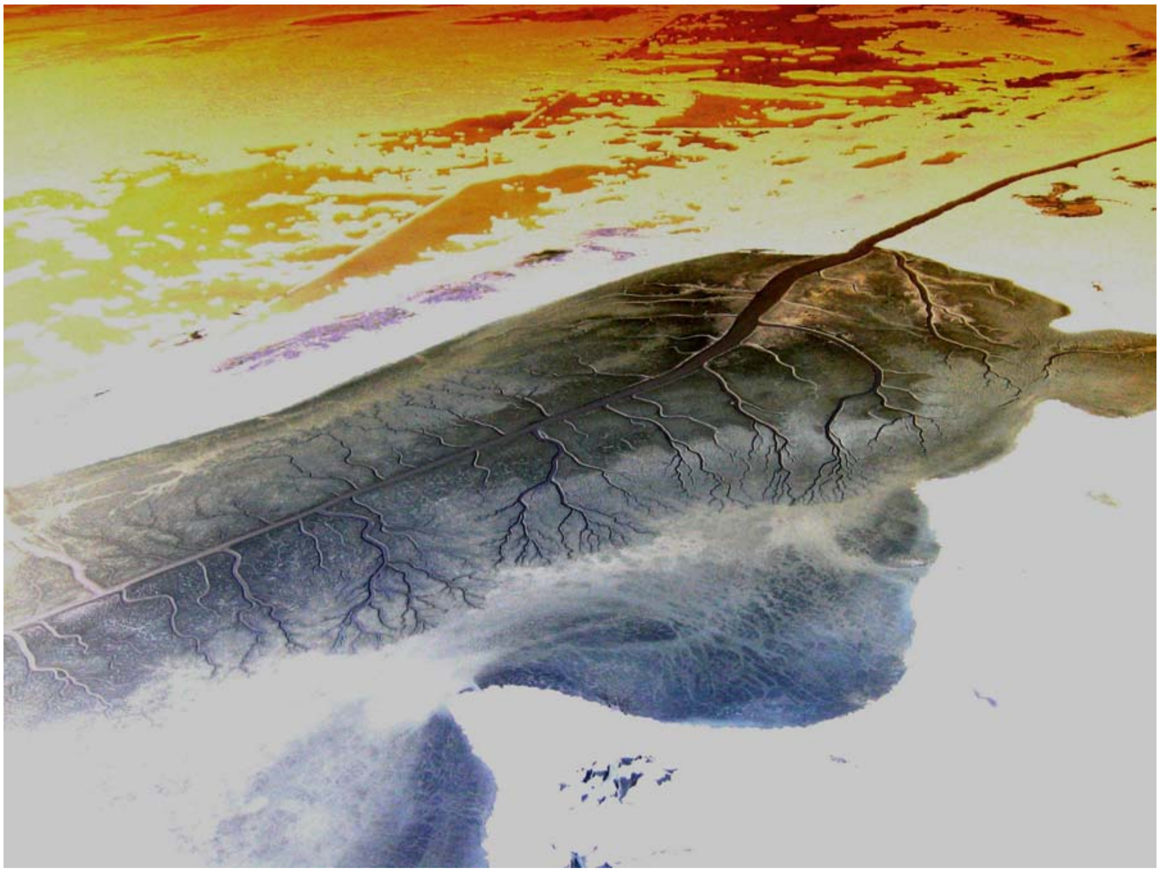
# Coastal Landscape and Channel Evolution Affecting Critical Habitats at Cape Sable, Everglades National Park, Florida

Harold R. Wanless and Brigitte M. Vlaswinkel



Final Report to
Everglades National Park
National Park Service, U.S. Department of Interior

June 15, 2005

# Coastal Landscape and Channel Evolution Affecting Critical Habitats at Cape Sable, Everglades National Park, Florida

FINAL REPORT

to

Everglades National Park
National Park Service
United States Department of Interior

by

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COVER IMAGES: Top: A color inverted oblique aerial photograph looking east across Lake Ingraham to the Homestead and East Cape Canals. Color inversion provides a 3-dimensional aspect to the flood tidal delta that is filling the southern third of Lake Ingraham with sediment carried in through the Lower East Cape Canal and Ingraham Canal (center right). Darker area near primary channel reflects most recent sediment deposition zone. Secondary channels, perpendicular to the primary channel, distribute sediment to the flanks of the delta in discrete lobes. Intertidal delta and shore muds are grey; surrounding wetlands are white as is the deeper part of Lake Ingraham. In the distance is the southern interior of Cape Sable, where wetland is white and open water areas of the collapsed marsh are orange. Photograph taken December 14, 2004. Bottom: White pelicans on the flood tidal delta in Lake Ingraham. This Page Above: Wading birds over Lake Ingraham, March 15, 2003.

# EXECUTIVE SUMMARY

Cape Sable is the canary for south Florida. Its exposed beaches have little natural renourishment source; its marl (firm carbonate mud) upland is a bit lower than the low-lying uplands elsewhere in south Florida; its wetlands are vast and mostly isolated from the modification of human manipulation seen elsewhere in south Florida, and it has seen its share of major hurricanes. Anything that will happen to other coastal areas of Everglades National Park and the 10,000 Islands, will likely happen to Cape Sable first.

This project documents the details of the geological and historical changes that have occurred on Cape Sable and describes the flow and sediment erosion-transport-deposition processes occurring on Cape Sable today. We evaluate the roles of human changes, sea level rise and hurricane events in driving the evolution of Cape Sable historically, today and in the future. We conclude with recommendations for the future management of Cape Sable in light of the stark reality of an anticipated further 60 centimeter rise in sea level in the coming century.

Cape Sable, as we know it, evolved following a small (less than one meter), rapid rise in sea level 2,500-2,400 years before present. From 2,400 years ago to the present the average rate of relative sea level rise was only 3-5 cm per century. This permitted carbonate sand and mud shorelines to form and stabilize our coasts. It also permitted biological production of coastal wetland peats to accumulate, build upwards, and expand. Cape Sable had evolved by 1900 to a broad freshwater to brackish interior wetland that was protected to the seaward by an emergent Marl Ridge to the southwest and south and a wide, mature mangrove forest to the northwest. Seaward of the Marl Ridge on the southwest coast was a line of lakes and mangrove swamps bounded to the west by shell beaches and capes. The interior margins, facing Whitewater Bay had a narrow mangrove fringe separating the interior marsh from the waters of the Bay.

Cape Sable is now in a phase of dramatic evolution in response to (1) a six-fold increase in the relative rise in sea level since 1930 and (2) some narrow canal ditches dug in the 1920s connecting interior lakes and the southern freshwater marsh with ocean water and tides. This historical increase in sea level over south Florida is in response to regional changes in the density and circulation of North Atlantic shallow and deep waters.

Beginning in the 1920s and 1930s, canals that cut through a coastal berm of mud formed by storms (Marl Ridge) initiated rapid saline water intrusion into the freshwater marshes of the southern interior of Cape Sable. By the 1950s these freshwater marshes had collapsed to open water as the underlying organic peat decayed and oxidized. Higher marl substrates in the interior marsh were colonized by mangrove. These canals also initiated rapid infilling of lakes and ponds with sediment brought in from offshore and recycled within the coastal complex (widening channels and collapsing interior marsh). In addition to cut canals, five new tidal creeks have opened since 1930 in response to 100-400 meters of storm-driven erosion along the southern and western mangrove coastlines. Two of these natural channels cut across the Marl Ridge, bringing saline tidal

inflow to the former freshwater marsh in the interior of southern and northern Cape Sable.

This 23 cm rise in sea level since 1930 has destabilized all of Cape Sables coastal and wetland environments. This rise has greatly increased the area and volume of water that incoming tides cover (tidal prism). In response, strong currents run through the canals and natural tidal channels and is causing rapid widening. As a result, Lake Ingraham, the adjacent Southern Lakes, and portions of the interior collapsed marsh are rapidly filling with organic-rich carbonate mud (at rates up to 15 centimeters per year). Interior southern marsh areas, initially stressed by water coming in through the cut canals, are now regularly flooded by tidal water that both washes across the once protective Marl Ridge and in through new natural channels. Saline tidal waters are also penetrating more effectively into the interior through the widening mangrove margins on the north and east margins of Cape Sable. The interior wetlands of central and northern Cape Sable are rapidly evolving in response. Most interior wetland communities are weakened, with the underlying peat decaying, the substrate subsiding, and the area in risk of widespread collapse to open water - as previously happened in the south. Open water is expanding and substrate levels are lowering in the central and northern interior.

Four major hurricanes crossed the Mangrove Coast between Cape Sable and Everglades City during the past century (1926, 1935, 1960 and 1992). The Category 5 and 4 storms of 1935 and 1960 passed directly across Cape Sable and devastated the tall mangrove forests, both at the coast and in the interior. Rapid post-storm peat decay and substrate subsidence, combined with rapidly rising sea level, has made recovery difficult, and portions of these wetland mangrove forests have evolved to open water.

Tropical carbonate sedimentation is commonly associated with communities which produce large amounts of organic matter in the form of

- Seagrass roots and detritus in marine lagoons,
- Mangrove or *Spartina* peats in saline coastal swamps & marshes,
- Sawgrass peats in freshwater marshes.

During times of rising sea level, these organic root and litter peats are recycled in response to erosion and re-deposition by prevailing processes and hurricane events. As this happens, biological processes (decay and nutrient blooms) will convert much of the organic matter into algal, cyanobacterial, bacterial and fungal remains.

Put simply, Cape Sable is responding to the overwhelmingly powerful force of rising sea level on a delicate, low-lying coastline aided by episodic triggers such as hurricanes, fires, freezes and small human modifications. In considering management options it is critical to understand the reality and implications of the historical sea level rise that has affected south Florida’s coastline over the past 75 years – and the high probability that this will continue and be complimented by a doubling or tripling as the result of global warming (IPCC, 2001).

Our recommendation is to make modifications necessary to assure a fair measure of safety to persons using the backcountry of Cape Sable. In considering such options, remain aware that the canals and creeks will continue widening and that blocking flow in one area will enhance flow in another. Closing the canals that have rapidly widened historically will likely have unintended and undesirable consequences.

The documentation of the pervasive saline invasion and tenuous wetland viability in the interior of southern, central and northern Cape Sable is one of the most important, but least understood findings of this study. We recommend that this becomes a major focus of research using an integrated team of scientists.

Understanding the nature or wetland collapse or evolution on Cape Sable and the nature of the decay products as they are released from these transitioning environments to the marine ecosystem will provide a critical calibration for assessing both future change and stresses to adjacent environments. These findings can then be applied to the mainland coastal wetlands which have a more complicated stress history because of changing freshwater delivery schedules and levels through human management.

Significant landscape changes are occurring in a number of areas as the result of saline intrusion, wetland collapse, enlarged tidal prism, rapid sedimentation, and shore and interior erosion. It would be sensible for the National Park Service to properly inventory the rates, styles and causes of change occurring to the entire coast of Everglades National Park.

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# INTRODUCTION

Cape Sable is the canary for south Florida. Its exposed beaches have little natural renourishment source; its marl upland is a bit lower than the low-lying uplands elsewhere in south Florida; it wetlands are vast and mostly isolated from the modification of human manipulation seen elsewhere in south Florida, and it has seen its share of major hurricanes. If something is happening to the environments on Cape Sable, it is important for south Florida to sit up and take note.

This is not an idle attempt at over-dramatic writing. South Florida has experienced a 23 centimeter (9 inch) rise in sea level since 1930. This is a relative rate of rise more than six times faster than for the previous 2,400 years. And Cape Sable is responding. In this time of rapid sea level rise, Cape Sable is also attempting to recover from two extreme hurricanes, which directly crossed the entire Cape at full force during the last century. The Cape Sable complex (Figures 1 and 2) is one of the first of south Florida's coastal wetland environments in which critical habitats are imminently threatened. Understanding how this isolated low-lying coastal ecosystem, with only small human modifications, is responding to hurricanes and other stressors in a time of rapidly rising sea level is fundamental to the future management of the entire natural and human modified coastal ecosystem of south Florida.

## Statement of Purpose and Approach

To provide a proper understanding of the nature and rates of future changes that will occur in these critical coastal marine to freshwater habitats, this project has documented the nature of and causes for historical change to the coastal, channel/canal and wetland systems of Cape Sable and monitored the current sediment and substrate dynamics. This project has used and integrated results of historical aerial photographic analyses; sedimentologic, geochemical and paleoenvironmental analysis of soft-sediment core borings and surface samples; monitoring of transport, erosion and accretion processes in channels, lagoons and wetlands; and an understanding of natural and anthropogenic stressors.

## Intended Use of Results

There are three aspects of application for this research project. First, the results are of direct application to management decisions on the natural and human modified portions of Cape Sable, decisions currently under urgent consideration by Everglades National Park. These include restoration feasibility of canals from the Gulf and Florida Bay to Lake Ingraham and across the marl berm to the inner freshwater marsh, efforts to maintain freshwater habitats on the interior of Cape Sable, and decisions on responding to the loss of both freshwater marsh and coastal mangrove habitat.

Second, this study provides an understanding of the response of a complex coastal beach/marl ridge/wetland/lagoon ecosystem in an area that has been largely unaffected by

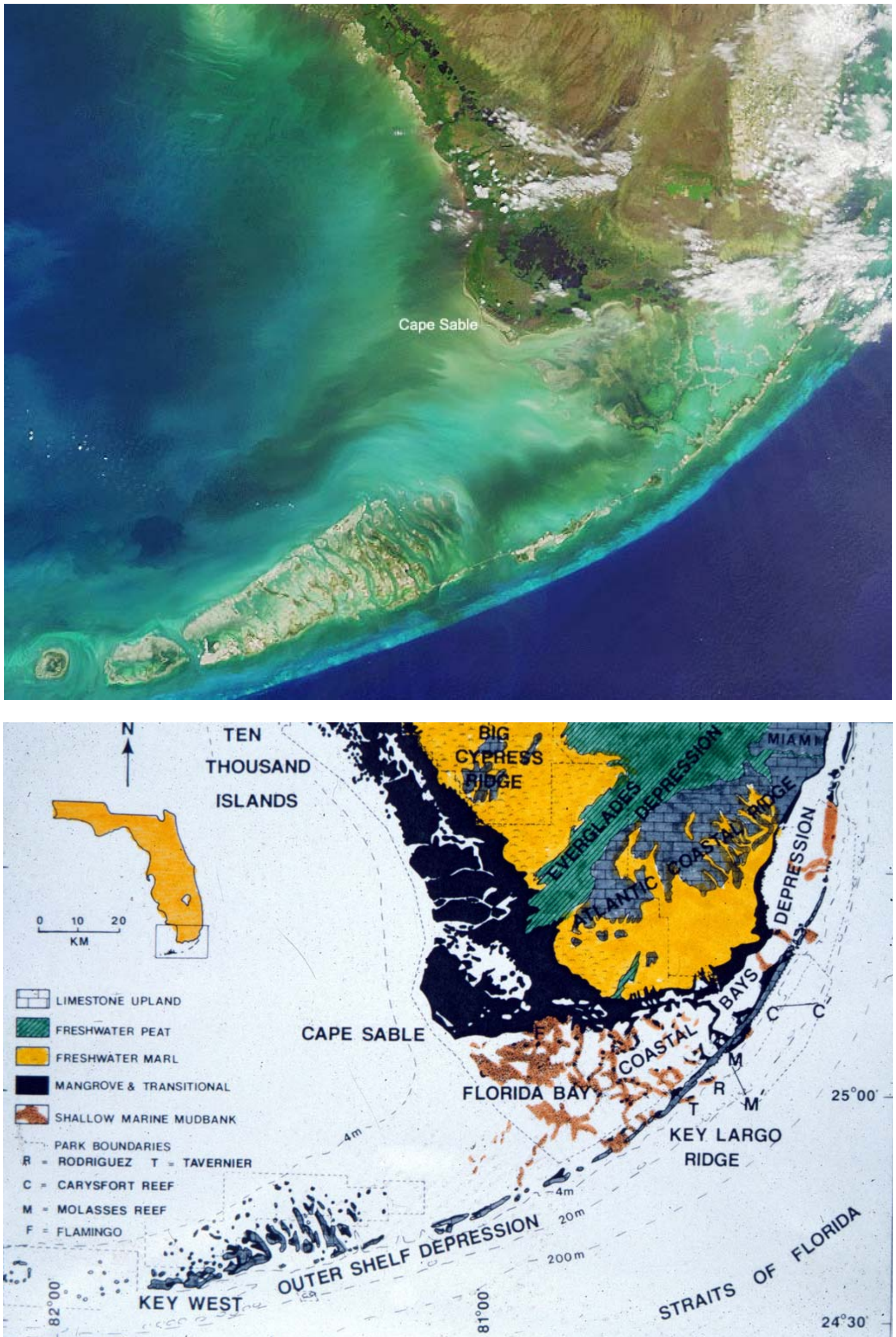



*FIGURE 1. Cape Sable is located at the southwest corner of the Florida mainland. It is bordered by Florida Bay to the south, the Gulf of Mexico to the west and Whitewater Bay to the northeast. It is connected to the mainland by an easterly-trending Marl Ridge. The lower Everglades is confined between Pliocene limestones of Big Cypress Ridge to the northwest and late Pleistocene oolitic limestones of the Atlantic Coastal Ridge to the southeast. It flows directly towards the center of Cape Sable, through which the Everglades discharged prior to 2,500 year before present.*


*FIGURE 2. Satellite image from 2005 of the Cape Sable area with place names. Image provided by USGS.*

historical changes in the discharges and water levels emanating from the Everglades. As such the Cape Sable region best reveals the ecosystem responses to natural regional stresses of hurricanes and relative sea level change. Understanding the changes in the Cape Sable System will make possible a better understanding of the causes for observed changes in the coastal Everglades elsewhere along the southwest coast, areas additionally influenced by human modification to water level and flow and landscape.

Third, Cape Sable provides an ideal test area for developing protocols for approaching the broader coastal Everglades. Cape Sable has a great variety of coastal environments with differing exposures, differing underlying substrates and relict topographic features, varying natural and anthropogenic modifications to the system, and differing spatial relationships between the coastal and interior freshwater environments. Two distinct extreme hurricanes have crossed Cape Sable since aerial photographic coverage has been available. Dramatic changes have occurred in both the natural and anthropogenically modified portions of the systems. All these provide an ideal opportunity to learn how best to approach an understanding of the coastal dynamics and evolution in the broader, more complex system.

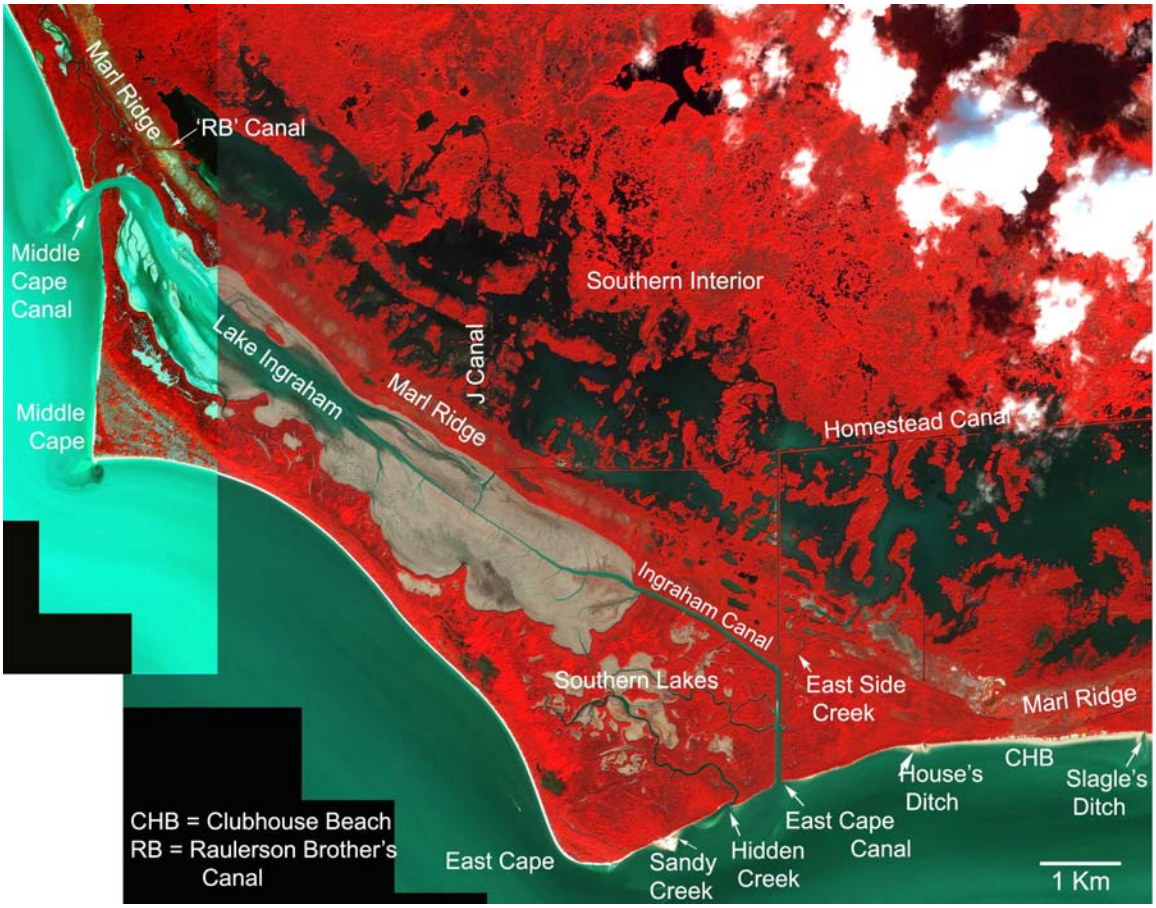



*FIGURE 3. Satellite image from 2005 of southwestern Cape Sable, the primary focus area of this research project. 'RB' is Raulerson Brother's Canal. Image © SpaceImaging, 2005.*

## Project Objectives and Research Goals

We pursued two objectives in an attempt to understand the dynamics and evolution of Cape Sable and two objectives to guide management decisions and future research along the channeled Mangrove Coast.

1. Document the historical patterns and rates of change of (a) the sandy, marl and wetland coastal systems; inland lakes and freshwater wetlands; and ntural and human-created channels.

2. Identify causes for the dramatic morphological ecosystem changes observed in the Cape Sable system (define the relative roles of prevailing processes, major hurricanes, historical sea level rise, human modifications and other).

3. Establish principles for system dynamics to be used as a "guide" for the evolution of other sensitive channeled mangrove-to-freshwater wetland complexes along the southwest coast of Everglades National Park.

4. Forecast the pattern and rate of the expected changes in the coming 50, 100, 200 years;

To meet these objectives we have focused on six research questions. These are (as stated in the original proposal):

- What are the historical and dynamic changes that have/are occurring in the depressions in the marl ridge adjacent to Lake Ingraham? We used aerial photography and field sampling of forming deltas to assess the rate of growth of tidal flow in natural and constructed channels. Field observations were made on historical and present community shift, substrate dynamics (subsidence/accretion), and spring tide flow dynamics across the Marl Ridge. We used this information and knowledge of the system dynamics to forecast the timing of inundation under various sea level rise and hurricane impact scenarios.

- What are the substrate dynamics of the interior wetland to the northeast of the Marl Ridge? Large areas of open water have appeared since construction of the Homestead Canal, East Cape Canal and Middle Cape/Raulerson.s Brother's Canals. We used historical aerial photography, coring, field observations and measurements of community shifts and substrate dynamics to determine timing and rates of changes. We assessed the impact of changing salinity and water level on community and substrate dynamics.

- What controls the rates of channel widening and evolution? To answer this we (a) studied the currents and channel edge response (erosion) in the rapidly widening constructed canals and in natural channels during neap and spring tides and during stronger winter storm flow; (b) documented cored sequences of the composition and physical properties of the sediment sequences; (c) determined processes that cause weakening of the channel margins (biological, waves); and (d) monitored rates and timing of channel erosion (both present and historical).

- What are the community and substrate dynamics on mangrove coastlines with differing exposures and substrate types? The answer will determine causes for different rates of coastline loss, substrate and community weakening, and causes for channel development. Areas to be studied include the coast just south of Middle Cape Canal, the coast adjacent to Little Sable Creek Mouth, the coast adjacent to Big Sable Creek, the protected coast adjacent to Little Shark River mouth, and protected coastline along Mud Bay and Joe River.

- How have mangrove/freshwater ecotones shifted in response to the 22 cm relative rise in sea level that has occurred since 1930? How have shore erosion and hurricane-induced loss of interior mangroves forests affected this shift? Has loss of interior freshwater wetlands (northeast of the marl ridge) been controlled by sea level rise or by a response to canal construction?

One research topic was to derive a solid scientific understanding of the rapid landscape responses from the constructed canals and abruptly opened natural channels.

- What are the sources for and rates of sediment infilling forming the flood and ebb tidal deltas and lake fillings in associated with Middle Cape Canal, East Cape Canal, Hidden Creek, and the now widening natural channels extending north from Middle Cape Canal? The answer will help to recognize other rapidly responding natural systems past and present, provide an understanding of what portion of eroded material is retained within the systems and what is redistributed seaward.

# GEOLOGIC HISTORY

## Origin of Cape Sable

by Harold R. Wanless and Kelly L. Jackson

### Evolution of Paleo-Everglades Drainage

The lower freshwater Everglades is defined by two subtle limestone topographic highs, a Pliocene ridge to the northwest and a Pleistocene ridge to the southeast. These confine an elongated NE-SW trending depression through which the Everglades flow (Figure 1). These two limestone highs create a gently sloping vertical gradient that confines the lower Everglades flow into a directional slough that leads directly towards Whitewater Bay and Cape Sable.

Evaluation of aerial photographs reveals evidence that the Everglades drainage in fact did used to flow out through what is now Cape Sable. The paleo drainage channels are reconstructed in Figure 4. The present drainage flows out through Shark River Slough to the north (main channel at the top of Figure 4). The basis for this paleodrainage reconstruction is as follows.

- The *green* zone includes the present-day channels of Watson River, North River, and Roberts River. These are aligned with the constructed lower Everglades drainage trend but are not prominent flow paths today.
- The *violet* zone extends across Whitewater Bay. These reconstructed flow paths connect a series of pronounced channel segments which serve no purpose today, but are interpreted to have been former continuation of the above described headwater rivers. Throughout Whitewater Bay, the pure organic peat sequence (1-3 meters in thickness over limestone) is degrading and eroding resulting in enlargement of Whitewater Bay. These segments are surviving remnants of once continuous channels.
- The *white* zone is a continuation across southwestern Whitewater Bay in an area with more abundant relict channels segments.
- The blue zone extends across Cape Sable. In the north the paleodrainage is interpreted to have flowed through Little Shark River. The next channel south is thought to have flowed through Mud Bay to Big Sable Creek. The channels to the south disappear into the central and southern Cape Sable. The evidence that these channels did once flow through Cape Sable is provided in the southern interior of Cape Sable near where the arrows terminate.
- The Yellow bands trending southeasterly and easterly are marl ridges that were first described by Roberts et al, 1977. These are coastal buildups that formed beginning about 2,400 years ago. The older (inner) of these are not continuous but disrupted by relict channel features, linear marl ridges paralleling the channel path and cusp features recording initial disruption of the coastal marl ridges by cross cutting channels (Figure 5).

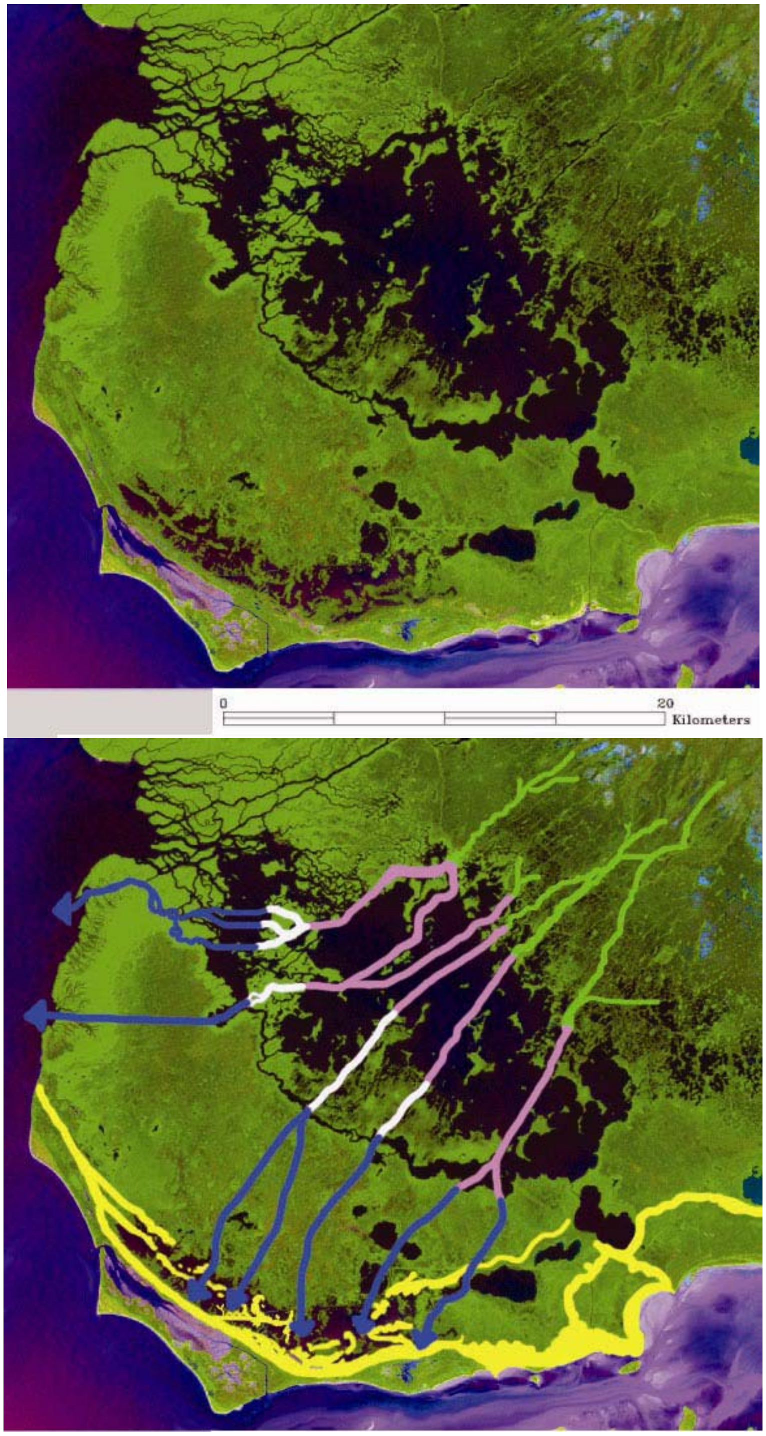



*FIGURE 4. Top – Satellite image map of Cape Sable, Whitewater Bay and the lower Everglades. Bottom – Map with interpreted Paleo-Everglades drainage shown from lower Everglades, across Whitewater Bay and through Cape Sable. Yellow are a sequence of Emergent Marl Ridges that formed following 2,400 years before present, eventually blocking the paleo-Everglades outflow paths (Base map provided by USGS).*

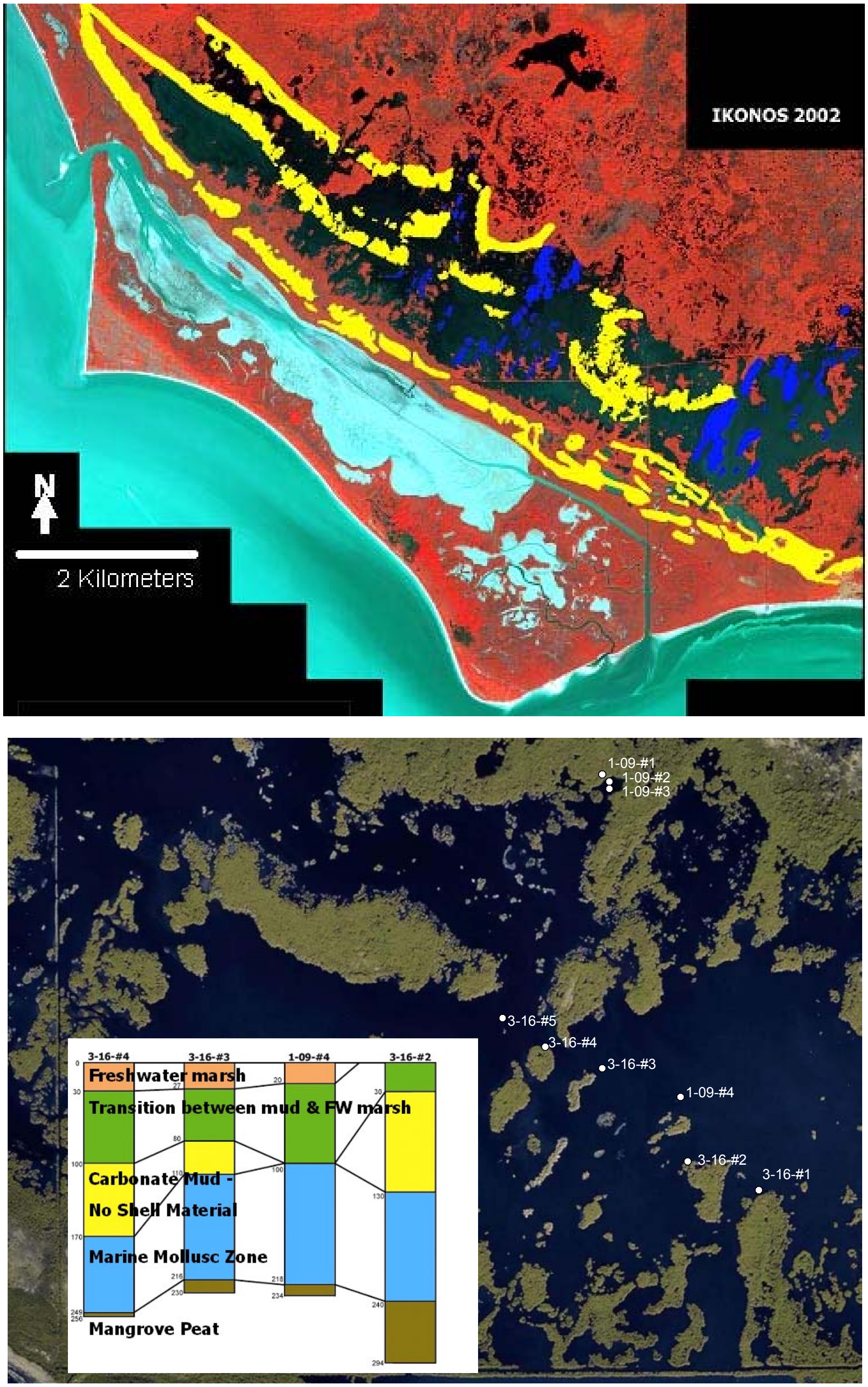



FIGURE 5. Top: Image of Cape Sable showing history of marl ridge growth (yellow) and of linear ridges (blue) associated with paleo-channel mouths. Base image © SpaceImaging.com. Bottom: Image of the locations of cores across the interpreted mouth of one of the paleochannels. Inset: Coring transect showing channel-mouth fill of increasingly restricted shelly carbonate mud to mud.

As explained below, this paleo Everglades paleodrainage is interpreted to represent conditions prior to 2,400 years ago.

**Formation of Coastal Marl Ridge and Blocking Paleodrainage**

The backbone of modern Cape Sable is a series of emergent mud ridges composed of firm, tan, detrital (transported) calcium carbonate mud (marl). These ridges sit on top of a sequence of grey marl that extends to the limestone bedrock 3-4 meters (10-13 feet) below sea level. The pattern of these ridges is shown in Figures 4 and 5.

Roberts et al (1977) cored the sediment sequences (Figure 6) and dated the ages of the marl ridges in a transect across Cape Sable. They found the oldest ridge dates at 2,280 years ago and the pronounced continuous Marl Ridge dated at 2,000 years ago ($^{14}C$ years). In other words, these coastal mud ridges advanced the coast seaward 1.5 to 2 km over a period of 400 years, flooding the system with carbonate mud in the process. The continuous 'Marl Ridge' is hereafter capitalized and refers to this specific feature.

Gelsanliter (1996) documented a fine scale sea-level history for south Florida with sea level rise stopping and slightly lowering at 3,200-2,500 years before present. This was followed by a small (one meter or less), rapid rise between about 2,500 and 2,400 years before present. At the end of this rise, sea level was about 1.2 meters below present level. Gelsanliter was working in the northern continuation of these marl ridges (between Lostman's River and Chatham River, Figure 6). She concluded that this small rapid rise destabilized the coastal system resulting in large volumes of sediment recycling landward over the following 400 or so years.

Thus, it appears that a coastal flooding phase between 2,500 and 2,400 years ago triggered this phase of rapid sedimentation which built a series of coastal marl ridges. The oldest ridges were disrupted in the Cape Sable area by Everglades outflow (Figures 4 and 5). This landward recycling of muddy sediment gradually overwhelmed these channel outlets and they infilled, producing linear levee ridges in the process. By 2,000 years ago, this infill and blockage was complete and the final barrier was formed (the continuous yellow ridge in Figure 5).

A cored transect was taken across the interpreted mouth of one of the paleochannels (Figure 5). The bases of the cores all contain a mangrove peat. Following the peat, the cores exhibit a marine shell layer that is intermixed with a fine mud. This marine shell layer is coarser at the base and represents when the channels were still exposed to open marine conditions before being completely infilled and blocked. The next layer is a carbonate mud zone that contains little or no shell material. This layer is significant because it represents the infilling and progressive isolation of the channels with a mud infill from the buildup of the coastal carbonate mud ridges. The layer above indicates a transitional zone from complete mud to freshwater marsh. In this layer, we begin to see *Hydrobia spp.*, which are tiny gastropods, indicative of highly stressed environments. Today, they are a common species in the inner transitional zone between marine and freshwater environments. The top layer is a (now collapsed as explained later) freshwater peat that is abundant with *Hydrobia spp.* Planospiral and pieces of pulmonate gastropods were found in the top and transitional zones indicating that the upper portion is in fact a freshwater marsh. The cored transect is a record of the active tidal paleochannels at the mouth of the former Everglades drainage. Only a shell hash lag at the base of the sequence is preserved. The mud dominated infill indicates a progressive isolation from the exchange with normal marine waters, reflecting the blocking of the channels by the coastal carbonate mud ridges. Classic channel deposits are not seen because this system is a mud-dominated system.

It is important to point out that these prograding ridges are recycled marine material and have nothing to do with outflow products of the Everglades paleodrainage. The former channels are draining through an environment of organic peat and limestone and provide essentially no mineral sediment to the coast.

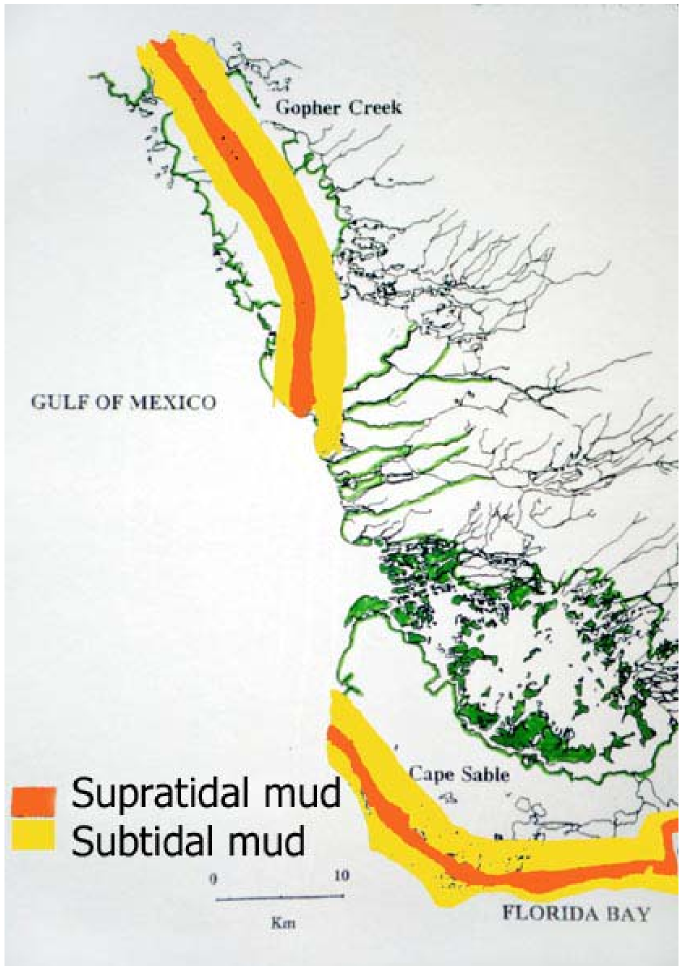
The emergent carbonate marl ridges between Lake Ingraham and inner Cape Sable and along the southern Cape Sable coast were built up as part of this vast carbonate tidal flat. The emergent marl ridge intersects the shoreline trending northwestward north of North Cape and is missing between Big Sable Creek and near Lostman's River (Figure 6). Whether this formed and was subsequently eroded or never formed along this sector is not known as the area is eroded to the limestone bedrock off of the present shore. In a subsequent section we do show that the northwest portion of Cape Sable is rapidly eroding (300 meters in 70 years), and thus the marl ridge trend was previously more extensive.

As the continuous Marl Ridge formed, the Cape Sable area was blocked as an Everglades drainage path. Discharge shifted north and now flows out through the Shark and Harney River systems

## Formation of Lake Ingraham and Present Cape Sable Shoreline

At 2,000 years before present, the shoreline of southwestern Cape Sable was the emergent marl ridge that presently occurs along the northeast (inner) side of Lake Ingraham. At some point following 1,600 years ago, a new shoreline was built to the east impounding Lake Ingraham and the smaller bays to the north and south. It is thought that this probably occurred about 1,200 years before present. Michaels (2001) conducted research on the sediment stratigraphy beneath and seaward of Lake Ingraham in an effort to refine the timing of this regressive shoreline step but was unable to pinpoint the event. Several sea level curves suggest a small sea level oscillation about 1,200 years before present, and this is likely the trigger.

A part of that seaward shoreline formation was the presence of at least one tidal channel/delta complex penetrating eastward into southern Lake Ingraham (Figure 7). This paleochannel is filled and blocked by the present sandy shoreline north of East Cape. A southeastern arm of this channel complex became exposed at the south shoreline of East Cape by 1950 and the result of stepwise hurricane storm erosion of the southern marl coastline (hurricane of 1935 and 1960). As there is insufficient sand



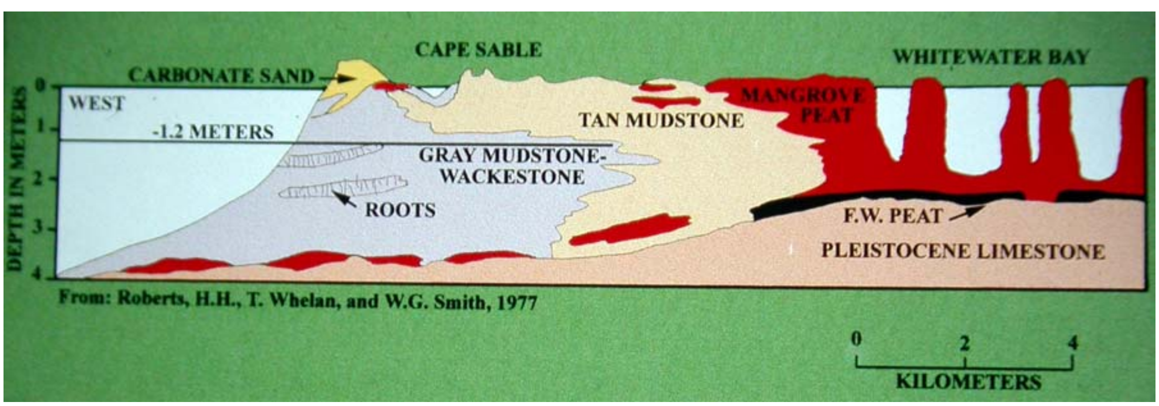




*FIGURE 6. Top: Map showing distribution of coastal carbonate tidal flat which built along the southwestern coast of Florida between 2,400 and 2,000 years before present, following a small rapid rise in sea level (information from Gelsanliter (1996) and Roberts et al (1977). Bottom: Cross section through Cape Sable from Middle Cape northeast to Whitewater Bay. The seaward (west) portion of Cape Sable is underlain by carbonate muds and shelly muds (wackestone). The landward portion is dominantly peat. Limestone bedrock is from 2 t o3.5 meters depth. Adapted from Roberts et al, 1977.*

to choke channels on the south facing shore, this channel became active feeding tidal waters into and out of the southern ponds and Lake Ingraham. This channel is known as Hidden Creek. As described in Everglades National Park documents (Davis, 1972) Hidden creek has been widening at about two feet per year since 1950 and has flow and transport conditions similar to that of East Cape Canal (see Fluid and Sediment Dynamics section). Importantly, Hidden Creek is the result of natural shore erosion re-exposing a natural creek to the shoreline. A second natural relict creek has been exposed along this southern facing shore (Sandy Creek in Figure 7) and is growing.

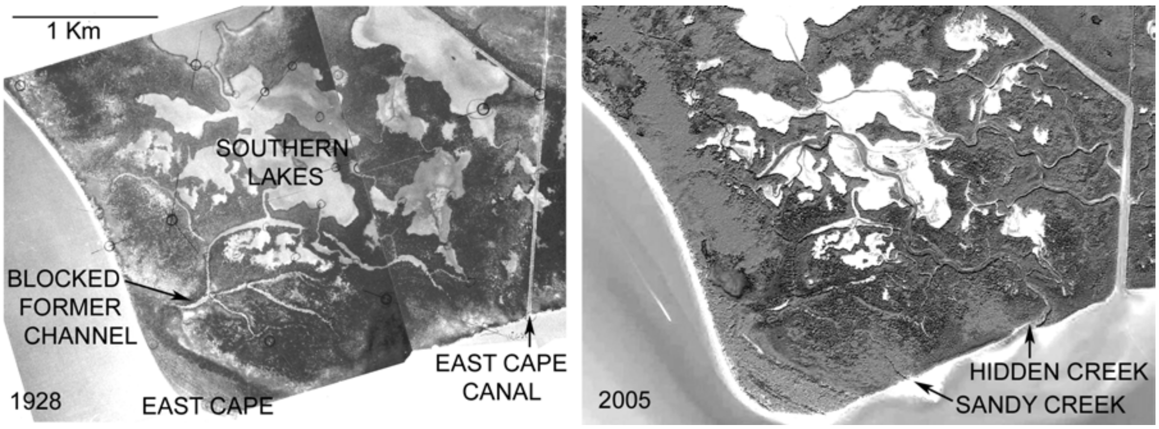



*FIGURE 7. Left - Aerial photograph from 1928 showing blocked former tidal channel and delta extending into southern Cape Sable, East Cape Canal just after dredging, and the southern Lakes. Right – Ikonos (© SpaceImaging) 2005 image showing Hidden creek and Sandy Creek, both evolved from arms of the blocked former channel; 80 years of tidal flow widening of East Cape Canal; and filling of the eastern Southern Lakes adjacent to East Cape Canal. Horizontal width of each photo is about 4 km.*

**Interior of Cape Sable**

The interior of Cape Sable, isolated from the sea by a continuous emergent marl ridge by 2,000 years before present, was a mix of low supratidal to shallow subtidal carbonate mud flats across the western and southern portion. The former paleo-Everglades drainage channels had filled with mud as the marl ridges blocked effective flow. Isolated from daily saline tidal flow, brackish to freshwater marshes formed in the lower areas. As sea level gradually rose, these marshes spread across the low, formerly emergent, portions resulting in a vast marsh broken by only a few lakes or tree-covered hammocks. The western and southern portions of interior Cape Sable record this history as a thick sequence of carbonate muds and shelly muds capped by a thin (less than one meter thick) layer of fresh- to brackish-water peat.

At 2,000 years before present, the eastern and northeastern portion of Cape Sable – as well as present Whitewater Bay – was a complex of recently abandoned Everglades' drainage channels bordered by mangrove and freshwater marsh. Many of these organic peat-producing communities had persisted along the margins of the paleo-Everglades drainage from 4,500 years before present when rising sea level first began to permit buildup of significant organic peat over the limestone. Areas between channels likely remained as fresh- to brackish-water marshes much like the areas adjacent to lower Shark and Harney drainage systems today. When first abandoned, the paleo-Everglades drainage channels were continuous and well defined. This inner portion of Cape Sable and Whitewater Bay thus contained a 2-4 meter-thick sequence of organic peat, extending from the surface to the limestone bedrock.

**Pre-Historical Degradation and/or Infilling of Wetlands Associated With Paleodrainage.**

This abandoned paleo-Everglades drainage channel and wetland complex began to degrade with time. As hurricanes, freezes, and fires set back the community or brought it below water level, oxidation and decay of organic matter rapidly lowered the substrate level, eliminating the possibility of wetland recovery. This natural collapse of former organic wetland is most dramatic in Whitewater Bay, where only scattered remnants of channel margins are preserved. Much of Whitewater Bay has now eroded down to the limestone bedrock surface. This process continues.

The mangrove/marsh complex on the mainland (northeast) side of Whitewater Bay is also in a sage of decay and erosion. Here, the complex pattern of small channels and narrow lines of mangrove surrounding innumerable small open water areas (Figure 8) hold a record of wetland loss. Coring or sampling the bottom in any of the small open-water areas reveals a bottom of dead and decaying mangrove peat. It is not understood what process causes this but the system is clearly in a negative state of evolution (i.e. decay, erosion and deepening). This is the characteristic style of present environment along the landward of margin of Whitewater Bay in the vicinity of Watson River, North River, and Robert's River, the interpreted main channels of paleo-Everglades Discharge. In moving from present-day Whitewater Bay to the present drainage through the Shark River and Harney River systems, this decaying wetland fabric disappears, and the wetland become solid and continuous cut only by active channels (Figure 2).

Approaching the Cape Sable side of Whitewater Bay, there is an increase in wetland (presently mangrove) and numerous shallow bottom subtidal areas in which the substrate is decaying and eroding peat. Although the wetland in this area is deteriorating, the loss is less complete in comparison to central Whitewater Bay. The reason for this is uncertain.

A shore-parallel channel, Joe River (Figure 2), separates the landward side of Cape Sable from Whitewater Bay. The origin of this channel is uncertain, but likely had its origin following the closure of the paleo-Everglades drainage and before the collapse of the peat sequences within Whitewater Bay.

The wetland along the Whitewater Bay/Joe River margin of northeast Cape Sable is sharp and well developed, although historically its composition has changed dramatically, as described in the section on historical changes. A core taken at the bayward margin of Mud Bay (Figure 2) by the senior author prior to this project was essentially entirely

*FIGURE 8. Degrading mangrove system along the landward side of Whitewater Bay is characterized by narrow channels and lines of mangroves bordering open-water areas. These open-water areas, to 1.5 meters in depth, are floored by decaying mangrove peat.*

living red mangrove roots to over 1.5 meters in depth. This suggests that healthy mangrove forests may maintain or slowly advance even shorelines that drop abruptly.

**Resulting Distribution of Holocene Sediment Sequences**

There are thus three basic sequences in the Cape Sable area. A sequence dominated by calcium carbonate mud (marl) characterizes the southern portion of Cape Sable and the western portion up to the vicinity of Big Sable Creek. This marl extends about half the distance across Cape Sable. This may be capped by as much as one meter of organic peat in the interior. Sequences entirely of organic peat dominate the landward and northern portions of Cape Sable and Whitewater Bay. Calcareous shelly sand dominates the western coast and capes. At the Capes, this forms a thick sand sequence, but along the beach arcs between, this sand forms only a beach and berm veneer over marl. These are illustrates elsewhere in the report (Figures 5, 6, 12, 13,

# HISTORICAL EVOLUTION OF CAPE SABLE

## Historical Stressors To Cape Sable

This study has used a sequence of historical aerial photographs complimented by recent satellite images including ultrahigh-resolution Ikonos images (1 $m^2$ pixel resolution) from 2002 and 2005 to trace changes in coastline positions, wetland community patterns, wetland/open-water relationships, and subtidal features (such as the deltas within Lake Ingraham). As described below, Cape Sable has experienced truly dramatic changes in many of these features over the past 80 years. We have focused on timing and trends of changes. Aerial photographs used are from 1927-1929, January 1935, 1940, 1953, 1964, 1973, and 1990. Satellite images are from 1995, 1999, 2002 and 2005.

In studying aerial photographs, we have sought to relate observed changes to probable causes. Causes include:

1. Human modifications to Cape Sable, mainly dredging narrow canals in the 1920s;
2. Hurricane events, especially the passage of Category 4 and 5 hurricanes;
3. Historical rise in relative sea level; and
4. Consequential enlargement of tidal prism and saline intrusion

**Human Modifications to Cape Sable**

Direct human modifications to Cape Sable mostly occurred prior to 1935 and were minor – at least at first glance. A road (track) extended from Flamingo along the Marl Ridge to at least northern Lake Ingraham and is still visible (Figure 9). In addition, there are

*FIGURE 9. Aerial view south shows visible vestiges of old road tracks on the marl ridge east of Middle Cape Canal. In the view a rising tide from Lake Ingraham (right) is spreading flood waters across the Marl Ridge. Photo taken July 31, 2004.*

scattered remains of buildings, largely swept away by the Labor Day Hurricane of 1935 (Wilkinson, 1935). The road out was actively used despite risky bridges crossing the canals that had been cut through the Marl Ridge. “The bridges, however, at Slagle's Ditch and at Durdin's Ditch (now sometimes called House's Ditch) were quite primitive. At Slagle's Ditch the bridge consisted of four sabal palm trunks, two on each side forming a concave runway for the car's wheels. At Durdin's Ditch the bridge was a trifle more elaborate, being made of two 12x 12 inch (or smaller) timbers, at car wheel distance apart with open water showing between” (Stimson, 1953).

The most significant human effect on Cape Sable was the construction of a number of narrow (3-4 meter wide) drainage canals across southern Cape Sable. Though small, they profoundly influenced the environmental dynamics of southern Cape Sable, Lake Ingraham and the Southern Lakes.

**Canal Construction.** Through the early to mid 1920s a series of dredging projects created a complex of canals across southern Cape Sable and between Cape Sable and the marine waters of the Gulf of Mexico and Florida Bay (Figures 10 and 11). The purpose of these canals appears to have been to drain the interior freshwater marsh so as to permit expanded agriculture and livestock grazing. The important interior canals include:

- Homestead Canal (an east-west canal extending the width of Cape Sable and connecting to Lake Ingraham);
- J Canal, a dead end north trending canal from the junction of Homestead Canal with Lake Ingraham;
- East Cape Canal (extending south from Homestead Canal to the coast);
- A diagonal canal connecting East Cape Canal with southern Lake Ingraham (hereafter called ‘Ingraham Canal’);
- Raulerson Brother’s Canal, a canal cutting the portions of the interior freshwater marsh and Marl Ridge, connecting the inner marsh with northern Lake Ingraham;
- Middle Cape Canal cutting from the north end of Lake Ingraham to the Gulf of Mexico coast; and
- Two canals cutting the southern Marl Ridge east of East Cape Canal, connecting the interior freshwater marsh with Florida Bay House’s Ditch to the west and Slagle’s Ditch to the East (two right arrows in Figure 10).

Firm carbonate mud, marl, forms the entire sediment sequence beneath all the sites where canals were dredged to the south and west of the junction of Homestead Canal and East Cape Canal (Figures 12 and 13). This marl defined the future behavior of these canals and of the sediment dynamic story as tidal flow increased in them.

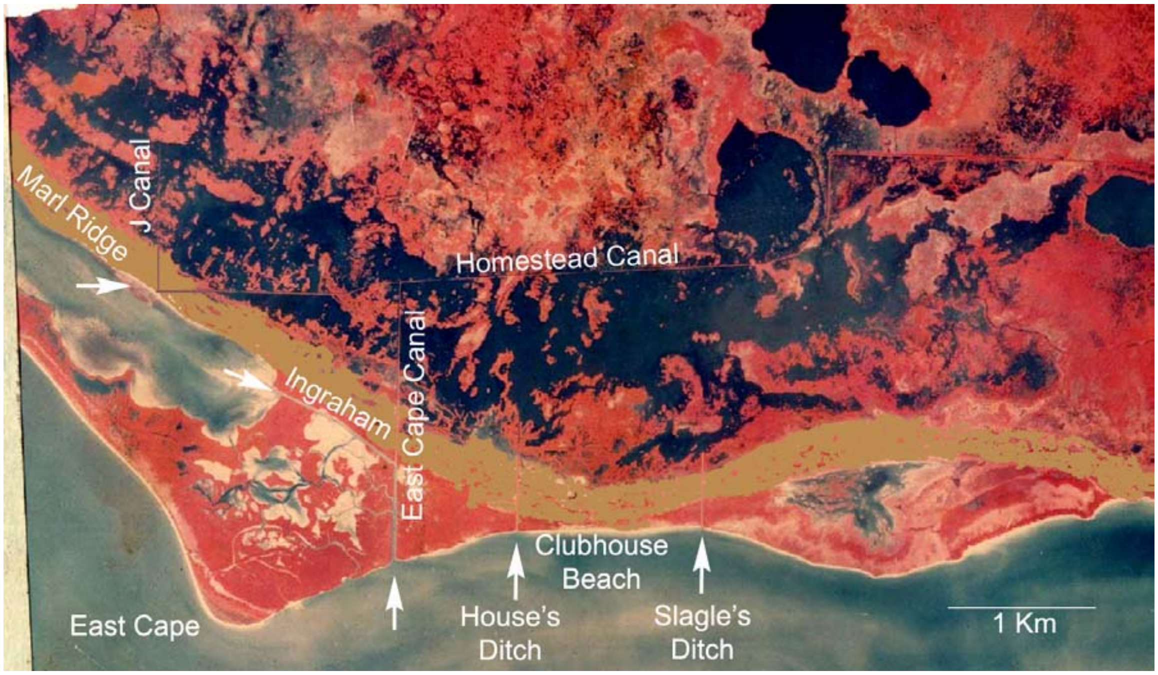



*FIGURE 10. Location of canals constructed across southern Cape Sable in the mid 1920s superimposed on 1973 satellite image. When canals were constructed, the interior of Cape Sable was a continuous marsh with isolated round lakes. Marl Ridge separating the interior of Cape Sable from the coastal and coastal lakes is highlighted in tan. Arrows point to canal connections with Lake Ingraham and marine waters of Florida Bay.*

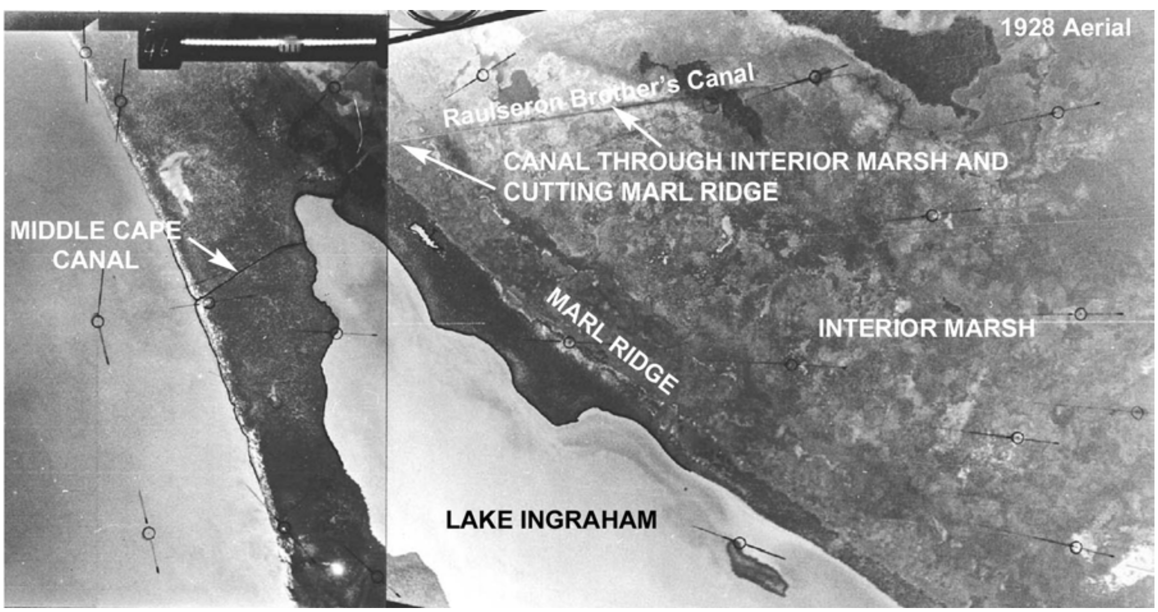



*FIGURE 11. Location of Canals constructed connecting Gulf of Mexico (left) to Lake Ingraham and the interior marsh of Cape Sable. Canals were constructed only 15-18 feet wide. Middle Cape Canal was blocked with beach sand fill until the Labor Day Hurricane of 1935. The inner canal across Marl Ridge is known as Rauerlson Brother's Canal.*

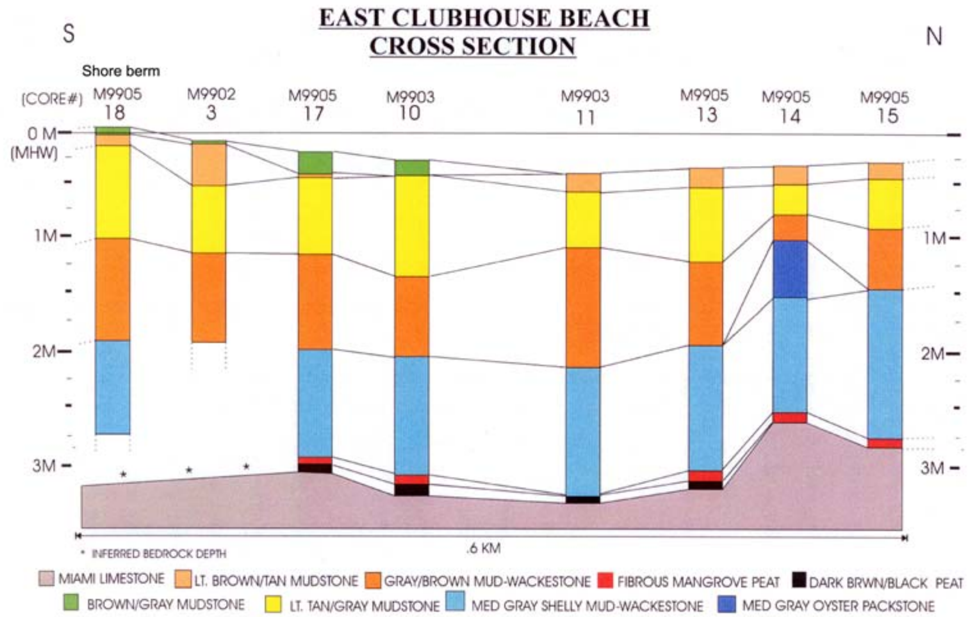



*FIGURE 12. Stratigraphic cross section from the south shore of Cape Sable inland (northward) for 0.6 km. This is similar to the sediment sequence cut by East Cape Canal. The entire sequence is fine-grained carbonate mud with a small amount of peat (red and black) at the base, except for a small oyster bar (dark blue) embedded in the sequence. From Michaels (2001).*

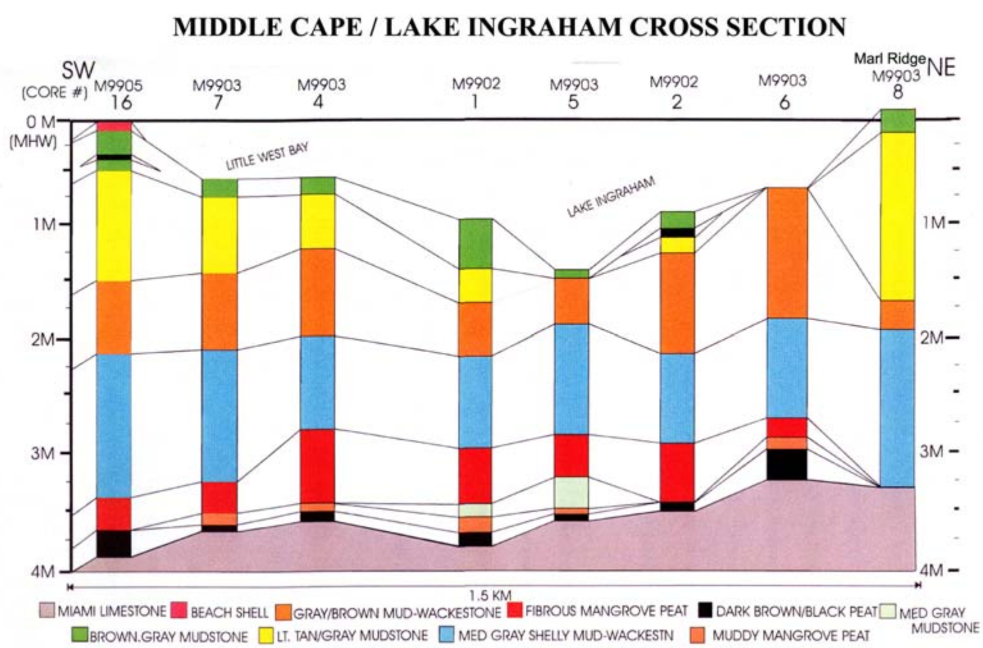



*FIGURE 13. Stratigraphic cross section across Lake Ingraham from the shore north of Middle Cape to the Marl Ridge. This is similar to the sequence cut by Middle Cape Canal. The sequence is entirely fine-grained carbonate mud and peat (red and black) except for a few centimeters of sand (scarlet at top of left core) at the ocean shore. From Michaels (2001).*

**Hurricane Impacts to Cape Sable**

Two or three historical hurricanes profoundly modified the nature of Cape Sable. Most severe of these was the Labor Day Hurricane of 1935, a Category 5 storm on the Safford-Simpson Scale. It moved northwest from the Florida keys and spread its strongest winds and tidal surge directly across all of Cape Sable (Figure 14). This caused several major changes in the landscape and coastscape of Cape Sable. Hurricane Donna in September 1960 was a strong Category 4 hurricane moving on a similar path and spread very strong winds and tidal surge across much of Cape Sable as well (Figure 15).

Semple (1936) describes the 1935 Labor Day storm's character on the interior of Cape Sable: "On the second day of September, 1935, the most devastating hurricane ever recorded in this section swept over the entire range of the Cape Sable Sparrow. The low ocean prairie [of Cape Sable] was completely covered with six feet of water, its surface lashed into great waves and spray …."

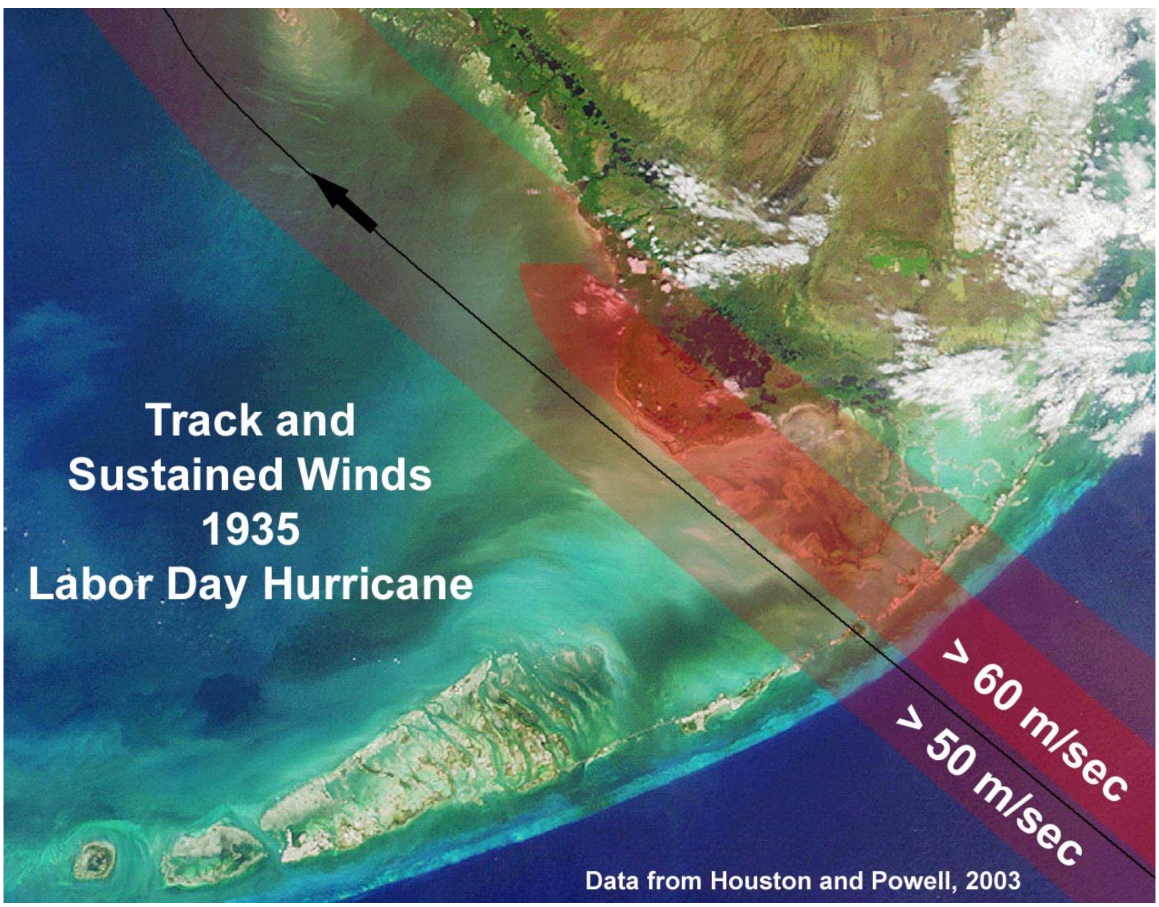



*FIGURE 14. Labor Day Hurricane of 1935 track and sustained winds superimposed on 2000 Satellite image of south Florida. Essentially all of Cape Sable was subjected to the strongest winds of this category 5 storm.*

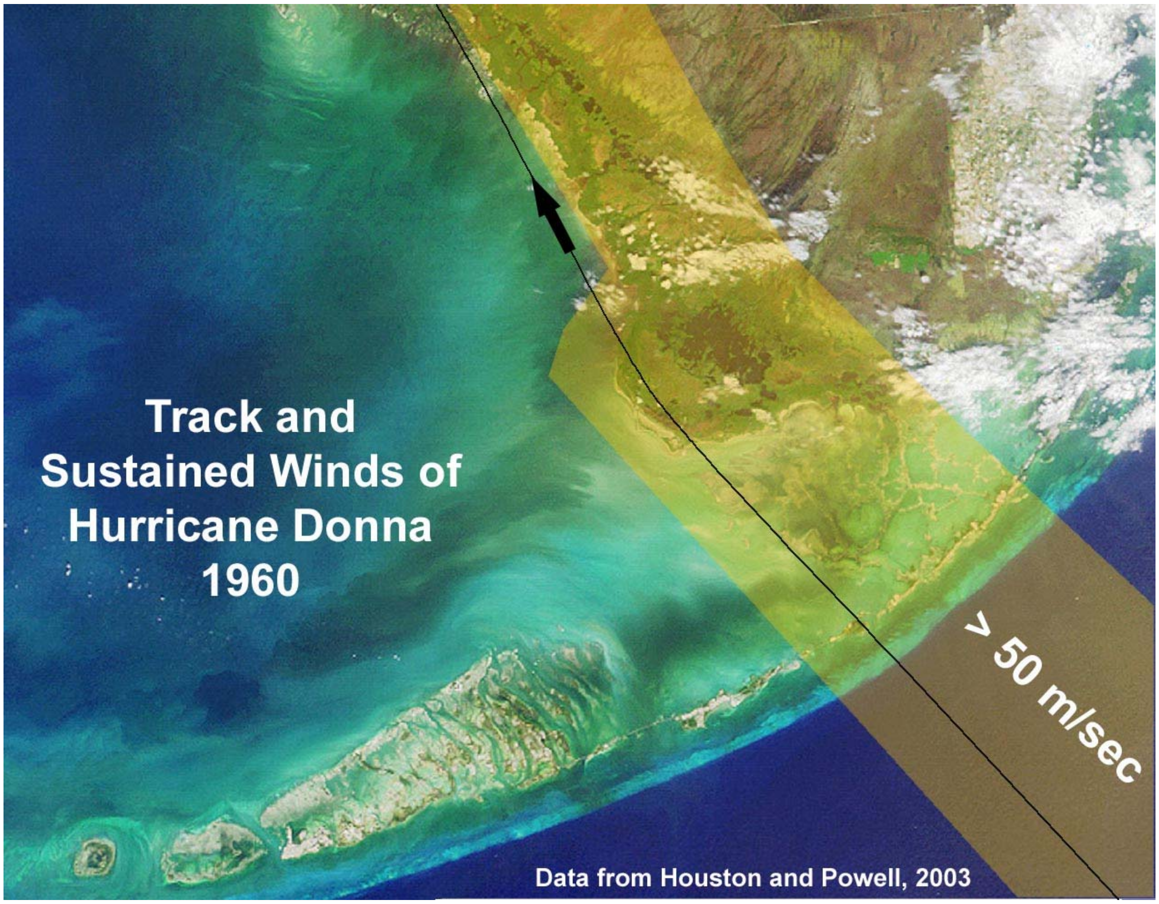



*FIGURE 15. Track and sustained winds of Hurricane Donna on September 10, 1960, is superimposed on a 2000 satellite image of south Florida. Again, all of Cape Sable was subjected to intense winds of the eye wall, and the ocean side received a direct onshore surge from the back side of the storm.*

These category four and five hurricanes have the ability to both instantly modify the landscape and to initiate changes that set into motion longer term evolution of the environment. Three and possible four dramatic changes result from these larger storms. First, they decimated the mangrove forest on Cape Sable from East Cape to the northern tip. The style of mangrove forest destruction was geomorphically different between the southern sandy beach/cape zone and the northern exposed mangrove coast. Second, the 1935 storm removed sufficient beach sand from the vicinity of Middle Cape Canal that the canal became and remained open to tidal exchange between the Gulf of Mexico and Lake Ingraham. Third, hurricanes have caused steps in erosion in the west- and south-facing coastlines of Cape Sable. Fourth, the effect of the 1935 hurricane on the interior marsh of Cape Sable is uncertain as we have, to date, found no aerial photographs following the storm. The nearest post-1935 photographs found to date are from 1953 by which time the interior marsh has altered far beyond the condition January 1935 (see Interior Marsh section below).

A speculative but important note to hurricane history in the Cape Sable area is the apparent lack of major hurricanes for a considerable period prior to the 1935 Labor Day

Hurricane. The mangrove swamp destroyed at Big Sable Creek was in part a very mature black mangrove forest with trees of great size and girth. This forest completely filled the coastal zone leaving the channels as barely visible lines. The size of the trees and the continuity of mature forest cover strongly suggest that this forest was at least on the order of 200 years in age. Following Hurricane Andrew, Risi et al. (1995) describe evidence for a 180 year old hurricane deposit exposed by shore erosion at Highland Beach some 30 km north of Cape Sable. This evidence was a 5-10 cm thick storm layer of carbonate mud capped by downed black mangrove trunks and branches which had burned. Carbon-14 dating was done on the outer growth rings of black mangrove charcoal, giving an age of 180 +/- 50 years before present (Tedesco et al., 1995).

**Relative Sea Level Rise**

Tide gauge records at Key West, Miami, and Naples record a similar, dramatic increase in the rate of relative sea level rise in south Florida beginning in about 1932. Key West has the longest record (Figure 16). This rise, 23 cm (9 inches) in 73 years, is over six times faster than the average rate over the previous 2,400 years and is becoming an increasingly dominating influence on coastal dynamics and evolution.

