THE GEO PROJECT
GEOSPATIAL EDUCATION & OUTREACH

www.geoproject.msstate.edu

TECHNICAL REPORT
NO. 5101

GEOSPATIAL ASSESSMENT OF SHIP ISLAND EROSION - DSAS TECHNICAL REPORT

Claire Babineaux
John Cartwright
Randall McMillen

Geosystems Research Institute
Mississippi State University

APRIL 2023

This work was supported through funding by the National Oceanic and Atmospheric Administration Regional Geospatial Modeling Grant, Award # NA19NOS4730207.

GRI

MISSISSIPPI STATE UNIVERSITY EXTENSION

NGI
NORTHERN GULF INSTITUTE

GEOSYSTEMS RESEARCH INSTITUTE, MISSISSIPPI STATE UNIVERSITY, BOX 9627, MISSISSIPPI STATE, MS 39762-9652

The Geospatial Education and Outreach Project (GEO Project) is a collaborative effort among the Geosystems Research Institute (GRI), the Northern Gulf Institute (a NOAA Cooperative Institute), and the Mississippi State University Extension Service. The purpose of the project is to serve as the primary source for geospatial education and technical information for Mississippi.

GEOSPATIAL ASSESSMENT OF SHIP ISLAND EROSION – DSAS TECHNICAL REPORT

Claire Babineaux[1] (claireb@ngi.msstate.edu)
John Cartwright[2] (johnc@gri.msstate.edu)
Randall McMillen[2] (randall@gri.msstate.edu)

[1] Northern Gulf Institute
[2] Geosystems Research Institute, Mississippi State University

INTRODUCTION

Coastal erosion is the process by which sediment is moved along a coast or removed from the environment by factors such as sea level changes, wave action, or flooding. Although coastal erosion affects all regions of the United States, the resulting impacts are highly localized to the regional environment, population, and economy (U.S. Climate Resilience Toolkit, 2021). The extent and severity of erosion increases as sea level rises and storm frequency intensifies.

In the United States, approximately 40% of the population lives in the coastal counties. In Mississippi, approximately 13% of the total population lives in one of the coastal counties. Approximately 5% of the state population is employed there earning over $6 billion and contributing more than $16 billion to the Nation's gross domestic product (NOAA OCM, 2022).

In the Gulf of Mexico, vast areas of coastal land have been lost or destroyed since the mid-1800s due to a combination of natural processes and human activities (Morton, 2008). Major storms cause dramatic land loss and substantial property damage about every 10 years (Morton, 2003). In recent years, the frequency and intensity of storms have increased. Monitoring shoreline position changes becomes more valuable because it specifies the dynamics between sea-level change, sediment supply, hydrography, and meteorology (Bush & Young, 2009).

Geospatial technologies are useful in identifying areas impacted by coastal erosion and other hazards, especially as the environment changes. These technologies are useful in helping to detect, track, and assess shoreline changes over time (Paris et al., 2013). Some causes of shoreline change include changes in sea level, storm occurrence, littoral drift, infrastructure, maritime shipping, and tourism. Shoreline change data are critical in providing a sound scientific basis for coastal management as well as understanding setbacks, change rates, assessments of hazard and risk, and coastal planning (Bush & Young, 2009). This information can also provide additional impact data on the type of shoreline engineering and management techniques required (Bush & Young, 2009).

Some historical approaches to shoreline delineation and mapping include deciphering hand-drawn maps, topographic sheets (T-sheets), and plane table surveys. With the advent of aerial imagery, the efforts to determine shorelines became more coordinated but less straightforward due to the amount of interpretation required by investigators (Paris et al., 2013).

As technology progresses, so do the methods for shoreline extraction. For example, ground-based systems, such as GPS, have been used to locate and capture the shoreline with a degree of interpretation by the operator. With GPS, the shoreline is often captured by mounting the device on an all-terrain vehicle or pole and traversed along the wet/dry line or other visible shoreline proxy with shoreline position coordinates captured automatically along the way (Paris et al., 2013).

Satellite and aerial-based technologies, such as radar and lidar, present investigators options of using geographic information systems (GIS), coupled with photogrammetry, for shoreline extraction and demarcation with high levels of accuracy and precision. Lidar-derived shorelines can be used to study large-scale impacts of storms on beaches (Stockdon et al., 2002). Multiple profiles that are closely spaced along the shore from the same location can be useful in resolving small-scale details, such as topography and morphologic change, in addition to determining natural variability of shoreline position (Stockdon et al., 2002). By using a lidar-based digital elevation model (DEM), a shoreline can be identified and extracted by first locating the elevation contour whose z-value matches a specified sea-level (orthometric) height or tidally derived datum (Paris et al., 2013).

Routine mapping of barrier systems using lidar and extraction of DEMs from historical aerial photogrammetry has permitted mapping of pre- and post-storm topography along large sections of barrier coastline and documents the response of the coast to intense storms (Davidson-Arnott, 2010). The purpose of this study was to analyze shoreline erosion temporally and identify areas on barrier islands impacted by erosion using geospatial technology and data, specifically lidar and high-resolution DEMs. These efforts can be used to help provide an understanding of historical shoreline movement, aide in the planning of future mitigation projects, and analyze barrier island migration.

BARRIER ISLANDS

Barrier islands are a constantly changing deposit of sand that forms parallel to the coast and are considered critical to protecting coastal communities and ecosystems from extreme weather. (NOAA, 2021; Davis & Fitzgerald, 2009). Some of the benefits of barrier islands include protection of coastlines from severe storm damage and the creation of habitats for wildlife (NOAA 2021; Davidson-Arnott, 2010; Klee, 1999).

Barrier islands need sediment, a transport agent, and an accumulation site to form (Klee, 1999). Because they are not attached to the mainland, barrier islands migrate relatively rapidly (geologically) in response to changing sea level and sediment supply, with significant movement occurring in response to large storm events (Davidson-Arnott, 2010; Hyndman & Hyndman, 2006).

Barrier islands occur on gently sloping coastal plains in many parts of the world and tend to form chains of islands, separated by tidal inlets that run parallel to the mainland coast and enclose a bay or lagoons that is typically 1-5 km wide (Davidson-Arnott, 2010; Davis & Fitzgerald, 2009). Offshore barrier islands are typically about 0.4 to 4 kilometers wide and stand less than 3 meters above sea level (Hyndman & Hyndman, 2006). Generally, barrier islands are wide where the supply of sediment is abundant and are relatively narrow where erosion rates are high or where the source of sediment was scarce during formation (Davis & Fitzgerald, 2009). The length of the island is partially a function of sediment supply but is also related to the energy (wave v. tidal) of the region (Davis & Fitzgerald, 2009).

Mississippi-Alabama Barrier Islands

Along the central gulf region, the Mississippi barrier islands stretch from Cat Island in the west to Petit Bois Island in the east. Each of the MS barrier islands have a unique evolutionary history that has altered its shape, position, and future vulnerability to storm impacts (Morton, 2008). For the Mississippi portion, the eastern islands (Petit Bois and Horn) are dominated by westward migration and the western islands (Ship and Cat) are typified by erosion (Figure 1) (Schmid, 2000).

