Morphodynamics of Mullet Key, West-Central Florida

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Morphodynamics of Mullet Key, West-Central Florida

by

Emeli Sandoval

A thesis submitted in partial fulfillment of the requirements for the degree of
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College of Arts and Sciences
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ABSTRACT

Mullet Key is a right angle barrier island located at the mouth of Tampa Bay, west-central Florida. Based on historical shoreline data from 1873, the Gulf (west)-facing section of the beach has been dynamic illustrating large beach advances and retreats of up to 500 m on a decadal scale, while the south (channel)-facing section of the beach has shown to maintain a stable shoreline. This study focuses on the morphodynamics of the Gulf-facing beach. Since the 1920s, most of the Gulf-facing beach has been accreting except at the southern end near the Tampa Bay main channel. However, over the past 17 years, severe beach erosion has occurred along the northern portion of the island while accretion occurred along the middle portion. The southern end of the island has been maintained through artificial beach nourishments. Analysis of 27 aerial images from 1942 to 2014 revealed that the above large shoreline variations can be explained by the initiation, emergence, landward migrating, shoreline attachment, and post-attachment beach adjustment of the swash-bar complex on the Bunces Pass ebb delta. Two cycles of the swash-bar complex attachments with a period of approximately 30 years were identified from the aerial photos spanning 72 years.

Twenty-eight beach-profiles spanning the 4 km Mullet Key Gulf-facing beach were surveyed 7 times on a bi-monthly basis from March 2014 to February 2015 to quantify the recent rapid changes, and to assess a yearly rate of shoreline change. Beach-profile analyses showed that the 120 m beach at the north-most tip in the immediate vicinity of Bunces Pass has lost a
small amount of sediment. The 360 m beach to the south has gained some sediment. The 670 m stretch of beach further south has had significant shoreline retreat at a rate of 10-15 m/year. The 2,400 m section southward has experienced some gain of sediment, while the 370 m nourished beach at the southernmost tip has had slight retreat. This beach change pattern illustrates a diverging longshore sediment transport. Nearshore wave and current conditions were measured during a cold front passage in December 2014 to quantify the hydrodynamic processes that induced the diverging longshore transport. Three wave and current gauges were deployed along the eroding and accreting sections. The hydrodynamic data reveal that the longshore transport divergence is caused by diverging flood tidal flow into Bunces Pass to the north and Tampa Bay channel to the south. Furthermore, the waves in front the eroding beach were higher than the adjacent accreting beach.
CHAPTER ONE:
INTRODUCTION

About 85% of our nation’s population’s lives near the coast, this makes coastal erosion a major concern for scientists, coastal managers, engineering designs and federal requirements (Boak and Turner, 2005). To accurately determine reasons for why there are coastal recession problems is a complex matter. There are two factors as to why there are shoreline changes, the first being natural influences and the second is human induced influences (Leatherman and Dean, 1991). Natural factors include incoming sand supply through longshore processes, sea level rise, geological evolution, storm frequency and severity, and everyday tides and waves. Human factors include, but are not limited to, nearby dredging, hard and soft engineering such as groins or jetties and beach nourishments (Leatherman and Dean, 1991).

Barrier island morphodynamics is controlled by the relative dominance of wave and tide forcing (Davis and Hayes, 1984; Davis, 2006). Barrier islands can be classified as either wave-dominated or mixed energy. Wave-dominated barrier islands tend to be long and narrow with tidal inlets located far apart at either ends, for example Santa Rosa Island along northwest Florida (Claudino-Sales et al., 2008; 2010). Tidal inlets associated with wave-dominated barrier islands tend to be unstable and migratory. Mixed energy barrier islands tend to illustrate a drumstick shape, for example Fripp Island in South Carolina (Hayes, 1994). The relationship between tide and wave heights depicting coastal morphology is illustrated in Figure 1.
Figure 1: Diagram plotting the relationships between mean annual wave height and tidal range (modified from Davis and Barnard, 2003).

Florida’s west-central coast facing the Gulf of Mexico is comprised of 29 barrier islands and 30 tidal inlets. West-central Florida coast consists of a low wave energy profile and small tidal range regime. The overall morphodynamics of the barrier islands in this region can change considerably with relative dominance of wave and tide forcing, ranging from wave-dominated to mixed energy barrier islands, as illustrated in Figure 1 by the red outlined circle (Davis and Barnard, 2003). Most of the west-central Florida barrier islands are heavily developed with a few remaining mostly pristine beaches. Mullet Key, which is investigated in this study, is located
near the mouth of Tampa Bay and is one of the few relatively pristine barrier islands along this coast.

Over the past 80 years, the Gulf-facing section of Mullet Key has experienced large shoreline variations. This study documents the historical morphology variations of Mullet Key based on time series aerial photographs from 1942 to 2014. Shoreline change was quantified based on historical shoreline surveys from 1873 to 2014 conducted by United States Geological Survey (USGS), National Oceanic Atmospheric Association (NOAA), and this study. Beach-profile surveys and nearshore wave and current measurements were conducted from March 2014 to February 2015 to investigate the processes associated with the beach changes. The overall goal of this study is to understand the complex morphodynamics of a barrier island as controlled by the dynamic interactions of waves and tides near the entrance of a large estuary.

**Literature Review**

Morphology evolution of barrier islands is strongly controlled by the dynamics of nearby inlets. The interactions of wave and tidal driven currents play a dominant role that shape barrier islands. Figure 2 illustrates the detailed terminology that is typically used to describe a barrier-inlet system. The features related with the dynamic barrier-inlet system include a main ebb channel, which happens to be the deepest section between the barrier islands in which ebb currents tend to concentrate in the channel, resulting in an ebb jet (Wang and Beck, 2012). Channel-margin linear bars which are formed from the interaction of the ebb jet and the longshore current are identified next to the main ebb channel, perpendicular to the barrier island coast. The interaction of the ebb jet and longshore sediment transport also lead to the deposition
of an ebb-tidal delta which is the key feature of the barrier-inlet systems. Wave refraction over the ebb delta and the associated reversal of longshore sediment transport is the process that is responsible for the morphology of the mixed energy barrier islands (Davis and Hayes, 1984; Hayes 1980). Swash-bars are built mainly by wave forcing and develop on top of the ebb delta. These bars may be identified on either side of the main ebb channel and they are typically intertidal and can even become emerged.

Figure 2: Model of morphology of ebb-tidal deltas. Arrows represent current direction (from Hayes, 1980).

Flood currents associated with the rising of tides tend to follow a different pattern than that of the ebb jet (Wang and Beck, 2012). A flood current directed towards the inlet is often observed to flow along the barrier beach adjacent to the inlet. These flood currents can be
responsible for beach changes and spit development in the vicinity of the inlet. The longshore flood current entering the inlet sometimes develops marginal flood channels as shown in Figure 2. The seaward end of the ebb delta can sometimes be relatively shallow depending on the inlet dynamics and sediment supply, in which case this feature is described as a terminal lobe. Terminal lobes often serve as a pathway for sediment to move from one (updrift) side of the inlet to the other (downdrift) side.

Hayes (1980), Davis and Barnard (2003), and Davis (2006) further discussed the sedimentary features associated with different types of tidal inlets. Slightly different from barrier island classifications as discussed above, tidal inlets can be classified as wave-dominated, mixed energy straight, mixed energy offset, and tide-dominated. Wave-dominated inlets are small and unstable with relatively high longshore sediment transport rates and generally have small ebb-tidal deltas (Davis, 2006). Tide-dominated inlet characteristics consist of having a stable and deep channel with a large ebb-tidal delta and channel margin linear bars oriented perpendicular to the shoreline resulting from interaction between ebb jet and longshore sediment transport (Hayes, 1980; Davis, 1994; Davis 2006; Wang and Beck, 2012). Unlike tide-dominated inlets, wave-dominated inlets tend to have straight shorelines that, with time, may ultimately close due to a deficiency of tidal prism flow in comparison with longshore sediment transport. Because of this high possibility of inlet closure, typical wave-dominated inlets often need to be supported by hard structures such as groins or jetties if they want to remain open to navigational purposes (Davis and Barnard, 2003). Mixed energy tidal inlets are controlled by a dynamic balancing of tidal forcing and therefore demonstrate morphologies that are in between a wave-dominated inlet and a tide-dominated inlet. Figure 3 illustrates the four types of inlet classifications.
Figure 3: Inlet classification illustrating the four main types. Bunces Pass is classified as tide-dominated (from Davis and Barnard, 2003).

A wave-dominated barrier island is typically associated with wave-dominated inlets. While mixed energy barrier islands can be associated with mixed energy inlets or tide-dominated inlets. Studies from Hayes (1980), Davis and Barnard (2003), and Davis (2006) all adopt the classification scheme in understanding the general morphology and morphodynamics of a barrier-inlet system. These studies demonstrate that wave-dominated barriers have low elevations, and are usually long and narrow with washover fans (Figure 4). Mixed energy barriers tend to be shorter and wider than wave-dominated barriers (Figure 5). They illustrate a drumstick shape with a wide section at one end of the island and a narrow section at the opposite end (Davis, 2006). Both wave-dominated and mixed energy barrier islands can have curved spits and/or dune ridges at the ends of the island. The small water bodies in between the beach/dune ridges are often referred to as catseyes ponds.
Figure 4: A) Overview of Santa Rosa Island located in Santa Rosa County, Florida is a classic example of a wave-dominated barrier island. B) Prominent dune ridges are visible at the western-most end and C) formations of catseye ponds are noticeable at the eastern-most end.
Figure 5: A) Dog Island located in Fanklin County, Florida is an example of a mixed energy drumstick shaped barrier island. B) Pronounced beach/dune ridges are clearly seen at the easternmost tip of the island.
Mullet Key is neither a typical wave-dominated barrier island nor a mixed energy drumstick barrier island. Instead it demonstrates a right angle morphology. Davis (1994) and Davis (2006) describe how right angle barrier islands form from wave-dominated and mixed energy barriers with tide-dominated inlets trapping sediment much like a jetty. Sediment moves through marginal flood channels from flood currents and accumulates on channel margin linear bars by the inlet generating right angle spits (Figure 6). Examples of right angle barrier islands in west-central Florida include North Bunces Key, Anclote Key, and Mullet Key. The formation of Mullet Key and North Bunces Key relate to the tidal forcing at the entrance of Tampa Bay.