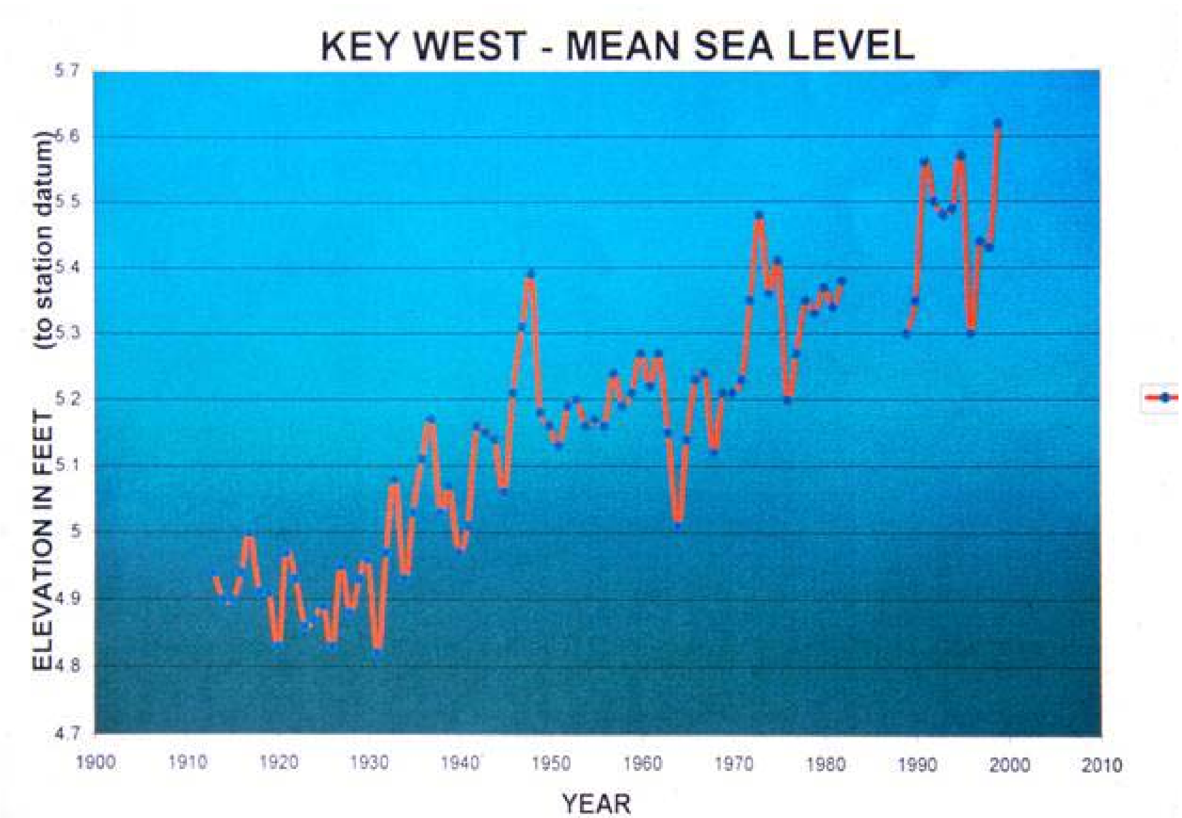



*FIGURE 16. Tide gauge record for Key West since installation in 1913. Numbers on vertical scale are arbitrary. Data from National Ocean Survey, National Oceanic and Atmospheric Administration.*

**Tidal Prism Enlargement and Saline Intrusion**

This dramatic rise in relative sea level has created a greatly enlarged tidal prism. Tidal prism is the volume of additional water that moves in to fill an area between the levels of low and high tide. On Cape Sable, the exposed mangrove coastlines and creek margins can be more deeply penetrated by tides acting over a higher level. This results in stronger tidal flow into and out of channels and exposed mangrove margins.

The Marl Ridge separating the interior of Cape Sable from Lake Ingraham and the associated bays to the north and south was emergent land with homesteads, agriculture and hyped real estate opportunities in the 1910s and 1920s (Bulletin of Cape Sable, 1918). The north-south section of the Marl Ridge (extending from Clubhouse Beach north to north of Northwest Cape; Figure 2 and 3) has been setback from the coast for the past 1,000 years or so. As a result it has not continued to grow upwards in response to storm flooding by sediment-laden waters. As a result this section of the Marl Ridge is essentially completely flooded by at least 80 high tides per year. This water, entering through the channels into Lake Ingraham, through other channels or across mangrove wetland, flows across the marl ridge into the interior of Cape Sable. With rising sea level and increasing frequency of flood waters flowing over the Marl Ridge, the tidal prism and incoming channel flow velocities has increased.

This enlargement of the tidal prism has been a significant factor in the saline intrusion into the interior of Cape Sable and the overall fluid and sediment dynamics of the system. This is examined further in the section on Fluid and Sediment Dynamics.

The coastal Marl Ridge along the south-facing shore of Cape Sable (from Clubhouse Beach east to Flamingo; Figures 2 and 3) is directly exposed to the flooding storm tides from Florida Bay and has continued to build upwards to the present. As a result, it is slightly higher and is only rarely flooded during the year.

The outer beaches of Cape Sable have a thick sequence of sand at the Capes and a thin veneer of sand along the arcuate east- and south-facing beaches between. This sand shore berm can be breached or overtopped during strong winter or tropical storms. Normal spring high tides generally do not overtop the sandy shores.

# Observed Historical Changes of Cape Sable

## Exposed Mangrove Coast and Big Sable Creek

Bischof (1995) documented dramatic changes to the Big Sable Creek complex and the channeled mangrove coastline at the northwestern end of Cape Sable. Historically a world famous site of a dense forest of huge black and red mangrove trees, this coast was devastated by the Labor Day Hurricane of 1935. The storm eroded about 100 meters of mangrove coastline and decimated the mangroves adjacent the channels far into the coastal swamp (Figure 17). As of the 1953 photograph, much of the interior forest had not recovered. A further step of mangrove loss occurred during Hurricane Donna in 1960, extending the mangrove destruction further inward (Figures 18 and 19).

Following Hurricane Andrew in 1992 (which was focused north of Cape Sable), mangrove biologist Dr. Tom Smith noted to the senior author that about half of the biomass of the red mangrove was in the root system. Wanless and his students began monitoring the decay subsidence of the mangrove forests destroyed by Hurricane Andrew, as well as subsidence initiated by the 1935 Hurricane in Big Sable Creek. The Big Sable Creek area was still subsiding through decay (Wanless et al, 1995). To date the mangrove peat substrates killed by the 1935 storm have lost about 1 meter in elevation as compared to living red mangrove substrates (Figure 21). This loss is about 70 cm through decay subsidence, 5 cm through erosion of the peat surface, and 23 cm through rising sea level. Looking at aerial photographs during our 1992-1996 study of the area suggested that little spatial recovery was occurring on the dead peat surface. Red mangrove rhizomes were observed colonizing, but would shortly die. Of greater concern were the areas near channels where the peat substrate was so low in the intertidal that deep excavating burrowers were beginning to mine the peat (Figure 20), a process that leads to rapid deepening of the organic substrate.

We did notice, however, that at some boundaries between the living mangrove forest and the dead peat, red mangrove roots and root hairs were extending laterally as much as 10 meters beyond the arching prop roots out into the dead peat substrate, and that the dead peat surface was positively elevating in association. It appears that, as the laterally extending roots prepared the substrate, mangrove colonization and expansion should be possible. In 1940, Davis suggested that mangroves can build land, a statement that has received much criticism, perhaps somewhat underserved. These insights may help explain the observations in the following paragraphs.

In comparing the photographs and drawings made of Big Sable Creek by Bischof (1995) with the satellite image from 2005, it is clear that the mangrove forests within Big Sable Creek have significantly advanced, reclaiming portions of the dead mangrove peat substrate (Figure 22).

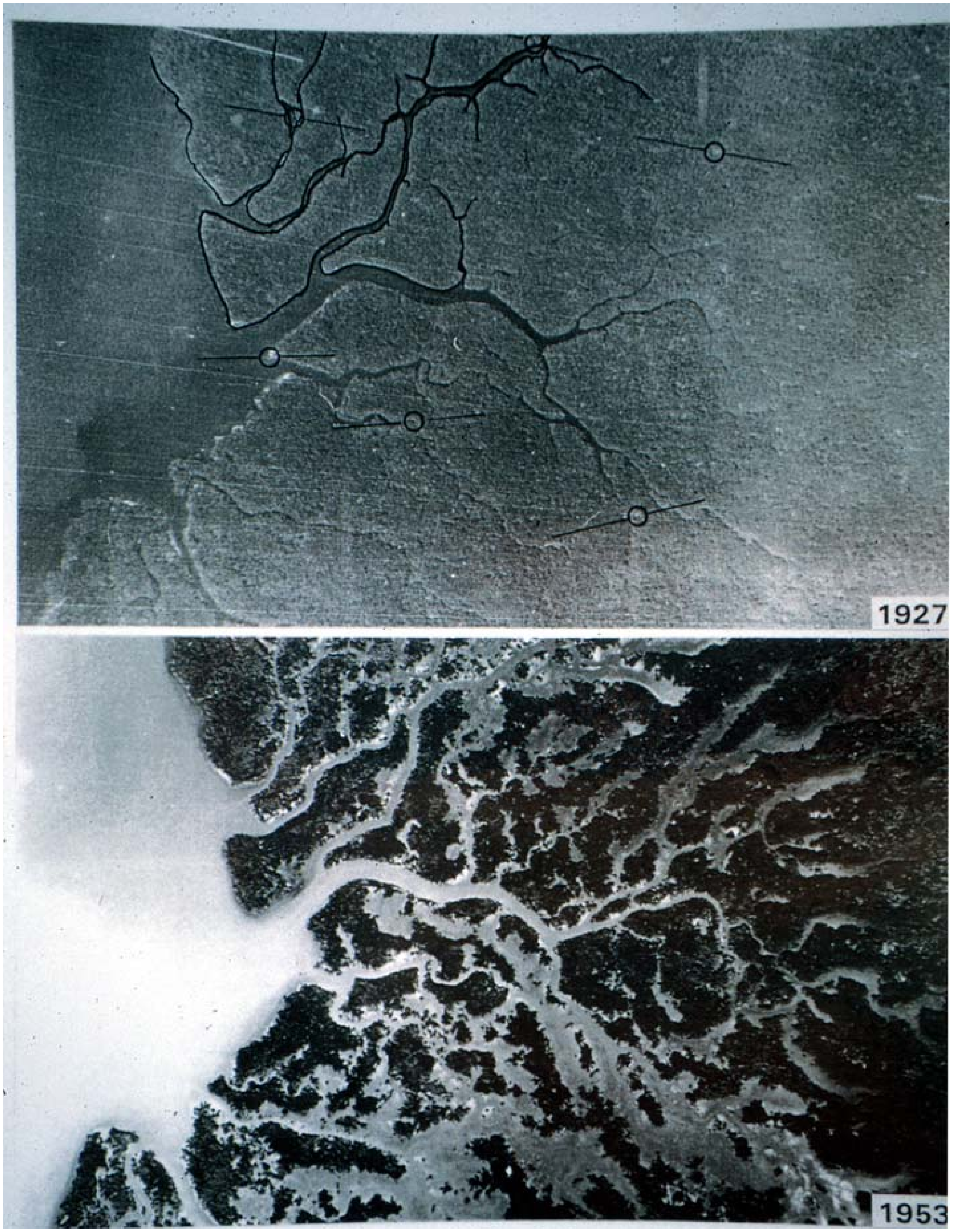



*FIGURE 17. Aerial photographs from 1927 and 1953 showing changes in the mangrove wetlands associated with Big Sable Creek. The entire change is thought to be the result of the wind and storm surge of the Labor Day Hurricane of 1935. Mangroves that survived or recolonized in the 18 years between the storm and the lower photograph appear as dark in the photograph. The Gulf of Mexico is to the left. Photographs are 2.5 km in horizontal dimension.*

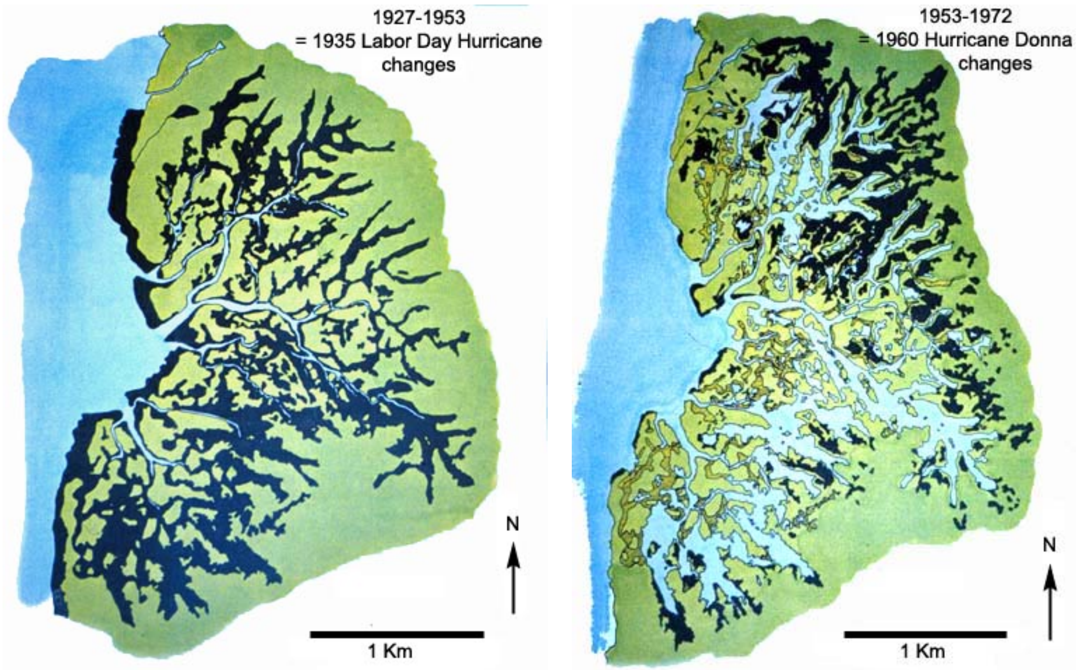



*FIGURE18. Maps of sequential changes in the Big Sable Creek area (from Bischof, 1995). Right: Loss of mangrove wetland (black) between 1927 and 1953 aerial photographs. This was caused by the Labor Day Hurricane of 1935. Areas where mangrove wetland recovered in the 18 years between 1935 and 1953 are shown in green. Left: Loss (Black) and gain (yellow) between 1953 and 1972 aerial photographs. This was caused by Hurricane Donna in September 1960. Mangroves that were damaged and recovered between 1960 and 1972 and mangrove that persisted are shown in green.*

*FIGURE 19. Oblique aerial photograph taken by Frank Craighead Jr. in 1962 of damage to Big Sable Creek area by 1935 and 1960 hurricanes. Note oriented trees downed by 1935 storm. (Montgomery Botanical Center Archives).*

*FIGURE 20. Where peat subsidence has brought the substrate surface to the lower intertidal, excavating mud shrimp burrowers accelerate the substrate subsidence process. Short cores laid on the burrowed surface illustrate the burrow networks*

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*FIGURE 21. The peat substrate level beneath surviving mangroves in Big Sable Creek is about one meter higher than the surface of the mangrove forest destroyed by the 1935 Labor Day Hurricane. About 75 per cent of the elevation loss is the result of substrate compaction and decay subsidence.*

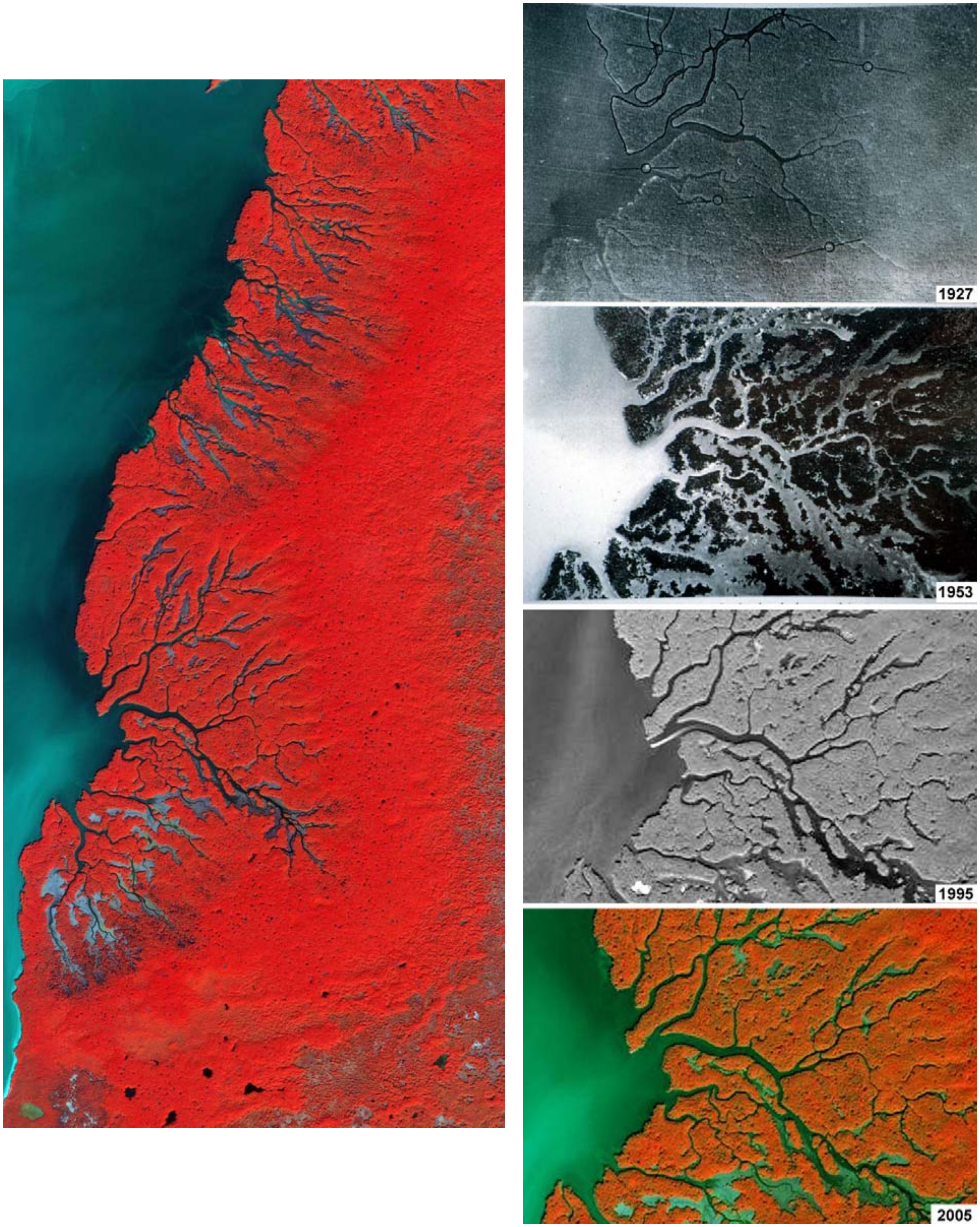


*FIGURE 22. Left – Ikonos satellite image (© SpaceImaging) from 2005 of Big Sable Creek and channel dissected mangrove coast of northwest Cape Sable and the wide mangrove forest inland. Right – Sequential aerial and satellite images of Big Sable Creek showing damage by 1935 storm (in 1953 aerial) and the very slow recovery.*

## Canal Evolution

The canals, cut in the mid 1920s to drain the interior of Cape Sable, resulted in a series of dramatic but unanticipated results. The most significant result was initiating daily tidal exchange with Lake Ingraham, the Southern Lakes and the southern interior of Cape Sable. The effects on these environments are described in separate sections.

East Cape Canal, Ingraham Canal, western Homestead Canal and Middle Cape Canal were cut through a dense, firm carbonate mud, commonly termed marl. Marl forms through the dewatering compaction of carbonate mud, deposited in subtidal, intertidal or supratidal environments. Although not cemented, it is very firm and cohesive. Marl will maintain a vertical wall on the side of a channel without slumping. Strong currents will only erode the surficial few millimeters of the marl that has been softened by water diffusing inward. Only in areas of persistent strong currents will marl channel margins erode. Hurricanes, which can generate strong storm surge flow for a few hours, have little effect.

Historical changes in the widths of Middle Cape Canal, East Cape Canal, and Hidden Creek are given in Table 1 and Figure 23 and are discussed in the following sections.

| Year | **1922** | **1928** | **1935** | **1950** | **1953** | **1964** | **1971** | **1972** | **1999** | **2005** |
|---|---|---|---|---|---|---|---|---|---|---|
| Middle Cape Canal | 16 | 30 | 30 | 80 | 100 | 178 | 186 | 190 | 305 | 338 |
| East Cape Canal | 16 | 65 | | 85 | 110 | 138 | 148 | 156 | 213 | 230 |
| Hidden Creek | | 0 | | 0 | 8 | 30 | 37 | 38 | 100 | 115 |

*TABLE 1. Width in feet of canals and creeks feeding Lake Ingraham. Measurements from 1922 to 1972 are from aerial photograph or field measurements provided in Davis, 1972; Measurement from 2005 is from a high resolution satellite image (pixel size 1 $m^2$).*

**Middle Cape Canal**. Two channel systems have significantly widened since construction. The first canal which has dramatically widened is Middle Cape Canal, connecting northern Lake Ingraham with the Gulf of Mexico. Cut in 1922 (Davis, 1972), this canal was choked with shore sand and remained inactive until the Labor Day Hurricane of 1935 removed the sand plug and significant sand from the adjacent shore system. Following this storm opening, Middle Cape Canal has widened at about 120 cm (4 feet) per year and is now more than 103 m (338 feet) in width (Figure 24). It is cut to the Pleistocene limestone surface about 3.5 meters below sea level. Flood and ebb tides through Middle Cape Canal can reach up to 3.5 m/sec (4 knots) and have upper flow regime characteristics with standing waves in the neck of the channel.

The seaward mouth of Middle Cape Canal is an active sandy beach which extends from Northwest Cape south to Middle Cape. The flood and ebb tidal currents of Middle Cape Canal intercept the longshore transport of the shelly beach sand both sucking it into the growing flood-tidal delta in Lake Ingraham and sweeping it seaward into an offshore ebb-tidal delta. As a result, in the 70 years of Middle Cape Canal's existence, there has been major erosion of Cape Sable's shoreline to the north and south of the Canal as sand became tied up in these tidal deltas. As the tidal prism for Middle Cape Canal has dramatically increased with the historical relative rise in sea level, the strong flood tides should continue or increase.

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**Lower East Cape / Ingraham Canals.** The second is the Lower East Cape Canal and Ingraham Canal, which connected offshore waters with the Southern Lakes and southern Lake Ingraham. This immediately became active and has been widening at a steady 60 cm (2 feet) per year. It is presently 70 m (230 feet) in width and cut to the Pleistocene limestone surface 3-4 meters below sea level. As described in the Fluid and Sediment Dynamics, tidal currents are commonly 0.5-1 m/sec (1-2 knots).

At its mouth, Lower East Cape Canal intersects a mangrove-capped marl coastline with only a thin veneer of shelly sand. The sand mostly forms a small berm a few meters in from the coast, a product of storm waves. The sediment sequence eroded by the widening channel is, thus, nearly entirely silt and clay sized particles of calcium carbonate and organic matter. As there is not a continuous beach along this portion of the south-facing coast, there is little longshore introduction of sand to the channel mouth

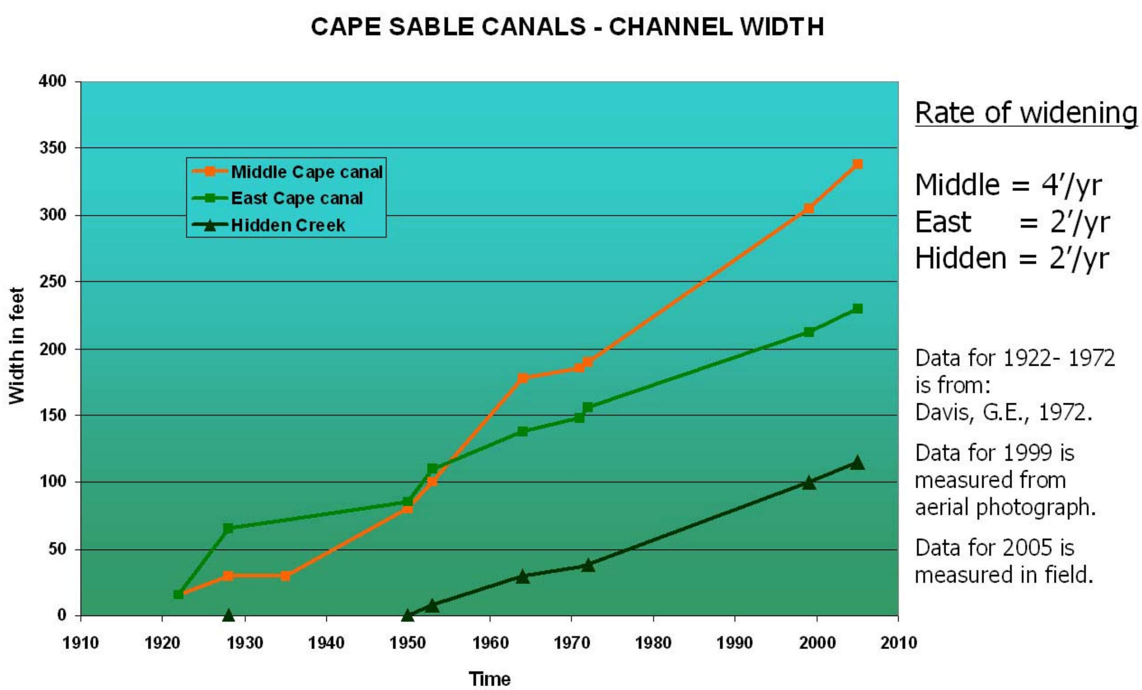



*FIGURE 23. Graph showing observed historical rate of widening of East Cape Canal, Middle Cape Canal and Hidden Creek. All are cut into a 3-4 meter-thick sequence of firm marl to the Pleistocene limestone bedrock.*

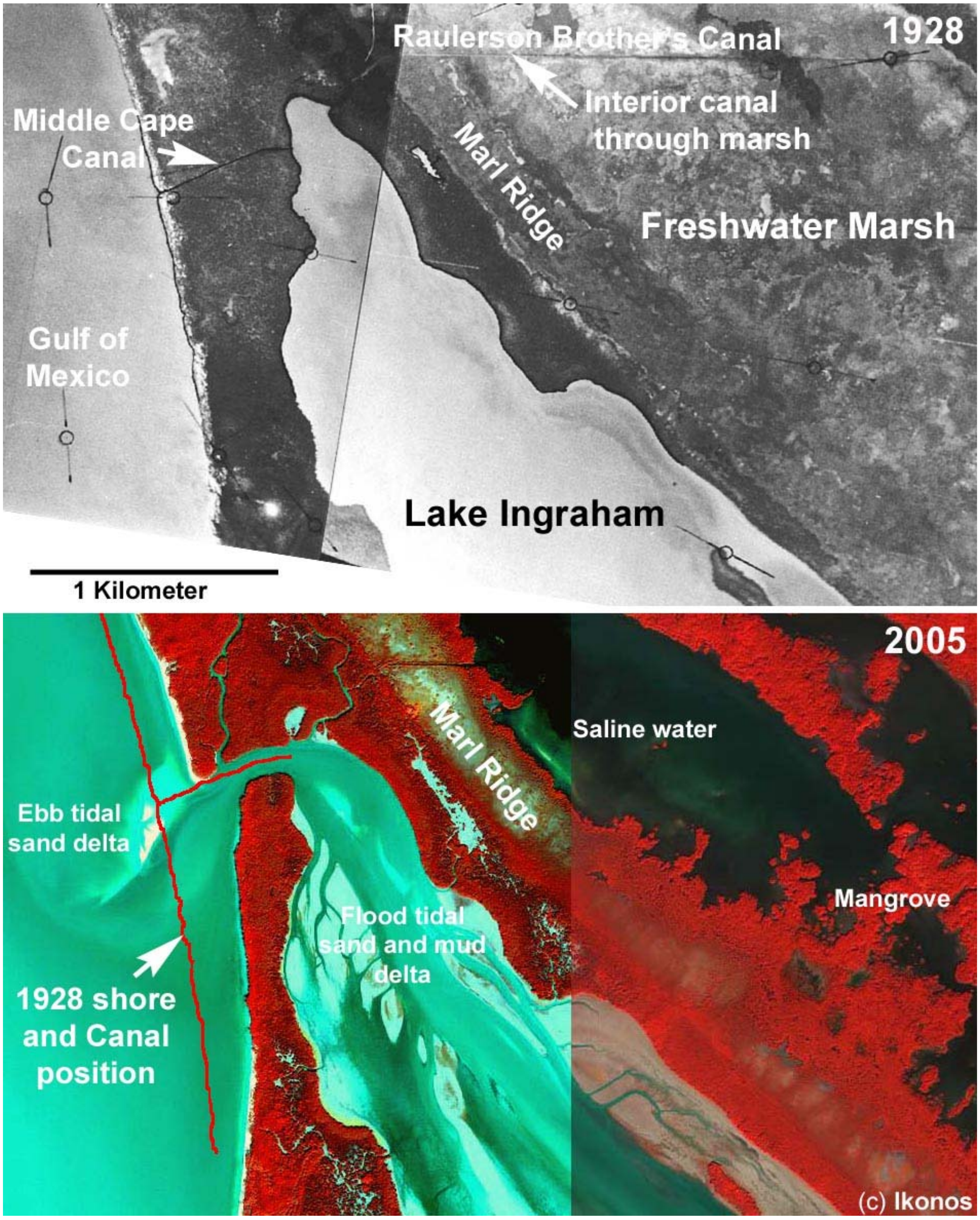



*FIGURE 24. Top: 1928 aerial photograph showing northern Lake Ingraham area with Raulerson Brother's Canal through Marl Ridge, and historical freshwater marsh. Middle Cape Canal did not open until the Labor Day 1935 Hurricane flushed sand from the canal. Bottom: Ikonos © satellite image showing Middle Cape Canal grown to 101 m (338 ft) in width, extensive flood and ebb tidal deltas, and conversion of interior marsh to subtidal saline water and mangrove. Over 150m (500 feet) of shore erosion has occurred to the north of the Canal; about 300 m (1000 feet), to the south. Net southward transport of beach sand is not reaching the shore south of Middle Cape Canal.*

**Canals Cutting Marl Ridge.**

The six canals constructed across the Marl Ridge (Figure 10, 11 and 24) provided the unintended consequence of causing salt water intrusion to the interior and increasing the tidal prism. Efforts to block flood tidal waters from entering the interior have been made by the National Park Service for over 20 years. These efforts have been largely unsuccessful because of three problems. First, two of the canals (East Cape and Homestead) are constructed across lower elevation portions of the Marl Ridge, which easily floods during higher tides. Second, the dams can only be built to the level of the surrounding land so, when there are high tides, flood current scour erodes the edges of the dam resulting in erosive channels. Third, the significant historical rise in sea level has increased the frequency of Marl Ridge flooding and flow stress on channels. Figure 25B illustrates a flooding tide over topping the sheet-piling dam constructed across inner East Cape Canal. A channel chute has formed around the east side of this dam causing strong constricted channel flow when dam is not overtopped. The same situation occurs at the west end of Homestead Canal. Despite the role these canals played in the initial saline intrusion into the southern interior of Cape Sable, they have widened little.

Slagle's Ditch, now blocked at the Marl Ridge, provides increasing flow to a small lake behind the East Clubhouse Beach peninsula to the east. House's ditch is also now essentially blocked at the Marl Ridge. Within Lake Ingraham, J Canal, which played an initial role in saline intrusion and marsh collapse (Figure 47), now appears to be choked and largely abandoned from flow. Raulseron Brother's Canal crosses a slightly higher portion of the Marl Ridge. It does not appear blocked across the Marl Ridge but has widened little. There is flow through this canal across the Marl Ridge today.

*FIGURE 25A. Photograph of ebb tidal water surging through a channel cut around the east side of the sheet-pile dam in inner East Cape Canal. Taken December 12th 2002.*

*FIGURE 25B. Oblique aerial view looking from the dam in upper East Cape Canal south to lower East Cape Canal and the coast. Main flow to the right is Ingraham Canal feeding to Lake Ingraham. East Cape Canal (left) feeds parallel for East Cape Canal across the Marl Ridge to the southern interior of Cape Sable. The constructed sheet piling dam in the foreground is built to land elevation but is being overtopped by the tide on November 7, 2003.*

## Outer Mangrove, Beach and Marl Coastline of Western and Southern Cape Sable

**Outer Mangrove Coastline of Northwestern Cape Sable.** The northwestern portion of Cape Sable has a tall red mangrove forest exposed at the shore. Sequential aerial photograph analysis shows continued erosion of this coast with individual major hurricanes causing as much as 100 meters of coastal setback. Northwest winds following passage of winter cold fronts also persistently attach this coast with strong wave agitation (Figure 26A). With about 40 fronts passing south Florida each year, these events play a significant role in the continued erosion of these coasts (Warzeski, 1976). The coastline is characterized by recently eroded tall red mangrove trees (similar to those shown in Figures 26A and 28). The mangrove peat substrate seaward of the shore is progressively deepening through wave erosion and burrow excavation (Figure 26B). This section of coastline contains a mix of marl and organic peat sediment, erosion of which yields a total loss of material to the shore system through oxidation and suspended transport).

Historical aerial photographs record dramatic erosion along this coastline: 200-300 m (650-975 feet) since 1935; 100-200 m (325-650 feet) since 1953 (Figure 28A and B).

**Birth of New Sable Creek, a New Tidal Channel**. Figure 28A and B record the effect of this shore erosion, combined with the historical rise in sea level and the 1935 Labor Day Hurricane on coastal and tidal channel evolution.

- In the 1928 aerial photograph (Figure 28A), shore erosion has recently brought part of meandering Little Sable Creek to the shore and isolated it into three segments: to the north is the original entrance, which now (in 1928) feeds only to a small dead end branch; in the center is an isolated shore-parallel meander belt that exits to the sea at both ends; and to the south is the new entrance to Little Sable Creek.
- In the 1953 aerial (Figure 28B), shore erosion has removed the about 100 meters (325 feet) of coastline, including a portion as a result of the 1935 Hurricane. Areas of hurricane damage to the mangrove forest (white) are visible. The original northern entrance to Little Sable Creek now feeds further into the wetland and heads across a low spot in the Marl Ridge in an area of hurricane damage. This enlarged creek thins and fades landward.
- By the 2005 Ikonos satellite image (Figure 28A and B), the new northern tidal creek has extended across the marl ridge and connected through a series of lakes well back into the interior of northern Cape Sable. In addition, the tidal creek is rapidly widening in response to an adequate tidal prism. We have named this new tidal channel New Sable Creek. It is enlarging much more rapidly than the northern portion of Little Sable Creek. Little Sable creek is restricted to the historical tidal prism within the wetland between the outer shore and the Marl Ridge. New Sable Creek has reached in to the expanding tidal prism of the interior. New Sable Creek is also carrying sediment (note filling bays) and saline waters far into the interior.

This channel formation and enhancement is a product of tidal flow responding to rapidly rising sea level and taking advantage of weaknesses provided by hurricane damage.

*FIGURE 26A Erosion on exposed mangrove coast by waves from 40 knot northwest winds following cold front passage in February, 1995. Forty to sixty cold fronts pass through south Florida per year causing persistent erosion stress on the exposed mangrove coast of northwestern Cape Sable. Photo taken at Shark Point near northwest tip of Cape Sable.*

*FIGURE 26B. Wave and current erosion, combined with activities of excavating burrowers rapidly deepen organic peats along the exposed mangrove shoreline of northwest Cape Sable and the associated channels.*

**Outer Beach North of Northwest Cape.** The beach north of Northwest Cape is erosional, having cut back 100-200 m (325-650 feet) since 1953 (Figure 28), a rate similar to that of the exposed mangrove coast to the north (Figure 17 and 18). North of Northwest Cape the sand on the shore diminishes, forming a decreasing veneer over the eroding marl and peat surface. Sand is lost from this northern end of the sand system by net southward longshore drift and storm overwash onto the cape (Figure 27).

**Outer Beaches Between Capes.** The southern part of North Cape has grown since 1953, fed by sand eroded from the north (Figure 28). Southward from North Cape the beach becomes increasingly erosional. This increased shore erosion peaks at Middle Cape Canal with over 150 m (500 feet) of shore loss since 1935 on the north side and over 300 m (1,000 feet) on the south side (Figure 24). This erosion is in large part the result of opening Middle Cape Canal by the 1935 Labor Day Hurricane. This erosion is in large part the result of opening of Middle Cape Canal by the 1935 Labor Day Hurricane. South of Middle Cape Canal historical erosion decreases to negligible at Middle Cape (see section on Coastal Dynamics).

*FIGURE 27. Post hurricane Andrew exposure of beach overwash stratigraphy at north end of beach north of Northwest Cape. Lower sand in scarp is washover from 1935 Labor Day Hurricane, overlain by soil, overlain by 1960 Hurricane Donna washover layer, overlain by soil and capped by 1992 Hurricane Andrew sand layer. Photo was taken in November 1992.*

Between the strand plains of Northwest Cape and Middle Cape, the narrow, arcuate beach ridge and beach contain little sand. The beach ridge and beach are a thin veneer of sand capping a thick sequence of carbonate marl and organic peat. As this beach ridge and beach migrate (erode) landward, the erosion of the intertidal and subtidal shore face releases only mud and organics. Replenishment of beach sand is provided only by the slow addition of shells and shell fragments being brought in by storms from offshore.

The persistent erosion of this beach arc is shown by the stumps of trees exposed in the lower intertidal of the beach front, marl and peat exposed (or nearly exposed) beneath the beach and offshore, and the presence of a single narrow sandy beach ridge along the coast.

Middle Cape Canal essentially blocks the net southward drift of sand along the shore, resulting in the doubling of the erosion rate to the south of the Canal. Sand on the beach south of Middle Cape Canal has been moving southward, but it has not been replenished. As a result the shore for nearly 2 km (1 mile) south of Middle Cape Canal has no sandy beach and only a tenuous beach berm. This berm is not at the shore but pushed some

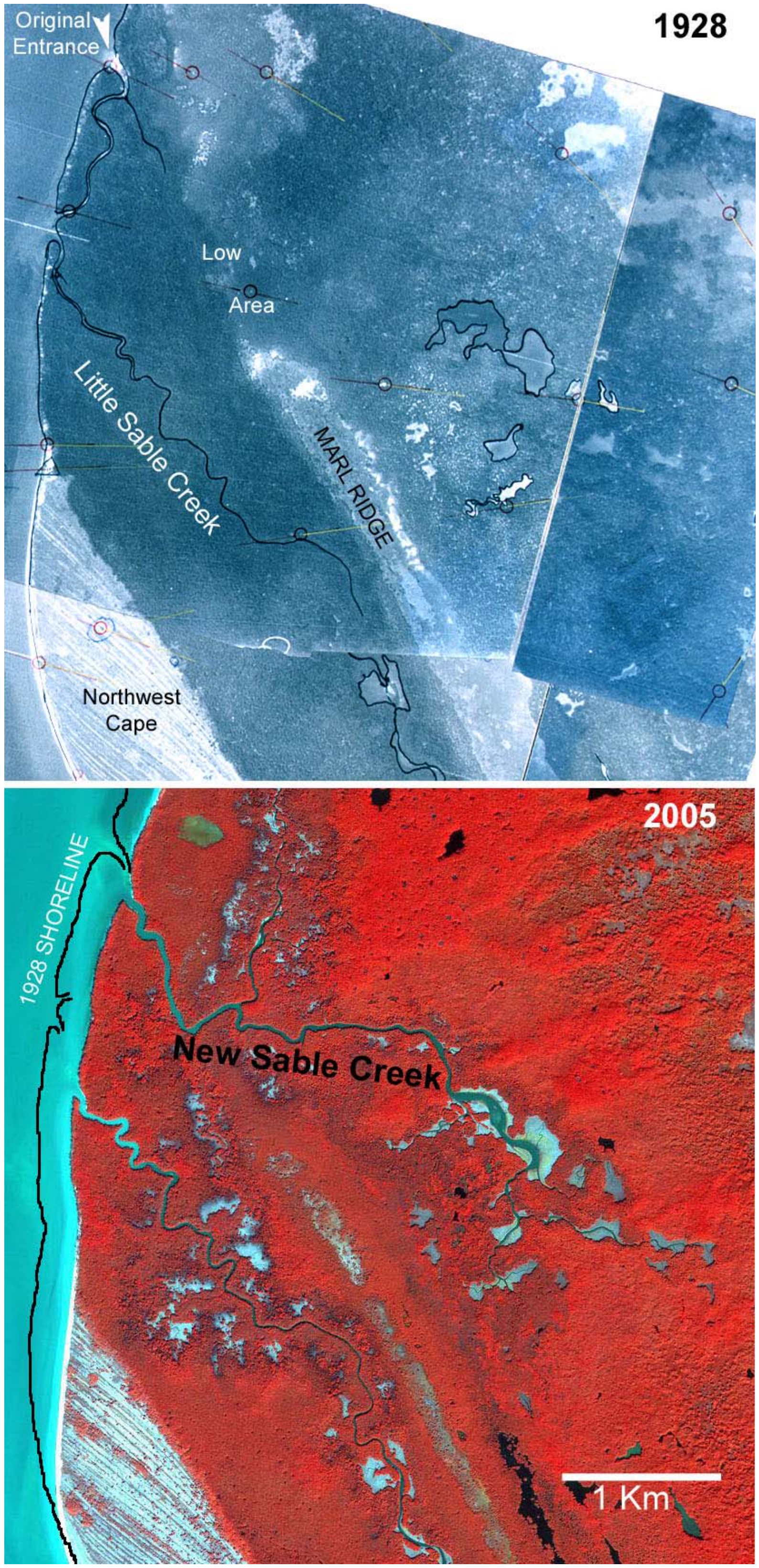



FIGURE 28A. Formation of New Sable Creek, a new tidal channel. Lower image © SpaceImaging.com.

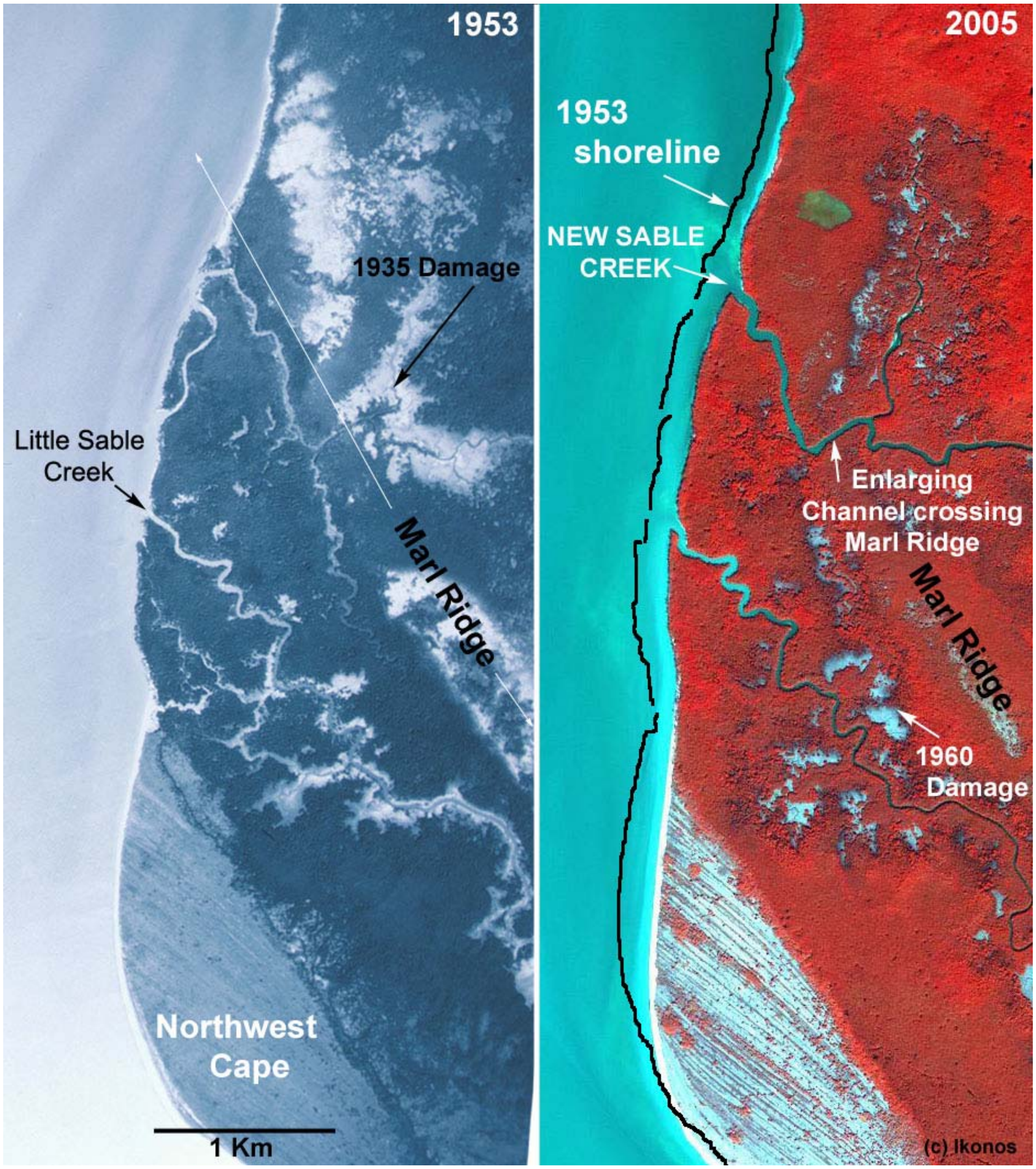



*FIGURE 28. Aerial images from 1953 and 2005 showing Gulf of Mexico coast of Cape Sable from North Cape north to where the Marl Ridge trends out to sea. North Cape is eroding on the northern side at about the same rate as the mangrove and marl coast to the north (it is slightly accretionary on the southern side, out of view). White line on 1953 photo is trend of Marl Ridge. Between North Cape and the Marl Ridge are two tidal creeks in the 1953 photo. Little Sable Creek extends southward and connects to the north end of Lake Ingraham. It has widened slightly in the 2005 image, especially in the first kilometer. The small creek to the north has become more directly open to the sea by 2005 because of shore erosion. In 1953 a small, fading branch of this channel crosses the Marl Ridge trend in an area of 1935 Hurricane damage. By 2005, this channel is greatly enlarged, likely the result of a large tidal prism accessed on the east side of Marl Ridge. Right image © SpaceImaging.com.*

meters into the mangrove swamp by storm waves. As a result, the shore south of Middle Cape Canal is an exposed mangrove forest with a marl and peat substrate (Figure 29).

Accentuated erosion has dramatically reduced the width of the mangrove forest separating the Gulf of Mexico from Lake Ingraham, and several relict natural tidal channels are essentially exposed at the coast, with only a minor filling by sand preventing them from becoming active (Figure 30). Activation of these channels should occur within the next 10 years or as the result of a significant hurricane. During spring tides, flood waters flow freely through this narrow stretch of mangrove coast to Lake Ingraham.

The arcuate beach between Middle Cape and East Cape is a similar thin shelly sand beach and berm over Marl. The historical rates of erosion have been small as the shore is not disrupted by a canal or inlet.

*FIGURE 29. View north to Middle Cape Canal showing sand starvation and eroded mangrove shore to the south of the inlet. View is from arrow in following figure.*


*FIGURE 30. A 1995 aerial photograph of Middle Cape Canal showing natural channels (arrows) that could become active within next 10 year with further shore erosion of hurricane scour of the thin sand berm along the coast. Photo location of Figure 29 is arrowed.*

**Sand and Marl Shoreline along Southern Coast.** East of East Cape, the sandy beach shoreline gradually diminishes, and by the area of East Cape Canal, there is only a low, thin sandy beach ridge in from the shore perched on the marl substrate (Figure 2). The marl substrate is exposed along most of this coast. Analysis of historical photographs indicates that this south facing shoreline erodes primarily as the result of significant hurricane events. The southern shore has eroded about 180 meters (585 feet) since the 1928 aerial photographs (Figure 31). Erosion occurred in two nearly equal steps, one between the 1928 and 1953 aerial photographs and a second between the 1953 and 1964 aerials. Only a very small amount of south-facing shore erosion has occurred between 1964 and 2005. These two steps in erosion are interpreted to be the result of the 1935 Labor Day Hurricane and Hurricane Donna in September 1960. Each storm stripped the trees and roots from the shore zone for about 75 m (250 feet). This lowered the shore level so that waves and burrowers could erode the substrate in the years following.

As the sediment sequence along this coastline is nearly entirely marl and minor organic peat (Figure 12), neither erosion of the shore nor widening of East Cape Canal and Hidden Channel provides sediment for the shore system. This eroding mud and peat either moves offshore or into the lakes fed by East Cape Canal.

**Lake Ingraham and the Southern Lakes**

Lake Ingraham and the Southern Lakes began a dramatic evolution in the 1920s which has accelerated to the present and been punctuated by the effects of two catastrophic hurricanes. Prior to canal construction, Lake Ingraham and the Southern Lakes were isolated fresh to brackish lakes within the coastal system. From the north, Little Sable Creek extended to Lake Ingraham over a long distance. From the south, saline water could have entered only during storm tides. Water depths in Lake Ingraham were 1-1.5 meters (3-5 feet).

Six stressor-induced changes play an important role in the evolution of these lakes:

1. opening the southern lake system in the 1920s, via dredged canals, to offshore marine water and sediment;
2. decimating the marginal wetlands and uplands by the 1935 Labor Day Hurricane;
3. initiating a northern opening to Lake Ingraham, through cleaning a sand-choked, dredged canal (Middle Cape Canal) during the 1935 Hurricane;
4. opening natural channels to the lakes through natural erosion of the south coast;
5. changes in the environment, the tidal prism, and tidal flow because of the historical rise in relative sea level; and
6. Transport of sediment material to the lakes from the interior of Cape Sable because of a complex interaction of rising sea level, tidal flow and drainage from the interior canals cut across the Marl Ridge.

The evolving fluid and sediment dynamic processes driving these changes are explained in the later section on Sediments and Sediment Dynamics. Geomorphic and spatial environmental changes are described below.

**<u>Influence of Lower East Cape Canal and Ingraham Canal.</u>** Opening the East Cape Canal / Ingraham Canal connection (Figure 31) in the mid 1920s permitted tidal exchange, salt water intrusion during the dry months, and freshwater discharge during the rainy months. The connection also brought in fine suspended muds from Florida Bay during storms. As the constructed canal was less than 6 m (20 feet) wide and probably not cut to the limestone bedrock, the volume of water would have been small at first. With time this canal connection cut to the limestone bedrock and began widening at a persistent 60 cm (2 feet) per year.

This canal system has provided large volumes of sediment into the coastal lakes. Sequential aerial photographs record the first focus of this sediment input was in filling the Southern Lakes (Figure 31). By 1953 the lake adjacent to canals were largely filled and dissected by distinct tidal channels. This shallowing continued until portions of these lakes built high enough in the intertidal zone for mangroves to colonize. By 1995, lakes near the Canals had largely evolved to mangrove mudflats. Filling further into the Southern Lakes continues and mangroves are expanding further into the system.

In southern Lake Ingraham, only a small delta had formed by the time of the 1953 aerial photograph (Figure 32). A single distinct channel extended northward from the Ingraham Canal opening, formed and maintained by motorboat traffic. This elongate form persisted as the flood tidal delta grew into Lake Ingraham. The rate of delta growth has progressively increased through the late 1980s and 1990s and is continuing today (Figures 32 and 34). With growth, the southern flood tidal delta has formed numerous side channels trending essentially perpendicular from the main channel towards the lake margins. One pronounced side channel connects Homestead Canal to the main delta channel and is maintained by ebb tidal discharge from Homestead Canal.

The southern flood tidal delta now forms a sediment body over four kilometers in length by 1-1.5 km in width and is 50-90 centimeters in thickness. Nearly the entire delta feature is emergent at low tide. The delta is highest near the Ingraham Canal entrance and along the margin of the primary channel (Figure 24 and 36). Secondary channels cut perpendicular across this levee and branch to the margins forming discrete lobes of sediment deposition (Figure 36 and inverted cover photo). The primary channel-margin levee remains emergent at the weaker high tides and is becoming colonized with mangrove seedlings near the south end (Figures 35, 36, 37 and 38).

Despite high rates of sedimentation on the delta (average over whole delta is 6.2 mc/year; maximum is 15 cm/year; see Sediments and Sediment Dynamics section), there are abundant surface algal and cyanobacterial mats, burrowing worms and other fauna which provide a desirable feeding habitat of a spectrum of wetland and wading birds.

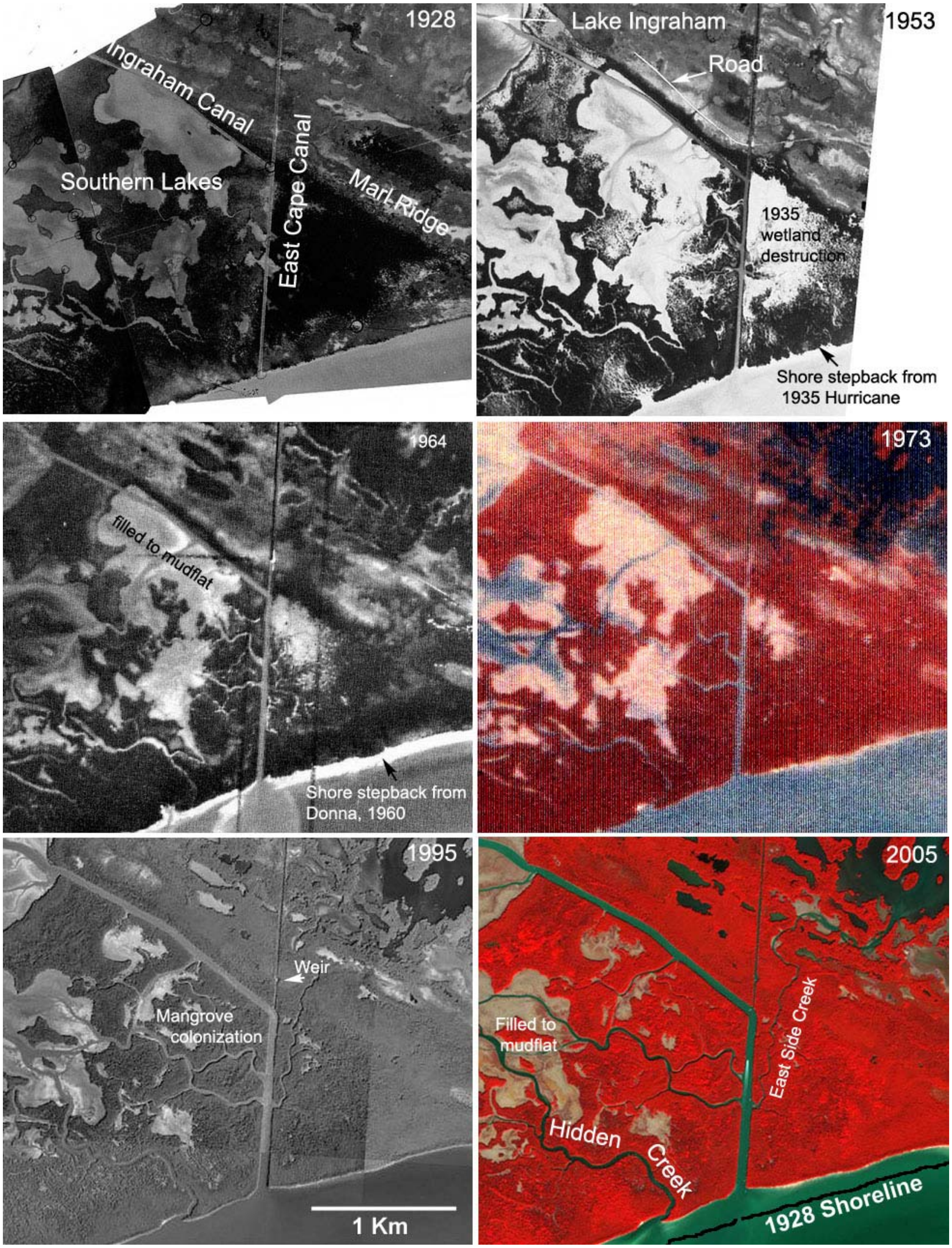



FIGURE 31. Sequential aerial and satellite images of the East Cape Canal area illustrating changes that have occurred from 1928 to 2005. These are itemized and discussed in text. The 2005 Ikonos image is © Spaceimaging.

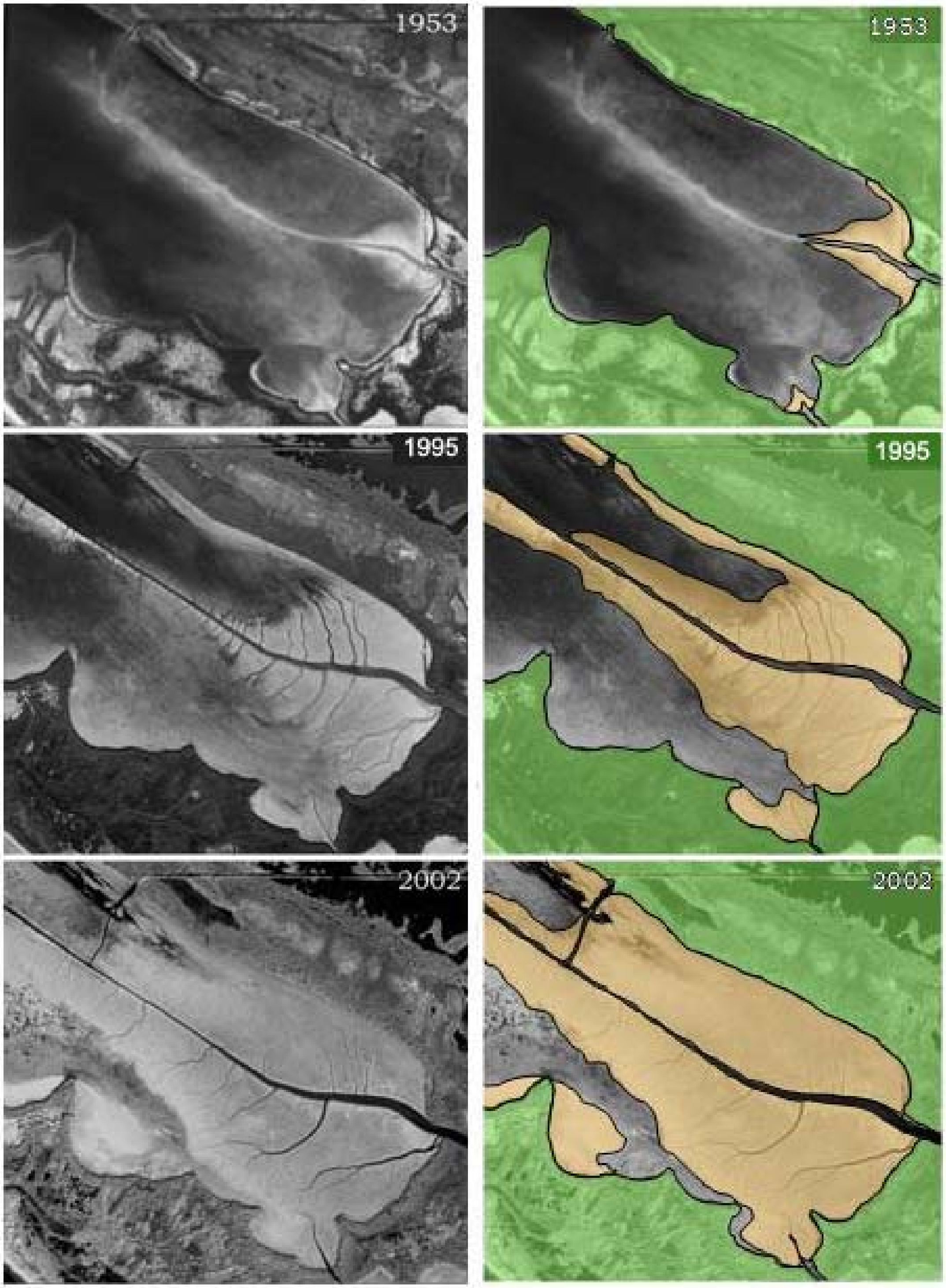



*FIGURE 32. Sequential aerial and satellite images with interpretative maps of southern Lake Ingraham showing growth history of the flood tidal delta from the East Cape Canal / Ingraham Canal system. The brown areas are out of water at most low tides; grey is subtidal and green is wetland. As the canal has widened and as the southern bays have filled, the southern flood tidal delta grown at an increasing rate. Sediment marker plots have recorded sedimentation rates on the delta as high as 15 cm per year in 2004-2005.*

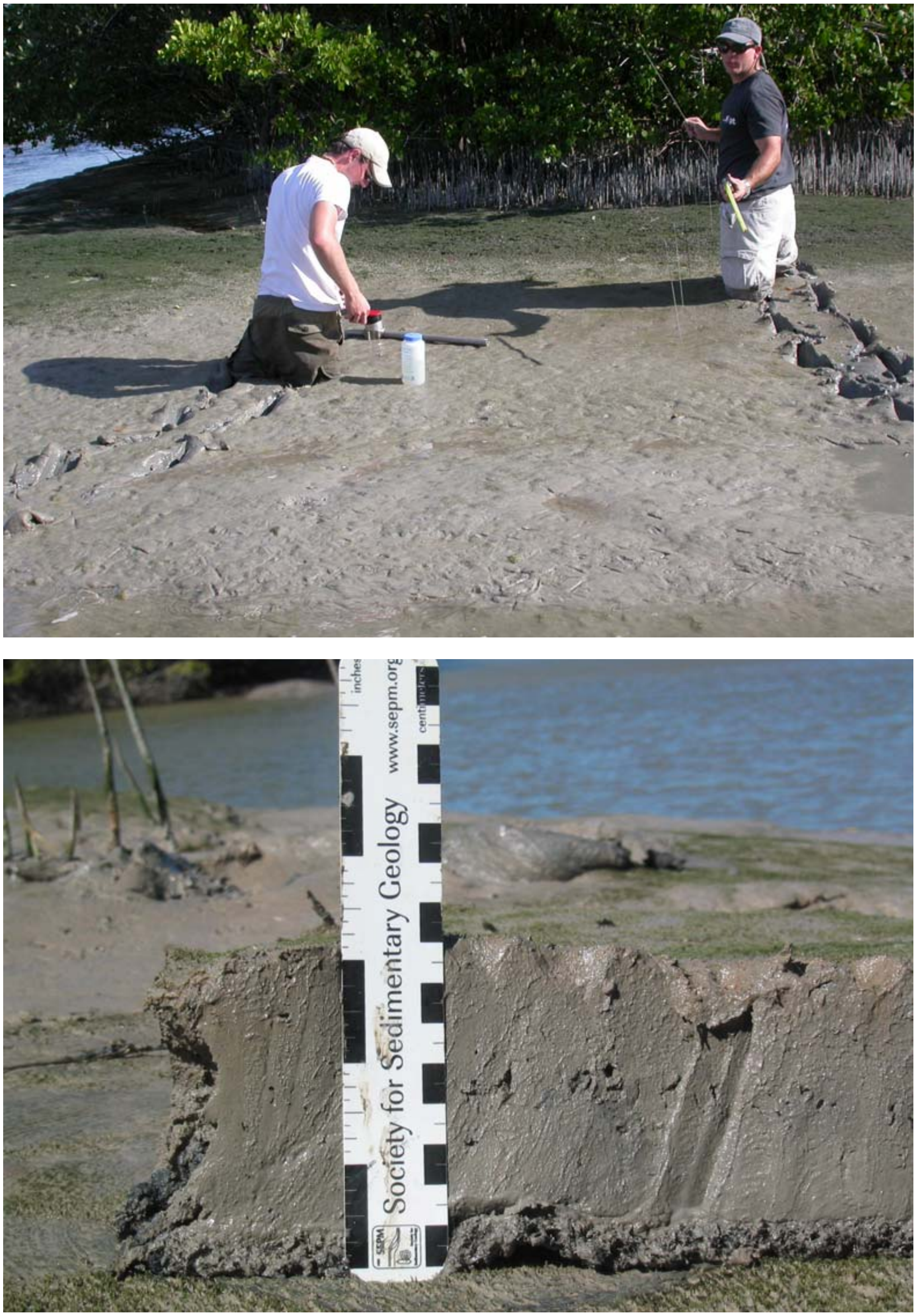



*FIGURE 33. Top: 'Standing' to sample and prepare sedimentation plots in rapidly accreting soft carbonate muds on small delta bar adjacent to East Cape Canal. Bottom: Six months of sediment accretion (8.5 cm) on carpet square #107 collected on January 17th, 2005. Annual accretion rates are as much as 15 cm/year.*

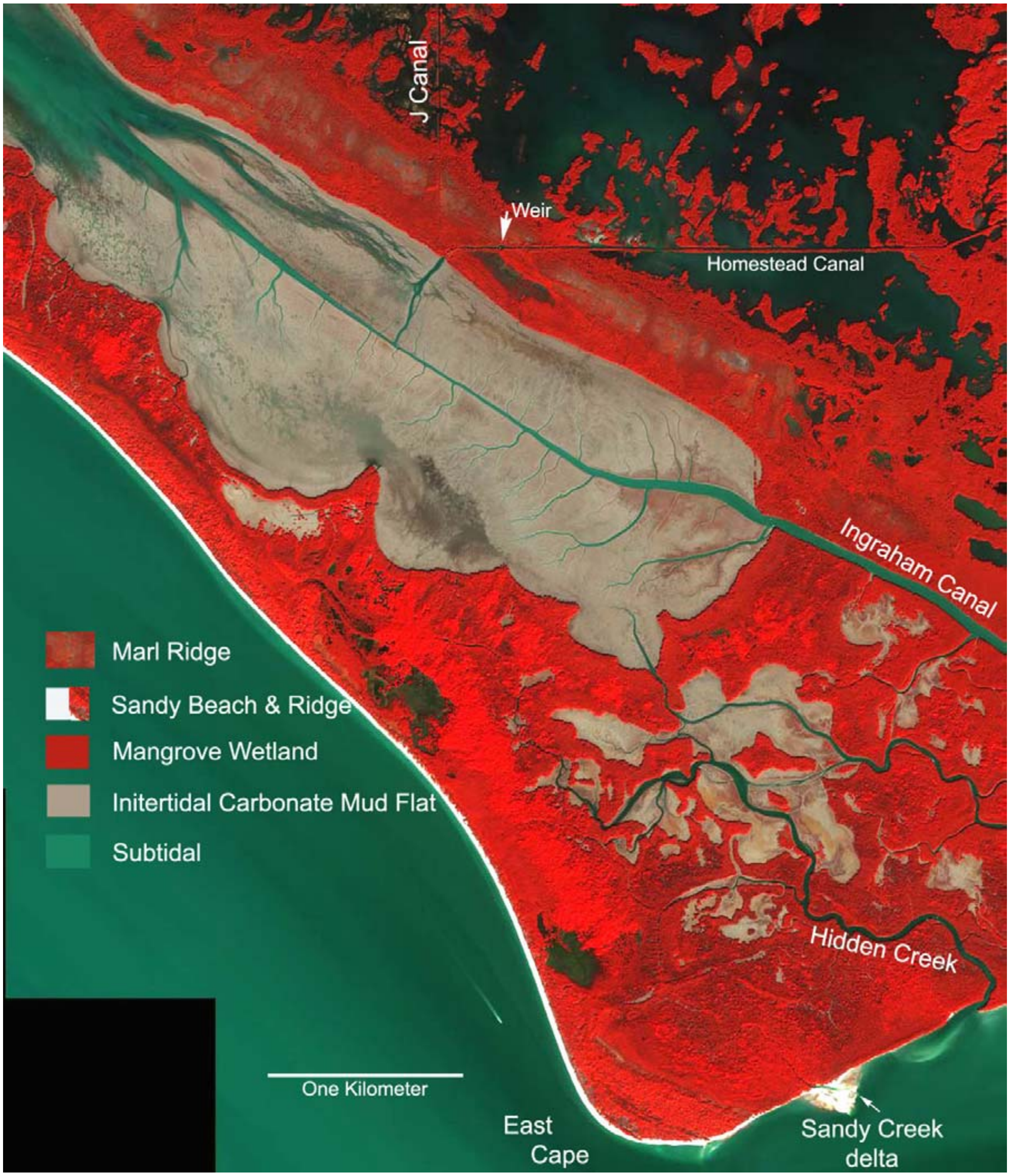



*FIGURE 34. Ikonos image of southern Cape Sable showing rapid infilling of the Southern Lakes and southern Lake Ingraham. Continuous elongate central channel is created by small boat traffic. Distinct side channel on north side drains from Homestead Canal, where the weir is inoperable. Ikonos satellite image © Spaceimaging.com.*

*FIGURE 35. Oblique aerial view to southeast taken July 17, 2003 near high tide showing shallow levee at margin of main channel of delta in southern Lake Ingraham.*

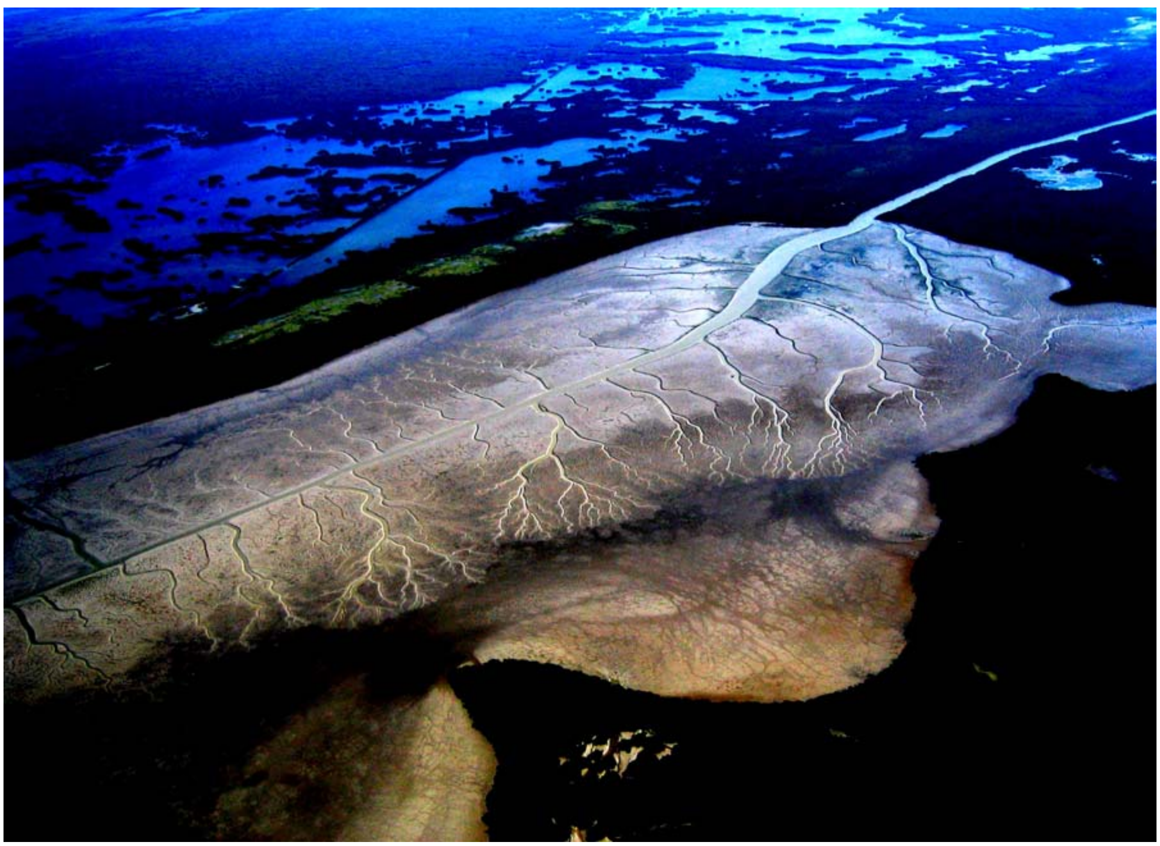


*FIGURE 36. Oblique aerial photograph taken December 14, 2004, accentuated to show growth of the southern flood tidal delta in Lake Ingraham. View is to southeast. Growth is by outward branching secondary channels, which cut the primary channel levee essentially perpendicularly. Each secondary channel splay provides a lobe of delta growth. In addition, storm redistribution of sediment is filling the marginal embayments in Lake Ingraham (foreground).*

*FIGURE 37. Oblique aerial photo near low tide looking northwest at the entrance of Ingraham Canal into Lake Ingraham. Algal growth and mangrove seedlings are colonizing the higher portions of the delta levee.*

*FIGURE 38. Mangrove seedlings and algal mats forming on the higher portions of the delta in southern Lake Ingraham.*

**<u>Effect of 1935 Labor Day Hurricane.</u>**

The Labor Day Hurricane of 1935 swept nearly all of Cape Sable with winds of 60 meters per second and a major storm surge (Figure 14). Semple (1936), visiting the area a year after the storm attempted to reconstruct the event: "The low ocean prairie was completely covered with six feet of water, its surface lashed into great waves and spray by a gale of one hundred and thirty miles an hour. In the mangrove forests the trees that were large and not flexible enough to bend with the storm were torn to pieces; only the smaller ones, by bending to the water, escaped." A U.S. Coast Guard 1935 Hurricane Report described the conditions at Middle Cape four days after the storm during an overflight to look for family members:

> "On September sixth at 10:20 a.m., Lt. Clemmer departed in the C.G. 255 with Mr. J. G. Stoddard as a passenger for a more thorough investigation of the Cape Sable region. Mr. Stoddard wishes to ascertain the fate of his daughter and son-in-law, Mr. and Mrs. Kossack, who had been vacationing at Mr. Stoddard's home on Middle Cape. Results of this search was negative, as this entire area had been wiped clean. Mr. Stoddard believed further search for his daughter and son-in-law to be futile as they had been left at his home with no means of escape. The cape has been swept so bare that not one piece of wreckage of his home could be found" (Wilkinson, 2005).

A comparison of the January 1935 aerial photographs with the next images so far found, in 1953, still provide a stark visualization of the 1935 storms destruction (Figures 39 and 40). The nearly complete destruction of the forested wetlands surrounding Lake Ingraham is visible, even though 18 years had passed between the storm and the 1953 aerial photographs. The aerial photographs after 1953 illustrate a very slow recovery to the wetlands bordering Lake Ingraham with some areas evolving to open ponds (Figure 39).

**<u>Opening and enlarging of Middle Cape Canal.</u>**

The 1935 Labor Day Hurricane also swept large volumes of the beach sand veneer from the shore, opening up the previously dug Middle Cape Canal and breaching the shore about 500 meters to the north. Middle Cape Canal remained open and has steadily widened at 120 cm (4 feet) per year since. In the 1953 aerial photograph, an initial flood tidal delta is visible (arrow in Figure 39). This portion of the flood tidal delta was and has remained a mix of sand and shelly gravel. The delta becomes fine sand and then mud inward and on the margins. This delta has continued to enlarge and evolve and now fills the northern two kilometers of Lake Ingraham. The central tidal channel remains broader, a reflection of the stronger tidal flow volume entering through Middle Cape Canal. Just into Lake Ingraham from the bend are distinct flood (to the right) and ebb channels. Through the east-west neck of Middle Cape Canal the channel is cut to limestone bedrock across its width. As the channel has enlarged, the flood tidal channel has reprofiled the northern margins of Lake Ingraham cutting the back along the inner (right) shore and isolating and filling embayments (Figures 39 and 40).