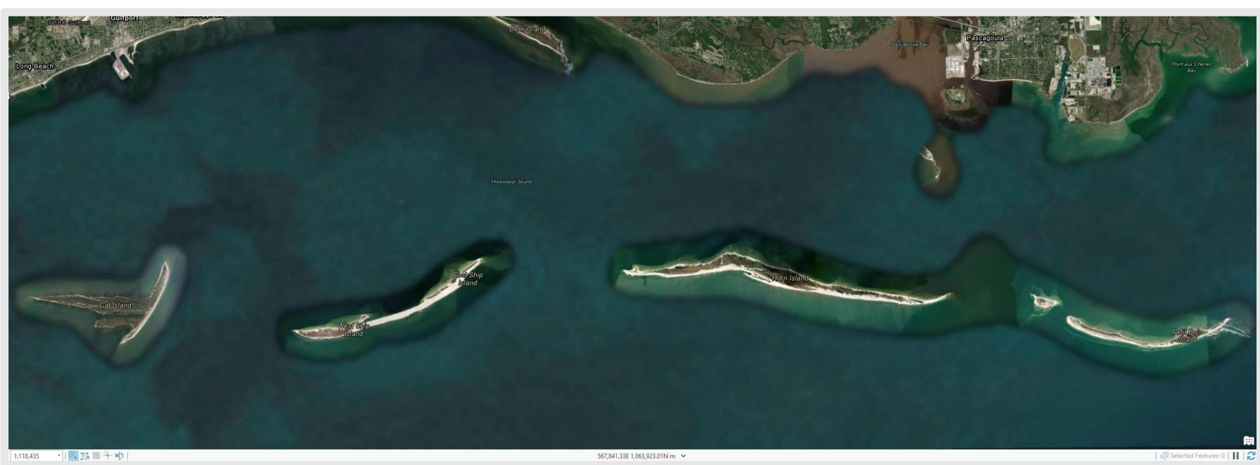

Figure 1: The barrier islands of Mississippi. From left to right: Cat, Ship, Horn, and Petit Bois Islands.

Study Area: Ship Island, MS

Located approximately ten miles south of Biloxi, Mississippi, Ship Island consists of East and West Ship Island. Currently the east and west islands are connected by a mitigation project along the narrow low tide bar historically known as Camille Cut. (Figure 2).

Figure 2: 2020 NAIP Imagery of Ship Island (USDA).

Ship Island was selected as the study area for this project due to its location and extensive morphological history. Ship Island serves as a recreational space, as well as a protective structure shielding coastal Mississippi from territorial losses due to hurricanes, extreme weather, and climate change (Casey, 2019). Ship Island has experienced robust changes to its shape and location of each major segment (Morton, 2008):

- Eastern: retreat along eastern spit and erosion of triangular segment
- Central: retreated landward
- Western: narrowed due to perimeter erosion

The morphological history of the island is dynamic because the island is historically prone to breaching by storms (Morton, 2008). Ship Island has experienced rapid evolution in its extent, especially since being breached by the 1947 Hurricane and then again by Hurricane Camille (Schmid, 1999). Historically, the island has been breached at least five times since 1850 (1852, 1893, 1947, 1965, 1969) (Morton, 2008; Nummedal et al., 1980).

Since Ship Island was breached by Hurricane Camille in 1969, the two resulting islands have evolved independently. West Ship Island has a higher elevation and a larger sand resource (dunes) than East Ship and is a more stable island (Schmid, 2003). Historically, East Ship Island is eroding and retreating, while West Ship Island generally progrades toward the northwest. Ship Island is the only barrier island in the Northern Gulf of Mexico to be associated with the geomorphic classification of rotational instability as opposed to translation (Figure 3) (Schmid, 2001).

Through a restoration project completed in 2019 by the US Army Corps of Engineers (ACOE), Ship Island is once again a continuous island. The restoration project eliminated what was called the “Camille Cut”. Restoration on the island also occurred near Fort Massachusetts to protect the fort from frequent inundation and destruction (Morton, 2008).

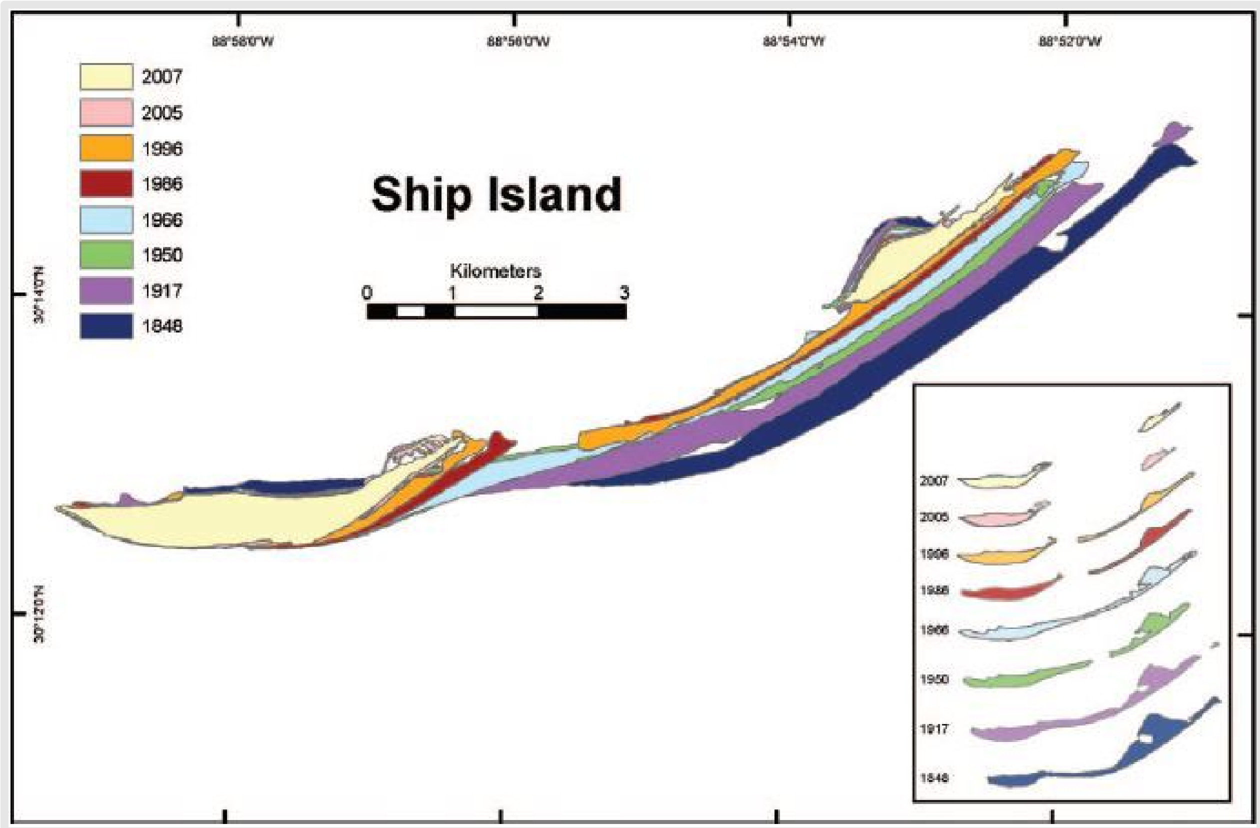

Figure 3: Morphological and spatial changes in Ship Island between 1848 and 2007, based on historical shorelines. From Morton, 2008.