![Diagram of Mullet Key and North Bunces Key](image)

Figure 6: Examples of right angle barriers from the central coast of the Florida peninsula (from Davis, 2006).

**Objectives**

This study aims at documenting the morphodynamics of the right angle Mullet Key barrier island based on historical aerial photos, historical shoreline surveys, beach-profile surveys, and nearshore hydrodynamic measurements. Twenty-seven time series aerial
photographs of Mullet Key from 1942 through 2014 were analyzed and compared. Morphological features examined from the aerial photographs include the emerging and migrating swash-bars over the large Bunces Pass ebb-tidal delta, the attachment point of the swash-bar and the subsequent changes of the newly created features. The historical shoreline changes of the Gulf-facing beach were examined based on eight shoreline surveys from 1873 to 2014 using ArcGIS 10.1. The shoreline positions for this study all represent the high water line (HWL) at the time of the survey.

A total of 31 beach-profiles were established along the shoreline of Mullet Key and surveyed 7 times from March 2014 to February 2015 at a bi-monthly basis to capture the short term detailed beach morphology changes. Beach-profile analysis was analyzed and processed using Regional Morphology Analysis Package (RMAP) developed by the Army Corps of Engineers.

In order to link the beach changes to nearshore hydrodynamic conditions, nearshore waves and currents were measured at three locations along the Gulf-facing section of Mullet Key. Wind, waves, and tides along with currents allow researchers to consider reasons for coastal morphology change and to quantify accretion and erosion trends along the shore. The specific objectives of this study are:

1. To document the morphological patterns associated with the emerging, migrating, and shoreline attachment of the swash-bar complex over Bunces Pass ebb delta and to identify potential cycles of the above swash-bar evolution.

2. To quantify the rate of shoreline change over the past 141 years from 1873 to 2014.
3. To examine detailed patterns of beach-profile changes and to quantify changes of contour lines and beach volume.

4. Linking the measured beach changes to the hydrodynamic conditions along the Gulf of Mullet Key.

5. To develop a conceptual model of the morphodynamics of Mullet Key.
CHAPTER TWO:
STUDY AREA

Mullet Key is located in west-central Florida in Pinellas County at the complex entrance to Tampa Bay. The Key itself is a right angle barrier island bounded to the north by Bunces Pass inlet. The south-facing portion of Mullet Key extends along the entrance of the Tampa Bay main channel. Egmont Key is located to the south of Mullet Key and Shell Key is located to the north. Bunces Pass is a tide-dominated inlet with a very large ebb-tidal delta (Figure 7).

Mullet Key is one of the few relatively pristine barrier islands along the west-central Florida coast. Limited artificial structures including a road, several parking lots, and a historical fort complex were built on the island. Mullet Key is part of a Pinellas County Park which is called Fort De Soto Park. Fort De Soto Park is made up of five islands which include Madelaine Key, St. Jean Key, St. Christopher Key, Bonne Fortune Key, and Mullet Key. The whole park itself is about 1,136 acres, making it the largest park in Pinellas County. The Gulf-facing portion of Mullet Key that runs from north to south is about 4 kilometers (2.5 miles) long (Figure 7). Fort De Soto Park is a very popular park bringing in about 2.7 million visitors per year (http://www.pinellascounty.org/park/05_ft_desoto.htm). The beaches at the park constitute a major attraction, therefore understanding the beach processes is crucial to the park.
Figure 7: Aerial image of Shell Key, Bunces Pass, Fort De Soto, Egmont Channel, and Egmont Key.
The overall wave energy along this coast is mild with average breaker heights estimated to be 0.25-0.30 m (Wang and Beck, 2012). The study area is characteristic of a mixed tidal regime. The spring tide is typically diurnal with a range of roughly 0.8 to 1.2 m, whereas the neap tide is semi-diurnal with a range of 0.4 to 0.5 m. Sediments along the west-central Florida coast are bimodal composed of siliciclastic and carbonate fractions. The siliciclastic component is primarily fine quartz sand with a mean grain size of roughly 0.17 mm. The carbonate fraction is mostly shell debris of various sizes. Mean grain size in the study area varies typically from 0.17 mm to 1.00 mm, controlled by the varying amounts of shell debris. The largest grain sizes are found in the channel thalweg where coarse lag deposits are concentrated.

**Geologic History**

Sea level fluctuates on a global scale and has been rising and falling for millions of years. The Gulf of Mexico is believed to have formed in the Jurassic to Cretaceous (Ellis and Dean, 2012). Since the Cretaceous, calcium carbonate has been developing and deposited to build a carbonate platform beneath the Florida we know of today (Berman et al., 2005). This carbonate platform had relatively shallow, warm, and clear tropical waters. Microbes, plants, and animals provided the necessary ingredients to build carbonate sediment. Sedimentary facies associated with carbonate sediment include lagoons, beaches, and tidal flats (Hine, 2013).

In the late Paleogene and early Neogene, Florida’s platform contained widespread dissolution features which resulted from the development of the Tampa Bay basin (Berman et al., 2005). It is because of sea level fluctuation that Florida is shaped the way it is today. Shorelines are snapshots in time of our coasts. Therefore shorelines are what have shaped the surficial
geology of Florida. South Florida was not connected to the contiguous United States in the manner that it is presently. In fact, Southern Florida was separated from North America by a deep-water channel known as the Suwannee Strait. During the Miocene, the Suwannee Straight was filled with sediments from the Appalachian Mountains. Because of this fulfillment Florida’s carbonate coast was thus exposed to siliciclastic sediment through southeastern rivers and streams carrying quartz sand (Davis and Bernard, 2003; Hine, 2013). Siliciclastic sediment accumulation along Florida’s peninsula occurred during the Pleistocene as a result of north to south longshore transport from breaking waves when sea level was higher.

Barrier islands formed during the Late Holocene when sea level rise rates slowed. Sediment deposition produced beach ridges that eventually prograded seaward (Hine, 2013). Barrier island length is characterized by neighboring inlets. Recent studies exemplify that the barrier islands and inlet systems along Florida’s coast are receiving little to no new terrigenous sediment (Davis and Barnard, 2003).

**Meteorological and Oceanographic Conditions**

Florida’s climate has remained relatively stable for the past 3000 years (Davis and Barnard, 2003). Florida’s climate is subtropical with seasonal weather variations. The coast of Florida has predominant southerly winds resulting from the Bermuda High to the east with anticyclonic circulations (Davis and Barnard, 2003). In the spring and summer, the weather conditions are typically calm except for the rare passages of tropical storms and hurricanes. Throughout the fall and winter, frequent (every 10-14 days) passages of cold front often result in prolonged strong northerly wind. The cold front winds generate northerly approaching high
waves, which is the main driver of the regional net southward longshore sediment transport. Hapner and Davis (2004) and Wang et al. (2011) found that a strong El Niño event may influence the winter weather patterns and result in abnormal sediment transport patterns and subsequent morphology changes along the west-central Florida coast.

Storms are a major factor influencing beach morphodynamics (Stone et al., 2004). Overall, storm impacts in the study area were not well documented. Compared to other parts of Florida, the west-central coast is relatively less prone to hurricane impact. Table 1 lists some of the past hurricanes and tropical storms that have significant morphological impact to the Florida Gulf coast (Davis and Barnard, 2003; Stone et al., 2004; Stott and Davis, 2003). For the study area, the hurricane in 1848 had significant impact in that it opened the John’s Pass inlet approximately 15 km north of the study area (Wang and Beck, 2012; Wang et al., 2011). The 1921 hurricane was the last significant storm that had a direct hit of the study area. Several tidal inlets were opened, followed by the corresponding closure of several inlets and significant changes of barrier island morphology (Davis and Barnard, 2003). Hurricane Elena in 1985 was a distal hurricane. However, due to its slow motion offshore of the west-central Florida coast, it generated sustained high waves and induced significant beach changes in the greater study area (Davis and Barnard, 2003). Hurricane Frances in 2004 also induced significant beach changes in the study area (Elko and Wang, 2007). Most recently, Tropical Storm Debby (Cheng and Wang, 2015), although a relatively weak storm, induced significant beach changes along the studied coast due to its large size and slow forward moving speed. No field study was conducted at Mullet Key during the above storms.
Table 1: List of hurricanes and tropical storms that have influenced damage along Florida’s west-central coast. (*) represents highest wind speed recorded. (**) represents highest recorded surge. Data from NOAA National Weather Service and Davis and Barnard, 2003; Stone et al., 2004; Stott and Davis, 2003.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Storm</th>
<th>Category</th>
<th>Wind Speed (mph)*</th>
<th>Surge (m)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1848</td>
<td>9/23 - 9/25</td>
<td>Hurricane- Great Gale</td>
<td>1</td>
<td>135</td>
<td>4.6</td>
</tr>
<tr>
<td>1921</td>
<td>10/20 - 10/30</td>
<td>Hurricane- Tarpon Springs</td>
<td>4</td>
<td>140</td>
<td>2.9</td>
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<td>-</td>
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Morphodynamics of Tidal Inlets Adjacent to Mullet Key

Bunces Pass is an inlet directly north of Mullet Key (Figure 8). Bunces Pass is a natural tide-dominated inlet with no human alteration. The inlet’s main ebb channel has remained relatively stable over the past century and is mostly used for recreational purposes. Recent studies estimate that the spring ebb-tidal prism is about 2.02 x 10⁷ m³ (Wilhoit, 2004). This inlet embodies a large ebb-tidal delta near the mouth of Tampa Bay (Davis, 1994), which constitutes a part of the huge Tampa Bay ebb-tidal delta. Bunces Pass has a maximum depth of 9.3 m extending about 1 km into the Gulf (Wilhoit, 2004). The large ebb-tidal delta contains distinctive channel margin linear bars along both sides of the channel. Numerous swash-bars exist on the extensive ebb delta (Figure 9). Marginal flood channels develop on both sides of the inlet.
Figure 8: Bunces Pass to the north of Mullet Key and an ebb-tidal shoal with visible swash-bars and a marginal flood channel. Photo courtesy of Pinellas County, taken by Dorian Photography.

