depth). The charcoal concentration in the 125–249-µm size class ranged from 0 to 161 particles/g dry weight; with the greatest number of particles at 3–4 cm depth (or during the late 1960s). Charcoal concentration in the 250–499-µm size class ranged from 0 to 40 particles/g dry weight; with the largest concentration at 10–11 cm depth (during the middle 1860s).

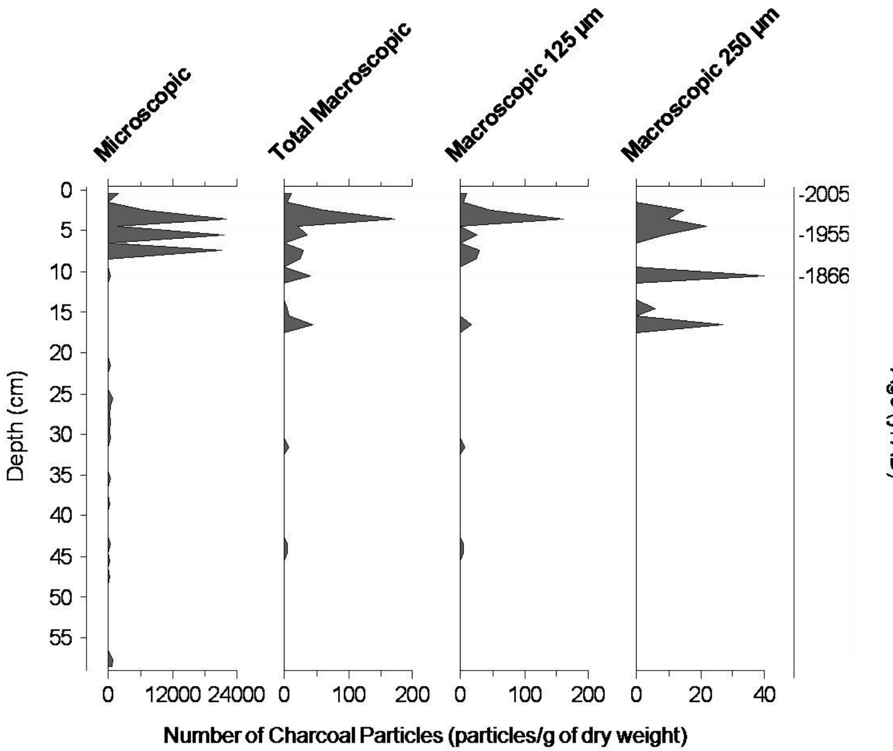


Figure 8: Charcoal concentration in particles/g of dry weight for all size classes for the 2A-14-2 core. The 500–999-µm and greater than 1,000-µm size classes are not represented because there was no charcoal found greater than 500 µm.

Charcoal accumulation rates (CHAR) of microscopic charcoal particles ranged from 0 to 290 particles/cm^2/year in the 2A-14-2 core (Figure 9). The greatest accumulation rates were present at 5–6 cm depth (during the middle 1950s). Other depths with larger accumulation rates were present at 7–8 cm depth (during the middle 1930s) and at 3–4 cm depth (the late 1960s). There was no accumulation at 8–9 cm depth (during the late 1910s) or at 1–2 cm depth (the early 1990s).

CHAR values for the all of the macroscopic size classes ranged from 0 to 1.5 particles/cm^2/year in the 2A-14-2 core (Figure 9). The greatest accumulation rate was at 3–4 cm depth (during the late 1960s). There was no charcoal accumulation at 9–10 cm depth (during the early 1900s) or at 6–7 depth (the middle 1940s).

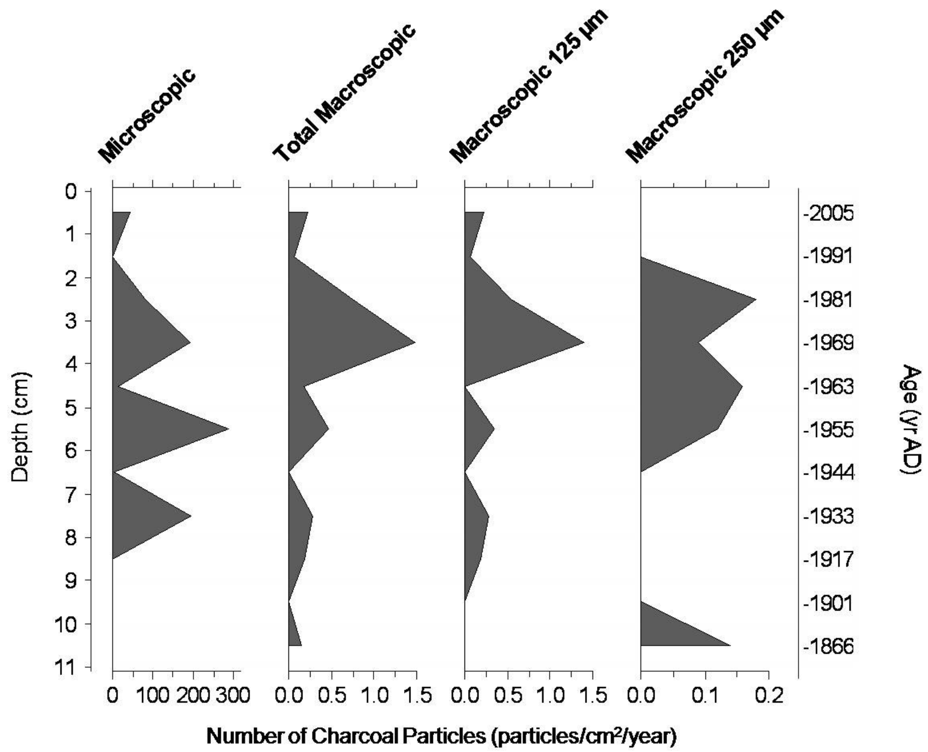


Figure 9: CHAR values for all size classes for the 2A-14-2 core. The 500–999-µm and greater than 1000-µm size classes are not represented because there was no charcoal found greater than 500 µm.

Ghost Tree Island 2A-15-6 Charcoal Record

Microscopic charcoal concentrations ranged from 0 to 328 particles/cm^3 in the core taken from the ghost tree island 2A-15-6 (Figure 10). Charcoal particles of this size were found in 17 different depth intervals, but only in the top 20 cm of the core. The greatest concentration of microscopic charcoal particles was present at 1–2 cm depth (during the early 1990s).

Total macroscopic charcoal concentration ranged from 0 to 14 particles/cm^3 (Figure 10). These larger charcoal particles were observed in 23 different depth intervals, with the greatest concentration in the top 20 cm of the core. An occasional particle was also found at 31–32 cm depth and at 21–26 cm depth. Charcoal concentrations in the 125–249-µm size class ranged from 0 to 5 particles/cm^3. Charcoal particles in this size class were only present in the top 26 cm of this core. Macroscopic charcoal concentrations in the 250–499-µm size class ranged from 0 to 9 particles/cm^3, with the greatest concentration in the top 20 cm of the core. Charcoal in the 500–999-µm size class ranged from 0 to 2 particles/cm^3. Charcoal particles of this size were only present in a few depth intervals, all in the top 16 cm of the core. Macroscopic charcoal concentration of particles that were 1,000 µm and larger ranged from 0 to 4 particles/cm^3. Only sections of the core between 12–13 cm and between 16–18 cm had any charcoal of this size.

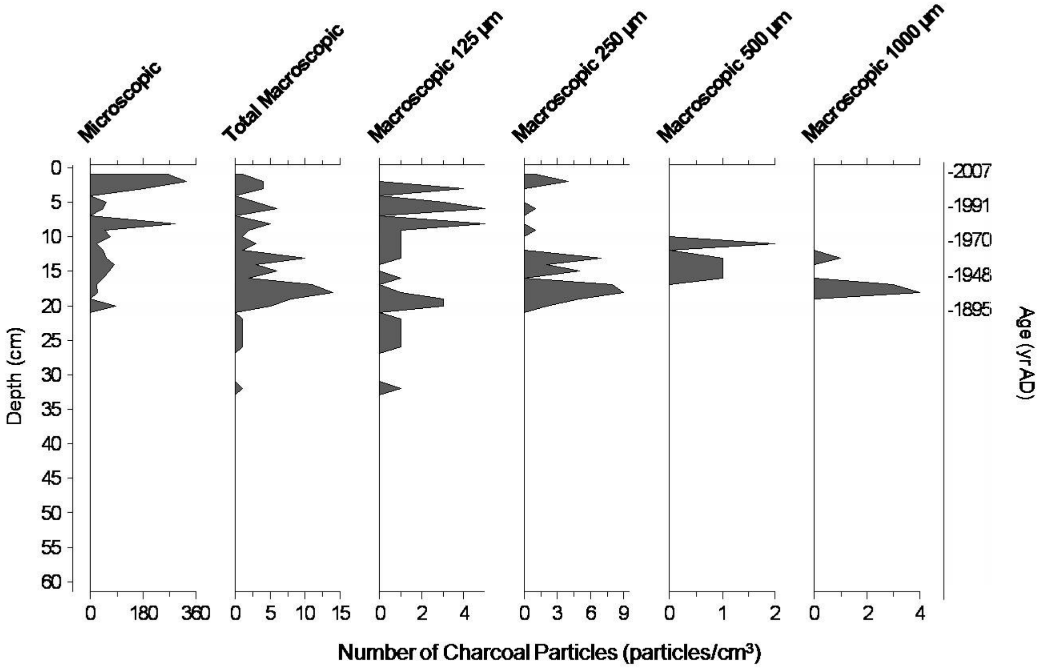


Figure 10: Charcoal concentration in particles/cm^3 for all size classes in the 2A-15-6 core.

Microscopic charcoal concentrations ranged from 0 to 3,604 particles/g of dry weight in different sections of the 2A-15-6 core (Figure 11). The greatest concentration of particles appeared in the top 20 cm of the core and no charcoal was present from 21–60 cm depth. The largest number of charcoal particles of any size was at 1–2 cm depth (during the early 21st century).