The gulf shoreline of West Ship Island was selected as the area of interest because of the island’s location, dynamic morphological history, consistency of data across the selected time series, and the presence of infrastructure on the island (Figure 4). West Ship Island has three distinct morphological regions that can be seen labeled in Figure 4 (Schmid, 2001):

a. the lower elevation western portion of the island (A)
b. the hummocky dune portion on the eastern portion of the island (B)
c. the eastern spit (C)

West Ship Island was analyzed for shoreline erosion from the southern side that is influenced directly by the Gulf of Mexico. To mitigate the effects of the restoration project connecting the two islands, the 2019 lidar-derived shoreline was clipped to match the general trend of the previous shorelines in the time series (Figure 5).

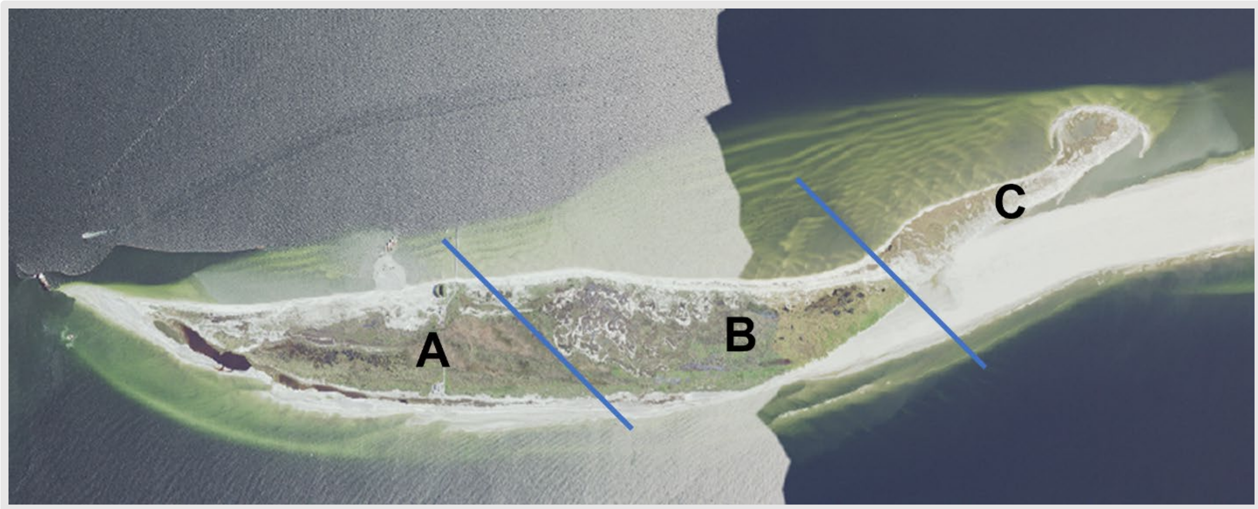

Figure 4: 2020 NAIP Imagery of West Ship Island (USDA).

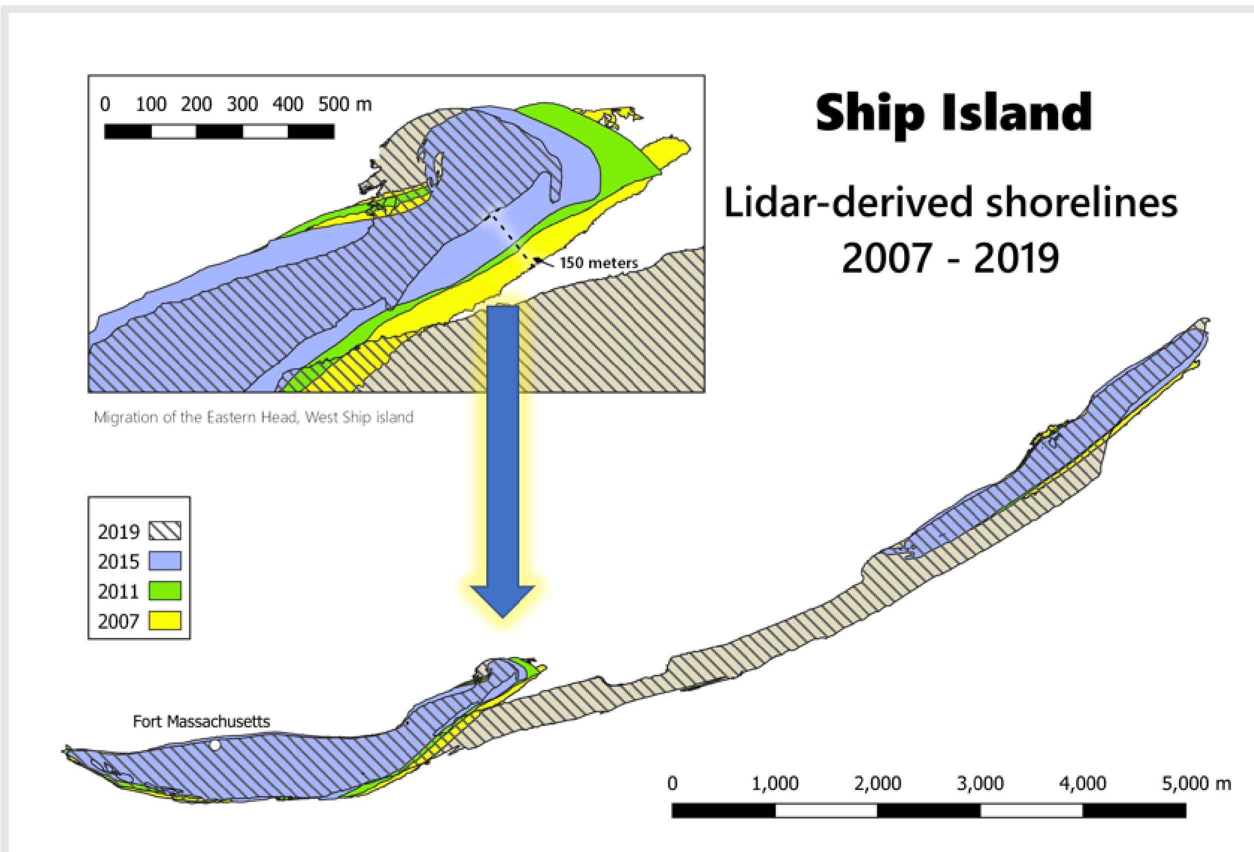

Figure 5: Morphological and spatial changes in Ship Island between 2007 and 2019 based on lidar-derived shorelines (GEO Project).

METHODS

This project incorporated lidar derived shorelines for shoreline change analysis. To maintain consistency across the data, DEMs were created for each year used in this project. All data preparation was completed using ArcGIS Pro 2.7, whereas analysis and forecasting were completed using ArcMap 10.8.1 (Figure 6).

