**Case Study: Deer Island, Florida Time Period Shoreline Analysis Using DSAS**

**Abstract**

Climate change perpetuation and sea level rise have led to Gulf of Mexico shoreline dynamics concerns. Shoreline dynamics in areas of coastal development have been intensely studied, however many under-developed shorelines have yet to be analyzed. In this study we used seven NAIP (National Agriculture Imagery Program) aerial images, from 1994 to 2019, of our study area near Cedar Key, FL. The cloud-free images were collected during relatively similar mean river discharge levels and during (mostly) the same season. We assessed the shoreline changes using ESRI’s ArcMap© spatial data analysis extension DSAS (Digital Shoreline Analysis Systems) on three different time periods in from the imagery, 1994-2007, 2010-2019 and 1994-2019. The DSAS analysis is a transect- based approach and is used to quantify shoreline changes on a linear ocean shoreline. From this analysis we determined the greatest areas of impact and have been able to speculate on possible factors that may contribute to an escalated shoreline change rate during a selected time frame.

**1. Introduction**

Shoreline changes can occur due to multiple factors including SLR (sea-level rise), anthropogenic human activity and hurricane intensity (Yu et al., 2011) . The combination of these processes can influence erosion and accretion. Shoreline changes may affect a shoreline’s resilience to storm surges including flooding and species diversity implications (Desantis et al., 2007). It was observed by USGS (United States Geological Survey) that shoreline changes along the Gulf of Mexico, specifically in Florida, were relatively steady between the 1800s and 1990s (Morton et al., 2005). Since then, the Gulf of Mexico coastline, with its low relief geomorphology particularly along the west coast of Florida, has been noted to be vulnerable to coastal erosion (Geselbracht et al., 2011).

***1.1 Climate change and SLR***

More recently, climate change induced SLR and its impacts on coastal zones is of growing interest. The Earth’s climate is warming due to an accumulation of greenhouse gases in the atmosphere, largely in part due to anthropogenic fossil fuel burning and deforestation. Warming climate change causes thermal expansion of sea water, and land ice to melt into the ocean, initiating SLR (Cazenave and Cozannet, 2013). Sea-level rise is considered to be a likely candidate for widespread global erosion. Erosion occurs when SLR drifts the high-water line (line on the shore where the water usually reaches at high water) landward in relation to the slope of the coastal area. Erosion on sandy beaches involves the relocating of sand from the beach to offshore. This is normally observed during storm events. Storm events temporarily increase the local sea-level of the sandy beach, and ultimately storm waves are able to reach higher elevations on the beach. After a storm event much of the sand returns back to the beach by swell waves during normal sea water levels. This exchange implies that sea water levels have a direct relationship with sandy beach erosion (Zhang et al., 2004).

***1.2 Characteristics of sandy shorelines and sedimentation***

Sandy shorelines are characterized by active environments and unstable substrata, which consists of sand, mixed sand, quartz, and/or silica. The unstable nature of sandy shores make a harsh ecosystem for biota and may incorporate a significant range of physical environment conditions and ecosystem functioning. These shorelines accumulate sediment accretion by wave deposited particles. Particles originate from inland erosion and may be transported by rivers (Brown and McLachlan, 2001). Sediment to sandy shores may also be added by marine biogenic sources such as pieces of marine skeletons, sponge spicules, and shell fragments (Brown and McLachlan, 1990). Threats to sandy shorelines include disruption of sand transport, storms, SLR, and human activities.

***1.3 Suwannee River sedimentation and discharge***

The Suwannee River is the second largest river in Florida spanning 396 kilometers long and is considered to be a significant point source of sedimentation near our study site, approximately 11 kilometers north. The Suwannee River is a partially spring-fed system which also drains the coastal plain of Georgia and provides a restricted point source input of siliciclastic sediment, creating a small 20-kilometer delta. The surrounding coastal regions of the Suwannee River are otherwise known to be sediment starved, but a great significant sedimentology event has been shown that the Suwannee River has reworked ancestral fluvial sands and serves as a source for sandier marsh sediments (Wright et al., 2002). The Suwannee River normally has high discharge peaks between February and April and low discharge peaks between August and October (Purtlebaugh and Allen, 2010). The average annual discharge is 300 m^3/c with a minimum of 83 m^3/c and a maximum discharge of 2400 m^3/c (Wright et al., 2002).

***1.4 Human development and impacts***

Three Florida counties encompass the region of our study site, Dixie, Levy, and Taylor. These counties which are projected to increase in human population by 2045 as depicted in Figure 3. These Florida counties are recorded to have lowest population densities along the Florida coastline (Geselbracht 2007). In the future it could be likely that businesses and people will want to develop housing along this shoreline. Human development on coastlines may accelerate coastal erosion by creating a fixed position of the shoreline and stabilizing inlets (Finkl and Charlier, 2003). Increased human developments may also negatively impact coastal species diversity. Species biodiversity is threatened by the increase of urbanization and environmental coastal degradation (Finkl and Charlier, 2003). Czech’s et al. (2000) documents urbanization as the highest cause for species endangerment. For example, the shorebird Piping Plover (*Charadrius melodus*) is known to forage and nest in areas of low human population (Thomas, Kvitek, and Bretz, 2002), implying that shoreline areas with higher human densities would not be an ideal habitat for this species. Species biodiversity, both vegetative and animal, could be at risk due to an increase of urbanization along coastlines (McKinney, 2006) and accelerated shoreline erosion.

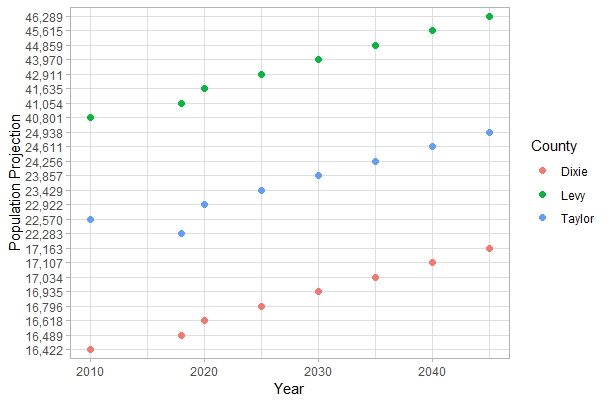


Figure 1- Generated figure based on census and projection data from Bureau of Economic and Business Research (<https://www.bebr.ufl.edu/population>).

***1.5 Big Bend habitats for species richness***

The Northeastern Gulf of Mexico region of Florida is ranked as an area of high importance for conserving and protecting habitats for at least 30 species of shorebirds. Within those thirty species, four threatened species are considered to be of “extremely high priority” for protection, and include the American Oystercatcher, Red Knot, Snowy Plover, and Piping Plover (Withers, 2002). The coastlines in the Big Bed region (Figure 2) are described as having low wave energy (described as waves falling well below the high-water line of a shore), which can be ideal for migrating shorebirds because low wave energy on shorelines can facilitate the accumulation of vegetative litter and food such as horseshoe crab eggs (Nordstrom et al., 2006). These shorebirds use the primarily cordgrass marsh shorelines habitats of the Big Bend for foraging, mating, and shelter. Shorebirds in the Big Bend have been reported to have the least abundance and species richness, in a study comparing Gulf of Mexico regions shorebird use of coastal habitats (Withers, 2002).

***1.6 Major Hurricanes in the Gulf of Mexico***

The Storm of the Century, hit the west coast on March 1993, was a Category 5 hurricane with wind speeds up to 160.9 kmh. The Storm of the Century caused devasting damage to the Waccasassa Bay (approximately 30 kilometers south of our study site), 3-meter water storm surges (Figure 2), a storm deposit which reached 12 cm on the levees and up to 2 cm on the marsh surface (Goobred and Hine, 1995). Hurricane Irma, also hit the west coast of Florida on September 2017, was recorded as a Category 3 hurricane (Figure 3), with wind speeds up to 193.1 kmh. Heavy amounts of rainfall were recorded with Hurricane Irma at a peak of 550 mm in Fort Pierce, Florida. Heavy rainfall and storm surges, highest record was 2.3 m, contributed to many creeks and rivers overflooding (Pinelli et al., 2018).