Total macroscopic charcoal concentration ranged from 0 to 109 particles/g of dry weight in the 2A-15-6 core (Figure 11). The greatest concentration of macroscopic particles was in the top 26 cm of the core, with most particles present at 12–13 cm depth (during the middle 1960s). There was no charcoal found in the core below 32 cm depth. In the 125–249-µm size class, charcoal concentration ranged from 0 to 50 particles/g of dry weight, with the greatest concentration at 7–8 cm depth (during the middle 1980s). In the 250–499-µm size class, charcoal concentration ranged from 0 to 70 particles/g of dry weight. The greatest concentration of particles in this size class was at 17–18 cm depth (during the middle 1930s). In the 500–999-µm size class, charcoal concentration ranged from 0 to 16 particles/g of dry weight, with the largest concentration present at 10–11 cm depth (during the early 1970s). For particles greater than 1,000 µm, concentration of charcoal ranged from 0 to 31 particles/g of dry weight. As with the 250–499-µm size class, the greatest concentration was at 17–18 cm depth.

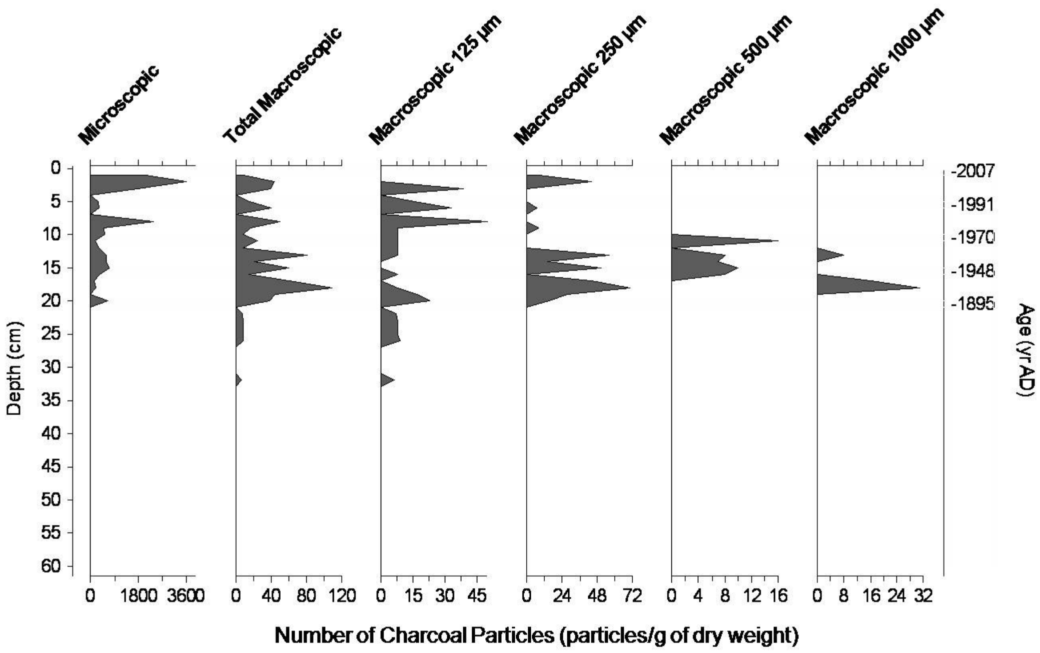


Figure 11: Charcoal concentration in particles/g of dry weight for all size classes in the 2A-15-6 core.

Microscopic CHAR values ranged from 0–139 particles/cm^2/year in the 2A-15-6 core (Figure 12). The highest accumulation rate was at 1–2 cm depth (around 2005). There was also a higher accumulation of charcoal (102 particles/cm^2/year) at 0–1 cm depth (around 2007).

Total macroscopic CHAR values in the 2A-15-6 core ranged from 0 to 2.8 particles/cm^2/year (Figure 12). The highest accumulation rate was at 12–13 cm depth (the middle 1930s). In the 125–249-µm size class, the accumulation of charcoal ranged from 0 to 1 particle/cm^2/year, with the largest accumulation rate at 5–6 cm depth (the early 1990s). In the 250–499-µm size class, charcoal accumulation ranged from 0 to 2 particles/cm^2/year. The greatest accumulation was at 12–13 cm depth (during the middle 1960s). In the 500–999-µm size class, charcoal accumulation ranged from 0 to 0.6 particles/cm^2/year. The greatest accumulation rate was found at 10–11 cm depth (the early 1970s). Accumulation rates for charcoal in the 1,000 µm and greater size class ranged from 0 to 0.67 particles/cm^2/year, with the greatest amount of accumulation at 17–18 cm depth (the middle 1930s).

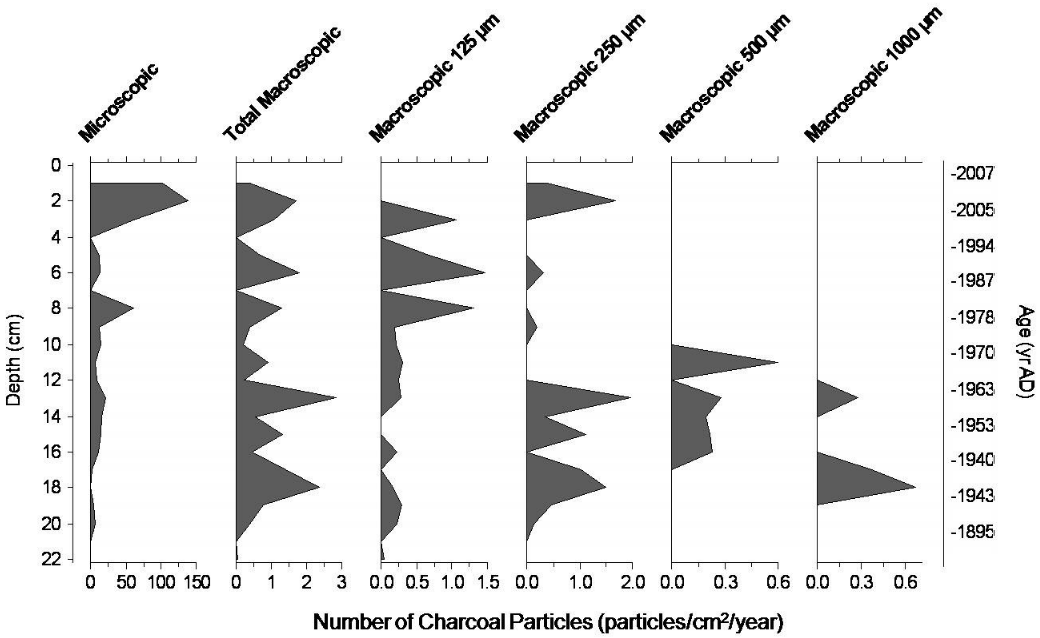


Figure 12: CHAR values for all size classes in the 2A-15-6 core.

Live Tree Island 2A-22-18 Charcoal Record

Microscopic charcoal concentrations in the core taken from tree island 2A-22-18 ranged from 0 to 2,315 particles/cm^3 (Figure 13). There is charcoal present throughout this core with particles found in 38 different depth intervals. The greatest concentration of microscopic charcoal in particles/cm^3 appeared in the bottom of the core from 28–60 cm depth and a substantial amount of charcoal particles was also present at 2–3 cm depth.

Total macroscopic charcoal concentrations ranged from 0 to 186 particles/cm^3 (Figure 13). Macroscopic charcoal was found at 41 different depth intervals throughout the entire core. The greatest concentration of larger charcoal particles appeared at 16–17 cm depth. Macroscopic charcoal concentration from the 125–249-µm size class ranged from 0 to 109 particles/cm^3, in the 250–499-µm size class it ranged from 0 to 63 particles/cm^3, and in the 500–999-µm size class it ranged from 0 to 9 particles/cm^3. Concentration of macroscopic charcoal particles at least 1,000 µm in size ranged from 0 to 5 particles/cm^3.

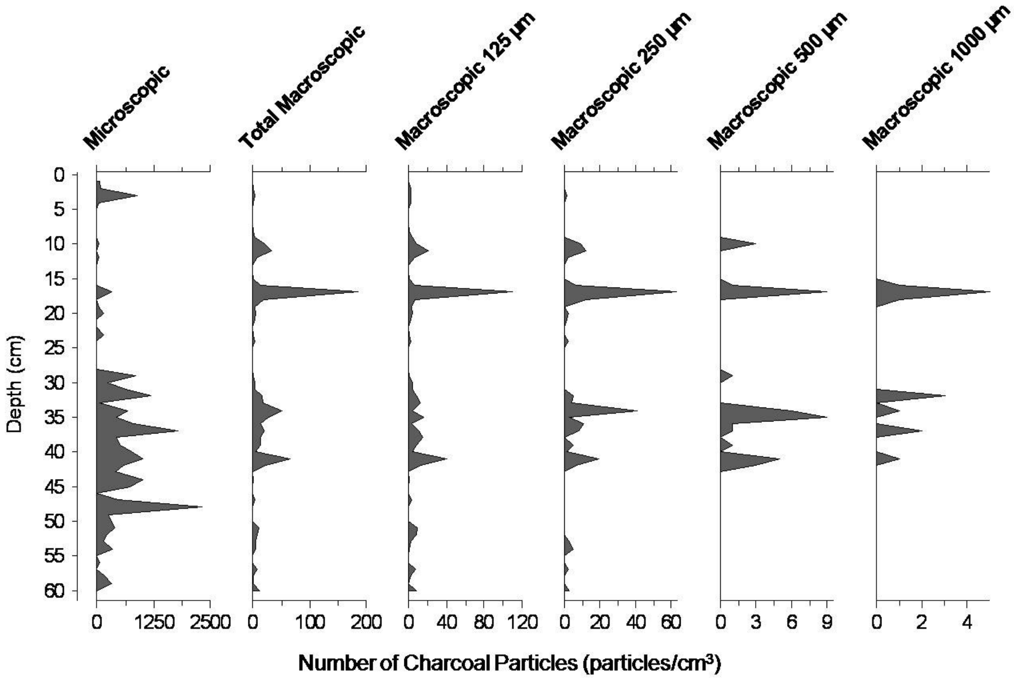


Figure 13: Charcoal concentration in particles/cm^3 for all size classes in the 2A-22-18 core. Pb-210 dates were unavailable for this core so dates are not included.