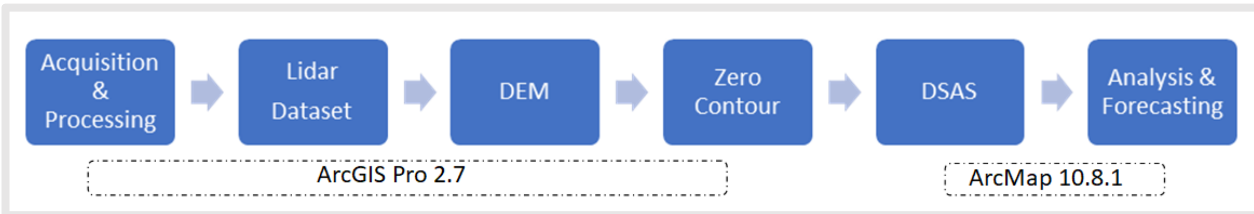

Figure 6: The generalized process from downloading the lidar datasets to final stages of analysis

Data Acquisition & Processing

Elevation datasets for this project were obtained from MARIS and NOAA's Digital Coast for use and analysis with ArcGIS Pro 2.7 and ArcMap 10.8.1. Datasets include lidar and DEM data collected every four years over a 12-year period (2007 – 2019) covering a consistent area of the Mississippi Gulf Coast.

The lidar (LAS) datasets were converted to DEMs using the *LAS Dataset to Raster* tool in ArcGIS Pro 2.7. For each year, this tool produced a raster using elevation values stored in the lidar points referenced by the LAS dataset. Once in a raster format, shorelines were delineated.

All the lidar datasets are QL1 or better, meaning they have a point spacing of 1 m or less (Table 1).

Table 1. Datum information.

Year	Projection	Zone	Horizontal	Vertical	Units	Grid spacing
2007	UTM	16N	NAD83	NAVD88 GEOID12B	Meters	1 meter
2011	UTM	16N	NAD83	NAVD88 GEOID12B	Meters	1 meter
2015	UTM	15N	NAD83 (2011)	NAVD83 GEOID12A	Meters	0.7 meters
2019	UTM	16N	NAD83 (2011)	NAVD88 GEOID12B	Meters	1 meter

Defining & contouring the shoreline

An idealized definition of the shoreline is that it coincides with the physical interface of land and water (Dolan et al., 1980). It is easy to define but difficult to capture since the water level is always changing (Li et al., 2001). Shoreline positions change continuously through time due to sediment movement through the system, therefore shorelines should be considered in a temporal sense, and the time scale will be dependent on the nature of the investigation (Boak & Turner, 2005).

A shoreline indicator is a feature that is used as proxy to represent the “true” shoreline position (Boak & Turner, 2005). Other studies have used a combination of the high-water line (HWL) and mean high water (MHW) lines in addition to a variety of indicators, including but not limited to debris lines, high tide water levels, and instantaneous water lines. These indicators are important due to the dynamic nature of the idealized shoreline boundary. For this study, the shoreline is defined as the point where land and water meet. In this case, a contour of 0m elevation was used to define this interaction and is considered the shoreline for this study.

To obtain a contour of zero, the *Contour List* tool was used. This tool allows the user to specify an individual value which will produce a single contour line. This tool is available in both the Spatial Analyst and 3D Analyst extensions within ArcGIS Pro 2.7. It generates contour lines by joining points of the same elevation using linear interpolation to produce a feature class of user specified contours from the raster surface. In this case, only one contour of zero meters (0m) was created with the result being a vector line delineating land from water.

For each year used in this study, lidar datasets were converted to DEMs from which shorelines were derived (Figure 7). Shorelines were delineated by identifying areas of 0 meters in elevation allowing for the identification of the interface between land and water, based solely on elevation. This approach eliminates some of the subjectivity associated with visual shoreline identification based on tonal gradation or wet-dry lines (Paris et al., 2013).

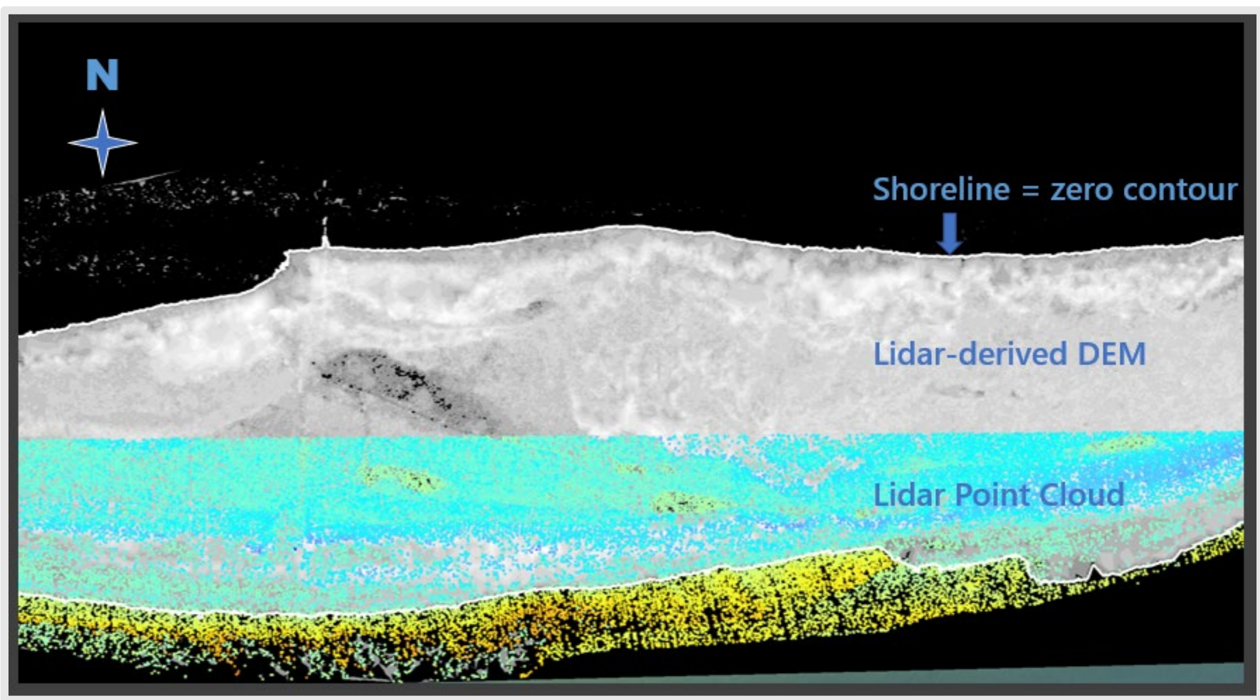

Figure 7: Lidar datasets for each year used in the study were processed into DEMs from which a zero contour could be extracted for use as a shoreline in the DSAS process.