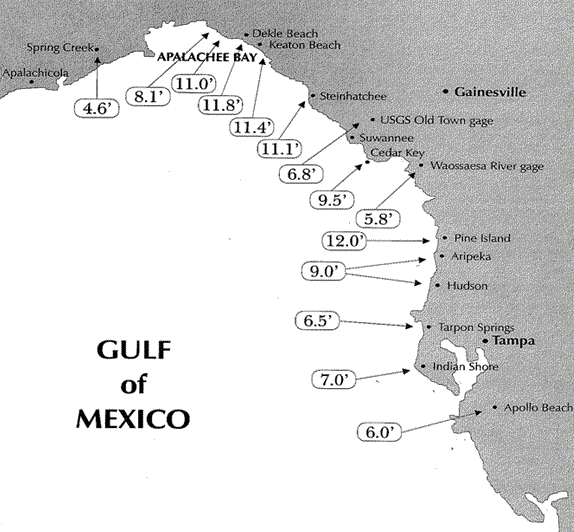
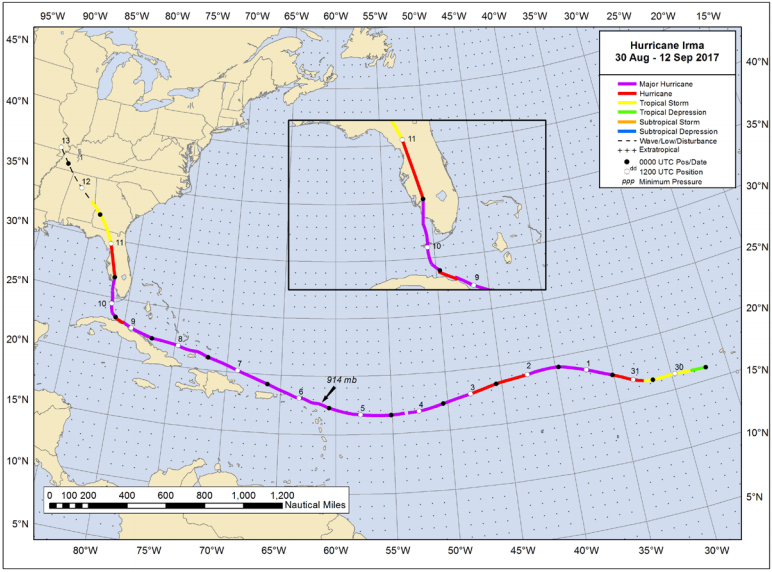


Figure 2- Storm surge, in feet, associated with the Storm of the Century, 1993. (National Hurricane Center)

Figure 3- The path and intensity of Hurricane Irma, 2017. (National Hurricane Center)

***1.7 Reason for effort***

This shoreline analysis study tried to identify possible factors that may be influencing shoreline loss. Since the study site is uninhabited, and tourism is not prevalent these were not considered as probable factors. The analysis was split into three time frames in order to locate an area of shoreline change where an identifiable factor may have triggered shoreline erosion or accretion. Two out of the three time frames spilt up the available imagery into equal years, however there are not an equal amount of imagery available covering each 12.5 year period (imagery spans a total of 25 years). The last time frame includes all imagery to calculate how much total shoreline was loss or gained from the years 1994 to 2019.

Shoreline loss as also need near our study site has also been captured recently. In the mid-1960s the US Army Corps of Engineers constructed spoil islands as part of the cross Florida barge canal project. These spoil islands consist of a straight line of islands perpendicular to the west Florida coast. Coastal changes have severely eroded or inundated these spoil islands, thus reducing habitat for animals (Vitale, 2019). Derrick Key is an example of a spoil island that was clearly visible in aerial photographs in 1982 and now the island is completely submerged (in 2016 photography). Major shoreline differences are noticeably observed in the 34 years, time between the imagery, for this specific spoil island. Large scale efforts to analyze shoreline changes in Florida have been studied in the past (Yu et al., 2010; Sassaman et al., 2017; Houston, 2015; Li and Gong, 2015), however it is interesting to note the effects of SLR on a smaller or regional scale, which might highlight processes which might be affecting ecosystems and habitats on a larger-scale.



Figure 4 - Island degradation of Derrick Key in the Cedar Keys, Florida from 1982 (left) to 2016 (right), (Vitale, 2019).

**2. Materials and methods**

***2.1 Study Area***

Our study area is located on the west-central Florida coastline in the Suwannee Sound region of the Big Bend (Figure 5). The selected shoreline is a small barrier island called Deer Island. Deer island is a privately owned uninhabited island approximately 13 kilometers north of the main villages of Cedar Key, Florida. Historically, Native Americans intermittently inhabited Deer island for thousands of years. Early Florida settlers were reported to live and camp on the island as well. The 1800 Florida census registered only 4 people to have identified this island as their home. There is a cabin near the south of the island depicted on a 1951 USGS Cedar Key Quadrangle map (USGS, 1955). This island is specifically located in the Big Bend Aquatic Seagrass Preserve and connects with the Lower Suwannee National Wildlife Refuge (http://www.beachrealtyfla.com/DeerIsland.htm). Deer Island is approximately 364217 square meters of total area and consists of 101171 upland square meters (27.7%) and 80937 square meters (22.2%) of wetland with elevations as high as 4.3 meters. The island is densely forested with large pines, cedars, palms, oaks, palmettos and many more plant species (<https://www.privateislandsonline.com/united-states/florida/deer-island>). The shoreline attributes reported on Deer island is about 1.3 +/- kilometers of Gulf of Mexico white sand beach and approximately 1.3 +/- kilometers of waterfront facing the mainland (<https://images1.loopnet.com/d2/Z4L1-alqEsAlhPT_YJ25N8OMkXU3L_mAPAZYXiq2OVg/document.pdf>).



Figure 5- Location of Deer Island, Florida. A) Map of the entire state of Florida; B) Zoomed into map scale of 2.3758 to study site; C) Zoomed into map scale of 0.03 to Deer Island with a scale bar in kilometers. Shoreline shapefile downloaded at my.fwc.com, (1 to 2,000,000 Scale, and digitized in 2017).

***2.3 Imagery selection process***

Locating relatively cloud-free imagery for a specific location in Florida can be an exhaustive effort. Since our study location is unpopulated and contains no popular historic landmarks, so historic aerial images are not frequently taken. To reduce the effort on locating usable imagery, Google Earth Pro was utilized. Google Earth Pro does not capture any of its own imagery, it does however locate and use imagery, in its finder view, that is comparatively cloud-free and with the highest resolution. Google Earth Pro was able to give minimal metadata of the imagery such as which agency captured the imagery and the date of the image, when using the time slider feature. Then USGS’s Earth Explorer (<https://earthexplorer.usgs.gov/>) was used to further locate the actual imagery and collect its metadata. After Upon inspection it was determined that NAIP (National Agriculture Imagery Program) was the agency that acquired the most frequent and most detailed aerial imagery of our study site. The specifications for NAIP aerial imagery require 1-meter ground sample distance with a horizontal accuracy that matches within six meters of photo-identifiable ground control points. These points are then used during imagery inspection. Contractually, NAIP makes attempts to comply with the specification that no more than 10% cloud cover be allowed in each aerial imagery tile. Aerial imagery are available as digital ortho quarter quad tiles (DOQQs) geotiffs, and which also correspond to the USGS topographic quadrangles (<https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/>). It was also important to select imagery that were fairly at the same time of the year, similar river discharge and precipitation levels. All imagery chosen are between the months of October through January. Normally, during the Florida winter months, precipitation and river discharge levels are generally low (Bhardwaj and Misra, 2019). The table below includes all metadata associated with the imagery used in this analysis. Furthermore, observed weather and median river discharge were collected, including the observed weather for the day of imagery collection and median river discharge measured.