Figure 9: Swash-bars and marginal flood channel along north Mullet Key. Photo courtesy of Pinellas County, taken by Dorian Photography.
The tidal inlet to the south of the Mulley Key is Egmont Channel, the main entrance channel to Tampa Bay (Figure 10). Tampa Bay is Florida’s largest estuary and its ebb-tidal delta is the second largest sediment body in the Gulf of Mexico (Berman et al., 2005). The channel itself is the largest tide-dominated inlet in Florida with a tidal prism of $6 \times 10^8 \text{ m}^3$ and a maximum depth of about 30 m (Davis and Barnard, 2003; Berman et al., 2005). Current velocities at the channel range from $1.8 \text{ m s}^{-1}$ during ebb tide and $1.1 \text{ m s}^{-1}$ during flood tide (Stott and Davis, 2003). The Egmont Channel is regularly dredged for safety navigation. Recently, the dredged materials have been used to nourish nearby beaches. Furthermore, the large Egmont Shoal, i.e., the ebb-tidal delta of Tampa Bay, is often used as a borrow area for beach nourishment projects in Pinellas County and Manatee County (FDEP, 2008).

Figure 10: The entrance of Tampa Bay.
History of Mullet Key and Fort De Soto Park

Hernando De Soto, a Spanish explorer and conquistador, discovered the Tampa Bay area in 1539. He began his exploration along the west coast of Florida and traveled north through Georgia, Alabama, and eventually Mississippi. De Soto was one of the first explorers who traveled up the Mississippi River (Pinellas County Parks and Preserves). The U.S. Army Corps of Engineers came to inhabit Mullet Key in February of 1849. Their goal was to use the island as a coastal defense site. In March of 1849, Mullet Key and Egmont Key (just south of Mullet Key in the middle of the Tampa Bay Channel) were classified for military use only.

The Spanish American war started in 1898 with Cuba. This conflict initiated the demand for Tampa Bay to acquire military defenses. The fortifications built on Mullet Key and Egmont Key began in 1898. The construction was a result of Henry B. Plant and the Secretary of War (Pinellas County Historic Guide). Clearing of the lands, a wharf, sleeping quarters, railways, and battery sites were all constructed within six months. The fort itself was named after the first explorer Hernando De Soto in April 1900. During this time the fort sustained artillery battery. In 1902 the fort was used as a medical facility and quarantine station to examine the health of immigrants and to inspect incoming foreigners on ships from external ports (Pinellas County Historic Guide).

In 1937 Pinellas County Board of Commissioners bought Mullet Key. Shortly after in 1941, the federal government bought the island as gun and bombing range during World War II. After World War II in 1948, the Pinellas County Board of Commissioners repurchased Mullet Key (Coastal Planning & Engineering, Inc. 2014) and Fort De Soto was officially termed a county park in May of 1963, making it open to the public. Today Ft. De Soto contains many
amenities for the public which include boating ramps, piers, camping sites, paved trails, picnic shelters, concession stands, birdwatching, and most of all many pristine beaches to enjoy. The park hosts approximately 2.7 million visitors per year. Therefore, understanding the complex beach processes along this right angle barrier island and maintaining a health beach environment is essential.

**Shore Protection Measures along Mullet Key**

The southern-most Gulf-facing section of Mullet Key has been nourished three times. The federal government authorized a Beach Erosion Control Study for Mullet Key in 1963. The following year in 1964 an L-shaped groin was constructed on the southern tip of Mullet Key. During this time about 106,000 cubic meters of dredging material from the back barrier bay was used for nourishment (Pinellas County Planning Document, 2014).

In 1973 the federal Beach Erosion Control Project placed 535,000 cubic meters of sand from the Egmont Channel along a 1.8 kilometers (1.1 miles) stretch of the southern beach of Mullet Key. Pinellas County and the U.S. Army Corps of Engineers designed the Fort De Soto Beach Restoration Project in 2006. This project was affiliated with the Beneficial Use of Dredged Material Program and used dredged sediment from the Tampa shipping channel to place a total of 268,000 cubic meters of sand along the southern tip of Gulf-facing section of Mullet Key and also on the south-facing beach along the Tampa Bay entrance channel (Pinellas County Coastal Management Program, 2013).
Various dune restoration projects have been conducted along most of the Gulf-facing beaches. Over the past 15 years, there have been over 70 dune restoration projects with over 700,000 sea oats installed (Wilson, personal communication 2015). Just within the past year in 2014, a total of about 53,905 sea oats have been planted along the northern tip of Mullet Key (Figure 11). The sea oats act to trap wind-blown sand and lead to initiation and growth of dunes. Well established dune fields in turn can protect the barrier island system from storm induced beach/dune erosion and overwash.

Figure 11: Sea oat restoration project at Mullet Key (image from Collins et al., 2014).
CHAPTER THREE:

METHODS

Various field and laboratory methods were used in this study to document the long-term as well as short-term beach changes and to understand the processes that cause these variations. Field methods include topographic surveys using a Real-Time Kinematic Global Positioning System (RTK-GPS) and electronic total system station. Nearshore wave and current measurements were also conducted to link the driving processes to the morphology changes along the Gulf. Historical aerial photos and shoreline surveys were obtained from various sources and analyzed using Geographic Information System.

Geographic Information Systems (GIS 10.1) was used to map and geo-reference 27 historical and recent aerial images that were obtained from the Florida Department of Transportation Aerial Photo Look-Up System (FDOT-APLUS), University of Florida Digital Collections, Google Earth, United States Department of Agriculture (USDA) Geospatial Data Gateway, and from Wilhoit (2004). All the data are projected in State Plane Florida West 0902 for the horizontal coordinate system and North American Vertical Datum of 1988 (NAVD88) for the vertical datum. A few of the images were oblique photos and could not be geo-referenced. The purpose of geo-referencing and analyzing the historical aerial images was to identify the cycle (if any) and the development of the emerging ebb-shoal from Bunces Pass ebb delta and to locate the attachment point related to the shoal.
Historical and recent shorelines were also examined using GIS. Historical shoreline data were collected from the U.S. Geological Survey (USGS) National Assessment of Shoreline Change database. Digital vector shorelines representing the High Water Line (HWL) for four time periods (1873, 1926, 1976, 1998) were obtained. Light detection and ranging (LIDAR) contour data was acquired from the National Oceanic and Atmospheric Administration (NOAA) for three time periods (2004, 2006, 2010). This LIDAR data was originally referred to NAVD88 0 m. The elevations were converted to HWL for comparability to the shoreline data from the USGS. Based on NOAA gauge 8726364 near the study area, NAVD88 +0.094 m equals mean high water (MHW); NAVD88 +0.170 m equals mean higher-high water (MHHW); NAVD88 - 0.370 m equals mean low water (MLW); and NAVD88 -0.464 m equals mean lower-low water (MLLW). The most recent set of shoreline data from 2014 was surveyed using RTK-GPS by this study.

In order to document detailed beach changes, beach-profile transects at 31 locations along the Gulf-facing and Tampa Bay Channel-facing beaches were established by this study. Horizontal and vertical survey control points (i.e., benchmarks) were established in March of 2014 using RTK-GPS. The locations of the beach-profile transects are illustrated in (Figure 12). Transects and beach-profiles were surveyed approximately bi-monthly following standard level-and-transit procedures using a TOPCON GTS-240NW series electronic total survey station and a 4 m prism rod. A total of 7 surveys were conducted along the 31 transects from March 2014 to February 2015 to capture the short term nearshore beach processes.
Figure 12: Thirty one beach-profile transects along Mullet Key.

The beach-profile processes, shoreline and volume change analyses were conducted using Regional Morphology Analysis Package (RMAP) developed by the Army Corps of Engineers. In the following, 28 Gulf-facing beach-profiles of the total 31 profiles surveyed are analyzed in detail. Little to no change occurred at the three profile locations along the south-facing beach. The Gulf-facing beach is divided into four sections. The first section from profile
lines FD1 through FD8, located at the northern tip of Mullet Key, represents an accretional area. The second section from FD9 through FD19, located at the northern middle portion of the island represents an erosional hotspot area. The third middle section from FD20 though FD26 represents an area were the beach is relatively stable to accretionary, while the fourth section from FD27 through FD28 at the southernmost tip is a slightly erosional area. Figure 13 demonstrates the four study area sections. The beach-profiles typically extend from the dune field seaward to the relative flat portion of ebb delta, which is generally about 100 m from the shoreline. Shoreline movements for each of the profiles were conducted at the mean sea level shoreline representing 0 m NAVD88. Volume calculations were conducted for shoreline position above 0 m and till the end of the surveyed profile.