DSAS Application

The Digital Shoreline Analysis System (DSAS) v5 software is an add-in to Esri ArcGIS desktop (10.4-10.7) developed by the U.S. Geological Survey that enables a user to calculate rate-of-change statistics from a time series of vector shoreline positions (Himmelstoss et al., 2021). Some features of the DSAS add-in include rate calculations, data visualization, statistical data, and shoreline forecasting (Figure 8). DSAS is effective in measuring historic shoreline geometry, identifying areas affected by morphological and temporal changes within the coastal environment (Himmelstoss et al., 2018). It should be noted that DSAS is useful to address features that can be represented as vectors, representing a particular point in time (Oyedotun, 2014).

Figure 8: The DSAS add-in toolbar (Himmelstoss et al., 2018).

The DSAS process includes acquisition and initial processing of the data, identifying shorelines and baselines, setting parameters, compiling metadata, setting transect parameters (length and spacing), and casting transects. Once transects are successfully cast, rate-of-change statistics can be calculated (Figure 9). Some of the useful capabilities of DSAS include:

- *Data visualization* allows for the display of statistical results on the transects via color ramps and aides in visually identifying areas of erosion and accretion.
- *Statistical calculations* allow for the evaluation of the nature and trend of shoreline dynamics (Oyedotun, 2014).
- *Shoreline forecasting* is useful in representing the possible future placement of the shoreline based on the data used.

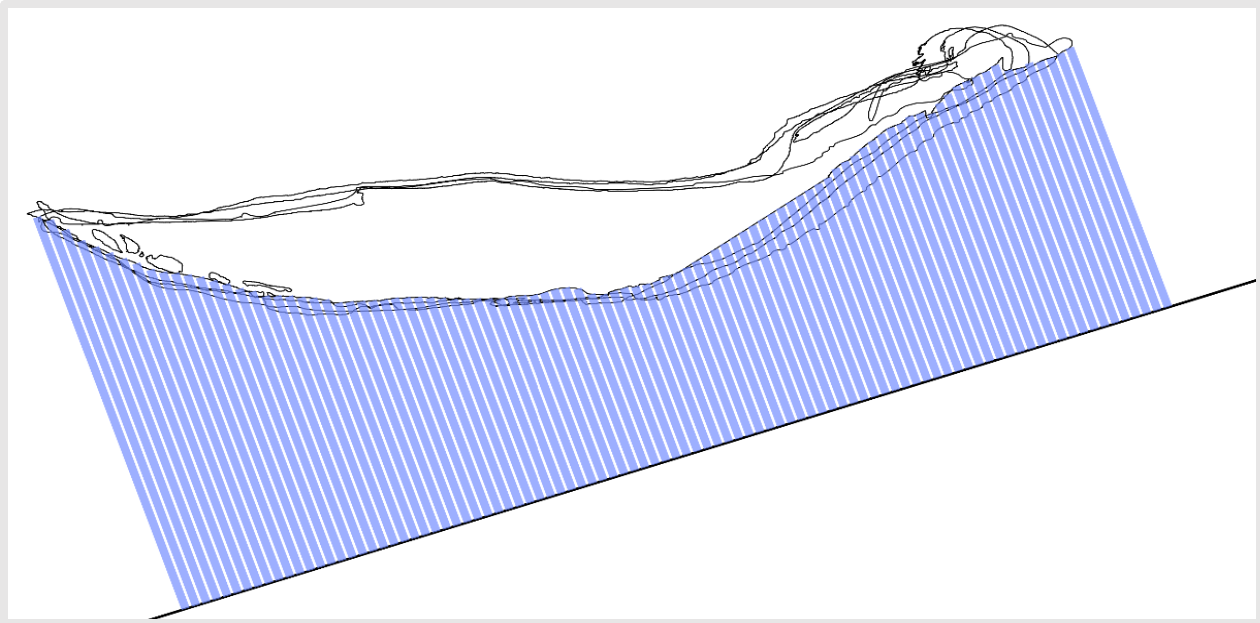

Figure 9: Example of cast transects within the DSAS Tool.

Forecasting

The forecasting capabilities of the tool are useful in gaining an better understanding for potential locations of the shoreline based on historical position data (Himmelstoss et al., 2021). The forecasting tool pulls the information for the data included in the study and provides the user with a 10-year and 20-year forecast line as well as positional uncertainty. It uses the Kalman filter to forecast future shoreline positions by combining observed with model-derived positions (Himmelstoss et al., 2018, 2021). Using the DSAS calculated linear regression rate it will estimate the position and change of the shoreline for every tenth of a year and then estimates the positional uncertainty for each time step (Himmelstoss et al., 2018, 2021). When the prediction is displayed, it is recommended that the uncertainty band is also displayed to visualize the uncertainty associated with the prediction (Himmelstoss et al., 2021).

While linear regression rate may be calculated with three or more shorelines, shoreline forecasting is not available for data with fewer than four shorelines. Thus, a shoreline forecast will not be calculated if the input data include fewer than four shoreline dates (Himmelstoss et al., 2018, 2021). Accurately predicting future sizes, configurations, and positions of the MS barrier islands depend on an accurate record of geological and historical changes to the islands, and knowledge of potential future conditions such as rates of sand supply, sediment transport, sea level rise, and storm frequency and intensity (Morton, 2008).

RESULTS

Changes in shoreline position were evaluated using transects cast perpendicular to an offshore baseline in DSAS v5. For this process, the following parameters were used:

- Search distance = 2500 m

- Transect spacing = 50 m
- Smoothing distance = 2500 m (default upper limit of effectiveness)
- Transects were clipped to the Shoreline Change Envelope

The baseline for this project was digitized as a single line that parallels the general trend of the study area along the gulf side of West Ship Island (Figure 9) for analysis.

Linear Regression Rate

The Linear Regression Rate (LRR) determines a rate-of-change statistic by applying a best-fit line to all shorelines along a specific transect. The slope of the line is an estimate of the shoreline rate-of change (Dolan et al., 1991). Although there is erosion along the length of the island, the highest rates are predominantly along the eastern spit and along the western edge (Figure 10).

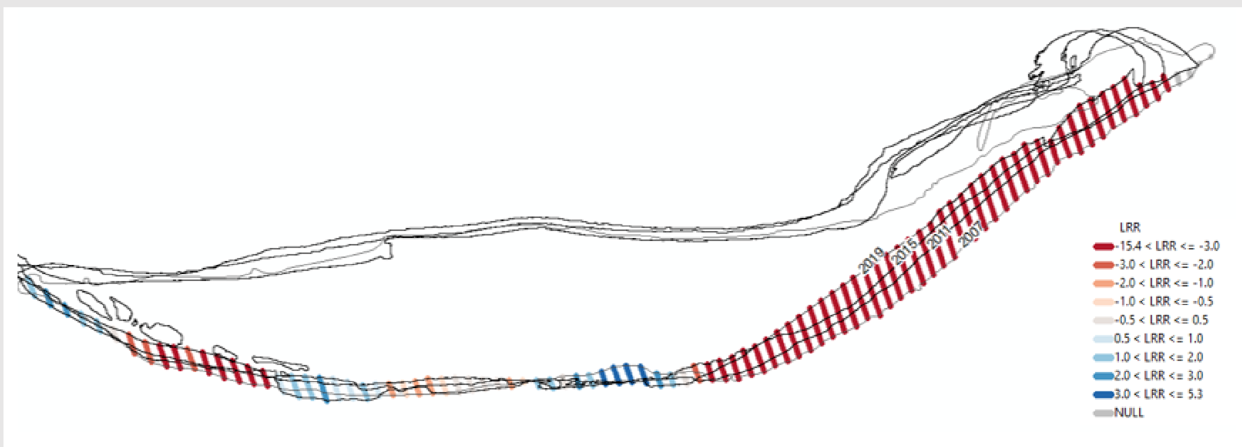

Figure 10: LRR output for West Ship Island, MS.