Microscopic charcoal particle concentrations ranged from 0 to 32,436 particles/g of dry weight in the core taken from 2A-22-18 (Figure 14). Charcoal concentrations in particles/g of dry weight were found throughout the core with the majority of the particles found between 28–59 cm depth, and the greatest concentration at 40–41 cm depth.

Total macroscopic charcoal concentrations ranged from 0 to 1,333 particles/g of dry weight in the core from 2A-22-18 (Figure 14). Charcoal was present in 41 different depth intervals throughout the core, with the majority of charcoal found in the bottom half of the core. As with the concentration of microscopic charcoal, the greatest concentration of larger charcoal was at 40–41 cm depth. Individual macroscopic size classes show generally the same pattern. The majority of the charcoal was present in the bottom half of the core. However, the greatest concentration of charcoal was present at 16–17 cm depth for all individual macroscopic size classes. Charcoal concentration in the 125–249-µm size class ranged from 0 to 981 particles/g of dry weight. Concentration of charcoal in the 250–499-µm size class ranged from 0 to 567 particles/g of dry weight. Concentration of charcoal in the 500–999-µm size class ranged from 0 to 81 particles/g of dry weight. Finally, charcoal at least 1,000 µm in size ranged from 0 to 45 particles/g dry weight.

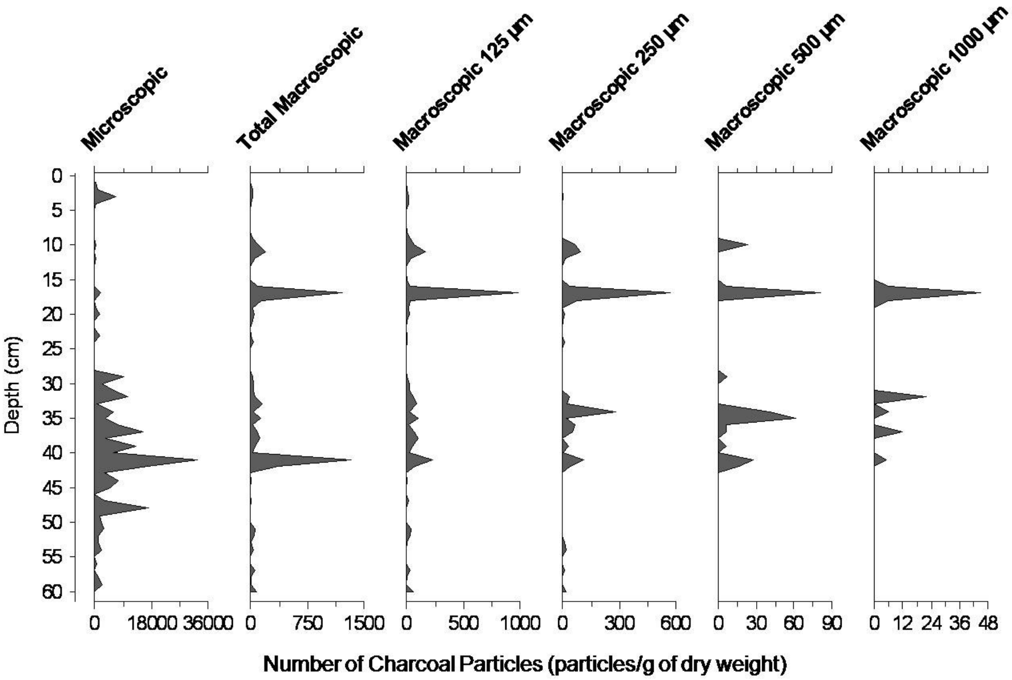


Figure 14: Charcoal concentration in particles/g of dry weight for all size classes in the 2A-22-18 core. Pb-210 dates were unavailable for this core so dates are not included.

Precipitation

Pb-210 dates available from cores taken from 2A-14-2 and 2A-15-6 allowed a comparison to be made between precipitation and fire activity for specific time periods. Because Pb-210 dates only give a close approximation of the age of sediments, data are grouped into five-year increments in order to generalize times at which precipitation events occurred.

The average annual precipitation in South Florida is 53 inches per year (Abtew and Huebner 2001). Annual precipitation values since 1900 ranged from 45.08 inches to 63.72 inches (Figure 15 and Table A12). There was an 18.64-inch difference between the group of years with the greatest precipitation in the late 1940s and the relatively dry period between 1910 and 1914.

There were several five-year periods of time in which South Florida exhibited lower-than-average annual precipitation (Figure 15 and Table A12). These periods included 1985–1989 (48.45 inches), 1970–1974 (52.79 inches), 1915–1919 (52.48 inches), 1910–1914 (45.08 inches), 1905–1909 (50.96 inches), and 1900–1904 (49.77 inches). Periods that exhibited higher-than-average precipitation included 1920–1924 (54.98 inches), 1925–1929 (55.58 inches), 1930–1934 (57.13 inches), 1935–1939 (55.68 inches), 1945–1949 (63.72 inches), 1950–1954 (56.24 inches), 1955–1959 (60.21 inches), 1960–1964 (53.65), 1965–1969 (58.88 inches), 1980–1984 (56.87 inches), 1990–1994 (61.76 inches), 1995–1999 (59.03 inches), 2000–2004 (53.38 inches), and 2005–2009 (55.00 inches).

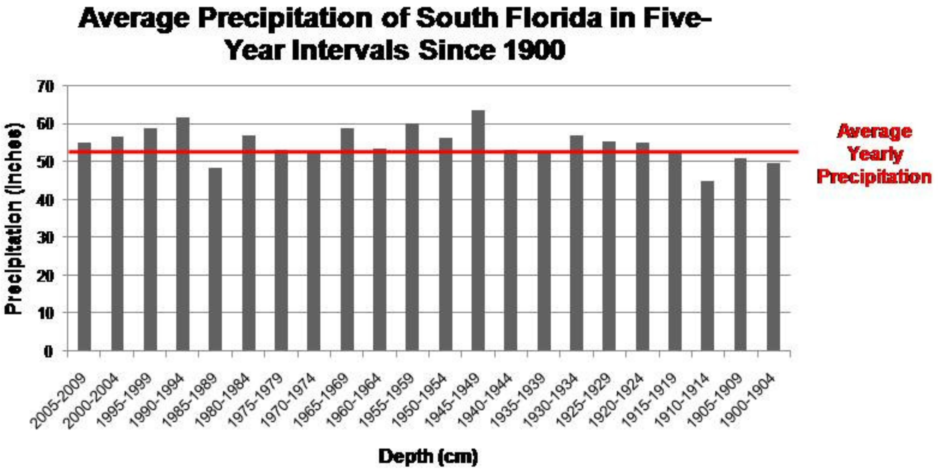


Figure 15: Average precipitation (inches) for South Florida in five-year intervals since 1900.

CHAPTER 5: DISCUSSION

Microscopic and macroscopic charcoal was present in all three cores, indicating the presence of both regional and local fires. In the cores from 2A-14-2 and 2A-15-6, the majority of the charcoal was distributed since the middle 1800s. In the core from 2A-22-18, there was a higher concentration of charcoal in the bottom 30 cm.

General trends in fires over time based on analysis of macroscopic and microscopic charcoal particles in tree island sediments:

The patterns of charcoal particles/cm^3 were the same as the patterns of charcoal particles/g of dry weight in all cores. Charcoal concentrations were converted to particles/g dry weight to account for the amount of water in the samples. This gives a more accurate representation of the amount of charcoal in the samples (Gardner and Whitlock 2001). Therefore, the emphasis for the discussion of general fire trends was based on the number of particles/g of dry weight.

Ghost Tree Island 2A-14-2

This ghost tree island is located in the central part of WCA-2A and is surrounded by slough and marsh areas. There was evidence of a higher number of regional and local fires since the middle 1800s demonstrated by the higher concentration of charcoal particles of all sizes found in the sediment core taken from this island. The core taken from this island contained more charcoal of all sizes than the core taken from 2A-15-6. However, there was much less charcoal found in this core than the core taken from 2A-22-18.

Several depth intervals from the 2A-14-2 core showed the same trends in both regional and local fire activity. Based on the presence of microscopic and macroscopic charcoal particles, there was evidence for both regional and local fire activity around the early to middle 1930s, the middle 1950s, the middle to late 1960s, the early 1980s, and the early 21st century.

Not all sections of the cores demonstrated the same trend of regional and local fire activity. Some years exhibited evidence for only regional fires, for example: the early 1900s and the middle 1940s. There were signs of local fire without evidence of regional fires during only two time periods: the late 1910s and the early 1990s.

The sediments deposited prior to the middle 1860s contained much less charcoal of any size than sediments deposited after this time, indicating more fire activity since the middle 1800s. There was almost no evidence for local fires before the middle 1860s suggesting fewer local fires before this time. There was also a lower concentration of microscopic charcoal particles in the core prior to the late 1800s, which indicates that fewer regional fires occurred. Even though sediment cores taken from wetlands generally avoid the depositional problems that occur within lakes due to water movement (Whitlock and Anderson 2001; Brunelle and Whitlock 2003), the Everglades originally experienced an undisturbed sheet flow throughout the ecosystem. The lack of charcoal particles found in 19th century sediments might be a result of the flow of water through the Everglades. However, if this was the case, it would be expected that more macroscopic charcoal would be evident than microscopic charcoal because smaller particles are more likely to be transported from the site of deposition. In fact, the opposite is true, with more microscopic charcoal present throughout the core. Based on the lower amounts of charcoal deposited prior to the early 1900s, this might mean that the wetland was wetter prior to drainage of the region and therefore, there were fewer fires.

Ghost Tree Island 2A-15-6

This ghost tree island is located in the eastern part of WCA-2A and is close to urban areas to the east. Most dated sections from the 2A-15-6 core contained both microscopic and macroscopic charcoal particles indicating the presence of both regional and local fires since the middle 1800s. The pattern of charcoal deposition in this core demonstrated that there was little to no fire in the area of this tree island prior to the early 1900s. Of all of the cores in the study, this core contained the least amount of charcoal.

Overall trends in the 2A-15-6 core show that there has been both regional and local fire activity during the early 1910s, the middle 1930s, the early 1940s to the middle 1980s, the early to middle 1990s, and post 2000. Conversely, there was no evidence for regional or local fire activity during the late 1800s, the late 1980s, or the late 1990s.