|  |  |  |  |
| --- | --- | --- | --- |
| Date | Median River Discharge (cfs)  Station ID= 02323500 | Observed weather | Metadata (USGS Earth Explorer) |
| January 20, 1994 | Value= 9710 | Avg Temp (C)- 3.41 Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 19.31 | Entity ID DI00000000018672 (found in DOQ)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 3  Sensor Type RGB |
| December 30, 1998 | Value= 6370 | Avg Temp (C)- 9.30 Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 25.75 | Entity ID DI00000001164809 (found in DOQ)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 3  Sensor Type RGB |
| November 02, 2007 | Value= 2350 | Avg Temp (C)- 19.31  Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 22.53 | Entity ID N\_2908356\_NW\_17\_1\_20071102 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 3  Sensor Type CIR |
| September 19, 2010 | Value= 4240 | Avg Temp (C)- 25.32 Precipitation (cm)- 0.00  Max Wind Speed (KPH)-24.14 | Entity ID M\_2908356\_NW\_17\_1\_20100919 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 4  Sensor Type CNIR |
| October 13, 2013 | Value= 8200 | Avg Temp (C)- 22.13 Precipitation (cm)- 0.00  Max Wind Speed (MPH)- 10 | Entity ID M\_2908356\_NW\_17\_1\_20131013 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 4  Sensor Type CNIR |
| November 12, 2015 | Value= 6070 | Avg Temp (C)- 19.27 Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 16.09 | Entity ID M\_2908356\_NW\_17\_1\_20151112 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 4  Sensor Type CNIR |
| October 26, 2017 | Value= 7990 | Avg Temp (C)- 12.60 Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 14.48 | Entity ID M\_2908356\_NW\_17\_1\_20171026 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 1.0  Units METER  Number of Bands 4  Sensor Type CNIR |
| November 10, 2019 | Value = 5190 | Avg Temp (C)- 14.12 Precipitation (cm)- 0.00  Max Wind Speed (KPH)- 11.27 | Entity ID M\_2908356\_NW\_17\_060\_20191110 (found in NAIP)  Map Projection UTM  Projection Zone 17N  Datum NAD83  Resolution 0.60  Units METER  Number of Bands 4  Sensor Type CNIR |

Table 1- Table of information for each aerial image used in this analysis including date, median river discharge, observed weather, and additional imagery metadata. River discharge information is calculated by data from <https://tidesandcurrents.noaa.gov/> at Cedar Key, Florida Station 8727520, and observed weather provided by [www.wunderground.com](http://www.wunderground.com). Imagery metadata is provided by USGS Earth Explorer, <https://earthexplorer.usgs.gov/> .

National Agriculture Imagery Program employed sensor types which had three band imagery categorized as RGB (red, green, blue), up until 2007. After 2007, four band color infrared imagery were collected and categorized as CIR/CNIR (red, green, blue, and infrared). Four band imagery is multispectral, which means the sensors can collect information from several parts of the electromagnetic spectrum. The metadata in Table 1 includes the sensor type associated with each image. Our November 2007 image is the first image in our series which uses color infrared (CIR/CNIR). The advantage of using CIR/CNIR imagery us that it allows the user to view the imagery in a false color for NDVI (Normalized Difference Vegetation Index) analysis. In this analysis our shoreline does need to identify vegetation on the sandy shoreline.

Most GIS software can only display three bands at one time. Vegetation can be seen on Deer island but it is not necessary for our DSAS analysis because the island vegetation is distinctly not integrated into the sandy shoreline. Additionally, the DSAS user manual does not have any recommendations for using or not using true color image composites. To specify a natural color display the settings in the GIS software should be band 1 set to red, band 2 set to green, and band 3 set to blue. True color in this instance is useful because the sandy shoreline of Deer island is in stark contract with the dark ocean water.

|  |  |  |
| --- | --- | --- |
| Sensor Type | Color and wavelength (µm) | Band and color channel to display true color |
| RGB | Blue 400–500  Green 500–600  Red 600–700 | 1 – Red channel  2 – Green channel  3 – Blue channel |
| CIR/ CNIR | Blue 400–500  Green 500–600  Red 600–700  Near Infrared 800–900 | 1 – Red channel  2 – Green channel  3 – Blue channel  4 – Near Infrared (not show in screen display) |

Table 2 - National Agriculture Imagery Program (NAIP) aerial imagery band wavelength ranges in units (µm) (<https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/APFO/support-documents/pdfs/fourband_infosheet_2017.pdf>)

***2.3. Digital Shoreline Analysis System (DSAS)***

The DSAS is a GIS-based system created and maintained by USGS (United States Geological Survey). For this analysis the DSAS ArcMap© extension was used. The DSAS extension casts transects along the baselines (starting point for transects) and measures the gaps between the shoreline positions during defined years. Baselines are constructed by the user, and in this analysis was created using the Buffer tool in ArcMap©. These shoreline positions provide the basic data needed to calculate their shifts. One of each type of change metric (as described in the DSAS Overview, <https://pubs.usgs.gov/of/2018/1179/ofr20181179.pdf>) was used in this analysis, an LRR (Linear Regression Rate) for statistical analysis and the Net Shoreline Movement (NSM) calculation for the distance measurement. A linear regression rate-of-change can be ascertained by fitting a least-squares regression line to every shoreline point in a transect. The regression line is positioned so that the sum of the squared residuals is at its most minimal. The linear regression rate is the slope of the regression line. The NSM is the distance between the oldest shoreline portion to the youngest shoreline position for each transect, calculated in meters. The LRR statistic was used it because all the data provided is used regardless of accuracy, and the calculations is based on accepted statistical notions. In contract NSM statistics only require the baseline position and the last shoreline position to make its calculations. The justification for using NSM statistics is to know the total measurement of erosion and/or accretion, which has high biological significance in that this will be the first time this kind of measurement will be conducted on our study site and even in the surrounding areas.

The DSAS analysis generates transects which are perpendicular to the reference user created baseline (Figure 6). The analysis describes an intersection point as the cross between the casted transect and the shoreline boundary for the given number of years. The DSAS analysis then uses the distance, in meters, to conduct various calculation, which were previously described. Using the distance between transects, the DSAS can also generate forecasted transects in a 10 and 20 year interval.

Figure 6 - Example of DSAS transect casting (<https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas?qt-science_center_objects=0#qt-science_center_objects>)

The DSAS calculations require an operational workflow to gather and create the necessary components. The components needed are shoreline baselines, additional shorelines of interest (varying in different time periods), DSAS transects (which are cast some the baseline and intersect the additional shorelines positions), measurement distances, measurement points, and shoreline uncertainty. All objects used in the DSAS are stored in an ArcMap© Personal Geodatabase, as per USGS requirements for this analysis. The DSAS operational workflow includes the following steps: (1) Set default parameters and fields to created shoreline and baseline layers, transects, shoreline calculations, metadata and file output locations; (2) Cast transects and select their maximum search distance, transect spacing, and smoothing distance; (3) Calculate change statistics such as confidence intervals, shoreline intersection threshold, rate of output display, and summary report; (4) Create data visualization for LRR and NSM; and (5) Shoreline forecasting for a 10 and/or 20 year forecast.

***2.4 DSAS parameters and selections***

Selected NAIP Geotiff aerial imagery were in the Universal Transverse Mercator (UTM) coordinate system, Zone 17 North and in the 1983 North American Datum (NAD83). (Table 1). Using ESRI’s ArcCatalog© and ArcMap©, separate shapefiles for each aerial image’s shoreline was create, traced, and digitized. Shorelines were then merged into a new single shapefile using the ArcMap© Merge tool. The ArcMap© Buffer tool was used to create a new shapefile that contained a 100-meter buffer around each shoreline in the new merged shorelines shapefile. A section of the buffer was selected to act as the baseline for transect casting for the DSAS calculations. The baseline selected can be found on the east side of Deer Island and is entirely inland. Both a baseline shapefile and merged shoreline shapefile are required for DSAS calculations (Figure 7, Inputs).