Hydrodynamic data, specifically tidal water level variations, waves, and currents, were collected by using three SonTek Triton-ADV gauges that were deployed on the Gulf-facing section of Mullet Key. Tidal current velocity and direction were measured during a spring-neap tidal cycle to understand the processes that drive the rapid beach changes. The northernmost triton was deployed on profile line FD5 about 25 m from the shoreline at an approximate water depth of about 1 m. The middle triton was deployed on profile line FD14 about 35 m from the shoreline at a depth of 1.5 m. The southernmost triton was deployed on profile line FD22 about 40 m from shoreline at a depth of about 1 m. The gauges were set to measure the nearshore wave and current conditions for 15 days during a passage of a cold front in December 2014 through January 2015. The red stars on figure 13 demonstrate the location of each triton. Beach-profiles were surveyed before and after the cold front and gauge deployment on December 19, 2014 and January 3, 2015 respectively Wind data was acquired from a nearby NOAA gauge 8726412 during the instrument deployment.
Survey of the Coast originated in the U.S. in the mid-1800s. By the late 1800s, topographic sheets, also known as T-sheets, were the conventional method for coastal mapping until aerial photography became the preferred method for coastal mapping. These methods however were not the best in identifying the shoreline. Aerial imagery at the time contained much distortion making it difficult to accurately identify coastal features. Mapping shoreline positions has been increasingly more accurate over the recent years with the use of laser ranging,
computers and GIS software. Today, LIDAR is used with GPS to create 2D and 3D topographic maps. This technology allows users to have a much better accuracy of mapping in general.

The HWL is a common proxy used in detecting the shoreline position by researchers and government agencies because it is visible in the field at the time of survey and it can be detected in aerial images (Leatherman, 2003). Other proxies that are of use include but are not limited to the vegetation line, dune line, bluff top, beach scarps, and dune crest (Leatherman, 2003). The HWL is defined as the wet/dry line seaward of the berm crest (Leatherman, 2003). Although most use the HWL as the typical shoreline indicator, controversy sometimes exists because there are many errors that can influence the precise location of the shoreline. One should always note that this feature is a snapshot in time; it may be significantly influenced by short-term daily to seasonal variations. Inaccuracies from aerial image mapping can include human error from manual shoreline interpretation, digitizing and image distortion, and surveying faults. Natural influences that impact accurate shoreline detection are seasonal changes, storm impacts, and even short-term variables such as water level height in association to wave and tidal variations (Leatherman, 2003; Pajak and Leatherman, 2002; Morton and Speed, 1998).
CHAPTER FOUR:

RESULTS

Historical Morphodynamics of Mullet Key

Twenty-seven historical aerial photos were examined to document the morphology variations of Mullet Key, particularly at the northern tip, Bunces Pass, and its ebb-tidal delta. The earliest photo was taken in 1942. The focus of this portion of the study is to identify the swash-bar complex development, emerging, onshore migration, attachment, and post-attachment shoreline evolution. It is worth noting that the identification of the morphological features from aerial photos is influenced by the photo quality and the tidal and wave conditions when the photo was taken. Therefore, the following analysis is somewhat subjective and qualitative.

The submergent sand-body, i.e., a large swash-bar complex, can be identified on the 1942 aerial photo (Figure 14). The swash-bar complex was oriented roughly northwest to southeast, with the southwest end at about 300 m from the shoreline. An emerging sand bar can be observed on the north side of Bunces Pass as well, which eventually evolves into North Bunces Key and later on into Shell Key. No significant artificial development can be observed from the 1942 aerial photo. Beach and dune ridges can be identified over the entire island. By 1945, the swash-bar complex (south of Bunces Pass) had become much wider and longer (Figure 15). No vegetation can be identified on the swash-bar complex suggesting that it is intertidal. The
The southwest tip of the swash-bar was still about 300 m from the shoreline. A patch of sea grass can be observed in between the intertidal swash-bar complex and the channel margin linear bar, indicating that the water there was shallow and calm. The island remained mostly pristine by 1945.

The swash-bar complex in 1951 grew significantly, and evolved to a crescent shape from its early linear shape in 1945 (Figure 16). Hurricane Easy, in 1950 was a category 3 hurricane that made its route through the Gulf and was within 50 nautical miles of Mullet Key. However, it was not documented as to whether or not Hurricane Easy had significance to the growth and migration of the swash-bar complex. The southwest end of the swash-bar complex had migrated onshore significantly and was about 100 m from the shoreline. No vegetation was identified over the swash-bars indicating that they were still mostly intertidal. Most of the patch of sea grass was covered by the migrating sand. The very northern end of the Mullet Key had gained a large amount of sand resulting in a wide beach there. The channel margin linear bar had also grown substantially along both sides of the channel (Figure 16). In addition, the sand-bodies north of Bunces Pass had also grown significantly and started to take a shape of a barrier island resembling present Shell Key. It is apparent that during the six years from 1945 to 1951, a large amount of sand over the Bunces Pass ebb delta had migrated landward and shoaled. The causes of this significant shoaling of ebb delta sand bodies are not exactly clear. Several potential contributions include 1) reduction of tidal prism of Bunces Pass due to human activities such as dredging of the main Tampa Bay channel and causeway constructions in the back-barrier bay; and 2) impact of a significant tropical storm or hurricane (Hurricane Easy). It is beyond the scope of this study to examine the detailed processes that drive swash-bar migration.
The crescent swash-bar complex had attached to the shoreline by 1957 (Figure 17). Vegetation was observed over the southern portion of the attached crescent bar indicating that the sand body had become emerged. A large catseye pond was formed between the attached crescent bar and Mullet Key. Most of Mullet Key still remained pristine. Dense vegetation had developed over the accreted beach since 1951 over the very northern end of Mullet Key. By 1962, significant human development occurred on Mullet Key, including construction of parking lots (or cleared land) at the northern end of the island (Figure 18). A large portion of the catseye pond was filled in. It is not clear if the infilling of the catseye pond was through natural storm overwash or by humans. The parking lots were landward of the catseye pond seen on the 1962 aerial. The beach south of the attachment zone had gained a substantial amount of sand indicating a southward longshore sand transport.

By 1970, the cycle of swash-bar emergence and attachment seemed to have been completed (Figure 19). This cycle included the initial swash-bar growth in the early 1940s, landward migration in the 1950s, and attachment at the shoreline in the late 1950s, and post attachment beach adjustment in the 1960s. This entire cycle lasted roughly 30 years. It is worth noting that during this cycle, significant human activities including causeway constructions, dredge and fill projects in the back-barrier bay, Tampa Bay channel dredging, road and parking lot construction on Mullet Key all occurred. In the 1970 aerial image, the post adjustment of the shoreline includes no swash-bar near the vicinity of Bunces Pass and a visible catseye pond by the attachment point. There are also growing beach ridges just south of the parking lot indicating beach growth by longshore sediment transport.
Figure 14: Image of Bunces Pass in 1942

Figure 15: Image of Bunces Pass in 1945 with a growing linear swash-bar complex.
Figure 16: A) Image of Bunces Pass in 1951 with a crescent swash-bar complex. B) Overview image of Mullet Key.

Figure 17: A) Image of Bunces Pass in 1957. B) Overview image of Mullet Key showing the attachment point.
Figure 18: Image of Mullet Key in 1962 with noticeable catseye pond.

Figure 19: Image of Mullet Key in 1970. Completed 30-year swash-bar complex emergence.
By 1973 there was an initial emergence of a linear northwest to southeast oriented swash-bar by Bunces Pass that was roughly 625 m in length and about 125 m in width (Figure 20). It is worthy to note here, that this trend also occurred in 1945 (31 years earlier) during the previous cycle. The southern tip of the bar was about 400 m away from the shoreline. Marginal flood channels are evident at the northern tip. Spit growth can be observed at the shoreline in the vicinity of Bunces Pass when compared to the 1970 aerial image. Recall that in 1973 the federal Beach Erosion Control Project placed 535,000 m$^3$ of sand along 1.8 kilometers of beach (sections 2 – 4) on the Gulf-facing portion of Mullet Key (approximately profile lines FD19 – FD27).

The linear swash-bar had grown by 1976 and was approximately 1,250 m in length and 200 m in width (Figure 21). It is also apparent that the swash-bar had migrated landward and was 250 m from the shoreline at the closest point, representing an approximate landward migration rate of 40 – 50 m/yr. Channel margin linear bars have expanded and grown considerably seaward since 1973 by Bunces Pass. The shoreline morphology at the northernmost tip of the island has changed shape, retreated and become more angular. Downdrift, the overall dry beach has accreted on the Gulf side as well as on the south-facing beach in the channel. By 1980, the channel margin linear bar had become connected to the swash-bar complex (Figure 22). The shape of the combined swash-bar complex changed significantly into a crescent shape and grew more towards the south. The bar was roughly 1,350 m long, 90 m wide at the north end, and 135 m wide at the south end at the time. The development and migration of this swash-bar is different from the earlier cycle swash-bar in 1951. It migrated closer to the shoreline further downdrift to the south. The south end of the bar was 250 m away from the shoreline. At the northernmost tip of Mullet Key, there was substantial shoreline retreat by Bunces Pass.
The crescent swash-bar complex had become considerably wider by 1984 (Figure 23). The southern tip of the bar was roughly 80 – 100 m from the shoreline, indicating a landward migration rate of approximately 40 – 50 m/yr towards the shoreline, similar to the rate observed during the earlier cycle. Vegetation growth is visible on the migrating swash-bar, indicating that the bar had become emerged. The northern tip of Mullet Key still remained at an erosive state; while the downdrift coast (sections 2 – 4) continued to accrete seaward. The morphology in this prograding stretch of beach contains visible beach/dune ridge growth. By 1986 (Figure 24), 13 years after the initial development of the swash-bar complex, the crescent swash-bar complex had attached to the shoreline. Compared to the earlier attachment cycle in 1957, with the attachment point at section 2, this attachment point was in section 3 (sections illustrated in figure 13) much further south due to a much bigger crescent bar complex. Vegetation was still observed over the swash-bar. An apparent observation to note on the attached swash-bar is a small inlet that was breached within the crescent bar. A possible mechanism for this breaching could be related to the distal passage of Hurricane Elena in 1985. However it is worthy to note again, that hurricane influences on the Mullet Key shoreline processes have not been well documented in the existing literature. A very large catseye pond formed from the crescent bar attachment at the northern tip. A large sand body complex (channel margin linear bars) seemed to be quite dynamic at the time and added a large amount of sediment to the north tip of Mullet Key. Dry beach gain at the attachment point was about 370 m from the Anderson Blvd.