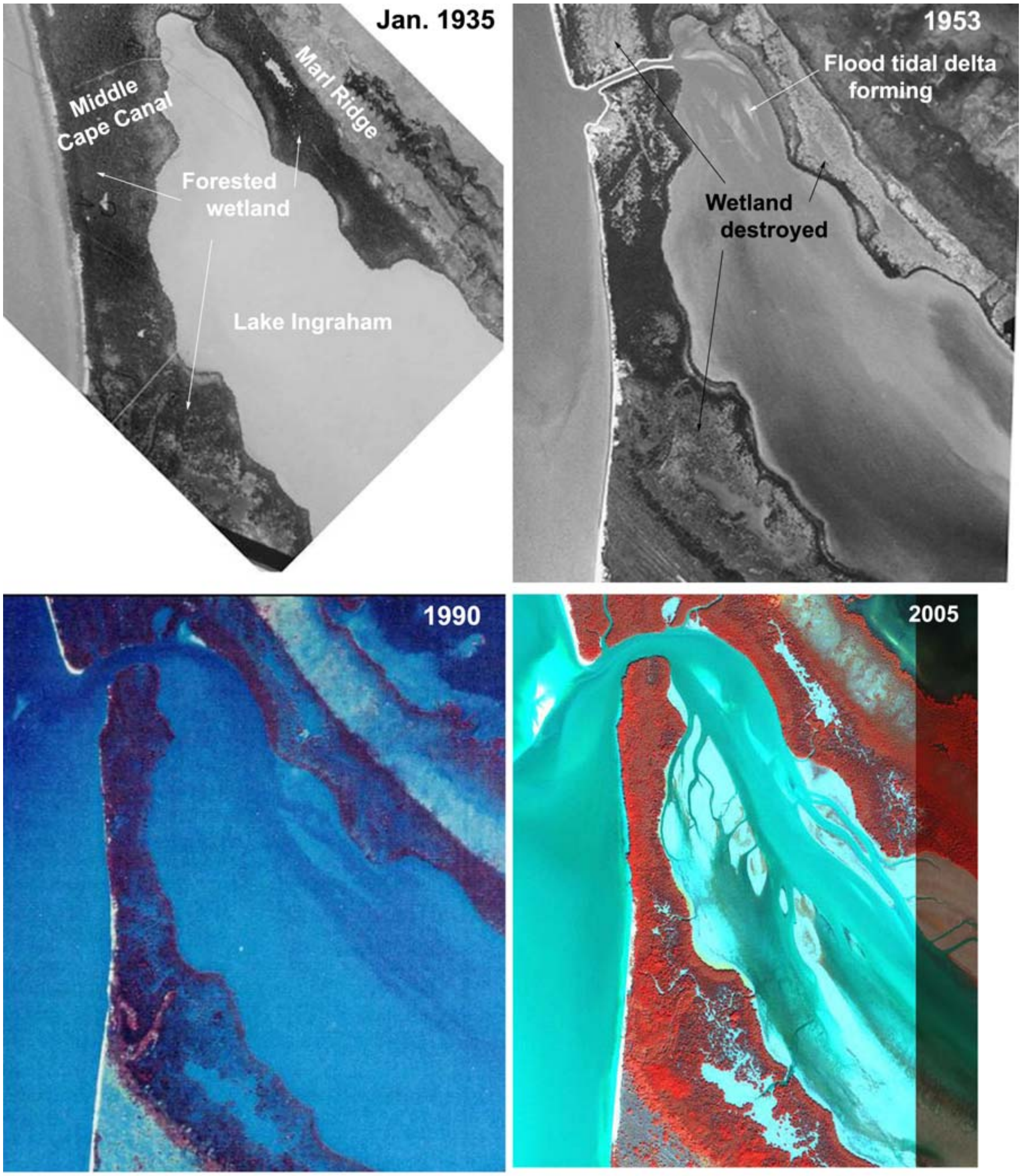



*FIGURE 39. Aerial photographs and satellite image of northern Lake Ingraham and Middle Cape Canal from January, 1935, 1953, 1990 and 2005. Middle Cape Canal was cut but blocked prior to the hurricane of 1935. Following it has widened at a steady 1.2 m (4 feet) per year and is now 103 m (338 feet) in width. The 1935 Labor Day Hurricane destroyed most of the coastal wetland bordering northern Lake Ingraham. Vegetation adjacent to the interior coastline and against the uplands recovered most completely. Significant portions evolved to open wetland. The flood tidal delta, actively growing by 1953 has shifted as it fills in northern Lake Ingraham.*

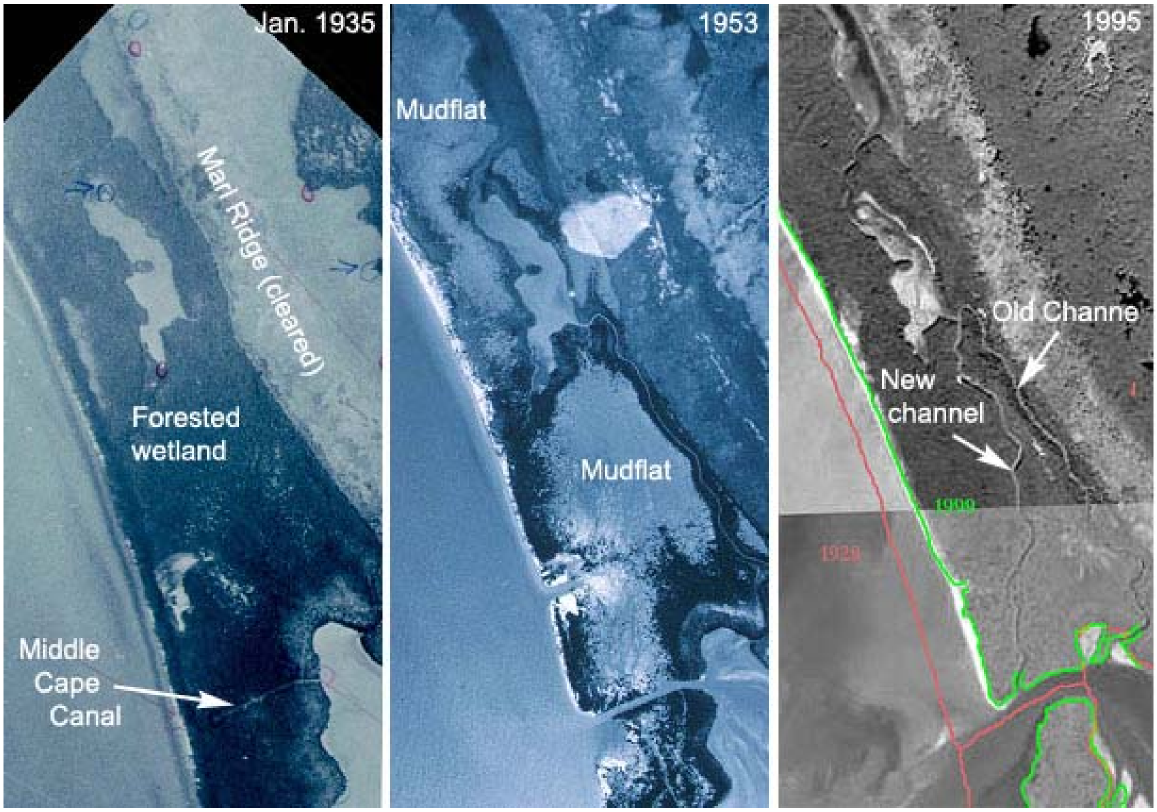



*FIGURE 40. Aerial photographs and satellite image of area north of Middle Cape Canal. The 1935 Labor Day Hurricane opened Middle Cape Canal and breached the coastline just to the north. The dense forested wetland between the beach and the Marl Ridge was largely flattened and smothered. Note that there was 18 years between the 1935 Hurricane and the 1953 aerial photograph. During the long process of recovery, a new channel formed along the southern portion of Little Sable Creek (Little Sable Creek continues north and emerges at the coast north of North Cape; see Figure 28. With continued coastal erosion, the southeast channel of Little Sable Creek will shortly emerge at the ocean shoreline.*

In addition, as the storm decimated wetland north of Middle Cape Canal recovered, a new eastern channel of Little Sable Creek emerged and has become dominant (Figure 40). It is steadily widening. The bay, visible in the upper middle of Figure 40, is rapidly filling with carbonate mud from flood tides (see right 1995 frame). The old, western channel is becoming clogged and now blocked by trees and branches from Hurricane Andrew (1992). The southern end of the old channel is maintained to the junction with the eastern section of Middle Cape Canal where it cut across the Marl Ridge.

## Marl Ridge Separating Lake Ingraham from Inner Cape Sable

Historically the Marl Ridge separating Lake Ingraham and the western lakes and forested wetlands from the interior of Cape Sable was apparently sufficiently emergent to be considered (or at least promoted) as ideal for agriculture and habitation. In 1918, the Cape Sable Improvement Company was promoting over 8,000 acres for sale, divided into 10 acre plots (See Appendix). These promotions, even by botanical notables such as

Perrine (1917 and 1918), was primarily focused on the exceptional quality of the marl deposits. Every crop imaginable was promoted but most especially sugar cane. In the January 1935 aerial photograph, the Marl Ridge, even as far north as at area of Middle Cape Canal, had been cleared (1928 image in Figure 40).

Importantly, the Marl Ridge is a continuous feature which has two sections at Cape Sable. The NW-SE trending sector begins north of Northwest Cape and angles inland trending SE and extends to near the south coast near Clubhouse Beach (Figures 2-4). This Marl Ridge sector separates the historically marshy interior of Cape Sable to the west from Lake Ingraham and the associated lakes and forested swamps to the east. This sector is not at the present shoreline, but was isolated from it some 1,000 years ago when the shore took a seaward step creating the outer capes. This interior position has isolated this Marl Ridge sector from significant upward growth by sediment from winter storms and hurricanes.

The second Marl Ridge sector is an east-west trending portion which extends from near Clubhouse Beach eastward to Flamingo (Figures 2-4). This sector is along the present shoreline with Florida Bay. It continues to actively build upwards as sediment layers are added during overwash events of stronger winter storms and hurricanes.

Although developed and apparently in some agriculture in the 1930s, the boundary conditions influencing the NW-SE ridge sector have dramatically changed since, largely because of both the 23 cm (9 inches) of relative sea level rise since 1932 and the increased tidal exchange that now occurs within Lake Ingraham. Prior to opening of East Cape and Middle Cape canals, the tidal fluctuation within Lake Ingraham should have been minimal, and the lake would have maintained an average water level oscillating near mean sea level. Now with greatly enlarged channels, the tide reaches the Marl Ridge on the landward side of Lake Ingraham essentially undampened.

Prior to field research we examined recent aerial photographs and satellite images and noticed that portions of the Marl Ridge appeared to have low zones in which mangroves and other wetland vegetation extend across the Marl Ridge (see redder bands across Marl Ridge on Figure 3, 24 and 34). We hypothesized that these low areas were sites where water would be flowing across the Marl Ridge from Lake Ingraham to the interior during higher tides.

We visited the Marl Ridge by helicopter on two occasions specifically to observe the interaction of high tides and the Marl Ridge. The first was a forecast +4.2 foot tide on July 19, 2004; the second was a forecast +4.9 foot tide on July 31, 2003. On each of these tides, a nearly continuous sheet of water was actively flowing across the Marl Ridge east of Lake Ingraham for nearly the entire length!

This flow across the Marl Ridge lasted several hours and in the case of the +4.9 foot tide ranged from 5 to nearly 30 cm (2-12 inches) in depth. The water was actively flowing across the Marl Ridge at velocities up to 0.3 meters per second (one foot per second) (Figures 41, 42, and 43). On this day, we had to leave the area before high tide was reached. On both of these days the wind conditions were calm. It should be noted that when this flooding was occurring, the Marl Ridge was a haven for the shore and wading birds, normally seen at low tide on the Lake Ingraham deltas.

Tidal forecast charts for 2004 indicate that +4.2 foot tides or greater, producing significant flow across most of the Marl Levee, occurred on at least 80 high tides during the year, plus what ever tides are pushed higher by the westerly winds following winter cold front passage. This flow also significantly enlarges the tidal prism and flow through Middle Cape and East Cape Canals.

A simple calculation can provide an idea of the volume of water that moves across the Marl Ridge into the interior of Cape Sable during one of these tides. If a 0.1 m thickness of water is moving across 8000 meters of Marl Ridge length at 15 cm/second for two hours (7,200 seconds), then 864,000 cubic meters of water would have moved across the Marl Ridge into inner Cape Sable on that single tide. As the water level is lower in the interior, this water will not flow out across the Marl Ridge but is trapped. As described in more detail in the Fluid and Sediment Dynamics section, part of this water flows out through the canals that were cut through the Marl Ridge – East Cape Canal, Homestead Canal and inner Middle Cape Canal. A part of this water remains within the interior, significantly elevating salinity.

*FIGURE 41. Co-author Brigitte Vlaswinkel and National Park Scientist Dr. Dewitt Smith walking on Marl Ridge south of inner Middle Cape Canal during flooding tide on July 31, 2004. View is south. Water is moving at about 20 cm/sec from right to left.*

*FIGURE 42. Water flowing eastward across Marl Ridge on rising tide on July 31, 2004.*

*FIGURE 43. Oblique aerial views of sediment-streaked water flowing into interior Cape Sable after flowing across the Marl Ridge on July 31, 2004. Note that lower water levels in the interior will easily receive overflow water, but it will not flow back out across the Marl Ridge.*

**Natural Tidal Creek Evolution**
Six natural tidal creeks have significantly evolved in response to increased tidal flow through them during the past 78 years of aerial photography coverage. Three are along the south coast: Hidden Creek, Sandy Creek and East Side Creek. Three are along the west to northwest coast: New Sable Creek, north exit of Little Sable Creek, and southern exits of Little Sable Creek..

**Tidal Creek Evolution on Southwest Coast of Cape Sable**. The most significant natural tidal creek on the south is Hidden Creek (Figure 44). Hidden Creek originated as a branch of an abandoned tidal creek that originally exited the coast to the west, north of East Cape (Figures 7 and 38). In the 1928 aerial photographs, this channel had not opened to the south shore. By 1950, Hidden Creek is open (Davis, 1972). Since that time, Hidden Creek has widened at a steady 60 cm (2 feet) per year. Its flood tidal waters flow through the Southern Lakes and into southwestern Lake Ingraham (Figures 31 and 34). Hidden Creek is a focus of sediment dynamics research presented in a later section.


*FIGURE 44. Oblique aerial photograph looking east along the south shore of Cape Sable to Hidden Creek and East Cape Canal (ECC). This erosional mangrove shore has eroded about 180 meters (585 feet) since 1928. Hidden Creek, part of an earlier tidal creek system, was isolated from the shore until about 1950. Since that time it has been widening at a steady 60 cm (2 feet) per year. If feeds into the Southern Lakes and southwest Lake Ingraham.*

Erosion of the south coast of Cape Sable has opened Sandy Creek, a creek just to the west of Hidden Creek (Figures 3 and 34). This tidal creek has formed a large ebb tidal sand delta by blocking the eastern drift of sand from East Cape (Figure 45). This is further depriving the coast of shore sand further east.

*FIGURE 45. View northeast towards East Cape from sand ebb tidal delta of a natural tidal delta of Sandy Creek, between East Cape and Hidden Creek (Figure 34). This creek initiated as the result of historical shore erosion along he south coast. The delta blocks the easterly transport of sand from East Cape. View is at low tide.*

East Side Creek (our name) formed off of lower East Cape Canal as the area was recovering from Hurricane Donna (Figure 31). East Side Creek is significant as it extends northward across the former Marl Ridge barrier into the southern interior of Cape Sable. East Side Creek has strong flow, is rapidly widening, and is feeding significant volumes of sediment into and out of the interior. Small lakes that East Side Creek crosses on its path are rapidly filling or have filled (Figure 46). During the time that the National Park efforts have been to block saline flow through East Cape Canal into the interior, East Side Creek has quietly been opening to offset these efforts. As explained in the dynamics section, East Side Creek provides considerable contribution of sediment-laden flow on ebbing tides, This moves into East Cape Canal and then Lake Ingraham.

**Tidal Creek Evolution on the west coast of Cape Sable**. North of North Cape, a historically small tidal creek entered the coastal wetlands and faded out. This creek (New

*FIGURE 46. Student Assistant, Kirk Nuzum, coring in a rapidly infilling lake along the course of East Side Channel. This natural, recently formed channel crosses the Marl Ridge feeding water and sediment into the southern interior of Cape Sable.*

Sable Creek on Figure 28), now greatly enlarged, passes eastward across the northern part of the Marl Ridge and into the northern interior of Cape Sable. Historical aerial photographs suggest that this channel effectively crossed the Marl Ridge in an area of 1935 hurricane damage, aided by rising sea level. The rapid widening of this creek is the result of a greatly enlarged tidal prism acquired as the 'A' Creek reached across into the interior of Cape Sable. As with other tidal creeks, it should be eroding into marl and organic peat, material that once eroded is easily transported and lost from the system.

Little Sable Creek is a NW-SE trending creek that historically extended from the coast north of North Cape southeast to the north end of Lake Ingraham (Figures 28, 30, and 40). It occupies the low wetland between the coastal beach to the west and the Marl Ridge to the east. It intersects the coast just south of New Sable Creek described in the previous paragraph. The northern entrance remains similar today as it was historically, although the mangrove coast has eroded, and the creek is somewhat widened over its first kilometer of penetration (Figure 28).

The southern end, where Little Sable Creek enters north Lake Ingraham has changed dramatically (Figures 24, 30, 39, 40). First, inner Middle Cape Canal trended off of the lower part of Little Sable Creek and extended across the Marl Ridge. Although inner

Middle Cape Canal, as it crossed the Marl Ridge does not look to have been very active until recently, its presence would not have encouraged flow northward through Little Sable Creek. Second, as the area recovered from the devastation from the 1935 Labor Day Hurricane, a new more easterly channel appeared and has become dominant (Figure 40). This channel is faintly visible in the January 1935 aerial photographs and then not visible in the 1953 photos. This new westerly channel is presently widening at about 60 cm (2 feet) per year and has strong flow. The old easterly channel, north of inner Middle Cape Canal, is filling and no longer navigable because of clogging debris from Hurricane Andrew in 1992. Third, the south entrance into the new, western Little Sable Creek entrance is in the widening Middle Cape Canal. As this north side coast continues to erode (Figure 40), this channel will soon be at the shore. At that point, it will either be filled (choked) with beach sand or provide another point for the disruption and loss of sand flow along the outer shore.

**Interior of Cape Sable**

Prior to canal construction the interior of Cape Sable was a freshwater marsh, probably with pockets of brackish marsh and swamp. The Marl Ridge provided a continuous boundary between Florida Bay and the interior from Flamingo west to Clubhouse Beach where the Ridge turned northwestward and continued north of Lake Ingraham and emerged at the coast north of North Cape and Little Sable Creek (Figure 3). The beaches and capes from East Cape to north of Northwest Cape provided a second, western barrier between the Gulf of Mexico and the interior. Only recently has a remnant section of northern Little Sable Creek penetrated eastward across the Marl Ridge barrier (Figure 28).

Northward along the west-facing Gulf of Mexico coast, the Cape Sable coast is a mangrove wetland into which Big Sable Creek and a series of smaller tidal creeks penetrate 2-3 kilometers inland. There is and was a broad coastal mangrove forest zone in association. These penetrating tidal creeks extend along the north side of Cape Sable but fade as the shoreline turns southeastward along the shore of Whitewater Bay. This interior coast historically appears to have been a wetland shore with a narrow band of mangroves along the edge yielding to inland to brackish and freshwater marsh wetlands within a few hundred meters at most. Although tidal waters could enter from the northwestern, northern and eastern coastlines of Cape Sable, it appears the freshwater head from local rainfall, combined with reduced salinities with in Whitewater Bay, limited mangrove and other saline communities from penetrating significantly into the interior. As sea level had been only very slowly rising prior to 1930, wetland communities would have build positive elevation within the interior wetland through peat and root accumulation. The probable lack of major hurricanes for some long time prior to the 1930s (see earlier section on Hurricane Impacts to Cape Sable) also should have promoted mature peat buildups both at the shore and in the interior.

Canal construction originally appears to have had a dramatic effect on the southern portion of the interior of Cape Sable. As we move towards the present, the dramatic rise in sea level become increasingly dominant in driving change in the vegetative communities and substrate stability throughout the interior of Cape Sable.

**Southern Interior.** The 1928 aerial photographs show the Homestead Canal, inner East Cape Canal, and inner Middle Cape Canal distinctly as they were cut through a vast freshwater marsh. In fact, the canals visible on these photographs are two lines: the narrow canal plus the line of dredged up material alongside. One flight line of January 1935 aerial photographs extends along Cape Sable at about the latitude of the Homestead Canal. In this photograph, there is clear evidence that the areas of marsh near the canals are collapsing and converting to open water (Figure 47). By the 1953 aerial photographs, much of the canal lines and the marsh itself are gone and the area converted to open water (Figure 48). This collapse of the marsh revealed small irregularities in underlying

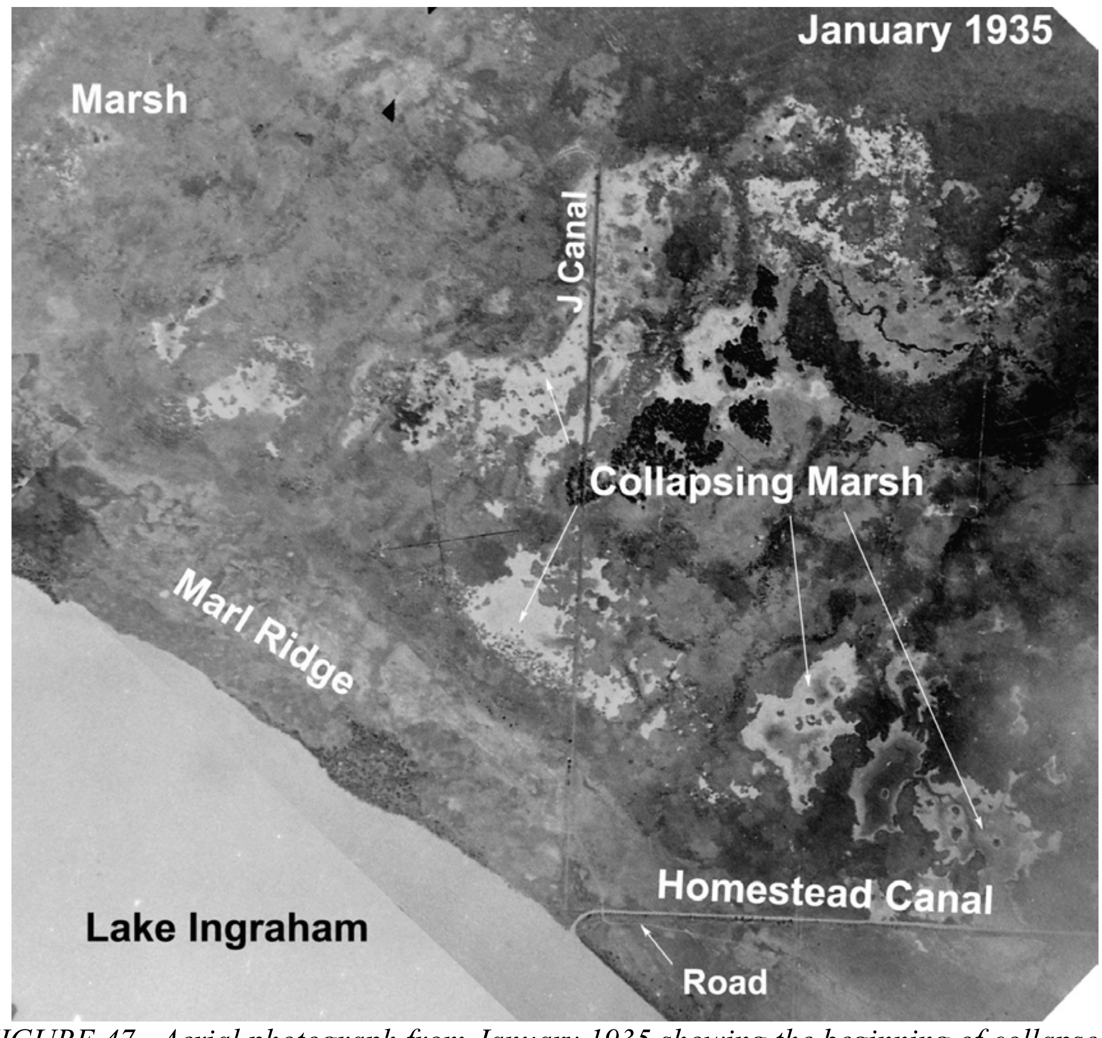



*FIGURE 47. Aerial photograph from January 1935 showing the beginning of collapse of the interior marsh adjacent to western Homestead Canal and a canal extending northward from the Lake Ingraham. Further from these canals, marsh survives. (Coast and Geodetic Survey acc614 #427 and 428).*

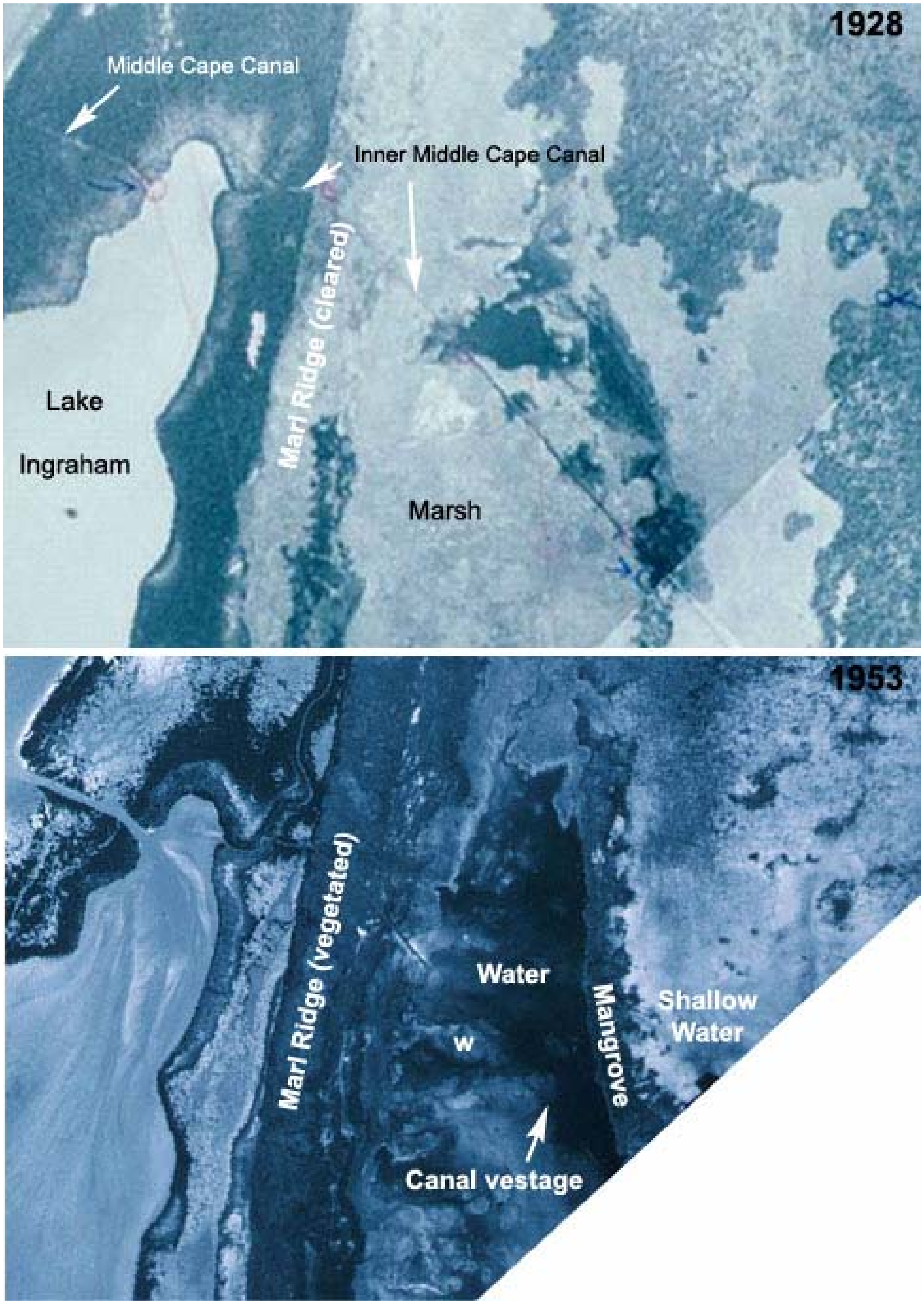



*FIGURE 48. Aerial photographs from 1928 and 1953 documenting the collapse of the marsh behind the Marl Ridge in the vicinity of Middle Cape Canal. Note the distinct Inner Middle Cape Canal in 1928 and its essential disappearance by 1953. "w" is one of several sediment washover lobes into the collapsed marsh area.*

marl topography, which had been hidden by the marsh and marsh peat (Figure 3). The higher marl areas became, by 1953, colonized by mangroves. As described in the Paleo-Everglades section at the beginning of the Results, most of these higher topographic features were older coastal marl ridges and channel margin levees formed several thousand years ago (Figure 4).

What caused much of the southern interior marsh to collapse by 1953? There are three possibilities to explain the collapse. First, the opening of the canals to the shore would have resulted in a lowering of the marsh levels. This would have revealed the pre-existing topography but cannot explain the total collapse of the peat and conversion to open water. Second, the 1935 Labor Day Hurricane, which was described as sending a six-foot storm surge plus waves across Cape Sable (Semple, 1936) could certainly have ripped up areas of marsh that were floating or not firmly attached to the substrate below. Indeed Craighead (1964) describes Hurricane Donna as lifting up whole areas of mangrove forest and moving those, creating instant new islands; Gunterspergen et al. (1995) and Cahoon (personal communication) describe Hurricane Andrew crumpling and rolling up large areas of marsh on the Mississippi Delta; and the visible 1935 elimination of the forested wetlands (probably mangrove) adjacent to Lake Ingraham (Figures 39 and 40) demonstrates the devastation that did occur on Cape Sable. It thus must remain a possibility that the 1935 hurricane caused or influenced a portion of this collapse of the southern interior marsh.

Third, abrupt saline intrusion through the constructed canals may have triggered the collapse of the interior marsh. Arguments favoring this conclusion are (a) the area of interior marsh collapse is adjacent to the areas of canal construction, not elsewhere, (b) the widespread collapse was well underway by the January 1935 aerial photographs, (c) the mangrove communities which formed on the higher marl topography reflect saline influence in the former marsh, (d) rapid salinity shifts would kill the freshwater marsh areas and initiate decay collapse before other vegetation (mangroves or salt marsh sedges) could move in to colonize and maintain the marsh surface, and (e) the sediment washover lobes ('w' in Figure 48) have come in after the marsh has collapsed. The evidence is convincing that saline intrusion along the constructed canals caused the collapse of the southern interior marsh of Cape Sable.

In our field research in open water areas of the southern interior, we found that there is a marl surface at 30-100 cm below the present mean water surface and that this is capped by only a few centimeters of soft organic muck (decayed peat). This cap is all that is left of the original marsh peat, which must have been 30-150 cm in thickness (the interior freshwater levels and marsh having been somewhat elevated by the unbroken Marl Ridge to the south and west). The nature of the sediment and sequences in the interior is discussed in the Sediment Inventory section below.

Since the widespread marsh collapse by 1953, the southern interior shows two important trends. First, the areas of open water have continued to gradually expand northward (Figure 49), and second, the areas colonized by mangrove have evolved (Figure 50).

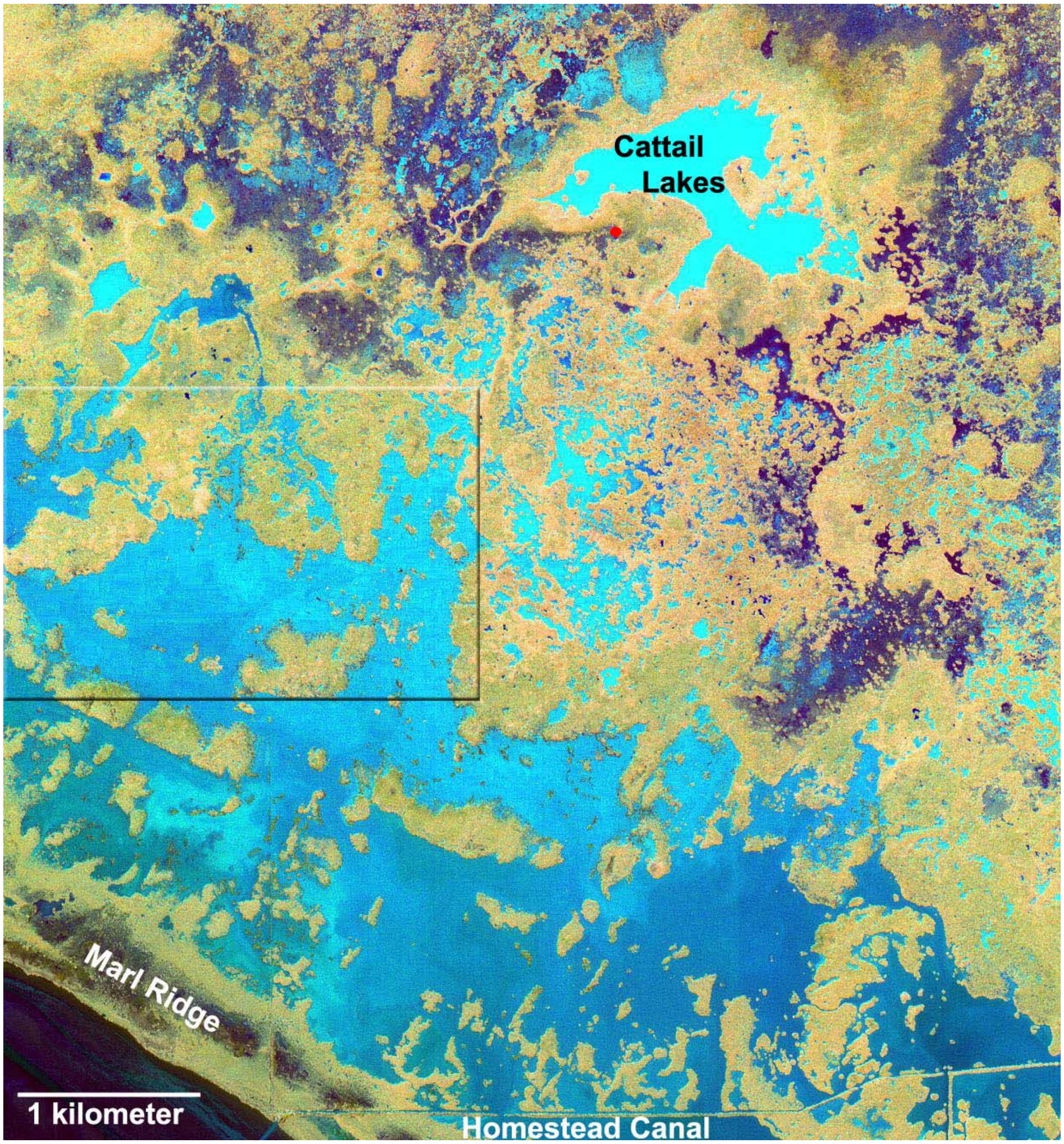



*FIGURE 49. Satellite image from 2002 showing mangrove (tan) and open water (blue) replacing marsh (purple). Most visible marsh areas are now a mix of sedges and shrubs. Open water areas are expanding northward. Boxed area is shown through time in Figure 50. The red dot site south of Cattail Lakes is illustrated in Figure 52.*

The northward expansion of open water is more patchy than the initial widespread collapse. We interpret this to be the results of a continued and gradually expanding saline intrusion into the interior marshes. This expanding influence is caused by the rise of sea level since 1932 which has caused increasingly frequent overwash of the NW-SE trending portion of the Marl Ridge by marine waters, rising base level of the sea which has decreased drainage from the interior, and the canals themselves. The canals are a complex influence. If they are not blocked by dams, they are a source of significant salt

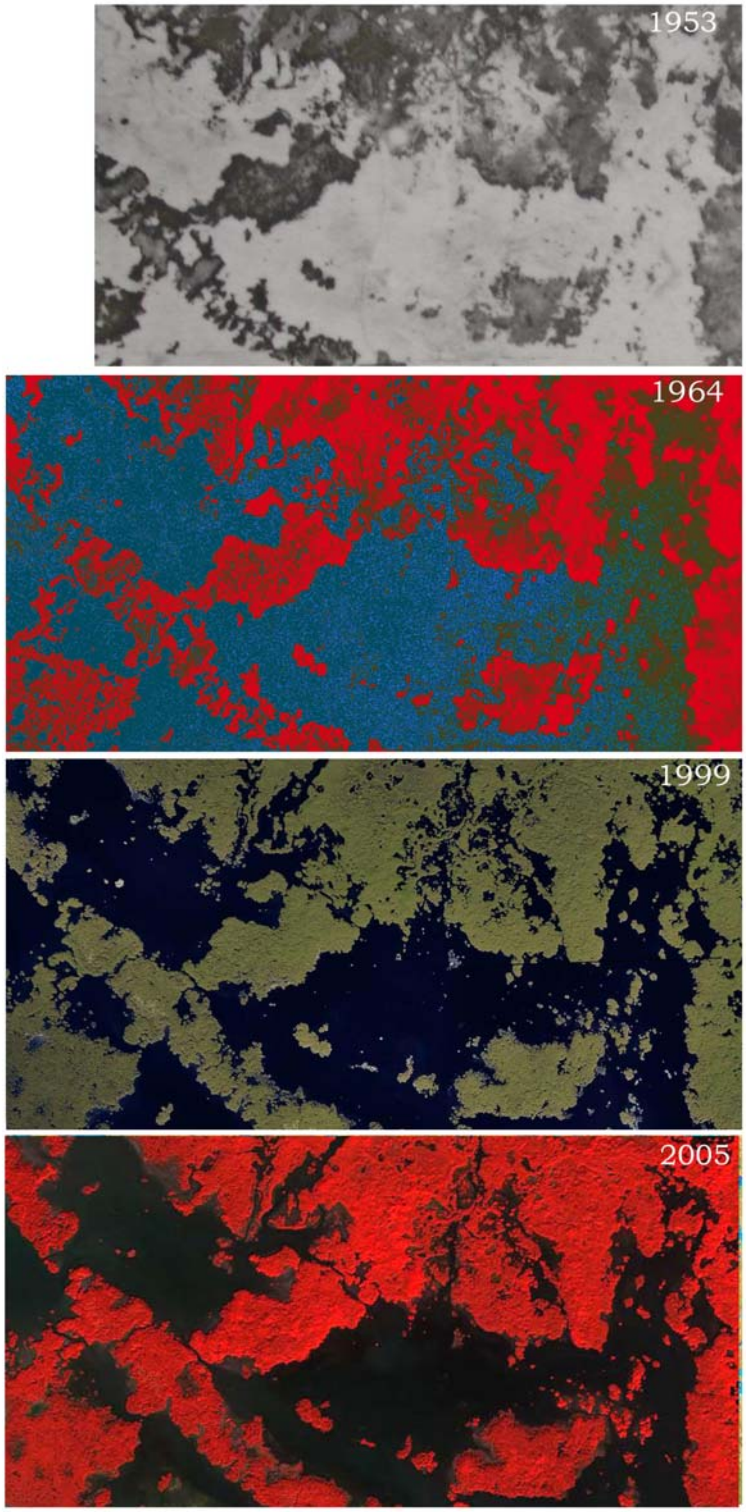



*FIGURE 50. Sequential aerial and satellite images of southern interior of Cape Sable from 1953 to 2005. The mangroves (dark, red or green) that formed on topographic marl highs has generally expanded filling in the smaller water gaps (light grey, blue or black). Some smaller mangrove islands have disappeared. Images are about 1.5 kilometers in height. See box in Figure 49 for image location.*

*FIGURE 51. Photos within southern interior area of collapsed marsh. From top left, coring adjacent to mangrove island, barnacles encrusting dead log, and spoonbills at low tide near western end of Homestead Canal.*

water introduction during flood tides. If the canals are blocked by dams, the marine waters and salt content that overwash the Marl Ridge cannot return seaward but are forced to build up and spread out across the interior.

The higher topographic marl areas were significantly colonized by mangroves by the 1953 aerial photographs. With time, most mangrove areas have expanded and filled in small water gaps, but a few mangrove areas have eroded away (Figure 50). Today, the southern interior is a complex of shallow open water less than one meter in depth (Figures 2, 3, and 10, 34, and 49-51). The water on our canoeing and helicopter visits was 20-43 parts per thousand (ppt) salinity. Barnacles and oysters grow in the intertidal; a variety of fish (including redfish), nurse sharks, crocodiles inhabit the waters; and shore and wading birds are abundant (heron, ibis, spoonbill, and white pelican). Black mangroves predominate on the marl highs, though a few higher areas have upland forests. Red mangroves are helping to expand some gently sloping interior shorelines. The more common abrupt shorelines margins have black mangrove to the edge.

**Central and Northern Interior.** The central and northern interior of Cape Sable looks, at first glance, as though the wetland is thriving (Figure 2). In a sense it is, but on a closer look the original freshwater wetland communities are being replaced by saline wetland communities. Furthermore, many areas experience a severe drop in wetland surface elevation or loss of the wetland altogether during this transition.

The following descriptions are the result of reconnaissance field work to assess the present nature of the central and northern interior wetland, and to see what is preserved of its original condition.

Simply put, the entire interior of Cape Sable is in transition from a freshwater wetland to a saline wetland. Most of the interior is dominated by red mangrove trees interspersed with open water areas. Scattered among this are small areas in which some marsh vegetation has survived. We visited three sites on February $10^{th}$, 2005.

First, a small area of marsh wetland just southwest of Cattail Lakes (see red dot in Figure __ for location) contained a nearly complete intermixture of freshwater, brackish, marine and hyper-saline flora – from sawgrass to mangroves to Salicornia (photos in Figure 52). The surface water salinity was 43 ppt and the sawgrass looked to be in poor condition. A core collected there illustrates just how tenuous the substrate elevation and survival is during a transitional phase (Figure 52). The upper 20 centimeters has an abundance of living roots, but there are few below. On drying the core, less than one tenth of the original volume was left. Organic matter is being consumed and oxidized, leaving little substrate of substance. The wetland is basically floating on an organic soup. It would not take much disturbance to lose this wetland to open water.

Second, a small marsh area west of Mud Bay in the northern interior provided a dramatic display of what happens when sawgrass dies out. At this site there ware patches of surviving saw grass and areas where the saw grass had recently died. There was a 75 centimeter loss in marsh elevation between the living and dead sawgrass areas, some

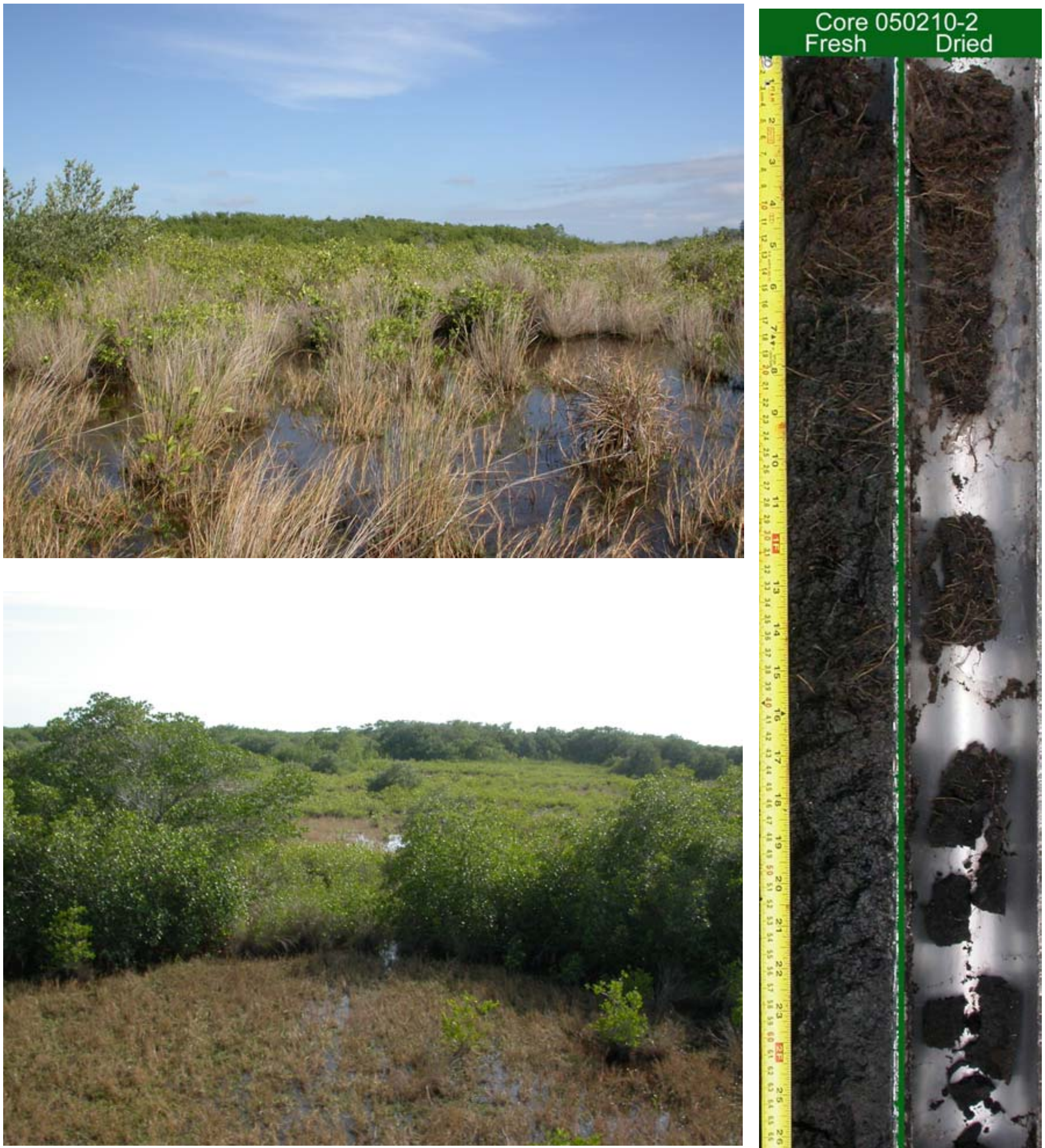



*FIGURE 52. Site undergoing transition from sawgrass to saline wetland, south of Cattail Lakes (see red dot on previous Figure for location). Salinity of surface water at the site was 43 ppt on February 10, 2005. Sawgrass was highly stressed and brown, and being replaced by mangroves and Spartina. Salicornia were abundant ground cover. Core #67, 67 cm in length, has abundant living roots to about 20 cm but few below. The left is the core wet and freshly opened. The right is after drying. On drying, the peat shrinks to less than one tenth of the original core volume. The core was not to the underlying limestone surface.*

boundaries sloped and some vertical drops (Figure 53). It appears that the peat rapidly oxidizes, decays, and compacts down to a position near water level. Scattered red mangroves are colonizing at the lower level. There are also other freshwater shrubs in the area. Surface water salinity was 28 ppt at the time of the February 10, 2005 visit.

This northern interior wetland west of Mud Bay has a curious pattern of water and wetland in the aerial photographs (Figure 54). There are E-W trending lineations of wetland vegetation. The areas between are lines of ponds subdivided by wetland vegetation. As shown at the bottom of Figure 54, both the E-W lineations and the small ponds in this interior wetland between Mud Bay and Big Sable Creek are fixed, unchanging features since 1929, even though the character of the wetland is changing form freshwater sawgrass to saline mangrove. Such pronounced stable linear wetland features must be physically formed, likely sediment (mineral or organic) depositional or erosional features resulting from a pre-historical major hurricane surge.

Third, a site just northeast of Fox Lakes had an extensive marsh containing a mix of *Spartina* and saw grass growing densely (Figure 55). The salinity was 9 ppt. A 78 cm (30 inch) deep core in the marsh revealed a robust dark reddish root peat in a darker peat matrix (Core #66; Figure 55). This appears to record living *Spartina* roots in a previous freshwater peat accumulation. This area has transitioned from fresh to saline marsh wetland, retaining an essentially continuous cover and robust peat production and substrate.

*FIGURE 53. Sawgrass marsh dying and wetland surface rapidly subsiding in northern Cape Sable interior west of Mud Bay. Sonny Bass, NPS, stands at boundary in upper photo; co-author Brigitte Vlaswinkel marks living sawgrass peat surface at 75 cm above dead, collapsed level in lower photo. Surface salinity was 28 ppt on February 10, 2005.*

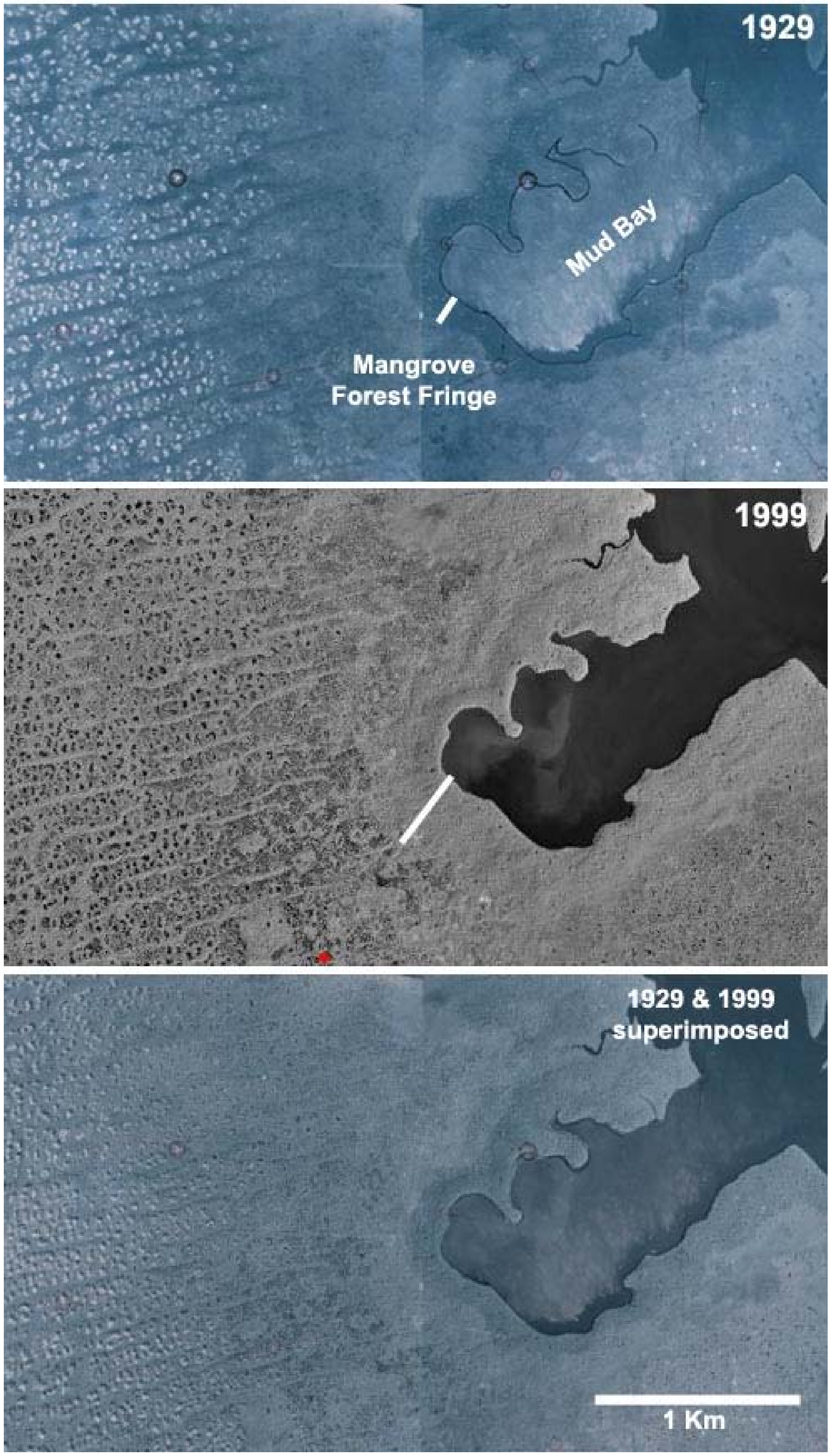



*FIGURE 54. Aerial images from1929 and 1999 of Mud Bay and the northeastern interior of Cape Sable. White bars highlight the inward expansion of the tall mangrove forest in response to sea level rise. Slightly offset superimposed images show that E-W linear wetland ridges and associated individual ponds have not changed over these 70 years. Red dot at bottom of 1999 image is approximate location of site in Figure 53.*

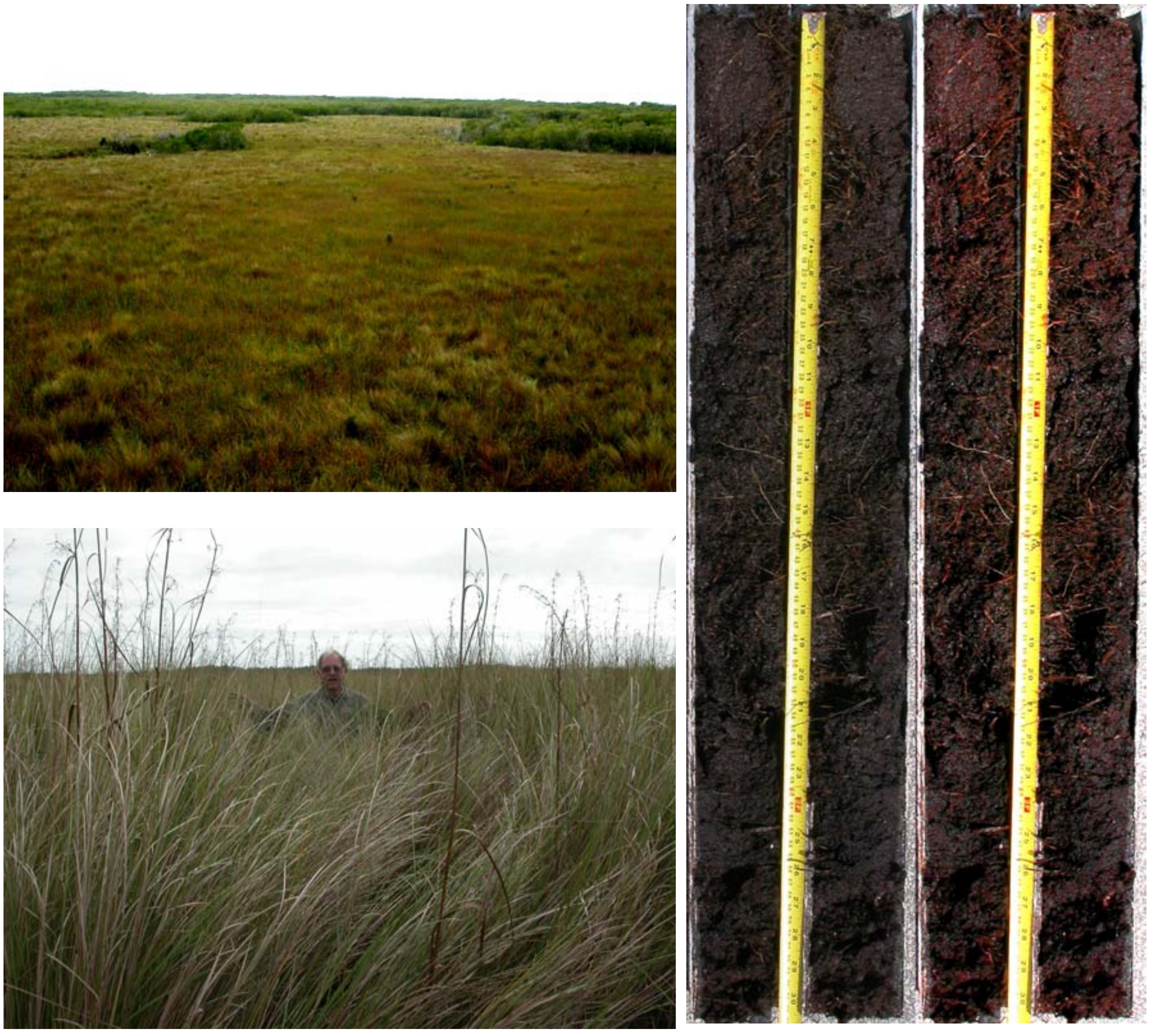


*FIGURE 55. Left: Aerial and ground photographs of mixed Spartina (clumps) and sawgrass (more uniform) marsh just northeast of Fox Lakes. Aerial photo is contrast enhanced to better differentiate marsh types. Co-author Harold Wanless provides scale for Spartina and sawgrass growth. Right: Core #66, 78 cm in depth from site, showing robust Spartina root peat in black peat matrix. Core on left is natural color; same core on right is color enhanced to show reddish nature of living Spartina root peat in matrix of black peat. Surface water salinity was 9 ppt on February 10, 2005.*

**Eastern Shoreline of Cape Sable Facing Whitewater Bay.**

**Mud Bay Area of NE Cape Sable.** Mud Bay, interpreted to be a relict of the Everglades drainage system prior to 2,500 years ago, is representative of the eastern coastline of Cape Sable facing Whitewater Bay (Figures 2 and 4). This coastline is isolated from human modifications made to southern Cape Sable and is not directly influenced by historical changes in Everglades water levels or flow schedules. Changes observed should reflect natural influences and trends, especially hurricane events and sea level changes. The most significant change observed along Mud Bay and the rest of the eastern coast of Cape Sable is the inward advancement of the fringing mangrove forest (compare white bars in the 1929 and 1999 images in Figure 54). In 1929 the mangrove forest fringe was less than 150 meters in width. By 1999, it had expanded to over 450 meters. This change is considered to represent the effects of sea level rise. Aerial photographs from 1940 show damage to the margin of this forest caused by the 1935 Hurricane, but essentially no shoreline erosion occurred during the 1929-1999 period.

**Whitewater Bay Shoreline of SE Cape Sable.** South of Mud Bay, the mangrove forest fringe thins but persists in the 1929 aerial photographs, and a pronounced, broad, generally featureless marsh extends into Cape Sable (Figure 56, top). Today, mangroves, *Spartina*, and other salt tolerant plants have moved into the former freshwater marsh and the coastal mangrove forest fringe has expanded. Small (dwarf) red mangroves are a common replacement. One coastal area, just west of the entrance to Tarpon Creek (southeast Whitewater Bay), retains a mangrove coastline by has a broad, continuous marsh behind (Figure 56). This is now a mix of sawgrass and *Spartina*. This area was pointed out to us by Dr. Sonny Bass with Everglades National Park.

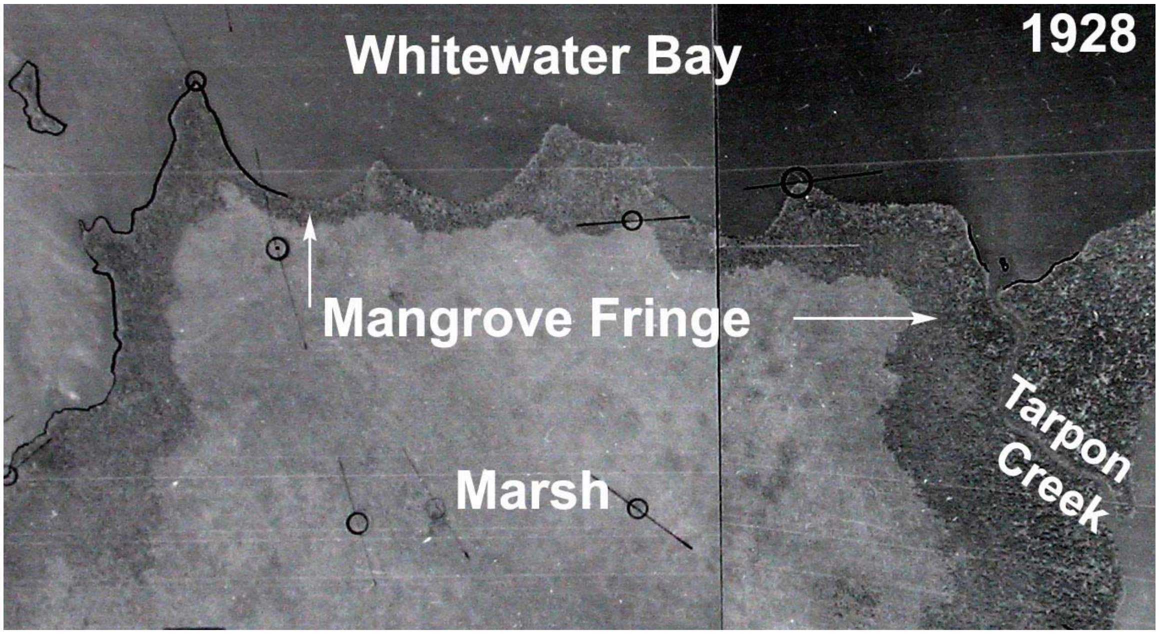



*FIGURE 56. Top: Aerial image from 1928 of southeastern Cape Sable coastline facing Whitewater Bay, just west of Tarpon Creek. There is a narrow (less than 100 meters in width) mangrove fringe with abrupt transition to interior freshwater marsh. Bottom: Oblique aerial photo to NW taken February 10, 2005 showing marsh still surviving. This is one of the few areas with surviving widespread marsh in the Cape Sable system. This site was pointed out to us by Dr. Sonny Bass, ENP-NPS.*

# SEDIMENTS AND SEDIMENT DYNAMICS

## Middle Cape Canal and Surroundings

The following hydrodynamic and sediment parameters have been measured at the mouth of Middle Cape Canal (figure 57): current velocity and direction, water level and the amount of suspended sediment in the water column (turbidity). All instruments were mounted on frames that were placed on the bottom of the inlet (3.5 m deep); parameters were collected continuously every 10 minutes over time periods ranging from days to 4 weeks. Table 2 orderly lists the station name, measured time period and type of data collected.

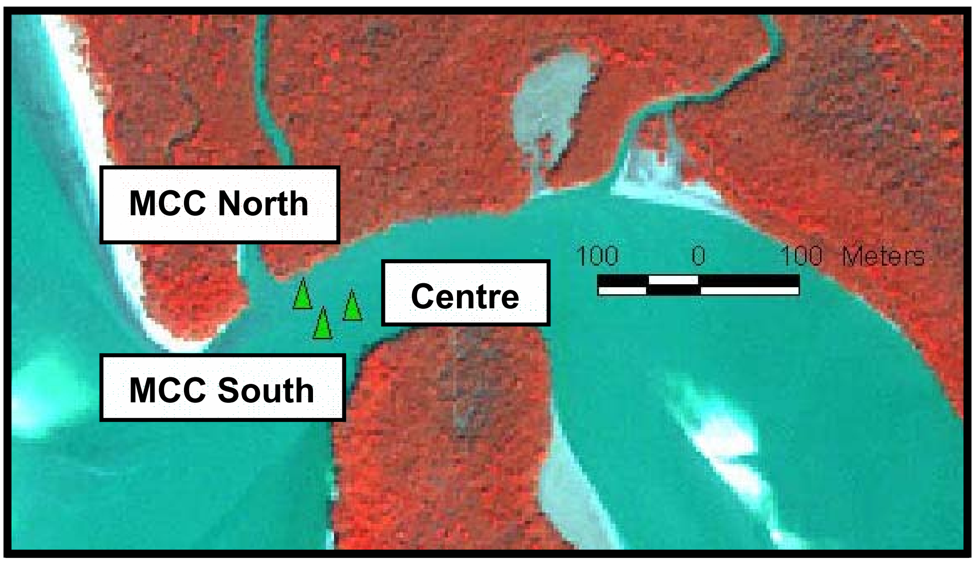



*FIGURE 57. Location of three hydrodynamic measurement stations in the mouth of Middle Cape Canal. (Ikonos multispectral image 2005, pixel size 4 $m^2$.)*

| | MCC CENTRE | MCC SOUTH | MCC NORTH |
|---|---|---|---|
| **01/09 – 02/09 2003 (winter)** | | Currents<br>Water depth | Currents<br>Water depth |
| **07/31 – 08/15 2003 (summer)** | Currents<br>Water depth<br>Turbidity | | |
| **01/22 – 02/02 2004 (winter)** | Currents<br>Water depth<br>Turbidity | | |

*TABLE 2. Hydrodynamic dataset collected in Middle Cape Canal (MCC) in 2003 and 2004*

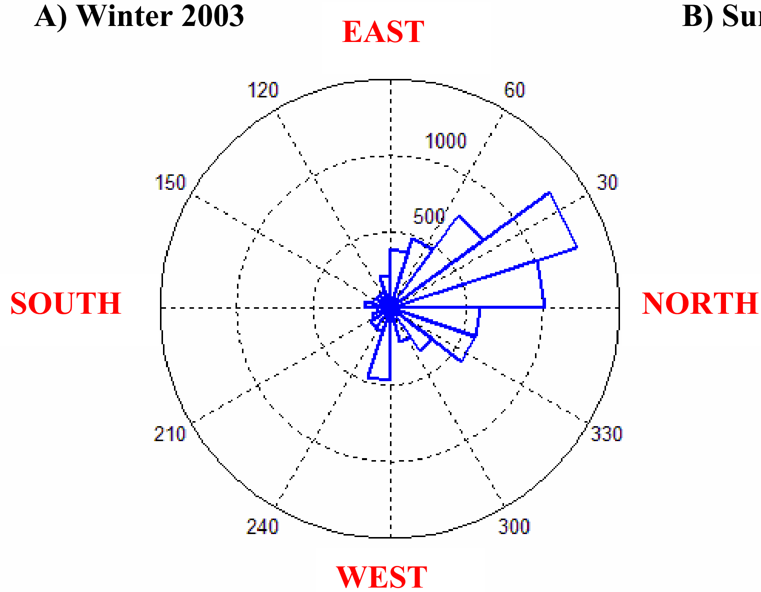
**Tidal and Current Patterns**

During the first measurement campaign in the winter of 2003, we measured current velocities and directions with ultrasonic current meters (Figure 58) at two locations in the inlet throat of Middle Cape Canal. During the four weeks of data collection, the weather was relatively mild but two strong cold front events moved through. The dominant wind direction was northeast (figure 59A) and the average wind velocity was 9 mph (Figure 60A). The wind data is collected at a meteorological station 1 nautical mile south of East Cape (25° 05.061' N, 81° 05.744' W) that collects meteorological data every 6 minutes (Figure 61)*( http://comps1.marine.usf.edu)*.

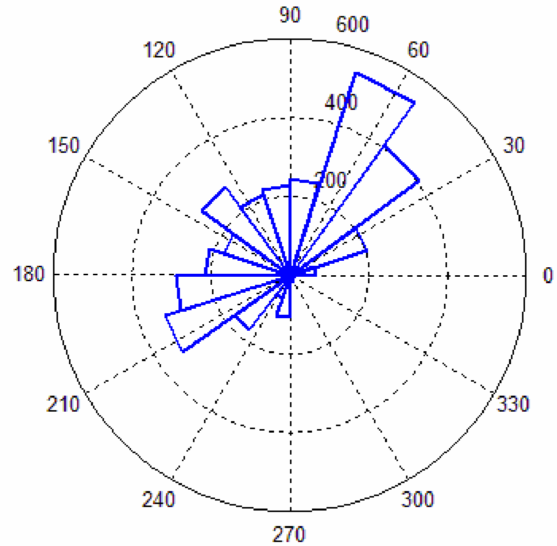
*FIGURE 58. Ultrasonic Current Meters*

*The ultrasonic current meter (UCM) applies the Travel Time Difference principle that uses the interaction effects between a moving fluid and acoustic waves. The velocity of the acoustic pulse varies with water temperature, pressure and salinity, for which the UCM compensates automatically. The instrument also measure pressure (water depth), has a real-time internal clock and a compass to establish true direction and velocity of the current. Velocity is measured in the X (cross-shore, $0^{O}$), Y (longshore, $90^{o}$) and Z (vertical). The sensor is programmed to provide 5 data samples each 10 minutes that are averaged into one value each 10 minutes. Accuracy of the current speed is 5 mm/s and 0.2% for the pressure sensor.*

**A) Winter 2003**




**B) Summer 2003**




**C) Winter 2004**

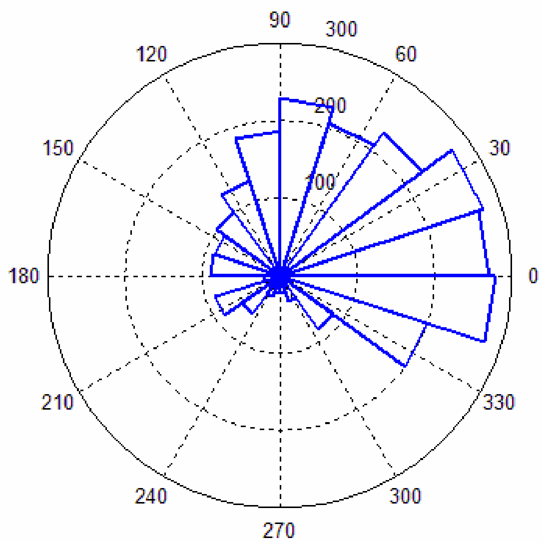
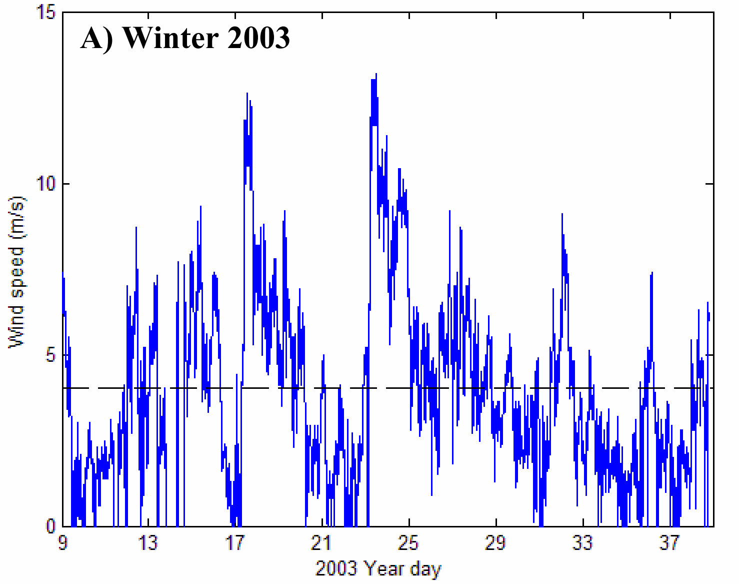
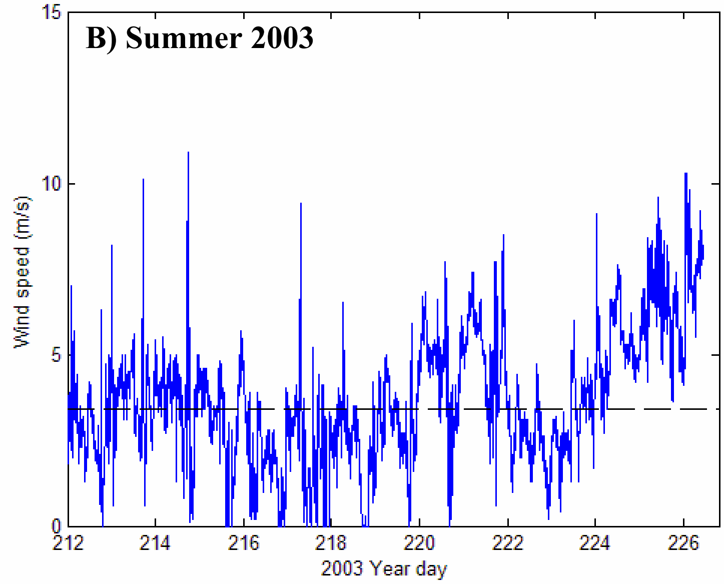



*FIGURE 59. Wind direction during measurement campaigns. Notice these matlab plots are projected with zero degrees (north) at x-axis and degrees move counter-clockwise (standard mathematical expression). Circular dashed lines indicate frequency of certain wind direction. For example, in the first graph: more than 1000 times did the wind come from around 30 degrees (northeast). A) Jan-Feb 2003; B) August 2003; C) Jan-Feb 2004.*
*Notice the seasonal effect on wind direction. Winters have a preponderance of north winds, summers have prevailing east-southeast winds.*



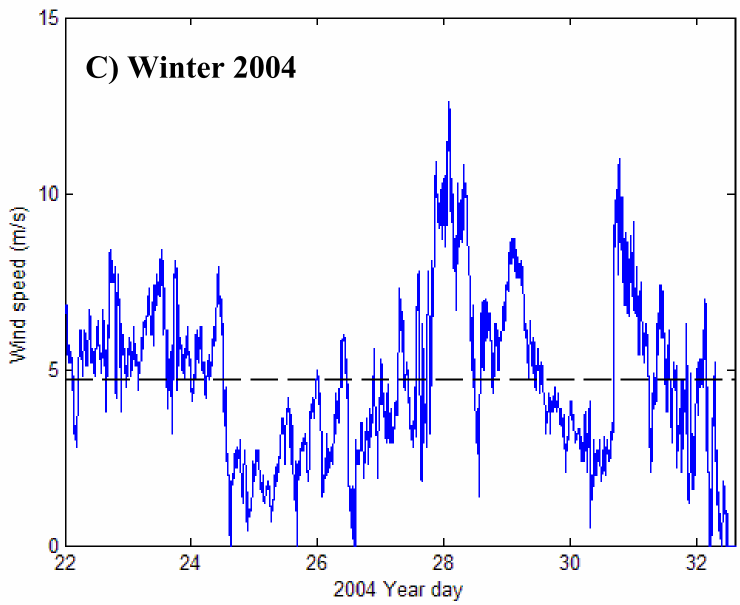




*FIGURE 60. Wind speed during measurement campaigns. Dashed lines are mean wind velocities. A) Jan-Feb 2003: Average wind speed is 4 m/s (9mph). Two cold fronts occurred, the first with max. wind speeds of 28 mph (Jan 17-18) and the second one with max. wind speeds of 30 mph (Jan 24-25). B) August 2003. Average wind speed is 3.6 m/s (8 mph). C) Jan-Feb 2004. Average wind speed is 4.7 m/s (11 mph). Two cold fronts moved through, first with max. speeds of 28 mph (Jan 28-29), second with max. speeds of 25 mph (Jan 31).*

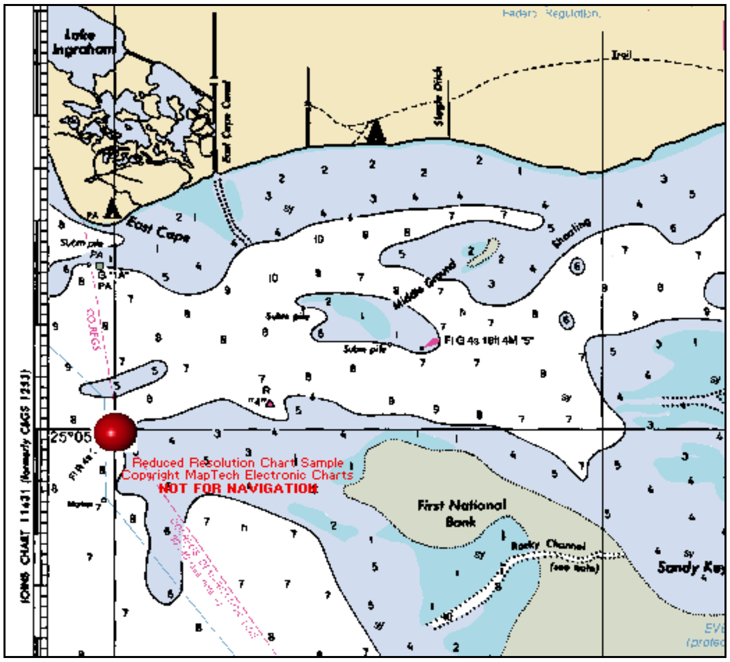



*FIGURE 61. Location of meteorological measurement station 1 nautical mile south of East Cape (http://comps1.marine.usf.edu/nfb). Photo by Burwell.*

The exact time of high and low tide at Middle Cape Canal is one hour ahead of the predicted times of high and low tide at East Cape (http://www.saltwatertides.com). The minimum neap tidal range at the mouth of Middle Cape Canal is approximately 0.6 meter while maximum spring tidal range is between 1.4 and 1.8 meter (data from field measurements). The average tidal range is approximately 1 meter. During spring tide, the tides have a very strong daily inequality (alternation of semi-diurnal tides with greater and lesser amplitude) (Figure 62). During neap tide the semidiurnal amplitudes are less unequal.