Some portions of the core provided evidence for only local fires. For example, sediments deposited during the late 1860s and the middle 1920s contained only macroscopic charcoal, indicating only local fires. There still may have been fires in the region during this time, but the charcoal particles may not have been transported to this particular tree island.

The lack of both macroscopic and microscopic charcoal particles in sediments deposited before the late 1860s suggest that this tree island and the surrounding landscape rarely burned before this time. This is consistent with data from the 2A-14-2 core. However, as with 2A-14-2, this may be an indication of a wetter landscape prior to drainage.

Comparison of Cores from 2A-14-2 and 2A-15-6

There are similar trends of charcoal particle concentrations between the two dated cores taken from the two ghost tree islands, 2A-14-2 and 2A-15-6. The two cores provided evidence for both regional and local fire activity during the middle 1930s, the middle 1950s to the middle 1960s, the early 1980s, and since 2000. During the early 1990s, there is an indication of regional fire events (but not local fires) based on the presence of microscopic charcoal in both of these cores. In the middle 1860s, there is evidence for regional fires in the 2A-14-2 core, but not in the 2A-15-6 core. This may mean that fires occurred upwind from 2A-14-2 and charcoal was transported to the site of deposition on 2A-14-2, but not on 2A-15-6.

Live Tree Island 2A-22-18

2A-22-18 is a live tree island located in the northern part of WCA-2A, just south of the Everglades Agricultural Area (EAA). Patterns of regional and local fire activity were similar in the 2A-22-18 core. Local and regional fire activity was present through the core suggesting that changing water levels might not have been as much of an influence on this island compared with the other two tree islands. This core contained the highest amount of charcoal compared to the cores from 2A-14-2 and 2A-15-6. However, because Pb-210 dates are not available for this core, it is unknown when this fire activity occurred. The top 6 cm of the core probably represents the last 120 years but the sediment below this point is likely much older (Joseph Smoak, pers. comm.).

There appears to have been more regional fire activity prior to the late 1800s as seen by the microscopic charcoal in the bottom 30 cm of the core. This indicates a greater incidence of fire prior to the beginning of drainage activities. In general, there was more local fire activity found throughout the core from 2A-22-18 than in the cores from 2A-14-2 and 2A-15-6. At least in the top 6 cm, this may be due to this tree island surviving the flooded conditions in WCA-2A during the 1960s and 1970s (Willard et al. 2006). As this tree island retained its elevation and woody species cover, more fires have occurred over time.

Charcoal Accumulation Rates (CHAR)

Accumulation rates of charcoal particles can only be calculated for samples that have been dated, so this discussion is limited to the cores taken from tree islands 2A-14-2 and 2A-15-6. CHAR values showed how much charcoal has been deposited per year over a given period of time. In both dated cores, accumulation rates corresponded with charcoal concentration\.

There was a much larger accumulation rate of microscopic than macroscopic charcoal particles in the 2A-14-2 core, indicating more regional than local fires in the area. This was expected because smaller particles can travel greater distances before being deposited. Smaller particles deposited at any given site might be a composite of particles derived from several different fires. There was accumulation of microscopic charcoal particles indicating regional fires during the middle 1860s to the early 1900s, the middle 1930s to the early 1980s, and the early 21st century.

Accumulation rates of macroscopic charcoal were much lower than for microscopic charcoal particles in the 2A-14-2 core, demonstrating more regional than local fire activity. The larger particles most likely came from fires that occurred at, or very near, the core sites and because 2A-14-2 has been a ghost island since around the 1960s, there were likely not as many opportunities for emergent vegetation to burn as in other areas of the Everglades. The macroscopic charcoal accumulation rates indicate that local fires occurred during the middle 1860s, the middle 1910s to the middle 1930s, and from the middle 1950s to the early 21st century.

As in the 2A-14-2 core, microscopic CHAR values were much greater than macroscopic CHAR in the core taken from 2A-15-6. It is likely that charcoal from many fires could have contributed to the particles deposited at the core site.

Microscopic charcoal accumulation rates for this core indicated that regional fires occurred from the late 1800s to the middle 1920s, the early 1940s to the middle 1980s, the early to middle 1990s, and in the beginning of the 21st century. The highest accumulation of charcoal has been since the turn of the 20th century.

Macroscopic charcoal is typically deposited at the site of a fire, which is likely the reason for the lower accumulation rates of macroscopic charcoal compared to microscopic charcoal in the 2A-15-6 core. Because this island has been a ghost island since the 1960s, it would be expected that there would be fewer fires here than in other, higher areas of the Everglades since that time. Accumulation rates of macroscopic charcoal for this core indicated that local fires occurred during the middle 1860s, the early 1910s to the middle 1980s, the early to middle 1990s, and in the early 21st century.

CHAR can be analyzed statistically using a decomposition approach that can create a time series of accumulation rates (Whitlock and Anderson 2003). The two components resulting from the decomposition approach are the background (the general trend in data over time) component and the peaks (the contribution of charcoal from a fire event) component. Statistical analysis of CHAR was not utilized in this study because Pb-210 dates were only available for the uppermost sections for two of the cores.

Comparison of recorded drainage activities since the early 1900s to fire activity:

It has been documented that Everglades drainage over the past century has caused an increase in fire frequency (Loveless 1959). However, there has been no research of fire activity in the area prior to the early 1900s. Evidence of an increased regional fire activity was expected since major drainage activities commenced in the early 1900s. In both of the dated charcoal records from 2A-14-2 and 2A-15-6, this is supported by a pattern of more microscopic charcoal, and therefore, more regional fire activity, over the past century. These results are supported by pollen studies that demonstrate that ridge environments in the area have undergone a transition to a drier state since the early 20th century (Bernhardt et al. 2004).

The charcoal record of the last century provided evidence of fires that corresponded with Everglades drainage activities (Table 1). The charcoal record from the 2A-15-6 core suggested that fires increased in the early 1910s. This may be a result of significant Everglades drainage beginning in the early 1900s (Light and Dineen 1994). The middle 1930s was also a period of increased fire activity as seen in charcoal data from the 2A-14-2 and 2A-15-6 cores. Evidence of an increase in local fire frequency in the 1940s from the 2A-15-6 core may be a result of lowered water levels at the time due to the construction of the Hoover Dike (Sklar et al. 1999; Grunwald 2006). Both the 2A-14-2 and 2A-15-6 cores contained evidence of increased local and regional fire activity in the middle 1950s. This may be due to development of the EAA and construction of the WCAs (Light and Dineen 1994). Water depths in WCA-2 were lower in the 1950s than in prior years due to impoundment of water before construction of the WCAs (McVoy et al. 2011). Land that became the EAA was eventually drained and this caused significant fires during the late 1930s (Grunwald 2006). Also, to clear land for crops such as sugarcane, farmers intentionally set fires in the EAA. Sugarcane fields are also burned prior to harvesting, although the fires are short-lived, lasting only 15 to 20 minutes (Baucum et al. 2012). This past burning could explain the evidence for an increase in regional fires during the 1930s based on microscopic charcoal from the 2A-15-6 core.

Authorities completed WCA-2A in 1961 (Rutchey et al. 2008). During the 1960s and 1970s, ponding was common in the southern region of WCA-2A due to the compartmentalization of the WCAs (Sklar et al. 1999). Pollen records from WCA-2A from this time indicated that higher water levels have had an influence on vegetation in the area (Bernhardt et al. 2004; Willard et al. 2006). Therefore, less fire activity would be expected in cores from 2A-14-2 and 2A-15-6 during this time. Microscopic and macroscopic accumulation of charcoal was low throughout the 1960s and 1970s except for a period during the late 1960s (as seen in 2A-14-2) when both macroscopic and microscopic charcoal accumulations were high. This does not correspond with drainage activities at the time, because the area around 2A-14-2 was flooded. The microscopic charcoal may have been transported from the surrounding areas if they became dry enough to burn because of the water being diverted to WCA-2A.

The completion of WCA-2A caused the study area to become compartmentalized (Sklar et al. 1999). While this created ponding in the southern part of WCA-2A, it also created drier areas in the northern areas. This may be an explanation for the presence of charcoal in 2A-22-18, which is located in the northern part of WCA-2A.

Since the 1980s, water levels in WCA-2A have been periodically lowered and efforts have been in place to restore the region's wetlands to a more natural state (Willard et al. 2006). An analysis of a change in vegetation over time from tree island 2A-15-6 indicates this site has been drier since the 1970s (Ewe et al. 2009). This island has undergone a transformation from mostly cattail (*Typha*) to sawgrass (*Cladium*)-dominated vegetation. A buildup of sawgrass (*Cladium*) and dead fuel materials due to ponding can ultimately lead to more destructive fires (Sklar et al. 1999). This may be why there was an increase in fire activity in the early 1980s as seen in cores from both 2A-14-2 and 2A-15-6.

Tree island 2A-22-18 is located just south of the EAA. The land that now comprises the EAA was originally burned for agricultural reasons (Grunwald 2006). Although many smaller crops grow there, the EAA is mostly devoted to sugarcane production (Galloway et al. 2005). Burning during sugarcane harvesting is common, which might explain some of the evidence for regional fires in the core taken from 2A-22-18 (Baucum et al. 2012). Due to the slope of the landscape, tree islands in the northern part of WCA-2A do not experience extreme changes in seasonal water levels and have shorter hydroperiods and lower flooding levels than tree islands in the southern portion of WCA-2A (Rutchey et al. 2011). Sloughs in the northern part of WCA-2A may be undergoing a transition to a drier state, leading to increased fire activity. This supports the evidence for more recent local fire activity present in the top of the core taken from 2A-22-18, as compared with cores from 2A-14-2 and 2A-15-6.

Leaf and sawgrass (*Cladium*) fires are believed to have occurred before drainage commenced in the late 1800s (McVoy et al. 2011). Low-intensity, surface vegetation fires are not closely tied with water levels so they do not provide much information about prevailing water regimes. However, peat fire frequency does provide information about water levels. Ash layers in soil have been examined that suggest peat fires were rare prior to anthropogenic drainage, which in turn suggests that peat rarely was dry enough to burn. However, pre-drainage fire frequency has not been studied extensively enough to make any definite conclusions. More charcoal studies are needed to determine how widespread fires were prior to anthropogenic drainage activities.