By 1991 the complex swash-bar attachment had adjusted. The inlet breach noted in the 1986 image had become wider separating the bar complex into two, a north bar complex and a south bar complex (Figure 25). This breach allows tidal processes in the catseye pond. There was heavy vegetation at the north bar complex, indicating an emergent sand body. It can be noted that
the strong ebb flow through Bunces Pass had shaped the north point of this complex into a right angle. Flood channels were apparent at the northernmost tip of Mullet Key, which once again underwent retreatment. The south bar complex had become more vegetated but thinner than in 1986. The post-attachment adjustment continued and by 1993 (Figure 26) the inlet breach had closed by a possible storm as indicated by an overwash fan there. A new 125 m wide inlet was breached and occurred in the north bar complex from 1991. In the 1993 aerial, the south bar complex had migrated closer to the shoreline of Mullet Key, therefore filling in the catseye pond. Beach ridges were notable at the attachment point.

By 1995 the inlet at the north became wider (about 240 m wide) (Figure 27). The catseye pond remained in the same shape as in the 1993 aerial photo. At this point, the only tidal influences at the catseye pond are from an opening at the north end by the first catseye pond from 1962. Significant dry beach accretion is apparent in sections 2 – 3. By 1997, section 3 of Mullet Key had substantial dry beach gain (Figure 28). The inlet by the north swash-bar complex and the south swash-bar complex had closed. At this point the swash-bar was approximately 2,250 m long. There were still tidal influences on the catseye pond from Bunces Pass, coming in from the marginal flood channel. Sea grass can be detected in the catseye pond, indicating shallow calm waters.

A narrow inlet was breached, and can be observed in 1998 (Figure 29). The northern sand body complex began to infill with overwash sediment, making a connection to the north tip of Mullet Key. Marginal flood channels were visible between the overwash and the Mullet Key shoreline. The south bar complex closed in on the catseye pond, but remained tidally influenced from the newly opened narrow inlet. The catseye pond was roughly 200 m in width and 900 m
long. By 2002 the narrow inlet had migrated slightly downdrift (Figure 30). Beach ridges continued to grow along section 3 making this section of the dry beach relatively stable. No offshore swash-bars are apparent from this aerial photo. In 2004 the catseye pond was moderately smaller, but maintained the same shape as in 2002 (Figure 31). The shoreline along the north tip of the catseye pond retreated slightly. This movement is comparable to the 2002 aerial photo. Channel margin linear bars are evident on both sides of Bunces Pass, with no emergent swash-bars.

By 2005, the north sand-body complex (swash-bar complex) was attached to the northernmost tip of Mullet Key (section 1) (Figure 32). The large catseyes pond had enclosed to the north, making the length of the pond about 625 m and the width about 175 m. More dune ridges are visible in section 3 (sea oat planting project). It is determined here that the cycle of swash-bar emergence and attachment started in 1973, and was completed by 2005. Therefore, this cycle included the initial swash-bar growth in the early 1970s, the landward migration in the late 1970s, the attachment at the shoreline in the late 1980s, and post attachment beach adjustment in the early 1990s. This entire cycle lasted approximately 30 years, similar to the previous cycle.

In 2006, Pinellas County and the U.S. Army Corps of Engineers designed the Fort De Soto Beach Restoration Project. This project placed a total of 268,000 m³ of sand along the southern tip of the Gulf-facing section of Mullet Key (FD25 – FD27) and also on the south-facing beach along the Tampa Bay entrance channel. The beach gain resulted from the nourishment project can be observed in section 4 of Mullet Key in the 2008 photo (Figure 33).
The channel margin linear bars by Bunces Pass grew more during this time, while the shoreline at the northernmost tip of Mullet Key retreats slightly in section 1.

Figure 20: Image of Mullet Key in 1973. With outlined nourishment. Arrow pointing to marginal flood channel and spit growth.


Figure 23: Image of Mullet Key in 1984 with crescent swash-bar complex migrating.
Figure 24: Image of Mullet Key in 1986 with newly formed inlet breach and attachment point of bar complex.

Figure 25: Image of Mullet Key in 1991 with catseye pond formation.
Figure 26: Image of Mullet Key in 1993, post adjustment.

Figure 27: Image of Mullet Key in 1995, post adjustment.
Figure 28: Image of Mullet Key in 1997.

Figure 29: Image of Mullet Key in 1998 with a new breach.
Figure 30: Image of Mullet Key in 2002.

Figure 31: Image of Mullet Key in 2004.
No linear swash-bar complex, as that seen on the 1945 and 1973 photos, can be identified on the 2010 photo (Figure 34). The swash-bars on the ebb-tidal delta are mostly disorganized. The northernmost tip of Mullet Key experiences shoreline retreat in sections 1 and 2. By 2013 a linear swash-bar complex, similar to that observed on the 1945 and 1973 photos, developed on the Bunces Pass ebb delta at the similar place as the previous cycles (Figure 35). Sections 3 and 4 remained stable with a wide dry beach with heavy vegetation over the numerous beach/dune ridges. A northwest to southeast oriented linear and emergent swash-bar complex with sparse vegetation was apparent in 2014 (Figure 36). The 2014 linear swash-bar complex was longer and wider than that in 2013. This is the third cycle of swash-bar development that resembles similar characteristics, with similar temporal and spatial scales, as the linear swash-bars noted in
previous aerial photos. From the 2014 aerial photo, shoreline retreat is visible in sections 1 and 2. Downdrift in sections 3 and 4 the shoreline remains relatively stable to accretionary.

Figure 33: Image of Mullet Key in 2008 with outlined section of nourishment project from 2006.

Figure 34: Image of Mullet Key in 2010 with submergent swash-bars.
Figure 35: Image of Mullet Key in 2013.

Figure 36: Image of Mullet Key in 2014 with a growing linear swash-bar complex.
In summary, two complete cycles of swash-bar complex initiation, growth, landward migration, shoreline attachment, and subsequent post-attachment adjustment can be identified from aerial photos from 1942 to present. Furthermore, the third cycle seems to have started in 2010. All the cycles bare substantial similarities in both temporal and spatial scales. A conceptual model illustrating the swash zone complex development, migration, and attachment is developed by this study and is discussed in the next Chapter.

**Historical Shoreline Change**

The swash-bar cycle depicted from historical aerial photos as discussed above is mostly qualitative. In order to examine the shoreline trend more quantitatively, eight shoreline surveys, including those of 1873, 1926, 1976, 1998, 2004, 2006, 2010, and 2014, along the Gulf-facing side of Mullet Key are analyzed (Figure 37). The cycles of swash-bar complex attachment and subsequent shoreline adjustment constitute the main controlling factor for the large variations of shoreline position, on orders of 500 m over decades. It is worth noting that the survey accuracy may vary over the years, and should have a general improving trend toward present. However, the large changes observed and discussed in the following should not be caused by survey uncertainties.

Substantial landward retreat of shoreline (represented by the location of mean high water) was measured from 1873 to 1926 along almost the entire Gulf-facing portion of Mullet Key. This is likely related to the erosion of an attached crescent shaped bar before the examined swash-bar formation cycle presented in this study. Seaward shoreline propagation was measured between 1926 and 1976 along the northern and middle portions of the island, resulting from the swash-bar
attachment in the late 1950s to early 1970s, as discussed previously (Figure 17 – Figure 19). Due to the long time interval between the two surveys, the shoreline change may be caused by more than one cycle. Seaward shoreline propagation on the order of 500 m was measured between 1976 and 1998 along nearly the entire Gulf beach. This is the result of the huge swash-bar complex attachment that occurred in the late 1980s. Based on the discussion above, the shoreline gain over this 20-year period was largely driven by one event of a swash-bar complex attachment, instead of gradual beach accretion. Therefore, an annualized rate of shoreline gain of, e.g., 25 m/yr, during this period can be very misleading and not correct. From 1998 to 2014, most of the northern and middle portion of the Gulf-facing beach experienced shoreline retreat. This trend continued till present. This represents the beach adjustment post swash-bar complex attachment that occurred in the late 1990s and early 2000s (Figure 28 – Figure 32). In the following section, the shoreline changes are examined in detail and at each location of the beach-profile surveyed by this study. The four sections illustrated in Figure 13 are used in the following discussion.

The first section of Mullet Key along the very northern tip from profile lines FD1 to FD3 (Figure 38), landward shoreline retreat was measured between 1873 and 1926, and further till 1976. A large seaward shoreline advance was measured between 1976 and 1998 corresponding to the swash-bar attachment observed in 1986 (Figure 22). After 1998, this section of beach has remained mostly stable to slight accretionary. Beach-profiles FD4 through FD8, show similar trends of change from 1873 to 1976, i.e., shoreline retreat. Also, a large shoreline advance was measured between 1976 and 1998 for profile lines FD4 through FD8 in response to the swash-bar attachment in 1986. After 1998, this section of the beach behaved differently as compared to the very northern end. Persistent erosion, instead of a stable to accretionary beach processes, was
measured. The rate of erosion appears to be rather constant over the 16-year period, at approximately 11 m/yr. This also represents the rate of erosion that is experienced presently.

Along the northern portion of the second section of Mullet Key from profile lines FD9 through FD19, shoreline retreat occurred between 1873 and 1926 (Figure 39 and Figure 40). Different from section 1 as discussed above, shoreline advance was measured between 1926 and 1976. This corresponds to the swash-bar attachment and adjustment that occurred in the late 1950s to early 1970s (Figure 17 – Figure 21). Shoreline advance was measured between 1976 and 1998, corresponding to the swash-bar attachment in 1986. After 1998, this section of the beach also experienced persistent erosion. The rate of erosion also appears to be rather constant over the 16-year period, at approximately 13 m/yr.