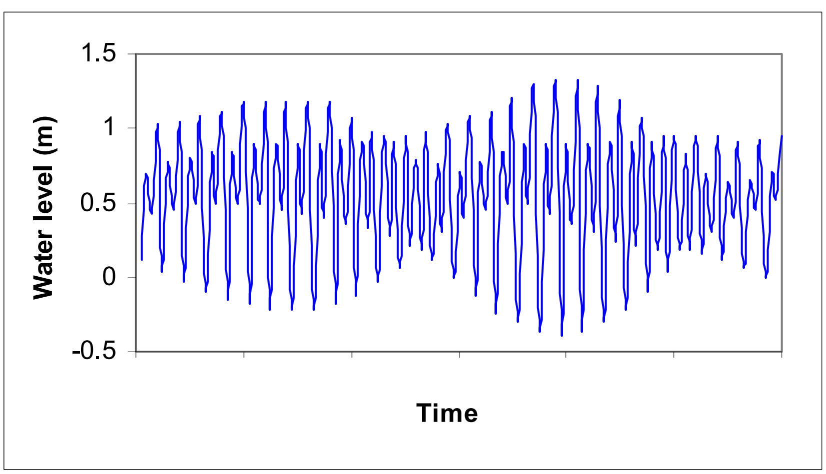



*FIGURE 62. Example of predicted tides for January 2004. Notice the large daily inequality during spring compared to neap tide (daily inequality = one large high tide is followed by a small high tide; one large low tide is followed by a small low tide, etc.).*

We can conclude from this first dataset that there is no significant tidal asymmetry at the mouth of Middle Cape Canal. However, there is a substantial time lag (up to one hour) between water level and current flow. As water level goes down after it reaches its highest point (slack high tide), water still flows in for considerable time. As water level slowly goes up again after slack low tide, water is still draining from the lake (Figure 63).

Because of this time lag, the flood and ebb flow have different pathways in the mouth of the inlet. The flood current comes in along the south bank of Middle Cape Canal, as ebb waters occupy the northern bank (outer curve) of the inlet (Figure 64). These observations were made with a boat-mounted current meter (Acoustic Doppler Profiler – Figure 65). Figure 66 is an example of two cross-sectional profiles measured across MCC inlet, displaying the high velocity core shifting from one side to the other with changing tidal phase. In general, the outflow is much stronger than the inflow in Middle Cape Canal (Figure 71): ebb velocities are sometimes twice as high as flood velocities. Currents during ebb tide can reach up to 200 cm/s, which is 4 knots. Upper flow regime is observed both during inflow and outflow (Figure 67). These velocities are extremely high for the present cross-sectional area of 338 feet, indicating that Middle Cape Canal is a tidal inlet out of equilibrium.

During the summer of 2003 and the winter of 2004, we measured again current speed and direction but this time also the amount of suspended sediment in the water column. We deployed an Acoustic Doppler Current Profiler (ADCP – Figure 68) simultaneously with a turbidity meter (Figure 69 and 70). Figure 71 and 72 display respectively the time series of summer 2003 and winter 2004. During the two weeks in August the winds were light (average 8 mph) and mostly from easterly directions (Figure 59B and 60B). During the two weeks in the winter of 2004 winds were mostly from the north (average 11 mph). Two moderately strong winter storms came through.

Hydrologic differences between dry and wet season are present. The maximum tidal range is higher in summer (1.8 m) than winter (1.4 m) and ebb velocities are consistently higher during the wet season. This is naturally an expression of increased rainfall during the summer months. More freshwater is draining through the canals and little creeks (Raulerson Brother's Canal, "J" Canal, Homestead Canal) that connect the inland marsh areas with Lake Ingraham.

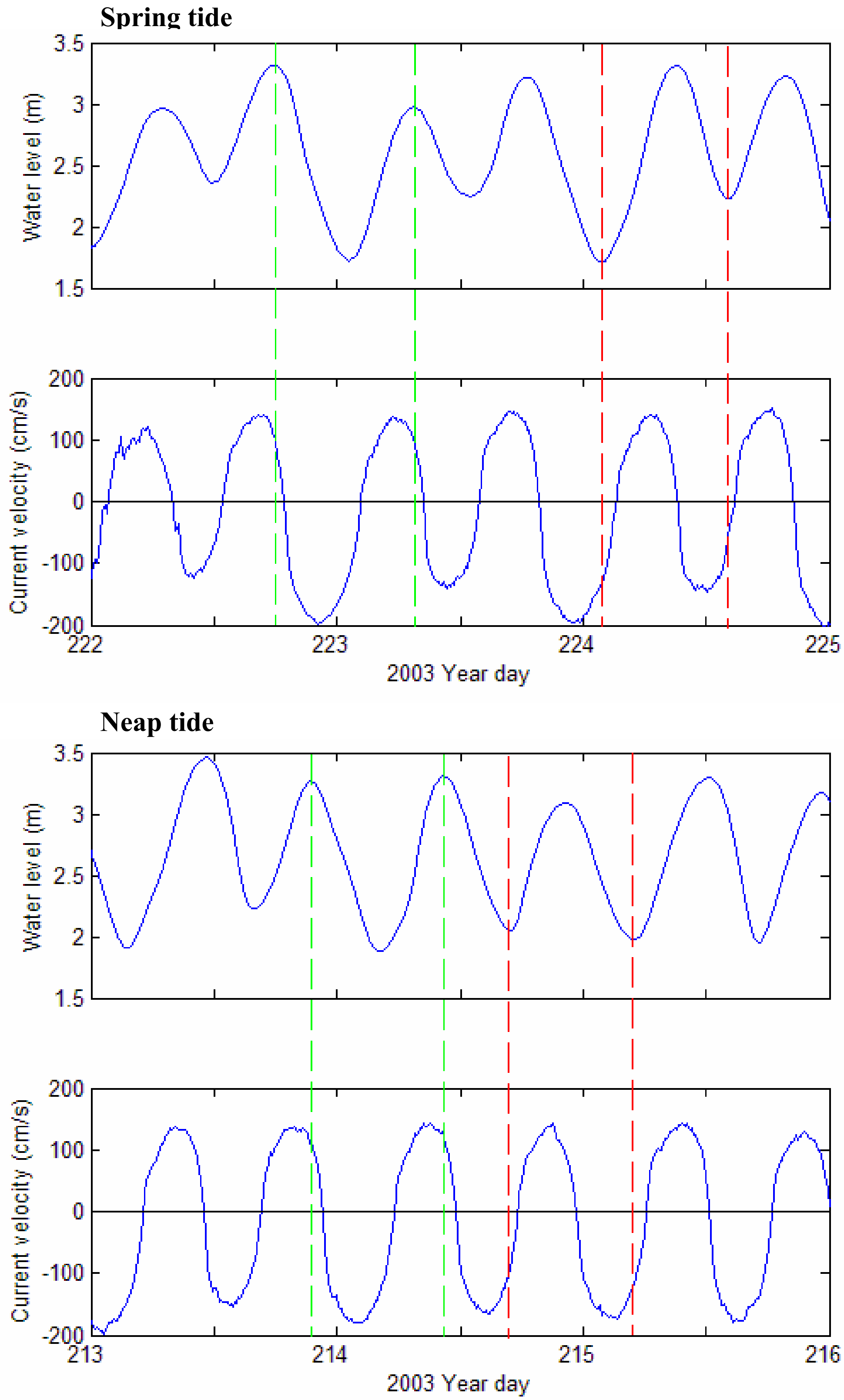



*FIGURE 63. Time series of water level and current velocities in MCC (August 2003) during spring tide (top) and neap tide (bottom). Positive velocities are incoming tide, negative velocities are outgoing tide. Green dashed lines cross the water level exactly at slack high water. 1) Notice that water is still flowing in at slack high tide (velocity is still positive). Red dashed lines cross the water level plot exactly at slack low tide. Notice that water is still flowing out (velocity is still negative). Spring tide: notice the daily inequality of water level and ebb velocities (one large, one small, one large, etc).*

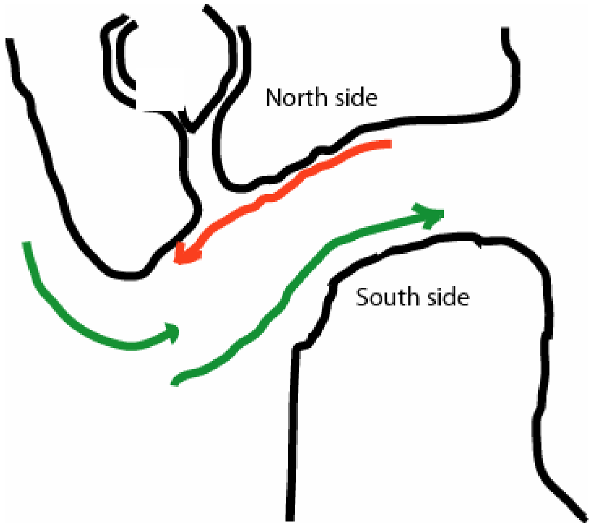
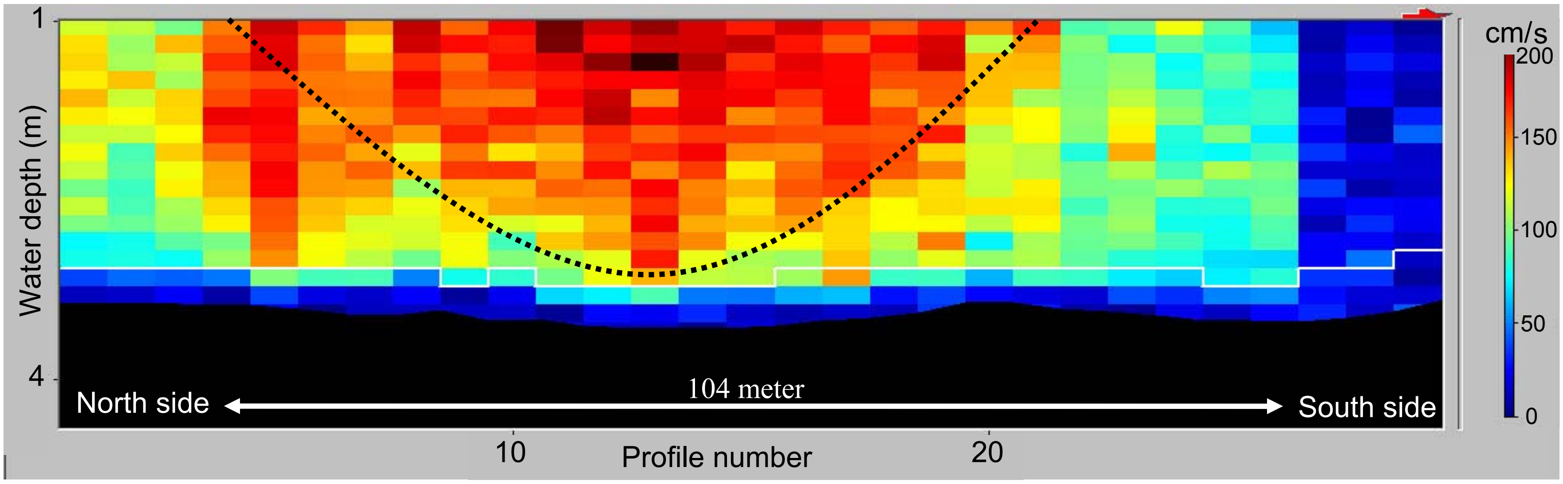



*FIGURE 64. Schematic plan view of the main pathways of the flood current (green) along the south side and the ebb current (red) along the north side of Middle Cape Canal inlet.*

*FIGURE 65. Acoustic Doppler Profiler (ADP) from Sontek, mounted on an Everglades Research vessel used during all the field measurements. The ADP measures water motion in three dimensions (X,Y,Z) throughout each profile of the water column as the boat travels from one side of the creek to the other. It also collects data on position, distance traveled and bathymetry. This information is used to calculate the net flux of water (discharge) throughout any cross-section. The accuracy is 5mm/s.*

**August 2003: Ebb**




**August 2003: Flood**

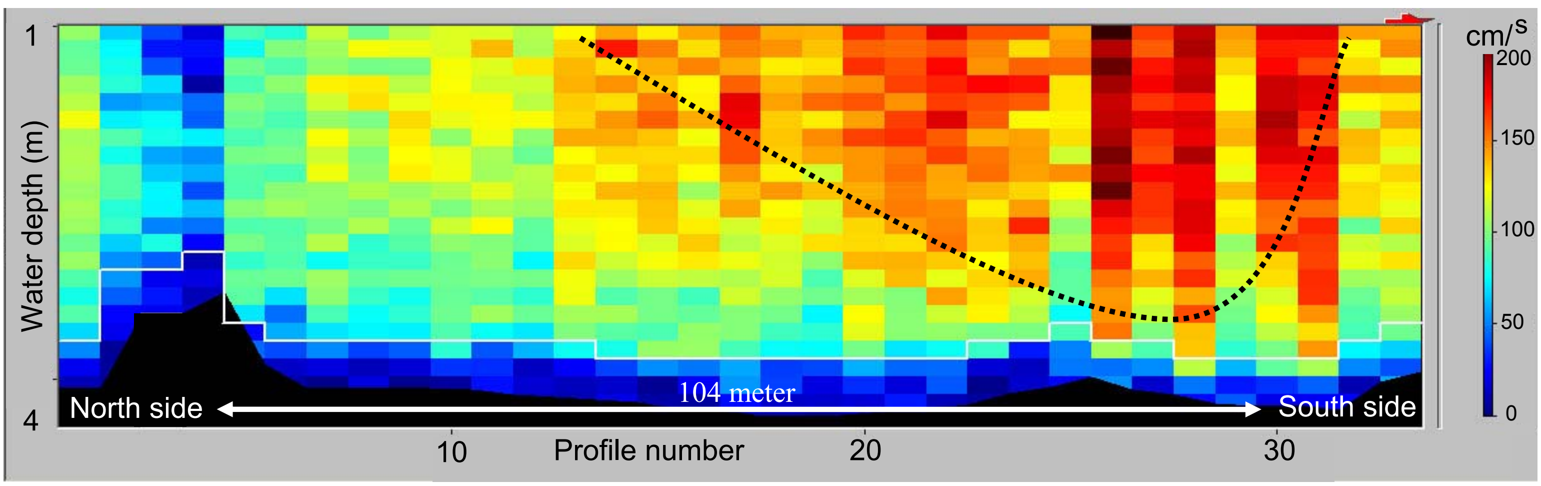



*FIGURE 66. Cross-sectional profiles of current velocities through Middle Cape Canal during maximum ebb (top) and flood velocities (bottom), measured with the ADP (August 11th 2003). Notice the shift of the core of highest velocities (red colors) from the north/middle side during ebb towards the south side during flood.*

*FIGURE 67. Upper flow conditions during flood tide at entrance to Middle Cape Canal on February 21st 2003 during calm weather. View is to south across channel. Red arrow points into direction of flow.*

*FIGURE 68. The Acoustic Doppler Current Profiler (ADCP) transmits narrow beams of sound from three transducers up into the water column and receives reflected sound echoes from plankton, suspended sediment and other particles. The frequency shift between the transmitted sound and echoes (The Doppler Effect) is used to compute the speed and direction of the particles and, thus, of the water in which they are suspended. The resulting backscatter is segmented into 25 cm depth cells which results into a detailed vertical profile of current speed and direction. Accuracy of the current speed is 5 mm/s.*

*FIGURE 69. The turbidity sensor transmits a light beam up in the water column and measures the amount of particles in suspension by the amount of reflected light. This optical device measures at the same frequency (every 10 minutes) as the current meters in order to easily correlate the data. The turbidity readings are calibrated in the lab to a standardized unit (Formazine Turbidity Units) and converted into suspended sediment concentrations on the basis of in situ water samples. A linear regression is applied to the water sample concentrations and the signal of the turbidity meter (Figure 70).*

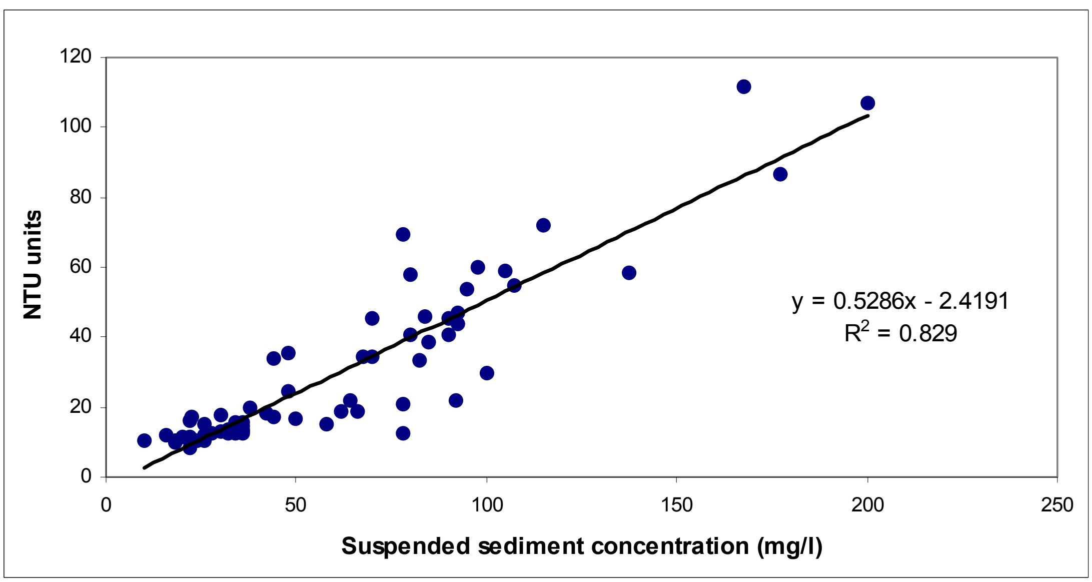



*FIGURE 70. Graph showing relationship between the dimensionless NTU values measured with turbidity meter ( Figure 69) and collection of 65 in situ water samples, which were filtered to obtain real suspended sediment concentrations. Linear regression is applied and $r^2$ is 0.83.*

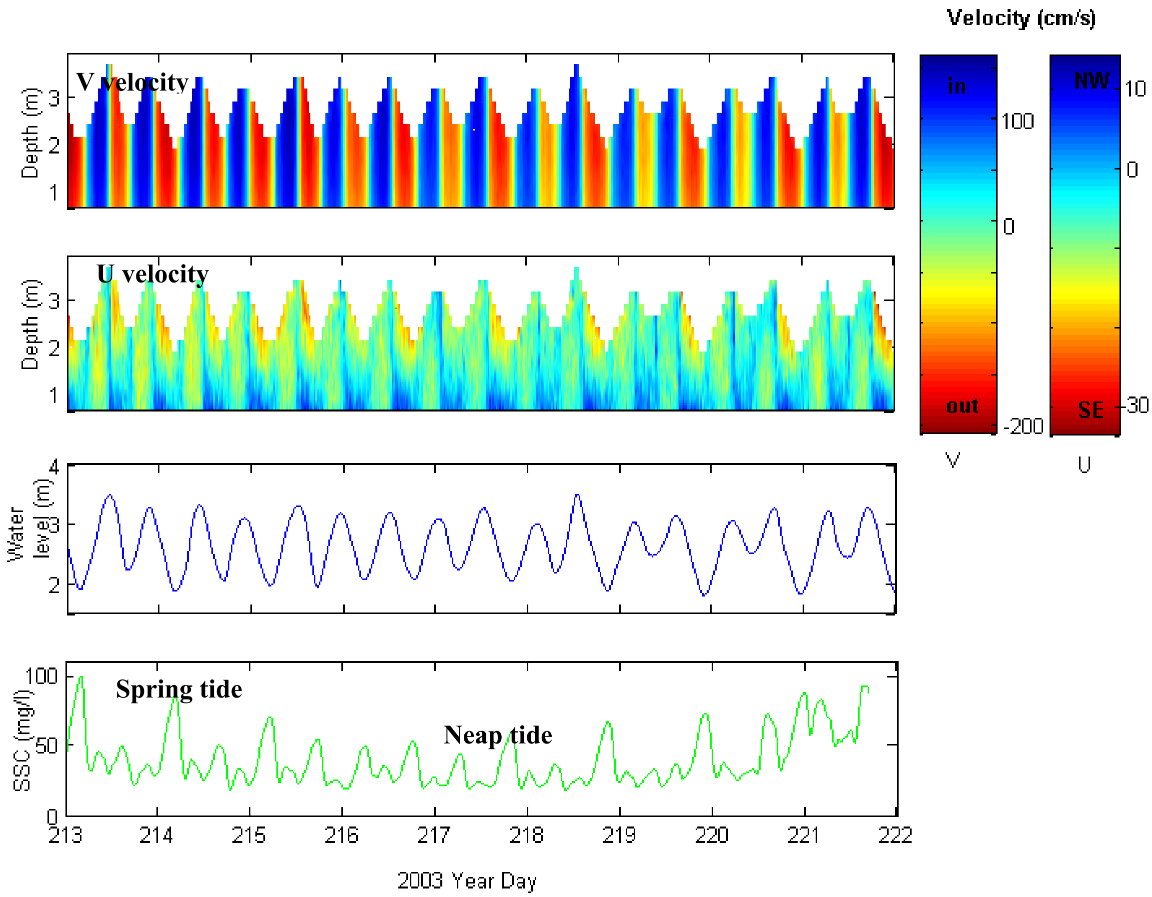



*FIGURE 71. Time series of collected data from August 1 to 10 (2003) in Middle Cape Canal. From top to bottom: V velocity, U velocity, water level and suspended sediment concentration. V velocity is the current velocity perpendicular to the axis of the measured channel and refers simply to in- and outflow. The U velocity stands perpendicular to the V velocity and gives information on shear velocity. Both V and U time series show an undulating vertical velocity profile, reflecting velocities throughout the entire water column as the water level goes up and down. In both velocity profiles the colors refer to the strength of the current: red and yellow tints being outflow, blue and green tints being inflow. The darker the color, the stronger the velocities. 1) Notice that the outflow is much stronger than the inflow; currents during ebb tide can reach up to 200 cm/s. These velocities are extremely high for the present cross-sectional area of 338 feet, indicating that Middle Cape Canal is a tidal inlet out of equilibrium. 2) Notice the effect of spring tide on the strength of the V velocity component, especially during ebbing tides. 3) The vertical velocity profile of the U shows that during ebb the surface water flows in a southeasterly direction (yellow-red colors), while the bottom water flows in a northwesterly direction (darker blue colors).This stronger surface current scours the southern banks of Middle Cape Canal entrance and induces large erosion rates to the south of the inlet. 4) Notice the effect of spring versus neap tide on the water level and consequently on sediment concentration (green time series). During spring tide, tidal amplitude is bigger and therefore velocities are generally higher. This causes more erosion of the channel banks and therefore the sediment concentration also increases.*

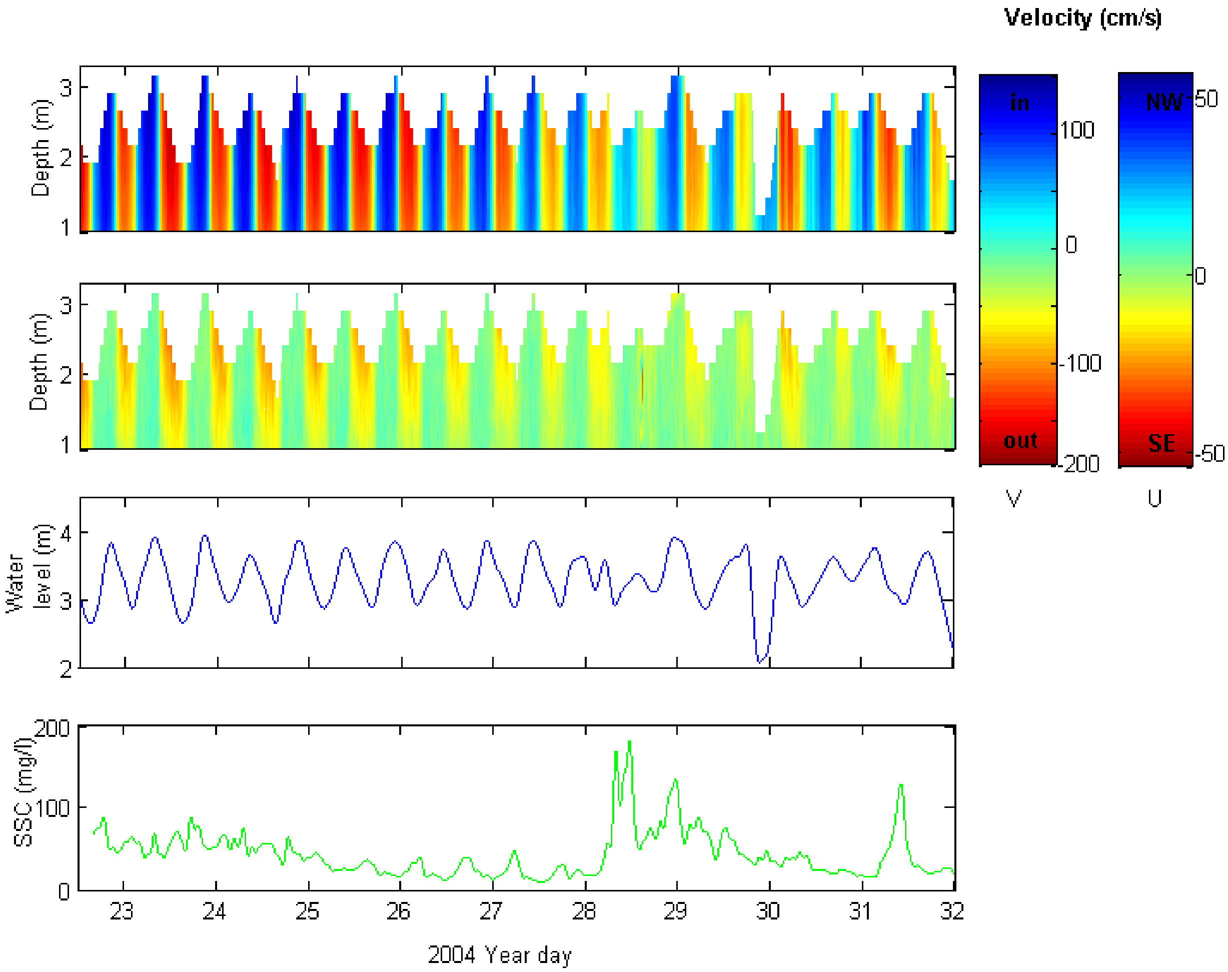



*FIGURE 72. Time series of collected data from January 23 to February 1st (2004) in Middle Cape Canal. For explanation of graph: see Figure 71.*

*1) Notice that the outflow is much stronger than the inflow; maximum current velocity during ebb tide is 188 cm/s, maximum current velocity during flood tide is 151 cm/s.*

*2) Notice the effect of spring tide on the strength of the V velocity component in the first half of the dataset.*

*3) Notice the large peaks in suspended sediment concentration (SSC) on January 28-29 and again on January 31. This is the result of strong onshore winds, stirring up sediment offshore and bringing it into Middle Cape Canal. Relatively good correlation is found between (onshore) wind speed and SSC ($r^2$=0.65) during winter 2004 field campaign.*

Hourly cross-sectional current velocity profiles have been made several days at MCC Centre in 2003/2004. The net flux of water that flows through the cross-section, which is called discharge, is measured with the Acoustic Doppler Profiler (Figure 65). Table 3 lists the maximum flood and ebb discharge measured during spring and neap tide. Discharge measurements have been carried out to obtain a correlation between current velocity and discharge (Figure 73). This correlation is needed to calculate sediment transports.

| DATE | SPRING/NEAP | MAXIMUM FLOOD DISCHARGE (M3/S) | MAXIMUM EBB DISCHARGE (M3/S) |
|---|---|---|---|
| 8/11/03 | Spring tide | 409 | 458 |
| 02/02/04 | Neap tide | 212 | 293 |

*TABLE 3. Maximum flood and ebb discharge through Middle Cape Canal inlet.*

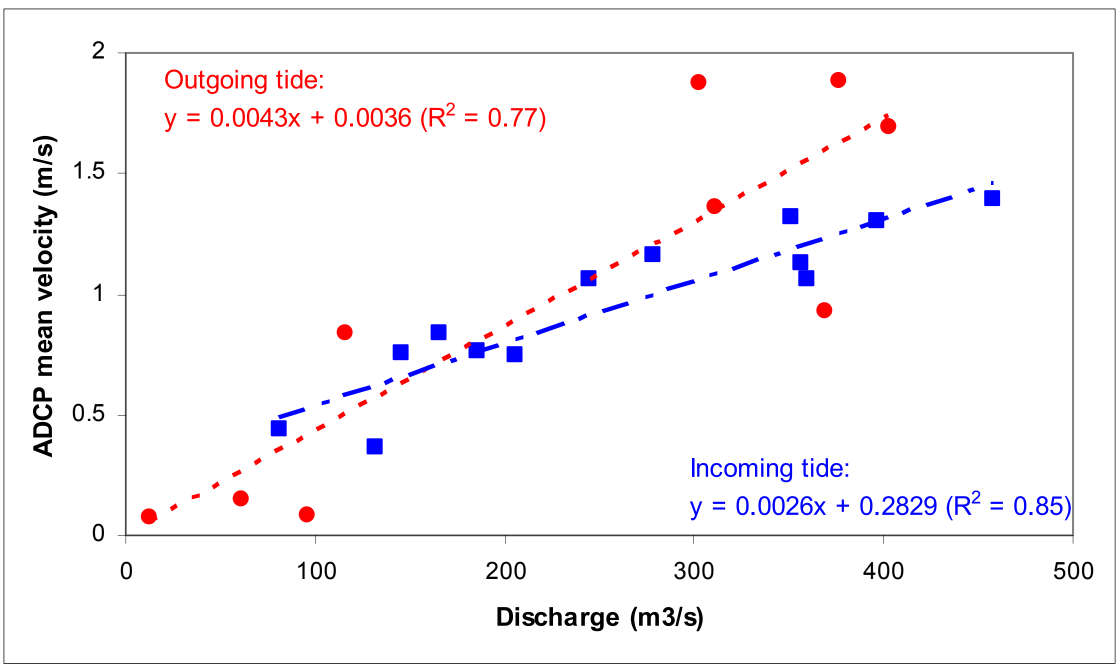



*FIGURE 73. Correlations between ebb and flood discharge and corresponding ebb and flood current velocities in Middle Cape Canal entrance. This correlation is used to create a dataset of continuous discharge measurements, necessary for the sediment transport calculations. Notice the different slopes for the incoming (blue, dot-dash) versus outgoing (red, dashed) correlations. Outgoing correlation slope is steeper, meaning that for the same discharge, higher velocities occur during ebb than flood.*

**Sediment Transport Processes**

Sediment transport flux, which is basically the flow of sediment per unit of area and unit of time, gives information about the total transport of fine particles in and out of a tidal inlet. Suspended sediment transport is calculated by multiplying discharge with suspended sediment concentration integrated over time.

We have calculated suspended sediment transport fluxes at Middle Cape Canal entrance on basis of extrapolated discharge and measured suspended sediment concentrations (SSC). The time series of current velocities measured by the ADCP are used to create time series of discharge through linear extrapolation. The correlations between discharge and current velocities are very good, with $r^2$'s of 0.77 and 0.88 (Figure 73).

As measured with *in situ* water samples during the first field campaign in winter 2003, sediment concentrations are fairly homogeneous throughout the water column. Therefore, the single point measurements that the turbidity meter takes, at a depth of approximately 1 meter above the sediment bed, are extrapolated over the entire vertical velocity profile. Bedload transport is neglected in this study, because fine suspended sediments comprise more than 95% of the accumulated sediments on the creek flanks and on the mudflats in Lake Ingraham.

Figure 74 shows the calculated time series of discharge, suspended sediment concentration and calculated sediment transport in kg/sec for the field days in 2003 and 2004. These sediment loads are integrated over a tidal cycle and the final results are expressed in sediment load (kg) per tide. In Figure 75 the incoming and outgoing sediment loads are displayed separately. Both during the summer and winter field campaigns, more sediment comes in through the inlet during flood than leaves during ebb. This is coherent with our observations that sediment is accumulating in Lake Ingraham. Table 4 gives an overview of the calculated sediment fluxes. For instance, the average amount of sediment that enters through MCC entrance on a single flooding cycle (± 6 hours) in the summer is 240 ton; the average amount of sediment that leaves on a single ebbing cycle (± 6 hours) in the summer is 145 ton. That is a ratio of incoming/outgoing sediment of 1.7. Keep in mind that those numbers are on basis of only a limited amount of days that the instruments were recording. Therefore, these budgets are not necessary representative for the annual tidal transport character of the system, especially considering the large differences of the tidal wave character that exists throughout the seasons (Figure 76).

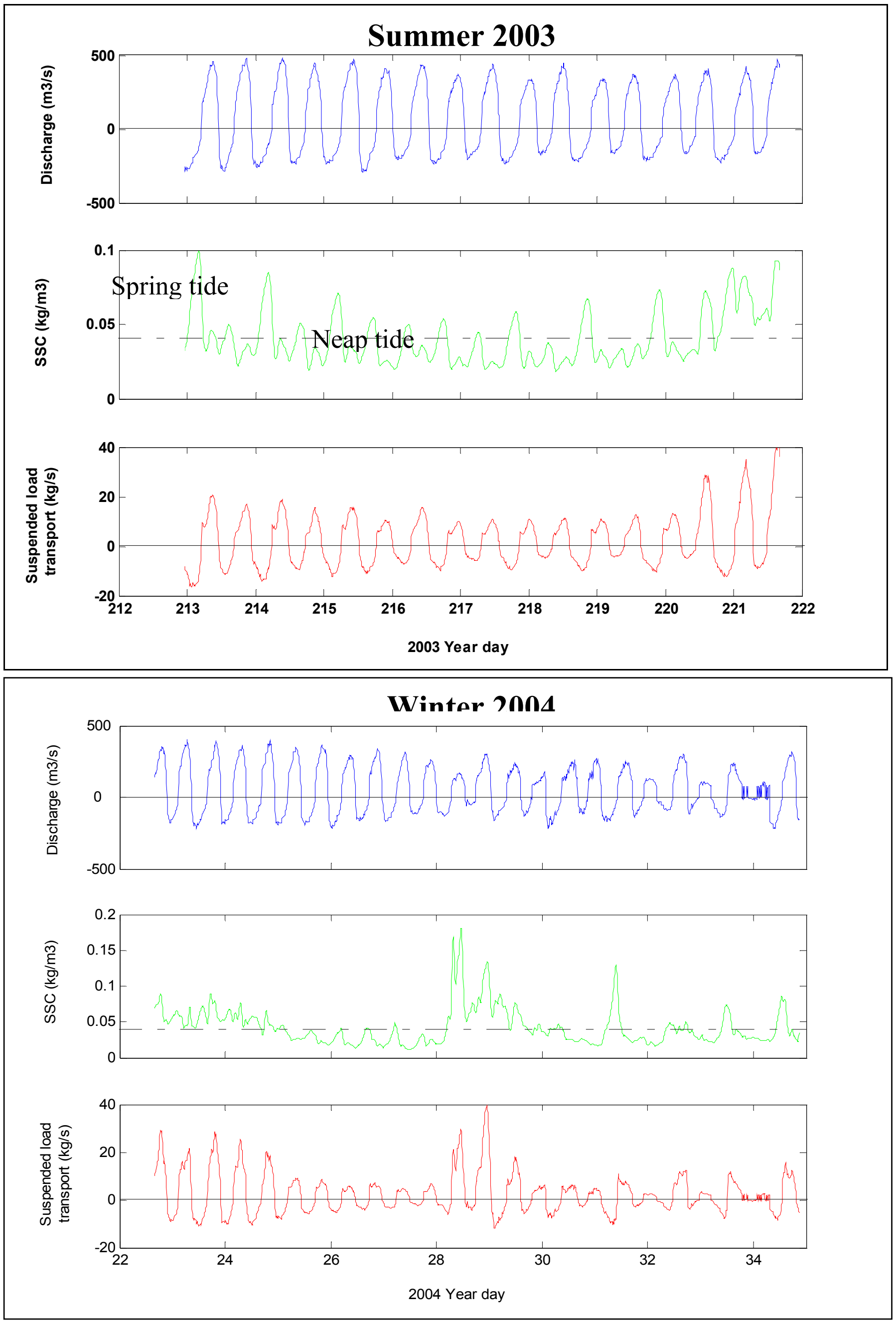
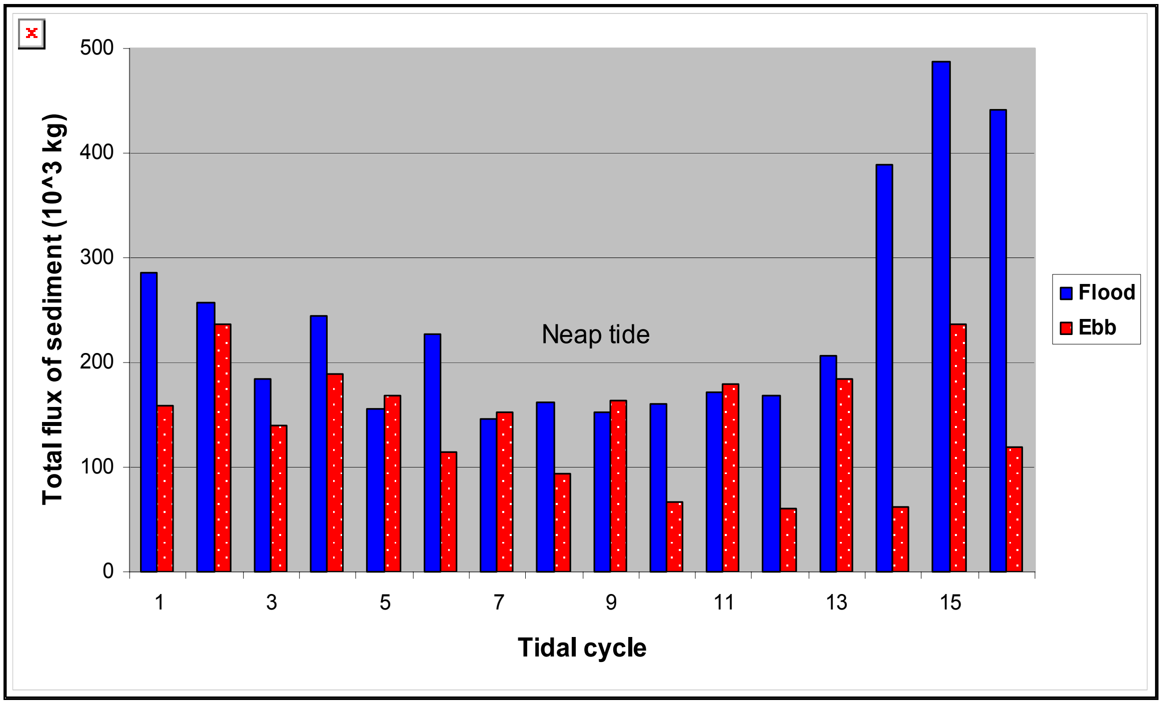



*FIGURE 74. Time series of discharge (calculated), suspended sediment concentration SSC (measured) and suspended load transport (calculated) for summer 2003 (top) and winter 2004 (bottom). Dash-dot lines in SSC plot are the mean suspended sediment concentrations (40 mg/l in summer, 43 mg/l in winter).*

*1) Notice the spring-neap tide signature showing up in the SSC time series of summer 2003.*
*2) Notice the large peak in SSC and resultantly also in the suspended load transport on year day 28-29 in 2004, which is the direct result of strong onshore winds.*



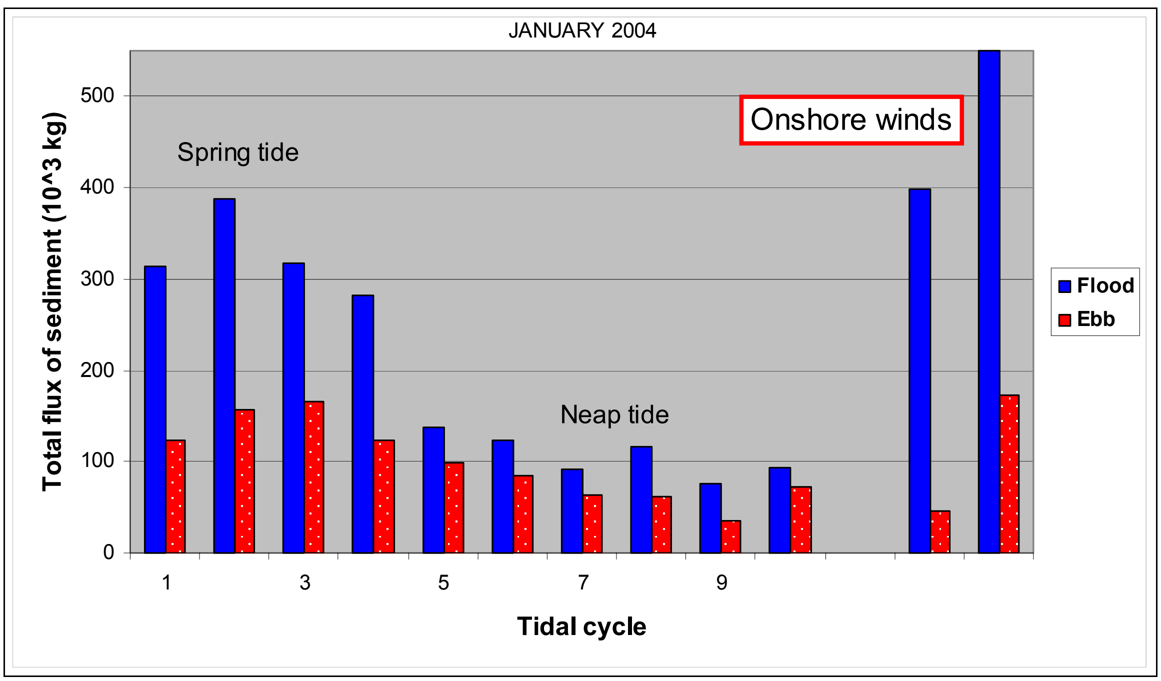




*FIGURE 75. Mass budgets for the suspended sediment load in Middle Cape Canal during August 2003 (top) and January 2004 (bottom). 1) Notice the spring-neap tidal signature and the general excess of sediment flux during flood portions of the tidal cycle, both during summer and winter. 2) Winter 2004: for comparison with "normal" tidal conditions, the sediment load measured during January 28th and 29th (winter storm conditions) is displayed as well (two last peaks to the right of January graph).*

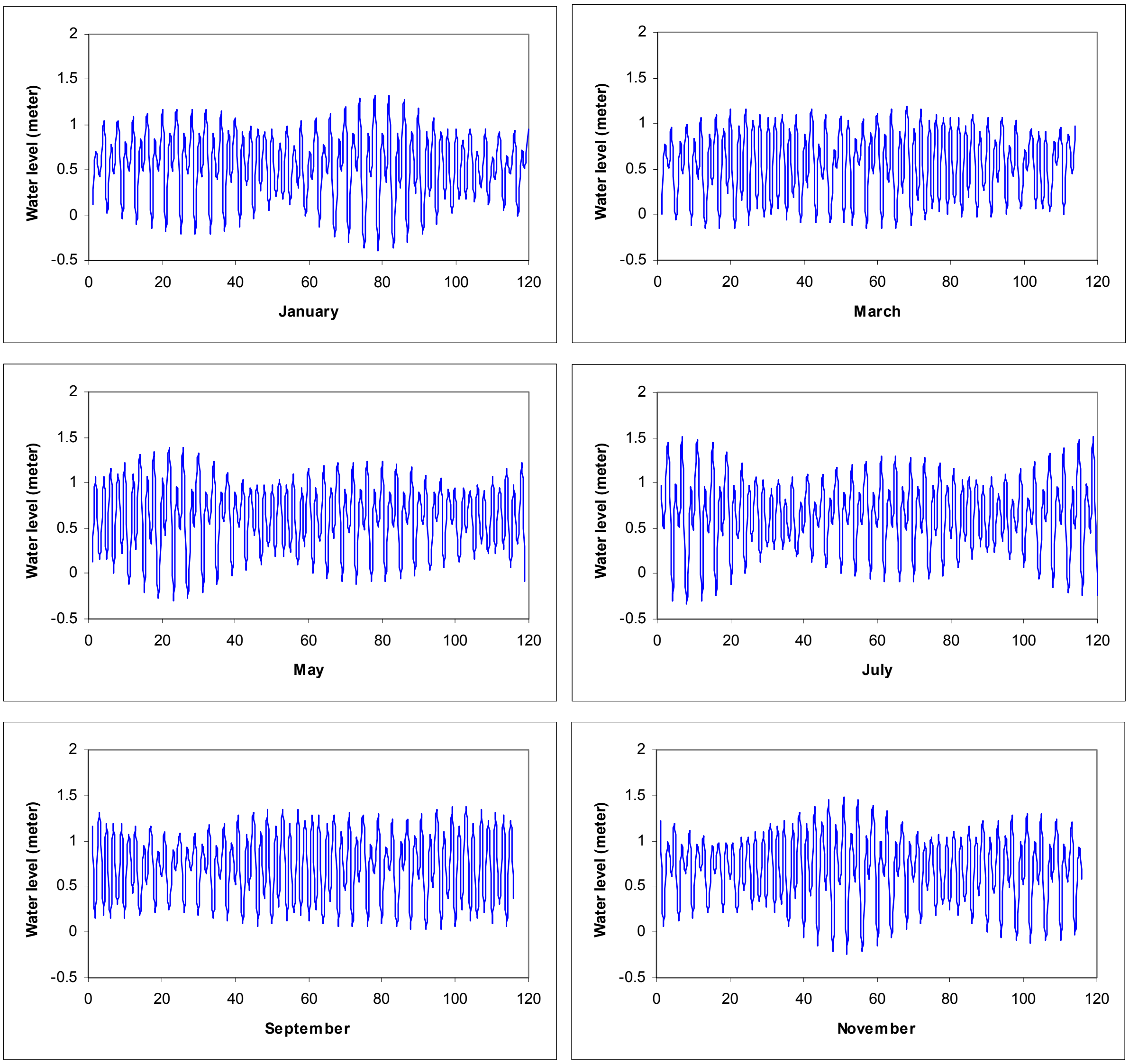



*FIGURE 76. Predicted water levels at East Cape for several months of the year 2004 ([http://www.saltwatertides.com](http://www.saltwatertides.com)). The tidal ranges are used as input for calculation of the extrapolated annual sediment transports at MCC entrance. Notice the large differences of the tidal wave character throughout the seasons.*

To get a more realistic sediment budget and cover all existing tidal ranges, we projected our sediment loads on an entire (arbitrary) year of predicted tides - 2004. For each measured sediment load, we matched the occurring tidal range of that time. After that, for each occurring tidal range in the entire year, we matched the closest sediment load available in our field dataset. Through this method we obtained a sediment budget that represents the tidally-driven sediment dynamics as best as possible.

The results show that slightly more sediment (380 ton) enters Lake Ingraham through MCC than leaves in one year (335 ton) (Table 4). This means that ~ 12% of the sediment transported into Lake Ingraham by daily tidal currents remains within the Cape. This corresponds with $69 \cdot 10^6$ kg of sediment stored within the lake. If this excess of 12% of suspended sediment were spread evenly over the northwest (blue) and central (green) marine portions of Lake Ingraham (Figure 77), the thickness of the sediment column would increase at a rate of 5.5 mm/year.

Bear in mind that this accumulation rate is derived from tidally-driven transport only and the effect of storms is not taken into account. As one can see in Table 4 and Figure 75b, the importance of strong onshore wind events coinciding with incoming tide have an enormous effect on the overall sediment input. This is confirmed by the good correlation between suspended sediment concentration and wind speed ($r^2$ = 0.65). To summarize, the indirect hydrodynamic calculations are good indicators for which processes are acting when and to what extent, but their absolute values of sedimentation rate might not be very accurate.

| | **Sediment load IN ($1 \cdot 10^3$ kg)** | **Sediment load OUT ($1 \cdot 10^3$ kg)** | **Ratio IN/ OUT** |
|---|---|---|---|
| Summer data | 240 | 145 | 1.7 |
| Winter data | 194 | 99 | 2 |
| Storm event data | 474 | 109 | 4.4 |
| EXTRAPOLATED | 380 | 335 | 1.1 |

*TABLE 4. Calculated average sediment loads per tide (IN = flooding tide; OUT = ebbing tide), both based on field data (light grey) as well as extrapolated on basis of field and predicted tides (darker grey). Notice that storm events increase the incoming sediment load more than twice. Also, higher outgoing sediment load in summer (145) compared to winter (99) is most likely a reflection of dry/wet seasonality.*

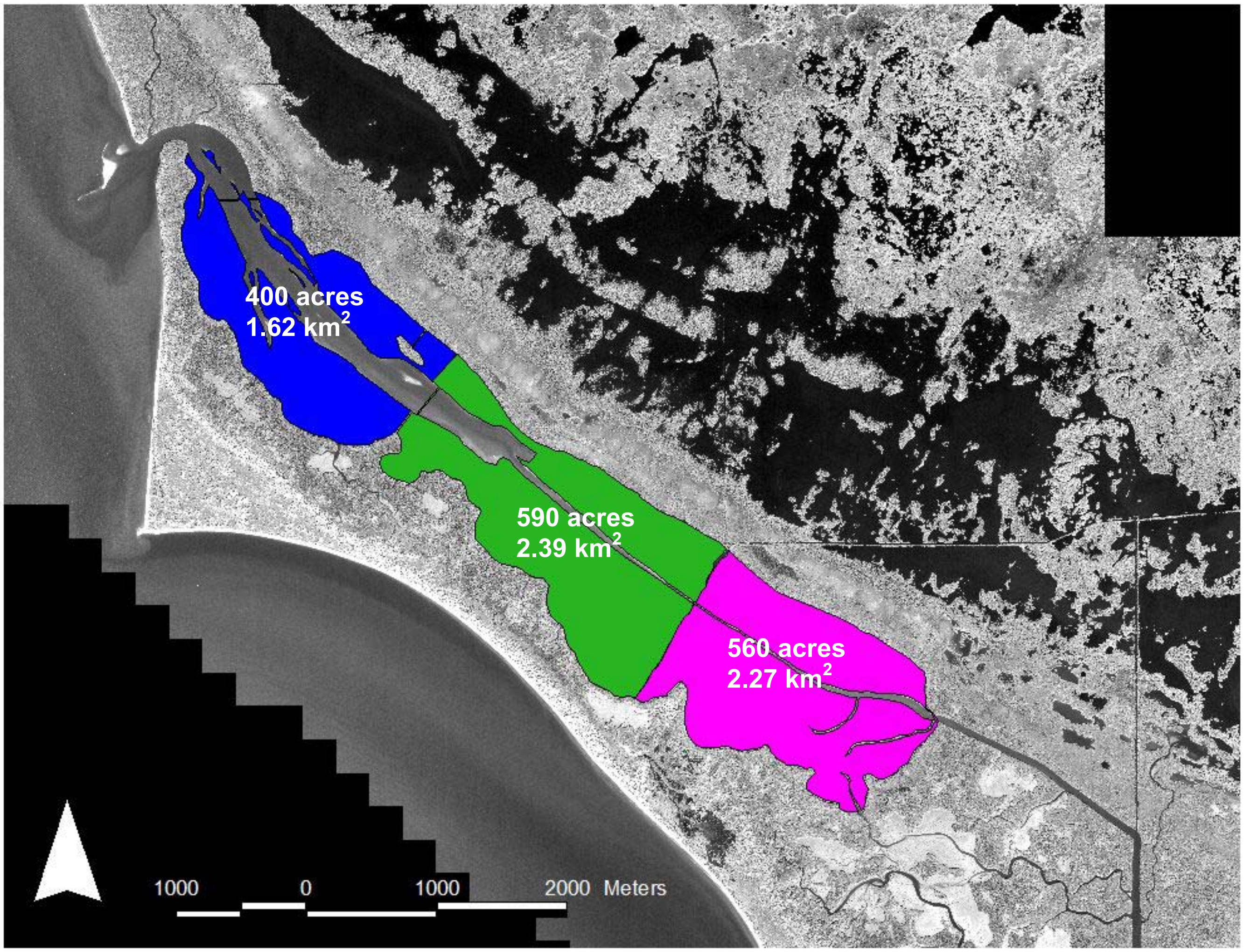



*FIGURE 77. Surface areas in Lake Ingraham: total intertidal mudflat area is 6.28 km$^2$. During each spring high tide these colored areas are submerged. Marine water enters through Middle Cape Canal (left top) and East Cape Canal (right bottom). Tidal node (location with only vertical tide, no horizontal tide) is at the boundary of green and pink areas – where Homestead Canal drains into Lake Ingraham. Blue surface area receives only sediment that enters through MCC; pink surface area receives mostly sediment that enters through ECC; green area contains sediments that arrive from both entrances (Ikonos panchromatic image 2005, pixel size 1m$^2$).*

**Sediment Dynamic Patterns**

Through *in situ* measurements on the intertidal mudflats in Lake Ingraham, an average accumulation rate of 6.2 cm/year ± 2cm is calculated. This is far more than the 5.5 mm/year sedimentation that is credited to the tidal forcing through Middle Cape Canal. On basis of those extraordinary high accumulation rates we have estimated the amount of net sediment that the lagoon receives per year: $392 \cdot 10^3$ $m^3$ or $565 \cdot 10^6$ kg of sediment (surface area of 6.32 $km^2$, mud density of 1443 $kg/m^3$).

We assume that sediments that enter through MCC do not reach the southeastern most portion of Lake Ingraham, because there is a tidal node exactly where Homestead Canal drains into Lake Ingraham (at the borderline between the green and pink area - Figure 77). A tidal node is the location where two water masses come together. At this point, only vertical tide exists; water level goes up and down but there is no direction of current. This tidal node acts as the physical boundary between water masses coming from Middle Cape Canal versus East Cape Canal. The water flowing out Homestead Canal West appears to drain to the northwest (MCC) during the first phase of ebb, and to the southeast (ECC) during the last phase of ebb.

The northwest and central zone are affected by sediment supplied through Middle Cape Canal, the southeast zone is mainly affected by sediments coming through Homestead Canal and East Cape Canal. The sediment patterns, local accumulation rates, type of sediment and grain size of the northwest and central accumulation zones are discussed together. In the following paragraph the southeast zone will be discussed separately.

Accumulation rates in the northwestern and central zone of Lake Ingraham range from 2 to 15 cm/year. This wide variety of rates is obtained from 25 soft sediment cores, which were taken in the intertidal and subtidal areas and 35 “sediment reference traps”, which were deployed on the intertidal mud flats. Tables 5 and 6 list the coordinates of the “reference traps” and sediment cores; Figure 78 shows a satellite image depicting trap and core locations.

Most cores show a similar sediment stratigraphy. A distinct boundary between sediment units can be detected around 70 cm depth (Figures 79 and 80). This boundary marks the beginning of marine sedimentation in Lake Ingraham after the lagoon opened up to the Gulf of Mexico in 1935 (Labor Day Hurricane breached the newly dredged Middle Cape Canal). Hence, the cores reveal 70 cm of deposition over the last 70 years: this corresponds to 1 cm of sedimentation per year. However, the “sediment reference traps”, which were deployed in June 2004, measure much higher accumulation rates, up to 15 cm/year (Figure 82). These rates are considered extraordinary high for such muddy and low-energy environments. These sediment dynamic patterns are a sign of a system that is “hungry” for sediment and thus out of equilibrium. Unknown is whether sedimentation in the lagoon is speeding up over the last years or whether the core information (1 cm/year) is “blurred” with processes that make past sedimentation rates appear slower (e.g. compaction, dewatering).

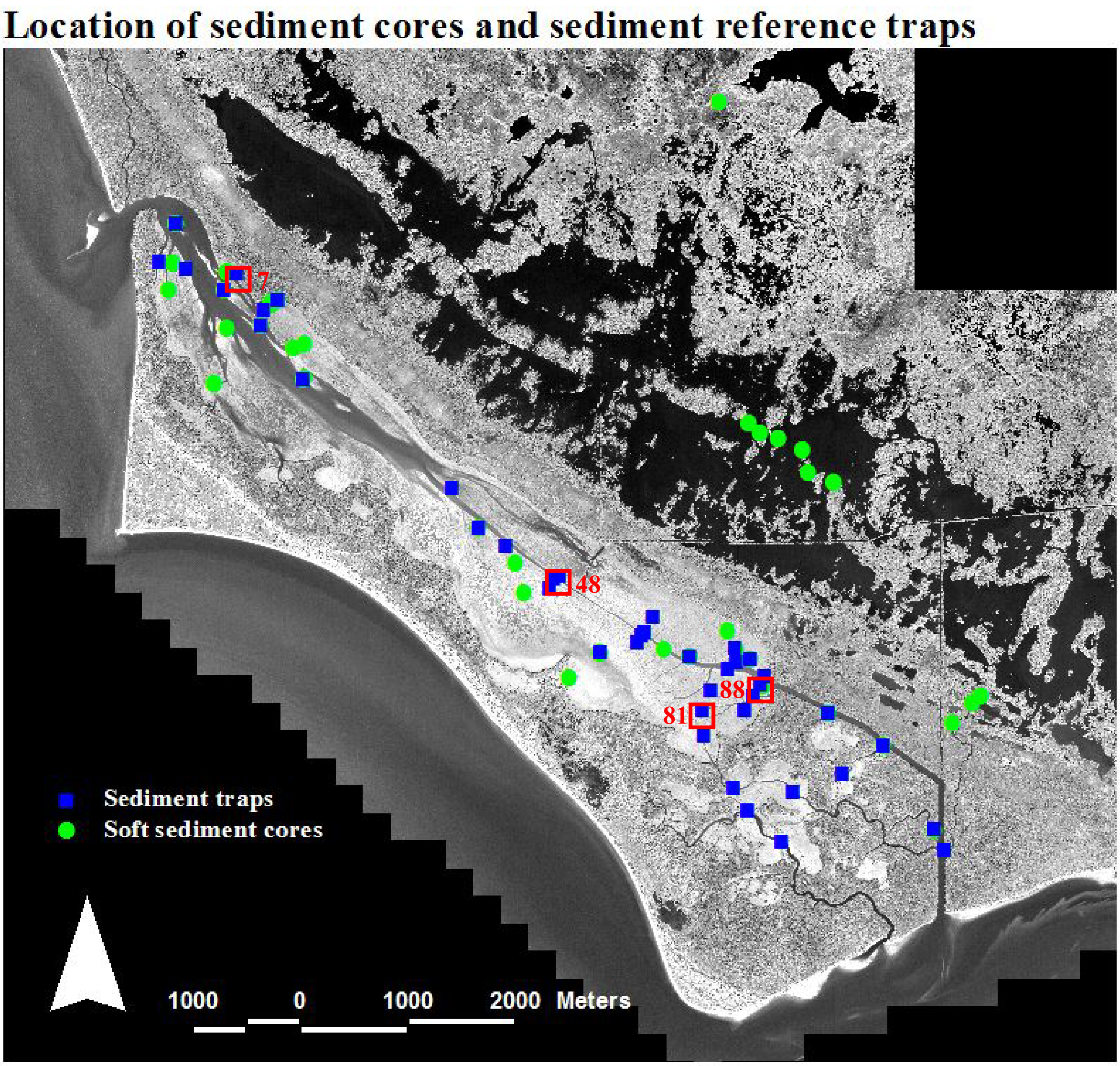



*FIGURE 78. Map depicting locations of sediment reference traps and sediment cores. Numbers 7, 48, 81 and 88 are highlighted for future reference. See Table 5 and 6 in text for coordinates.*

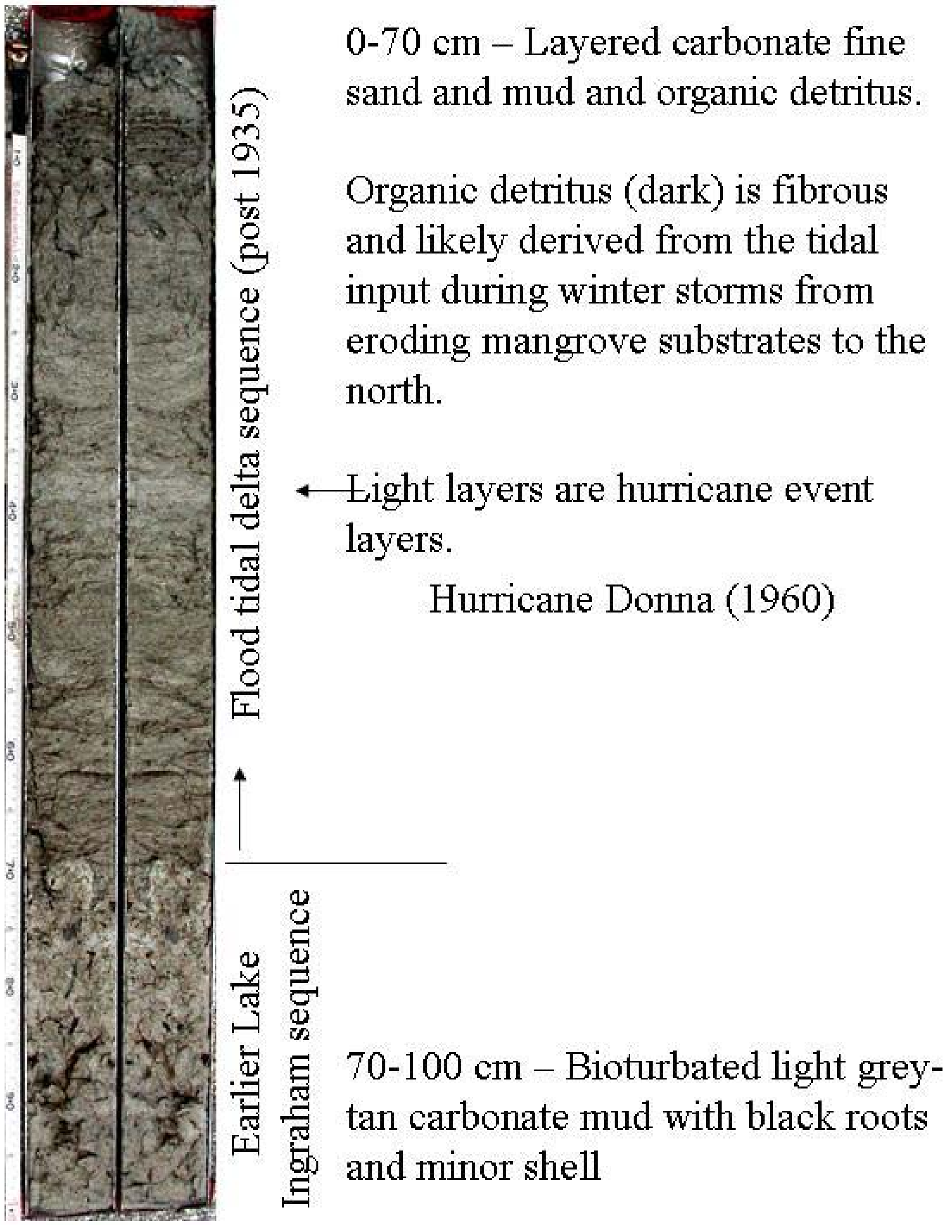



*FIGURE 79. Example of a split core from flood tidal delta in northwest part of Lake Ingraham (core 24). Layered delta sequence (above 70 cm) has accumulated over the past 70 years, following opening of Middle Cape Canal by the 1935 Labor Day Hurricane. Light layers are carbonate sands washed in by tropical storm and hurricane events. The darker layers are organic-rich carbonate fine sand and mud swept into Lake Ingraham by prevailing tides and winter storms. Much of the particulate organics are fibrous, and likely derived from the eroding coastal mangrove system to the north. See Figure 80 for location.*

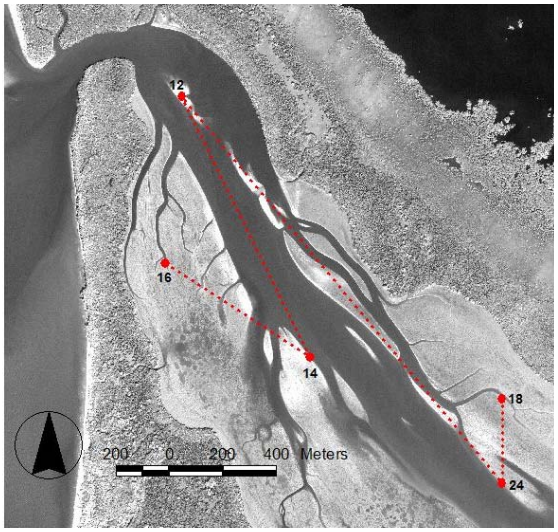
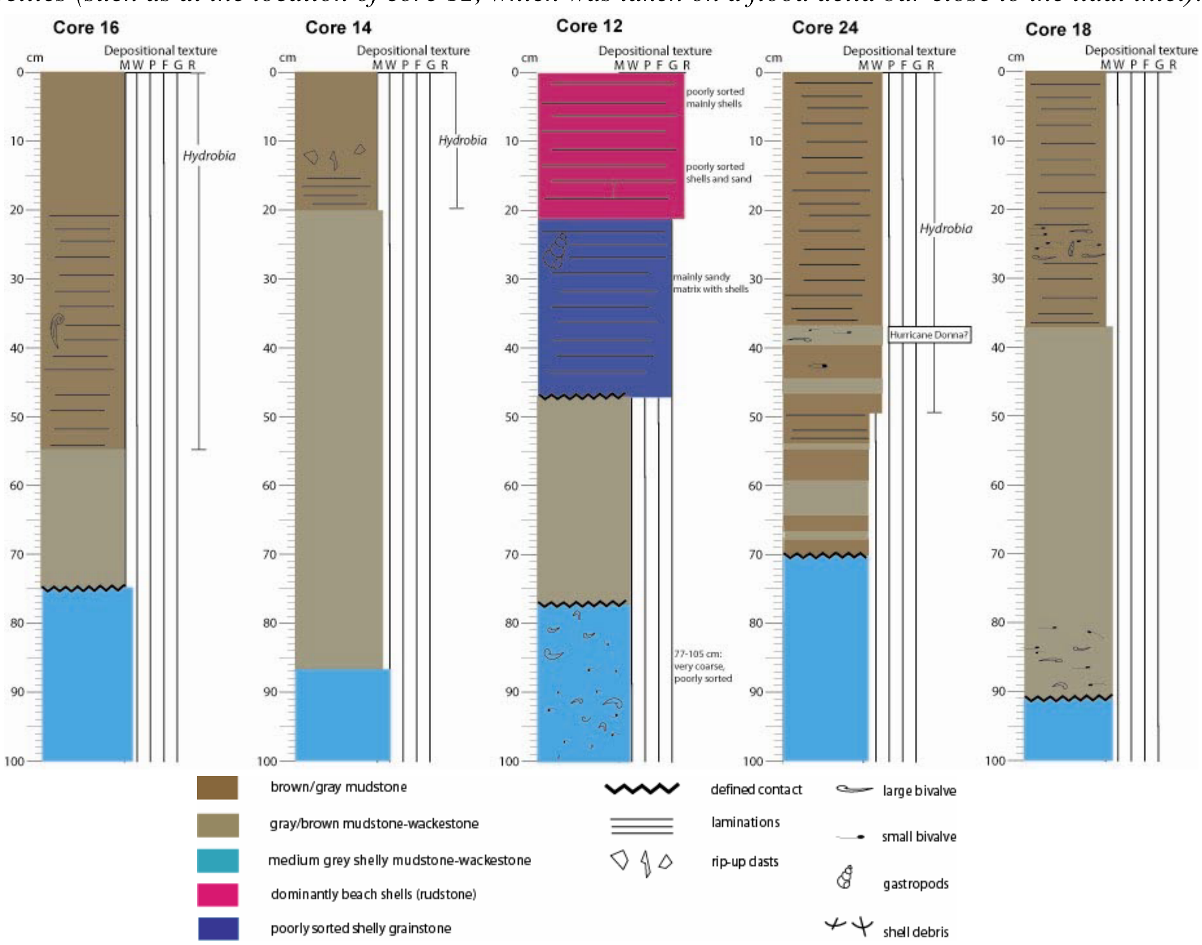



*FIGURE 80. Map (left) depicting a profile of cores taken in the northwest section of Lake Ingraham (close to Middle Cape Canal inlet). Log drawings of core 16-14-12-24-18. Five major Holocene sedimentary units can be classified. The medium grey shelly mud to wackestone (light blue) occurs throughout most of the vertical sediment sequences around 70-90 cm sediment depth. It is the unit that represents the fresh - to brackish water depositional environments that dominated before opening of Lake Ingraham. A gray/brown mudstone-wackestone overlays the medium gray shelly mudstone-wackestone. This unit generally has a low concentration of shell material, but red mangrove roots are common. The unit on top, a brown/grey mudstone, is highly organic and loosely compacted. <u>Hydrobia minuta</u> (stress indicator species) are present. Lamination occurs towards the top, but bioturbation disturbs many sedimentary structures. Poorly sorted shelly grainstone and beach shells are found occasionally in areas with high current velocities (such as at the location of core 12, which was taken on a flood delta bar close to the tidal inlet).*



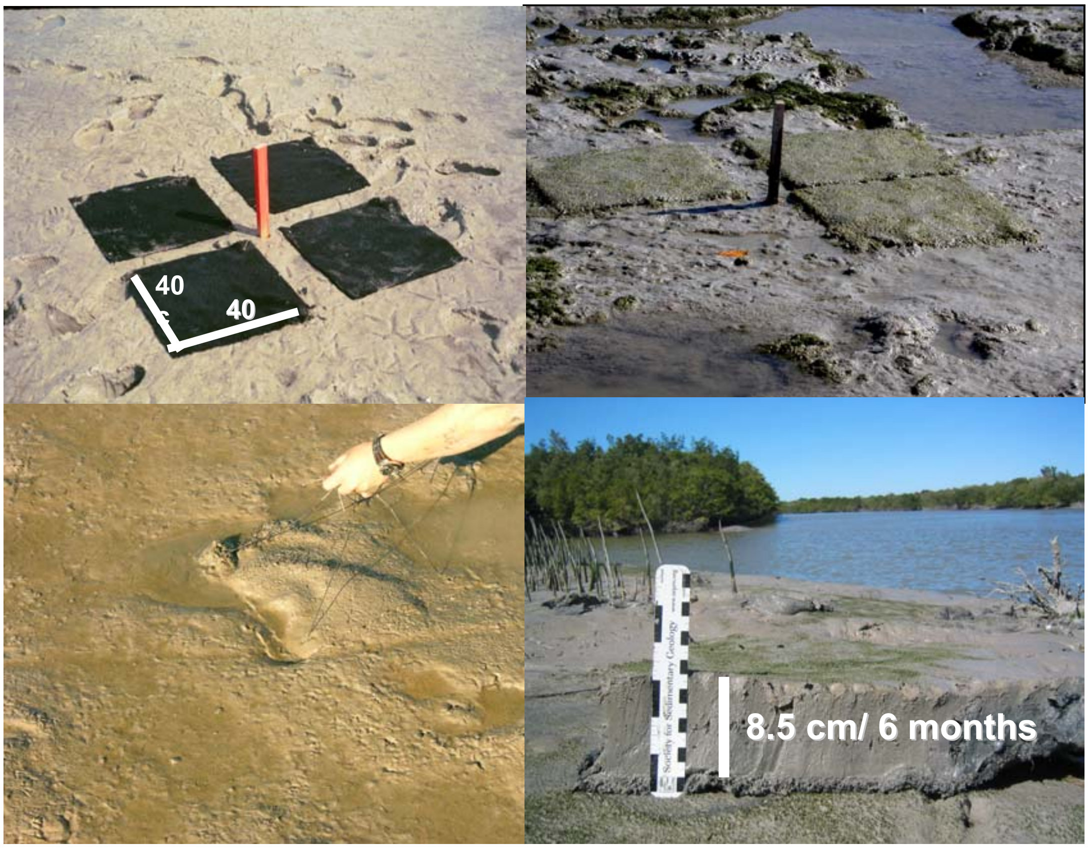
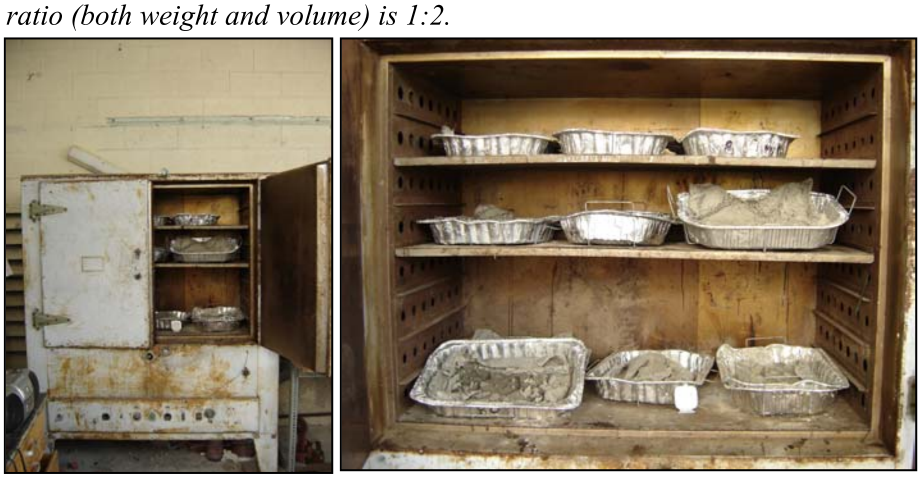
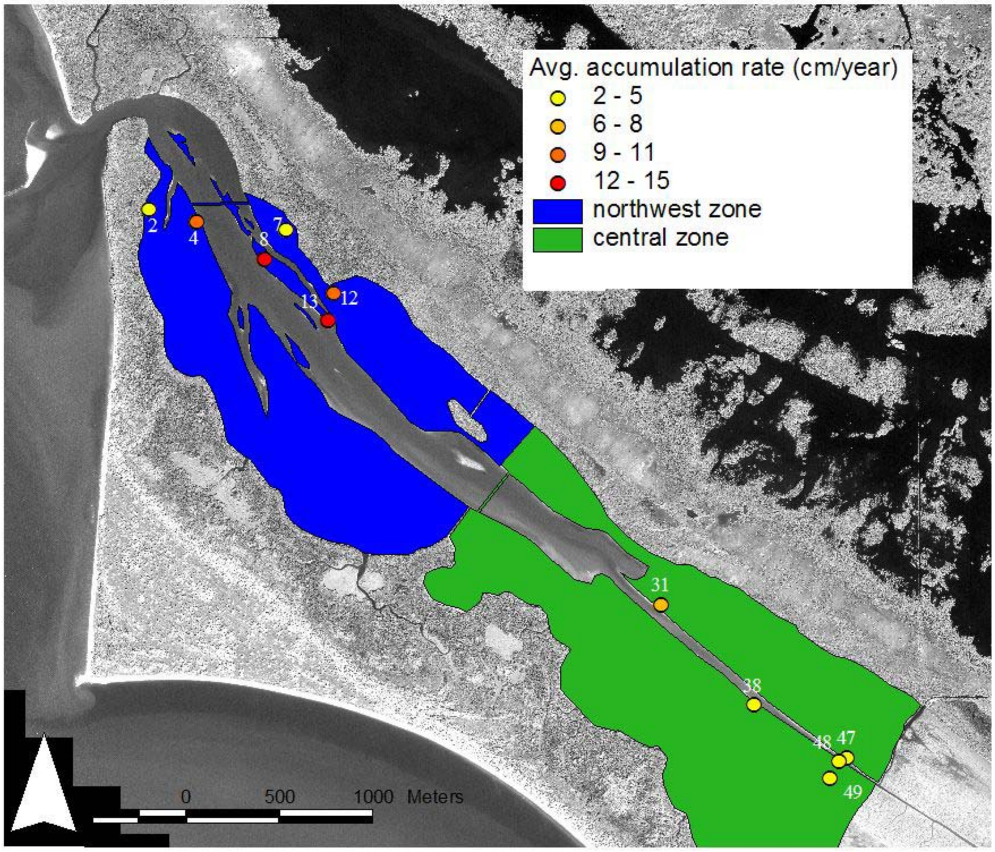



*FIGURE 81. In situ accumulation rates are obtained by "sediment reference traps": 40 x 40 cm carpet tiles that act as reference surface. These "reference traps" have been deployed at 35 locations on the intertidal mudflats in Lake Ingraham and along creek sides in East Cape canal. At each location 4 carpet tiles were put down with metal rods and respectively after 1, 2, 4 and 6 months the carpets were collected. An advantage of this method is that even very small amounts of deposited sediment can be measured with acceptable accuracy (approximately 50 grams). Besides, unlike with vertical sticks, the sediment traps do not disturb the settling process and do not generate scouring.*
*Notice the 8.5 cm sedimentation in only 6 months that was recorded at carpet tile # 107!*
*The weight is a measure of sedimentation rate over time (grams/month). For each individual carpet tile the weight is converted to vertical accumulation rate per year. Standard deviation is determined for the 4 sedimentation rates. In the lab the carpet tiles were dried in an oven (bottom), weighted and converted to a vertical height (z). Average density of collected mud is 1443 kg/m$^3$) and the dry/wet mud ratio (both weight and volume) is 1:2.*





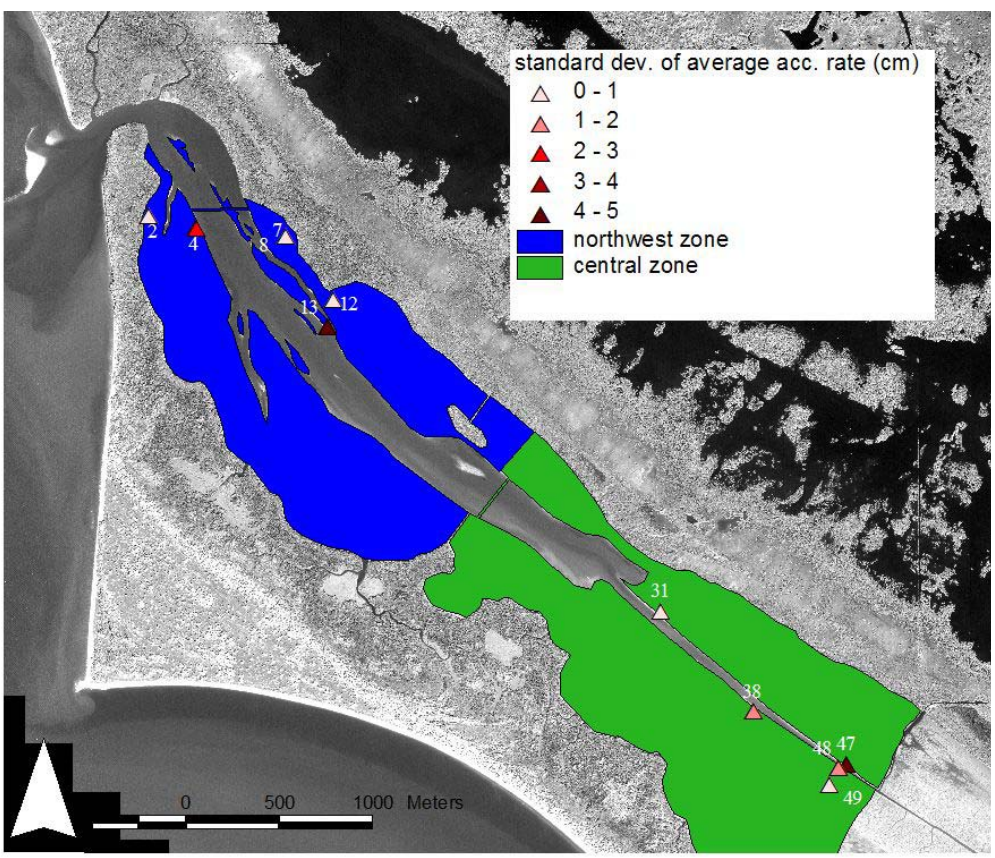




*FIGURE 82. Average accumulation rates (top) and standard deviations (bottom) derived from sediment reference traps for northwestern and central zone. Highest accumulation rates are observed in the northwestern zone and, within this zone, highest rates are observed closest to the channel (see figure 83). Highest standard deviations are also closest to the channel.*

The northwestern zone, which is closest to Middle Cape Canal entrance, experiences maximum accumulation rates of 15 cm/year; in the central zone this rate is maximum 7 cm/year. In both zones a good correlation exists between the accumulation rate and the distance to the channel (Figure 83). These observations lead us to the conclusion that the rate of sedimentation depends on acting hydrodynamics, specifically current speed. From field observations we have learned that the current velocities are higher in the northwestern zone than in the central zone, and velocities are, in both zones, higher close to the main channel than on the mudflats further away from the channel. Higher currents are able to pick up more and coarser sediment and therefore higher currents result in more sediment supply and thus more chance of sedimentation.