Comparison of precipitation records from the study area since the early 1900s to the present to fire activity:

Charcoal concentration data were compared to precipitation records to evaluate possible links between historical fires and precipitation patterns (Table 1). Generally, South Florida is wet, even in drier years, and receives an average annual rainfall of 53 inches (Abtew and Huebner 2001). This value was used to determine whether a period of years had higher or lower than average precipitation.

Analysis of rolling five-year average annual precipitation can indicate whether an area has a greater chance of fires during a given period of time. Years with less precipitation can be expected to have more fire activity than years with more precipitation (Hallet and Walker 2000). Willard et al. (2006) used pollen indicators to demonstrate a persistence of shallower water depths after drought. That study also demonstrated that tree islands developed during historical drier times, like drought years, indicating that climate changes have an influence on plants and therefore, tree islands. Charcoal data from cores taken at 2A-14-2 and 2A-15-6 was insufficient to support any assumptions about precipitation and fire activity.

Below-average precipitation levels might be expected to cause higher instances of fires. The core taken from 2A-15-6 contained moderate to high amounts of charcoal during the 1910s and early 1940s, and the region experienced below-average to average precipitation during this time. In the core taken from 2A-14-2, a higher concentration of microscopic charcoal during the middle 1950s indicated an increased amount of regional fire activity. This increase in fire activity is consistent with a dry winter period documented during 1956 (Loveless 1959; Abtew and Huebner 2001). Fires swept the marsh that year, completely destroying some of the tree islands by burning the peat substrate (Loveless 1959). In the core taken from 2A-15-6, a high macroscopic charcoal concentration that indicated local fires during the early 1960s was consistent with a drought period during that time (Abtew and Huebner 2001).

Periods of below-average precipitation did not always correspond with charcoal evidence for increased fire frequency. In the core taken from 2A-14-2, lower amounts of charcoal were deposited in the 1910s, which was a period of below-average precipitation. Lower concentrations of charcoal were also present in 2A-14-2 and microscopic charcoal concentrations were lower in 2A-15-6 during the early 1960s, a period of average precipitation. In the core taken from

2A-15-6, a lower concentration of microscopic charcoal was present during the early 1940s and there was no charcoal at all in sediments dated to the late 1980s. The early 1940s and late 1980s both experienced average to below-average precipitation levels. Precipitation levels did not correspond to decreased fire activity during these time intervals.

Above-average precipitation typically results in decreased fire activity. Charcoal records from many periods of time supported this. In the core taken from 2A-15-6, the late 1940s and the late 1950s experienced above-average precipitation and low concentrations of charcoal. The samples from the middle 1930s had decreased evidence for regional fires, but increased evidence for local fires. In the core taken from 2A-14-2, there was a decrease in local fires during the early to middle 1930s, but an increase in regional fires. The middle 1960s experienced a decrease in fire activity according to charcoal evidence from the 2A-14-2 core. This corresponded with lower amounts of charcoal in the 2A-15-6 core. In both cores, there was little to no evidence for fire activity in the 1990s and above-average precipitation was experienced by the region.

Although an area may experience an increase in precipitation, it does not necessarily mean there will be less fire activity. The late 1960s and the early 1980s experienced above-average precipitation, yet samples from 2A-14-2 that represented these time periods contained moderate to high levels of charcoal. This was supported by the charcoal record from 2A-15-6. Even though there was above-average precipitation from 1980 to 1984, there was a documented drought period during the early 1980s, which could explain the increase in fire activity (Abtew and Huebner 2001). In the middle 1980s, moderate to high levels of charcoal were present along with above-average precipitation. Also, since 2000, there was moderate to high amounts of charcoal deposited in the core from 2A-15-6 despite above-average precipitation during this time.

The comparison between charcoal and precipitation records throughout the last hundred years offered inconclusive evidence of whether precipitation played a major role in fire activity in WCA-2A. Although several time periods supported a directly proportionate relationship of increased/decreased levels of precipitation with fire activity, many periods did not, making the data inconclusive. Because the average precipitation over a five-year period was used for comparison with charcoal data, it may not have been an accurate representation of what precipitation was actually like on a year-by-year basis. Precipitation may have been higher during a specific year (or part of a year), while in another year (or part of a year) within the same five-year span of time a drought may have occurred and caused an increased fire activity. In addition, some depths represented more than five years of deposition so this made it difficult to determine trends between the charcoal record and precipitation. Finally, because of the lack of data available that represents precipitation over the past 100 years, some of the stations used in the precipitation analyses might not have been close enough to the site to present an accurate representation of rainfall in WCA-2A. According to Harvey et al. (2005), the largest and most rapid fluctuations in surface water level in WCA-2A are caused by water releases from WCA-1 and not from precipitation. Results of this study indicate drainage and anthropogenic changes had a greater impact on fires within the study area when compared to precipitation.

Table 1: Comparison of drainage and precipitation records to fire activity in 2A-14-2 and 2A-15-6.

COMPARISON OF DRAINAGE AND PRECIPITATION TO FIRE ACTIVITY						
			2A-14-2		2A-15-6	
TIME	**PRECIPITATION**	**DRAINAGE ACTIVITY**	**LOCAL FIRE ACTIVITY**	**REGIONAL FIRE ACITIVITY**	**LOCAL FIRE ACTIVITY**	**REGIONAL FIRE ACITIVITY**
Early 2000s	Above average	Since 1980, efforts to restore the Everglades to a more natural state have been in place	Low	Low	Moderate	High
Late 1990s					None	None
Middle 1990s					Low	Low
Early 1990s			Low	None	Moderate	Low
Late 1980s	Below average				None	None
Middle 1980s	Average				Moderate	High
Early 1980s	Above average		Moderate	Moderate		
Late 1970s	Below average	Modifications continue for water supply purposes			Low	Low
Middle 1970s					Low	Low
Early 1970s					Low	Low
Late 1960s	Above average		High	High		
Middle 1960s		Development of WCAs leads to more water in the study area	Low	Low	Low	Low
Early 1960s	Below average				High	Low

Late 1950s	Above average	Increased drainage due to development of EAA; western and northern boundaries of WCAs constructed			Low	Low
Middle 1950s	Average		Low	High	Moderate	Low
Early 1950s		Eastern border of WCAs constructed			Moderate	Low
Late 1940s	Above average	Increased drainage			Low	Low
Middle 1940s	Average		None	Low		
Early 1940s	Below average				High	Low
Late 1930s	Average					
Middle 1930s	Above average	Decreased water flows due to construction of Hoover Dike	Low	High	High	Low
Early 1930s		Construction of canals complete				
Late 1920s	Average	Fragmentation of wetland due to construction of Tamiami Trail				
Middle 1920s					Moderate	None
Early 1920s						

Late 1910s		Increased drainage due to construction of canals lead to decreased water levels	Low	None		
Middle 1910s	Below average					
Early 1910s					Moderate	Low
Early 1900s			None	Low		
Late 1800s		Drainage begins			None	None

CHAPTER 6: CONCLUSION

This thesis provides a fire record from tree islands located in Water Conservation Area 2A (WCA-2A) in the Florida Everglades since the late 1800s. Microscopic charcoal records from the three tree islands examined in this study (2A-14-2, 2A-15-6, and 2A-22-18) demonstrated that fire has been common in the region, especially since the early 1900s. This corresponded with major changes in hydrology that began in the early 1900s. Macroscopic charcoal records from the three tree islands also indicated that local fires have occurred on or near tree islands in this study since the late 1800s, especially on 2A-14-2 and 2A-15-6.

This study demonstrates that anthropogenic changes to the wetland over the last century have had a significant impact on fire frequency in WCA-2A. Fire records from ghost islands 2A-14-2 and 2A-15-6 showed an increase in fire frequency in this area coincided with major hydrologic changes since the early 1900s. The core taken from the live tree island 2A-22-18 also demonstrated that increased fire events occurred along with hydrologic changes within the last approximately 120 years. The close proximity of 2A-22-18 to the Everglades Agricultural Area (EAA) and the intentionally set fires in the agricultural area might have had an impact on, or have been the source of, fires in the northern part of WCA-2A, as seen in the charcoal record from that tree island. There was less charcoal present in sediment cores from 2A-14-2 and 2A-15-6 than in the sediment core from 2A-22-18. This might be due to the fact that 2A-14-2 and 2A-15-6 have been submerged in water for the most part since the 1960s due to the compartmentalization of the WCAs.

This study also examined the impact of precipitation on fire activity in WCA-2A. Precipitation did not appear to be the main driving force of fires in the area since the late 1800s. Precipitation and drought have had some impact on fire activity in the region. However, while several time periods supported a directly proportionate relationship of increased/decreased levels of precipitation with fire activity, many periods did not, which made the data inconclusive. A more detailed analysis is required to make a better conclusion on this data. It would be helpful to examine individual years of precipitation and fire data to gain a better understanding of how precipitation has affected fires on a yearly basis.

Fires that have occurred in WCA-2A in the past can be attributed to changes in regional hydrology. An increase in peat fires since drainage began indicates that drier conditions are causing more severe, longer burning fires (McVoy et al. 2011). Charcoal records derived from sediment cores taken from 2A-14-2 and 2A-15-6 demonstrated an increase in regional and local fire activity since drainage was initiated. This impact from drainage activities supports ecological restoration plans that call for a return to pre-1900 hydrology. Even though water is impounded in WCA-2A and it is often flooded, many of the surrounding areas have been drained and are drier than before drainage began. Many areas of the Everglades require more water, and less fire, to return to a more natural state. The EAA was drained for agricultural activities and the urban areas to the east were drained for development. This comparison between hydrologic activity and fire has implications for water management because, as seen by evidence from the past, altered water levels may have an impact on fire events by increasing the number of fires in the area – which impacts ecological composition and succession in the system.

The comparisons of the charcoal record to drainage and precipitation data from this study were qualitative. Statistical analyses were not used because Pb-210 dates were only available for two of the cores, there were no other variables besides charcoal from the core to compare, and there were issues with the precipitation data. However, a statistical analysis of the Charcoal Accumulation Rates (CHAR) could have been conducted if dates were available for all three cores (Whitlock and Anderson 2003). The results of the time series of CHAR can be compared to other measured variables such as fossil pollen percentages , pollen concentrations, or historical climate data, in order to determine relationships between charcoal concentrations and these variables (Beaty and Taylor 2009). The time series analysis of CHAR can identify individual fire events and statistics such as mean, median, and standard deviation can be determined for the fire return intervals (Hallet and Walker 2000; Beaty and Taylor 2009). If precipitation records had been from weather stations closer to the study sites, and likely more representative of local precipitation patterns, it would have been appropriate to determine if peaks in charcoal concentration or accumulation were correlated with periods of low precipitation.