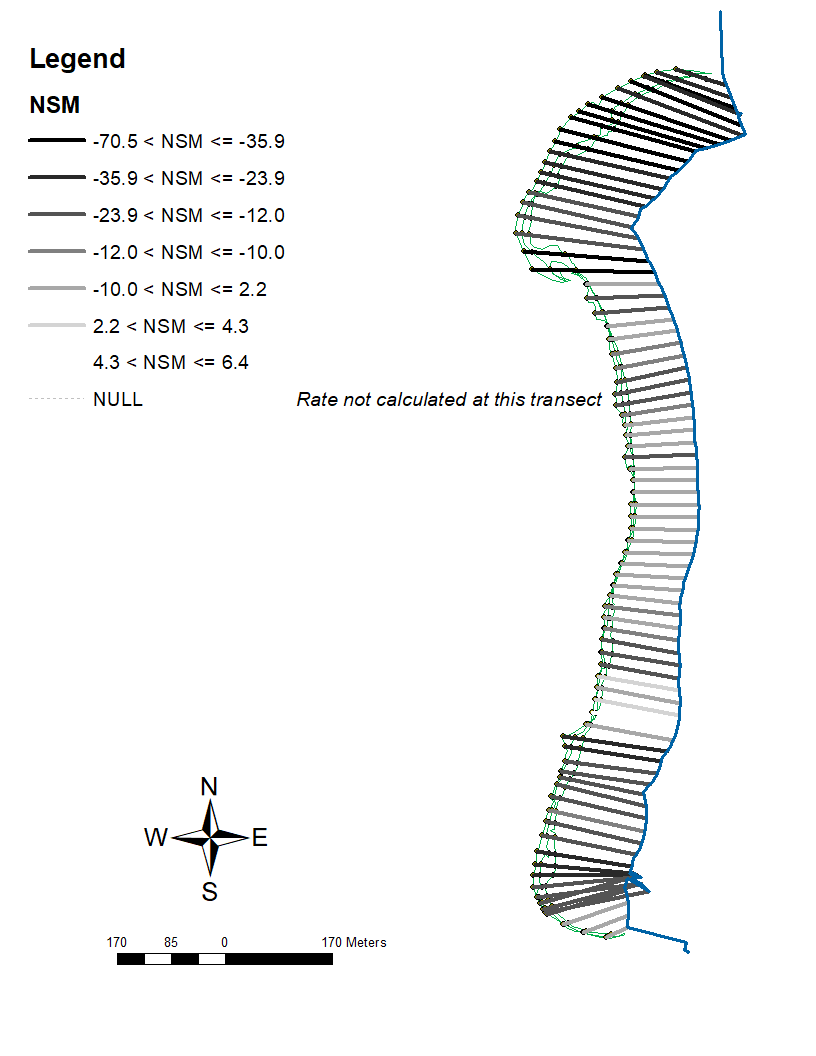
The parameters set for this analysis were a 20-meter transect spacing, a 2000-meter search distance for shorelines, and a smoothing distance of 500 meters. A 20-meter transect spacing was the minimum transect spacing allowed for the size of the study site. A 2000-meter search distance looks for shorelines 2000 meters way from the baseline. A smoothing distance is a user- specified smoothing value which can facilitate and orthogonal transect intersect by creating a baseline (which is not displayed in the final product). The intention of the smoothing distance is to prevent transects from intersecting with one another when there is a curve in the baseline. The larger the smoothing distance results in a longer reference line and produce more uniform transect orientations, which is recommended for smaller shorelines. The default setting for 90% confidence interval too calculate LRR and NSM rates remain unchanged.



Figure 7 - DSAS components and operational workflow.

**3. Results**

The calculations for the shoreline analysis are displayed in a black and white colorramp. The LRR coloramp displays rates of change of meters per year. The NSM coloramp displays the distance of measurements in meters. The DSAS calculations follows the standard that a negative rate implies erosion and a positivie rate implies accretion. The interpretation of the results go as follows.

***3.1 Shoreline analysis from 1994-2007***

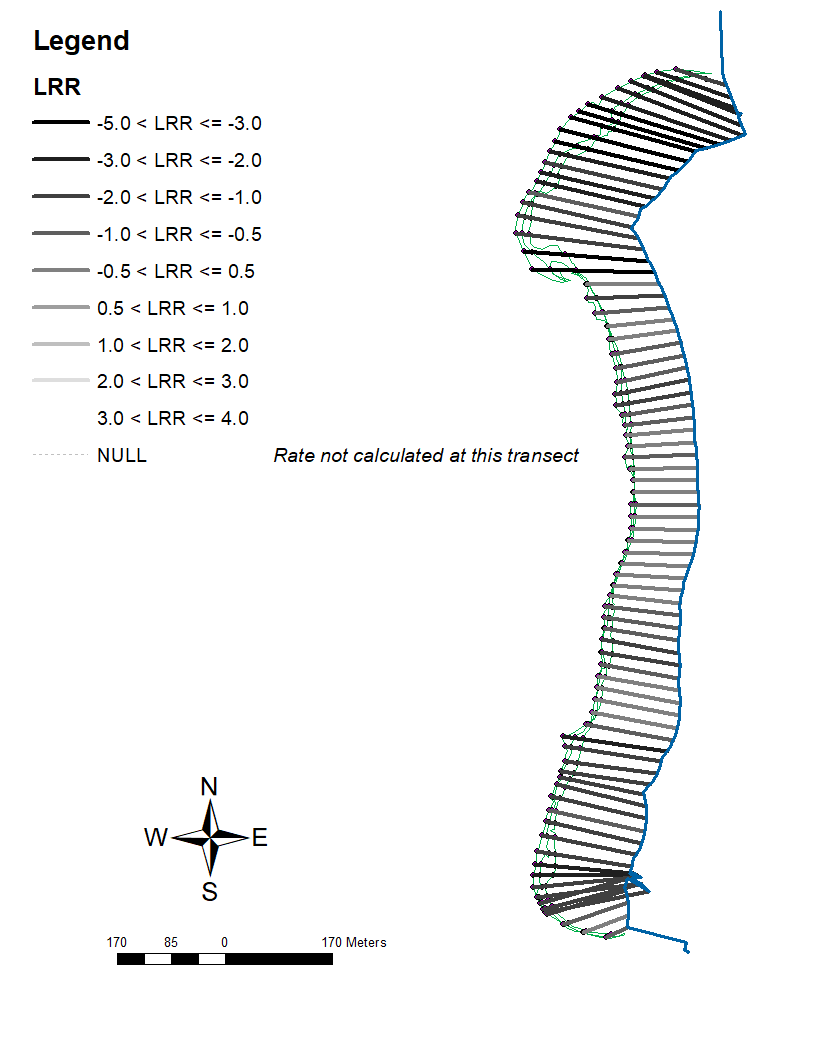


Figure 8 - Results of Linear Regression Rates model (left) and Net Shoreline Movement model (right). Shorelines are located on the west side of each panel. Baselines are located on the east side of each panel. The imagery used in this analysis is from 1994-2007.

|  |  |  |
| --- | --- | --- |
| Range (LRR) | Count | Percentage of total transects (n=82) |
| -5.0 < LRR <= -3.0 | 7 | 8.5% |
| -3.0 < LRR <= -2.0 | 12 | 14.6% |
| -2.0 < LRR <= -1.0 | 25 | 30.5% |
| -1.0 < LRR <= -0.5 | 17 | 20.7% |
| -0.5 < LRR <= 0.5 | 21 | 25.6% |
| 0.5 < LRR <= 1.0 | 0 | 0% |
| 1.0 < LRR <= 2.0 | 0 | 0% |
| 2.0 < LRR <= 3.0 | 0 | 0% |
| 3.0 < LRR <= 4.0 | 0 | 0% |

|  |  |  |
| --- | --- | --- |
| Range (NSM) | Count | Percentage of total transects (n=82) |
| -70.5 <NSM <= -35.9 | 10 | 12.2% |
| -35.9 <NSM <= -23.9 | 13 | 15.9% |
| -23.9 <NSM <= -12.0 | 26 | 31.7% |
| -12.0 <NSM <=-10.0 | 6 | 7.3% |
| -10.0 <NSM <= 2.2 | 24 | 29.3% |
| 2.2 <NSM <= 4.3 | 2 | 2.4% |
| 4.3 <NSM <= 6.4 | 1 | 1.2% |

Table 3- Count statistic of the range, transect count of that range, and percentage occurring of that particular range off DSAS calculations from 1994-2007 LRR rates (left) and NSM distance (right).