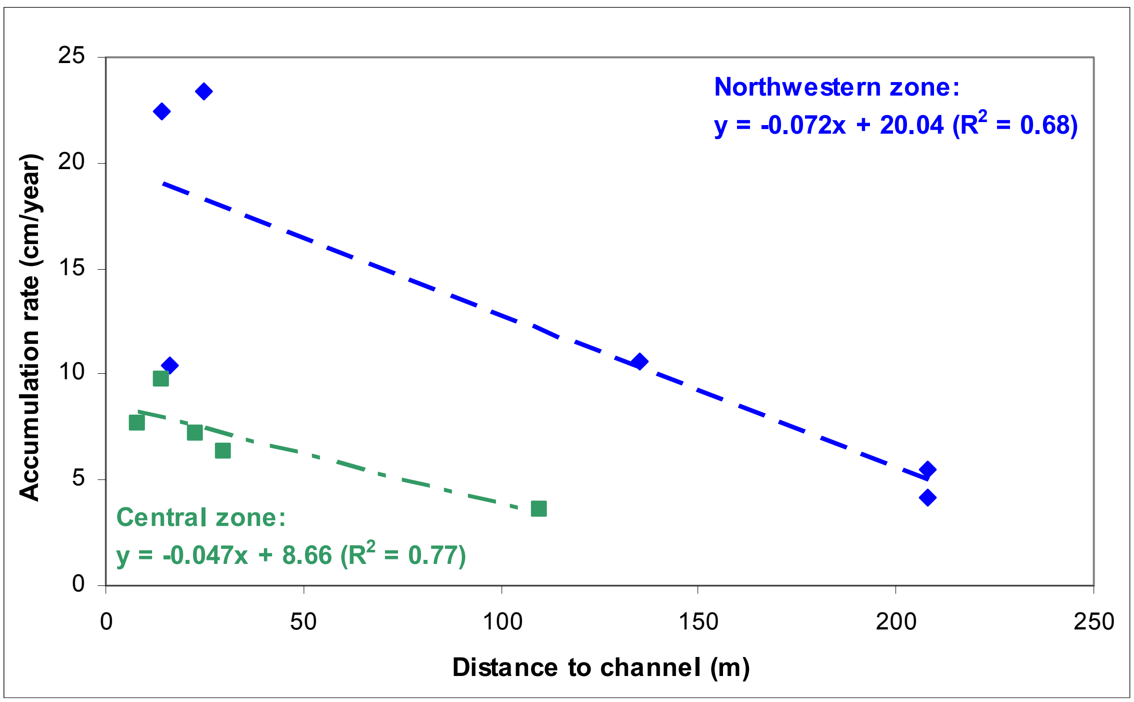



*FIGURE 83. Relationship between accumulation rates and distance to main channel for northwestern and central zone. Accumulation rate is directly related to distance to main channel ($r^2$'s are 0.68 and 0.77). Rate of sedimentation depends on current strength. Close to the main channel higher current speeds are observed and this is the direct cause of higher sedimentation rates.*

The type of sediment that is accumulating is examined through sedimentologic and geochemical methods. All sediment reference traps and a selection of representative cores were analyzed for sediment constituents and grain size. These methods provide information on transport processes and sediment sources in a spatial setting.

Sediments in the Cape Sable study area are made up mainly of calcium carbonate skeletal components (shell fragments, foraminifera – see Figure 84) and organic matter (OM). Less than 5-10% are non-carbonate, non-organic components that contain sponge spicules (Figure 85C/D), diatoms (Figure 85A/B), pollen grains and minor quartz, transported from the Appalachian Mountains by rivers that drain north in the Gulf of Mexico. The weight percentage of calcium carbonate in most surface samples of the northwestern and central zone is between 66 and 76 % (Figure 86). Since the insolubles are less than 5-10% this map (Figure 86) can also be translated into an organics distribution map. In general, one can conclude that approximately 70% of the sediments are originally derived from the carbonate marine environments and 30% originates from saline and freshwater marsh environments. *In situ* production of sediment within Lake Ingraham occurs only in the subtidal mud environment. The total production of carbonate mud or peloid aggregates by green algae such as *Penicillus* and *Udotea* and by calcareous epiphytic organisms on seagrasses such as *Thalassia* and *Diplanthera* is insignificant compared to the imported carbonate and organic sediments (Gebelein, 1977).

Sizes range from coarse sand (1000 μm) to very fine clay (0.6 μm). An electro-resistance particle size analyzer (Coulter Counter) is used to analyze grain sizes of the surface sediment reference traps.  Figure 87 shows the spatial variability of the mean grain size. All surface samples but one are very silt- to clay-sized particles (less than 62 microns, with most being less than 22 microns).  The overall very small grain size confirms that sediment transport is mainly through suspended load. On the flood tidal bars within Lake Ingraham coarse shelly carbonate material can be found, and this is represented by the 143 μm of carpet tile #8. The grain size distribution appears to be trimodal (Figure 88). Three modes can be distinguished at approximately 0.8 μm, 6 μm and 50 μm. Figure 89 shows images of these three sediment modes taken with an SEM (Scanning Electron Microscope). The peak of sediment with size 0.8 μm is made up of aragonite needles, which are formed in Florida Bay and the Gulf of Mexico by green algae such as *Penicillis* and *Halimeda* (Figure 89A). The 6 μm sediment peak appears to be made up of carbonate aggregates of these needles but also of other carbonate chips derived from bio-erosion and physical abrasion (Figure 89B). The 50 μm sediment peak is caused by the presence of foraminifera, organic material and carbonate aggregates (Figure 89C, D).

| Carpet tile # | Northing | Easting | Carpet tile # | Northing | Easting |
|---|---|---|---|---|---|
| 2 | 486059 | 2784802 | 79 | 491343 | 2781010 |
| 4 | 486310 | 2784735 | 80 | 491190 | 2780820 |
| 7 | 486790 | 2784689 | 81 | 491122 | 2780671 |
| 8 | 486670 | 2784535 | 86 | 491119 | 2780397 |
| 12 | 487042 | 2784351 | 87 | 491692 | 2780952 |
| 13 | 487009 | 2784207 | 88 | 491644 | 2780872 |
| 31 | 488757 | 2782692 | 89 | 491583 | 2780768 |
| 38 | 489279 | 2782160 | 90 | 491496 | 2780627 |
| 47 | 489768 | 2781878 | 95 | 491398 | 2779904 |
| 48 | 489756 | 2781856 | 102 | 491526 | 2779705 |
| 49 | 489687 | 2781766 | 104 | 491948 | 2779871 |
| 58 | 490643 | 2781503 | 107 | 492792 | 2780305 |
| 59 | 490561 | 2781355 | 107A | 492277 | 2780608 |
| 60 | 490547 | 2781326 | 109 | 492410 | 2780037 |
| 61 | 490499 | 2781261 | 112 | 491845 | 2779415 |
| 77 | 491409 | 2781207 | 116 | 493268 | 2779531 |
| 78 | 491418 | 2781076 | 117 | 493356 | 2779335 |

*TABLE 5. Transverse Mercator northing/easting coordinates of sediment reference traps deployed in Lake Ingraham*

| Core # | Northing | Easting | Core # | Northing | Easting |
|---|---|---|---|---|---|
| 12 | 486221 | 2785154 | 34 | 490995 | 2781136 |
| 14 | 486699 | 2784184 | 40 | 486576 | 2783667 |
| 15 | 486193 | 2784779 | 42 | 486690 | 2784702 |
| 16 | 486162 | 2784529 | 43 | 487116 | 2784399 |
| 17 | 487096 | 2784415 | 44 | 487167 | 2784446 |
| 18 | 487415 | 2784030 | 45 | 487317 | 2783988 |
| 24 | 487407 | 2783704 | 46 | 490168 | 2781153 |
| 25 | 491341 | 2781372 | 47 | 490992 | 2781130 |
| 26 | 491422 | 2781203 | 48 | 491670 | 2780855 |
| 27 | 489031 | 2782332 | 49 | 491560 | 2781110 |
| 28 | 489376 | 2781995 | 62 | 487416 | 2783715 |
| 29 | 489459 | 2781718 | 63 | 487009 | 2784207 |
| 30 | 490168 | 2781167 | 64 | 486672 | 2784539 |
| 31 | 489874 | 2780931 | 69 | 486221 | 2785154 |
| 33 | 490751 | 2781196 | | | |

*TABLE 6. Transverse Mercator northing/easting coordinates of soft sediment cores taken in Lake Ingraham*

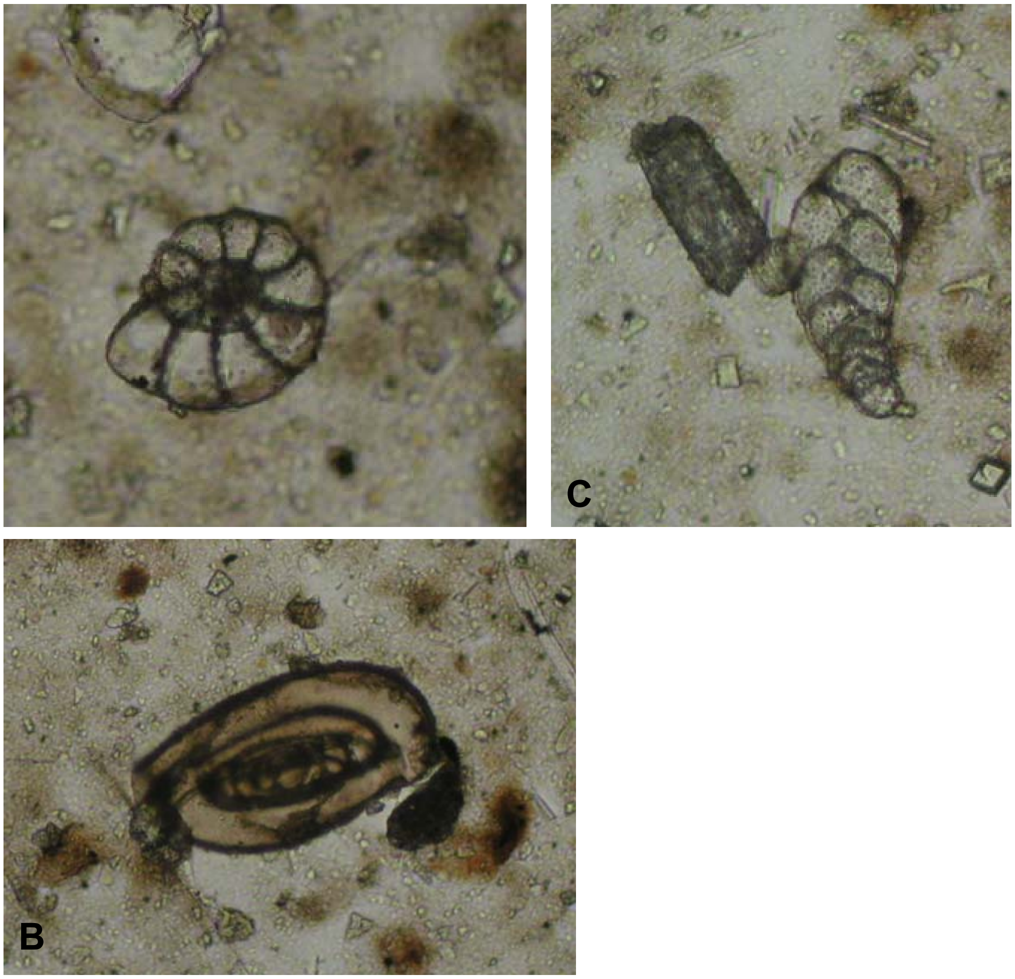



*FIGURE 84. Photomicrographs of most common foraminifera species found in Lake Ingraham (core 30). Plane polarized light. 40x magnification.*

*A) Ammonia sp*

*B) Miliammina sp.*

*C) Agglutinated Textularia sp. .*

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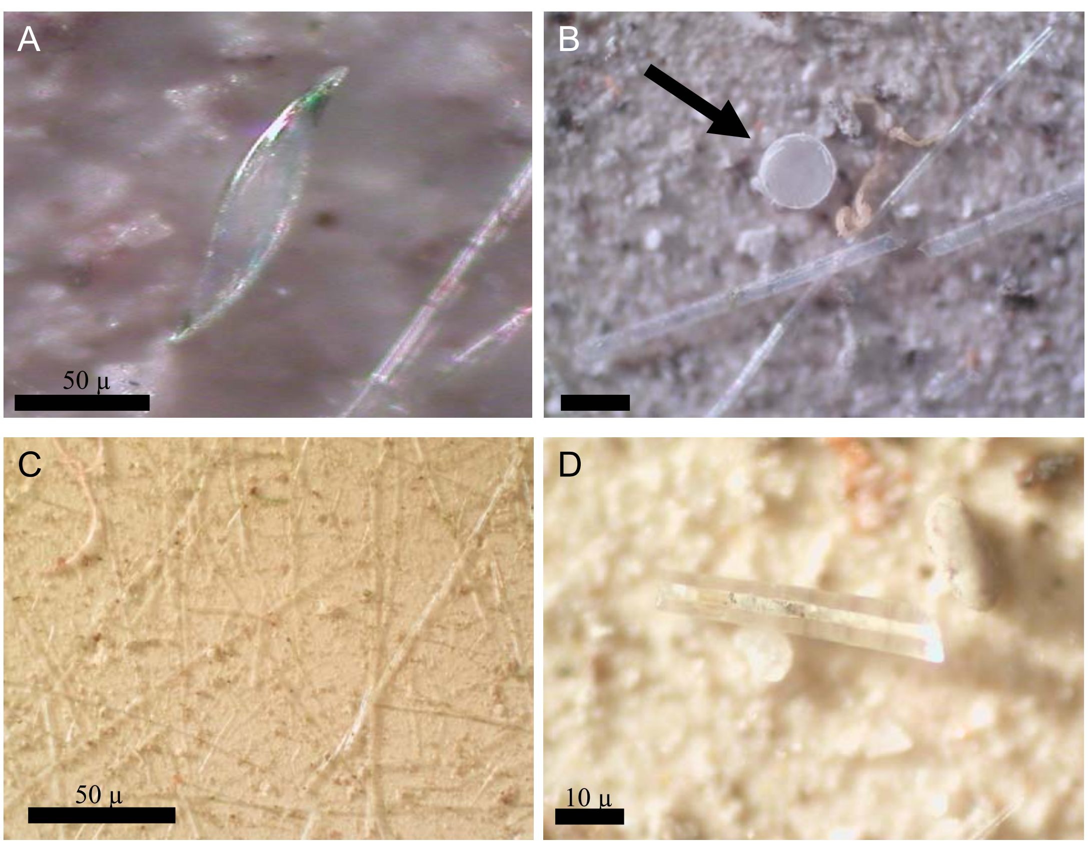



*FIGURE 85. Photomicrographs of most common diatoms in water column. (A) Gyrosigma sp, (B) Thalassiosira sp.,and (C) and (D) echinoderm spicules. Suspended sediment sample Middle Cape Canal, August 2003.*

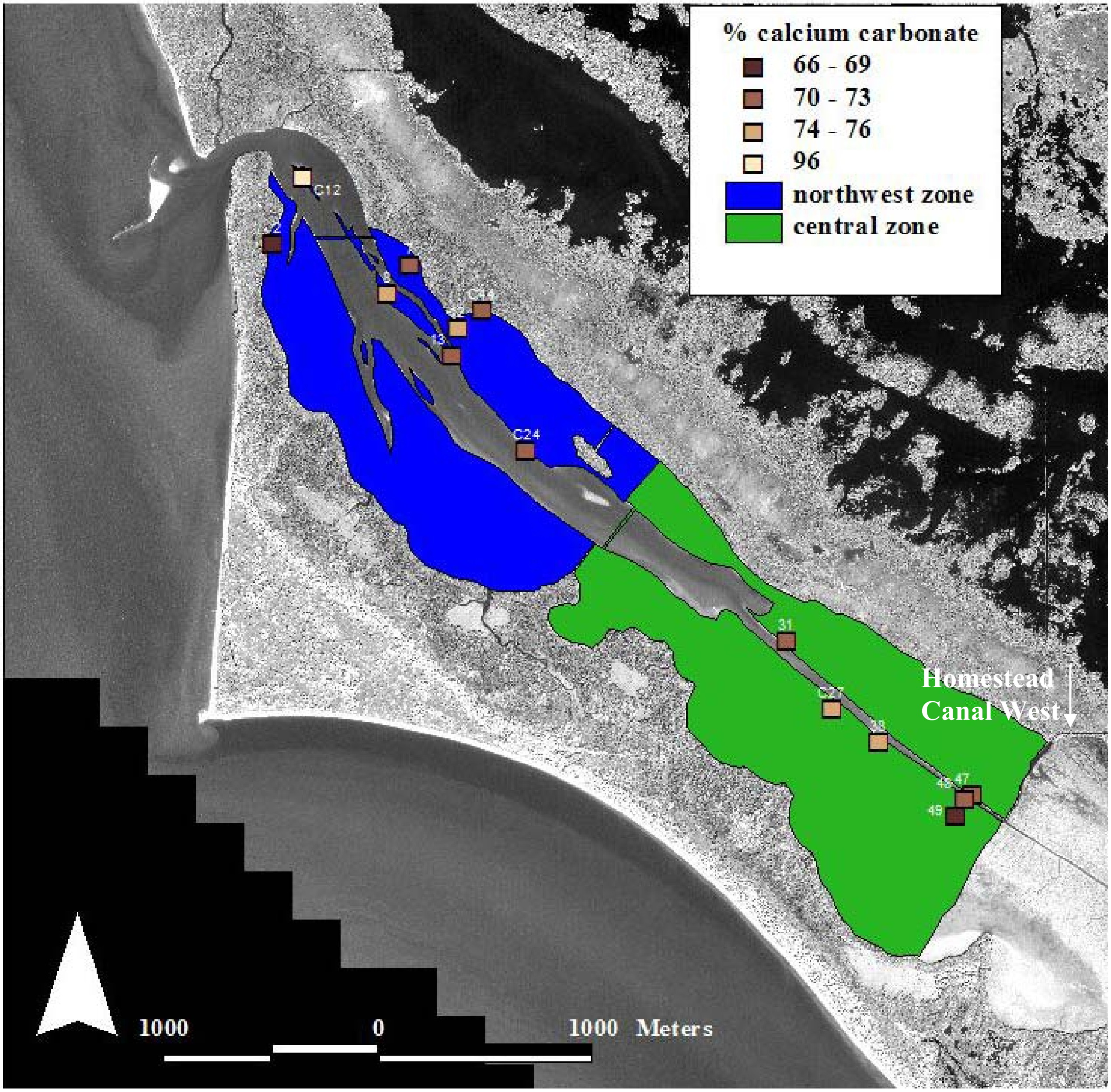



*FIGURE 86. Amount of calcium carbonate in weight percentage of the sediment reference traps and some cores. Notice that C12 (core 12) is almost 100% calcium carbonate: this is the poorly sorted shelly grainstone that is identified in core 12 (see Figure 80). Notice that southeast corner of the central zone contains less carbonate and more organic material. This is due to their proximity to Homestead Canal West end, which drains particulate organic matter from the collapsed freshwater marsh into Lake Ingraham.*

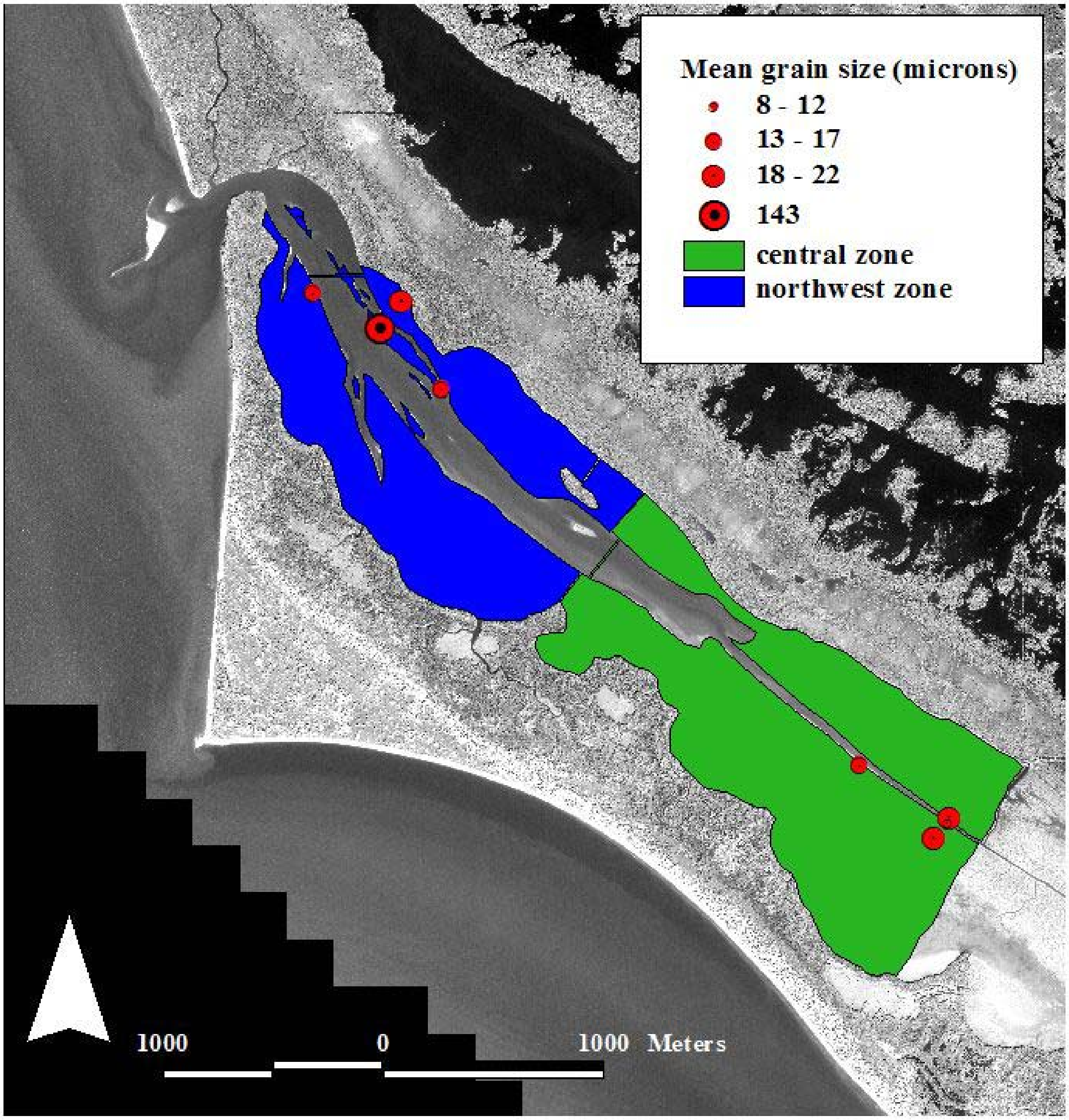



*FIGURE 87. Mean grain size in µm from several sediment reference traps. Notice that the mean grain size is less than 22 µm (except # 8, which is 143 µm and contains a lot of coarse carbonate shell material). This very small grain size defines all samples as silt to clay sized, with many silt particle being aggregates. All samples are very poorly sorted.*

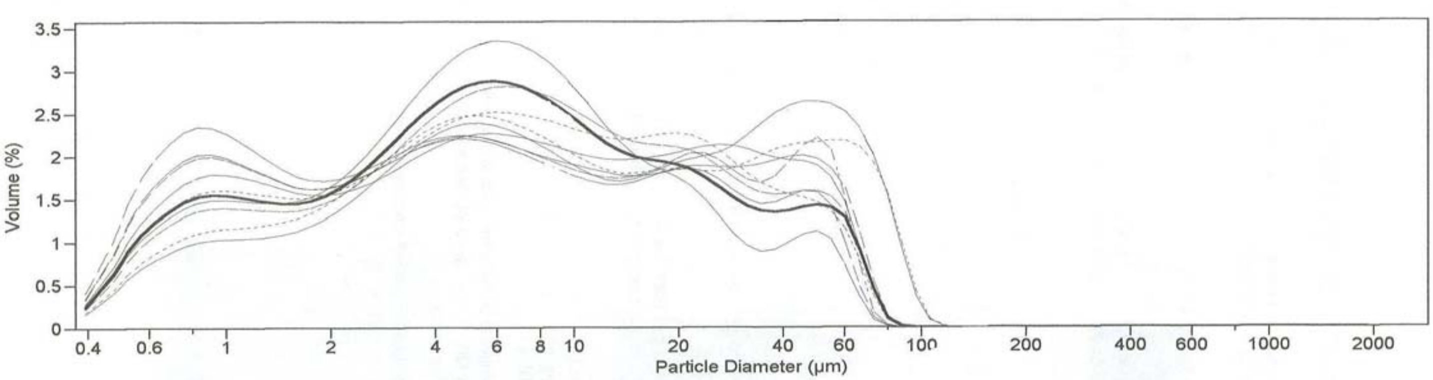



*Figure 88. Trimodal grainsize distribution for selected sediment reference traps. Notice the peaks at approximately 0.8 µm, 6 µm and 50 µm. This trend is observed in all sediment reference traps.*

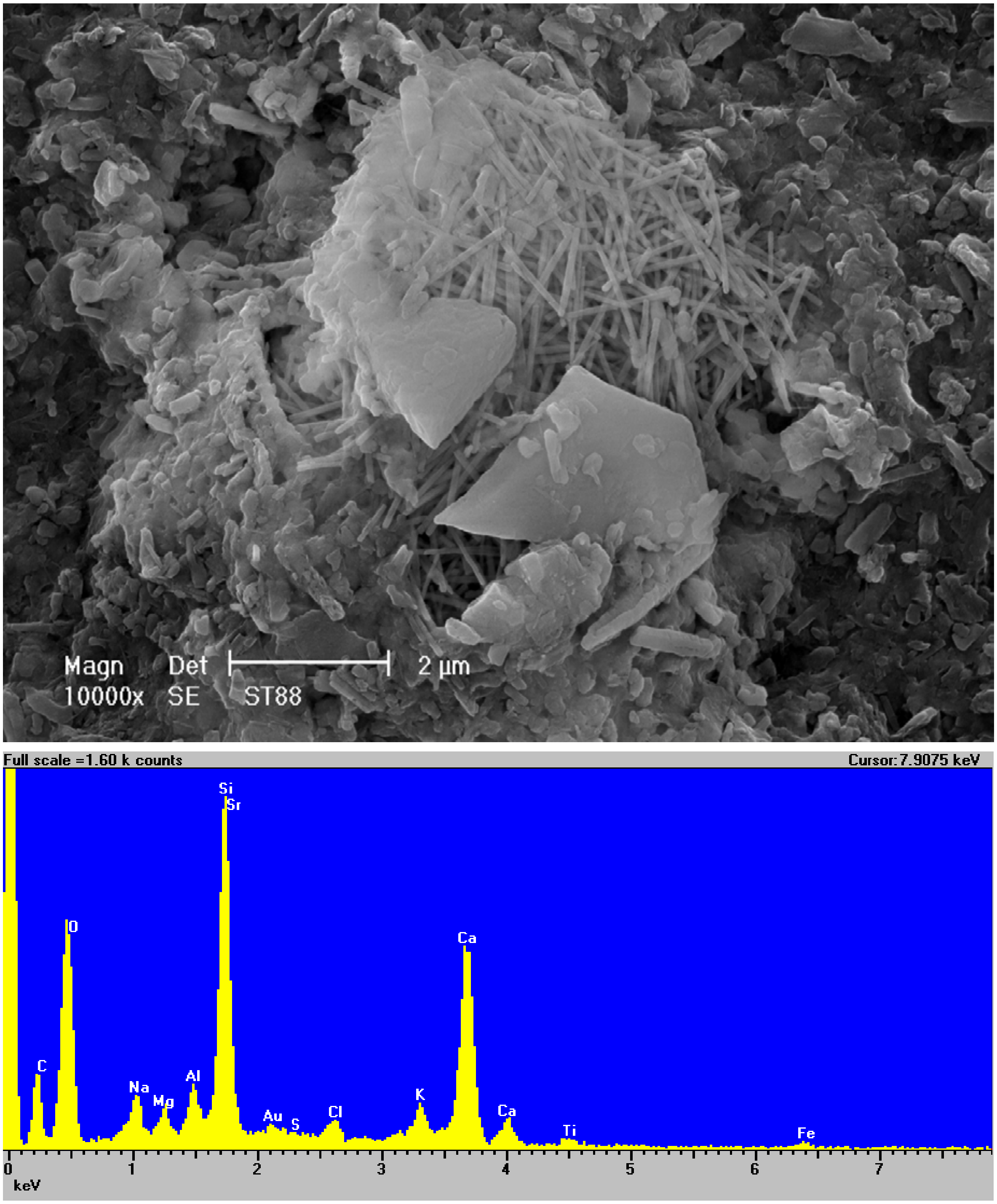



*FIGURE 89A. (Top) SEM image of sediment reference trap # 88, 10,000 x magnification (see figure 22 for location). Aggregate of aragonite needles, formed in Florida Bay by green algae such as Penicillus, Halimeda etc. The modal peak of 0.8 µm, found in all grain size distributions in Lake Ingraham, is most likely caused by these unusual small aragonite needles. (Bottom) Element spectrum of # 88 depicting the presence of Strontium (Sr), indication of aragonite.*

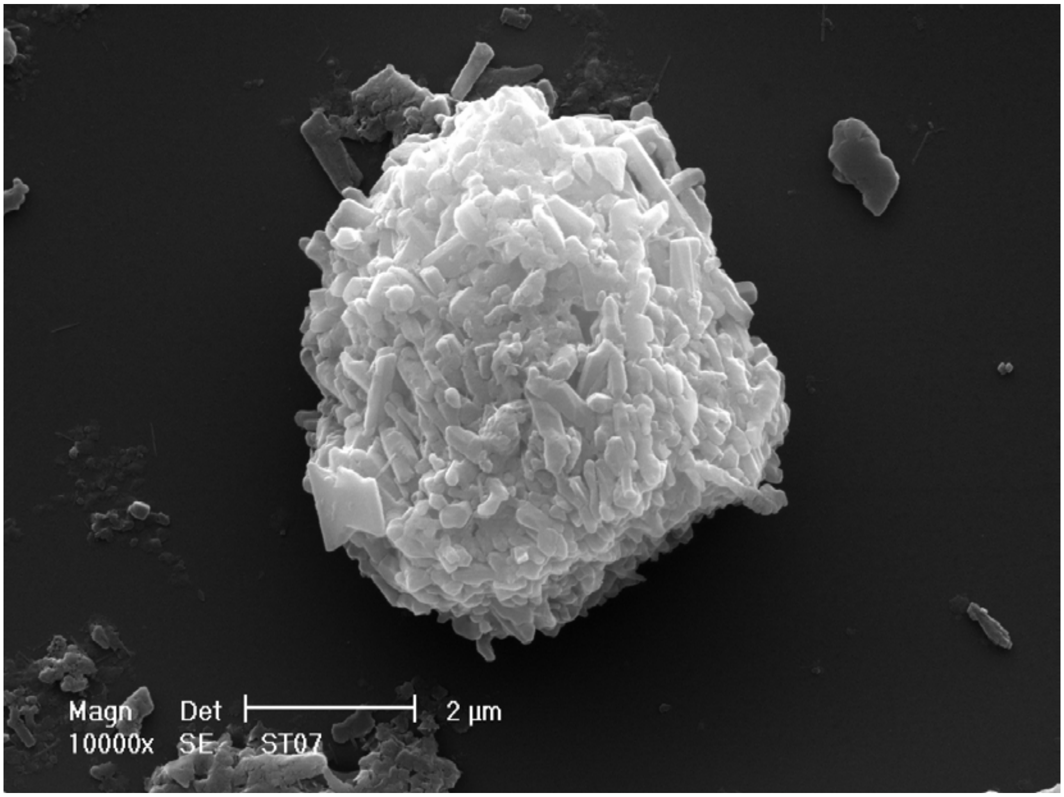



*FIGURE 89B. SEM image of sediment reference trap #7 (10,000 x magnification). Aggregate of carbonate bits that form a ball with diameter of approximately 5-6 µm. The modal peak of 6 µm, found in all grain size distributions in Lake Ingraham, is most likely produced by those aggregates*

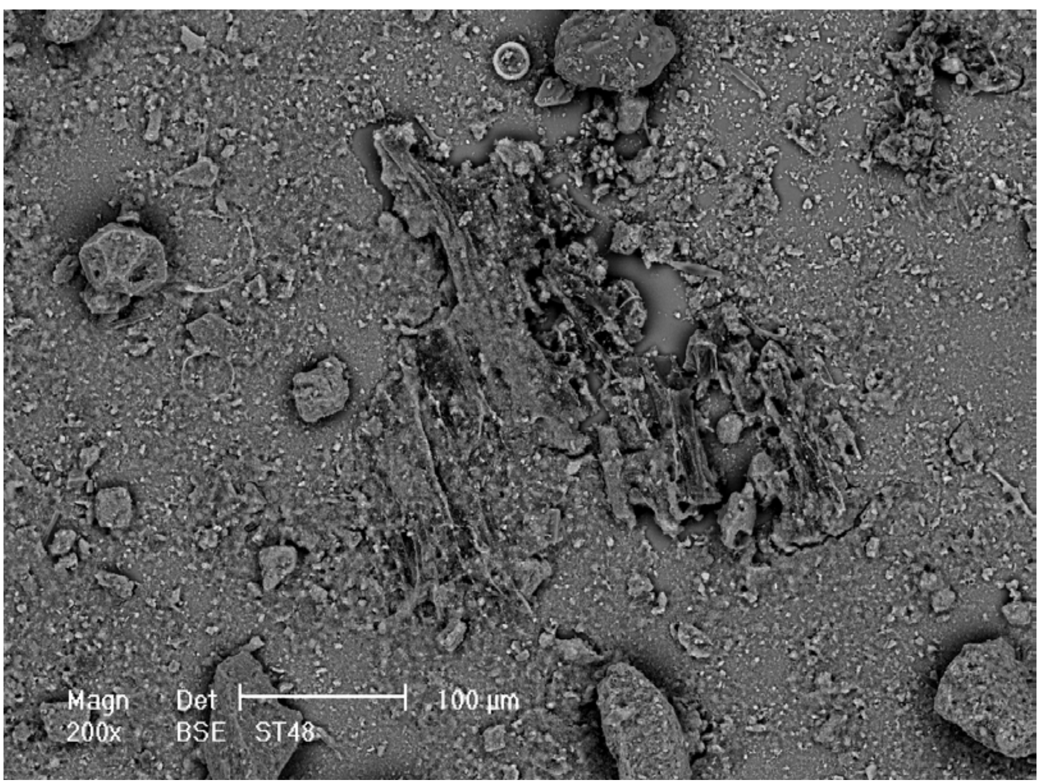



*FIGURE 89C. BSE (backscatter) image of sediment reference trap #81 (200x magnification). The modal peak around 50 µm is the result of the abundance of forams, diatoms, large carbonate aggregates and organic particles.*

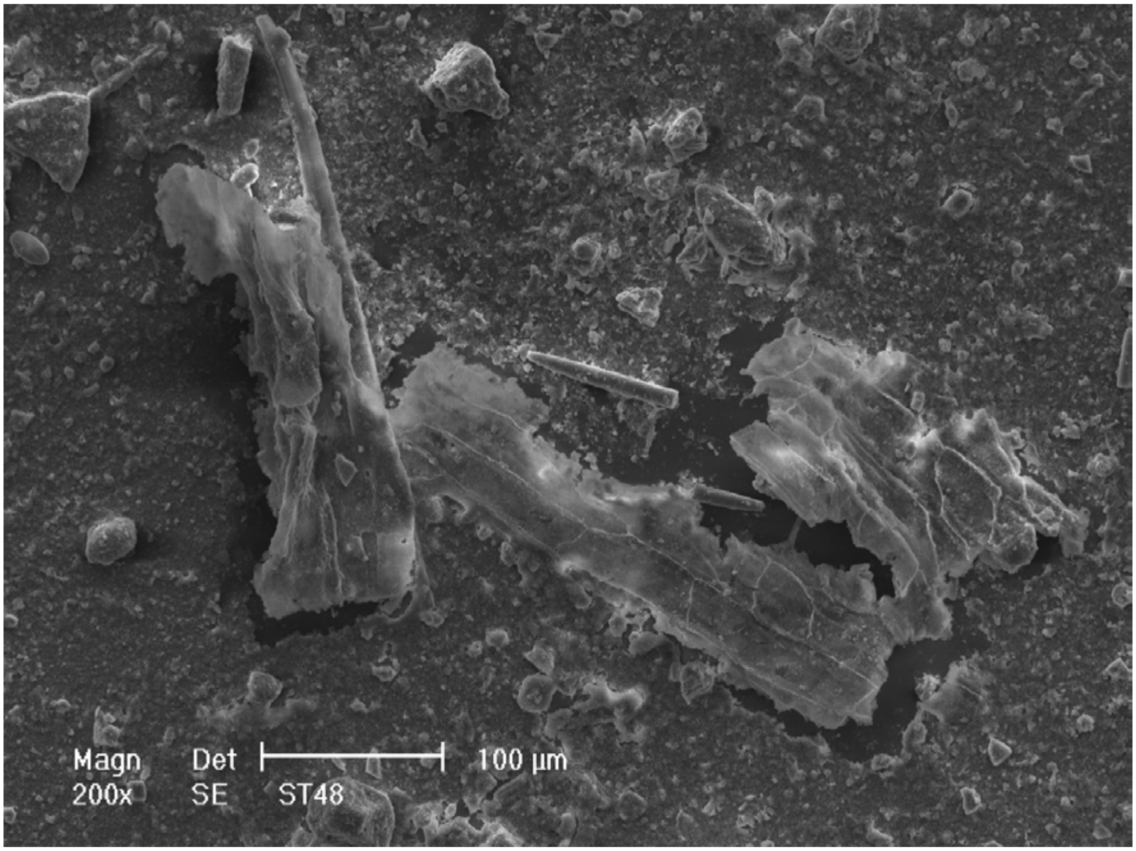



*FIGURE 89D. SEM image of sediment reference trap #48 (200x magnification). The modal peak around 50 µm is partly made up by organic particles like these.*

## East Cape Canal and Surroundings

The following hydrodynamic and sediment parameters have been measured in East Cape Canal, Hidden Creek and Lake Ingraham (Figure 90): current velocity and direction, water level, turbidity, salinity and temperature. As in Middle Cape Canal, all instruments were mounted on weighted frames that were placed on the sediment bed; parameters were collected continuously every 10 minutes over time periods ranging from days to 4 weeks.

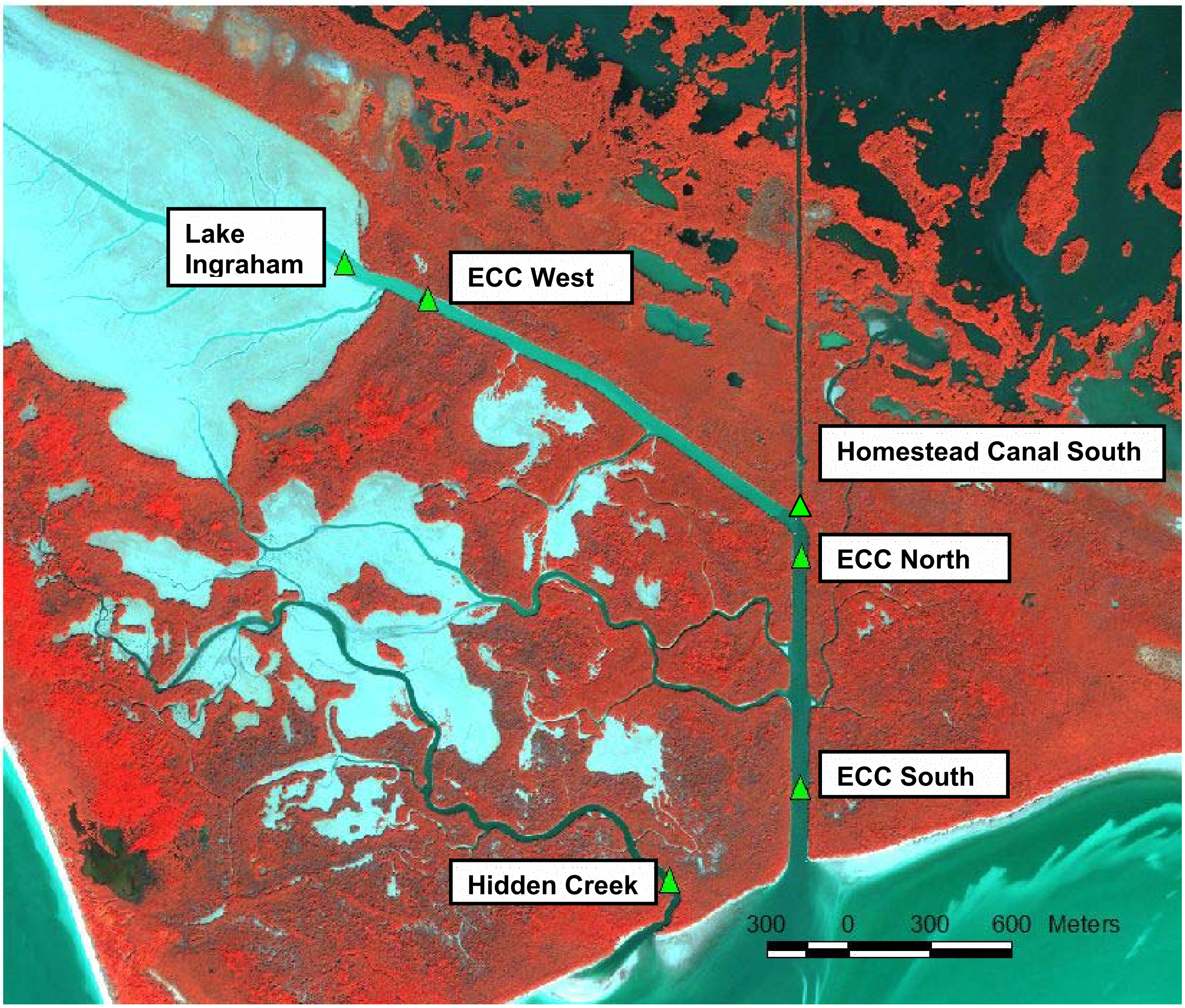



*FIGURE 90. Location of the hydrodynamic measurement stations in the vicinity of East Cape Canal. (Ikonos multispectral image 2005, pixel size 4 $m^2$.)*

TABLE 7 orderly shows the station name, measured time period and type of data collected. Equipment failure and breakdown has caused lot of data loss and therefore our data set around East Cape Canal is not as complete as we had intended. Especially at ECC South, many of our attempts to collect valuable field data failed.

| | **ECC SOUTH** | **ECC NORTH** | **ECC WEST** | **LAKE INGRAHAM** | **HIDDEN CREEK** |
|---|---|---|---|---|---|
| **01/09–02/09 2003 (winter)** | | | | | Currents<br>Water depth |
| **07/31–08/15 2003 (summer)** | Turbidity | | | | Currents<br>Water depth |
| **02/02 – 02/22 2004 (winter)*** | Turbidity<br>(2 days) | | | | Turbidity |
| **04/10 – 04/13 2004 (spring)** | Turbidity** | | | | |
| **07/25–08/09 2004 (summer)** | Currents<br>(3 days)<br>Turbidity | | Currents<br>Water depth<br>Turbidity | | |
| **02/19 – 03/15 2005 (winter)*** | | Sal./Temp<br>Water depth<br>Turbidity | | Sal./Temp<br>Water depth<br>Turbidity | |

*TABLE 7. Hydrodynamic dataset collected around East Cape Canal in 2003, 2004 and 2005. * = measurements at different locations are not synchronous. ** = Turbidity meter is recalibrated and has a different measurement range.*

## Tidal and Current Patterns

During our first and second measurement campaign in January and August of 2003, we only retrieved valuable hydrodynamic measurements in Hidden Creek. The meteorological conditions at this time are displayed in Figures 59 and 60. The tidal wave in Hidden Creek follows very closely the tidal wave in East Cape Canal; there is no time delay of slack high and slack low tide between the waterways. There is a strong daily inequality in the tidal amplitude (Figure 91). The minimum neap tidal range measured at Hidden Creek is 0.8 meter while maximum spring tidal range is 2.5 meter. The currents are characterized by an asymmetric time velocity profile, both during spring and ebb tide (Figure 92). Current velocities are of equal strength during incoming and outgoing tide. Maximum peak velocities reach 80 cm/s during spring tide.

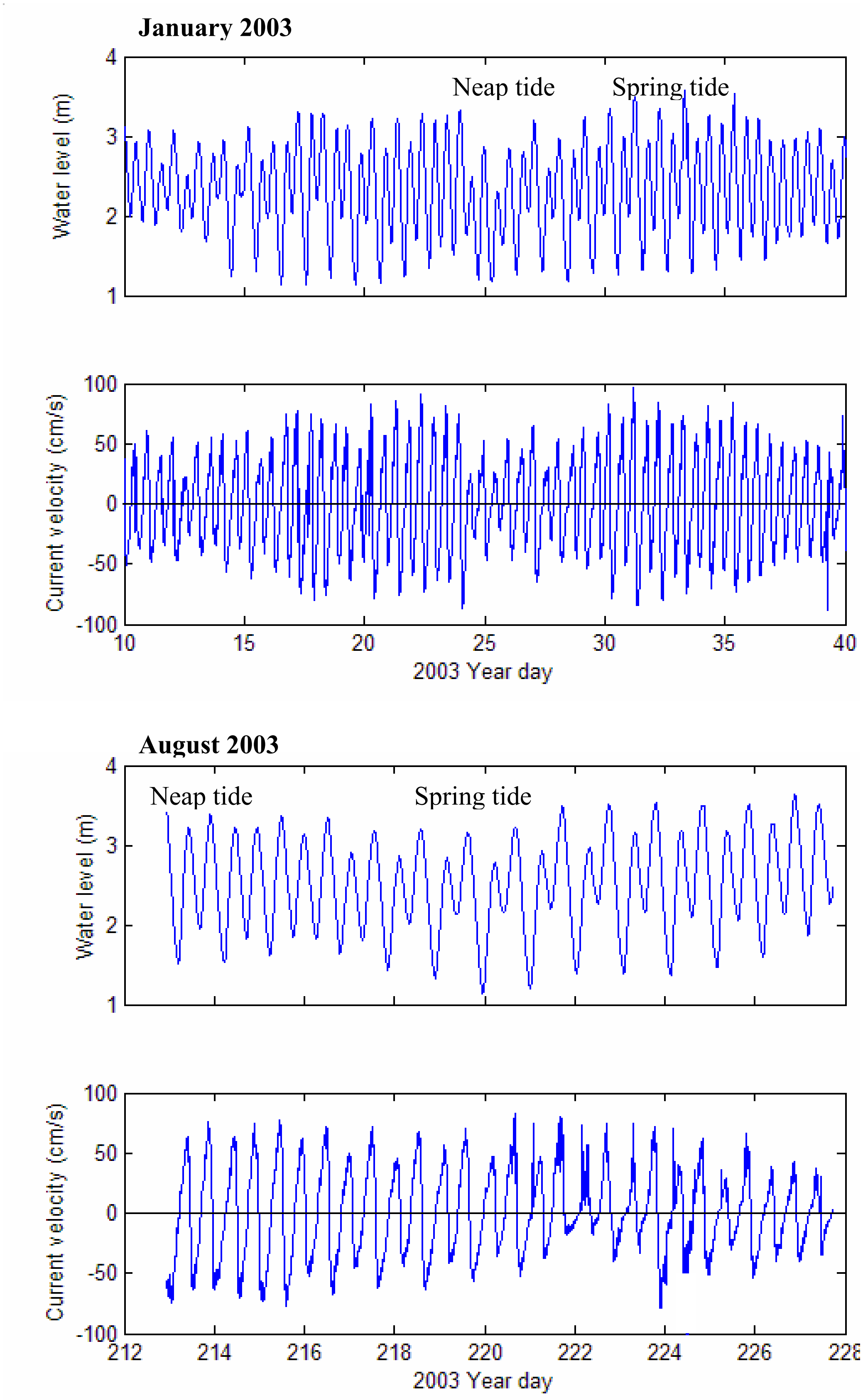



*FIGURE 91. Time series of water level and current velocities measured in Hidden Creek 30 days in January 2003 (top) and 15 days in August 2003 (bottom). Positive current velocities are incoming tide, negative velocities are outgoing tide.*

*Notice the strong tidal daily inequality and the effect of the spring-neap tidal cycle (see figure 36 as well). Notice that the flood and ebb velocities are more or less similar. Maximum peak velocities are 80 cm/s.*

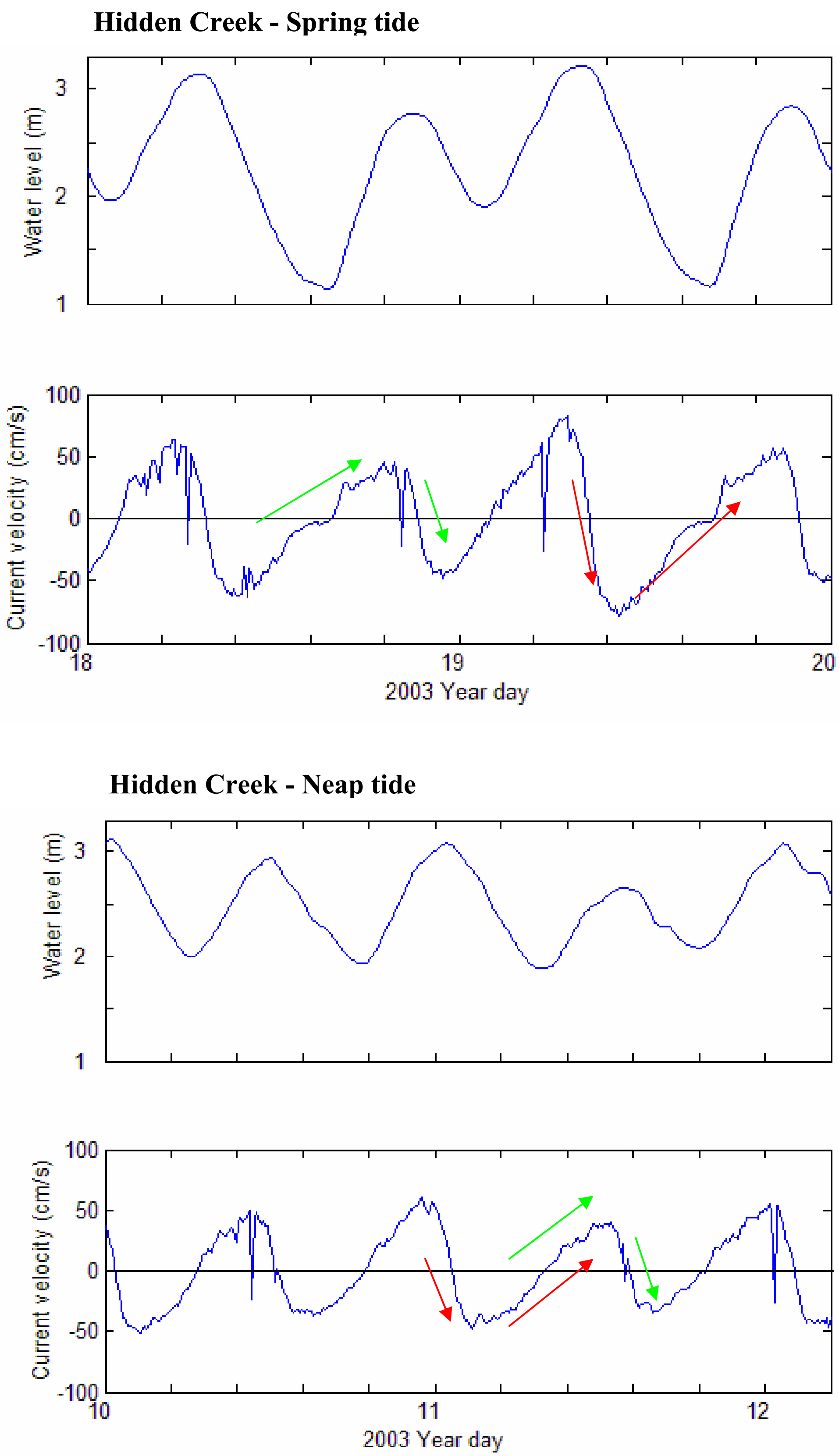



*FIGURE 92. Detailed time series of water level and current velocities in Hidden Creek (January 2003) during spring tide (top) and neap tide (bottom). Positive velocities are incoming tide, negative velocities are outgoing tide.*

*1) Notice the daily inequality of the tide and the variability in velocity from one tide to the other, especially during spring tide.*

*2) Notice the asymmetric time velocity profile: the first period of flooding occurs slower than the second part of flooding (green arrows), while the first part of ebbing occurs faster than the second part of ebbing (red arrows). This can be explained by the complex morphology (sinuosity) of Hidden Creek.*

Continuous water level measurements do not exist at the entrance of East Cape Canal (ECC South). In 2004 and 2005 we did collect tidal data at ECC West (Figure 93), ECC North (Figure 95) and Lake Ingraham (Figure 96). All three locations show a strong daily inequality of the tide. The maximum tidal range at ECC West and North is 1.3 meter; at Lake Ingraham we have measured a maximum tidal range of 1.7 meter.

An attempt to obtain synchronous time series of sediment concentrations and current measurements at ECC South and ECC West failed. The ultrasonic current meter that was measuring at ECC South broke down just 4 days after deployment on July 26$^{th}$ 2004 (Figure 97). From the 4 days of synchronous collected current data, we can conclude that current patterns are more or less similar at the entrance of East Cape Canal (ECC South) and close to Lake Ingraham (ECC West).

The Acoustic Doppler Current Profiler (ADCP) that collected data for a period of 16 days at ECC West measured maximum peak velocities of 149 cm/s during flood tide and 93 cm/s during ebb tide (Figure 93). Furthermore, we see a substantial time lag between water level and current flow at ECC West (Figure 94). As water level goes down after it reaches its highest point (slack high tide), water still flows in for considerable time. As water level slowly goes up again after slack low tide, water is still draining from the lake. This phenomenon is also observed at Middle Cape Canal entrance. These observations are valuable and they will become important when discussing the sediment transport processes through East Cape Canal.

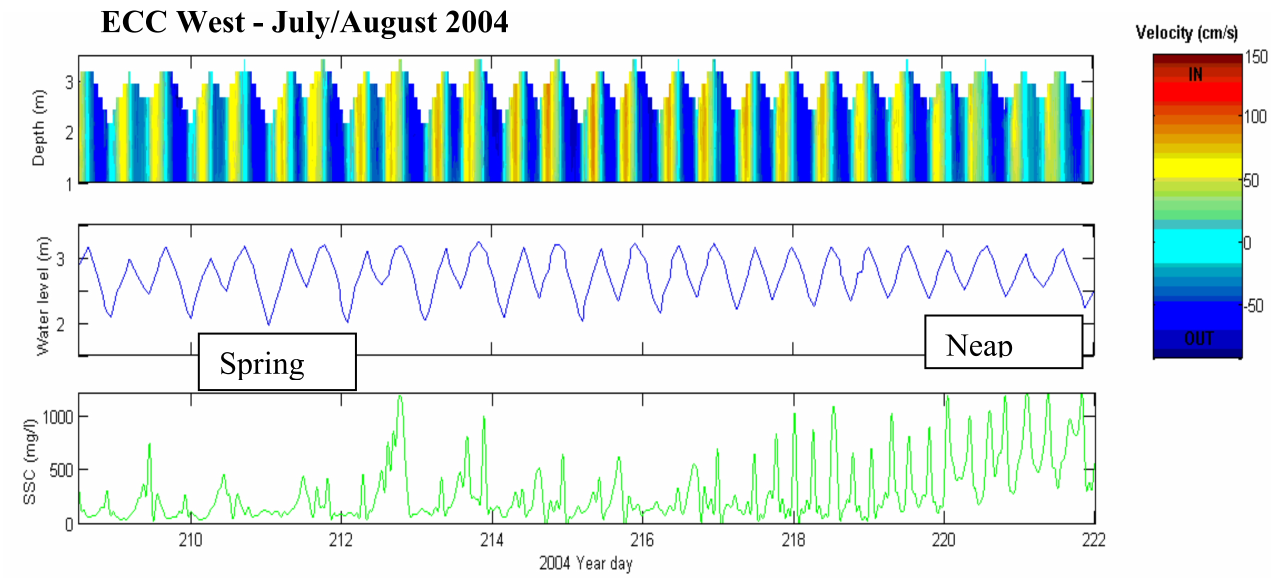
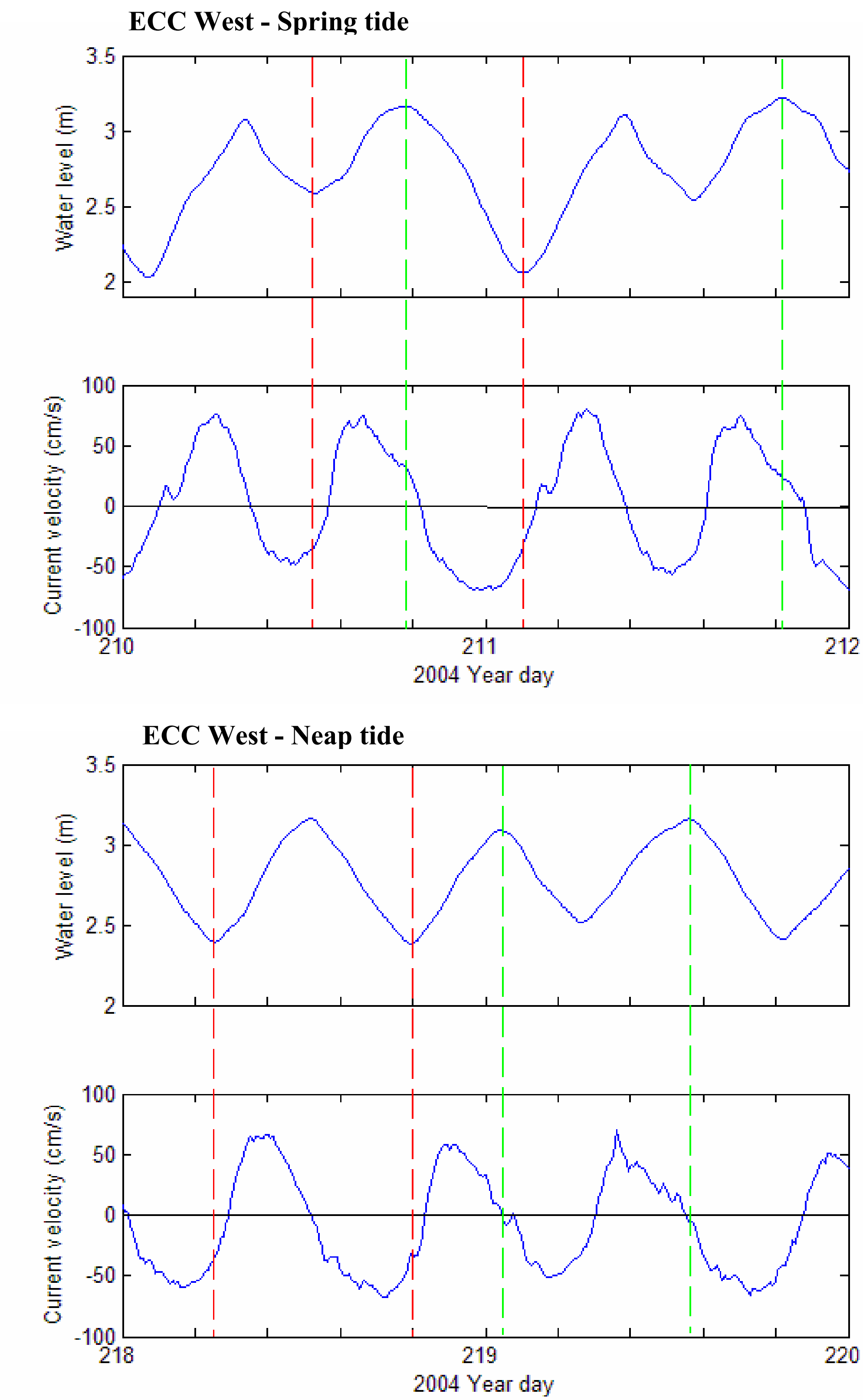



*FIGURE 93. Time series of V velocity (colors) and water level (blue line), measured by the ADCP, and suspended sediment concentration (green line), measured by the turbidity meter, from July 26$^{th}$ till August 9$^{th}$ 2004 at ECC West. V velocity is the current velocity perpendicular to the axis of the measured channel and refers simply to in- and outflow. The V velocity time series show an undulating vertical velocity profile, reflecting velocities throughout the entire water column as the water level goes up and down. The colors refer to the strength of the current: red and yellow tints being inflow, blue and green tints being outflow. The darker the color, the stronger the velocities.*

*(1) Notice the daily inequality of water level during spring tide (one large tide, small tide, large tide, etc.)*
*(2) Maximum flood velocities reach 150 cm/s, maximum ebb velocities reach almost 95 cm/s.*
*(3) Notice the irregular character of the sediment concentration amplitude. Many peaks coincide with slack high tide. However, peaks also appear at slack low tide. The effect of spring/neap tide on sediment concentration seems to be absent.*
*(4) Notice the increase of sediment concentration towards the end of the time series (year day 218-222). Extensive rain is not causing these sediment peaks, since rainfall has not been recorded in the surrounding rain stations from ENP and the USGS. Cause of peaks remains unclear.*




*FIGUR 94. Detailed time series of water level and current velocities in ECC West (August 2004) during spring tide (top) and neap tide (bottom). Positive velocities are incoming tide, negative velocities are outgoing tide. 1) Notice the daily inequality of the tide and the higher current velocities during spring tide. 2) Notice the time lag between water level and current flow. Red dashed lines cross the water level at slack low tide.*

*Notice that water is still flowing out at slack tide (velocity is still negative). Green dashed lines cross the water level are exactly at slack high water. Notice that, during spring tide only, water is still flowing in at slack high tide (velocity is still positive).*

**Sediment Dynamic Processes**

The lack of a complete hydrologic dataset combined with a complicated sediment pattern has made the sediment transport dynamics from East Cape Canal to the entrance to Lake Ingraham difficult to understand. In order to fully capture the hydrologic and sediment linkages between Lake Ingraham, the interior former freshwater marsh and the canals connecting to Florida bay, we have incorporated geochemical analyses of particulate matter with the hydrodynamic and sedimentologic observations.

Realize that the average load of suspended sediment concentration in the field area (Table 8) is extremely high compared to other estuarine settings (Chesapeake Bay River: 45 mg/l; South San Francisco Bay: 15-80 mg/l; Marco Island: 10-35 mg/l). Within the study area, differences can be large as well. The East Cape area has much higher concentrations than the Middle Cape area and this is a result of different sediment source. Florida Bay contains on average more suspended carbonate sediment than the Gulf of Mexico. In addition, most canals in the southeastern part of the study area are connected across the Marl Ridge to the interior marsh areas northeast of Lake Ingraham and, thus, function as transport ways for the organic particulate matter that is moved around.

| | MEASUREMENT PERIOD | AVERAGE SUSPENDED SEDIMENT CONCENTRATION (MG/L) |
|---|---|---|
| MCC Centre | August 2003 | 40 |
| | January 2004 | 43 |
| Hidden Creek | February 2004 | 60 |
| ECC North | February 2005 | 102 |
| HSC South | Spring/summer 2004 | 115 |
| Lake Ingraham | March 2005 | 209 |
| ECC South | August 2004 | 228 |
| ECC West | August 2004 | 353 |

*TABLE 8. Average suspended sediment concentrations for all measurement stations, from least to most. Measurement periods range from 8 to 15 days continuously (measurements every 10 minutes). HSC South is at the intersection of Homestead Canal South with ECC (Figure 90). These measurements are not from a turbidity meter but are in situ water samples, filtered to obtain mg/l sediment concentrations.*

In Hidden Creek we have not obtained synchronous time series of suspended sediment concentration and current velocities. Therefore, we can not calculate sediment transports for Hidden Creek. Figure 98 shows the sediment concentration time series measured at Hidden Creek in February 2004. In most cases, two sediment peaks of approximately the same magnitude can be observed during a tidal cycle: one at maximum flood velocity and one at maximum ebb velocity. This is the direct consequence of an equally strong current during ebb and flood.