Future studies should address how water levels and precipitation might have impacted fire activity in other areas of the Everglades. It would be useful to compare the results of this study to studies from other areas of the Everglades to get a complete understanding of the impacts of the hydrologic changes in the area. Future studies should also address the issue of how water managers can restore pre-drainage hydrology and preserve tree islands at the same time (Sklar et al. 1999). However, the historic Everglades will never be completely restored because only half of the original Everglades remain (Grunwald 2006).

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APPENDICES

Appendix I: Charcoal Data

Table A1: Bulk density and mass sedimentation rate data for the 2A-14-2 core.

2A-14-2 BULK DENSITY AND MASS SEDIMENTATION RATE DATA			
DEPTH (cm)	**DATE**	**BULK DENSITY (g of dry sediment/cm^3 wet sediment)**	**MASS SEDIMENTATION RATE (mg/cm^2/yr)**
0-1	2005	0.096	22.30
1-2	1991	0.198	14.13
2-3	1981	0.127	11.75
3-4	1969	0.099	8.72
4-5	1963	0.044	7.27
5-6	1955	0.113	13.33
6-7	1944	0.099	9.27
7-8	1933	0.100	9.22
8-9	1917	0.118	7.16
9-10	1901	0.126	8.23
10-11	1866	0.123	3.48
11-12	N/A	0.127	N/A
12-13	N/A	0.124	N/A
13-14	N/A	0.137	N/A
14-15	N/A	0.148	N/A
15-16	N/A	0.154	N/A
16-17	N/A	0.111	N/A
17-18	N/A	0.151	N/A
18-19	N/A	0.153	N/A
19-20	N/A	0.149	N/A
20-21	N/A	0.143	N/A
21-22	N/A	0.138	N/A
22-23	N/A	0.143	N/A
23-24	N/A	0.147	N/A
24-25	N/A	0.131	N/A
25-26	N/A	0.149	N/A
26-27	N/A	0.132	N/A
27-28	N/A	0.143	N/A
28-29	N/A	0.139	N/A
29-30	N/A	0.135	N/A

Appendix I (Continued)

Table A1 Continued			
30-31	N/A	0.143	N/A
31-32	N/A	0.134	N/A
32-33	N/A	0.148	N/A
33-34	N/A	0.144	N/A
34-35	N/A	0.147	N/A
35-36	N/A	0.157	N/A
36-37	N/A	0.154	N/A
37-38	N/A	0.146	N/A
38-39	N/A	0.156	N/A
39-40	N/A	0.161	N/A
40-41	N/A	0.174	N/A
41-42	N/A	0.167	N/A
42-43	N/A	0.181	N/A
43-44	N/A	0.185	N/A
44-45	N/A	0.178	N/A
45-46	N/A	0.171	N/A
46-47	N/A	0.141	N/A
47-48	N/A	0.182	N/A
48-49	N/A	0.181	N/A
49-50	N/A	0.205	N/A
50-51	N/A	0.237	N/A
51-52	N/A	0.228	N/A
52-53	N/A	0.226	N/A
53-54	N/A	0.224	N/A
54-55	N/A	0.238	N/A
55-56	N/A	0.193	N/A
56-57	N/A	0.196	N/A
57-58	N/A	0.178	N/A
58-59	N/A	0.186	N/A

Appendix I (Continued)

Table A2: Bulk density and mass sedimentation rate data for the 2A-15-6 core.

2A-15-6 BULK DENSITY AND MASS SEDIMENTATION RATE DATA			
DEPTH (cm)	**DATE**	**BULK DENSITY (g of dry sediment/cm^3 wet sediment)**	**MASS SEDIMENTATION RATE (mg/cm^2/yr)**
0-1	2007	0.126	48.71
1-2	2005	0.091	38.48
2-3	2002	0.103	34.17
3-4	1998	0.117	33.60
4-5	1994	0.190	42.93
5-6	1991	0.150	44.98
6-7	1987	0.143	44.07
7-8	1983	0.123	26.11
8-9	1978	0.103	23.26
9-10	1973	0.131	26.55
10-11	1970	0.124	37.37
11-12	1965	0.148	30.71
12-13	1963	0.090	35.09
13-14	1957	0.141	26.77
14-15	1953	0.098	21.77
15-16	1948	0.131	29.04
16-17	1940	0.182	23.11
17-18	1934	0.128	21.51
18-19	1924	0.177	17.14
19-20	1911	0.130	10.07
20-21	1895	0.123	7.49
21-22	1869	0.138	5.30
22-23	N/A	0.123	N/A
23-24	N/A	0.120	N/A
24-25	N/A	0.110	N/A
25-26	N/A	0.116	N/A
26-27	N/A	0.125	N/A
27-28	N/A	0.142	N/A
28-29	N/A	0.146	N/A
29-30	N/A	0.149	N/A

Appendix I (Continued)

Table A2 Continued			
30-31	N/A	0.147	N/A
31-32	N/A	0.155	N/A
32-33	N/A	0.155	N/A
33-34	N/A	0.161	N/A
34-35	N/A	0.148	N/A
35-36	N/A	0.158	N/A
36-37	N/A	0.164	N/A
37-38	N/A	0.176	N/A
38-39	N/A	0.202	N/A
39-40	N/A	0.222	N/A
40-41	N/A	0.220	N/A
41-42	N/A	0.199	N/A
42-43	N/A	0.198	N/A
43-44	N/A	0.178	N/A
44-45	N/A	0.184	N/A
45-46	N/A	0.129	N/A
46-47	N/A	0.183	N/A
47-48	N/A	0.176	N/A
48-49	N/A	0.180	N/A
49-50	N/A	0.214	N/A
50-51	N/A	0.184	N/A
51-52	N/A	0.157	N/A
52-53	N/A	0.140	N/A
53-54	N/A	0.163	N/A
54-55	N/A	0.164	N/A
55-56	N/A	0.168	N/A
56-57	N/A	0.174	N/A
57-58	N/A	0.234	N/A
58-59	N/A	0.148	N/A
59-60	N/A	0.162	N/A

Appendix I (Continued)

Table A3: Bulk density and mass sedimentation rate data for the 2A-22-18 core.

2A-22-18 BULK DENSITY AND MASS SEDIMENTATION RATE DATA			
DEPTH (cm)	**DATE**	**BULK DENSITY (g of dry sediment/cm^3 wet sediment)**	**MASS SEDIMENTATION RATE (mg/cm^2/yr)**
0-1	N/A	0.107	N/A
1-2	N/A	0.080	N/A
2-3	N/A	0.136	N/A
3-4	N/A	0.162	N/A
4-5	N/A	0.162	N/A
5-6	N/A	0.198	N/A
6-7	N/A	0.197	N/A
7-8	N/A	0.193	N/A
8-9	N/A	0.178	N/A
9-10	N/A	0.186	N/A
10-11	N/A	0.167	N/A
11-12	N/A	0.121	N/A
12-13	N/A	0.125	N/A
13-14	N/A	0.160	N/A
14-15	N/A	0.143	N/A
15-16	N/A	0.152	N/A
16-17	N/A	0.154	N/A
17-18	N/A	0.128	N/A
18-19	N/A	0.102	N/A
19-20	N/A	0.110	N/A
20-21	N/A	0.129	N/A
21-22	N/A	0.119	N/A
22-23	N/A	0.110	N/A
23-24	N/A	0.109	N/A
24-25	N/A	0.112	N/A
25-26	N/A	0.113	N/A
26-27	N/A	0.099	N/A
27-28	N/A	0.094	N/A
28-29	N/A	0.093	N/A
29-30	N/A	0.101	N/A

Appendix I (Continued)

Table A3 Continued			
30-31	N/A	0.101	N/A
31-32	N/A	0.112	N/A
32-33	N/A	0.082	N/A
33-34	N/A	0.110	N/A
34-35	N/A	0.125	N/A
35-36	N/A	0.109	N/A
36-37	N/A	0.116	N/A
37-38	N/A	0.122	N/A
38-39	N/A	0.119	N/A
39-40	N/A	0.128	N/A
40-41	N/A	0.030	N/A
41-42	N/A	0.035	N/A
42-43	N/A	0.135	N/A
43-44	N/A	0.134	N/A
44-45	N/A	0.140	N/A
45-46	N/A	0.146	N/A
46-47	N/A	0.154	N/A
47-48	N/A	0.134	N/A
48-49	N/A	0.184	N/A
49-50	N/A	0.162	N/A
50-51	N/A	0.155	N/A
51-52	N/A	0.162	N/A
52-53	N/A	0.130	N/A
53-54	N/A	0.161	N/A
54-55	N/A	0.148	N/A
55-56	N/A	0.144	N/A
56-57	N/A	0.138	N/A
57-58	N/A	0.141	N/A
58-59	N/A	0.142	N/A
59-60	N/A	0.142	N/A

Appendix I (Continued)

Table A4: Charcoal particles/cm^3 for all size classes in the 2A-14-2 core.