These results were compared to the US Geological Society's (USGS) Coastal Change Hazards Portal (Figure 11). The short-term LRR for this area in the Portal are representative of short-term rates calculated using three or more shorelines for a time of approximately 30 years from 1960 and later. Areas of higher rates of erosion coincide with those representing the extreme short-term rates in Figure 10.

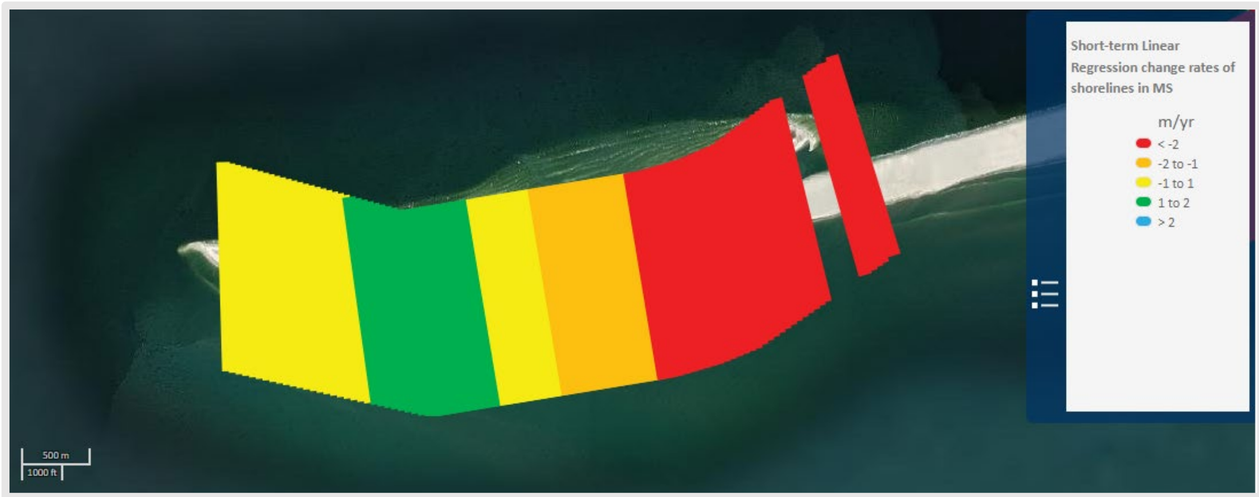

Figure 11: Short-term Linear Regression change rates of shoreline erosion for Ship Island, MS (Himmelstoss et al., 2017c).

Net Shoreline Movement

Net Shoreline Movement (NSM) is the distance between the older and more recent shorelines. The leading edge on the eastern spit was the most impacted with other areas along the western end and central portion are also impacted by moderately high erosion rates (Figure 12).

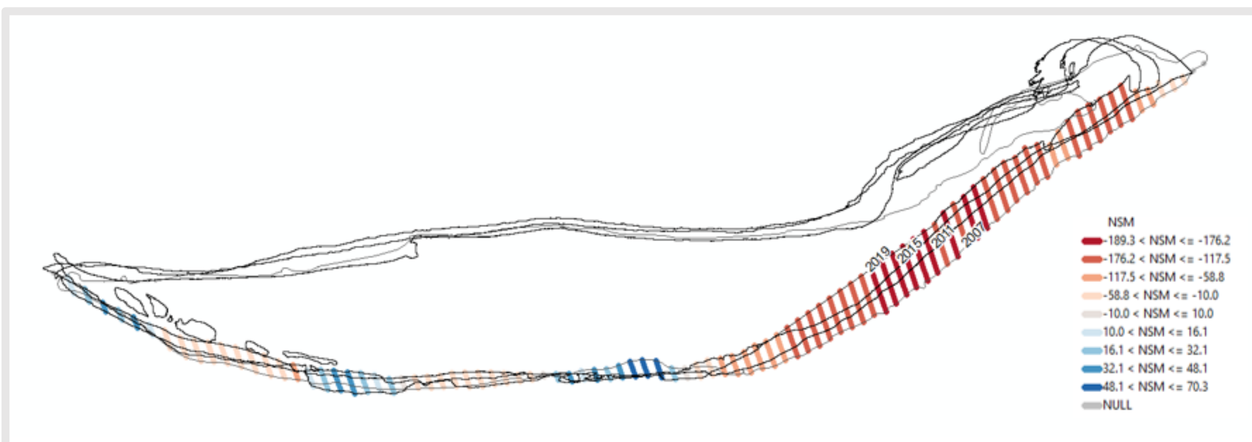

Figure 12: NSM output for West Ship Island, MS.

End Point Rate

The End Point Rate (EPR) is the calculation of the distance of total shoreline movement divided by the time between the oldest and youngest shorelines. The EPR is the most used method for calculating short term rates of change and only requires two shorelines (Dolan et al., 1991). The highest areas of EPR are along the eastern spit (Figure 13).

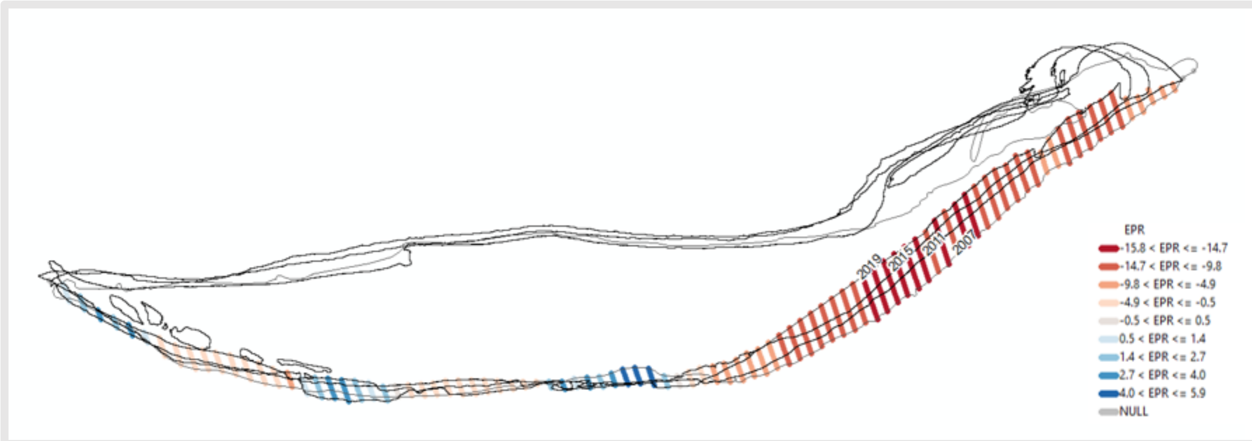

Figure 13: EPR output for West Ship Island, MS.