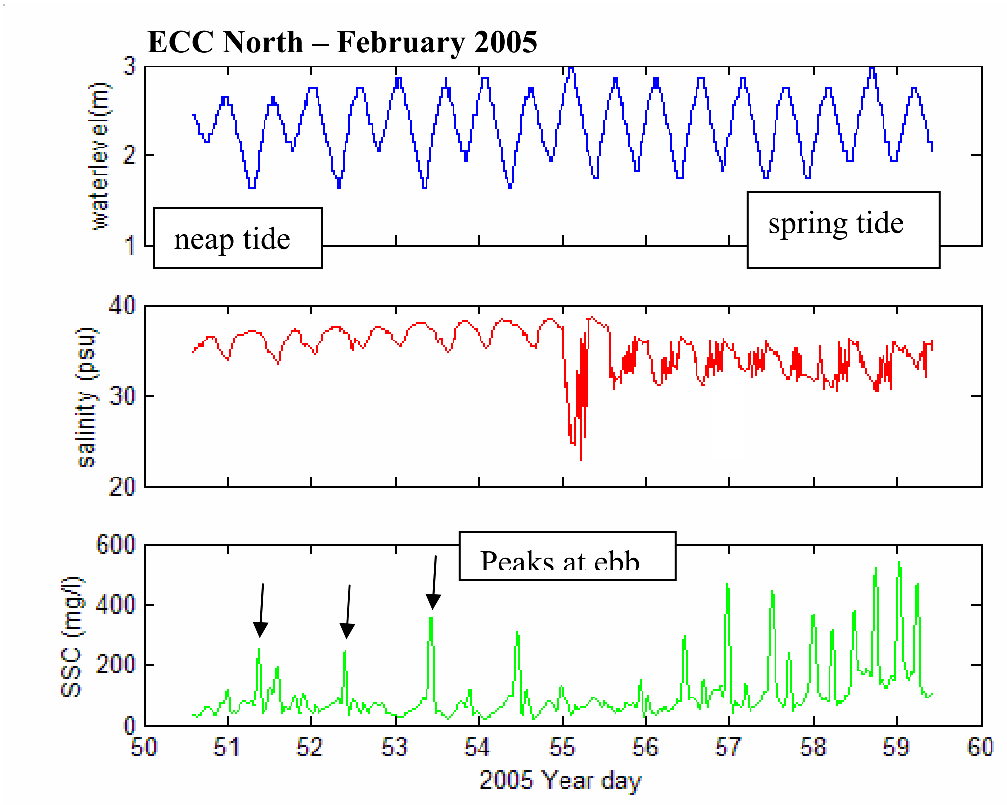
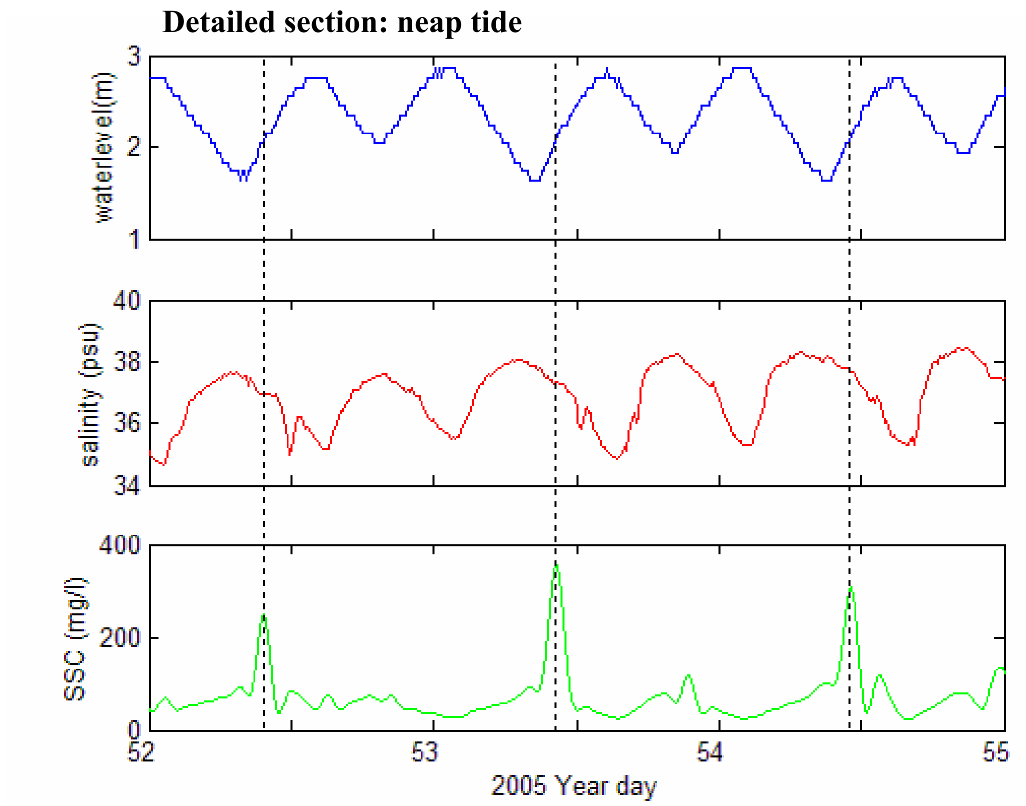



*FIGURE 95. Time series of water level (blue), salinity (red) and suspended sediment concentration (green) for ECC North measured in February 2005 with a CTD (Conductivity – Temp - Depth) and turbidity meter. 1) Notice the drop in salinity on day 55 caused by extensive rain that same day. 2) Notice sediment peaks occur toward end of ebb. During neap tide, every other low tide gives a peak. During spring tide, every low tide gives a peak.*




*Detailed section:*

*1) Notice the regular salinity pattern. As water level goes down (ebb tide), salinity increases till maximum 38‰ at slack low tide. As water level goes up and Florida Bay water flows in, salinity drops to regular seawater norms (35‰).*

*1) Notice sediment peaks appear right after slack low tide. Field observations provide evidence that even though water level is rising, waters are still draining from nearby HSC South and Lake Ingraham (Figure 93).*

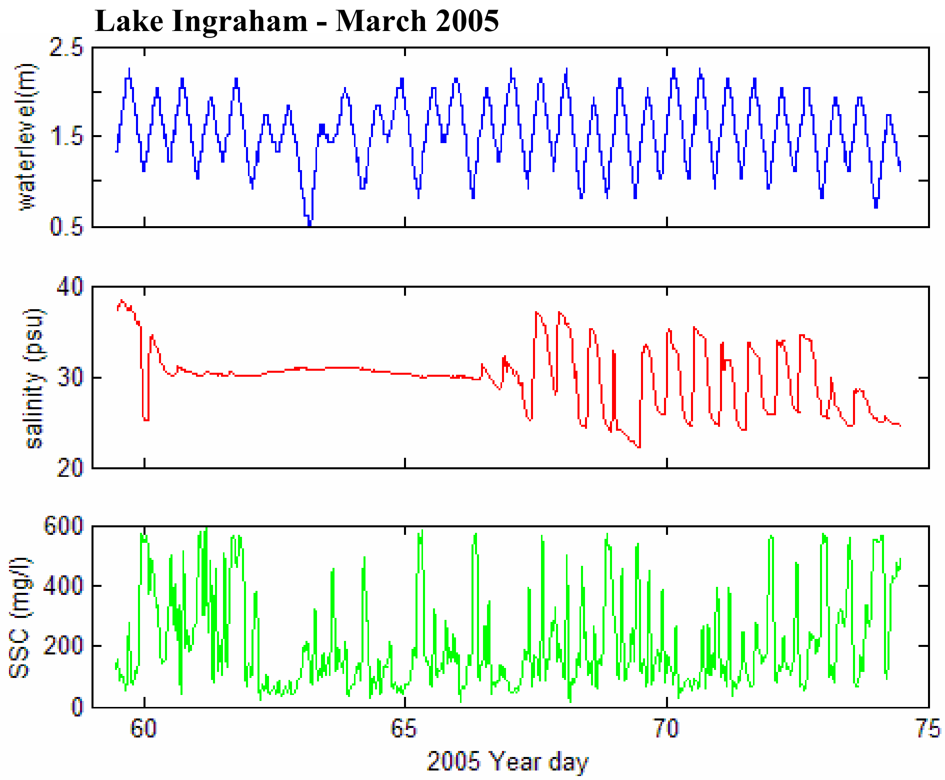
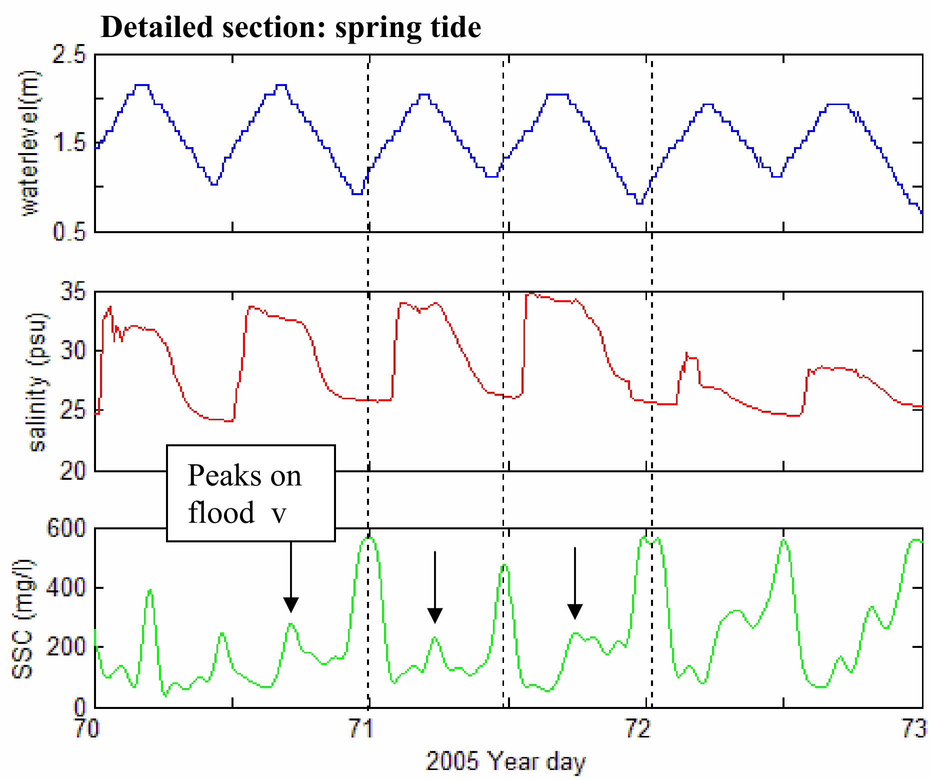



*FIGURE 96. Time series of water level, salinity and suspended sediment concentration for Lake Ingraham measured in March 2005 with a CTD and turbidity meter. 1) Notice salinity signal is semi-stable from year day 60-66. Reason is unknown.*

*2) Low salinities (~25‰) are result of extensive rain events and prove that fresh water drains through HSC West into Lake Ingraham.*

*3) Notice large sediment concentrations and, compared to ECC North and South, a more irregular sediment signal.*




*Detailed section:*

*1) Notice the regular salinity pattern. Salinity leaps from ~25‰ to normal sea water salinities (35‰) every tide. Jumps occur some time after each slack low tide, but coincide with the reversal of outgoing to incoming tide.*

*3) Notice large sediment peaks right after slack low tide. Salinity data confirms that these peaks appear during outgoing currents (salinities are low!). Notice smaller peaks right after slack high tide, carried in by 35‰ seawater.*

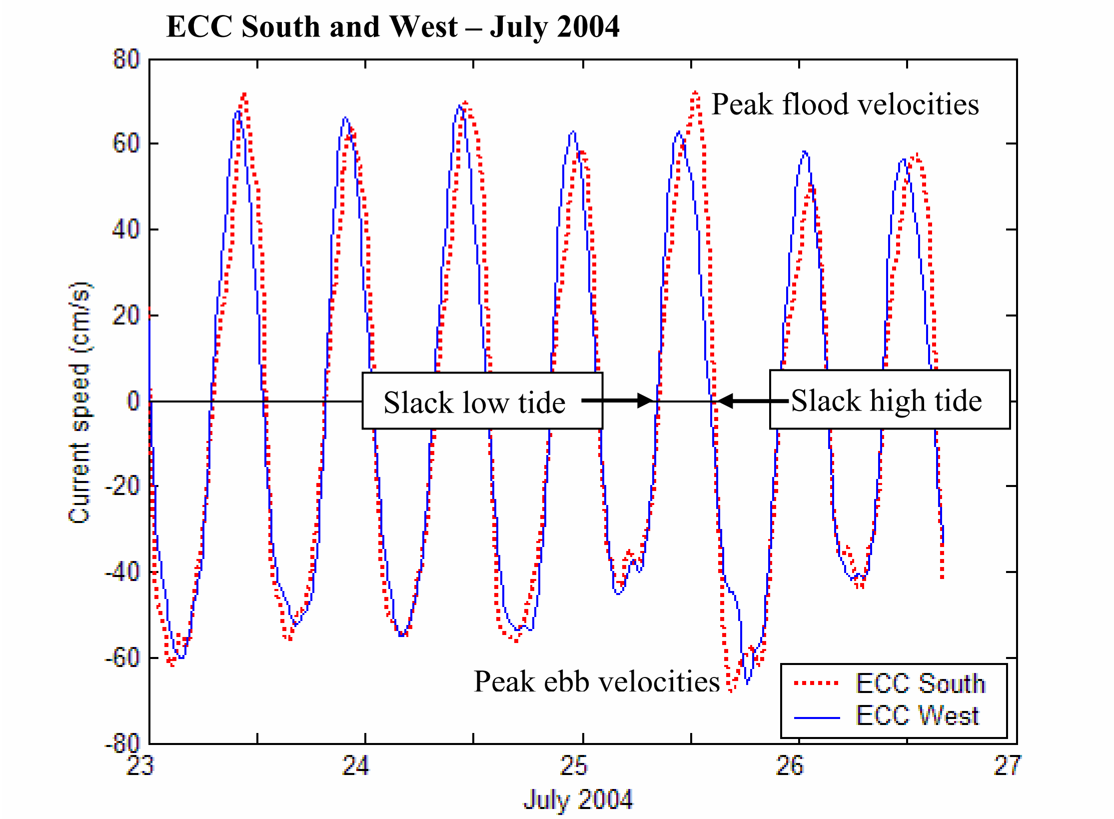



*FIGURE 97. Current velocities for ECC South and ECC West during a few days in July 2004 before the instrument at ECC South broke down on July 26th. Positive velocities are incoming tide, negative velocities are outgoing tide. Notice that the velocity pattern and amplitudes at ECC South and ECC West are very similar. Slack high and low tide is at the same time. Peak flood velocities are slightly later at the entrance of ECC; peak ebb velocities are slightly earlier. This means that while the flood velocities at ECC West are diminishing, they are still increasing at ECC South. This is probably due to the effect of freshwater draining though Homestead Canal West into Lake Ingraham and resisting the incoming waters through ECC. Velocities at ECC West will therefore decrease.*

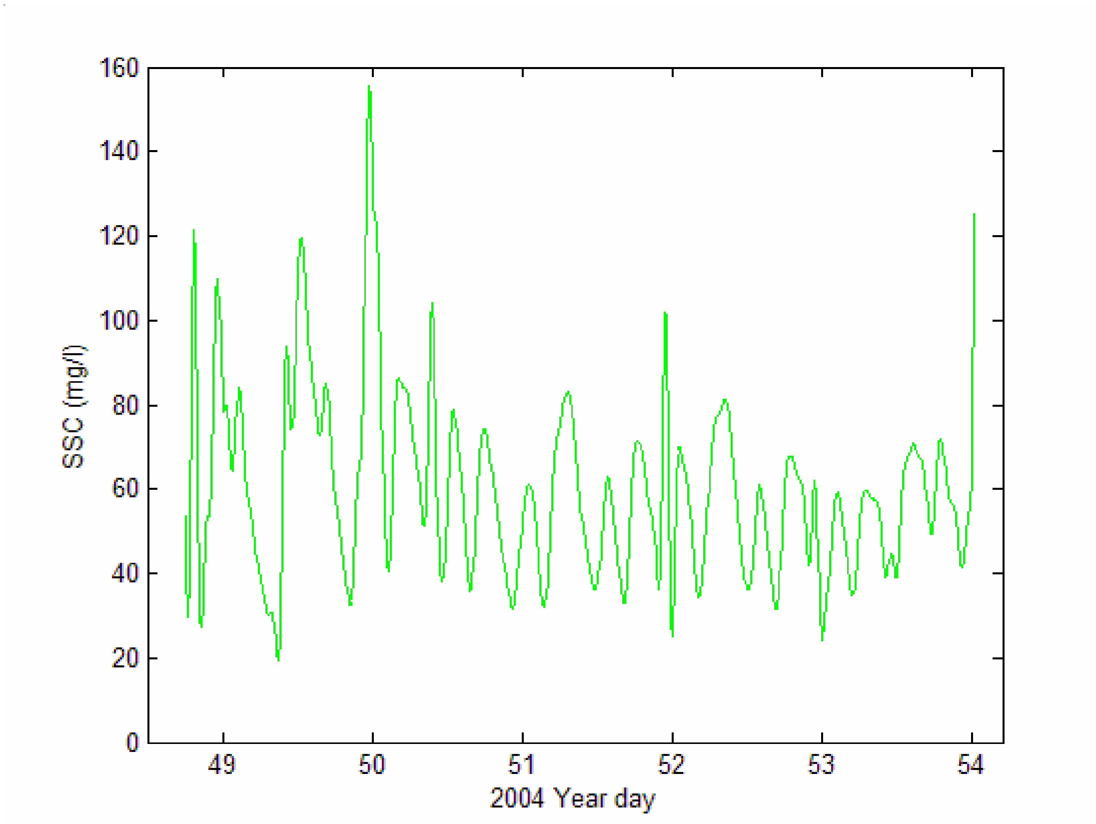



*FIGURE 98. Time series of suspended sediment concentration at Hidden Creek in February 2004. Tidal and current data is not available. However, field observations confirm that sediment peaks of comparable amplitude occur during each maximum flood and ebb velocities. This is the direct consequence of an equally strong current during ebb and flood.*

The long term suspended sediment signal at the entrance of East Cape Canal (ECC South) was first monitored during the summer of 2003 and again in the summer of 2004. Current and tidal data is not available for both periods. Figure 99 depicts the very peculiar trend that is observed in both cases. A strong sediment peak (~ 1000 mg/l) shows up at the end of each ebbing tide during spring tide and at every other ebb during neap tide. The second important observation is the fact that very little sediment from Florida Bay flows into East Cape Canal on an incoming tide.

The second data set from ECC South (August 2004) coincides with sediment time series measured simultaneously at ECC West (Figure 100). Unlike the regular tidal pattern showing up in the time series at ECC South, ECC West does not show a great deal of orderliness. Many sediment peaks coincide with slack high tide. However, peaks also appear at slack low tide and every so often at times of highest (ebb or flood) velocities. Keep in mind that slack tide does not imply that horizontal water movement is zero (see explanation Figure 94). Therefore, sediment peaks that occur at slack high tide are still directed towards Lake Ingraham, as the current is still flowing in. The effect of spring/neap tide on sediment concentration seems to be absent. The complexity of the sediment pattern is partly a result of the near presence of several little creeks draining close to ECC West, adding "noise'' to the signal.

*Figure 99A*

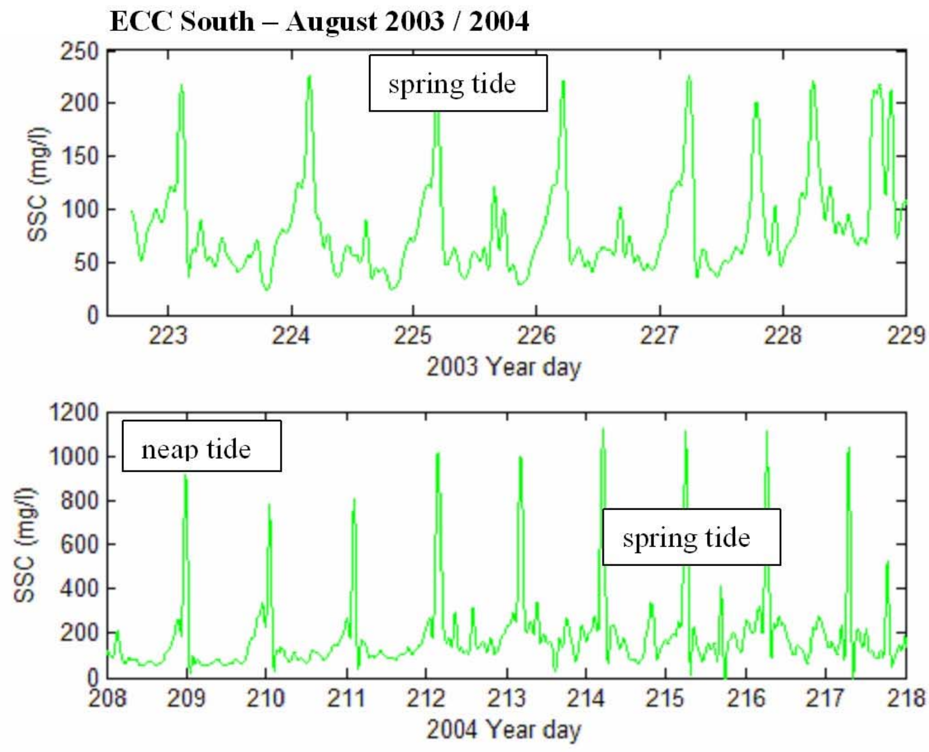



*Figure 99B.*

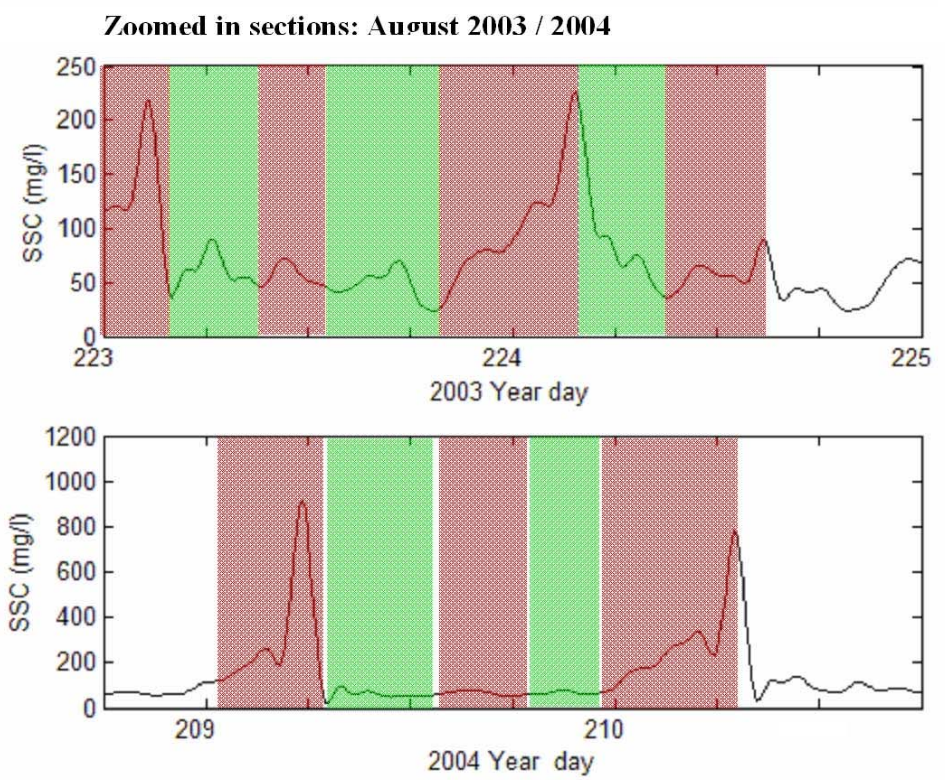


*FIGURE 99A). Time series of suspended sediment concentrations (SSC) in ECC South during August 2003 and August 2004 and B) zoomed in sections where green areas are flooding tide, red areas are ebbing tide.*
*Synchronous current and tidal data does not exist. However, field observations and tidal predictions provide proof that observed sediment peaks occur at the end of each ebbing tide.*
*1) Notice the difference in maximum sediment concentrations. In August 2003 peaks reach around 220 mg/l; in August 2004 peaks reach around 1000 mg/l. In August 2003 sediment concentrations were too high to be read by the turbidity sensor, which had its upper limits set to 220 mg/l. The readings are therefore cut off; sediment concentrations are highly underestimated and cannot be read as realistic values. However, the time series are still useful to pick up trends in the sediment concentrations through time. After August 2003 the turbidity sensor was recalibrated in the factory to allow readings up to 2000 mg/l.*
*2) August 2003: notice the strong spring tidal effect on the amount of suspended sediment in the water and the occurrence of sediment peaks: a very large peak is followed by 3 smaller peaks. The large peak occurs at the end of every other ebbing tide. The smaller peaks are at respectively the next flood – ebb – flood again. Notice that during neap tide, there is no sediment peak on the incoming tide.*
*Figure 99B clearly shows again the dynamics of sediment concentration through the individual tidal cycles. The flooding and ebbing time periods show up in colored blocks.*
*2) Time series in August 2004 cover both a neap and spring tide. Again, notice the difference in sediment peaks during ebb and flood.*
*Conclusion: Florida Bay does not carry a significant source of sediment into East Cape Canal under normal weather conditions. Instead, sediments seem to be transported towards Florida Bay. However, the southeastern part of Lake Ingraham is silting up extremely fast, so this outward transport of sediment through ECC seems controversial. This controversy will be later explained in the text. .*

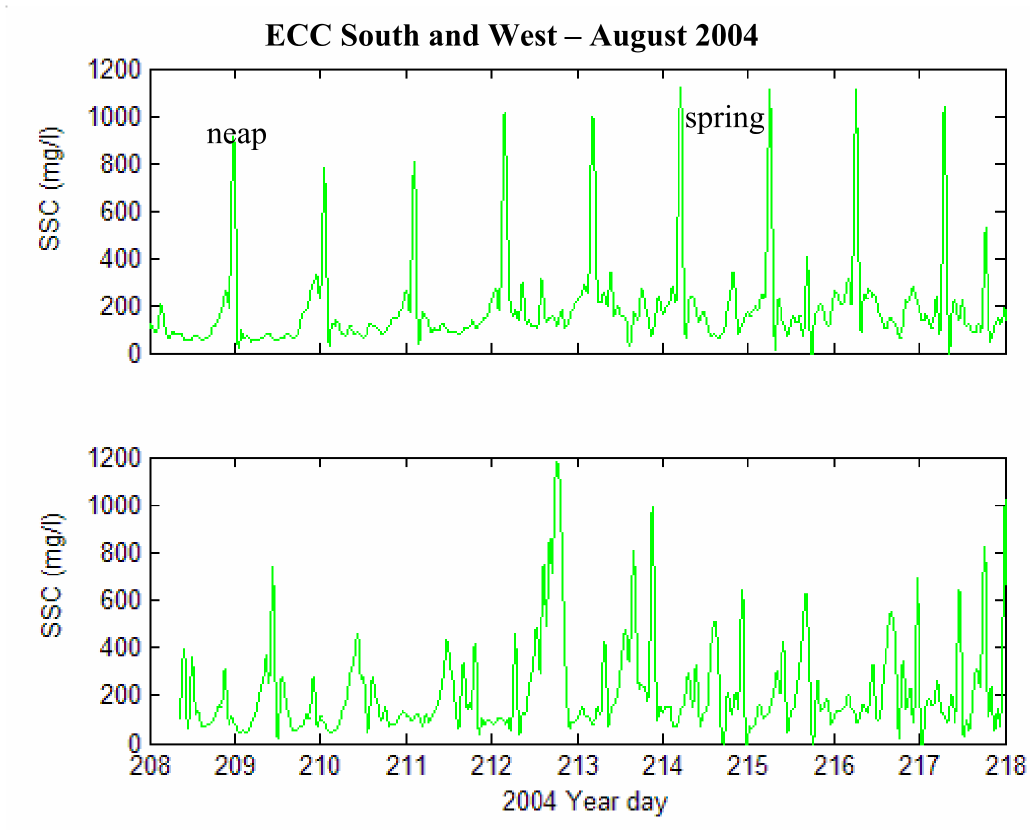



*FIGURE 100. Time series of suspended sediment concentration measured simultaneously at ECC South (top) and ECC West (bottom) in August 2004 (see Figure 93 for current and tide time series in conjunction with sediment at ECC West).*

*1) Notice again, the regular sediment pattern at ECC South (large peaks at end of every other ebb), but an irregular pattern at ECC West. Many peaks coincide with slack high tide. However, peaks also appear at slack low tide and at times of highest ebb/flood velocities. This 'noisy' signal is most likely caused by the drainage of many small creeks in the vicinity of ECC West measurement station plus the effect of Lake Ingraham complicating the sediment dynamics even more.*

To investigate more thoroughly the sediment transport pathways in and out of East Cape Canal, we have obtained sediment concentration and, additionally, salinity measurements at ECC North (Figure 95) and Lake Ingraham (Figure 96). These time series, measured in February/March 2005, are not simultaneous with each other or with measurements done in ECC West and South. Nonetheless, if tidally-driven trends exist, this will surely become apparent. ECC North shows exactly the same pattern as ECC South, except that concentrations are twice as low: sediment peaks of 250-500 mg/l appear towards the end of ebbing tide (Figure 95). The regular salinity pattern (Figure 95 – detailed section) provides additional information about the source of the water mass that is transporting these sediment loads. The salinity of out-flowing waters is on the order of 38‰, while incoming Florida Bay waters have salinity values around 35‰. We can conclude from this data that water draining through Homestead Canal South leaves its signature (hypersaline or fresh, depending on hydrologic conditions inland) on the water mass draining through East Cape Canal. Geochemical analyses of sediments and particulate matter might resolve the approximate origin of the different water masses merging in East Cape Canal (see second paragraph below).

At Lake Ingraham station (Figure 96), the sediment signal can be compared with ECC West. Sediment peaks occur mainly around slack tide but "noise" complicates the tidally-driven trend. Besides the dominant large peaks at ebb (~ 600 mg/l), important to notice are the smaller sediment peaks (~ 200 mg/l), occurring right after each slack high tide (Figure 96 – detailed section). These sediment loads are carried in to Lake Ingraham at the very last phase of flooding by typical sea waters (35‰). The fate of this sediment is to settle out and form fine sediment deposits on the submerged mudflats.

In an attempt to resolve the origin of different water masses that converge in East Cape Canal, we measured the carbon isotopic signal of particulate matter in suspended sediment samples throughout a tidal cycle at three stations in East Cape Canal (Figure 101). Carbon isotopes ($\delta^{13}C$) can be effective indicators of organic material (OM) provenance. It is likely to expect that organic matter that is transported from the inland freshwater marshes is derived from sawgrass (*Cladium* sp.), while OM that is brought in from Florida Bay is expected to derive from seagrass (mainly *Thalassia testudinum*), benthic algae, or marine phytoplankton. Organic matter that is eroding from the sides of tidal creeks and canals is expected to have a mangrove signal (mainly *Rhizophera mangle* and *Avicennia germinans*). Organic carbon isotopes are obtained with the ANCA all-round mass spectrometer of the Stable Isotope Laboratory at the Rosenstiel School for Marine and Atmospheric Science (University of Miami). The end-member isotopic values important for this study are displayed in Figure 101: sawgrass peat (~ -26 to -27‰) and Florida Bay water (~ -21%). Notice that all three stations carry lighter water on an ebbing tide than on an flooding tide. ECC South displays the largest isotopic range (from -23.65 to -21.65). The large sediment peaks that are observed at the end of ebb certainly carry part of a sawgrass signal; the incoming Florida Bay water has its OM isotopic signal partly from plankton and seagrasses. The most stable carbon isotopic signal throughout the tide is seen at ECC West. The watermass passing ECC West reflects a good mixture of end-members. This data shows once more that sediments with different origins are being carried through East Cape Canal towards their final destination: Lake Ingraham and the Southern Lakes (west of ECC and south of Lake Ingraham).

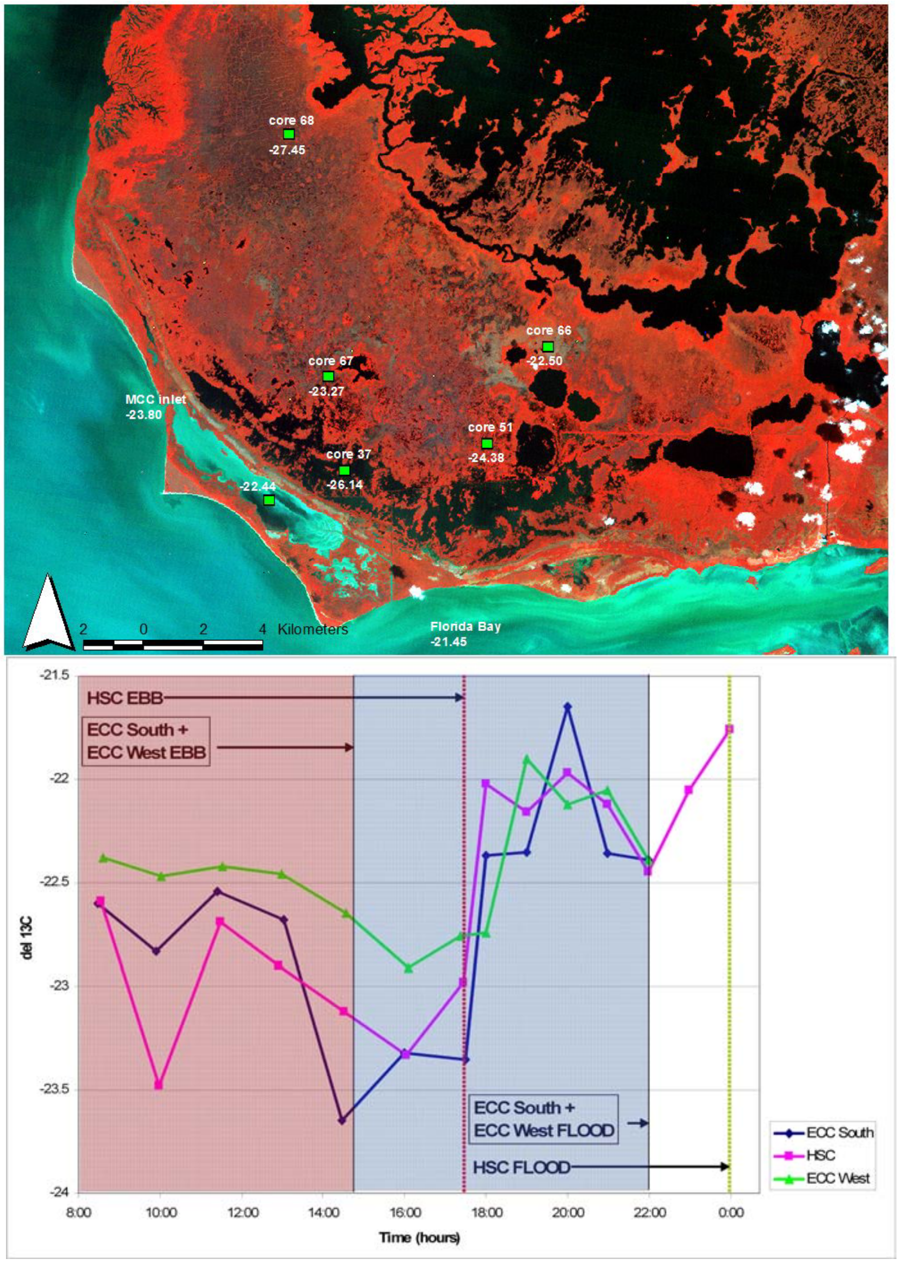



*FIGURE 101. Overview of some carbon isotopic values around Cape Sable. Very light values (~ -26 to -27 $\delta^{13}C$) are sawgrass, heavier values (~ -21 to -23 $\delta^{13}C$) are mixture of plankton / seagrass.*

*Below: graph of $\delta^{13}C$ values for particulate matter in water samples at 3 different stations (1/16/05). 1) Notice that all 3 stations carry lighter water on an outgoing tide than on an incoming tide. 2)ECC South displays the largest isotopic range. The large sediment peaks that appear at the end of ebb certainly carry part of the sawgrass signal (-23.65); the incoming Florida Bay water (-21.65) has its descents partly from plankton and seagrasses. 3) Most stable carbon signal throughout the tide is at ECC West: reflection of best mixture of end-members. This graph shows once more that sediments with different origins are being carried through ECC.*

We have not calculated the suspended sediment transport flux at ECC West, as this would introduce too much uncertainty due to the complicated and variable sediment dynamic processes at this station. Most important to understand are the sediment dynamic patterns: where does sediment come from and where does it go to. Quantitative information about the rates of sediment movement is given by the sediment reference traps.

**Sediment Dynamic Patterns**

The southeastern zone in Lake Ingraham is affected by sediment supplied through East Cape Canal mainly, and to a certain extent through Hidden Creek and Homestead Canal West. *In situ* accumulation rates range from 3 to 14 cm/year (Figure 102). Highest accumulation rates are measured along the channel banks in East Cape Canal. The first (oldest) part of the delta extending into Lake Ingraham has relatively low sedimentation rates, since this area has filled up most of its accommodation space. Juvenile mangroves are spreading on these mudflats and stabilizing the land rapidly (Figure 103). Higher accumulation rates (5-7 cm/year) are observed on the lower mudflats further into Lake Ingraham and away from the main channel.

Figure 104 shows a core transect across the southeastern delta. The boundary between freshwater and marine sedimentation is clearly discernible in every core, but occurs over a wide range of depths: close to the main channel this defined contact lies around 80-90 cm depth, further away along the lake border this contact occurs around 45-50 cm depth. The core stratigraphy translates into very low deposition rates (~1cm/year) and underestimates the actual accumulation rates on the bare mudflats (as is the case in the northwest and central zone of Lake Ingraham). The sediment constituents and grain size (Figure 106) of surface samples is very similar to that in the northwestern and central zone, except for significantly higher organic matter percentages in the surface sediments (Figure 105). The average amount of OM in the southeastern delta is 32%, while in the northwest and central zone the average is 26%. In the collapsed freshwater marsh, OM percentages are usually around 55%. For comparison, organic content in Florida Bay sediments is around 3-10%. Figure 107 shows the distribution of organic matter from the surface to 1.5 m depth for several selected cores. The upper 20 cm usually contains more organic material, which is broken down with depth.

The synthesis section at the end of this chapter will summarize the most important sediment dynamic findings for the entire study area and connect the results into a logic explanation of ongoing processes and patterns.

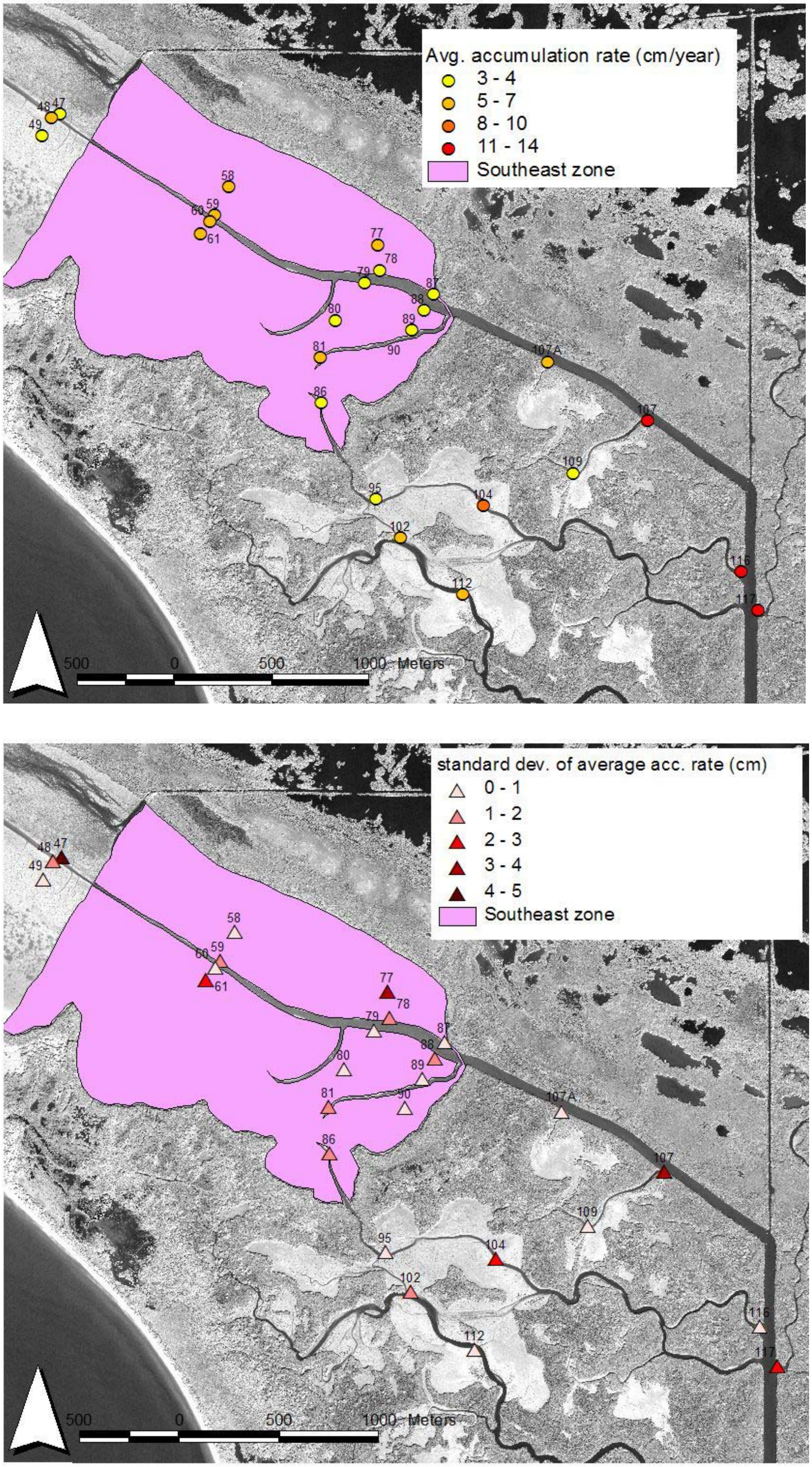



*FIGURE 102. Average accumulation rates (top) and standard deviations (bottom) derived from sediment reference traps for the southeastern zone. 1)Highest accumulation rates are observed along the channel banks in East Cape Canal. 2) Notice the relatively low accumulation rates (3-4 cm/year) on the oldest part of the delta in Lake Ingraham. This mudflat area has quickly filled up most of its accommodation space.. Juvenile mangroves are moving in on the bare mudflat and spreading their seedlings rapidly. Neap high tides do not fully submerge this area anymore. Instead, higher accumulation rates (5-7 cm/year) are observed on the lower mudflats further into Lake Ingraham and away from the main channel. 3) Higher accumulation rates results naturally in higher standard deviation among the 4 measured carpet tiles.*

*FIGURE 103. Photos of juvenile mangroves on growing deltas in southern Lake Ingraham (top in distance, October 25, 2003) and the Southern Lakes (bottom, December 11, 2002), American crocodile provides scale.*

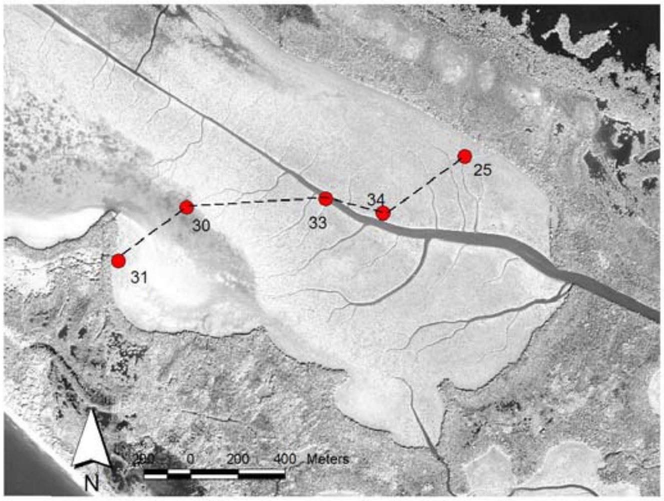
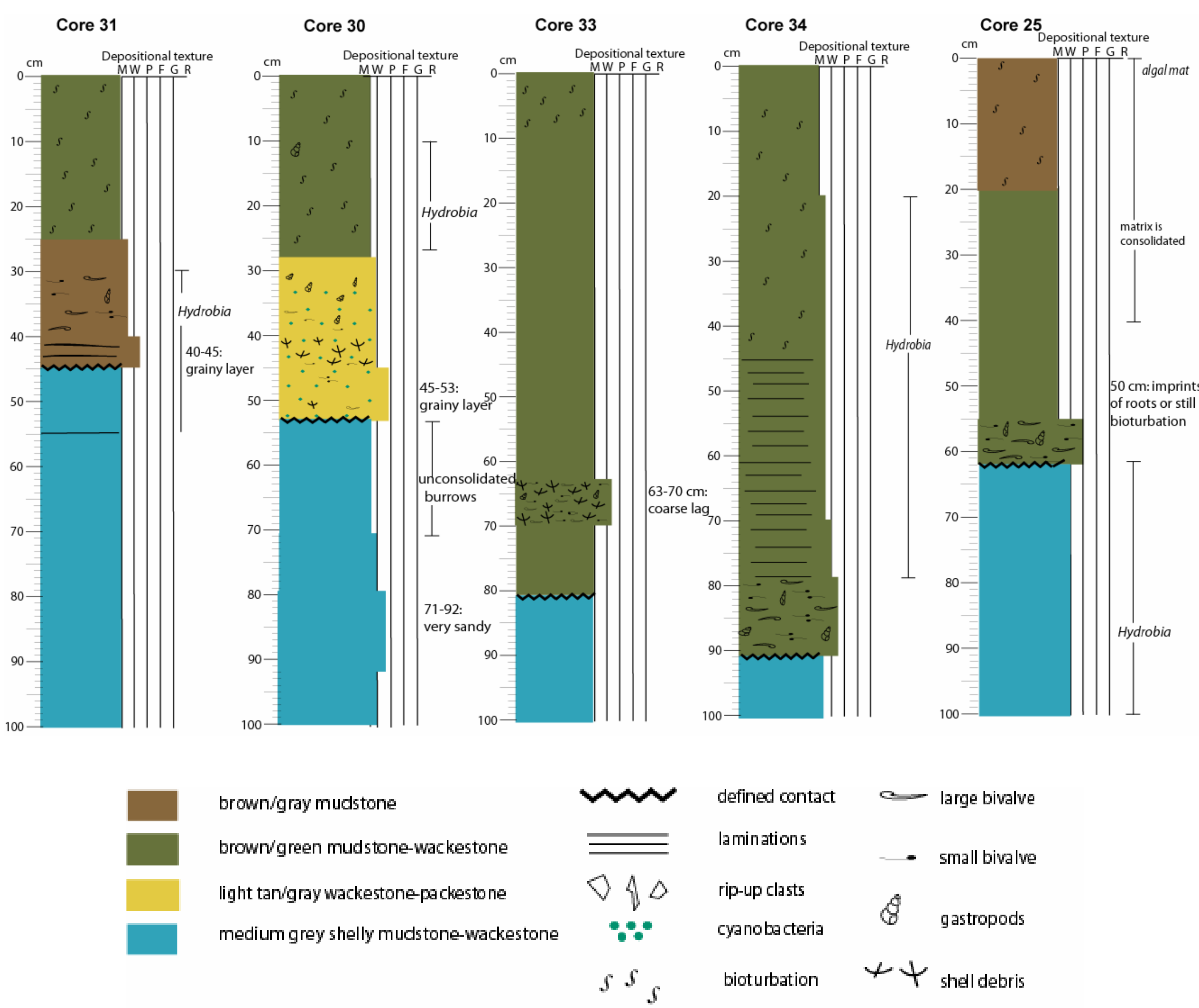



*FIGURE 104. Map (left) depicting a profile of cores taken in the southeast section of Lake. Log drawings of core 31-30-33-34-25. Four major Holocene sedimentary units can be classified. The medium grey shelly mud- to wackestone (light blue) is the unit that represents the fresh - to brackish water depositional environments that dominated before opening of Lake Ingraham. Close to the channel (where higher accumulation rates are measured), this unit occurs around 80-90 cm depth, whereas along the edges of Lake Ingraham the unit appears around 45-60 cm. A green/brown shelly wacke-packestone layer that turns into a mud-wackestone overlays the grey shelly mudstone-wackestone. This unit is highly organic (greenish color) and loosely compacted. Hydrobia minuta sp. is present. Bioturbation is intense throughout most of the upper cores.*



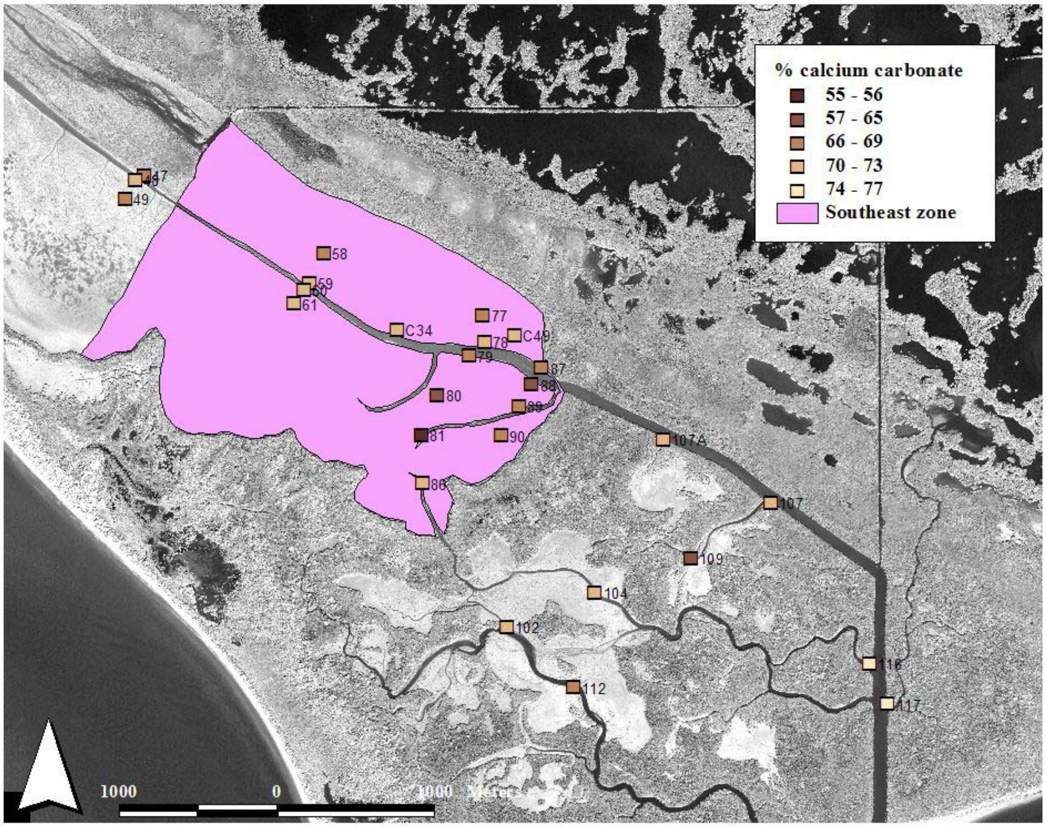



FIGURE 105. Amount of calcium carbonate in weight percentage of the sediment reference traps and some cores. Notice that carbonate % within Lake Ingraham are lower (more organics) than along the banks in East Cape Canal and within the pond areas between ECC and Lake Ingraham. Reference trap # 81 has 55% carbonate, which is the lowest in the entire area. Core 37, taken from within the collapsed freshwater marsh, also contains 55% carbonate (Figure 107).

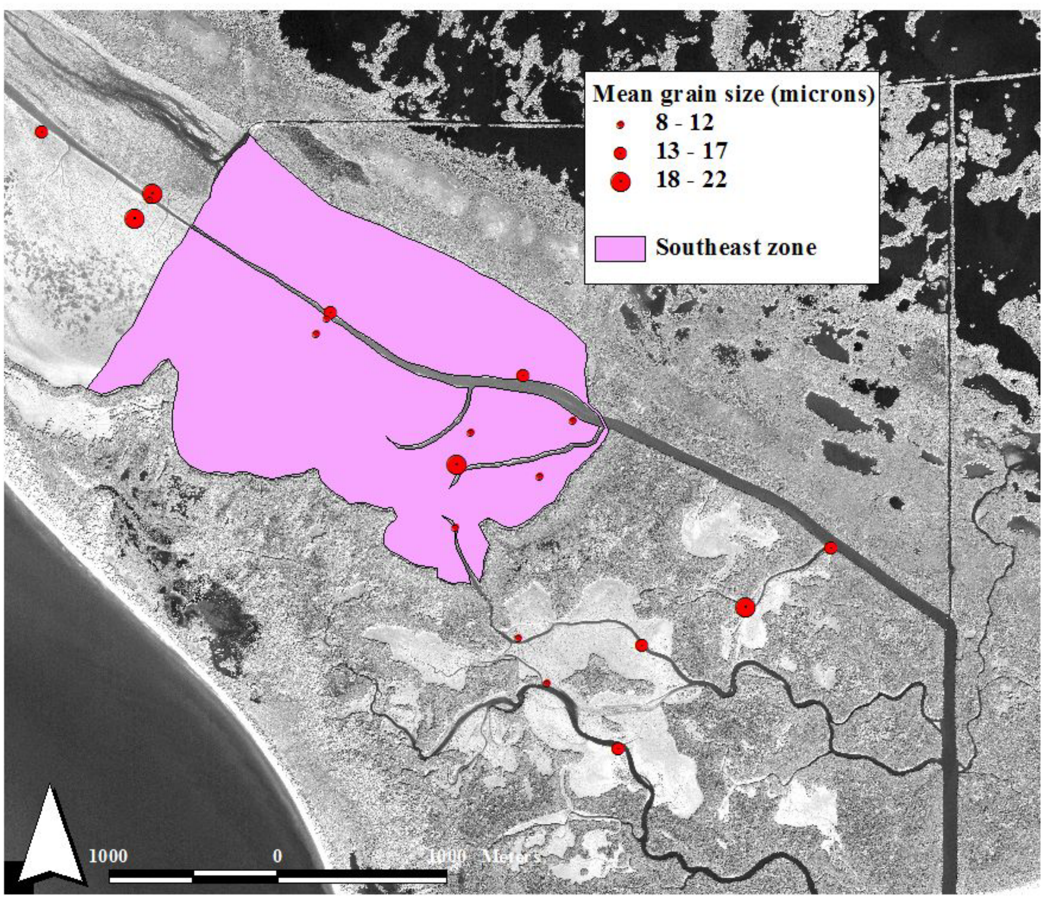



FIGURE 106.. Mean grain size in µm from the sediment reference traps. Notice that the mean grain size is less than 22 µm (same as in northwestern and central zone). This very small grain size defines all samples as silt to clay sized. All samples are very poorly sorted. See Figure 89 for SEM images of samples # 88, 81 and 48.

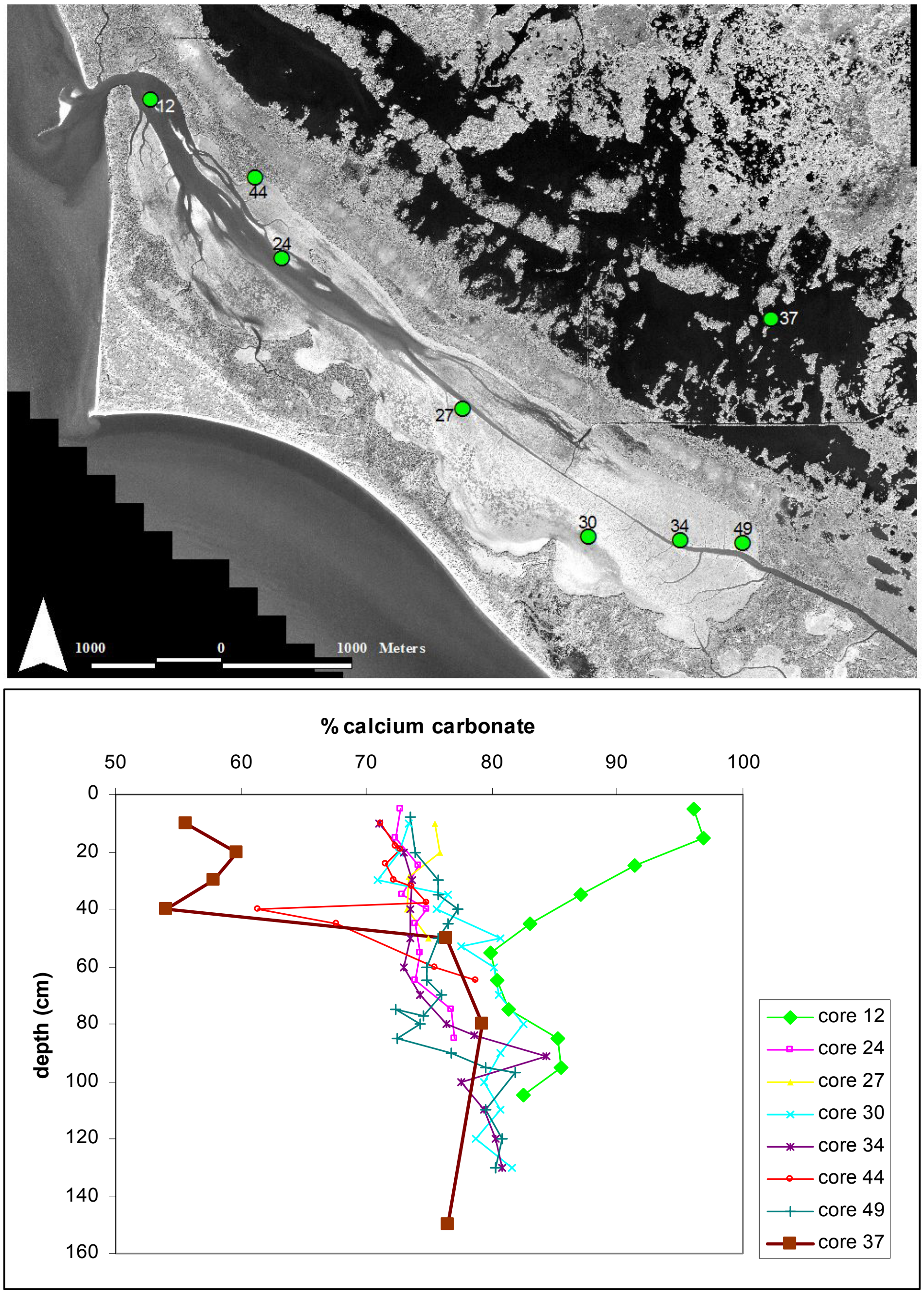



*FIGURE 107. Map (top) with locations of cores that have been analyzed for calcium carbonate % (bottom). Notice the 2 extremes: core 12 contains almost 100% calcium carbonate at the surface (shelly carbonate shoal bar in the inlet of MCC). Core 37 (in collapsed fresh-water marsh) contains only 55% calcium carbonate at the surface (and 45% organic matter). This high organic matter content in the upper sediment layer is indicative for the collapse of the freshwater marsh. The other cores lie in the middle and contain around 75% carbonate, 25% organic material. Usually the first 20 cm has higher organic matter concentrations but with depth the organic material is broken down.*

## **Coastal Dynamics**

We made an attempt to monitor shoreline dynamics at seven locations along the shoreline between East Cape Canal and Middle Cape Canal (Figure 108). Table 9 lists the coordinates of the locations where cross-shore transects of metal rods were placed. Over time, many rods got bent by wave action or simply disappeared. The results are far from complete, but still they give a general idea about the beach and mangrove shoreline dynamics between the two capes. Most transects have been monitored on an irregular basis approximately for a total time period of 6 to 18 months.

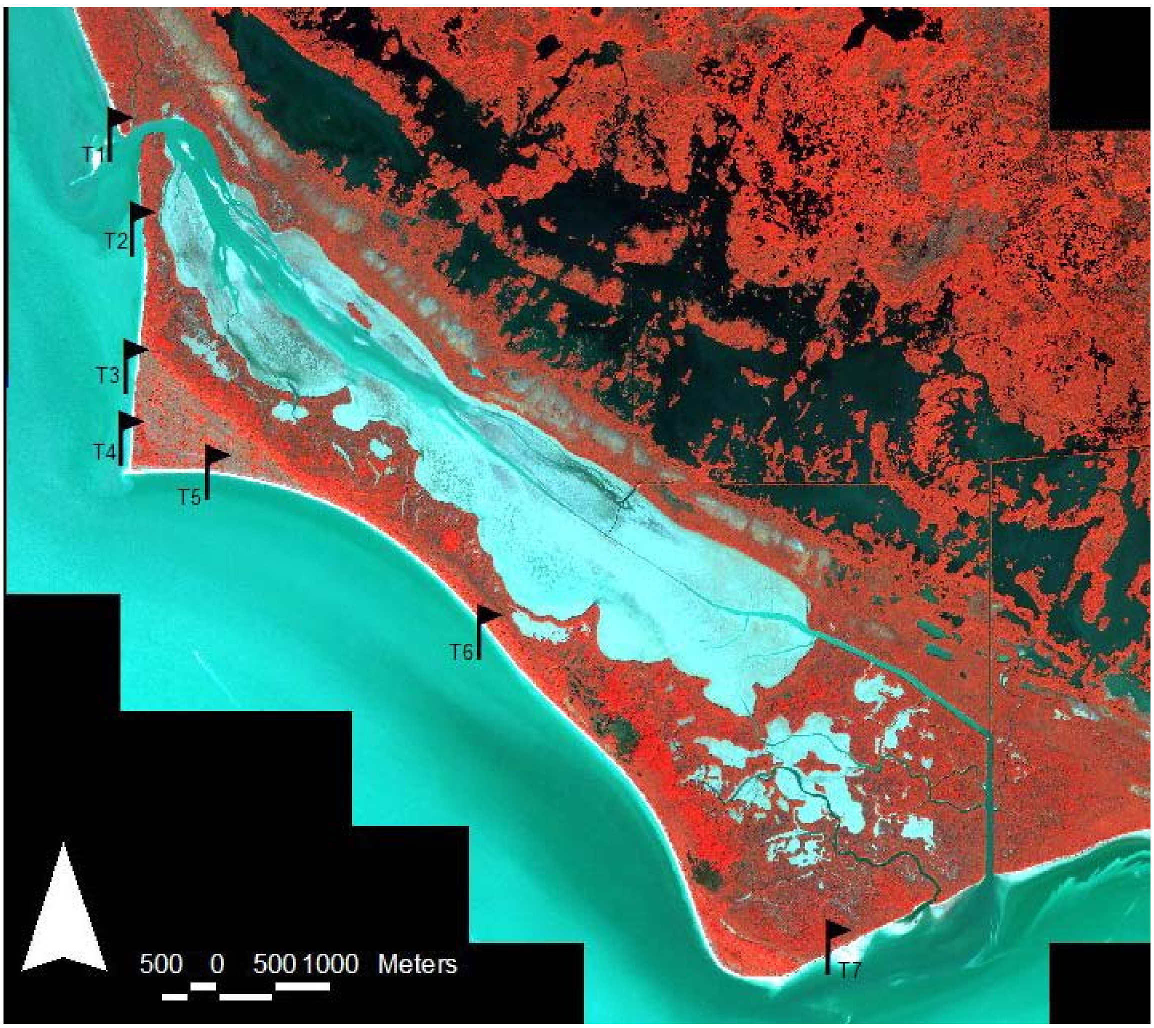



*FIGURE 108 Location of the beach transects between East Cape Canal and Middle Cape Canal. (Ikonos multi-spectral image 2005)*

| BEACH TRANSECT | NORTHING | EASTING |
|---|---|---|
| T1 | 485659 | 2785275 |
| T2 | 485859 | 2784441 |
| T3 | 485800 | 2783227 |
| T4 | 485745 | 2782600 |
| T5 | 486507 | 2782287 |
| T6 | 488912 | 2780888 |
| T7 | 490796 | 2778187 |
| T8 | 491993 | 2778101 |

*TABLE 9. Northing/easting coordinates of beach transects*

On the beach north of Middle Cape Canal inlet (T1), measurements were taken frequently for a short period of time in the winter of 2003 and 2004, in order to capture the short-term dynamics of the beach profile. The variation of the height of the sediment bed is measured using a washer around the metal rod. During maximum flood velocities some erosion usually takes place. Sediment underneath the washer is eroded and the washer drops. If, during ebb tide, sedimentation occurs, the washer is buried under the deposited sediment. The advantage of this method with respect to rods without washer is the possibility to measure absolute erosion and sedimentation. Even when net changes are zero, information is obtained about static or dynamic equilibrium status of the sediment bed.

Figure 109 shows an aerial photograph of Middle Cape Canal inlet and the approximate location of the individual profiles at the beach. Over a time period of 4 weeks in 2003 (Feb 14$^{th}$ – March 11$^{th}$) and again during 4 weeks in 2004 (Jan 12$^{th}$ – Feb 19$^{th}$), we observed a general trend of upper beach accumulation and lower beach erosion (Figure 110 - 111). The beach profile steepened, a typical phenomenon during fair weather: the lower beach erodes and sediment is 'washed over' onto the higher beach. Beach dynamics was significant during this period of winter storms. Table 10 shows the maximum and average erosion and sedimentation rates measured. Maximum erosion rates per week are approximately 30 cm for all profiles and during both winters. These high erosion rates always occur around the low water line. Profiles 1 and 2, located closest to the tidal inlet, experience higher overall erosion rates as the outgoing current hugs this side of the channel. Visual observations during 3 years of field work can confirm the extremely high variability of the beach morphology around Middle Cape Canal inlet.


*FIGURE 109. Middle Cape Canal on an outgoing tide (Dec'04). Notice location of profiles 1,2,3,4 and 5 along the northern beach of the inlet. Each profile has 5 to 12 sticks measuring weekly beach changes over a short period of time (1 month) in winter 2003 and winter 2004.*

| | **MAX / AVG EROSION (CM)** | | **MAX / AVG SEDIMENTATION (CM)** | |
|---|---|---|---|---|
| ***2003*** | | | | |
| Profile 1 | -30 | -9.9 | 24.4 | 6.2 |
| Profile 2 | -29.4 | -10.3 | 38 | 16.3 |
| Profile 3 | -33.8 | -6.2 | 15.8 | 4.8 |
| Profile 4 | -23.7 | -3.4 | 27.6 | 9.2 |
| Profile 5 | -30.6 | -5.5 | 44.4 | 11.8 |
| | | | | |
| ***2004*** | | | | |
| Profile 1 | -44.9 | -12.3 | 33.5 | 12.1 |
| Profile 2 | -38.9 | -10.0 | 33.6 | 10.4 |
| Profile 3 | -23.7 | -2.2 | 39.8 | 7.7 |
| Profile 4 | -12.3 | -2.4 | 36.5 | 7.3 |

*TABLE 10. Maximum and average erosion and sedimentation rates for profiles measured during 4 weeks in winter 2003 and 4 weeks in winter 2004.*

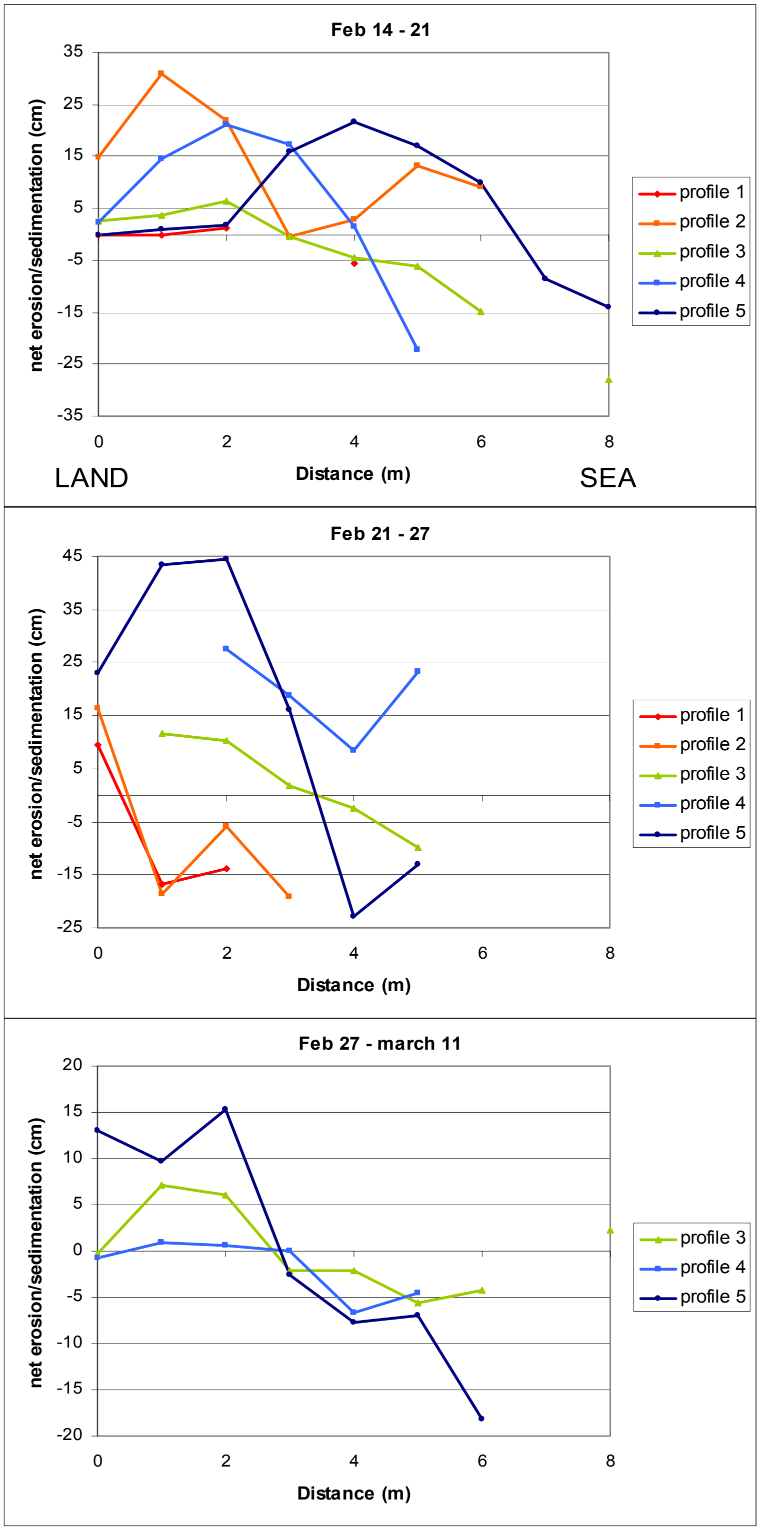



*FIGURE 110. Net erosion/sedimentation rates for 5 profiles at Middle Cape Canal beach in winter 2003. (see Figure 109 for location). The general trend shows accumulation on the upper beach and erosion on the lower beach. Net sedimentation rates can be as high as 45 cm in 6 days.*

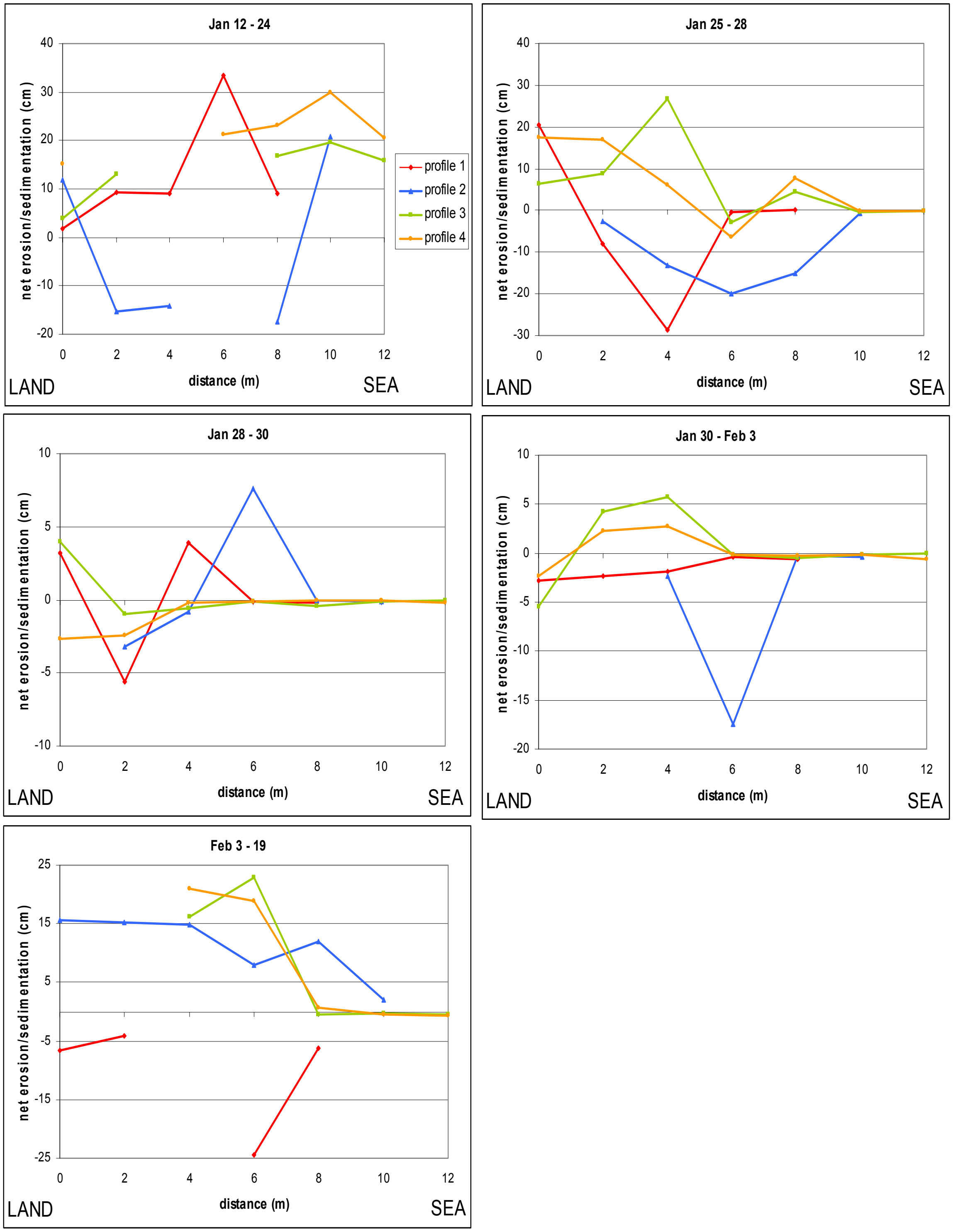



*FIGURE 111. Net erosion/sedimentation rates for 4 profiles at Middle Cape Canal beach in winter 2004. (see Figure 109 for location). Many rods get bent or disappeared, so transects are not always continuous. Most accumulation happens on the upper beach, just as in winter 2003. These are overwash deposits that slowly move landward into the mangrove forest. Profile 1 and 2 (closest to the inlet) seem to be most erosional.*

Transect 2 (T2; Figure 108) runs just south of Middle Cape canal inlet where the thin veneer of beach sand has disappeared over the past decades and mangroves face direct wave action from the Gulf of Mexico (Figure 112). From aerial photographs large erosion rates have been determined since 1935 (Figure 24). However, from September 2003 till January 2005 we have not had measurable erosion at this location (Figure 113).

Transect T3 is located on the far north side of Middle Cape where a 20 meter stretch of beach is bordered landward by palmettos surrounded by low vegetation such as shrubs and succulents (Figure 108). From September 2003 to August 2004 ± 25 cm erosion occurred close to the waterline (Figure 113). However, by January 2005, the lower beach profile recovered and was back at its initial height. The beach is in short-term dynamic equilibrium.

*FIGURE 112. Eroding mangrove shoreline south of Middle Cape Canal. Location of transect 2 (T2). Looking north, towards Middle Cape Canal. Notice the absence of a beach and the mangroves falling over. The measuring rods of T2 are about 3 meters inside the mangrove forest and therefore did not record any erosion to date.*

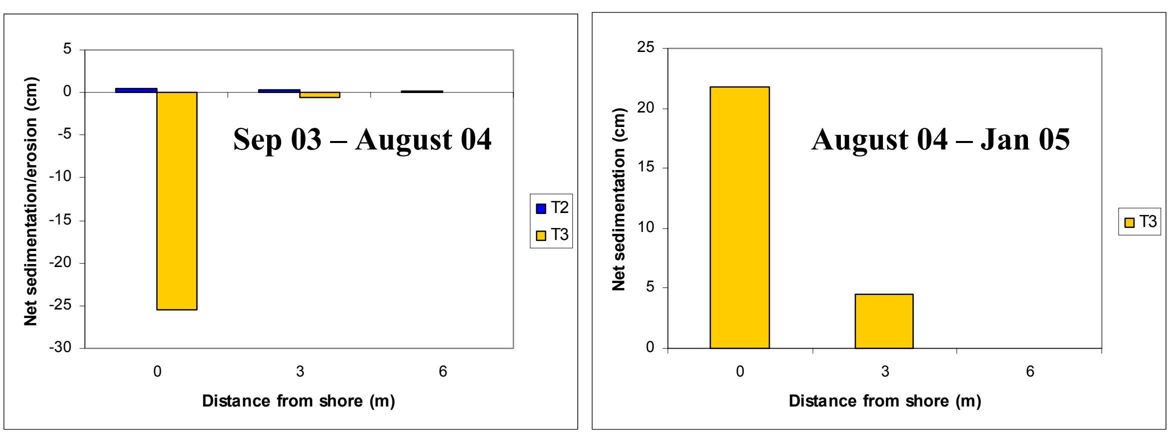



*FIGURE 113. Sedimentation / erosion patterns at beach transects T2 and T3 from September 12$^{th}$ 2003 to August 22$^{nd}$ 2004 (top) and from August 22$^{nd}$ 2004 to January 29$^{th}$ 2005 (bottom). T2 remains unchangeable; T3 shows a short-term dynamic equilibrium: net change over 1.5 year is insignificant.*

T4, T5 and T6 (Figure 108) are monitored from January 2004 till January 2005 (55). T4 monitors significant erosion of the lower beach during 7 months straight (Jan – August 2004) and then disappears. T5 monitors mostly erosion, especially of the upper beach. Some time after August 2004 T5 also disappears. T6 seems to be in short term dynamic equilibrium: 20-30 cm erosion alternates with 20-30 cm sedimentation.

At T7 (Sandy Creek; Figure 108) we have placed 3 separate rod profiles that measured beach changes from December 2003 till August 2004 (Figure 113). From December 12$^{th}$ till January 13$^{th}$, the west bank of Sandy Creek (profile 1) extends considerably, and the most seaward rods most likely get buried in the sand, as they disappear afterwards. Overall erosion is measured from January 30$^{th}$ until June 6$^{th}$ 2004. However, from visual observations, Sandy Creek has shown to be a very dynamic area that has built out large shelly deltas on both sides of the creek. As the tidal creek is growing in dimension and receives a larger tidal prism, it has functioned as an efficient sediment trap for sediment that is eroding from the beaches to the west and north and is slowly making its way around East Cape.  Even though no obvious accumulating trend can be discerned from the intermittent beach transect measurements, we can state that Sandy Creek is building an extensive beach/delta complex.

Along the shoreline from Sandy Creek to East Cape Canal, large shoals are present and growing seaward. The shoreline around East Cape Canal and Hidden Creek (see Figure 44) has never had a significant beach protecting its mangrove foreshore. Since East Cape Canal and Hidden Creek have opened, the shoreline has stepped back considerably (Figure 31). The eroded carbonate and organic mud has dispersed. The shore from Sandy Creek east to Flamingo is mostly flanked by a shallow subtidal, gradually eroding, organic carbonate marl.

**Dynamics Associated with Tropical Storms.**

From December 2002 till March 2005, the time period of our intensive field studies, Cape Sable was not hit directly by a category hurricane. The 2003 hurricane season did not bring any hurricanes to south Florida. In 2004, Florida had four significant hurricanes come ashore (Charley, Frances, Ivan and Jeanne, see Figure 116). However, Cape Sable stayed out of reach of any of the hurricane force winds. Hurricane Charley was the only hurricane that initiated significant wave heights on the west facing shorelines of Cape Sable and consequently triggered some beach erosion, especially at T6 (see Figure 117).