The DSAS results, Figure 8 (left) display that there were relatively high LRR rates between the years of 1994- 2007. The high LRR erosion rates (Table 3, left) range from -5.0 to -3.0 (m/yr) and the highest LRR accretion rates range from 3.0 to 4.0 (m/yr). The most frequent LRR rate is -2.0 to -1.0 (m/yr) accounting for 30.5% of all transects calculated. The least frequent LRR rates are the accretion rates between -0.5 to 0.5 (m/yr) accounting for 25.6% of all transects calculated. For the NSM (Table 3, right), the highest erosion distance measurements range from to -35.9 meters (n= 10) and the maximum accretion distance measurements range from 4.3 to 6.4 meters (n= 1). The most frequent NSM distance is -10.0 to 2.2 meters accounting for 29.3% of all transects calculated. The least frequent NSM distance is the accretion distance between 4.3 to 6.4 meters accounting for 1.2% of all transects calculated. In the NSM analysis, there is only one transect line that falls in the maximum range of accretion, all other transects are displaying low to moderate erosion meter measurements.

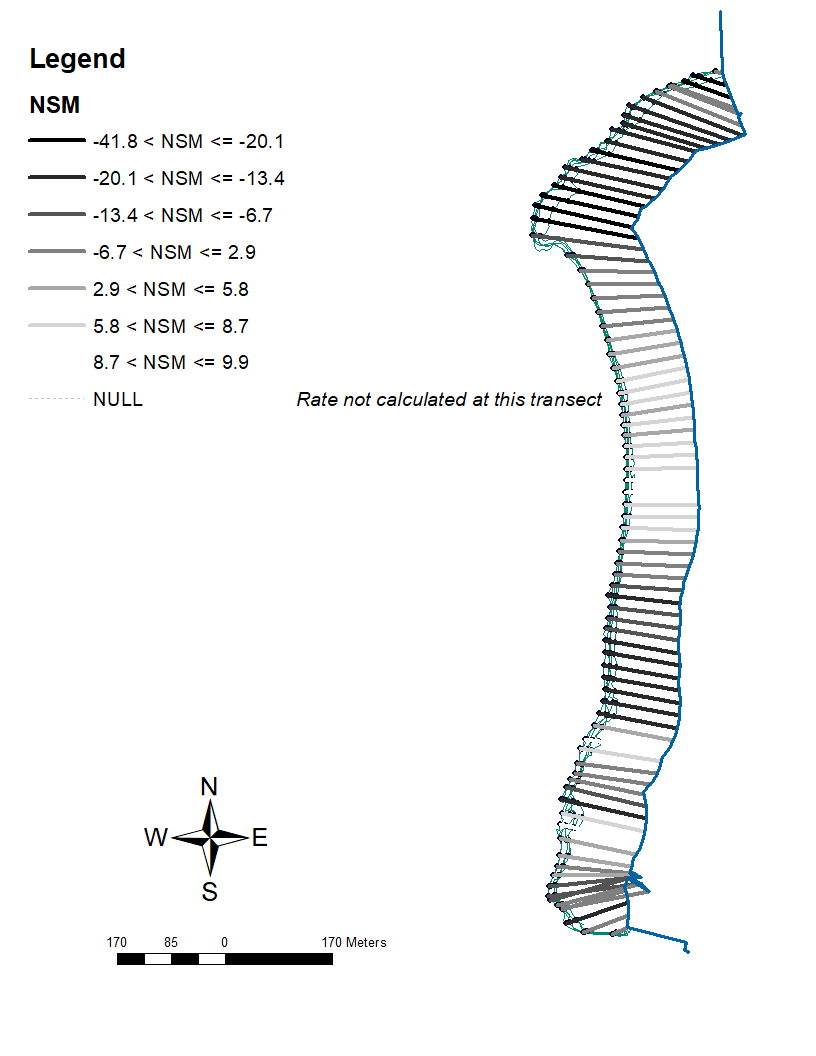
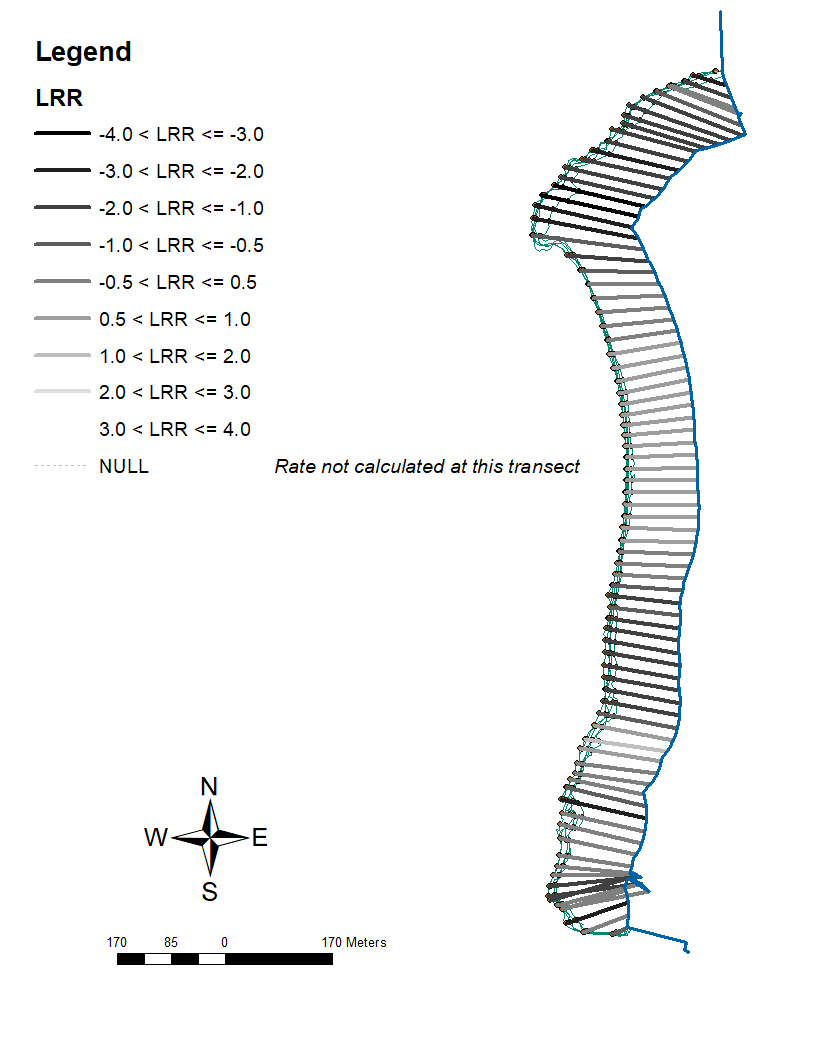
***3.2 Shoreline analysis from*** ***2010-2019***

Figure 9- Results of Linear Regression Rates model (left) and Net Shoreline Movement model (right). Shorelines are located on the west side of each panel. Baselines are located on the east side of each panel. The imagery used in this analysis is from 2010-2019.

|  |  |  |
| --- | --- | --- |
| Range (LRR) | Count | Percentage of total transects (n=82) |
| -4.0 < LRR <= -3.0 | 2 | 2.4% |
| -3.0 < LRR <= -2.0 | 6 | 7.3% |
| -2.0 < LRR <= -1.0 | 23 | 28.0% |
| -1.0 < LRR <= -0.5 | 8 | 9.8% |
| -0.5 < LRR <= 0.5 | 23 | 28.0% |
| 0.5 < LRR <= 1.0 | 19 | 23.2% |
| 1.0 < LRR <= 2.0 | 1 | 1.2% |
| 2.0 < LRR <= 3.0 | 0 | 0% |
| 3.0 < LRR <= 4.0 | 0 | 0% |

|  |  |  |
| --- | --- | --- |
| Range (NSM) | Count | Percentage of total transects (n=82) |
| -41.8 <NSM <= -20.1 | 6 | 7.3% |
| -20.1 <NSM <= -13.4 | 19 | 23.2% |
| -13.4 <NSM <= -6.7 | 10 | 12.2% |
| -6.7 <NSM <= 2.9 | 21 | 25.6% |
| 2.9 <NSM <= 5.8 | 10 | 12.2% |
| 5.8 <NSM <= 8.7 | 12 | 14.6% |
| 8.7 <NSM <= 9.9 | 4 | 4.9% |

Table 4 - Count statistic of the range, transect count of that range, and percentage occurring of that particular range off DSAS calculations from 2010-2019 LRR rates (left) and NSM distance (right).