Shoreline Change Envelope

The Shoreline Change Envelope (SCE) is a measure of the total shoreline movement considering all available shoreline positions and reporting distances without reference to specific dates. Despite the change in color ramp, there is consistency with which part of the island has experienced the most erosion. In this case, the island has experienced the most movement along the eastern spit (Figure 14).

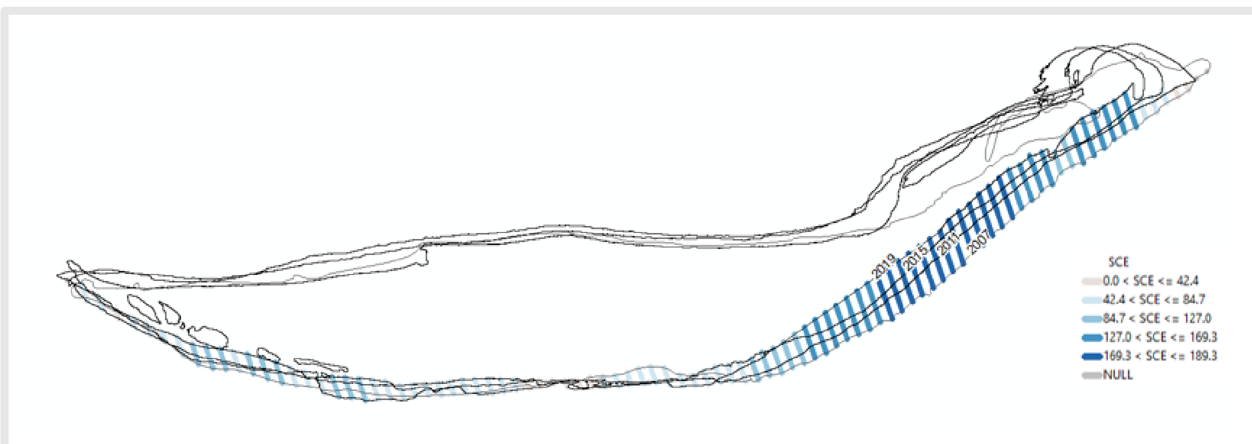

Figure 14: SCE output for West Ship Island, MS

Forecasting results

Figure 15 shows the 10-year shoreline forecast line and uncertainty band in blue. The 20-year forecast line and uncertainty band are represented by the brown line and polygon. As previously mentioned, the 2019 shoreline was clipped to the area of interest and follows the general trend of the data from the previous years because 2019 is the only year within the data range in which there was data for one island (after restoration) compared to two in the previous years. The general trend is the shoreline is stepping inland or towards the west, indicating erosion, which can also be seen in Figure 5.

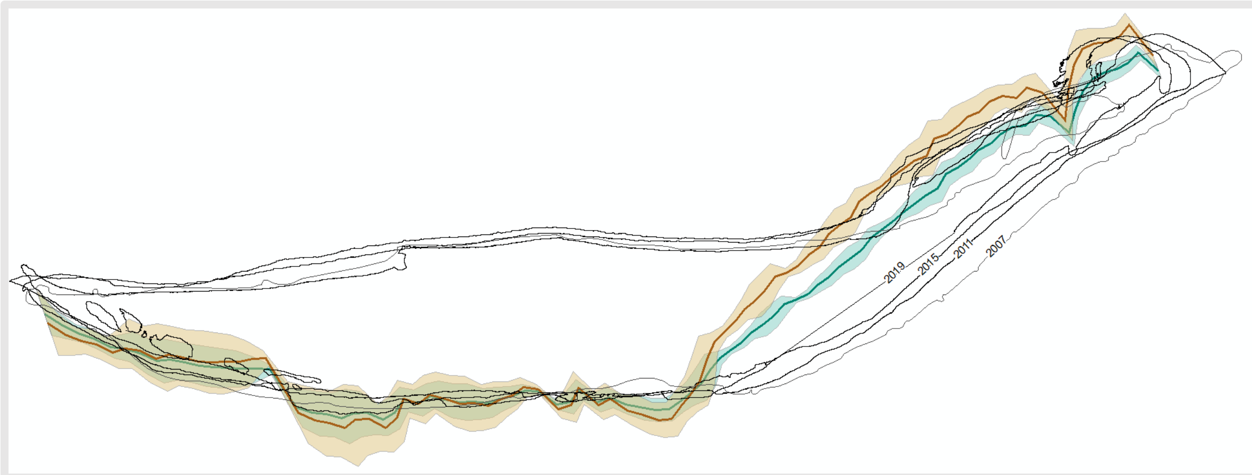

Figure 15: Forecast for clipped data.

Because Ship Island was restored to pre-Hurricane Camille status through an ACOE restoration project (completed in 2019), it is wise to have a forecast for the island without the clipped 2019 shoreline that follows the general trend of the previous shorelines. Figure 16 follows the format of the previous image and includes the clipped forecast in addition to an unclipped one that includes the restored 2019 shoreline. The unclipped forecast indicates a drastically different situation where the shoreline progrades towards the Gulf of Mexico. The influence of the ACOE restoration project is visible through this forecast.

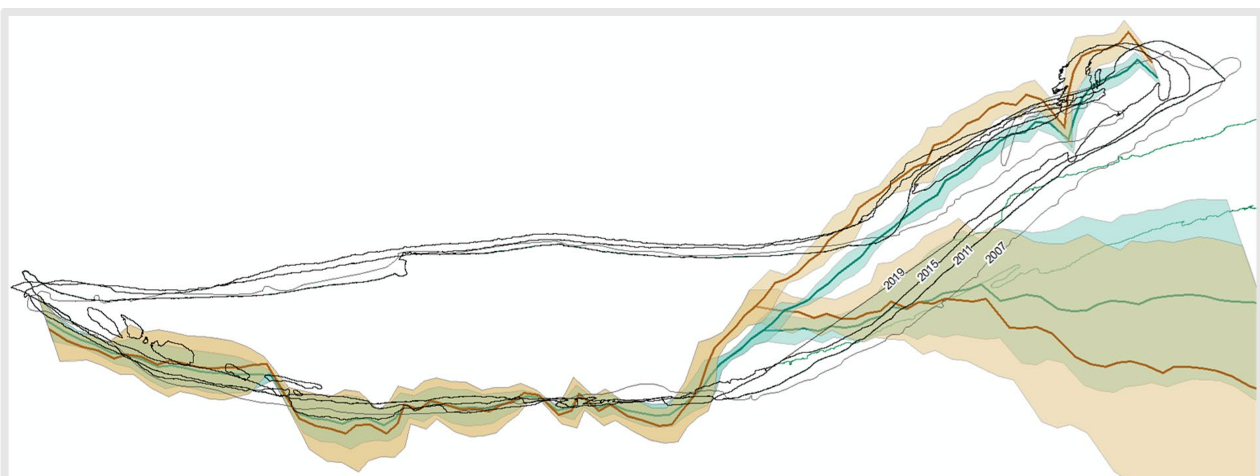

Figure 16: Forecast for both clipped and unclipped data.