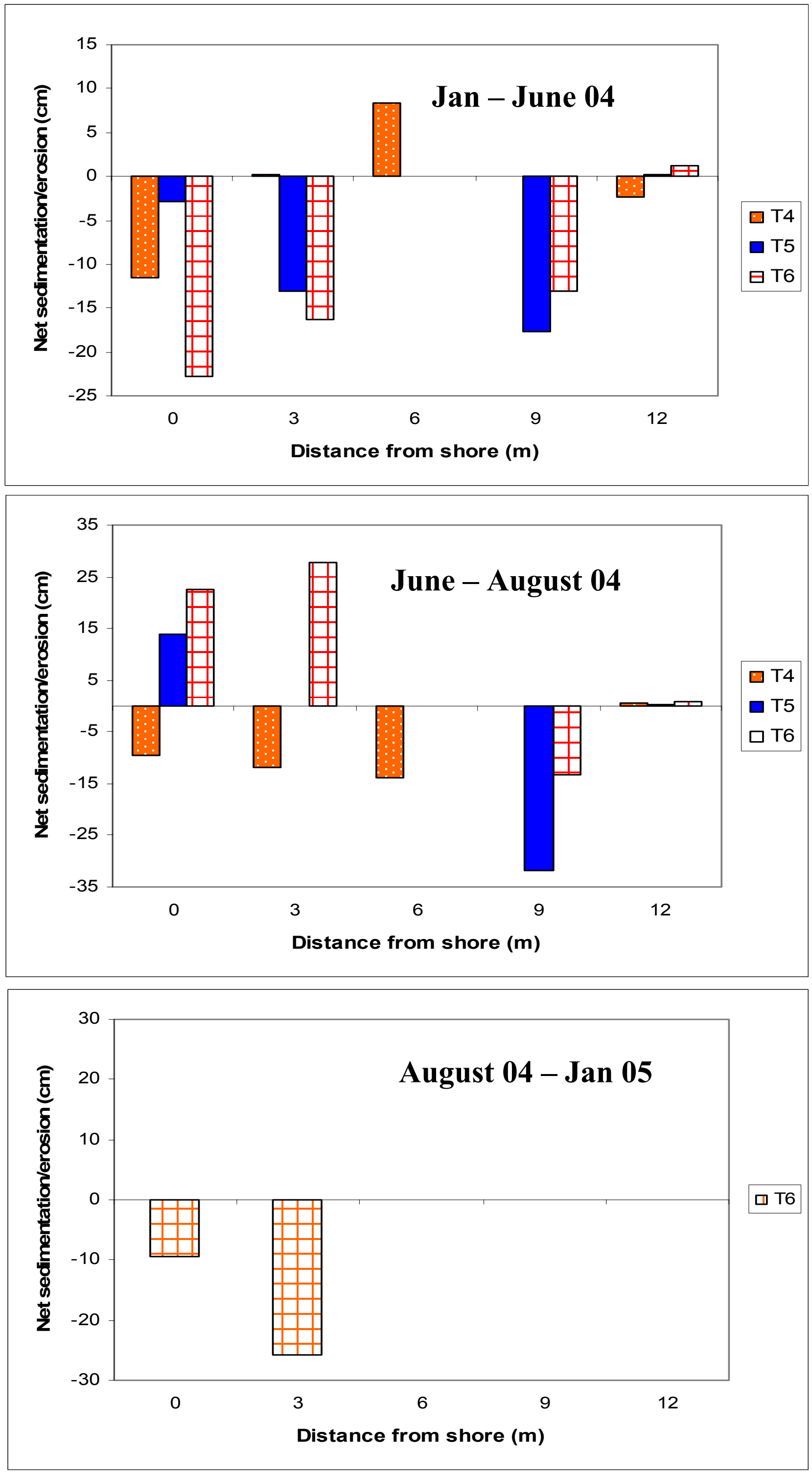
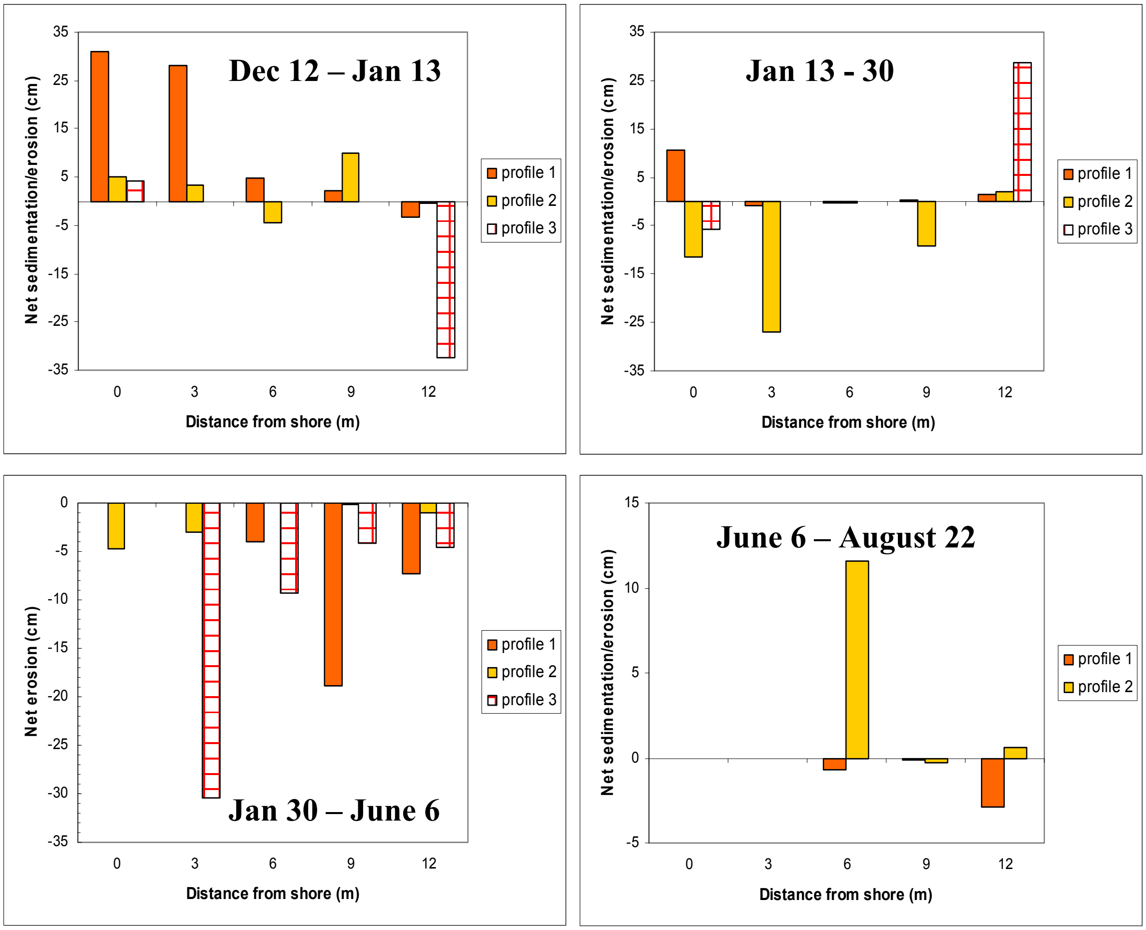



*FIGURE 114. Sedimentation / Erosion patterns at beach transects T4, T5 and T6 from A) January 30th to June 6th 2004, B) June 6th to August 22nd 2004 and C) August 22nd to January 17th 2005. T4 shows erosion of the lower beach for the entire period. Some time after August 22nd all rods in T4 disappear.*



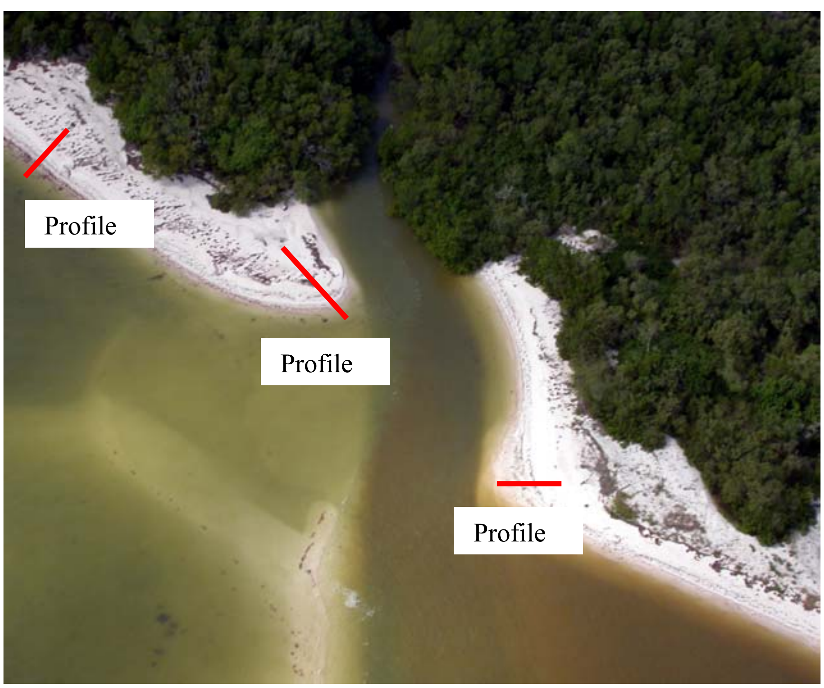




*FIGURE 115. Erosion/ Sedimentation patterns at Sandy Creek (T7) from December 2003 untill August 2004. Photo shows location of profiles 1, 2 and 3. Profile 1 measures large sedimentation rates from Dec 12th – Jan 13th 2004. The most seaward rods of profile 1 disappear (get buried most likely) in the months after. Visual observations confirm dynamic and rapid morphological changes that occur around Sandy Creek.*

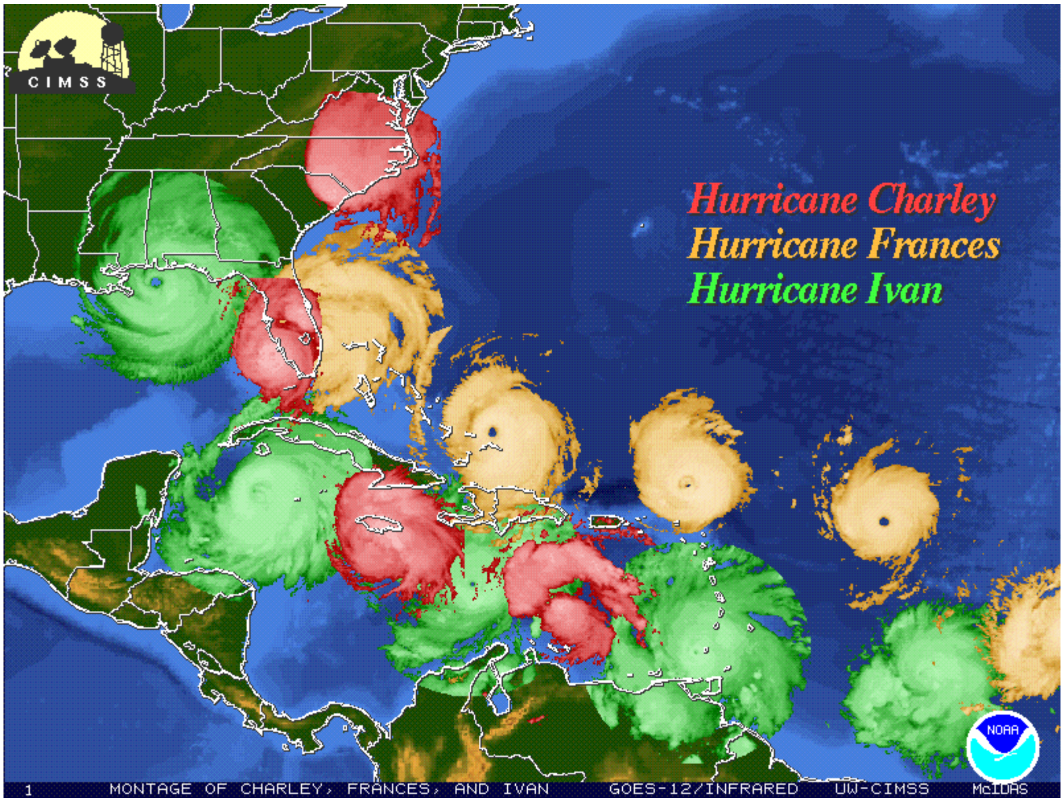



*FIGURE 116. Compilation of the storm tracks of three hurricanes that affected South Florida in 2004 (source: NOAA). Category 4 Hurricane Charley (Landfall on August 13$^{th}$), Category 2 Hurricane Frances (Landfall on September 5$^{th}$) and Category 3 Hurricane Ivan (September 16$^{th}$). Category 3 Hurricane Jeanne (Landfall on September 26$^{th}$) is not included in this figure.*

Figure 117. Photographs of Hurricane Charley's signature at beach location T6 between East Cape and Middle Cape showing large weed and shell overwash deposits, a sharp beach escarpment with a 15 cm-thick coarse shell layer on top.

# EVALUATION OF FINDINGS

## Geological Dynamics and Sea Level

Cape Sable is a geologically recent sediment body, as are the mangrove coast to the north, the 10,000 Islands, the mud banks in Florida Bay, and the sandy barrier islands along our Atlantic and Gulf coasts. For all of these, the environments, form and substrates are the product of a small oscillation in sea level between 3,200 and 2,400 years before present (ybp) followed by a time of very gradually rising sea level between 2,400 years ago and the present. The average rate of relative sea level rinse since 2,400 ypb, when sea level stood about 120 cm below present level has been only 3-5 cm per century. This has permitted sand and mud shorelines to form and stabilize our coasts and also for biological production of coastal wetland peats and shallow-marine skeletal remains to accumulate, build upwards, and expand.

We have entered a new era of more rapid sea level rise. Tide gauge records document an increase in the rate of sea level rise beginning about 1930. Since that time relative sea level has risen more than 23 cm (9 inches) and all the coastal and shallow marine environments listed above are unstable and either actively eroding and evolving or unstably situated awaiting a triggering event. This rate is equivalent to 30 cm (one foot) per century. This increase in the rate of sea level rise appears to be the result of an expanded western North Atlantic Ocean as surface water and deep waters are expanding as salinity and temperatures change (Cabanes et al., 2001). It is regional, affecting especially the Atlantic and Gulf coastal of North America; it is real, causing the ocean to encroach inward; it should continue; and it is a part of human-induced global climate change.

This post-1930 rate of rise is on the order of 6 times faster than the average rate of relative for the previous 2,400 years. Mangrove biologists suggest rates of 15 cm/ century are the upper limit for mangroves; coastal geologists see on the order of 150-300 meters (500-1000 feet) of landward barrier island migration for every foot of sea level rise on a coastal plain. The present rate of sea level rise is overwhelming the system and initiating significant erosional and inundational changes. Cape Sable just happens to be one of the most vulnerable and one which has received several natural and anthropogenic triggering events in the past century.

In addition, the United National Intergovernmental Panel on Climate Change (2001) has forecast a further significant rise in sea level in the coming century, with a consensus rate at about 60 cm (2 feet). This would likely be in addition to the regional steric-induced rate we are presently having.

The following page (Figure 118) illustrates the senior author’s understanding of how south Florida’s coastal environments will change with a further 60 cm (2 foot) rise in sea level. This is based on our understanding of underlying limestone topography, the distribution of coastal and shallow marine sedimentary deposits and their response to sea level stress, and the dynamics of biological environments.

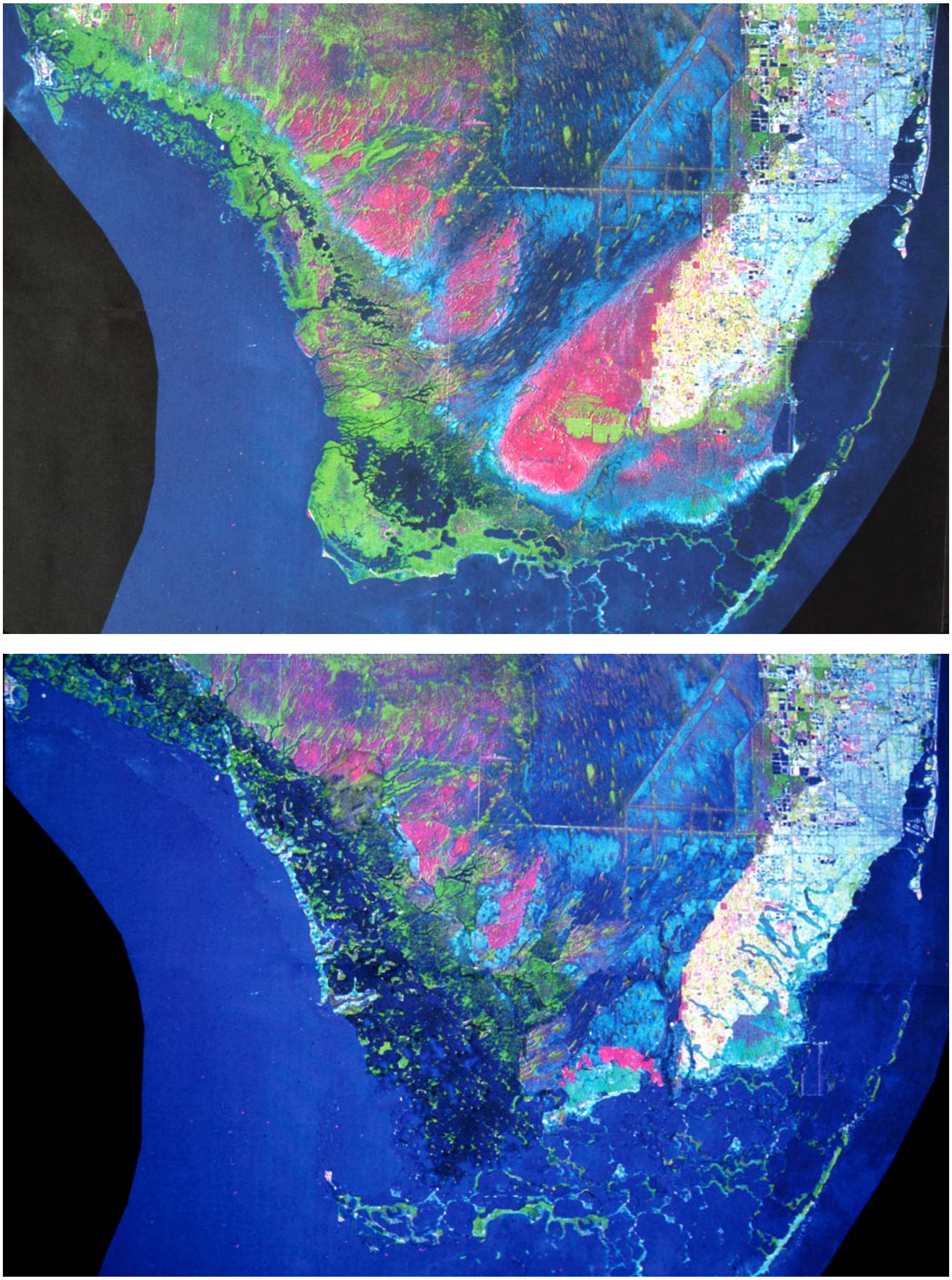


*FIGURE 118. Comparison of south Florida in 1995 with a preconstruction of the same area in 100 years assuming a 60 centimeter (2 foot) rise in sea level (Wanless, 2002). Cape Sable and the lower Everglades should become highly evolved as a result of this transgression.*

## Historical Changes and Causes

In an effort to improve Cape Sable for human use, a series of canals dug in the 1920s across the southern interior, the interior Marl Ridge, and the coastal sand and marl ridges resulted in salt water intrusion into Lake Ingraham, the Southern Lakes, and the freshwater-marsh interior. This initiated a rapid and widespread collapse of the southern interior freshwater wetland and conversion to shallow open water with patches of mangrove forming on higher marl topography.

The category 5 1935 Labor Day Hurricane devastated the mangrove forests of Cape Sable, eroded the marl and mangrove shorelines 50-100 meters back, and ended attempts at colonization of the outer capes or the Marl Ridge behind Lake Ingraham. It also initiated a period of rapid subsidence of the dead mangrove peat on the dead mangrove forests, and opened up Middle Cape Canal between north Lake Ingraham and the ocean.

Recovery from the 1935 Hurricane, as well as from Hurricane Donna and other lesser storms, would occur in association with a new influence on Cape Sable – a rapidly rising sea level Figure 16). This rise, beginning 1930, has persisted at about 3 mm/year and resulted in a relative sea level rise in south Florida of more than 23 cm (9 inches). Because of this rise in sea level, changes initiated by canal construction are now happening because a higher ocean level penetrates more deeply into the coastal mangrove forests all around Cape Sable and regularly floods over the Marl Ridge, historically a fairly effective barrier between the sea and the interior freshwater marsh.

This rise in sea level has greatly enlarged the tidal prism (the area and thus volume of water that is reached by a flooding tide) of waters entering through both cut canals and natural channels. This increased tidal prism is found both in lakes and ponds reached by tidal flow and also in the broad mangrove wetlands adjacent to canals and channels. The tidal prism was also enlarged following the 1935 Hurricane when wetlands were flattened (reducing flow resistance) and mid to high intertidal mangrove substrates initiated subsidence.

Instant access to a large tidal prism area occurred by connecting Lake Ingraham and the Southern Lakes to the sea by the cutting of East Cape/Ingraham Canals in the 1920s and Middle Cape Canal (opened in 1935). One to two knot currents feeding in and out of these former lakes have caused persistent erosive widening of the canal margins at 60 cm per year for East Cape Canal (now 71 m [230 feet] in width) and 120 cm per year for Middle Cape Canal (now 104 m [338 feet] in width). There should be no decrease in this widening in the foreseeable future as many of these flood tides now reach into the expanded tidal prism provided by flow across the Marl Ridge into the interior of Cape Sable. In addition, two natural channels, hidden creek and Sandy Creek, have opened up from the south coast into the Southern Lakes and on to Lake Ingraham. Hidden Creek, with similar flow velocities to East Cape Canal, is also widening at 60 cm (2 feet) per year.

Two natural tidal channels have extended their reach across the Marl Ridge over the past 50 years and are connected to the essentially unlimited tidal prism of the interior. The one in the south, East Side Creek, extending into the open water of the collapsed marsh of the southern interior, is widening at a rate that appears similar to East Cape Canal and hidden Creek (60 cm / year). The other, here termed New Sable Creek, has formed on the open mangrove coast north of Northwest Cape in response to rising sea level. This channel has extended across a slightly lower portion of the Marl Ridge into the large tidal prism of the interior wetland and is rapidly widening (Figures 28A and B). The role of tidal prism is well illustrated by a comparison of the histories of northern Little Sable Creek (stable tidal prism and little channel widening) and New Sable Creek (expanding tidal prism and rapid channel widening) (Figure 28A and B). These creeks illustrate the rapid evolution of coastal tidal channels in a time of rapidly rising sea levels.

Mangrove forest dynamics, in a time of rapidly rising sea level is very much dependent on coastal exposure, underlying substrate, and hurricane events.

- The protected eastern coast of Cape Sable, facing Whitewater Bay, has had little erosion of the margin or the interior. Rather, the mangrove forest has widened, expanding progressively into the former freshwater marsh (from 150 meters in width in 1929 to over 450 meters in 1999). This coast has essentially no tidal creeks penetrating form the coast.
- The north and northeastern exposed mangrove coasts of Cape Sable are penetrated by a great number of tidal creeks and have a substrate that is mainly organic peat. Tidal surges associated with both the 1935 Hurricane and 1960 Hurricane Donna flattened large interior areas of the mangrove forests adjacent to the tidal creeks. Many of these areas are still struggling to recover, and significant areas have had post-storm peat subsidence that has lowered the substrate into the lower intertidal or subtidal making recovery impossible. Historical coastal erosion by hurricanes and winter storms has set back the northeastern coast 200-300 meters since 1928. The width of the tall mangrove forest has not appreciably advanced into the interior along these coasts.
- Tall mangrove forests should not be correlated with 'old' or 'mature'. The core winds of category 4 and 5 hurricanes essentially flatten mangrove forests having trees of some stature. Essentially all the tall mangrove trees along the entire Mangrove Coast from Chatham River (near Everglades City) south to East Cape and Flamingo have been destroyed by the Hurricane of 1926 (Chatham to Lostman's Rivers area), the 1935 Labor Day Hurricane (Broad River to Flamingo), Hurricane Donna in 1960 (Everglades City to Flamingo), and/or Hurricane Andrew in 1960 (Chatham River to Harney River). At best the tall forests of this coast are only about 40 years old. Within the red mangrove forests of northern and northeastern Cape Sable are large, dead black mangrove stumps and trunks – relicts of the former higher intertidal forests before 1935 or 1960. Why have these returned as red and not black mangrove forests? It is likely both a mixture of post-storm substrate subsidence of the decaying dead peat and historical sea level rise. Will the forests, in the absence of future major hurricanes regain their mature, higher intertidal black mangrove stature? Current and anticipated future rates of sea level rise should make this most unlikely.

- In the vicinity of Lake Ingraham, mangrove forests were totally eliminated by the 1935 Hurricane. This is an area in which the substrate is firm carbonate mud. The forests have slowly, but progressively returned mostly as red mangrove (Figures 31, 39 and 40). The carbonate marl with roots would not be prone to as severe post-storm substrate subsidence as with pure peat substrates. Nevertheless, these areas also had to contend with rising sea level.
- In the collapsed freshwater marsh of the southern interior of Cape Sable, the collapse exposed areas of higher relict marl topography. Black mangrove has colonized those areas and persisted despite hurricanes. In the January 1935 aerial photograph (figure 47) areas of mangrove (dark) can be seen beginning to replace marsh along the margins of collapsed wetland, but the mangrove type is uncertain.
- In areas of rapidly building, organic-rich carbonate mud, mangrove will rapidly colonize the substrate once in has build shallow enough into the intertidal. This is seen in the Southern Lakes and is beginning at the south end of the delta in Lake Ingraham. In previous work following Hurricane Andrew, we found a similar situation. Organic-rich carbonate deltas formed by Hurricane Andrew (1992) along Broad River promoted rapid growth of mangrove, at the same time that surviving mangrove were still dying in the decaying peat of the adjacent damaged mangrove forest. During a period of rapidly rising sea level, this process of rapidly filling bays followed by rapid colonization of mangroves will be key to filling coastal depressions and preventing landward overstepping as the outer coasts erode.

The past and future evolution of the interior of Cape Sable must be considered in two parts – the human impacted south and the non-human impacted central and north. The southern interior records the effects of a sudden intrusion of saline water into a freshwater marsh. The result is a rapid death of the freshwater marsh with nothing coming in to replace it. Decay of the layer of freshwater organic peat was too fast relative to influx of mangrove and *Spartina* colonization and the wetland was lost. Shallow and emergent marl topography that became exposed on marsh collapse became sites of mangrove colonization, primarily black mangrove. This colonization has continued to today expanding and filling in these areas of shallower substrate. This scenario does not address the possible negative stress that decaying freshwater wetland peat may have on colonization by mangrove seedlings. Dead, decaying mangrove peat substrates are a serious detriment to mangrove recolonization because of toxic conditions produced by decay products released by the decaying peats.

The central and northern interior of Cape Sable is essentially unaffected by human modifications. Here, if marginal mangrove and interior freshwater peat buildup had kept pace with the historical rise in sea level, one would expect little change in the wetland communities or boundaries. This has not happened! Rather, we have found that salinities have increased all across the interior of central and northern Cape Sable and that wetland communities are changing in response. We have also documented a gradual increase in small open water areas in the central and northern interior. In some areas the loss of freshwater sawgrass marsh is being accompanied by at least a 75 centimeter lowering of the peat substrate as the peat decays and erodes. This lowering is releasing large volumes of particulate organic detritus into the local environment, which may be a stress on wetland viability. Coring in areas where freshwater marsh has been replaced by healthy, dense wetland of either mangrove or *Spartina*, we find a thick dense organic peat. But coring in areas of transition where the sawgrass is dying and the colonizing saline wetland is sparse, we find a thing layer of roots below which is a watery zone of decaying peat. These areas are prone to total wetland loss with slight provocation (hurricane, fire or freeze setback) or perhaps just trough the course of time (stress of continued decay and substrate subsidence).

Small scale rises in sea level can have dramatic influences on coastal processes. Sea level influences coastal dynamics which dictate patterns that interface both marine and freshwater environments. This was clearly shown in our reconstruction of the Everglades paleo-drainage and the formation of the marl ridges which provide the framework for modern Cape Sable.

## The Dynamics Driving Cape Sable's Evolution

As mentioned before, Cape Sable is the canary for south Florida. Anything that will happen to other coastal areas of Everglades National Park and 10,000 Islands, will happen to Cape Sable first. Cape Sable presents a coastal system that used to be in steady-state equilibrium, but that has been disrupted by external forces and this has altered the system's vector. Figure x theoretically portrays the situation. As the system is "searching for" and moving towards new steady-state equilibrium, large morphologic, hydrologic and ecologic alterations take place on a short time period (in the order of decades), indicating a perturbed system. It is this condensed time scale and the availability of data since perturbation ($t_1$ in Figure 119, which is around the 1930s), that makes the Cape Sable complex an excellent field site to study. Other coastal systems in south Florida manifest, or will manifest in the near future, the same dynamic behavior, only perhaps on different temporal or spatial scales.

One of the main questions that we need to answer in order to understand the dynamic

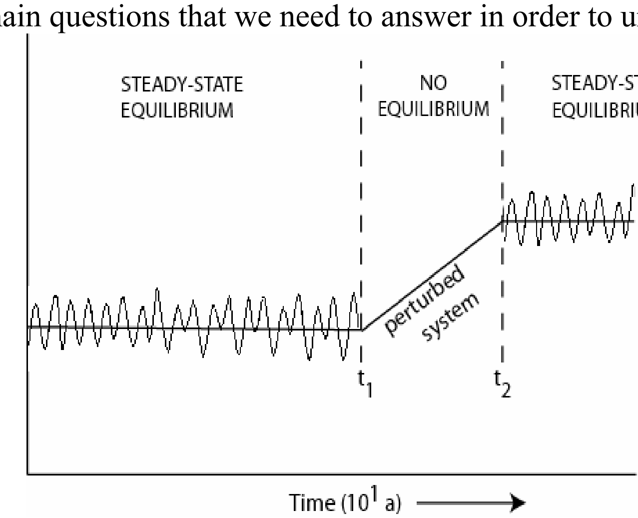



*FIGURE 119. A steady, but sensitive system becomes perturbed due to changes in external forcing mechanisms (sea level rise, hurricanes, fires, canal construction, etc.) and changes its system vector. New steady-state equilibrium will be reached within a relatively short time span.*

evolution of Cape Sable deals with the sediment dynamics: 1) where does sediment come from, 2) where does it go to, 3) which processes are responsible and 4) how fast are these processes? This project has documented extremely large volumes of fine carbonate and organic sediment that is moving among the coastal zone in south Florida. We have characterized the muds being released from Cape Sable's eroding coastline, collapsing and decaying wetlands, and widening canals and channels. A part of this is the nature of the Mangrove Coast and Florida Bay; a part is from hurricane damaged and destabilized environments; and a part is from coastlines, channels and wetlands destabilized by rising sea level. This sediment it being redistributed throughout south Florida's shallow marine, coastal and wetland environments. The extraordinary rates of erosion and deposition - and of wetland collapse and colonization – documented here for Cape Sable are or shortly will be occurring throughout much of Everglades National Park and Florida.

**Dominant Processes**

Our data set has given us no doubt to conclude that the sediment dynamics in Middle Cape Canal inlet and the accumulation processes on the nearby intertidal areas in Lake Ingraham are driven mostly by storm processes. There is a good correlation between wind speed and sediment concentration in Middle Cape Canal, which confirms the importance of winter storms on the sediment transport processes. Figure 120 shows an

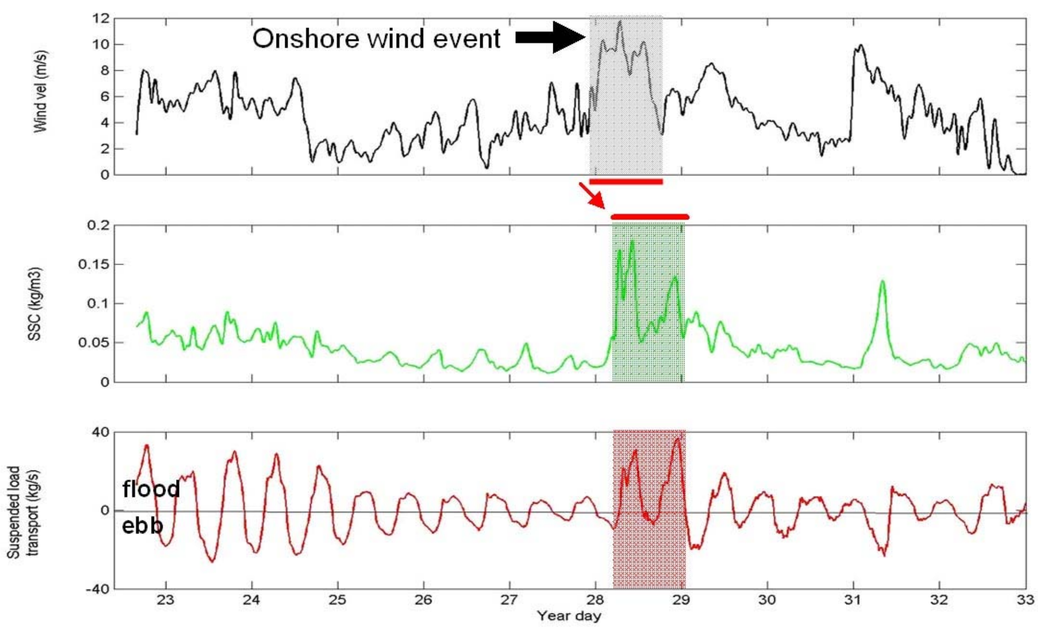



*FIGURE 120. Time series of wind velocity, suspended sediment load and suspended sediment transport in MCC during 10 days in January 2004. On January 28th, winds picked up to 27 mph (arrow). The effect of wind stirring up sediment in the Gulf of Mexico was observed some hours later as the first incoming tide transported large suspended sediment concentrations (peaks in green area). During two consecutive flood tides (red area), the sediment flux into Lake Ingraham was ~ 30-40 kg/sec, while during the day before (with calm conditions) the positive sediment flux was only ~ 5-10 kg/sec. This is a 6-fold increase of sediment transport due to a strong onshore wind!*

example of a 6-fold increase of the incoming sediment flux due to increased wind velocity, as opposed to the sediment flux during calm conditions.

Besides the strong impact storms prove to have on sediment distribution, we see a very clear correlation between the neap-to-spring tidal cycle and the amount of sediment in the water column (Figure 74). Spring tides have a larger tidal range and therefore larger velocities; larger velocities result in higher suspended sediment concentrations and overall higher transports. Therefore the daily tidal currents do contribute to a steady import of sediment (12% of the sediment transported into Lake Ingraham remains within the Cape), but the winter storms definitely make the largest contribution to the net sediment flux.

We have supporting data to conclude that the sediment dynamics through East Cape Canal and the accumulation processes on the nearby intertidal areas in Lake Ingraham and the Southern Lakes are driven to a large extent by the tides. This will be explained in detail further on in this section. Unfortunately, we did not collect current and sediment data during rough conditions in East Cape Canal. However, on February 14th 2004 we did make an important qualitative observation that leads us to believe that strong onshore winds also have a direct effect on the amount of suspended sediment in the water column close to East Cape. Figure 121 shows that on that afternoon in February 2004, a milky sediment plume enters East Cape Canal on the first incoming tide after winds picked up from the south (towards the shore here).

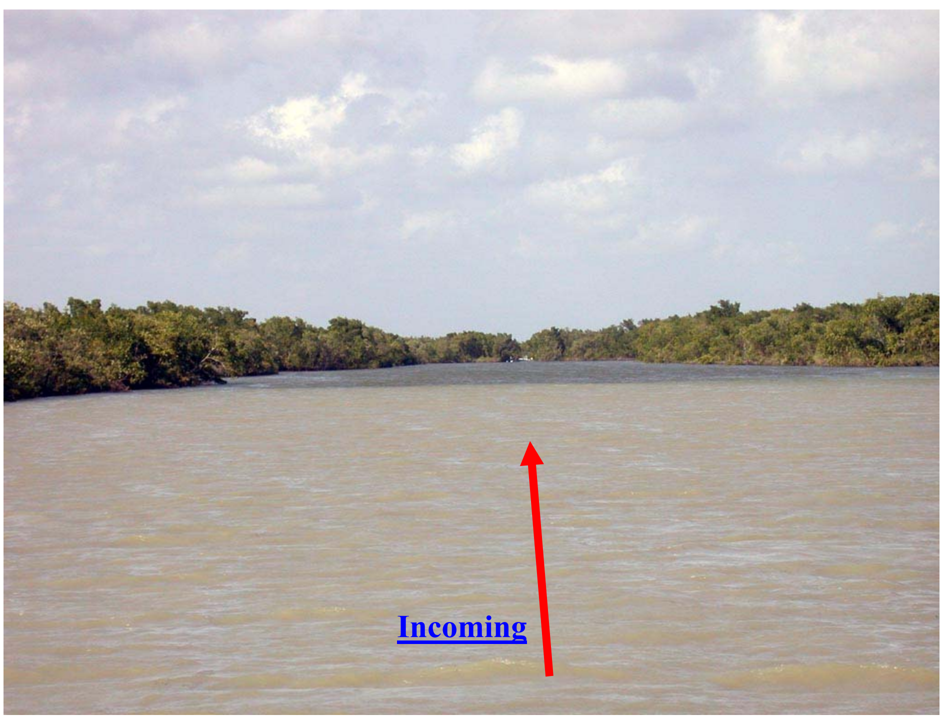



*FIGURE 121. On February 14th 2004 a cold front moved through the region and south winds picked up in the afternoon. Notice the murky water plume that entered East Cape Canal in the first flooding tide after increased winds.*

The overpowering effect hurricanes can have on the sediment dynamics of a system is well understood and documented at Cape Sable. Besides the daily tidal forces and the forty-some winter storms per year that move sediment around, hurricanes are a third, and very important force for sediment (re)distribution. From December 2002 till March 2005, the time period of our intensive field studies, Cape Sable has not been hit directly by a category 4 or 5 hurricane. The 2003 hurricane season did not bring any hurricanes to south Florida. In 2004, Florida crossed four times by strong hurricanes (Charley, Frances, Ivan and Jeanne; Figure 116). However, Cape Sable was not affected by hurricane force winds. Hurricane Charley was the only hurricane that initiated significant wave heights on the west facing shorelines of Cape Sable and consequently triggered some beach erosion (Figure 117).

## Accumulation Rates

The rate of short term accumulation in the intertidal zones of Lake Ingraham and the Southern Lakes was measured directly with 34 sediment reference traps that were deployed from June till December 2004. The average *in situ* accumulation rate is 6.2 cm/year ± 2 cm. The maximum observed rate at one location (#13) in Lake Ingraham was an extraordinary 22 cm/year! The average rate was obtained from combining and averaging data of 4 sediment reference traps, placed at the same location but for different time periods, cumulatively for 1, 2, 4 and 6 months. This method would allow us to capture a seasonal trend of sedimentation patterns or the footprint of a single storm. However, we did not observe significant differences in the accumulation rates between different months. This confirms our observation that daily tides make a considerable contribution to the extreme sedimentation rates that were monitored. Distinct coarser or thicker storm layers were not detected on the sediment reference traps in the Southern Lakes or Lake Ingraham, not even after the passage of hurricane Charley.

## Evolution of Middle Cape Canal and Surroundings

Middle Cape Canal at present is a mature, yet rapidly enlarging tidal inlet. One would never guess that it once was a 5 meter wide cut. As for flow velocities, it can compete with other tidal inlets along the Gulf coast, such as Blind Pass, Johns Pass, Clearwater Pass and Hurricane Pass. Maximum velocities reach 2 m/s (4 knots); maximum measured discharge is nearly 500 $m^3$/s. Table 11 summarizes tidal and current characteristics at all measurement stations. As with any other natural tidal inlet, Middle Cape Canal features flood and ebb tidal deltas (Figure 122).

Many researchers (e.g. Dronkers, 1998; Escoffier, 1940; Kraus, 1998; Leopold and Maddock, 1953; O'Brien, 1931, 1969, 1972) have looked at empirical relationships between inlet throat cross-sectional area and tidal prism. Both parameters are important to consider when trying to understand inlet stability. The relationship between tidal prism and minimum channel cross-sectional for Gulf Coast systems can be empirically determined. This is more applicable to channels cut in sand rather than marl but provides an idea as to the degree of present disequilibrium.

| | | FLOOD PEAK VELOCITY (CM/S) | EBB PEAK VELOCITY (CM/S) | ASYMMETRIC CURRENT FLOW | DAILY INEQUALITY OF TIDE | MAX TIDAL RANGE (M) | TIME LAG WATER LEVEL - CURRENT FLOW |
|---|---|---|---|---|---|---|---|
| **MCC Centre** | *Summer '03* | 161 | 208 | | √ | 1.8 | √ |
| | *Winter '04* | 151 | 188 | | √ | 1.4 | √ |
| **Hidden Creek** | *Winter '03* | 89 | 96 | √ | √ | 2.4 | |
| | *Summer '03* | 83 | 78 | √ | √ | 2.5 | |
| **ECC West** | | 149 | 93 | | √ | 1.3 | √ |
| **ECC North** | | n/a | n/a | n/a | √ | 1.3 | |
| **ECC South** | | n/a | n/a | | √ | n/a | n/a |
| **Lake Ingraham** | | n/a | n/a | n/a | √ | 1.7 | |

*TABLE 11. Summary of tidal and current observations (2003/2004/2005) at the measurement stations in study area.*


*FIGURE 122. Oblique aerial photograph of ebb and flood tidal deltas at Middle Cape Canal. Inlet throat is over 100 meters wide; channel thalweg is 4 meters deep till bedrock. South of Middle Cape Canal the coast is very narrow (< 180m) and a small creek from Lake Ingraham makes its way almost to the coast. Looking towards northwest. Photo taken December14th, 2004.*

$A_c = 9.311 \times 10^{-4} \cdot P^{0.84}$, in which $A_c$ is the minimum cross-sectional area in square meters and P is the tidal prism in cubic meters (Seabergh and Kraus, 1997). The tidal prism entering through Middle Cape Canal is estimated at $5.4 \cdot 10^6$ $m^3$. With the present cross-sectional area of ~364 $m^2$, this tidal inlet is not in equilibrium. According to this equation, Middle Cape Canal will erode at least another 16 meters in the cross section, to be in equilibrium with the current tidal prism. The tidal prism is ultimately controlled by the area of the back barrier basin and tidal range. As the area of the back barrier basin (now including the collapsed freshwater marsh) has extended and will extend even more in the coming years, the tidal prism will naturally increase as well (as therefore the cross-sectional area).

It is important to estimate how much the tidal prism will potentially increase over the coming decades, as well as it is essential to know the sediment supply relative to the tidal prism. Obviously, the collapsed freshwater marsh cannot keep up with the increasing tidal prism, since sedimentation is minimal behind the Marl Ridge. Therefore, subsidence in the collapsed freshwater marsh through decay and removal of peat sediment will need to be monitored carefully in order to get an accurate estimate of increased tidal prism.

By increasing the tidal prism, tidal inflow and outflow velocities through Middle Cape Canal inlet will increase. As the inlet channel already reaches bedrock, scour will occur laterally to the banks of the inlet channel. This will increase the cross-sectional area of the inlet. Most of the channel widening should continue to come from erosion of the south side of the inlet, where mangrove peat and marl is facing direct current and wave action, and is not protected by beach sand. However, as the stronger ebb flow hugs the north bank of the inlet channel (Figure 64), undercutting and scouring by supercritical flow will result in significant beach erosion and set back of north side overwash deposits. The rate of widening of the inlet channel is controlled by the rate of increase of tidal prism. This rate of tidal prism increase is projected to be high, as the Marl Ridge is overtopped by many flood tides and creeks through it are rapidly widening to feed saline water into the collapsed freshwater marsh. This is intensifying because of rapidly rising sea level.

The higher flow velocities through Middle Cape Canal will consequently result in more sediment transport. An (indirect) correlation exists between current velocities and accumulation rates within the northwestern zone and central zone of Lake Ingraham (Figure 83). Therefore we can expect to continue seeing high sedimentation rates within the intertidal zones. These high sedimentation rates (average 6.2 cm/year) exceed the rate of newly created accommodation space by relative sea level rise (and increased tidal prism). Therefore Lake Ingraham will convert relatively rapidly into a supratidal mangrove- capped mudflat environment with dissecting tidal creeks.

Were sea level not rapidly rising, velocities and dimensions of the Middle Cape inlet channel would eventually approach equilibrium. Erosion processes along the banks due to scouring would slow down. However, as Middle Cape Canal inlet has grown wider, sea level has been widening and at high tide levels, more of the incident wave energy can travel further into the lagoon and more and more water is feeding across the Marl ridge into the interior tidal prism. This will increase erosion of the shoreline features inside the lagoon during strong onshore winds. Shoreline will continue to be attacked by powerful waves during cold fronts and larger storms.

Narrowing or closure of Middle Cape Canal, which would be an engineering and financial challenge, will trigger most likely a natural breach south of the present inlet through the ± 180 m narrow strip of mangroves (Figures 30 and 122). During a helicopter flight in December 2004 we observed that, during spring high tide, this narrow strip of land was completely submerged and saline waters were slowly flowing towards Lake Ingraham.

**Evolution of East Cape Canal and surroundings**

During a first field reconnaissance of the area in December 2002, the dynamics at Middle Cape Canal seemed far more complex and relevant to the story of Cape Sable's evolution than the dynamics around East Cape Canal (Figure 123). In fact, East Cape Canal appeared to be the simple answer to the extensive delta that was being built in the southeastern lagoon: this canal provided obviously the only pathway large amounts of sediment from Florida Bay could be fed to Lake Ingraham. The opposite turned out to be the case: dynamics around East Cape Canal are quite complicated and we can accredit this awareness to the valuable dataset we collected on tidal, current, discharge and suspended sediment concentrations at various stations in the area. Table 11 summarizes the most important tidal and current characteristics at the measurement stations.

The waters around Cape Sable have unusually high concentrations of suspended particulate matter (silt and mud-sized particles of carbonate and siliceous skeletal remains and organic material). During calm weather, average concentrations in the inlet of Middle Cape Canal are ~ 40 mg/l and average concentrations at the inlet of East Cape Canal are 50-80 mg/l. This difference in sediment concentration is the result of a different bottom composition between Florida Bay and the Gulf of Mexico. Offshore of Middle Cape Canal, you find hard rock bottom communities from which much fine sediment is produced but in which little remains, energy transporting it elsewhere. Middle Cape Canal also receives organic and carbonate being released from erosion of the mangrove coast to the north (see plumes in Figures 1 and 129). East Cape Canal is adjacent to and fed by tidal waters moving in and out of Florida Bay. Florida Bay is a site of extensive carbonate mud banks 2-4 meters in thickness, intense biogenic mineral and organic sediment production (cyanobacteria, calcifying green algae (*Penicillus, Udotea*), benthic foraminifera, and seagrasses (*Thalassia, Syringodium, Halodule*). This local mud source results in higher overall suspended sediment concentrations in the water column, especially during winter and tropical storms. Both entrances have local erosion of the 4-meter thick marl sequence (along the coastline and canal walls) as a significant source.

An important observation made near the entrance (ECC South) is the presence of extremely large sediment concentrations (± 1000 mg/l) during the last phase of ebb (Figure 99 and 124). Large sediment peaks also appear more north in East Cape Canal, likewise at the end of ebb (station ECC North, Figure 95). The waters carrying these large quantities of suspended sediment are flowing out of Homestead Canal, which also

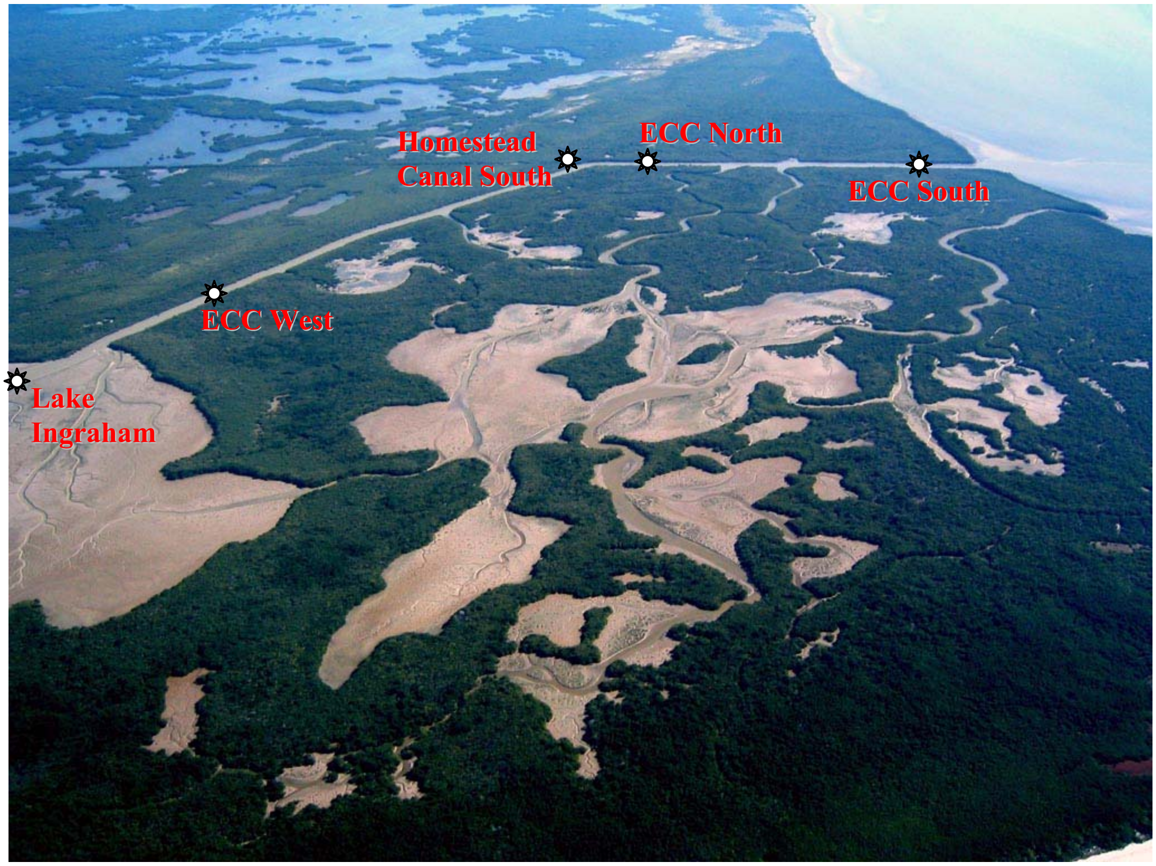



*FIGURE 123. Oblique aerial photograph of East Cape Canal, Hidden Creek, Homestead Canal, the Southern Lakes and part of the southeastern delta in Lake Ingraham with the positions of the measurement stations. Several hydrologic and sedimentologic linkages between these different 'players' are responsible for the complicated sediment dynamics and patterns observed.*

has large sediment peaks at the end of ebb tides (Figure 95). Depending on the season, salinities of the waters draining from Homestead Canal can be highly variable. We measured salinities of 25‰ after recent precipitation and 38‰ after some days without precipitation. Salinities up to 43‰ have been recorded further back in the collapsed freshwater marsh.

At the west end of East Cape Canal (station ECC West, Figures 93 and 94), but also within Lake Ingraham (station Lake Ingraham, Figure 96), sediment peaks occur both during ebb and flood (Figure 124). The 'flood sediment peaks' are carried in by waters with normal seawater salinities (35‰), the 'ebb sediment peaks' are carried out by waters with varying salinities, reflecting the inland precipitation events. These low- or very high-salinity waters drain from the collapsed freshwater marsh through Homestead Canal West into Lake Ingraham and ECC West.

Carbon isotopic analyses of the particulate matter of the 'ebb sediment peaks' at ECC South and Homestead Canal South feature a light $\delta^{13}C$ signal (sawgrass/mangrove), in comparison with a heavier $\delta^{13}C$ signal (seagrass/plankton) from the flood tidal waters originating from Florida Bay (Figure 101). The geochemical analysis shows that

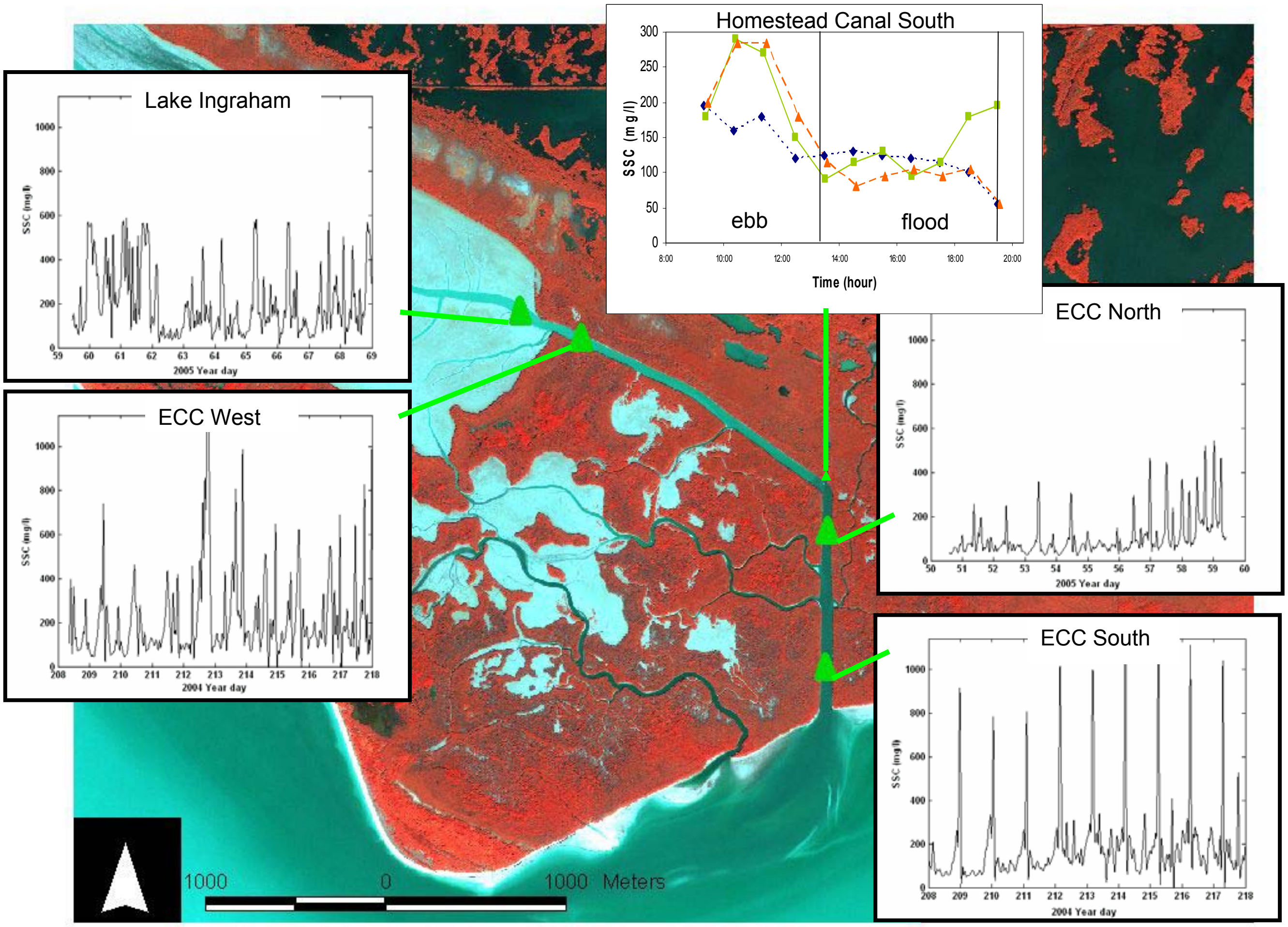



*FIGURE 124. This graph gives an overview of the suspended sediment patterns observed throughout the southeastern region. Notice regular sediment patterns at ECC South and ECC North and more complicated ('noisy') sediment patterns at ECC West and Lake Ingraham. Sediment peaks at ECC South, ECC North and Homestead Canal are observed during the last phase of ebb. Sediment peaks at ECC West and Lake Ingraham are observed both during ebb and flood. Do not compare the amplitude of the sediment signal between stations, since the time series were not recorded simultaneously (and the spring/neap tidal effect on concentrations can be large).*

sediments with different origins and mixtures are being carried through East Cape Canal throughout a tidal cycle. The intermediate values may also reflect a marine to upland microbial signal.

Taking a more distant look at the movement of sediment and water through the canals in the southeastern zone, we observe two distinct water masses in East Cape Canal an ebbing tide in November 2002. Figure 125 is an Ikonos satellite image that displays three band ratios on which Principal Component Analysis (PCA) has been applied. The

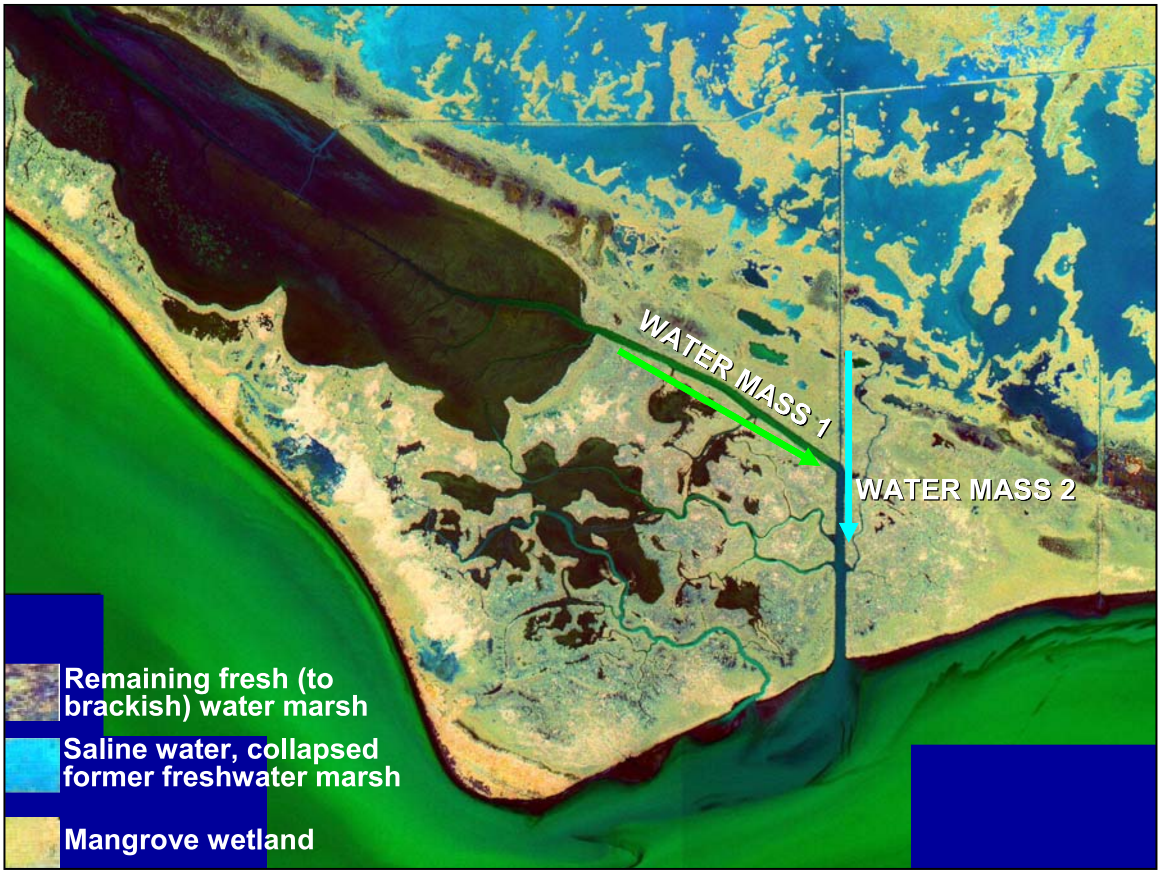



*FIGURE 125. Modified Ikonos satellite image (© SpaceImaging), band ratios ¾, ¼, ½ after PCA. Image was taken on an ebbing tide in November 2002. Water mass 1 sinks underneath water mass 2, indicating that saline water drains from Lake Ingraham and meets less saline water that drains directly from the collapsed freshwater marsh through Homestead Canal South and East Side Creek. Dark color in Lake Ingraham and the Southern Lakes is the spectral reflectance of the intertidal mudflats.*

spectral band ratios neatly separate marine water from brackish / freshwater. Saline water flowing through ECC West (green water mass 1) sinks under less dense water coming from Homestead Canal South (turquoise water mass 2). The two water masses merge and flow southward through East Cape Canal. This observation supports the suspended sediment data that shows that a different water mass carries large sediment peaks out through Homestead Canal South (and East Side Creek) during each ebbing tide.

We conclude on basis of geochemical and sedimentologic data that the large sediment peaks measured during ebb at ECC South, ECC North and Homestead Canal contain an important component of carbonate and organic particulate matter that originates from the collapsed freshwater marsh. A typical sediment sample in the collapsed freshwater marsh contains 45% organic matter and 55% calcium carbonate (from the marl underlying the freshwater peat and canal wall erosion; core #37, old Figure 107). The organic matter is mainly freshwater peat that has been broken down by cyanobacteria bacteria and fungi. Enormous amounts of this decayed organic matter are literally waiting to be carried away. The slightest flow can easily erode this substrate which is best described as organic 'soup' or floc, as it has no consistency anymore.

Flood tidal waters now easily penetrate across or through the Marl Ridge and become trapped in the interior. The waters flowing across the Marl Ridge will not flow out that way as they flow into a lower water level in the interior. Additionally very intense rainfall will result in high flow volumes out the canals through the ridge. As a consequence, every ebbing tide and major rainfall event results in large volumes of trapped water flushing out from this new shallow back barrier basin through western Homestead Canal and East Cape Canal. As these waters 'flush' the collapsed freshwater marsh, they carry large quantities of sediment. We have observed in the field that this 'sediment draining' through western Homestead Canal, northern East Cape Canal (also called south Homestead Canal), and East Side Creek continues 3-4 hours after the tide began ebbing. As heavy sediment plumes continue to flow out of northern East Cape Canal (and East Side Creek), they meet the incoming flood waters and mix right in the bend of East Cape Canal. We have observed these organic-rich sediment plumes evolving into vortices and then being carried along towards and into Lake Ingraham by the incoming tide. An animation made in cooperation with RPM (Realizing Perfect Momentum) uniquely visualizes the movement of sediment through a tidal cycle (This is in the disc attached to the National Park copy of this Final Report).

The final destination of these mixed organic-carbonate sediments is partly hypothesized (through observations!) and partly well documented. It is assumed that large amounts of these fine-grained mud and silts find their way into Florida Bay and beyond to the Florida Keys and reef tract (Figures 1 and 29). However, sedimentologic and geochemical data from cores and sediment reference traps in Lake Ingraham and the Southern Lakes suggest that a large portion of the material is recycled and stored within the Cape Sable coastal system. The rapidly accumulating intertidal mudflats in Lake Ingraham and the Southern Lakes typically contain 70-75% calcium carbonate and 25-30% organic matter. These sediments cannot come exclusively from Florida Bay for two reasons. First, very little sediment in fact, is carried into East Cape Canal by daily tides. The time series do not show significant sediment peaks at ECC South during incoming tidal flow (Figure 124). Second, sediments originating from Florida Bay are mainly calcium carbonate and do not contain the high amounts of organic matter that are found on the rapidly building mudflats.

In a broader context, the results of this study facilitate generation of a new model for transgression on low-energy shorelines, including the recycling re-distribution of transgressive organic matter on these coasts. Figure 126 is a cross-sectional sketch of Cape Sable that could represent any coastal system with a beach ridge, back-barrier lagoon with tidal flats and a freshwater marsh system behind a supratidal ridge. What this study has demonstrated is the complete redistribution of sediments and a more or less inversion of facies. The former *intertidal* environments of Lake Ingraham become *supratidal* as the lake has silted up above mean sea level; and the former *supratidal* freshwater marsh environments become *intertidal to subtidal* as more open water areas evolve and saline waters more easily enter over the Ridge. Importantly, this recycling involves a change in the nature of the organic matter. Eroded mangrove litter and root peat and freshwater saw grass peat is mostly processed by cyanobacteria, bacteria and fungi during the decay and re-distribution process. Transgression is not a simple process of environmental and facies back stepping, but involves a more complicated re-arrangement of environments and transformation of materials as this study has shown.

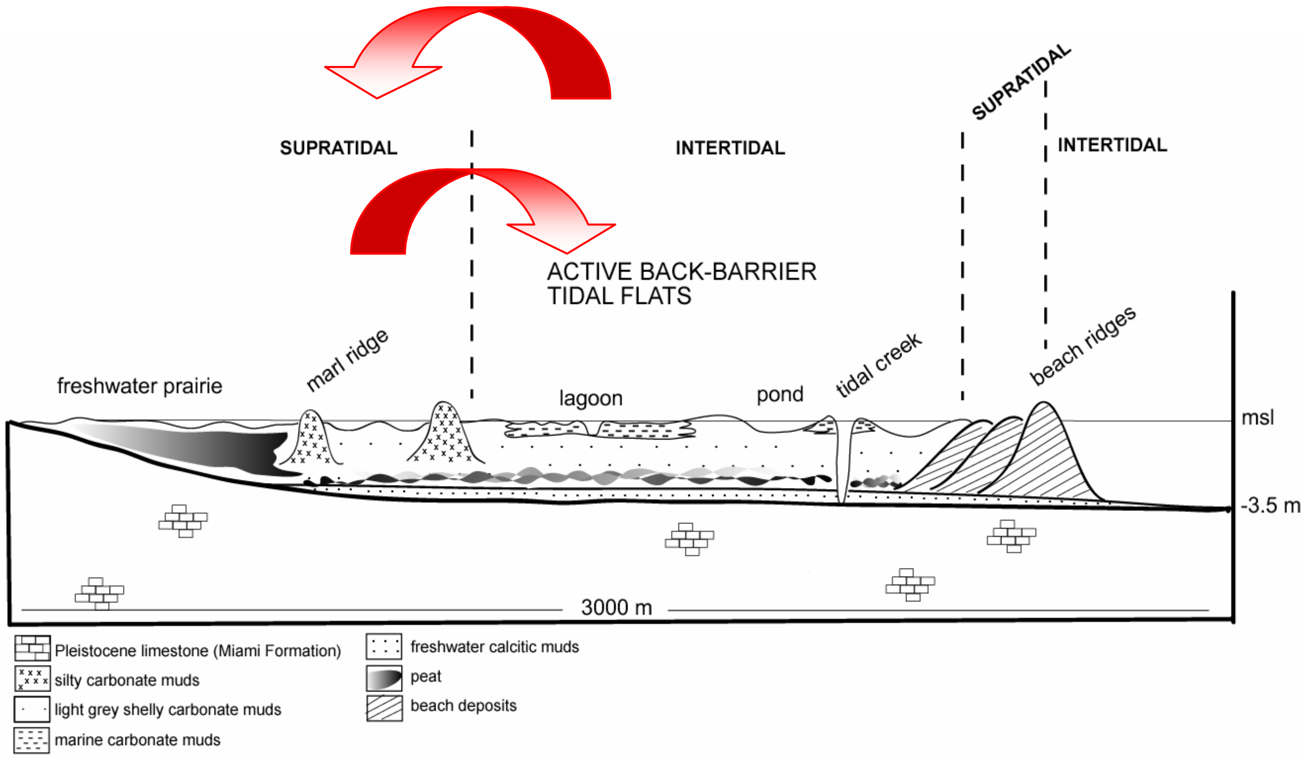



*FIGURE 126. Cross-sectional sketch of Cape Sable or any other coastal system with a beach ridge, back-barrier lagoon with tidal flats and a freshwater system with supratidal environments behind a ridge. Transgression results in inversion of facies: intertidal (lagoon) becomes supratidal (rapidly accumulating mudflats); supratidal (freshwater marsh) becomes intertidal (freshwater marsh collapses and open water returns).*

## Map of Bio-Sedimentary Surface Environments

The facies map in figure 127 is the product of analysis of the November 2002 Ikonos image. The approach for analysis of the remote sensing data includes the following steps: 1) analysis and preliminary mapping with the Ikonos data, 2) validation by field study; and 3) final mapping.

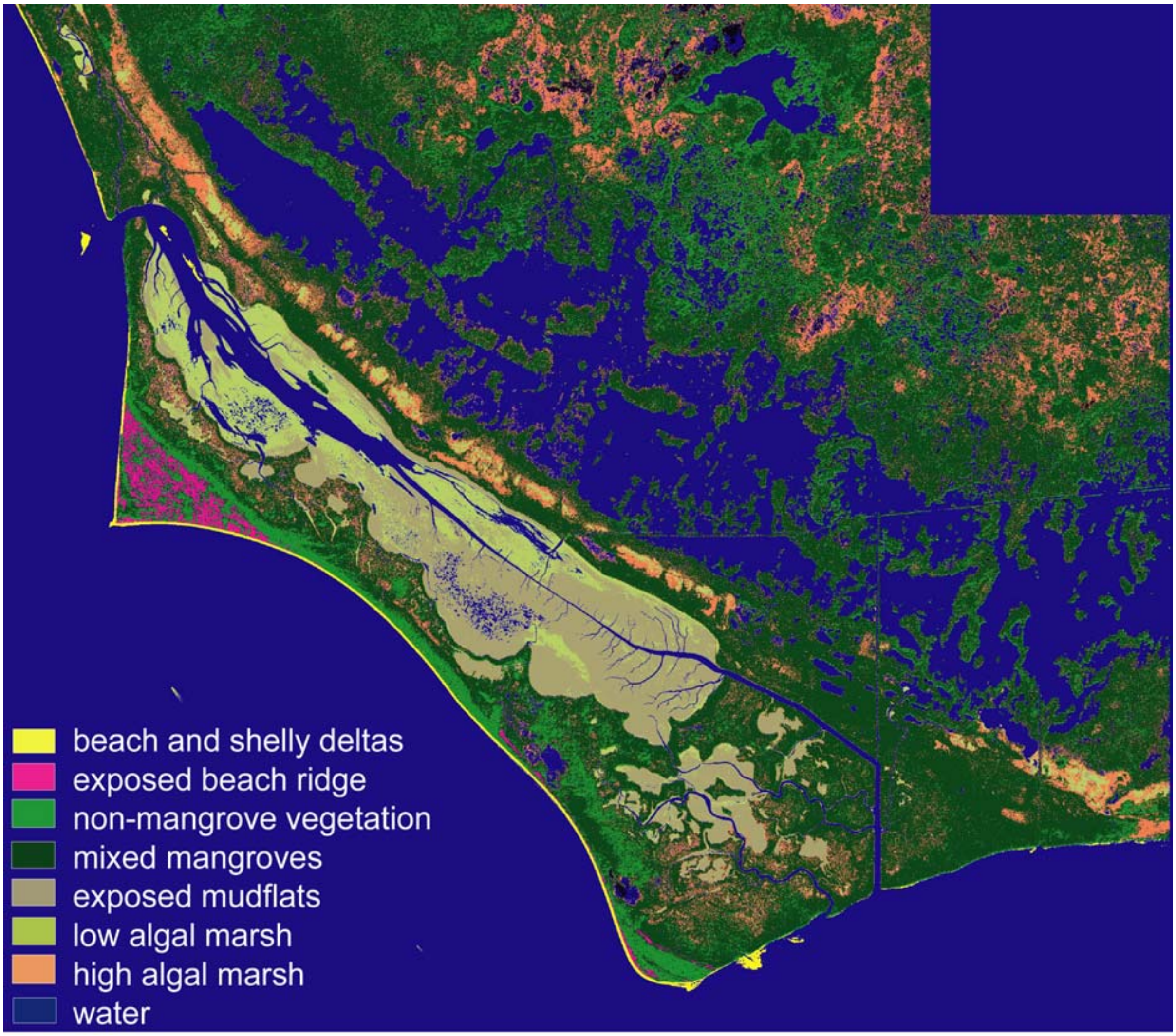



*FIGURE 127. Ikonos image from 2002 (© SpaceImaging) of Cape Sable showing infilling of the Southern Lakes and southern Lake Ingraham. Continuous elongate central channel is created by small boat traffic. Distinct side channel on north side drains from Homestead Canal, where the weir is inoperable.*

To separate areas with different spectral signatures measured with the spectrometer, the multispectral Ikonos data is analyzed first, while the panchromatic data also provides important, independent means to refine interpretations. A "guided classification" is used afterwards. In this method, one area is chosen as a 'focus area'. In this focus area, in which facies boundaries and ecotones are known, the multispectral space that uniquely identifies each area (principal components of blue, green red, near infrared bands) is identified. These data ranges are then extrapolated to the rest of the Ikonos image to create a thematic map of spectral lithotopes. This approach is ecologically and sedimentologically reasonable also, because it utilizes ground truthed, field-based, sedimentologically significant classes and environments as the primary input, rather than merely a statistical separation of the data.

The primary remote sensing data that is used for this project comes from the IKONOS satellite. This satellite was launched in September 1999 and it is operated by Space Imaging. This sensor is one of the first next-generation, high-resolution satellites that started commercial operations. The satellite provides two general types of ultra-high resolution imagery: panchromatic (one band) and multispectral (four bands, including blue, green, red and near infrared portions of the spectrum). Figure 127 shows the relative spectral response and wavelength of response for the panchromatic and multispectral bands. Panchromatic imagery has 1 $m^2$ pixel size, whereas multispectral data have $4m^2$ pixels. Table 12 summarizes technical information about the Ikonos sensor.

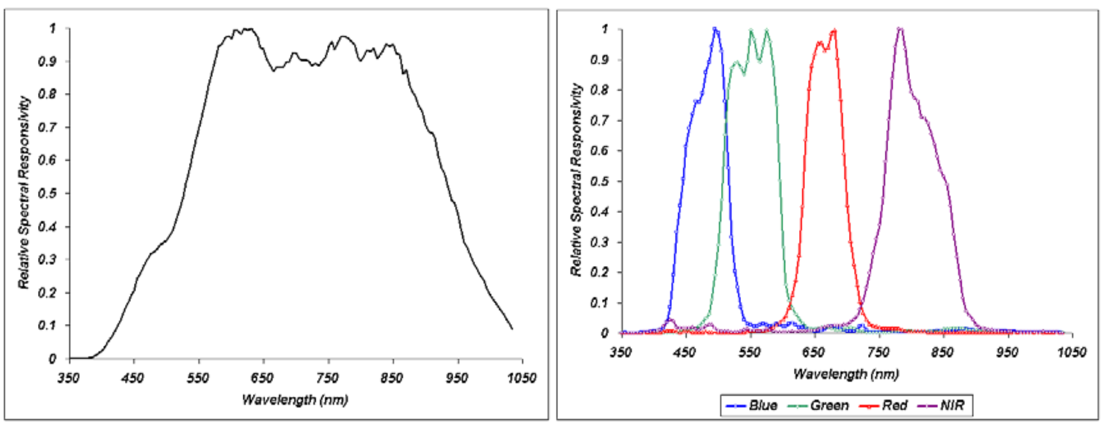



*Figure 128. Ikonos panchromatic (a) and multispectral (b) relative spectral response (Space Imaging website: http://www.spaceimaging.com/products/ikonos/index.htm)*

| **Ikonos Characteristics** | |
|---|---|
| Spectral bands (µm) | 0.45 – 0.9 (panchromatic)<br>0.45 – 0.52 (blue)<br>0.52 – 0.60 (green)<br>0.63 – 0.69 (red)<br>0.76 – 0.90 (near IR) |
| Swath width | 11.3 km |
| Orbit altitude | 681 kilometers |
| Satellite passage period | ± 3 days |
| Ground resolution | 1 m (panchromatic) and 4 m (multispectral) |

*Table 12. Ikonos characteristics*

# RECOMMENDATIONS

## Management recommendations

Put simply, Cape Sable is responding to the overwhelmingly powerful force of rising sea level on a delicate, low-lying coastline aided by episodic triggers such as hurricanes, fires, and freezes and small human modifications. In considering management options it is critical to understand the reality and implications of the historical sea level rise that has affected south Florida's coastline over the past 75 years – and the high probability that this will continue and be complimented by a doubling or tripling as the result of global warming (IPCC, 2001).

Blocking northern East Cape Canal or western Homestead Canal at the existing dams is not recommended because these are critical outlets for sea water that washes over the Marl Ridge into the interior. Because of this frequent flood-tide washover of the Marl Ridge, the water in the southern interior will becoming increasingly saline and less able to retain the rainfall it receives. By leaving the Canals open, this water has a means to escape. If these are effectively blocked, then the overwash saline water will be trapped in the southern interior, water levels will rise in the southern interior (as the water cannot so easily return seaward), flow velocities in other channels and canals (East Side Creek, J Canal, and Raulerson Brother's Canal) will increase, and these trapped elevated saline waters will spread further into the eastern and central interior.

The strong velocities in Middle Cape Canal, East Cape Canal, and western Homestead Canal are not unique. Naturally formed Hidden Creek, East Side Creek and New Sable Creek also have strong velocities. These are the natural hazards a person encounters in venturing into a backcountry destabilized by rising sea level and expanding tidal prisms.

Our recommendation is to make modifications necessary to assure a fair measure of safety to persons using the backcountry of Cape Sable. In considering such options, remain aware that the canals and creeks will continue widening and that blocking flow in one area will enhance flow in another.

Closing East Cape Canal would greatly enhance tidal velocities and rate of channel widening in Hidden Creek and Sandy Creek (naturally evolved tidal channels). Closing Middle Cape Canal will enhance velocities in widening of East Cape Canal and Hidden Creek. In addition, shore erosion will likely open the new western channel of Little Sable Creek to the shore soon in and case, of storm will soon open one of the small channels to the south. These is only a small amount of sand in the seaward shore and ebb tidal delta system near Middle Cape Canal, and closing the canal will not slow the wave erosion of the exposed mangrove capped marl sequence. Recall that Lake Ingraham and associated lakes and wetlands were decimated by the 1935 Hurricane and that these environments recovered in concert with marine tidal input through Middle and East Cape Canals. To isolate these would diminish an environment that is beneficial and widely used by a variety of wildlife. Because of rising sea level, the collapsing interior marsh is creating many isolated brackish interior lakes, not dissimilar to the historical Lake Ingraham.

The wildlife in the Southern Lakes, Lake Ingraham, on the Marl Ridge during tidal washover, and in the southern interior is among the most diverse and exciting that can be found in Everglades National Park (Figures 129 and 130). It would seem most logical to find a way for naturalist visitors to Everglades National Park to access and benefit from these dynamic and vibrant habitats. The richness of the experience is what most naturalists are seeking. Done right, this would also be an experience in both seeing nature at is richest and in learning how our Everglades coastal environments are evolving in response to sea level rise and hurricanes.

Cape Sable is a dynamic system and an awe-inspiring and powerful display of our evolving Earth. We should manage Cape Sable and present to visitors its wonders in the same way that we do the power, awe and wonder of places like Mt. St. Helens.