2A-14-2 CHARCOAL PARTICLES/CM^3						
DEPTH (cm)	**MICROSCOPIC**	**TOTAL MACROSCOPIC**	**125 µm**	**250 µm**	**500 µm**	**1000 µm**
0-1	187	1	1	0	0	0
1-2	0	1	1	0	0	0
2-3	896	8	6	2	0	0
3-4	2190	17	16	1	0	0
4-5	78	1	0	1	0	0
5-6	2457	4	3	1	0	0
6-7	30	0	0	0	0	0
7-8	2118	3	3	0	0	0
8-9	0	3	3	0	0	0
9-10	13	0	0	0	0	0
10-11	40	5	0	5	0	0
11-12	0	0	0	0	0	0
12-13	0	0	0	0	0	0
13-14	0	0	0	0	0	0
14-15	0	1	0	1	0	0
15-16	0	0	0	0	0	0
16-17	0	5	2	3	0	0
17-18	0	0	0	0	0	0
18-19	0	0	0	0	0	0
19-20	0	0	0	0	0	0
20-21	0	0	0	0	0	0
21-22	62	0	0	0	0	0
22-23	0	0	0	0	0	0
23-24	0	0	0	0	0	0
24-25	0	0	0	0	0	0
25-26	116	0	0	0	0	0
26-27	44	0	0	0	0	0
27-28	16	0	0	0	0	0
28-29	63	0	0	0	0	0
29-30	35	0	0	0	0	0
30-31	65	0	0	0	0	0
31-32	0	1	1	0	0	0
32-33	0	0	0	0	0	0

Appendix I (Continued)

Table A4 Continued						
33-34	0	0	0	0	0	0
34-35	0	0	0	0	0	0
35-36	52	0	0	0	0	0
36-37	0	0	0	0	0	0
37-38	0	0	0	0	0	0
38-39	22	0	0	0	0	0
39-40	0	0	0	0	0	0
40-41	0	0	0	0	0	0
41-42	0	0	0	0	0	0
42-43	0	0	0	0	0	0
43-44	62	1	1	0	0	0
44-45	0	1	1	0	0	0
45-46	39	0	0	0	0	0
46-47	0	0	0	0	0	0
47-48	22	0	0	0	0	0
48-49	0	0	0	0	0	0
49-50	0	0	0	0	0	0
50-51	0	0	0	0	0	0
51-52	0	0	0	0	0	0
52-53	0	0	0	0	0	0
53-54	20	0	0	0	0	0
54-55	0	0	0	0	0	0
55-56	0	0	0	0	0	0
56-57	0	0	0	0	0	0
57-58	147	0	0	0	0	0
58-59	131	0	0	0	0	0

Appendix I (Continued)

Table A5: Charcoal particles/g of dry weight for all size classes in the 2A-14-2 core.

2A-14-2 CHARCOAL PARTICLES/G DRY WEIGHT						
DEPTH (cm)	**MICROSCOPIC**	**TOTAL MACROSCOPIC**	**125 µm**	**250 µm**	**500 µm**	**1000 µm**
0-1	1947	10	10	0	0	0
1-2	0	5	5	0	0	0
2-3	7055	62	47	15	0	0
3-4	22121	171	161	10	0	0
4-5	1772	22	0	22	0	0
5-6	21743	35	26	9	0	0
6-7	303	0	0	0	0	0
7-8	21180	30	30	0	0	0
8-9	0	25	25	0	0	0
9-10	103	0	0	0	0	0
10-11	325	40	0	40	0	0
11-12	0	0	0	0	0	0
12-13	0	0	0	0	0	0
13-14	0	0	0	0	0	0
14-15	0	6	0	6	0	0
15-16	0	0	0	0	0	0
16-17	0	45	18	27	0	0
17-18	0	0	0	0	0	0
18-19	0	0	0	0	0	0
19-20	0	0	0	0	0	0
20-21	0	0	0	0	0	0
21-22	449	0	0	0	0	0
22-23	0	0	0	0	0	0
23-24	0	0	0	0	0	0
24-25	0	0	0	0	0	0
25-26	778	0	0	0	0	0
26-27	333	0	0	0	0	0
27-28	111	0	0	0	0	0
28-29	453	0	0	0	0	0
29-30	259	0	0	0	0	0
30-31	454	0	0	0	0	0
31-32	0	7	7	0	0	0

Appendix I (Continued)

Table A5 Continued						
32-33	0	0	0	0	0	0
33-34	0	0	0	0	0	0
34-35	0	0	0	0	0	0
35-36	331	0	0	0	0	0
36-37	0	0	0	0	0	0
37-38	0	0	0	0	0	0
38-39	141	0	0	0	0	0
39-40	0	0	0	0	0	0
40-41	0	0	0	0	0	0
41-42	0	0	0	0	0	0
42-43	0	0	0	0	0	0
43-44	335	5	5	0	0	0
44-45	0	5	5	0	0	0
45-46	228	0	0	0	0	0
46-47	0	0	0	0	0	0
47-48	120	0	0	0	0	0
48-49	0	0	0	0	0	0
49-50	0	0	0	0	0	0
50-51	0	0	0	0	0	0
51-52	0	0	0	0	0	0
52-53	0	0	0	0	0	0
53-54	89	0	0	0	0	0
54-55	0	0	0	0	0	0
55-56	0	0	0	0	0	0
56-57	0	0	0	0	0	0
57-58	825	0	0	0	0	0
58-59	704	0	0	0	0	0

Appendix I (Continued)

Table A6: CHAR values for all size classes in the 2A-14-2 core.

2A-14-2 CHAR (particles/cm^2/year)						
DEPTH (cm)	**MICROSCOPIC**	**TOTAL MACROSCOPIC**	**125 µm**	**250 µm**	**500 µm**	**1000 µm**
0-1	43.49	0.22	0.22	0.00	0.00	0.00
1-2	0.00	0.07	0.07	0.00	0.00	0.00
2-3	82.90	0.74	0.55	0.18	0.00	0.00
3-4	192.90	1.48	1.40	0.09	0.00	0.00
4-5	12.89	0.17	0.00	0.16	0.00	0.00
5-6	289.84	0.47	0.35	0.12	0.00	0.00
6-7	2.81	0.00	0.00	0.00	0.00	0.00
7-8	195.28	0.28	0.28	0.00	0.00	0.00
8-9	0.00	0.18	0.18	0.00	0.00	0.00
9-10	0.85	0.00	0.00	0.00	0.00	0.00
10-11	1.13	0.14	0.00	0.14	0.00	0.00

Appendix I (Continued)

Table A7: Charcoal particles/cm^3 for all size classes in the 2A-15-6 core.

2A-15-6 CHARCOAL PARTICLES/CM^3						
DEPTH (cm)	**MICROSCOPIC**	**TOTAL MACROSCOPIC**	**125 µm**	**250 µm**	**500 µm**	**1000 µm**
0-1	263	1	0	1	0	0
1-2	328	4	0	4	0	0
2-3	184	4	4	0	0	0
3-4	0	0	0	0	0	0
4-5	53	3	3	0	0	0
5-6	46	6	5	1	0	0
6-7	0	0	0	0	0	0
7-8	290	5	5	0	0	0
8-9	52	2	1	1	0	0
9-10	71	1	1	0	0	0
10-11	23	3	1	0	2	0
11-12	45	1	1	0	0	0
12-13	53	10	1	7	1	1
13-14	84	3	0	2	1	0
14-15	68	6	0	5	1	0
15-16	45	2	1	0	1	0
16-17	23	11	0	8	0	3
17-18	26	14	1	9	0	4
18-19	0	8	3	5	0	0
19-20	89	5	3	2	0	0
20-21	0	0	0	0	0	0
21-22	0	1	1	0	0	0
22-23	0	1	1	0	0	0
23-24	0	1	1	0	0	0
24-25	0	1	1	0	0	0
25-26	0	1	1	0	0	0
26-27	0	0	0	0	0	0
27-28	0	0	0	0	0	0
28-29	0	0	0	0	0	0
29-30	0	0	0	0	0	0
30-31	0	0	0	0	0	0
31-32	0	1	1	0	0	0
32-33	0	0	0	0	0	0

Appendix I (Continued)

Table A7 Continued

33-34	0	0	0	0	0	0
34-35	0	0	0	0	0	0
35-36	0	0	0	0	0	0
36-37	0	0	0	0	0	0
37-38	0	0	0	0	0	0
38-39	0	0	0	0	0	0
39-40	0	0	0	0	0	0
40-41	0	0	0	0	0	0
41-42	0	0	0	0	0	0
42-43	0	0	0	0	0	0
43-44	0	0	0	0	0	0
44-45	0	0	0	0	0	0
45-46	0	0	0	0	0	0
46-47	0	0	0	0	0	0
47-48	0	0	0	0	0	0
48-49	0	0	0	0	0	0
49-50	0	0	0	0	0	0
50-51	0	0	0	0	0	0
51-52	0	0	0	0	0	0
52-53	0	0	0	0	0	0
53-54	0	0	0	0	0	0
54-55	0	0	0	0	0	0
55-56	0	0	0	0	0	0
56-57	0	0	0	0	0	0
57-58	0	0	0	0	0	0
58-59	0	0	0	0	0	0
59-60	0	0	0	0	0	0

Appendix I (Continued)

Table A8: Charcoal particles/g of dry weight for all size classes in the 2A-15-6 core.

2A-15-6 CHARCOAL PARTICLES/G DRY WEIGHT						
DEPTH (cm)	MICROSCOPIC	TOTAL MACROSCOPIC	125 µm	250 µm	500 µm	1000 µm
0-1	2089	8	0	8	0	0
1-2	3604	44	0	44	0	0
2-3	1786	39	39	0	0	0
3-4	0	0	0	0	0	0
4-5	278	16	16	0	0	0
5-6	306	40	33	7	0	0
6-7	0	0	0	0	0	0
7-8	2357	50	50	0	0	0
8-9	504	17	8	8	0	0
9-10	541	8	8	0	0	0
10-11	185	24	8	0	16	0
11-12	304	8	8	0	0	0
12-13	588	81	8	56	8	8
13-14	595	21	0	14	7	0
14-15	693	61	0	51	10	0
15-16	343	15	8	0	8	0
16-17	126	60	0	44	0	16
17-18	203	109	8	70	0	31
18-19	0	45	17	28	0	0
19-20	684	38	23	15	0	0
20-21	0	0	0	0	0	0
21-22	0	7	7	0	0	0
22-23	0	8	8	0	0	0
23-24	0	8	8	0	0	0
24-25	0	8	8	0	0	0
25-26	0	9	9	0	0	0
26-27	0	0	0	0	0	0
27-28	0	0	0	0	0	0
28-29	0	0	0	0	0	0
29-30	0	0	0	0	0	0
30-31	0	0	0	0	0	0
31-32	0	6	6	0	0	0

Appendix I (Continued)

Table A8 Continued						
32-33	0	0	0	0	0	0
33-34	0	0	0	0	0	0
34-35	0	0	0	0	0	0
35-36	0	0	0	0	0	0
36-37	0	0	0	0	0	0
37-38	0	0	0	0	0	0
38-39	0	0	0	0	0	0
39-40	0	0	0	0	0	0
40-41	0	0	0	0	0	0
41-42	0	0	0	0	0	0
42-43	0	0	0	0	0	0
43-44	0	0	0	0	0	0
44-45	0	0	0	0	0	0
45-46	0	0	0	0	0	0
46-47	0	0	0	0	0	0
47-48	0	0	0	0	0	0
48-49	0	0	0	0	0	0
49-50	0	0	0	0	0	0
50-51	0	0	0	0	0	0
51-52	0	0	0	0	0	0
52-53	0	0	0	0	0	0
53-54	0	0	0	0	0	0
54-55	0	0	0	0	0	0
55-56	0	0	0	0	0	0
56-57	0	0	0	0	0	0
57-58	0	0	0	0	0	0
58-59	0	0	0	0	0	0
59-60	0	0	0	0	0	0

Appendix I (Continued)

Table A9: CHAR values for all size classes in the 2A-15-6 core.