The results displayed in Figure 9 demonstrate a different outcome compared to Figure 6. The high erosion LRR rates (Table 4, left) in this analysis range from -3.0 to -4.0 (m/yr) and the highest LRR accretion rates range from 3.0 to 4.0 (m/yr). The LRR erosion rates during 2010-2019 do not go as high as in 1994-2007. The most frequent LRR rate is -1.0 to -2.0 (m/yr) accounting for 28% of all transects calculated. The least frequent LRR rates are the accretion rates between 1.0 to 2.0 (m/yr) accounting for 1.2% of all transects calculated. For the NSM (Table 4, right), the highest erosion distance measurements range from -20.41 to -41.8 meters (n= 6) and the maximum accretion distance measurements range from 8.7 to 9.9 meters (n= 4). The most frequent NSM distance is -6.7 to 2.9 meters accounting for 25.6% of all transects calculated. The least frequent NSM distance is the accretion distance between 8.7 to 9.9 meters accounting for 4.9% of all transects calculated. The figure above depicts Deer Island as having moderate to high LRR erosion rates, while the NSM shows accretion in the center of the island with some acute high erosion locations in the north and south end of the island.

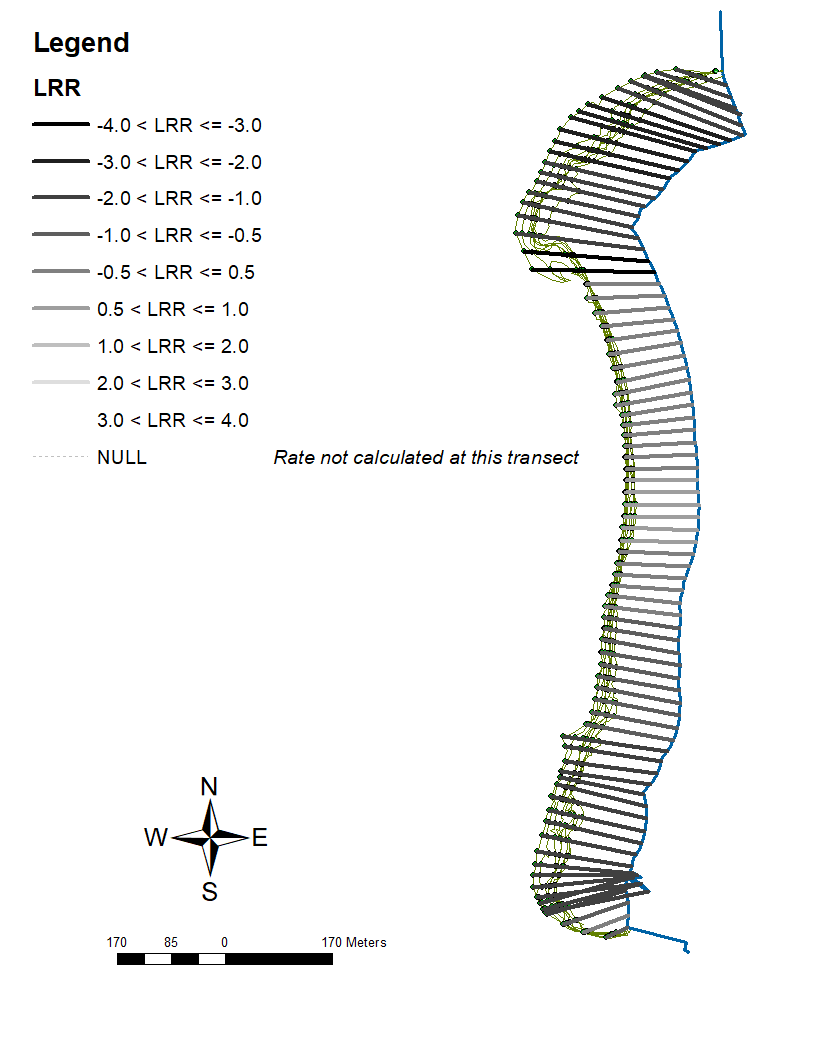
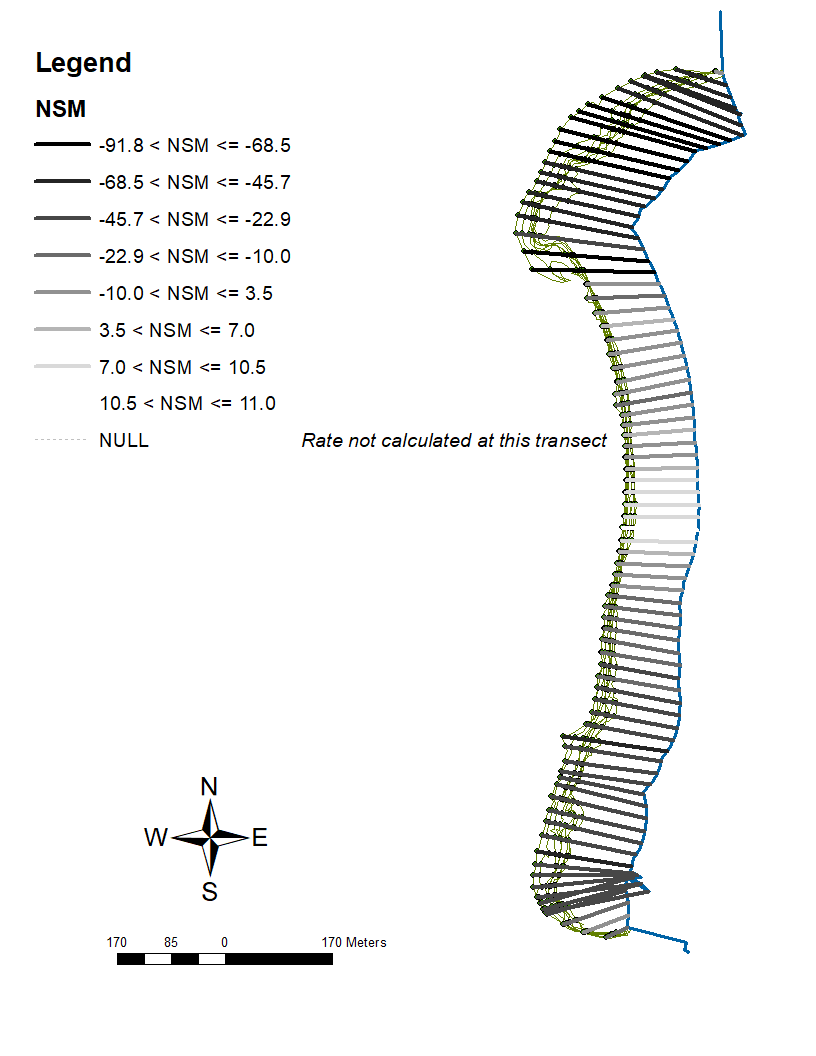
***3.3 Shoreline analysis from 1994-2019***

Figure 10- Results of Linear Regression Rates model (left) and Net Shoreline Movement model (right). Shorelines are located on the west side of each panel. Baselines are located on the east side of each panel. The imagery used in this analysis is from 1994-2019.