**Incorporating Future Sea Level Projections into Management Decisions.**

In our proposal we stated that we would offer forecasts for Cape Sable for the coming 50, 100, and 200 years. As preamble, we should note that the IPCC (2001) forecasts assume a smooth and gradual increase of sea level in response to global warming. That is not how climate and sea level have worked over the past 15,000 years. Sea level rose out of the last glaciation in a series of jumps and stalls. These jumps occurred as some ice sheets rapidly collapsed, ocean current dynamics changed, or temperature of surface water or deep water formation changed density. It is unlikely that our $CO_2$-forced warming will just be a smooth, gradual response. That said, we will consider a smooth gradual response of a further 30 cm (one foot) response for the coming 50 years, 60 cm (2 foot) response for the coming 100 years, and 150 cm (5 foot) response for the coming 200 years.

**Fifty Years**. A further 30 cm (1 foot) relative rise in sea level is assumed from the present rate (15 cm/ 50 years) from current regional influences plus 15 cm for one fourth of the anticipated global rise over the coming 100 years. This moderate global sea level rise scenario of 60 cm in the coming century is one agreed upon by scientists of the ICPP in 2001. In addition, we should anticipate around 6-7 hurricanes to pass over the areas over this 50-year period (statistically this area receives hurricane force winds on the average once every 7.5 years). We might assume two of these hurricanes would be in the category 3-5 range.

This 30 cm rise, combined with hurricane events will increase erosion of the exposed mangrove coast, result in more significant washover of coastal sand into the mangrove wetlands (further decreasing the effectiveness of the sand as a shore stabilizing influence). This increased exposure and wave vulnerability, combined with winter storms and hurricanes should result in 300-400m of further coastal erosion on the exposed ocean side of Cape Sable. This will move the coast into the present area of northern and southern Lake Ingraham (whether or not Middle Cape Canal is closed) and possible to the area of the Marl Ridge.

*FIGURE 129. Top: Roseate spoonbills in the southern interior of Cape Sable, March, 2003. Bottom: Wading birds on Lake Ingraham, March, 2003.*

*FIGURE 130. Top: Roseate spoonbills, southern delta in Lake Ingraham, 1998. Bottom: American Crocodile on mud bar at entrance to East Side Creek, January 2004.*

The Marl Ridge will be overtopped by essentially every tide and have nearly 60 cm of water flowing across it on the higher tides. This flow, combined with the push to have return flow out will initiate some significant new channels. The southern margin of Cape Sable, bordered by a slightly higher segment of the Marl Ridge (from Clubhouse Beach to Flamingo), will be inundated frequently by the higher tides, but storms will also build up new sediment on this Marl Ridge segment in an attempt to keep pace. The interior of Cape Sable will become entirely saline wetland and open marine water ponds with marine waters entering unimpeded from all sides. The amount of wetland will depend on the success of the transition from former fresh and brackish water wetland to marine (see the first recommended critical research topic). Numerous rapidly widening tidal channels will be feeding water and sediment to and from the interior, and may play a critical role in building substrate to maintain wetlands (as has been the case for the Southern Lakes in the past).

Wetland and coastal set backs from category 4 and 5 Hurricanes will cause increased difficulty in recovery and, thus will play a key role in the timing of wetland loss. Minus setbacks by major storms, freezes and fires, mangrove wetland peat production would be making a valiant effort to keep pace with this sea level rise. But storms will happen, and the wetland will become increasingly dissected.

**One Hundred Years.** We will use a 60 cm rise for the 100 year scenario. This should perhaps be 90 cm, adding the present regional influence rate (30 cm per century) plus the future anticipated global prediction (60 cm per century). This rise should be complemented by 12-14 hurricanes of which four are in the category 3-5 strength range.

The result for a 60 cm (2 foot) sea level rise in the coming century is suggested in Figure 118. Cape Sable is survived only by a few remnant patches of wetland perched tenuously atop marl highs or protected areas in which mangrove have survived aided by storm debris accumulation. Though gone as a widespread island, there is still a vast shallow marl flat just beneath the surface. This firm marl is not easily moved (witness the upper flow regime conditions that have persisted in Middle Cape Canal since 1936, yet widened it only at 120 cm per year.). But it is actively eroding and supplying amazing amounts of fine carbonate and organic mud that is being dispersed elsewhere. In contrast, the area of the Shark-Harney Rivers outlet, Whitewater Bay, and the inner side of Cape Sable is mostly an organic peat substrate. This will be mostly lost as it is more rapidly eroded and then oxidized or transported away (Figure 118).

**Two Hundred years.** The U.S. Environmental Protection Agency has been using a 150 cm (five foot) rise in global sea level for two hundred years scenarios.

With a 150 cm sea level rise, Cape Sable will become a wonderful memory available only in those reports and images preserved above that level and protected from hurricanes, mildew, and a throw-away society for over two centuries.

## Critical Further Research

This documentation of the pervasive saline invasion and tenuous wetland viability in the interior of southern, central, and northern Cape Sable is one of the most important, but least understood findings of this study. We recommend that this becomes a major focus of research using an integrated team of scientists. Understanding the fate of saline encroachment on freshwater wetlands on Cape Sable (removed from the additional stresses of changing freshwater delivery schedules to the lower Everglades) will provide a critical calibration for understanding these other areas with additional stressors.

We would recommend a careful look at historical rates and patterns of change in shore erosion, channel width and form, and wetland characteristics along the entire coast from Cape Sable to Everglades City and the 10,000 Islands. Significant landscape changes are occurring in a number of areas as the result of saline intrusion, wetland collapse, enlarged tidal prism, rapid sedimentation, and shore and interior erosion.

As Illustrated in Figure 131, Cape Sable, the Mangrove Coast and the 10,000 Islands are releasing large volumes of organic-rich sediment in various stages of decay. While some of this is cycling back into this coastal system (such as on the deltas in Lake Ingraham and the southern Lakes), much is being dispersed southward into Florida Bay and through the Keys to the reef tract and beyond. We would suggest that the rates at which organic material being released, the decay processes and products prior to release and during transport, and the pathways of dispersal should be carefully documented. These releases, a mixed product of sea level rise and recent hurricanes, are a significant and increasing stress on our coastal environments. Stresses include water clarity, light penetration, nutrient pulses, oxygen demand, siltation and plankton and benthic microbial blooms.

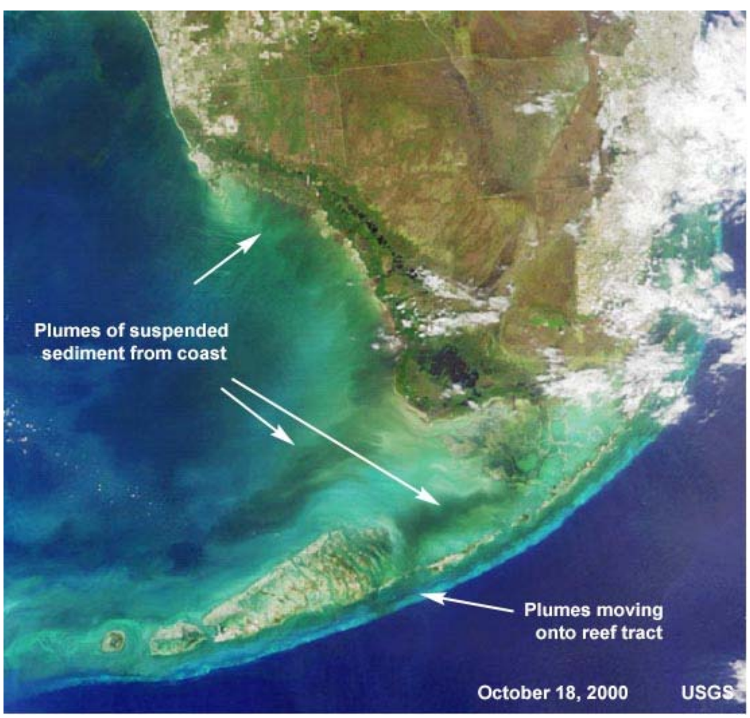



*FIGURE 131. Suspended particulates moving out from the southwest Florida Coast.*

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# APPENDIX

## PERTINENT HISTORICAL ARTICLES ON HISTORICAL HUMAN ACTIVITIES ON CAPE SABLE
From Florida Archives

# BULLETIN of CAPE SABLE, FLORIDA

**You are always strongly impressed with statements made by persons whose only object is to tell of interesting people, or countries, or places, which have appealed to them with an extraordinary and peculiar attraction, and in which they have no interest for gain, but only the wish to have their knowledge be of assistance to others.**

**The articles herein are copied from publications of the highest standing in the State and throughout the South.**

**The "Florida Grower" is the official organ of the Fruit and Vegetable Growers of Florida. They maintain a department of investigation for the purpose of ascertaining true facts before advising inquirers.**

**The "Manufacturers' Record" is the leading industrial publication in the U. S. south of the Ohio River. Communications must be from reliable sources to receive consideration.**

**Other sources of information are equally trustworthy.**

IF, AFTER READING THESE PAGES YOUR INTEREST IS AWAKENED TO ONE OF THE GREATEST OPPORTUNITIES IN OUR COUNTRY, WE SHOULD BE PLEASED TO HEAR FROM YOU, AND GO INTO THE MATTER MORE FULLY AS TO THE POSSIBILITIES FOR YOURSELF.

KEEP IN MIND THAT CAPE SABLE WILL PRODUCE ANY CROPS GROWN IN THE SOUTH OR IN CUBA. THAT FLORIDA WILL SOME DAY GROW ALL THE CANE NECESSARY TO SUPPLY THE UNITED STATES WITH SUGAR. PERFECTION OF SUGAR CANE SOIL IS ON CAPE SABLE.

## Remarkable Rosources of a Section Practically Unknown

By Lindley Heimburger, B. S. in Agriculture, M. S. Agricultural Efficiency Engineer, Tampa, Fla.

(Manufacturers Record) August 6th, 1917.

The South as a whole, especially we Floridians, do not realize the crisis the nation is experiencing, due to the world-wide shortage of foodstuffs, and especially now that we are an active party in the great war which involves fully 90 per cent. of both the peoples and resources of the entire world.

The true seriousness of this food shortage situation was most forcibly impressed upon me a few weeks ago when I was called to the nation's active hub, New York City, in the capacity of an experienced Southern agricultural engineer, to give testimony as to ways and means of meeting this shortage issue, and especially the possibilities the South today offers in the immediate production of large supplies of foodstuffs.

It is probably true that Florida at the present time is the most misrepresented and least understood State in the Union. Though the first State to be discovered geographically, Florida is the last of the States to receive serious economic development. . . . .

About the middle of April, 1917, the writer, in the capacity of an agricultural engineer, had occasion to investigate lands in the Cape Sable country for some Chicago financiers who were contemplating making investments in that part of Florida.

Though this Cape Sable territory will in the very near future be but two days' distance from New York, due to isolation it is today one of the least known spots in the United States. Though the writer has had over 25 years of extensive agricultural and horticultural experience in Florida, he was doomed to meet with many surprises in the Cape country, at the tipmost end of the North American Continent.

How many of us who may pose as being familiar with general conditions in Florida—physical, climatic, soils, economic diseases and insect pests—would be fully prepared to accept all the following facts pertaining to an extensive territory located at the most southerly point on the mainland of the United States?

First—A place in the Land of Flowers where the very soil is not the familiar Florida sand, nor is it Miami limestone rock, nor even Tallahassee clay or Everglades muck.

Secondly—A section where the characteristic Florida pine is conspicuous by its absence; a land, though naturally rather low, where the elsewhere ever-present saw palmetto is entirely absent.

Thirdly—Though the most wonderful grass country the writer has ever seen, where the very native deer grow to such a size that they nearly do justice to the Jersey cow, this section of Florida is probably the only part of the entire South that is naturally free of Texas-fever cattle ticks.

Fourthly—Though the mosquito is present, both malaria and yellow fever is unknown to the few "Conch" families living in this Cape Sable land; the same is applicable to that most dreaded of all Southern scourges, the hookworm disease. This Cape country is one of the few sections in Florida where soil conditions are of such a physical nature as to make the existence of the hookworm disease an impossibility.

Fifthly—Strange as it may seem, though this Cape Sable territory has the distinction of being the only spot on America's mainland with a record of never having experienced a killing frost in winter, this same section enjoys probably the most delightful seaside summer climate to be found in the entire South, being in the only part of our country that is fully within the tropical trade winds belt.

Sixthly—a land as nearly immune to destructive storms as any spot on our earth can be, protected by hundreds upon hundreds of miles of natural barriers to the east, southeast, south and southwest, the nearest and most important of these being the Great Bahama Banks, the Island of Cuba and the Florida keys, reefs and bars, which practically surround the cape on the three exposed sides.

Seventhly—One of only two sections of Florida where excellent dirt King split-log dragged roads can be constructed for from \$3 to \$5 per mile.

Eighthly—A spot where adjacent waters teem with the greatest quantities and numbers of species of food fishes of any similar area of the world.

Ninthly—A naturally tractor farming land, without the usual Florida grit, gear-grinding troubles, whose beautiful grass-covered prairies can be fully prepared for food crop planting at an outside initial cost of \$3.50 per acre.

Tenthly—A wonderland in a country well blessed by God, whose diversified development along lines that combine a truly tropical horticulture with the very important livestock-agricultural units, will shortly surprise the food-consuming world; a section that will enjoy all the advantages and privileges of water transportation and rates, railways and auto highways.

A point brought out during my recent trip to New York City that seemed to favorably impress financiers and business men was the fact that, due to Florida's crop-growing season of 365.25 days, together with both an abundant and quite well distributed rainfall, it is possible for the intelligent, enterprising and industrious agriculturist to produce three and even four food crops from the same land each year, as against one crop produced by the Northern farmer, together with unexcelled transportation facilities, both by land as well as by water, and the fact that the quickest relief in solving the national food shortage situation should naturally be expected to come from those sections best favored by climatic conditions.

A careful study of the 10 sections of epitomized statements of fact relating to the natural advantages of this Cape Sable territory given above will probably convince the average reader that this area of extreme South Florida is well-nigh ideal for the production of great quantities of human food products in continuous rotation, and that the quickest and most immediate results can be obtained by taking advantage of this exceptional opportunity to aid our beloved country in her dire extremity.

The soils of Cape Sable can be divided into two broad soil types, i. e., basic marl prairies, characterized by supporting an exclusive growth of native grasses, most of which being of species having high pasturage values, have a soil for the first six inches composed principally of decayed grass in various stages and degrees of decomposition; this first six inches of soil is underlaid with approximately eight inches of marl, highly impregnated with humus; from this point the soil is nearly pure basic marl, which extends to a total depth of from 10 to 15 feet; at a depth of from 10 to 15 feet from the surface the oolitic and coraline limestones are reached, characteristic to the Florida keys and the extreme South Florida mainland. It is this hard oolite, limestone that outcrops at Miami and surrounding territory which makes land clearing so slow and expensive.

The other class of Cape Sable soils belong to the basic marl hammock type, characterized by supporting a strictly tropical growth of trees, vines, herbs and other plants, with but little grass. About the first six inches of the soil of this hammock soil type is composed of finely decomposed leaf-mold; this is underlaid with about eight inches of rich marl carrying a large amount of humus, and this, in turn (as in the prairie type), with a pure marl to a total depth of from 10 to 15 feet, when the coraline and oolitic limestones are reached. The main distinguishing characteristics between the prairie and hammock soil types is that the soil of the former is composed largely of decayed grass and the latter of leaf-mold; the natural drainage of both is fair, though these two land types are quite flat in topography and are susceptible to perfect drainage at very low cost.

These Cape Sable hammocks are the only truly tropical forest growths to be found in the United States proper, and though the growth is very dense the land can be cleared at relative low cost, as the trees are in every case shallowly footed and can be easily pulled with suitable power.

The hammocks contain a vast amount of very interesting botanical material; practically all the species present are truly tropical, and this little known land should prove to be a veritable paradise to the botanist. Without quoting botanical names, it might be of interest to give the following very incomplete partial list of native flora: Tropical buttonwood, pawpa, sable palm, mastic plum, African dogwood, pigeon plum, cinnamon, rubber trees, tropical tree cotton, gumolimbo, manginela, black mangrove, Cherokee tree bean, something like half a hundred species of orchids and other air plants, and many species of tropical cacti. Also the true red Honduras mahogany is found native to this part of Florida.

As the writer specialized in agricultural bacteriology in college and university, he can vouch for the following: The old theory that soil fertility is solely a chemical problem has been exploded by the teachings of modern agricultural science. Today we know that true soil fertility is more a matter of biology (soil bacteriology) than of chemistry. Oxygen, a slight alkalinity of the soil and an abundance of humus, together with a proper degree of temperature and moisture condition of the soil medium, are prerequisite factors for a maximum growth and development of these soil micro-organisms so essential to every fertile soil. These Cape Sable marl soils are by chemical nature nothing more than carbonate of lime in a very finely divided physical state, therefore they are basic in character and can never become acid, but must always show an alkaline reaction. Again, marl soils to a very marked degree resemble the typical clay type of soils in the physical properties of great moisture absorption and conservation powers, as well as to hold and retain much plant food that might otherwise be subject to loss by leaching. Still by far the most valuable property of basic marl soils is the fact that they offer an ideal slightly alkaline environment for the life-giving soil bacteria.

There are but two legumes commonly known to the American farmer that comply fully, as to their contents of protein and fats, with the requirements of an army war ration; these are the soy bean and the peanut: All things considered, the soy bean must be conceded to be best adapted to fulfil the very exacting requirements of a nation at war. This legume has a very wide range of economic growth, is remarkably free from insect enemies and plant diseases, and can be cheaply grown and harvested by the same farm equipment required to grow the common navy bean.

Though the soy bean has been the main protein food for hundreds of millions of people in the Orient for many thousands of years, this legume is practically unknown as a human food in America, though by all, when properly prepared for the table, the soy bean is conceded to be superior in flavor and to have a greater palatability than our well-known common navy bean.

Like all other legumes, the soy bean is a wonderful nitrogen "fixer," and is closely rivaled by only one other competitor in the South, i. e., the velvet bean, as a great soil improver. As this nitrogen "fixing" power is solely dependent upon the activities of certain forms of (root tubercle forming) bacteria, and they, like all other soil micro-organisms, require a soil showing a slight alkaline reaction, it goes without stating that a basic marl soil is well adapted to the growing of soy beans.

Due to abundant and well-distributed rainfall, a frostless growing season of 365.25 consecutive days, a soil by chemical, physical and biological nature best adapted to modern scientific cultural practices; a land with fair natural drainage and easily susceptible to expedient perfect drainage, with unexcelled transportation facilities within easy reach, there is no plausible reason why these Cape Sable lands should not be put to work immediately producing very much needed human foodstuffs.

By immediate action it would be possible to produce a crop of soy beans on these marl soils this summer. This crop should not only yield an excellent crop of beans, but should also "fix" a large amount of nitrogen that could be utilized by at least two other crops of food-stuffs, i. e., cabbage and onions, from off the same land before a year had gone by, making a total of three crops for the season. Today navy beans are selling on the New York market for almost $10 per bushel; the onion is a greater household luxury than the Florida grapefruit, and even the homely cabbage of the past is today one of our leading aristocrats.

Because of the great immediate necessity of human food supplies, we can safely defer for the present the development of the livestock possibilities, and especially the tropical fruit-growing industry, though it is perfectly true that the livestock unit, for many obvious reasons, will ultimately have to be included in any scheme of agricultural or horticultural development in this Cape Sable land before the full measure of success can possibly be achieved.

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# The Florida Grower

May 11, 1918.

## CAPE SABLE COUNTRY.

PALMETTO, FLA., April 27, 1918.—(To the Florida Grower)—Referring to your article on Cape Sable, by Mr. Heimburger, would be pleased to have you answer a few questions, concerning this Cape Sable country, if it will not put you to much trouble, as we are very much interested and with further information, if favorable, will investigate that country thoroughly.

Can this land be bought? If so, from whom and what price per acre? What is the best way to get to this land? Is there a way to get what you raise out of there? Is the soil adapted to the growing of sugar cane? Is there a possibility of a railroad in the near future?

Please let me know the best possible way to get into that country. V. N.

Note—The lands in question at Cape Sable are owned by corporations and individuals. The largest land owners in this country are the East Coast railroad with main office at St. Augustine; the Cape Sable Development Co., Miami; and the Cape Sable Farms Co., Miami. In wholesale quantities we judge that these lands can be purchased for about $25.00 per acre. At retail these same lands are sold at from $50.00 up. We believe that there is a great future in this country, as this is the only spot on the American continent where killing frost is unknown. These lands are fertile basic marls. They all require a certain amount of drainage, but this can be accomplished at a relatively low cost, much lower in the case of these prairie lands than would be the case with heavy hammocks.

We consider that these lands are better adapted to the growing of sugar cane than any other soils in America, and are sure that there are none better even in Cuba. Analysis shows that cane grown on these lands has very few equals anywhere else in the world in sucrose content. The average cane as gathered in an immature state in Louisiana will show only 12 per cent to 14 per cent sucrose with a low coefficient of purity. On the other hand cane grown at Cape Sable under intensive farming and good management, using the best hybrid types of seed, should average not less than 17½ per cent to 18½ per cent sucrose with a very high coefficient of purity. In Louisiana it is necessary to cut the cane during the first part of November because of the danger of killing frost, also in Louisiana it is necessary to replant each year. At Cape Sable owing to its immunity to excessive cold the cane can be allowed to thoroughly mature, being cut the middle of February when it shows the highest sucrose content; also it is important to state that in this very mild climate, sugar cane is a true perennial and it is only necessary to plant cane once each 6 or 8 years. The writer saw cane this last summer at Cape Sable growing wild which was at least 20 years old. He cut an individual cane which measured 22 feet in length and saw and measured one taken out of the same wild cane thicket that measured 37 feet long and calipered 2½ inches in diameter at the butt. At present Cape Sable has no railroad facilities but evidently the East Coast Railroad will build a branch from Homestead as soon as the development in this country warrant this expenditure. There are excellent possibilities of water transportation already at Cape Sable, and it is an easy matter to lighter across Florida bay, a distance of 35 miles, to Long Key, the nearest East Coast R. R. shipping point, in 5 hours time. Deep water (25 feet) is to be had a short distance from the beach at one point of the cape.

## The Florida Grower

September 28, 1918.

### A CORRECTION AND INFORMATION

Lakeland, Fla.—(To the Florida Grower) We note in your issue of August 31 your answer to two inquiries about Cape Sable lands. Will you kindly make the following corrections as to the facts now existing.

The lands formerly owned by the Cape Sable Development Co., Miami, Fla., were bought by us from them on December 17, 1917. Inquiries for these lands sent to this company are forwarded to us. We know of no land owned on Cape Sable by the Cape Sable Farms Co. They have been acting as a selling agency for lands placed in their hands.

In your answer to "Minneapolis, Minn.," you refer to the boat service and the possibility of a hard-surfaced road. Allow us to say that this company has operated a mail boat between Long Key and Cape Sable for several months, making regular trips on Thursdays. Also other trips when necessary for the accommodation of passengers to and from the Cape. And this fall will make at least two regular trips a week and oftener if necessary.

We should appreciate inquiries being referred to us and we will take pleasure in giving them information about Cape Sable.

O. C. LANPHEAR, Secretary,
Cape Sable Improvement Co., Lakeland, Fla.

Note—This tells it all about Cape Sable, and we, personally, are glad to be informed as to the changes and improvements going on in this favored section. We can bespeak for thorough reliability in this information.

## The Key West Citizen

June 3, 1918.

### CAPE SABLE.

We desire to call attention to the article in this issue on "Unique Cape Sable," written specially for The Citizen by F. Page Wilson, a man who knew the Miami section on the eve of its marvelous development, and who has been practically all over the state sizing up the various sections for farming and fruit-growing. His expressed belief that Cape Sable possesses the largest body of really fine soil in the state, united with the best mainland climate in the United States, should be a matter of the deepest congratulation to thise who have the interests of Monroe county at heart. Whether or not the cape will ever actually eclipse Miami in its wonderful development as a residential and tourist centre, the former has the fundamental assets of a great agricultural producer, and these are what count in the end.—Editor.

# UNIQUE CAPE SABLE

(By F. PAGE WILSON.)

The writer was in Dade county two years before the extension of the Florida East Coast Railway gave impetus to a development which has been the marvel of the whole country. He saw the jungle lining the shores of Biscayne Bay give place to the magic city of Miami, the rocky pine-lands of Cocoanut Grove and the back country became dotted with beautiful groves of grapefruit and tropical fruits, the scattered and modest abodes of the early settlers give place to the imposing residences of the fruit-grower and the wealthy winter tourist.

A recent trip to Cape Sable, which is within the boundaries of Key West's own county, convinced him that that district even now shows all the ear-marks of a coming development which shall equal or even eclipse that of our neighboring county. While it is difficult to believe that any other region can produce a rival to that famous Biscayne coastline centering in beautiful Miami, it is not difficult to show that Cape Sable is going to surpass it in some very important respects.

Cape Sable's general landscape is pleasing too; and so is its gentle curving coast-line. Deep water for transportation will not be hard to find. But it is its fundamental resources as an agricultural producer that we are considering now, and this is where an observer becomes frankly enthusiastic.

Anyone who, like the writer, has had extensive experience through the state, seeking the ideal location for sub-tropical products, knows the difficulty of selecting a district of any size presenting in combination all the following requirements:

1 Safe climate.
2 Good soil.
3 Safety from overflow and drought.
4 Good transportation.

One of the glories of our state is its infinite variety. There is good land in practically every county in Florida. But the good land is apt to be spotty, that is, interspersed with or surrounded by soil of a poor or indifferent character. Or the climate, while delightful for a winter holiday, may scarcely be safe enough for some of the products which people come to Florida to grow. Or again, the land, while good enough in itself, may be very hard to clear, or it may require heavy outlay for drainage canals.

Such a happy combination of soil and climate as is called for above is indeed elusive in any country on earth and, frankly, the writer did not expect to find it in south Florida, much as he believes in this great state. But that is precisely where he did find it—at the southernmost tip of the peninsula—at Cape Sable.

First, as regards the climate. One clue is given in the preceding paragraph. In Miami, a few miles farther north, frost is comparatively rare, but at Cape Sable ,according to the government figures kept for many years, no killing frost has ever been recorded. In February of last year, when the cold wave descended farther south than ever previously recorded, the only damage noticeable was that the tips of some of the tomatoes and sweet potato vines were slightly scorched. Cape Sable is not only the farthest south, but it possesses the additional great advantage of being protected on the north and northwest by a large body of salt water known as Whitewater Bay.

Secondly, the land itself. The writer has no wish to detract from any other section of Florida, but he does claim that Cape Sable is unique in that it presents absolutely the largest body of uniformly good soil in the state. And when he says "good," he means it in the same sense that the Illinois and Alberta prairies are good. These, this far-south land somewhat resembles, except that the cape prairie is interspersed here and there with typical hammock, containing the plant growths—some of them rare and valuable—peculiar to this latitude. The prairie produces a luxuriant wild growth of grasses, including Bermuda (at least, that is what it looks like) and many others much relished by animals. To plow and put into shape for planting —which even now is being done by tractor—costs only about $5 per acre, while the hammock costs more, although the timber as a rule is shallow-rooted and, some of it being valuable, practically pays for the cost of clearing.

The writer dug holes, several of them, and miles apart throughout this great expanse of fertile territory, and this is what he found in all. First, from five to eight inches of blackish loam. Next, five or six or more inches of friable shell marl of a greyish color and mixed with humus. Then comes marl, which extends down some nine to fifteen feet until it reaches the typical soft coralline rock formation of this section. The hammock is largely similar, except that in addition the surface soil for a depth of four or five inches consists of leaf-mold.

He saw no sand (not even on the beach, which is composed of ground-up shell); no rock; no palmettoes.

Dr. Lindley Heimburger, former Assistant Chemist to the State of Florida, who spent considerable time in a careful investigation of this unique region, draws attention to a fact of the utmost importance to anyone contemplating agricultural or horticultural pursuits. Owing to this Cape Sable soil being based on marine marl, it is not sour, nor, from its very nature, can it ever be sour. On the other hand, the presence of lime gives it the slight alkaline reaction so necessary for proper plant growth, especially of the valuable legumes.

Drainage, that bug-a-boo of so many otherwise good lands in south Florida, is an easy problem here. Much of the land is in no special need of drainage at all, in fact, good crops are being grown without it today, as also, it may be added, without a particle of fertilizer of any kind. But good farming, either in the north or south, sees to it that the land is kept at all times in the right condition in regard to aeration of the soil and removal of all superfluous moisture, and so ditches will be dug through the lower lands into which ordinary farm drains can be dug as required by the farmers themselves in any section.

One thing should be borne in mind in this connection, viz, that owing to the topography of the Cape Sable country, it is not affected by the height of water in the Everglades or Lake Okeechobee, from which it is practically cut off by Whitewater Bay. Extend south for a very few miles the southern tip of that water and the Cape Sable country immediately becomes an island. All it needs to care for is its own rainfall, which is not excessive. No huge outlay, therefore, for canals or dams.

Some of Florida's muck lands are wonderfully fertile when reclaimed, and the Everglades will yet astonish the world, but for a well-balanced, long-enduring soil, adapted for the production of the best quality and largest variety of products, there can be no doubt whatever that this Cape Sable land is far superior. Also, it is much freer from frost and will hold the moisture better under cultivation.

The last requirement in our ideal location as given above, viz., transportation, is where Cape Sable is lacking; and this is precisely the reason that, in spite of the fact that the comparatively few people who have visited the cape have all been impressed with its great and certain future, it is only now that its development has begun.

An occasional schooner traverses the smooth seas between it and Key West, but the best way to get there is to arrange for a motor boat from Long Key, from which it is distant about 30 miles. An extension of the Dixie hard-surface high-road is now in course of construction from Homestead and will be completed as far as the county line this fall, after which Monroe county takes up the work and in fact has already assented to a bond issue for that purpose.

In the near future there is no doubt but that the F. E. C. Railway will build a spur to tap the resources of this unique region when they are a little further developed. In fact, a group of men closely affiliated with the F. E. C. Railway are the largest owners of land there.

Key West has a very live interest in the speedy up-building of this fertile mainland section of its own county, although it is perfectly true that Miami will profit too. The point is this. Even before the completion of the railroad, the completion of the high-road will bring a large influx of actual settlers. Now, the situation of the cape in relation to Key West is such that a large proportion of its traffic, coming and going, is bound to pass through this city, for the very simple reason that water transportation is cheaper than rail. Here, in fact, lies not only Key West's opportunity, but another wonderful advantage for Cape Sable compared with most other sections.

And be it remembered that Cape Sable is no small addition to the productive resources of South Florida. There are 70,000 acres of the richest, quickest-to-get-into-condition soil in the state, allied with the finest climate, summer and winter. Enough to provide material for a dozen large sugar mills. (Cape Sable is already famous for its syrup and the writer saw fields of cane which had been rattooning for fifteen years, although it was hard to credit). And there would still be room for hundreds of growers of winter vegetables and tropical fruits, to say nothing of a few cattle ranches.

This is the outstanding fact which grips the visitor's mind, that not only does Cape Sable possess the safest and best climate in the United States, and land which is equal to the best, but there is of this such a large area of uniformly high fertility as to provide a magnificent back-country for a city of any size that can be conceived there.

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## The Florida Grower

June 1, 1918,

### CAPE SABLE CLIMATE.

MIAMI, FLA., May 21, 1918.—(To the Florida Grower)—I note answers to readers on Cape Sable. Government Weather Bureau shows 30 degrees on January 26, 1905. In 1886 ice formed at Key West. M. B. PAGE.

Note—Light frosts have been known to occur at Cape Sable, but it will be shown, if you read the answers appearing in the Florida Grower that the statements made in regard to climatic conditions at the Cape were qualified in each case. You will note that the term "killing" was used to qualify "frost" or "freezes."

We visited the Cape last year, a short time after the disastrous freeze of early February, which was the worst on record for the lower East Coast, and we can vouch that we saw no visible indications at the Cape of frost damage, though the natives there acknowledged that on February 3rd they saw a very light white frost.

Nature cannot tell falsehoods and any experienced biologist can come to the Cape today and by making a careful study of the native flora indigenous to the Cape Sable country, will verify our statements that this is the only spot on the mainland of our continent that shows a true tropical flora. If the Cape country was subject to disastrous freezes wild sugar cane, many years old, Honduras mahogany, innumerable tropical orchids, tropical palms, bananas and similar species sensitive to cold could not exist.

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## The Florida Grower

May 18, 1918.

### WANTS FOGGY COUNTRY.

HYMES, CAL., April 28, 1918.—(To the Florida Grower)—Has Treasure Island, near Leesburg, been sold, and was it to be sold as a whole or in small tracts? Is there any muck or overflow or bottom land in Florida? I contemplate going to Florida and will be thankful for information. I want to locate where there is plenty of fog on account of the fact that I wish to raise a vegetable that requires dampness, and I also want to be in a FROSTLESS LOCATION similar to Treasure Island. Please inform me where such places are located. What is the average prices of a good pair of horses? What is the freight rate from Florida to New York City? Are there many artesian wells in Florida and at what points? What kind of a place is Moore Haven and what do they raise there? Is South Florida less frostless than the Central and Northern parts and is the land good and productive there?

JOHN G. GRITZINGER.

Note—We are sending you two copies of the Florida Grower, one containing an account of a visit to Treasure Island and Moore Haven, the other a story of Cape Sable and Florida City. At the time the story was written Mr. E. H. Mote of Leesburg, was offering the whole island for sale. I do not believe he ever sold it, though of this I am not sure.

The type of soil you describe in the latitude you want may be found at Florida City or Cape Sable, but I fear you will have to get along without fogs, as we simply do not have them in this State. It would be impossible for me to give you set figures on freight rates from Florida to New York City, as every commodity takes a different rate and every loading point necessarily has a different rate because of distance. Citrus fruits from Jacksonville to New York take a rate of 46 cents per box, the weight of the box being based at 80 pounds. Vegetables take many different rates, beans, for instance, being 39 cents per hamper. Of course vegetables are largely shipped from Florida at a time when the weather is warm in the south, and this means that they must be iced, with consequent icing charges. The time is about six days.

Good horses may be had at about $250 each and mules $500. There are very many artesian wells in Florida, and they may be had at almost any point near either coast and in some places back as far as twenty miles or more from the coast.

The further you go south the less danger of frost, but it is also true that groves located on the south or southeast shore of a body of water might be more immune from frost than another less protected, even though the former were 100 miles further north. It is said that there is no record of a frost at Cape Sable.

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## The Florida Grower

### LIKES CAPE SABLE.

PUKWANA, S. D., April 20, 1918.—(To the Florida Grower)—I receive the Florida Grower every week and read it from cover to cover, ads and all. I have made four trips to Florida with the intention of buying land and always found some knockers that discouraged me. Yet I wanted some Florida land and bought 640 acres (a square section) in the Cape Sable country unsight and unseen. I bought it on the recommendation of a friend who told me that the Cape Sable country could not be beaten in the State, and I would like some information about that country. Can corn be raised there? Do you think alfalfa could be raised there successfully, and how about sugar cane? Do you think oranges and grapefruit would do well there? I am partial to sugar cane and if it can be grown successfully I expect to put in about 400 acres. How is it for stock-raising and general farming? I have asked you a lot of questions and I hope you will answer as many of them as you can.

J. A. S.

Note—it is true that all countries have knockers and Florida is no exception, though we are sure there is less ground for knocking Florida than any other State in the Union.

We do not think you made a mistake in purchasing the section of land you refer to at Cape Sable, as we are sure this country has a great future. Last summer the writer had an opportunity to study this area at close hand in the capacity of an agricultural engineer, and he has great faith in its future.

Alfalfa will grow on the rich humic marls at Cape Sable, but we consider that this legume is not as valuable as a forage crop in South Florida as Japanese kudzu, Florida beggargrass and the Florida velvet bean. We are sure corn will grow successfully at Cape Sable. As to sugar cane, this plant is perfectly at home on these rich marls.

There is probably not another spot on the American continent more favorable for cane sugar production than this Cape Sable country. Oranges and grapefruit undoubtedly will grow successfully here, but we are sure these lands are more valuable for the production of the more tender varieties of the citrus family, such as limes and lemons.

We are sure that the commercial production of select types of Key limes for the soft drink trade, and the production of Tahiti limes to take the place of the commercial lemon, will be a coming horticultural industry at Cape Sable. We are sure this latter fruit is far superior in every way to the best lemons to be had on our markets, also that they can be produced much more economically at Cape Sable than lemons can be raised in Southern California. It must be understood that a livestock unit should be included in every agricultural or horticultural development at the Cape, whether it be the growing of cane sugar, limes, pineapples or cocoanuts.

# Florida Can Control All American Sugar

## THIS STATE HAS FINEST OPPORTUNITY TO HOLD IN ITS HAND CULTURE AND MANUFACTURE OF THE SUGAR OF THIS COUNTRY

The Tampa Morning Tribune, Sunday, October 25, 1914.

(By R. E. Rose, State Chemist of Florida.)

Few American consumers, outside the sugar-cane fields of Louisiana and the sugar beet of Colorado, New Mexico, and other Western States, realize the vast sums of money paid out by Americans for imported sugar, an article no longer a luxury, but recognized as one of the staple foods of men and animals.

I shall not go minutely into the statistics; suffice it to say that the world's consumption of sugar is now practically 17,000,000 long tons of 2,240 pounds each, or 18,500,000 tons of 2,000 pounds each. Of this practically forty per cent or 7,500,000 tons is beet sugar, grown and manufactured in Europe, principally in those countries now involved in war—Belgium, France, Austria, Germany and Russia. With the exception of some 500,000 tons of beet sugar, grown in the West, the sugar used in America is cane sugar. Beet sugar is seldom known east of the Missouri River.

Of the cane sugar of the world (practically 11,500,000 tons of 2,000 pounds each) the United States consumes 3,000,000 tons annually—practically one-third of the world's production of cane sugar. Of beet sugar, she consumes some 500,000 tons (the yield of Western beet sugar for 1914, is estimated at but 300,000 tons.) Conceding that the Western beet sugar production will be 500,000 tons, it will be noted that America uses but one pound of beet sugar, where she uses six pounds of cane sugar.

By far the largest amount of beet sugar grown in Europe, is used by England. Until this war began, England used far more beet than cane sugar. The present high prices of sugar was caused largely by England purchasing vast quantities of refined Cuban cane sugar from American and Canadian refineries, with vast quantities also of ninety-six per cent Cuban sugar. These purchases caused the world's prices to advance to three times the normal value of sugar, within ten days of the declaration of war.

The most conservative estimates show that at least one-third of the world's annual supply of sugar—some 6,000,000 tons of beet sugar—will not be produced this year. It is also probable that the production of beets in the West will be considerably reduced, from 500,000 tons to 300,000 tons, for lack of beet seed from Germany.

Should the war cease today, the European crop having been largely neglected and destroyed, the factories destroyed or damaged, and transportation disorganized, the harvest of those fields which are not ruined will yield but a small proportion of the average crops.

The world's production of sugar has never exceeded the demand. Seldom is there any surplus carried over from one season to the other.

With the loss of one-sixth of the world's supply for one year, it will require several years to again balance production and consumption, with the probability of the practical destruction of industry in Europe.

### American Consumption.

Americans consume the greatest amount of sugar per capita—some ninety pounds, or 3,500,000 tons per annum—of which she produces, including that from her insular possessions—Hawaii, 4,800; Porto Rica, 280,000; the Philippines, 186,000; domestic beet, 500,000 (?); domestic cane 300,000—practically 1,750,000 tons, produced by the United States and her territories, or less than one-half of the American consumption, making it necessary to import, principally from Cuba, 1,750,000 tons, at present prices, costing $120 per ton, or $210,000,000 (two hundred and ten million dollars), which retails to our people at $160 per ton (eight cents per pound), or $280,000,000 (two hundred and eighty million dollars), paid by the American consumer for imported sugar.

Sugar is the only agricultural product of any magnitude (except coffee and tea) that America imports. Cane sugar, under proper conditions of soil and climate, can be, and is, produced for much less than beet sugar, under the most favorable conditions. It can, and has been, demonstrated that cane sugar can be grown, manufactured and sold at a profit, at less than the cost to grow and manufacture beet sugar.

While fine crops of cane of the best quality are grown in all the Gulf States, in a belt averaging one hundred miles from the Gulf Coast, all of the State of Florida is practically adapted to the plant, particularly the peninsular portion of the State, where prior to "the war between the states" large sugar plantations were found.

Cane sugar (pure, granulated sugar) can, under proper conditions of culture and manufacture, be made and sold at a large profit, at from $3.25 to $3.75 per 100 pounds.

It is not probable, in fact improbable, that the world's supply of sugar will meet the demand for at least three years, in which time Florida should so firmly establish herself that it would be impossible to take the business from her; having a soil and climate equal to Cuba's for sugar growing, with American methods of culture and manufacture, she can, and I believe will, yet produce all the sugar the nation now imports.

The probabilities are that not only one year's crop of European beet sugar will be lost, but that fully two years crops will be lost, with the possibility of the destruction of the beet sugar industry of Europe. That sugar will sell for less than six cents per pound wholesale, during the next three years, is not to be expected. That it will sell for much more, is highly probable, and that it will be many years before the world's supply will again meet the demand, is also probable.

### A Sure Crop.

I have long advocated the culture of cane and manufacture of sugar as one of the most profitable and surest crops for the Southern States bordering the Gulf. Even under normal conditions and in competition with the world, and the "American Sugar Refining Company," I believe that the time is now ripe, and the opportunity at hand for Florida, with her fertile soil, semi-tropical climate, and abundant rainfall, to establish an agricultural industry that will yield immense profits to her farmers, merchants, manufacturers and capitalists.

My advice to all farmers is, to plant just as much cane this fall as possible, as the demand for seed cane will be great. Numbers of inquiries have come to me recently for seed cane, that most necessary and expensive item in establishing a sugar plantation of any considerable acreage.

Sugar or syrup making, however, to secure the greatest profits, requires modern apparatus, just as do the modern dairy, or creameries, cotton factories or flouring mills. It means co-operation between growers and manufacturers, merchants and bankers, the farmer to devote his skill and labor to the production of the largest tonnage of the best cane, the manufacturer to use the best modern machinery, apparatus and his best skill in securing the largest amount and the highest grade of sugar from the farmers cane. This is the practice of the best growers and manufacturers of Europe and the West. Also that of the most progressive of the Cuban growers and manufacturers. Florida farmers, bankers, and merchants can, if they will, "get together," co-operate for mutual assistance, what in my opinion, will make Florida the wealthiest agricultural State in the Union.

**Every County Produces.**

It is not necessary to discuss the best localities. All have some advantages. Each county in the State produces cane of the highest quality. So far, its manufacture has been of the crudest and most primitive type, wasteful methods employed.

Particularly adapted to cane culture and sugar manufacture are the vast bodies of rich lands of the southern part of the peninsula, now being so successfully drained and made fit for culture. That these lands are peculiarly adapted to cane culture has been fully demonstrated. That they will yield as large a tonnage of cane, with as high a sugar content as do the Cuban soils, has been time and again demonstrated.

With modern methods of culture, fertilizing, harvesting and manufacture, Florida should, in but a few years, if she will embrace the opportunity now offered her, add to her other agricultural assets, the enormous amount now expended for imported sugar, a sum now upwards of two hundred and ten millions of dollars per annum, and increasing annually.

# CAPE SABLE

**Knowing the very conservative and reliable statements made in the literature issued by the Florida East Coast Railroad Company, you will appreciate the following, which we quote from their booklet, "Cape Sable Florida."**

## CLIMATE.

Cape Sable is located at the extreme southerly end of Florida's peninsula and possesses many natural and peculiar advantages. The entire Cape Sable region is as nearly immune from cold and frost as any habitable portion of the United States, and facts will substantiate the statement that no record exists of any damaging frost. The waters which protect from frost at the same time protect from extreme summer heat, from which, as is well known, other portions of the country suffer greatly; and here cool, comfortable nights insure restful, upbuilding sleep.

## THE SOIL.

The base soil of the Cape Sable region is technically called a marine marl composed of disintegrated shell and transformed vegetable matter. In certain localities this is overlaid with from four to six inches of muck, and in the hammock portions by from two to four inches of leaf mould. As may be readily seen, the result is farm land of unusual quality of productivity and admirably adapted to a great variety of crops. When one has seen this soil and its amazing crops, he will realize with enthusiasm what is meant by having Nature "work with" him.

## THE CROPS.

SUGAR CANE.—There are fields of cane at Cape Sable that have been constantly producing for twenty years, making sirups of the finest quality, and at the rate of 600 gallons per acre. This sirup finds a ready wholesale market at 65 cents per gallon, or $390.00 per acre per year. Bear in mind that this is wholly without expense for special cultivation, and is the result of but the most ordinary effort.

TOMATOES, PEPPERS AND EGG-PLANT.—The best qualities of each of these vegetables may be produced for both early and late markets, without fertilizer; and one may confidently expect a yield of from 250 to 350 crates per acre. Without fertilizer, this may be considered quite remarkable, and these should yield an average of $1.00 per crate.

SWEET AND IRISH POTATOES AND ONIONS.—These make a wonderful growth on hammock soil. Furthermore, on these new lands there is not and never has been even a trace of fungous diseases. Better still, to date insect pests are almost unknown and it is believed that by watchfulness they could be altogether prevented. Crops of sweet and Irish potatoes and onions mature in from 90 to 120 days and are raised at a cost not in excess of $75.00 per acre. A most conservative yield is considered 60 barrels per acre.

MELONS AND SQUASH.—These are produced in great abundance and the best qualities result on lands where is the greatest proportions of shell. Melons and squash from the Cape Sable region are finding ample local market in Key West and nearby towns.

## LOCATION OF THE CAPE SABLE REGION.

As before stated, Cape Sable is at the extreme south end of the peninsula of Florida, being 40 to 60 miles northeast of Key West, the latter point being easily accessible by a short, pleasant trip by boat over the blue and sparkling waters of Florida Bay and the Gulf of Mexico. Homestead and other points on the East Coast will soon be reached by the much-talked-of Ingraham Highway, which is a fine, hard-surfaced automobile road built of the coralline rock so very plentiful in this locality. This highway, now under construction and soon to be completed, runs from Miami, "The Magic City," to the Cape.

By the Ingraham Highway one will reach many of the best hunting and fishing grounds in the South. The lover of real sport may take his launch and in Whitewater Bay and among the Ten Thousand Islands will, if he be a faithful disciple of Isaac Walton, find anything from the toothsome bottom-fish or gamey mackerel to the royal tarpon, king of game fish and a fighter of quality.

## OUTDOOR PLEASURES.

When tired of fishing, one may go ashore with a rifle and hound and follow the deer to its haunts in the hammock. Should he be overtaken by night, it will be an easy matter to arrange a 'coon hunt, and anyone who has ever partaken of this variety of sport knows that an evening spent in a 'coon hunt is by no means thrown away.

Those who prefer the shotgun may go either afoot or afloat and find duck, coot and curlew. In fact, game is very plentiful throughout the Cape Sable region and with ordinary care in shooting, good hunting may be preserved here for many years to come.

Outdoor lovers who like to prowl about in a new and interesting locality may spend many an hour with camera, sketch-book or butterfly net, and right at one's very door or not far afield will find ample use for all of them. It is not generaly known that the orchids alone in and near Cape Sable will claim the attention of the botanist for fully a year. Nature has been unusually generous in her lavish distribution of vegetation of all kinds.

## POULTRY RAISING.

Poultry is a necessity and a welcome addition to any home. In the Cape Sable region, turkeys, chickens and ducks have thus claimed but little attention, but to that small amount given they have responded gamely and generously and have shown they have little if anything to fear from natural enemies. So the man with ten acres and the ever helpful hen can be almost as thoroughly independent as the much-referred-to "Miller of Dee."

## OTHER PRODUCTS.

SWITCH GRASS AND MESQUITE.—These native grasses furnish abundant and nutritive pasture for horses, mules and cattle. They may be supplemented by Para, Natal, Rhodes grass and several other species well adapted to this particular soil and climate. Should one care to raise grain, kaffir corn, corn, oats and rice will make thrifty growth and develop heavy yields.

LIMES.—These are practically indigenous to the region, bear early and are unusually free from insect pests and fungus diseases. The demand for limes is increasing more rapidly than the groves can be set out and the fruit ripened. Cape Sable lands may be set out in limes at a cost of $50 to $100 per acre, and have brought an average net return after the third year of from $250 to $300 per acre.

## IN CONCLUSION.

To motor boat enthusiasts, beautiful Florida Bay, Whitewater Bay and Ten Thousand Islands give cruising and fishing grounds, the waters of which are protected from all storms and are filled with fish both for food and sport. From the waters of Florida Bay over 500,000 pounds of fish are taken annually to aid in filling a demand far in excess of the supply.

Cape Sable is at present the location of the only commercial cocoanut grove in the United States, the entire output of which goes to New York.

The construction of a large dehydrating plant at Cape Sable is under contemplation and if the plans now being very seriously considered are put through as expected, the plant will have a capacity of dehydrating daily 1,000 bushels of vegetables. The dehydrating process extracts the moisture of vegetables or fruits, and large quantities of either may be reduced to small volume and kept indefinitely in glass or tin. When ready for use, they are put in water and take up the amount originally extracted, at the same time retaining their texture and flavor. In fact, it is similar to evaporated fruits with which all are familiar. Should this plant be constructed, a prodigious quantity of the fruit and vegetable crop will be preserved and carry out the National policy of conservation.

# CAPE SABLE NEW UNDEVELOPED EMPIRE

**Most Southern Point on Mainland of United States is Its Distinction.**

**SETTLED 25 YEARS AGO.**

**Old Inhabitants Enjoy Freedom of Entire Country But Anxious For Appearance of New Faces.**

Lake Worth Herald, April 12, 1918.

Partly to get a rest of a few days and partly to get acquainted with the Cape Sable country of which we had heard so much we forgot all about business the latter part of last week and visited the most southern point on the mainland of the United States.

Upon our return a great many subscribers urged that we tell them of our trip and we decided to make the story general, hence this article. Thursday afternoon at four o'clock the writer accompanied by Mrs. F. L. Hines, of El Paso, Texas, and John Gainer and Geo. D. Stone of this city, left for Miami in Mr. Stone's car. At 7:00 we arrived in the Magic City where we enjoyed supper. Then followed a tour of the city until 9 o'clock when we returned to the station and boarded the Pullman car which is open at that hour but which does not leave until early in the morning.

At five o'clock in the morning we were up and enjoying the ride across the keys which are connected by long spans of cement structures which carry the trains thirty feet above the water. Long Key, which was our railroad destination, was reached at 5:30. We were joined here by D. K. Cartter and A. H. Thomas, Lake Worth; L. H. Bradshaw, Delray; Mr. and Mrs. Pierce and son, Higgins, Texas; Mr. and Mrs. L. Simmons and J. F. Rice of Louisville, Ky. Here is the famous fishing camp operated by the Florida East Coast Railway and which like all of the hotels in which this company is interested, is arranged for comfort as well as sport. The main building contains rest rooms, office, guest rooms and dining room. Surrounding the main building are a score or more of buildings suitable for large or small parties of friends. These are filled all during the fishing season which is now at an end for this year.

After breakfast which was served at 6:30, we went aboard the cruiser Magnet. Soon the start was made and for four hours we enjoyed the most delightful water trip it has ever been our experience to make. In places the water is shallow, being not more than six or seven feet deep. This journey by boat across the Bay of Florida is magnificent. The greater part of the time was spent within sight of several of the larger keys but about the middle of the run there was a period of 30 minutes when we were out of sight of land.

Shortly after twelve o'clock we landed on the East Cape of Cape Sable, the most southern point of main land in the United States. On the right looking towards the water was the Gulf of Mexico while on the left was the Bay of Florida. Dinner was served promptly and soon we were making a trip over the country which is much different from this section of the state and in fact from any other section of the state so far as soil and vegetation is concerned. The land is as level as a prairie and for the most part covered with various kinds of grasses. Here and there are hammocks of buttonwood and wild cotton, stopper wood, cork wood, gumbo limbo, black, red and white mangrove, mastic wood, wild lime and many other varieties. Not all of these are found in the same hammock but in general these are the trees that are found wherever there are trees.

The grasses which make good forage are about as numerous as the trees and they are all native. What the residents call Bermuda but which is unlike the Bermuda of our own section of the state, grows in great quantities. Mules, horses and cows are fond of it. Another is the salt bush. This has about as much water content as cactus, and a taste which is not unlike salted clover and therefore pleasant.

The residents are comparatively few but they have been on the Cape for many years. One of the old settlers is S. L. Roberts, who with his boys settled 20 years ago. They have erected comfortable dwellings and from all accounts find so much to do from one season to the other that they are busy all the time. Sugar cane is the only crop that has been extensively cultivated. Vegetables are grown but not for market. We visited the syrup mill and saw the farmers making the famous Cape Sable product of the cane. Several gallons were purchased for which the price of 60 cents per gallon was paid. We were shown tomatoes, cabbage, peppers, onions and carrots in addition to fruit trees of several varieties, including limes, bananas, mulberry, sapodilla and cocoanut.

In this section the royal palm grows wild as also does the Sable palm which is not found in any other place in Florida or Cuba. It is not more than 20 miles from there to Royal Palm Hammock, which is an estate belonging to the Federated Women's Clubs of Florida. The Cape Sable Highway now under construction will pass this hammock and go on down to East Cape on Cape Sable. It is expected that the Dade county section of the road will be finished early this Fall.

After talking about fishing with the residents it seemed that every fish that inhabits the salt water must at some time of the year visit the water around Cape Sable. So many different varieties were named that it was impossible to remember more than a few. Clams, oysters and crabs are plentiful as well as pompano, mullet, kingfish, mackerel and bluefish. This is also a great place for the well known sand shark. This shark is not the man eater and is so much of a coward that any fish half his size can easily chase him to deep water.

It was while going along the shore in search of the shell grounds that a fish fight was witnessed. For at least a mile along the shore the water was being thrown about and splashed and an enquiry elicited from the skipper, Capt. D. E. Powers, the information that there was a fish fight. The tide which when on the ebb drops four feet was just flowing through the wide and deep channel from the Gulf. Pompano in great numbers were coming in, closely followed by schools of shark in search of a delicate meal of young pompano. However, before the meal was finished several schools of porpoise put in appearance and then followed a red hot fight with the porpoise doing all the fighting and the shark trying hard to get away. The weapon of the purpoise is his nose. His terrific speed and weight are also assets which enable him to effect much damage when he hits or bunts a shark and kills him. Fiteen to twenty-five of these big cowards of the deep from three to five feet in length were thrown up on shore while others were killed in the water. When a porpoise hits a shark in shoal water the shark generally takes the shortest route to the shore and there he stays. Sometimes in his effort to escape death a shark will come towards shore so fast that he lands high and dry.

One of the largest and most wonderful cocoanut groves in the world is located on East Cape. It is the property of the Waddell estate. One hundred thousand trees are said to be growing on the 1180 acres. Some of the trees were planted before the civil war. The nuts are hulled here and the meat shipped by schooner to New York to the manufacturers of shredded cocoanut. The nuts are hulled by hand and the workmen will average a nut every 20 seconds. Those who have tried to hull a cocoanut with an axe and have quit after twenty minutes hard labor will appreciate that these workmen are artists.

Directly north from East Cape is a large body of water called White Water Bay. Forests of mangrove trees grow in this vicinity. Two hundred men are now employed removing the bark from the trees for which they receive 20 cents per hundred weight. Most of this work is done by negroes. The bark is shipped to New York and other points where it is used in the manufacture of leather and dyes.

Around the bodies of fresh water on the cape are millions of birds of rare varieties. These places are known as rookeries. Here the egret, the long white heron and many other varieties of plumage birds as well as game birds are hatched. The laws of the state of Florida are very strict and the penalty for disturbing the birds is heavy.

The soil is a heavy black loam with a bluish colored clay subsoil. There is absolutely no sand and therefore an auto is free to go in any direction. The shore is a mixture of ground shell and coral rock and is used by the residents with cement for building purposes. When wet it has a slick, somewhat soapy feeling which reduces the friction of water and therefore is much used for construction along the water front.

Meals during the visit were served at regular hours in the Club House which is operated by T. J. Powers who with his assistant, A. R. Livingstone, acted as guides in the trips thru the country. The return trip to Long Key, which is 30 miles distant, was started at noon Saturday and as the party was in no hurry to arrive at the key speed was reduced so that all might see the sun set in the Gulf of Mexico. It was a sight of a lifetime. On the day previous the party had the pleasure of seeing the sun rise out of the Atlantic and set in the Gulf. Pullmans were taken that night for home. The trip was fine, and thoroughly enjoyed by all to the extent that at the first opportunity many will go again.

BETWEEN YOU AND US. If you contemplate ever making an investment in the Sunny South NOW is the time to put your DOLLARS where they WILL GROW.

The statements made in the foregoing articles by wholly uninterested, reliable, and competent men should be conclusively convincing that there is a great future for Cape Sable.

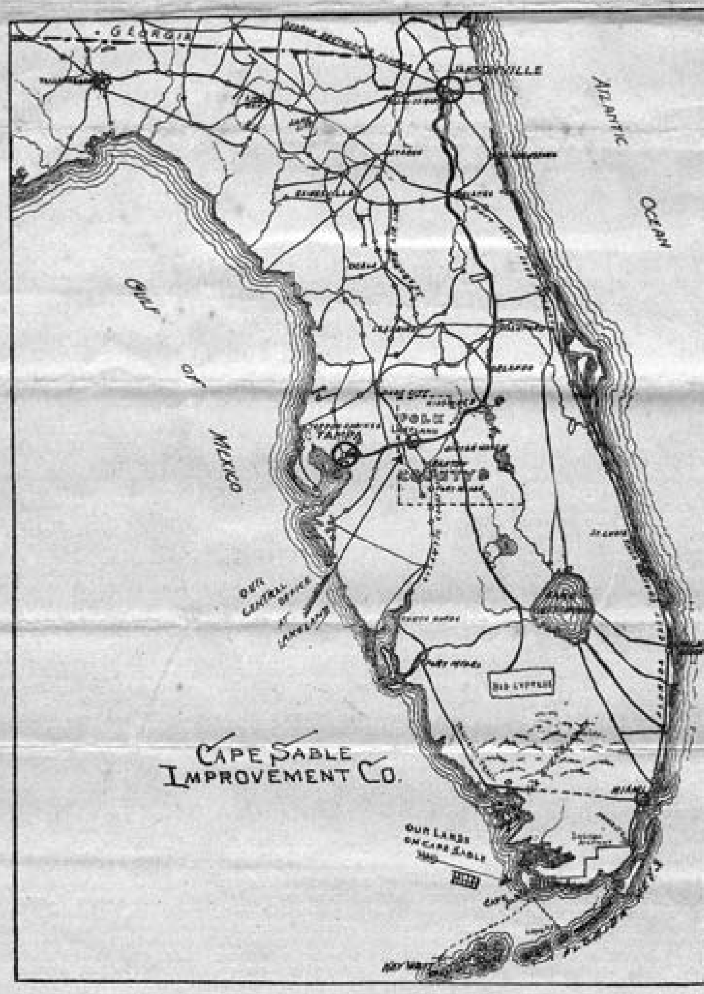
We have nearly 8,000 acres divided in tracts of 10 acres up.

The location is on Florida Bay, and is unsurpassed. The new Highway will run through the entire tract so that none of the land is more than one mile from this main road.

Our object in compiling this "Bulletin" is to to have YOU get personally acquainted with US and our LAND. We are a Florida Corporation and know Florida.

Prices and terms, and how to reach Cape Sable, on request. DON'T DELAY! ASK US NOW.

CAPE SABLE IMPROVEMENT CO.,
Lakeland, Florida.



THE TROPIC MAGAZINE

VOLUME V FEB.-MAR., 1917 NUMBER 5-6

# CAPE SABLE

BY

D. LeBaron Perrine

THE Cape Sable country has always held a peculiar fascination for me over that of all other parts of Florida. It has seemed to me that Florida being good and southern Florida better it must follow that the extreme southermost tip of the peninsula could only be described in the superlative and I felt that having seen all the better part of Florida I was leaving the best until the last. Not that I deliberately postponed my plan to visit the Cape. That would have been an unnatural thing for me to do, for when enjoying a table-de-hote I always want my desert first, and in thinking of Florida years ago my imagination pictured the extreme south of it as the most desirable from a climatic viewpoint. It is probable that had our geographies pictured that region as habitable, my first destination in this state would have been Cape Sable.

I believe that it is this desire of most people for the extremely best in climate that has resulted in the wonderful growth of the cities of South Florida in the few years since it has been proven to be an habitable region, and that it will naturally follow, when the Cape Sable highway is completed and people get to see the country as it really is, that its development will be the most rapid and wonderful of any ever seen in this or any other state.

But let us go back to the beginning of our Cape Sable trip, which happened one Thursday evening when at about ten o'clock I boarded a waiting pullman on the sidetrack at Miami and went to sleep with the moonlight flooding my comfortable berth. Being one of those fortunates to whom sleep is a habit not easily broken, the making up of the train and its departure from the station about two o'clock in the morning hardly disturbed me, and I awoke at the porter's gentle suggestion that Long Key, my first desitination, was only half an hour away. I found the dressing room already occupied and was pleased to find that our Mr. Bright of Miami was on a business trip to Cape Sable at this fortunate time.

I say "our Mr. Bright" advisedly and in Miami, to whom he belongs, the phrase needs no explanation, for the Bright Brother's farm, an immense tract of land located on the edge of the Everglades only a few miles from the city, is one of the points of interest that no worth-while investigator is ever allowed to overlook, for here has been demonstrated as nowhere else in Florida, the practical and peculiar advantages of this region for the raising of pure bred stock as a profitable business proposition. His experiments in forage plant and stock breeding here have been of great value to intending settlers and his farm is as valuable, from a sight-seer's viewpoint, as the Deering or other estates, showing not only how money is spent, but also how money can be made right here in tropic Florida.

We found Mr. J. F. Powers with the launch "Magnet" waiting for us at Long Key and that Mr. Jule M. Burguieres had arrived on our train and was to be a member of our party to visit the Cape.

Mr. Burguieres is an extensive cane planter and sugar mill owner in Louisiana and is looking to South Florida as a field for future operations in this profitable business, recognizing the many advantages it offers over any other section as to climate and fertility, and his visit to the Cape was to satisfy himself as to soil conditions there.

It is Mr. Bright's rule not to break his fast until the mid-day meal, so he did not join us in an excellent breakfast at the famous Long Key fishing camp, but the rest of us fully made up for his neglect of opportunity, and with feelings of great satisfaction boarded the Magnet and were soon on our way across Florida Bay.

The trip across from Long Key to Cape Sable is a delightful little sea voyage (though the water is mostly less than ten feet deep). Navigating the intricate "horseneck shoals", passing Sand Key, where the stolen millions of the pirate Gasparilla are supposed to lie buried, and an occasional glimpse of a sea turtle, shark or other sea monster made the thirty-odd miles seem short indeed.

East Cape with its fringe of cocoanut trees was soon sighted, and the white club house which was to be our destination came into view.

Mr. Samuel Untermyer, the famous New York lawyer and financier, with a party of friends, was reported on the way to Cape Sable in Mr. Untermyer's big houseboat Nirodha; we were all watching to see if it had preceeded us, and were pleased to find that it was safely anchored not far from the shore. The Magnet, drawing but three feet of water, was taken in direct to the club house dock where we landed and made our way to the hospitable club house with its broad verandas facing directly south toward the waters of the Gulf of Mexico.

A unique feature of the club is its separate sleeping rooms built on posts that afford air on all sides. These little houses covered tent-fashion with canvas make wonderfully airy and comfortable apartments.

Soon after our arrival the honking of an automobile horn drew our attention to the prairie and a Ford car came dashing up the trail. Of course, one rather expects to see Fords anywhere, but just having read of William Jennings Bryan and of his presence in Washington on a peace mission, surprise was pardonable I believe, to see him come riding into this camp on the farthest tip of Florida shotgun in hand and surrounded with evidences of his shooting skill. With Mr. Bryan, and who had shared in the sport of duck hunting on Coot Bay, was Mr. Walter R. Comfort of New York. Mrs. Bryan was also with them, but had seemingly devoted her attention to the flora rather than the fauna of this region and her trophies were some fine specimens of cactus and air plants

(Continued on Page 134)

# CAPE SABLE

(Continued from Page 82)

that no doubt will add to the beauty and interest of the charming Villa Serena on Biscayne Bay. Adaptability seems to be the Bryan keynote and no matter where they chance to be, whether in the formal social life of the nation's capital, on the rostrum as speakers before vast audiences, as host and hostess in their beautiful Miami home, or roughing it in the wilderness, they are always refreshingly natural, interesting and interested in their surroundings. Notwithstanding our many "offences" during a recent trip with the great commoner (we always carry a camera) he smilingly consented to pose as a nimrod with Mr. Comfort and the thirty-one duck and coot that were victims of their morning's sport. Mrs. Bryan consented to be included in another picture "not for publication"—objecting to her costume. She need have no fear, however, that the broad straw sombrero was not becoming to her, for one of the party, considered a competent authority, remarked privately to us that "Mrs. Bryan must have been a beautiful girl and was now a charming woman."

Soon after our arrival at the club house we had been served an appetizing luncheon and it had been planned on the return of the hunting party with the necessary Ford that we should make a tour of investigation over the broad prairies that stretch for miles from the club house door. We were all prepared to start as soon as a boat would bring Mr. Samuel Untermeyer, together with other members of the party from the houseboat Nirodha.

With Mr. Untermyer were his brother, Isaac Untermyer (a New York capitalist); Francis E. Baker, presiding judge of U. S. Court of Appeals at Chicago; Minor Whitney, vice-president of the United Fruit Co. of New York; Mr. Walter R. Comfort, a large candy and ice cream manufacturer of New York (who makes sixty-five thousand gallons of ice cream a day and uses four million pounds of sugar a year in his various factories); and Mr. Wm. P. Smith, of the law firm of Shutts, Smith & Bowen, of Miami.

Probably never before in the history of the cape had such a distinguished company of men met here each with his own particular enthusiasm for development projects of great magnitude and along lines in which they were individually famous. Their opinions could not but be valuable. Though familiar with farming and soil conditions since boyhood, I waited with great interest to see if my first impressions of this location and soil would be verified and if these men of proven knowledge would agree that here was an opportunity for the greatest development ever attempted in this state of great achievement.

(To be Continued)

NOTE.—The continuation of this article in our next issue will be illustrated with halftones from photographs taken during the trip, and also a map of the region described, drawn by Mr. Livingston, the civil engineer who accompanied the party.

THE TROPIC MAGAZINE

VOLUME VI APRIL, 1917 NUMBER 1

The Club House Camp at Cape Sable

# CAPE SABLE

BY

D. LeBaron Perrine

(Concluded)

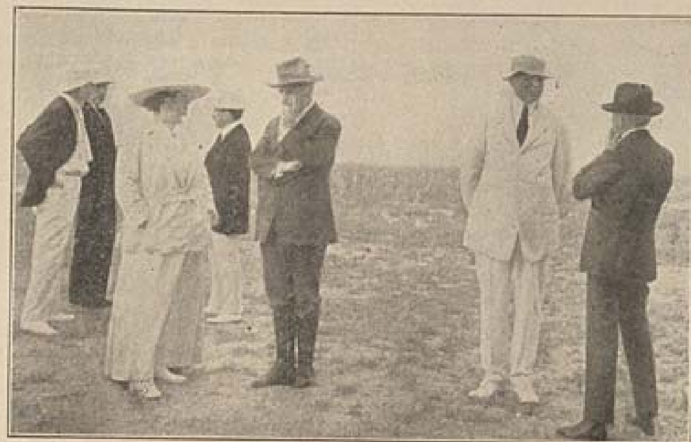
IN my former article I mentioned the Vice President of the United Fruit Company who was one of Mr. Untermyer's guests in his houseboat at at Cape Sable, but an error made his name appear as Minor C. Whitney which should have read, Minor C. Keith. I do not know what Mr. Keith's impressions of the Cape Sable country were, but it would be a fortunate occurrence indeed for South Florida if his interest should be aroused in this region, for Mr. Keith's life has been spent in tropical development projects of great magnitude, and he has stopped at no obstacles that have come his in way. The name of Minor C. Keith is one to conjure with in South America where he is best known. Besides begin "the father of the banana industry" he has achieved distinction as a builder of railroads through fever-infested swamps and almost impassible mountain ranges to reach the rich fruit lands of the interior. The things he has accomplished in South America would make the comparatively simple problems of South Florida development seem easy to a man of such vast resources of indomitable will and purpose as he.

The second day of our visit at the Cape was one of our normal perfect days and we started early in the Ford with Mr. Powers and Mr. Livingston as guides to show us the country northwest of the camp. Both of these men are thoroughly familiar with this region and enthusiastic about its opportunities. Mr. Livingston, who is an expert Civil Engineer, is well posted about it through the work he has done here. Mr. Comfort, Mr. Bright, Mr. Burguieres and myself made up the rest of our party in the Ford, and we bowled along at a good pace over smooth prairies for several miles, taking samples of soil and an occasional picture. We saw acres of Bermuda grass about which Mr. Bright's enthusiasm was aroused to high pitch, and he declared he had never seen anything like it in natural pasture lands, though he had seen nearly all of the best ranges in the United States, Canada and Mexico. Mr. Burguieres, too, seemed to be pretty well satisfied as to the prospects for sugar cane on these lands where a tractor could easily turn furrows for miles of continuous plowing.

As Mr. Comfort and Mr. Burguieres were to join the party on the Nirodha before they sailed we hurried back, and after seeing them safely on the launch Mr. Powers, Mr. Bright and myself made another trip in the Ford to the Roberts cane mill and homestead to see about a cargo of syrup that the Magnet was to carry back to Miami. The Roberts families are the real pioneers here, having lived at the Cape for about eighteen years; their healthy children and apparently happy and prosperous home life, augurs well for the settlers that will surely come when railroads and good highways open the country to them.

**Bermuda and Other Grasses of the Cape Sable Prairies**

Mr. Bright said these were the best grazing lands he had ever seen

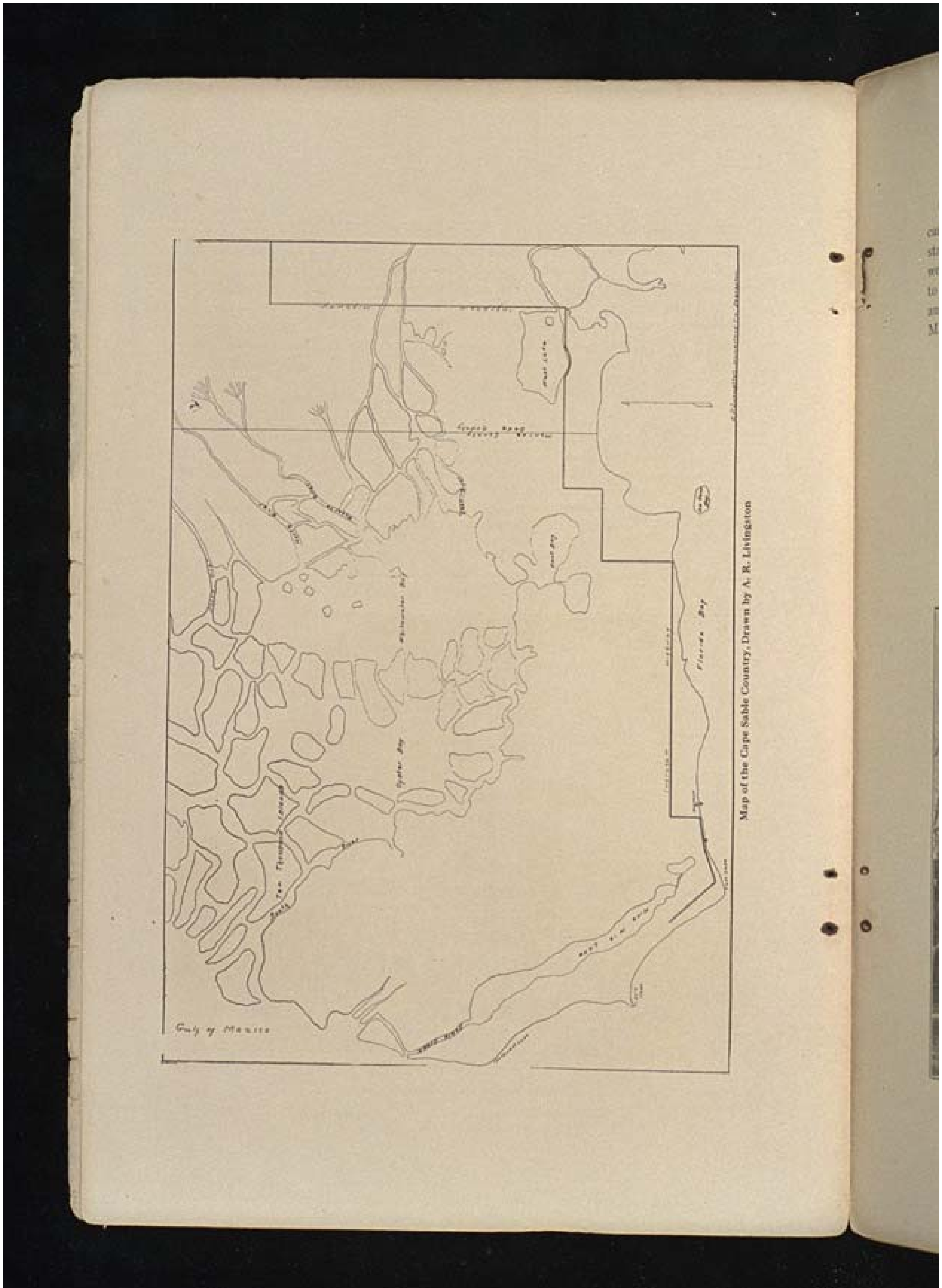


**Some Notable People at Cape Sable**

Mr. Bright, Mr. Untermeyer, Mr. Comfort, Mr. Smith and Mr. Burguiries discussing the wonderful possibilities there

**Sugar Cane at Cape Sable--One of the Roberts Brothers Cane Fields**

Sirup from this cane is made at Cape Sable and finds ready sale at Miami and Key West

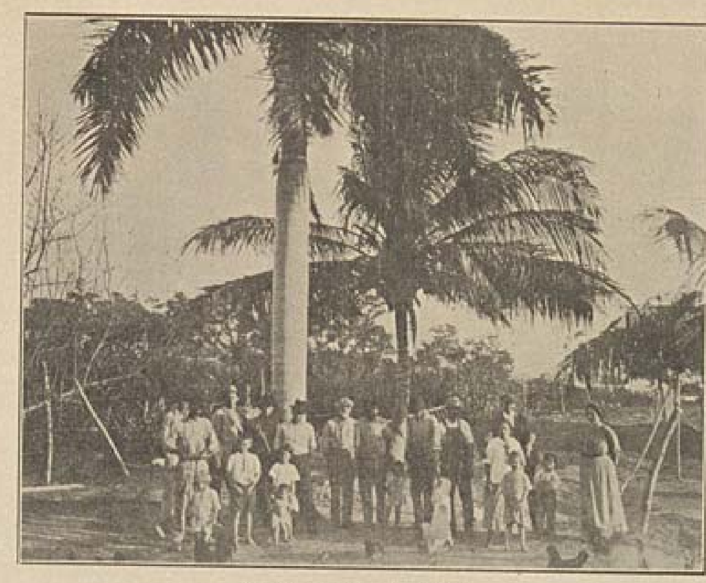



Map of the Cape Sable Country, Drawn by A. R. Livingston

There were delays in getting the cargo of syrup loaded so we did not get started until the next morning and as we missed getting to Long Key in time to take the morning train, Mr. Bright and myself decided to stay with the Magnet on the trip through to Miami.

The incidents that happened on this part of our trip would make a story in themselves, and I wish that space would permit me to tell it, but that must go until another time. I will only add that we reached Miami safely, having spent more time than we anticipated on the way, but having had a voyage that I shall always look back to with pleasure.

NOTE—Since writing the above The Pioneer Plantation Co. has been incorporated to immediately plant three thousand acres of the Cape Sable lands to staple crops in response to the present demand of the nation for the increased production of food supplies. As a financial project, this will no doubt be successful in a large way, and as a response to the need of the nation is an example of what may be done in a country of unlimited agricultural resources.



**The Roberts Family of Cape Sable**

No doctor has ever been needed for this healthy family during the eighteen years they have lived at Cape Sable

Map of the Cape Sable Country. Drawn by A. R. Livingston