2A-15-6 CHAR (particles/cm^2/year)						
DEPTH (cm)	**MICROSCOPIC**	**TOTAL MACROSCOPIC**	**125 µm**	**250 µm**	**500 µm**	**1000 µm**
0-1	101.67	0.39	0.00	0.39	0.00	0.00
1-2	138.70	1.69	0.00	1.69	0.00	0.00
2-3	61.04	1.06	1.06	0.00	0.00	0.00
3-4	0.00	0.00	0.00	0.00	0.00	0.00
4-5	11.98	0.68	0.68	0.00	0.00	0.00
5-6	13.79	1.80	1.48	0.31	0.00	0.00
6-7	0.00	0.00	0.00	0.00	0.00	0.00
7-8	61.56	1.31	1.31	0.00	0.00	0.00
8-9	11.74	0.40	0.19	0.19	0.00	0.00
9-10	14.39	0.21	0.21	0.00	0.00	0.00
10-11	6.93	0.90	0.30	0.00	0.60	0.00
11-12	9.34	0.25	0.25	0.00	0.00	0.00
12-13	20.66	2.84	0.28	1.97	0.28	0.28
13-14	15.95	0.57	0.00	0.35	0.19	0.00
14-15	15.11	1.33	0.00	1.11	0.22	0.00
15-16	9.98	0.44	0.23	0.00	0.23	0.00
16-17	2.92	1.40	0.00	1.02	0.00	0.37
17-18	0.00	2.35	0.17	1.51	0.00	0.67
18-19	4.37	0.77	0.29	0.48	0.00	0.00
19-20	6.85	0.39	0.23	0.15	0.00	0.00
20-21	0.00	0.00	0.00	0.00	0.00	0.00
21-22	0.00	0.04	0.04	0.00	0.00	0.00

Appendix I (Continued)

Table A10: Charcoal particles/cm^3 for all size classes in the 2A-22-18 core.

2A-22-18 CHARCOAL PARTICLES/CM^3						
DEPTH (cm)	MICROSCOPIC	TOTAL MACROSCOPIC	125 µm	250 µm	500 µm	1000 µm
0-1	63	0	0	0	0	0
1-2	82	2	2	0	0	0
2-3	893	3	2	1	0	0
3-4	54	2	2	0	0	0
4-5	0	0	0	0	0	0
5-6	0	0	0	0	0	0
6-7	0	0	0	0	0	0
7-8	0	1	1	0	0	0
8-9	0	4	4	0	0	0
9-10	52	21	9	9	3	0
10-11	0	33	21	12	0	0
11-12	40	8	6	2	0	0
12-13	0	0	0	0	0	0
13-14	0	0	0	0	0	0
14-15	0	1	1	0	0	0
15-16	0	14	6	6	1	1
16-17	336	186	109	63	9	5
17-18	0	19	6	12	0	1
18-19	44	3	3	0	0	0
19-20	160	6	4	2	0	0
20-21	0	3	2	1	0	0
21-22	0	0	0	0	0	0
22-23	163	1	1	0	0	0
23-24	0	4	2	2	0	0
24-25	0	0	0	0	0	0
25-26	0	0	0	0	0	0
26-27	0	0	0	0	0	0
27-28	0	0	0	0	0	0
28-29	866	2	1	0	1	0
29-30	250	4	4	0	0	0
30-31	632	4	4	0	0	0
31-32	1186	16	8	5	0	3
32-33	63	17	13	4	0	0

Appendix I (Continued)

Table A10 Continued						
33-34	682	52	4	41	6	1
34-35	438	28	16	3	9	0
35-36	797	15	3	11	1	0
36-37	1787	22	11	8	1	2
37-38	443	15	15	0	0	0
38-39	537	14	8	5	1	0
39-40	779	5	4	1	0	0
40-41	1021	65	40	19	5	1
41-42	593	23	13	7	3	0
42-43	418	0	0	0	0	0
43-44	1024	1	1	0	0	0
44-45	723	0	0	0	0	0
45-46	0	0	0	0	0	0
46-47	474	3	3	0	0	0
47-48	2315	0	0	0	0	0
48-49	276	0	0	0	0	0
49-50	336	0	0	0	0	0
50-51	403	10	10	0	0	0
51-52	225	8	8	0	0	0
52-53	165	5	2	3	0	0
53-54	360	6	1	5	0	0
54-55	0	0	0	0	0	0
55-56	75	0	0	0	0	0
56-57	0	9	7	2	0	0
57-58	179	2	2	0	0	0
58-59	340	1	0	0	0	0
59-60	0	12	9	3	0	0

Appendix I (Continued)

Table A11: Charcoal particles/g of dry weight for all size classes in the 2A-22-18 core.

2A-22-18
CHARCOAL PARTICLES/G DRY WEIGHT

DEPTH (cm)	MICROSCOPIC	TOTAL MACROSCOPIC	125 µm	250 µm	500 µm	1000 µm
0-1	467	0	0	0	0	0
1-2	1019	25	10	0	0	0
2-3	6565	22	15	7	0	0
3-4	332	12	20	0	0	0
4-5	0	0	0	0	0	0
5-6	0	0	0	0	0	0
6-7	0	0	0	0	0	0
7-8	0	5	10	0	0	0
8-9	0	22	33	0	0	0
9-10	277	112	71	71	23	0
10-11	0	197	170	97	0	0
11-12	327	66	47	15	0	0
12-13	0	0	0	0	0	0
13-14	0	0	0	0	0	0
14-15	0	6	6	0	0	0
15-16	0	92	38	38	6	6
16-17	2065	1207	981	567	81	45
17-18	0	148	39	79	0	6
18-19	431	29	19	0	0	0
19-20	1450	54	26	13	0	0
20-21	0	23	13	6	0	0
21-22	0	0	0	0	0	0
22-23	1483	9	6	0	0	0
23-24	0	36	13	13	0	0
24-25	0	0	0	0	0	0
25-26	0	0	0	0	0	0
26-27	0	0	0	0	0	0
27-28	0	0	0	0	0	0
28-29	9308	21	7	0	7	0
29-30	2477	39	29	0	0	0
30-31	6015	39	27	0	0	0
31-32	10592	71	59	37	0	22

Appendix I (Continued)

Table A11 Continued

32-33	772	158	87	27	0	0
33-34	6197	36	27	284	41	6
34-35	3504	128	108	20	61	0
35-36	7315	27	19	70	6	0
36-37	15402	94	71	51	6	12
37-38	3630	122	102	0	0	0
38-39	12917	67	51	32	6	0
39-40	6082	31	24	6	0	0
40-41	32436	1333	229	109	28	5
41-42	16943	371	77	41	17	0
42-43	3093	0	0	0	0	0
43-44	7639	7	5	0	0	0
44-45	5167	0	0	0	0	0
45-46	0	0	0	0	0	0
46-47	3076	19	21	0	0	0
47-48	17274	0	0	0	0	0
48-49	1500	0	0	0	0	0
49-50	2071	0	0	0	0	0
50-51	2858	64	42	0	0	0
51-52	1387	49	35	0	0	0
52-53	1273	15	8	13	0	0
53-54	2236	37	4	22	0	0
54-55	0	0	0	0	0	0
55-56	523	0	0	0	0	0
56-57	0	65	35	10	0	0
57-58	1271	14	11	0	0	0
58-59	2394	7	0	0	0	0
59-60	0	84	63	21	0	0

Appendix II: Precipitation Data

Table A12: Precipitation data for South Florida since 1890 (Southeast Regional Climate Center 2011). The darkened areas indicate that no data was available.

Year	Average Precipitation: Belle Glade	Average Precipitation: Canal Point	Average Precipitation: Ft. Lauderdale	Average Precipitation: Ft. Myers	Average Precipitation: Ft. Pierce	Average Precipitation: All Stations (inches)
2005-2009	■	45.94	64.73	55.54	53.82	55.00
2000-2004	44.10	77.69	63.44	56.54	50.15	56.85
1995-1999	53.35	55.95	74.42	49.00	62.42	59.03
1990-1994	58.20	60.77	69.83	57.54	62.48	61.76
1985-1989	42.86	48.16	53.33	51.66	46.21	48.45
1980-1984	49.33	53.08	69.01	56.81	56.15	56.87
1975-1979	50.63	50.15	61.97	54.86	48.19	53.16
1970-1974	55.95	47.50	56.29	52.01	52.24	52.79
1965-1969	58.50	54.52	68.70	57.49	54.73	58.88
1960-1964	53.30	51.64	51.27	48.59	63.46	53.65
1955-1959	59.52	61.33	65.22	60.24	54.78	60.21
1950-1954	47.28	57.21	69.34	51.15	■	56.24
1945-1949	64.96	■	86.62	60.24	43.05	63.72
1940-1944	55.93	■	48.80	58.80	48.91	53.12
1935-1939	53.67	■	50.66	53.72	53.96	53.00
1930-1934	59.65	■	67.61	51.36	49.91	57.13
1925-1929	56.56	■	61.27	50.37	54.1	55.58
1920-1924	■	■	58.75	57.76	48.42	54.98
1915-1919	■	■	59.42	■	45.54	52.48
1910-1914	■	■	■	43.53	45.86	45.08
1905-1909	■	■	■	48.53	53.38	50.96
1900-1904	■	■	■	43.91	55.62	49.77