|  |  |  |
| --- | --- | --- |
| Range (LRR) | Count | Percentage of total transects (n=82) |
| -4.0 < LRR <= -3.0 | 2 | 2.4% |
| -3.0 < LRR <= -2.0 | 7 | 8.5% |
| -2.0 < LRR <= -1.0 | 32 | 39.0% |
| -1.0 < LRR <= -0.5 | 12 | 14.6% |
| -0.5 < LRR <= 0.5 | 23 | 28.0% |
| 0.5 < LRR <= 1.0 | 6 | 7.3% |
| 1.0 < LRR <= 2.0 | 0 | 0% |
| 2.0 < LRR <= 3.0 | 0 | 0% |
| 3.0 < LRR <= 4.0 | 0 | 0% |

|  |  |  |
| --- | --- | --- |
| Range (NSM) | Count | Percentage of total transects (n=82) |
| -91.8 <NSM <= -68.5 | 9 | 11.0% |
| -68.5 <NSM <= -45.7 | 15 | 18.3% |
| -45.7 <NSM <= -22.9 | 21 | 25.6% |
| -22.9 <NSM <= -10.0 | 11 | 13.4% |
| -10.0 <NSM <= 3.5 | 16 | 19.5% |
| 3.5 <NSM <= 7.0 | 4 | 4.9% |
| 7.0 <NSM <= 10.5 | 5 | 6.1% |
| 10.5 <NSM <= 11 | 1 | 1.2% |

Table 5 - Count statistic of the range, transect count of that range, and percentage occurring of that particular range off DSAS calculations from 1994-2019 LRR rates (left) and NSM distance (right).

|  |  |
| --- | --- |
| total number of transects | 82 |
| average distance | -29.1 |
| number of transects with negative distance | 67 |
| percent of all transects that have a negative distance | 81.70% |
| maximum negative distance | -91.71 |
| maximum negative distance transect ID | 12 |
| average of all negative distances | -36.83 |
| number of transects with positive distance | 15 |
| percent of all transects that have a positive distance | 18.29% |
| maximum positive distance | 10.91 |
| maximum positive distance transect ID | 44 |

Table 6- Summary statistics calculated by DSAS, DISTANCE: NSM (Net Shoreline Movement, m)

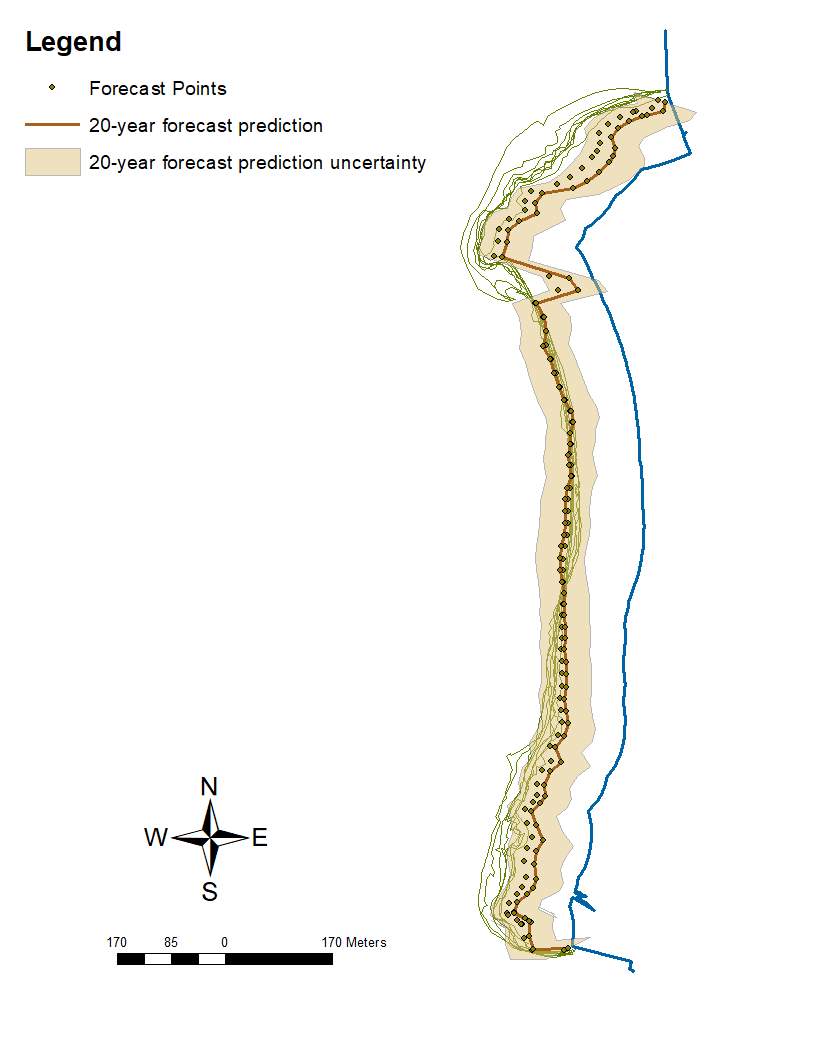
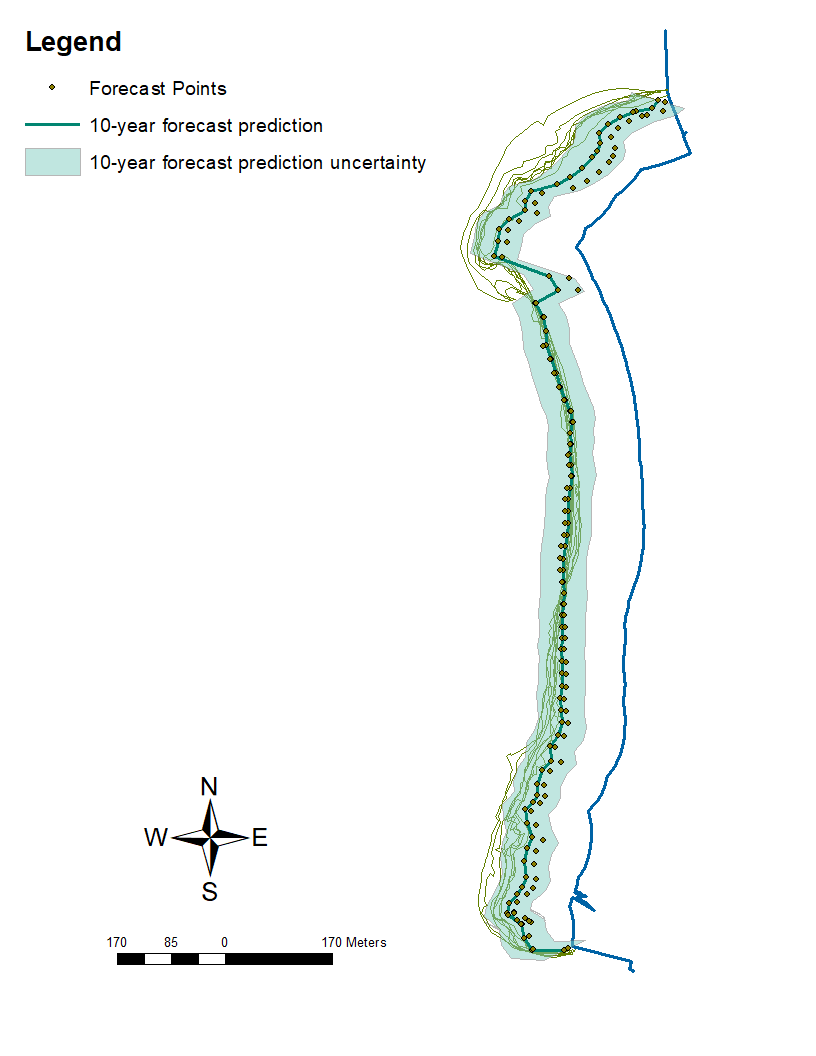
|  |  |
| --- | --- |
| total number of transects | 82 |
| average rate | -0.95 |
| average of the confidence intervals associated with rates | 0.49 |
| reduced n (number of independent transects) | 900.00% |
| uncertainty of the average rate using reduced n | 0.17 |
| average rate with reduced n uncertainty | -0.95 +/- 0.17 |
| number of erosional transects | 63 |
| percent of all transects that are erosional | 76.83% |
| percent of all transects that have statistically significant erosion | 69.51% |
| maximum value erosion | -3.32 |
| maximum value erosion transect ID | 22 |
| average of all erosional rates | -1.33 |
| number of accretional transects | 19 |
| percent of all transects that are accretional | 23.17% |
| percent of all transects that have statistically significant accretion | 10.98% |
| maximum value accretion | 0.62 |
| maximum value accretion transect ID | 44 |
| average of all accretional rates | 0.31 |