Along the southern portion of the second section from profile FD15 through FD19 (Figure 40), shoreline retreat occurred between 1873 and 1926. Similar to the section (FD9 – FD14) further north as discussed above, shoreline advance was measured between 1926 and 1976, corresponding to the swash-bar attachment from 1957. Shoreline advance was measured between 1976 and 1998, corresponding to the swash-bar attachment from 1986. From 2004 to 2010, the shoreline remained relatively stable. FD19 behaved differently as compared to the other locations. This is because this profile is located at the vicinity of a small inlet. The inlet migrated during this period of time (Figure 29 and Figure 32) and opened and closed a few times. The shoreline retreat rate increased significantly recently from 2010 to 2014, a retreat rate of nearly 17 m/yr was measured.

Between 1873 and 1926, the third section of Mullet Key from profile lines FD20 through FD24 shoreline retreat was apparent (Figure 41). Different from the first and second sections as
discussed above, this third section of Mullet Key had significant shoreline retreat of up to 700 m. The shoreline remained stable for lines FD20 and FD21 from 1926 to 1976. There is a significant shoreline advance from 1926 to 1976 for FD22 and FD23. This shoreline advance could be part of the nourishment that took place in 1973 along this section of Mullet Key. Shoreline advance was measured between 1976 and 1998 for all lines (FD20 – FD24). This corresponds to the swash-bar attachment in 1986. From 1998 to 2006, this section of the shoreline remained stable. Slight shoreline retreat occurred for profile lines FD20 and FD21 from 2010 to 2014. A rate of erosion of approximately 10 m/yr was measured for this recent 4-year period. This could be related to the fact that the two lines are located at the vicinity of the inlet by the catseye pond. FD22 – FD24 remained stable through these years.

The fourth section of Mullet Key from profile lines FD25 through FD28 show the same trend in shoreline retreat from 1873 to 1926 (Figure 42). Profile lines FD25 and FD26 both show shoreline advance from 1926 to 1976. It is worthy to note that this advance is not influenced by the swash-bar attachment in 1957. This section of the beach is too far downdrift to have been affected by the attachment. FD25 though FD27 all show shoreline retreat from 1976 to 2006. Recall that in 1963 an L-shaped groin was placed at this vicinity. FD27 and FD28 remained stable until 1998. In 2006 this section of the beach was nourished and can be noticed from the 2006 to 2010 shoreline advance in lines FD25 to FD27. All of the lines, except for FD25 began to erode from 2010 to 2014, at a rate of 7 m/yr.

In summary, the historical shoreline analysis further demonstrates the cycles of change associated with the morphodynamics of the swash-bar complex. Specifically, the shoreline analyses illustrates that the post-attachment shoreline adjustment is mostly landward retreat, and
furthermore, at approximately 10 m/yr. As discussed in the following section, similar shoreline retreat rate, although with some alongshore variations, was measured based on time-series beach-profile survey from March 2014 to February 2015, indicating that presently the system is still in the post-attachment beach adjustment phase. It is worth noting that 10 m/yr is a very fast rate of beach change as compared to a typical beach behavior along west-central Florida coast which ranges from 1 – 10 m/yr (Roberts and Wang, 2012).

Figure 37: Mullet Key shoreline change from 1873 to 2014.
Figure 38: Mullet Key shoreline change from 1873 to 2014 for FD1 – FD8.

Figure 39: Mullet Key shoreline change from 1873 to 2014 for FD9 – FD14.
Figure 40: Mullet Key shoreline change from 1873 to 2014 for FD15 – FD19.

Figure 41: Mullet Key shoreline change from 1873 to 2014 for FD20 – FD24.
Figure 42: Mullet Key shoreline change from 1873 to 2014 for FD25 – FD28.

**Beach-Profile Changes**

A total of 31 beach-profiles were surveyed seven times, roughly bi-monthly, from March 2014 to February 2015. The beach-profile data are analyzed here to examine the detailed morphologic pattern of beach changes along the Gulf and to verify if the longer term erosion rate as identified above continues presently. In addition, the surveyed beach-profiles allow us to investigate where the eroded beach sand is reworked and deposited, i.e., if the sand was moved offshore or along the beach. Since all of the beach-profiles extend seaward onto the large Tampa Bay ebb-tidal delta complex, the commonly used depth of closure for the greater study area (Wang and Davis, 1999) does not directly apply. The morphology of the beach-profiles varied substantially along the Gulf-facing Mullet Key. Figure 43 demonstrates the locations and
approximate lengths of each of the surveyed profiles. In the following, the characteristics of the
beach-profiles, illustrating the nearshore bathymetry, are discussed.

Profile FD1 extends northward directly into Bunces Pass (Figure 44). It illustrates a plane
slope dipping in to the relatively deep channel. Profiles FD2 and FD3 extend across the bend of
the shoreline at Bunces Pass entrance (Figure 45 and Figure 46). A fairly wide sub-aerial beach
of up to 90 m extends along these lines. The elevation of the sub-aerial beach is quite low,
mostly around 0.5 m NAVD88. This makes the beach subjective to flooding by storm surges and
storm wave runup. The profiles illustrate a steep foreshore dipping onto the ebb delta platform at
water depth of roughly 1.5-2 m. Profile FD2 showed nearly 10 m of shoreline retreat while the
nearby FD3 showed similar amount of shoreline advance, indicating dynamic shoreline changes
directly at the inlet entrance. FD4 also extends across the wide and low sub-aerial beach with a
steep foreshore (Figure 47). A small channel occurs at the toe of the foreshore, likely scoured by
flood tidal flow through the marginal flood channel. The beach at this location gained
persistently, of approximately 25 m, during the 11-month study period. FD5 extends across the
extensive and shallow Bunces Pass ebb-tidal delta platform, eventually connecting with the
channel margin linear bar (Figure 48). FD5 also showed shoreline advance over the 11 months
study period. It should be noted that this profile was used as one of the wave-current gauge
deployment (discussed in the next Chapter) lines. The general trend of shoreline advance
measured along these profiles at the very northern tip agrees in general with the trend observed
from the historical shoreline data.
Figure 43: Locations and lengths of 29 of the 31 survey profiles.
Figure 44: Profile FD1 located in section 1, directly by Bunces Pass.

Figure 45: Profile FD2 located in section 1.
Figure 46: Profile FD3 located in section 1.

Figure 47: Profile FD4 located in section 1.
Profiles FD6, FD7, FD8, FD9, and FD10 extend across a section of the island that is frequently overwashed by storms. The most recent overwash event occurred in June 2012 during the passage of Tropical Storm Debby. The overwash platform (or lobe) is the widest, of nearly 150 m, at FD6, with an elevation of approximately 0.5 m NAVD88, which is lower than the active berm at about 0.7 m NAVD88. The foreshore slope is gentler as compared to the profiles to the north. This section of profiles extends seaward onto the flat Bunces Pass ebb-tidal delta with a water depth of 1.5 – 2.0 m. No nearshore bar features exist within 100 m from the shoreline. Trend of shoreline retreat was measured at all the five locations, consistent with that observed from the long-term shoreline data.
Figure 49: Profile FD6 located in section 1, extends along overwash platform of Mullet Key.

Figure 50: Profile FD7 located in section 1, extends along overwash platform of Mullet Key.
Figure 51: Profile FD8 located in section 1, extends along overwash platform of Mullet Key.

Figure 52: Profile FD9 located in section 2, extends along overwash platform of Mullet Key.
Profiles FD11, FD12, FD13, and FD14 (Figure 54 through Figure 60) are experiencing severe beach erosion presently, i.e., the present erosional hot spot. The dense vegetation presently at the shoreline may have slowed the rate of erosion as compared to a barren beach (Figure 55 and Figure 59). A small dune field, with tree type vegetation, had developed along this stretch of the beach. An erosional scarp was developed and has been retreating landward during the study period (Figure 57). Similar to the profiles further north, the foreshore extends onto a wide and flat Bunces Pass ebb-tidal delta with no bar features within at least 100 m from the shoreline. It is worthy to note that a wave and current gauge was deployed on FD14 as discussed in the next Chapter. The overall trend of shoreline retreat agrees with the trend
observed from the long-term historical shoreline data, which is about 11 m/yr of shoreline retreat.

Figure 54: Profile FD11 located in section 2.

Figure 55: Significant overwash in section 2, during the passage of a cold in January 2014. Image from Google Earth.
Figure 56: Profile FD12 located in section 2.

Figure 57: Erosion near FD12, looking north (image courtesy of Jim Wilson, Fort De Soto Park Manager, 2014).
Figure 58: Profile FD13 located in section 2.

Figure 59: Significant erosion during a cold front in February 2015 at FD13, looking south. The dead trees were cut to give access to beach goers.
Profiles FD15, FD16, and FD17 (Figure 61 through Figure 63) are experiencing severe beach erosion at the dry beach. This section of Mullet Key is at the south end of the present erosional hot spot. High erosional scarp and its landward retreat are apparent, retreating landward about 10 m during the study time frame. The width of dry beach along this stretch is only about 6 – 10 m for FD 15. FD17 still has a wide stretch of dry beach extending about 55 m from the dune line. The foreshore slope dips gently, to about negative 2 – 2.5 m NAVD88. The landward dipping slope of the bar is steep, as compared to the seaward dipping bar slope, indicative of a onshore migrating bar (Roberts and Wang, 2012, Brutsche et al., 2014). In other words, the nearshore bar illustrated an onshore migrating trend during most of the 11-month study period. The overall trend of shoreline retreat agrees with the trend observed from the long-term historical shoreline data, which is about 10 – 15 m/yr.
Figure 61: Profile FD15 located in section 2.