Table 7- Summary statistics calculated by DSAS, RATE: LRR (Linear Regression Rate, m/yr)

The results in Figure 10 includes all the shorelines from Figures 8 and 9 for its LRR and NSM calculations. The high erosion LRR rates (Table 5, left) in this analysis range from -3.0 to -4.0 (m/yr) and the highest LRR accretion rates range from 0.5 to 1.0 (m/yr). The most frequent LRR rate is -1.0 to -2.0 (m/yr) accounting for 39% of all transects calculated. The least frequent LRR rates are the accretion rates between 0.5 to 1.0 (m/yr) accounting for 7.3% of all transects calculated. For the NSM (Table 5, right), the highest erosion distance measurements range from -91.8 to -68.5 meters (n= 9) and the maximum accretion distance measurements range from 10.5 to 11 meters (n= 1), which is also the least frequent NSM distance. The most frequent NSM distance is -45.7 to -22.9 meters accounting for 25.6% of all transects calculated. The largest erosion measurement distance is seen at the north end of Deer Island, while the middle has some areas of accretion and light erosion. The south side of Deer Island has some acute peaks of erosion, however not as high as the north end.

Tables 6 and 7 display the statistics summary generated by DSAS. In the NSM statistics summary there are a total of 67 transects with a negative distance making up 81.70% of all transect. The maximum negative distance (erosion) is 91.71 meters, while the maximum positive distance (accretion) is 10.91 meters. For the LRR analysis the average rate of yearly erosion is 0.95 meters. For erosional transects (n=63) the average rate is -1.33 m/yr while for accretional transects (n=19) the average rate is 0.31 m/yr. The LRR analysis clearly shows that erosion is occurring at 4 times the rate of accretion on our study site.

***3.4 Shoreline analysis for 10 and 20-year prediction***

Figure 11- Shoreline prediction for 10-year (left) and 20-year (right), including uncertainty. Shorelines are located on the west side of each panel. Baselines are located on the east side of each panel. Forecast points were created by DSAS to assist in the prediction model. The thicker black (left) and brown (right) lines depict the DSAS shoreline prediction. The lighter shaded region indicates the uncertainty of the predicted shoreline.

The DSAS calculations for future shoreline predictions are depicted in Figure 11. The 10-year prediction (left) demonstrates a uniformity of erosion particularity in the south and center of Deer Island. The north end of Deer Island has an acute area right before the shoreline bulge that is projected to be completely eroded by the 10-year prediction. The center of Deer Islands has a slight accretion area, but the majority of the 10-year projection is predicting that the west shoreline of Deer Island will erode. The 20-year prediction is very similar to the 10-year prediction model, but with more drastic erosion in the north end. The most eroded section of Deer Island (toward the north end) is getting close to the baseline.

**4. Discussion and conclusion**

Despite analyzing such brief time periods on a small shoreline, many changes have occurred. Note that in Figure 8, a small hook shoreline feature (on the north end) can be observed and is completely gone by the time period of Figure 9. Even erosion of small features such as that hook like shoreline can make an impact on the available habitats for animals. Many species depend on shorelines for food, nesting, and shelter (O'Connell et al., 2005). Shorebirds rely on shorelines for feeding habitats during migration in the winter months. Habitat loss, due to erosion, limits the availability of food and resources for these shorebirds, possibly resulting in increased competition. This increased competition may exclude individuals from a foraging site, increase mortality rates for these excluded shorebirds, and ultimately lead to limitations in numbers (Galbraith et al., 2002). The Big Bend region of Florida is already experiencing low shorebird species richness and population abundance, implying that an area already struggling with species biodiversity, despite the lack of human impact, will at least have negative shorebird impacts because of consistently eroding shorelines. During a high erosion storm event, many sandy-shore animals may also be washed up to shore, stranded up shore, or left to die due to exposure. Sandy- shore creatures naturally are able to survive storm events due to their defense mechanisms but are not always able to survive in the event of significant shoreline erosion (Brown and McLachlan, 2002). Whether shorelines erode slowly, but constantly, or in a storm event, extreme shoreline erosion negatively impacts animal species.

Results in this analysis suggest that more shoreline erosion occurred during the 1994- 2007 time frame compared to the later time frame of 2010-2019. The transects results depict more erosion in the NSM analysis (Figure 8, right) than compared to the time frame of 2010- 2019 analysis (Figure 9, right). It is curious for us to think about how and why this seemingly obvious drastic NSM erosion has occurred in the earlier time frame analysis. A year prior to the first imagery in the time series the Storm of the Century hit the Big Bend region. There is evidence during this storm event that sandy coasts were susceptible to shoreline erosion (Goobred and Hine, 1995). Years of dramatic storm clusters in the Gulf of Mexico (1994- 2015, retreat erosion rate of − 5.49 ± 1.4 m/year) indicate significant morphological changes of the coast and could have possibly delayed natural beach recovery (Sankar et al., 2018). Despite the Storm of the Century happening prior to our shoreline analysis, an abrupt shoreline change due to an intense weather event coupled with SLR might have triggered an unbalance of natural erosion and accretion rates on Deer Island during the 1994- 2007 time frame, especially considering storm clusters encompassed this time frame.

It is interesting to note, that although the overall shoreline experienced erosion, there is evidence accretion might have occurred in the middle of the shoreline during 2010-2019 (Figure 9). Table 6 notes that only a total of 10.91 meters was gained in accretion. Accretion for our study site can only come from intense meteorological events since there is a scant supply of sand being dispersed by the Suwannee River (Goodbred et al., 1998). However, it is unclear how much accretion can occur with the perpetuation of sea- level rise consistently stressing the sandy shoreline substrate. Sea-level rise has the second greatest effect on shoreline change on the east side of Florida, but has very similar effects on the west side. There is a possibility for Florida to provide beach nourishment to areas where erosion is evident, but with increasing sea-level rise competing, it may be difficult to evaluate shoreline change (Houston, 2019). Currently there is no schedule to provide beach nourishment to our study site.

During this study, one main source of error arises with the missing imagery years 2007- 2008 and 2011- 2012. If those missing years were available for analysis, it would provide a closer interpretation of the true erosion differences between the two 12 to 13-year time periods. Since our study site is uninhabited and remote, it is not surprising to see that NAIP is not contracted to fly over this area every year. Overall, we are able to see that erosion has occurred through the majority of the shoreline. Another source for possible errors are the digitization of each shoreline. Since each available imagery was used to digitize the years’ shoreline, the digitization of each shoreline might not be exact. However, the resolution of each image was at least 1-meter resolution, which may be considered “high” resolution in comparison to 30-meter resolution from Landsat 7 and 8 (Fisher et al., 2017), which Landsat imagery can also be used for analysis. The higher the resolution is, the more likely the digitized shorelines are accurate. Errors can arise within individual variability while digitizing.

The prediction models are based on a linear regression rate calculated by DSAS, termed Kalman filter (Kalman, 1960). The Kalman filter conducts an analysis to minimize the error between the observed and modeled shoreline position to develop the forecast where the rate and uncertainties are considered (Long and Plant, 2012). Our prediction models project that more shoreline erosion is to be expected (Figure 11). This be can concerning since currently our study site is not impacted by human development, however that may change in the future if people do decide to build residential or commercial properties. The prediction models may be used as a reliable source of information for land management directors who seek to protect uninhabited shorelines along the Big Bend.

This study has revealed brief historical trends of coastal evolution along an undeveloped sandy shoreline. This study may enhance the database of historical shoreline analysis in Florida. The shoreline statistics revealed elevated rates of erosion during the first-time frame 1994-2007. Storm and storm clusters may significantly impact barrier island morphology. Long term sea-level rise and sediment supply are considered major factors that stimulate shoreline erosion and/or accretion (Sankar et al., 2018), which may be contributing to the consistent erosion of our study site. This research has proven that sandy shorelines are susceptible to rates of high erosion that may lead to permanent shoreline loss.

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