Figure 62: Profile FD16 located in section 2.
Profiles FD18 and FD19 (Figure 64 and Figure 65) are two widest profiles with roughly 135 m of dry beach. These profiles intersect across the catseye pond. The dry beach seaward of the pond is accretionary, of 8 m during a 5 month period. The dry beach landward to the catseye pond remains stable. Profiles FD20, FD21, FD22, FD23, FD24, and FD25 (Figure 66 – Figure 71) extend across a section of the island that in general relatively stable to accretionary. The dry beach is about 1 – 1.5 m NAVD88. The foreshore slope along these profiles dips gently seaward. A dynamic sand bar is measured along this stretch of the island, migrating landward and seaward throughout the study period.
Figure 64: Profile FD18, located in section 2.

Figure 65: Profile FD19, located in section 2.
Figure 66: Profile FD20, located in section 3.

Figure 67: Profile FD21, located in section 3.
Figure 68: Profile FD22, located in section 3.

Figure 69: Profile FD23, located in section 3.
Figure 70: Profile FD24, located in section 3.

Figure 71: Profile FD25, located in section 3.
Profile lines FD26, FD27, and FD28 (Figure 72 – Figure 74) extend along the southernmost tip of Mullet Key. Recall that in 1964 an L-shaped groin was installed, and since then this section has been nourished three times. No nourishments have occurred during the time frame of the survey study period. Profile FD26 extends along a wide stretch of dry beach at about 1.5 m NAVD88, with the shoreline remaining relatively stable. FD27 and FD28 have an intertidal zone that is retreating at a rate of roughly 5 m/yr, likely related to the adjustment of the last beach nourishment in 2006. The foreshore slope for these profiles is relatively steep as compared to the profiles further north. FD29, FD30, and FD31 extend along the Tampa Bay Channel (Figure 75 – Figure 77). This section of profiles remains very stable during the study period and is not discussed in detail here.

Figure 72: Profile FD26, located in section 3.
Figure 73: Profile FD27, located in section 4.

Figure 74: Profile FD28, located in section 4.
Figure 75: Profile FD29, extending into the Tampa Bay Channel.

Figure 76: Profile FD30, extending into the Tampa Bay Channel.
Figure 77: Profile FD31, extending into the Tampa Bay Channel.

**Profile-Volume and Shoreline Change**

A spatial pattern of profile-volume gain and loss is apparent along the Gulf-facing beach. Figure 78 illustrates profile-volume change extending to the seaward end of the survey profiles. As illustrated and discussed above, most of the profiles converge at the seaward end of the survey. The very northern tip (FD1 and FD2) of Mullet Key showed slight beach-profile volume loss. The northern end from FD3 to FD6 showed considerable volume gain of up to 60 m$^3$/m during the 11 months period. The erosional hot spot occurred along the northern portion of Mullet Key extending from FD7 to FD18. Profile-volume loss of up to nearly 40 m$^3$/m over the entire surveyed profile was measured along this stretch of the beach. Profile change measured at
FD19 is abnormally influenced by the small dynamic inlet present at the location. Therefore, the volume change at FD19 does not represent any regional trend. Profile-volume gain of up to 20 m$^3$/m was measured from FD22 to FD26. Volume loss across the entire profile was measured south of FD26 along the nourished section of the beach.

Figure 78: Profile-volume change extending to the seaward end of the survey profiles.

Profile-volume changes were also calculated above NAVD88 zero, referred to as shoreline here (Figure 79). The profile-volume changes above shoreline contour illustrate a similar pattern as that of the volume change over the entire profile, as discussed above, but with a smaller magnitude. This suggests that the profile-volume changes were caused by gradients in longshore sediment transport resulting in volume loss or gain across the entire profile. A gradient in cross-shore transport would result in a near zero volume change across the entire profile because sediment eroded from one section of the profile would deposit in the other portion of the profile.
The volume change patterns discussed above suggest that the sediment eroded from the erosional hot spot (FD7-FD18) is transported alongshore in both north and south directions and deposited along the adjacent beaches. In other words, the erosional hot spot is caused by a diverging longshore transport. In the following chapter, the processes that drive the diverging longshore transport are discussed.

Figure 79: Profile-volume change above the shoreline (NAVD88 0 m).

Shoreline (defined here as NAVD88 0 m) changes illustrate a similar pattern as that of the shoreline profile-volume change, as expected for the erosional hot spot from FD9 – FD17 (Figure: 80). This hotspot is due to the longshore transport divergence. The very northern tip (FD1 and FD2) of Mullet Key showed notable shoreline loss of up to 11 m. The northern end from FD3 to FD8 showed considerable volume gain of up to 30 m during the 11 months period. The erosional hot spot is still apparent from the shoreline contour change from FD9 to FD17 (section 2 of Mullet Key). Contour change measured at FD19 was not included in this shoreline
contour measurement due to its tidal influences prompting large shoreline gain. Shoreline gain from FD21 to FD26 suggests that the middle hotspot location is certainly a divergent zone of sediment transport. Shoreline loss is evident at the southern section of Mullet Key with a stable shoreline at the last 3 profile lines along the channel.

![Profile contour change above the shoreline (NAVD88 0 m).](image)

**Figure 80:** Profile-contour change above the shoreline (NAVD88 0 m).
CHAPTER FIVE:

DISCUSSION

Processes of the Diverging Longshore Transport

As described above, the erosional hot spot along the northern-middle portion of Mullet Key is caused by a divergence in longshore sediment transport. It is therefore important to document and understand the driving mechanisms of this longshore transport divergence, especially during energetic conditions when active sediment transport occurs. A series of field measurements were conducted during a passage of an energetic winter cold front to quantify the mechanisms that cause the longshore transport divergence. Three Sontek Triton ADV gauges that are capable of measuring directional wave, current, and water level fluctuations were deployed in the nearshore zone (Figure 13). One Triton ADV (#2) was deployed roughly in the middle of the erosional hot spot at profile FD14 (Figure 81). One (Triton #3) was deployed near the northern end where beach accretion was measured (Figure 82). One (Triton #1) was deployed in the southern section where accretion was measured (Figure 83). Because the major goal is to study sediment transport along the beach, the gauges were deployed in the nearshore zone just outside of the breaker zone estimated for the energetic conditions. It should be noted that wave breaking occurs in a very complicated pattern over the large ebb delta. The measurements conducted here focused on quantifying the wave (and subsequently breaking wave) directly seaward of the beach environment.
The nearshore wave conditions are significantly influenced by nearshore bathymetry characteristics. At locations #2 and #3, the profile extends onto the flat ebb-tidal delta platform (Figure 81 and Figure 82), while at location #1, a distinctive nearshore bar exist directly seaward of the gauge (Figure 83). All the gauges were deployed in a water depth of 1.0 - 1.5 m relative to mean sea level, or about 0.5 m to 1.0 below Mean Lower Low Water. The deployment lasted 15 days from December 19, 2014 to January 3, 2015. The Triton #2 was hit by a small vessel on December 25th 2014 which significantly tilted the current meter. The pressure sensor continued to operate properly, but the current sensor could not function when tilted at a very high angle.

The wave measurements were conducted every 1.5 hours sampling at 2 Hz for 512 seconds. The tide and tidal current measurement were conducted every 15 minutes. The tidal water level and tidal currents are represented by values averaged over a 2-minute period to remove the high-frequency wave motion. The beach-profiles were surveyed at the beginning and the end of the gauge deployment. Meteorological conditions, particularly wind speed and direction, were obtained from a nearby NOAA gauge station 8726412.

The wind conditions associated with the winter cold front passage during the measurement period are shown in Figure 84. This particular cold front is somewhat abnormal in that the duration of pre-frontal southerly was longer than that of the post-frontal northerly wind. The pre-frontal wind was also stronger than the post-frontal wind. Therefore, this frontal passage likely generated a net northerly longshore transport, opposite to the regional net annual southerly longshore transport. A sharp switch of wind direction occurred on December 25th 2014.
Figure 81: Immediate profile lines on FD14, before and after gauge deployment with Triton gauge location.

Figure 82: Immediate profile lines on FD5, before and after gauge deployment with Triton gauge location.
Figure 83: Immediate profile lines on FD22, before and after gauge deployment with Triton gauge location.

Figure 84: Wind conditions from December 20, 2014 to January 3, 2015.
Figures 85 – 87 illustrate the wave heights measured at the three locations. Wind speeds are also plotted in these figures. Overall, the relationship between wind speed and wave height is not as clear as expected. Generally, higher waves were measured during the pre-front period with stronger wind. However, the pre-front wind direction was mostly shore parallel with a slight offshore component. Modulation of tide on wave height is apparent. High tide typically corresponds to higher waves due to less friction loss and wave breaking over the complex shallow shoals. This is particularly clear at Triton #1. At low tide, the nearshore bar becomes almost emerged (Figure 82) blocking most of the incident wave energy.

Higher waves were measured directly seaward of the erosional hot spot at Triton #2, as compared to the other two gauges (Figures 85 – 86). The highest wave during the 15-day period was 0.57 m at the erosional hot spot, versus 0.44 m at the northern end and 0.32 m at the southern portion. The higher wave should result in more active sediment suspension by wave breaking. This combined with the flood-influenced flow pattern discussed above explains the longshore transport divergence.

Figure 88 illustrates the measured tidal water level fluctuations and current at Triton #3. The tidal cycles are clearly recorded in the water-level data. The influence of the cold front passage on the tides is apparent around December 25th 2014. In general, the current velocities also demonstrate apparent cycles, similar to the water-level cycles. Furthermore, the velocity curves are roughly 90 degree out of phase as compared to the water-level fluctuations. These indicate that the measured flow velocities were mostly driven by the rising and falling of tides, obvious because of the proximal location of this gauge to the tidal inlet. The northerly directed
flow (i.e., flood flow) was moderately stronger than the southerly directed flow, suggesting the flood flow preference in the marginal flood channel.

The current velocity pattern measured by Triton #2 at the erosional hot spot is quite different from that at Triton #3 location. The water level variation was nearly identical as that at #3. A northerly directed current was measured during the rising tides but without a clear peak. Much weaker flow was measured during the falling phase of the tide. In other words, a clear preference of northerly flow driven by rising tide was illustrated by the hydrodynamic data collected at the erosional hot spot. This would result in a northerly net transport at this location, which explains the persistent erosion. The easting velocity which is roughly perpendicular to the shoreline is small, as expected.

At the southern Triton location, nearly identical tidal water fluctuation was measured as compared to the other two gauges. The flow pattern is apparently driven by tides because of the cyclic variations and the roughly 90 degree phase shift. Furthermore, the southerly directed flow was generally stronger than the northerly directed current, except during the passage of the cold front on December 25 2014. Stronger northerly directly flow was measured during the pre-frontal phase due to the strong southerly approaching wind, while strong southerly flow occurred during the post-frontal phase due to strong northerly approaching winds. A similar pattern was also measured at Triton #3 near Bunces Pass. The overall stronger southerly directed current measured at this location can be explained as the “alongshore flowing” flood flow toward the main Tampa Bay channel at the southern end of Mullet Key.
Figure 85: Wave heights and wind speed measured on FD5.

Figure 86: Wave heights and wind speed measured on FD14.
Figure 87: Wave heights and wind speed measured on FD22.

Figure 88: Tidal water level fluctuations and current on FD5.
Figure 89: Tidal water level fluctuations and current on FD14. Note a shorter measuring length.

Figure 90: Tidal water level fluctuations and current on FD22.
The longshore transport divergence driven by gradients on alongshore flood tidal flow, as discussed above, is different from the broadly accepted wave-refraction interpretation proposed by Hayes (1979). Hayes suggested that the reversal of longshore transport at the downdrift side of the inlet is caused by wave refraction over the ebb delta resulting in a reversed longshore current. Our measurements here indicate that the reversal is mainly driven by decreasing of the alongshore flood tidal flood away from the inlet. In addition, wave height along the section of the beach that is not directly sheltered by the shallow ebb delta tends to be greater than the sheltered area. This also contributes to the more active sediment transport at the erosional hot spot at the divergent zone.

**Cycles of the Swash-Bar Attachment**

As described above, the long term evolution of Mullet Key morphology is controlled by the initiation, the expansion and emergence, the onshore migration, shoreline attachment, and post-attachment adjustment of the swash-bar complex. The time-series analysis by this study starting from 1942 have revealed two complete cycles of the swash-bar attachment events, with a recent new cycle developing. The first cycle initiated in 1942 and was completed in 1970. The second cycle initiated in 1973 and was completed in 2005. Therefore, the swash-bar emergent and attachment cycles seem to have a period succession of approximately 30 years. Based on recent aerial photos, a new cycle initiated around 2010. The most recent aerial photo from 2014 shows the growth and emergence of the linear swash-bar, indicative of a new cycle.
Based on the aerial images, it takes about 3 years after a cycle has been completed for a submergent sand body complex to develop into a significant linear shape. During these initial 3 years, the submergent sand-body complex becomes visible at the vicinity of Bunces Pass, along with development of channel margin linear bars along both sides of the inlet. At this point in the bar complex development, the swash-bar is measured to be approximately 300 m to 400 m away from the shoreline at the southernmost end of the swash-bar complex. The growth and expansion of the swash-bar complex also increases in size. For example, the 1973 swash-bar expanded from a 625 m length and 125 m width bar to 1,250 m by 200 m in roughly 3 years as shown in the 1976 photo (Figure 21). About 5 – 7 years following, the development of the bar complex and the channel margin linear bars also expands and eventually attach into one larger swash-bar complex. Once attached, the original linear shape that was once oriented northwest to southeast of the bar complex becomes more of a crescent shape due to the adjoining with the channel margin linear bar.

The joining of the linear bar and channel margin linear bar both expands horizontally and vertically. This can be seen in both cycles in 1951 (Figure 16) and in 1984 (Figure 23). As the crescent shaped swash-bar becomes more emergent by expanding it begins to develop vegetation, while continuing to migrate onshore. The migration rate of both crescent shaped swash-bars from the two cycles above is calculated to be approximately 40 – 50 m/yr. The first cycle began its bar complex development in 1942. By 1957, 15 years later, the southernmost section of the bar had welded onto the beach. The second cycle started its bar complex in 1973. By 1986, 13 years later, the bar had become attached onto the beach. Both cycles have shown that it takes roughly 15 years from the initiation of a swash-bar complex to its attachment at shoreline.
Once the bar complex welds onshore, a catseye pond forms seaward of the main shoreline and landward of the bar. Based from the two cycles, both attachment points at Mullet Key have occurred on the southern tip of the migrating bar. Based off of the historical shoreline data from Figure 37, the large seaward advance from 1976 to 1998 in all of the profiles results from a sand bar complex attachment that occurred in 1986. After the attachment, the shoreline data from 1998 to 2014 indicate a relative constant rate of shoreline retreat of approximately 10 – 15 m/yr along the central portion of the newly accreted beach.

A conceptual model is proposed here depicting the cycle of swash-bar attachments, illustrated in Figure 91. The swash-bar complex development and attachment cycle is composed of five phases that include:

1) The initiation of complex bars and sand-bodies in a linear morphology near the Bunces Pass inlet: this phase takes approximately 3-5 years.

2) The expansion, growth, and development into a crescent shaped sand-bar complex: this phase takes roughly 5 – 7 years.

3) The continued onshore migration: this phase takes about 5 – 7 years.

4) The shoreline attachment, shoreline propagation and development of accretionary beach morphology features, such as beach/dunes ridges and catseye ponds: this phase takes about 3 – 6 years.

5) The post-attachment adjustment and shoreline evolution: this phase take about 10 years.
Figure 91: Conceptual model illustrating one cycle with five swash-bar complex phases. Each illustration represents the end of each phase. Phase 0 is the ending phase from the previous cycle, denoting no swash-bar complex or channel margin linear bar formation. Phase 1 includes the initiation, emergence, and growth of the swash-bar complex. During this phase the channel margin linear bars also propagate seaward. Phase 2 includes the evolution of the crescent shaped swash-bar complex. Phase 3 is the onshore migration. Phase 4 is the shoreline attachment. Phase 5 includes the post-attachment adjustment.

It should be noted that the transitions among different phases are gradual. The above division is somewhat subjective. Presently, Mullet Key is in the beginning phase of a new swash-bar development cycle. From the 2013 aerial photo (figure 35), it is evident that the swash-bar complex has developed into a linear form. Based on field observation, a substantial expansion of the swash-bar complex occurred after Tropical Storm Debby in June 2012. Presently, the swash-bar complex has expanded substantially and become partially emergent. However, it still
illustrates a linear shape and therefore is still in phase 1 of the cycle based on the above conceptual model.

Based on the conceptual model developed here, the evolution of this cycle of swash-bar complex can be predicted as follows:

1) In approximately 6 years (2020), the linear bar observed today will develop into a crescent shape.

2) From 2020 to about 2025, the crescent bar will continue migrating onshore.

3) By roughly 2030 a new attachment point will have become affixed to the shoreline resulting in a significant shoreline gain of several hundred meters at the attachment point and to the north, forming another catseye pond between the present shoreline and the new shoreline.

4) The swash-bar complex attachment will end the current trend of shoreline erosion. In other words, based on the conceptual model developed here, the present trend of shoreline erosion will continue till about 2030, or another 150 m of landward shore retreat can be expected from now till 2030.

5) Starting 2040 the post-attachment shoreline erosion will begin.
Mullet Key is neither a typical wave-dominated barrier island nor a mixed energy drumstick barrier island due to its right angle morphology. This study documented the morphodynamics of the Gulf-facing beach through historical aerial photos, historical shoreline surveys, beach-profile surveys, and nearshore hydrodynamic measurements.

The 27 historical aerial photos from 1942 to 2014, demonstrate two 30-year cycles that display similar patterns both spatially and temporally. Five swash-bar phases can be identified during each cycle, including 1) initiation of the swash-bar complex, 2) emergence and expansion, 3) onshore migration, 4) shoreline attachment, and 5) post-attachment beach adjustment. The swash-bar complex initiation lasts about 3 years. The expansion, growth and emergence of the swash-bar complex transforms the linear shaped bar complex to a crescent shape. This phase takes roughly 5 – 7 years. The landward migration phase, with the bar complex moving at a rate of approximately 40 – 50 m/yr, lasts 5-7 years. The shoreline attachment phase takes about 3 years, followed by the post-attachment beach adjustment phase, lasting about 10 years. Presently, Mullet Key is at the beginning of a new cycle, i.e., phase 1. A linear swash-bar complex can be identified since 2010 and has been expanding and emerging during the past 4 years.
Historical shoreline analyses from 1873 to 2014 further demonstrate the morphological change patterns as identified qualitatively from the aerial photos along the Gulf-facing section of Mullet Key. Since the 1920s, most of the Gulf-facing beach has been accreting owing to the two shoreline attachment events of the swash-bar complex in 1957 and 1986, except at the southern end near the Tampa Bay main channel. However, over the past 17 years, severe beach erosion at a rate of 10 – 15 m/year has occurred along the northern portion of the island while accretion occurred along the middle portion. Beach-profile data collected by this study from March 2014 to February 2015 confirm the above shoreline change pattern and further reveal that the recent beach erosion and accretion are associated with a divergence of longshore transport. Nearshore wave and current measurements demonstrated the driving forces of the longshore transport divergence are caused by a diverging flood flow along the beach. At the erosional hot spot in the middle portion of the Gulf-facing beach, the flood flow diverges. To the north, the flood flow enters Bunces Pass, while it enters the Tampa Bay channel to the south. Furthermore, the waves in front of the eroding beach were higher than the adjacent accreting beach.
REFERENCES


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Pinellas County Parks and Preserves. Fort De Soto Park. Historic Guide.


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