DISCUSSION

Monitoring changes in the position of the shoreline or other shoreline markers indicates the dynamic relationship between the coastal environment and all the forces acting on it. Documenting shoreline change is critical for coastal management and permitting in that this practice can help establish erosion rates, identify impacts of storms and sea level changes, and provide a historical understanding of island morphonology. Shoreline change calculations also provide useful and effective recommendations for coastal management strategies (Bush & Young, 2009).

Like Martinez et al (2009), shoreline change maps were produced using DSAS to determine the spatial and temporal distribution of shoreline movement in addition to documenting geomorphologic evolution. Like Himmelstoss et al. (2017b), this report defines long-term as greater than 80 years, and short-term as 20-50 years. This study used twelve years of data (2007 – 2019) spaced out in four-year increments, which in comparison to other DSAS applications would be considered extremely short-term with the possibility of changes that are not necessarily storm driven or directly associated with the effects of storms.

Statistical Results

The statistical results and shoreline change indications within the study area coincides with results from other studies where HWL and MHW lines are used shoreline indicators (see: Boak & Turner, 2005; Morton et al., 2005; Morton & Miller, 2005; Harris et al., 2006; Morton, 2008). These results also coincide with the results for shoreline change, long- and short-term, on the US Geological Society's (USGS) Coastal Change Hazards Portal (Himmelstoss et al., 2017a).

A visible comparison between the LRR results of this project and those available on the USGS Coastal Change Hazard Portal indicate a higher erosion potential along the eastern spit of West Ship Island. In this comparison, the same areas of the study area are impacted by higher levels of erosion. The areas of erosion along the eastern spit are on the leading eastern edge of the island and smaller pockets along the western edge and coincides for each of the produced statistics (EPR, NSM, SCE).

As discussed in Oyedotun (2014), the accuracy of the results from this study are only as accurate as the input data. In this case, only twelve years of recent data were used, represented as four lidar- and DEM-derived shorelines with the shoreline being defined as a zero-elevation. Using elevation over other shoreline indicators significantly reduces the subjectivity associated with identifying the shoreline. For consistency purposes, DEMs were derived from lidar data for each year, even for years where DEMs were readily available. When creating the DEMs, special care was taken to verify that the process of formation was consistent.

Forecasting

Multiple sources state that to portray long-term forecasts, a minimum of 10 – 12 years are needed because more shorelines and more years would provide a more precise forecast. This should be done in caution as natural processes have changed in frequency and intensity throughout history. For this study, there are a total of 12 years visually portrayed by four shorelines, which is the minimum required by the tool for many of the calculated statistics.

The precision of the forecasts relies on the accuracy of the data and the uncertainty associated with this example is high. This is due to both the limited time frame and the clipping of the 2019 shoreline. The 2019 shoreline skews the results due to the mitigation and reconnection of East and West Ship Island which can be seen in Figures 11 and 12. Suggestions for increasing the precision of the forecasts include using more historical shorelines and digitizing a baseline with multiple nodes that would allow for transects to be perpendicular to the shoreline.

CONCLUSIONS

DSAS and the results it provides allows coastal researchers to identify areas that are affected by erosion by providing data visualization and statistics. For this project, DSAS was useful and successful in determining which areas on the gulf side of West Ship Island are more heavily prone to erosion. The rate of change statistics calculated in this study coincide with those produced by other studies, as well as those reported in the USGS Coastal Change Hazards Portal.

The forecasting capability of this tool is useful in visually portraying potential temporal changes and future shoreline positions. This functionality should be used with caution and the forecasts should always be responsibly reported, including both the projected future position and the associated uncertainty band.

Based on the application of this method, the eastern spit of West Ship Island generally has higher rates of erosion than other portions of the island, which could be caused by rotational instability the island is known for. The general direction of movement is towards the northwest and the overall movement can be seen in Figure 4.

In addition to investigations of shoreline erosion, this method and DSAS could be utilized in erosion assessments of soil erosion mitigation (see Nicu, 2021), assessing disaster risk associated with sea level changes and storm occurrence, and identifying areas where mitigation and protection is needed. The role of using geospatial technology for applications like this include precise measurements, reduction of subjectivity in shoreline determination, and in-depth analyses of geomorphic changes related to erosion.

WORKS CITED

American Society for Photogrammetry and Remote Sensing (ASPRS) (2008). LAS Specification: Version 1.2. https://www.asprs.org/a/society/committees/standards/asprs_las_format_v12.pdf

Boak, E. H., & Turner, I. L. (2005). Shoreline definition and detection: a review. Journal of coastal research, 21(4 (214)), 688-703.

Bush, D.M., and Young, R. (2009). Coastal features and processes, in Young, R., and Norby, L., Geological Monitoring: Boulder, Colorado, Geological Society of America, p. 47–67, doi: 10.1130/2009.monitoring (03).

Casey, A. (2019). Defending the Shoreline: From Cannon to Beach Nourishment in Gulf Islands National Seashore. Environment & Society Portal, Arcadia, no. 19. Rachel Carson Center for Environment and Society. doi.org/10.5282/rcc/8772.

Colbert, A. (2022). A Force of Nature: Hurricanes in a Changing Climate. NASA Jet Propulsion Laboratory.

Davidson-Arnott, R., Bauer, B., & Houser, C. (2019). Introduction to coastal processes and geomorphology. Cambridge University Press.

Davis Jr, R. A., & FitzGerald, D. M. (2009). Beaches and coasts. John Wiley & Sons.

Himmelstoss, E.A., Kratzmann, M.G., and Thieler, E.R., (2017a), National assessment of shoreline change – A GIS compilation of updated vector shorelines and associated shoreline change data for the Gulf of Mexico: U.S. Geological Survey data release, https://doi.org/10.5066/F78P5XNK.

Himmelstoss, E. A., Kratzmann, M. G., & Thieler, E. R. (2017b). National Assessment of Shoreline Change: Summary for Updated Vector Shorelines and Associated Shoreline Change Data for the Gulf of Mexico and Southeast Atlantic Coasts. US Department of the Interior, US Geological Survey.

Himmelstoss, E.A., Kratzmann, M.G., and Thieler, E.R., (2017c). National assessment of shoreline change – A GIS compilation of updated vector shorelines and associated shoreline change data for the Gulf of Mexico: U.S. Geological Survey data release, https://doi.org/10.5066/F78P5XNK.

Himmelstoss, E.A., Henderson, R.E., Kratzmann, M.G., and Farris, A.S., (2018). Digital Shoreline Analysis System (DSAS) version 5.0 user guide: U.S. Geological Survey Open-File Report 2018–1179, 110 p., https://doi.org/10.3133/ ofr20181179.

Himmelstoss, E.A., Henderson, R.E., Kratzmann, M.G., and Farris, A.S. (2021). Digital Shoreline Analysis System (DSAS) version 5.1 user guide: U.S. Geological Survey Open-File Report 2021–1091, 104 p., https://doi.org/10.3133/ofr20211091.

Himmelstoss, E.A., Farris, A.S., Henderson, R.E., Kratzmann, M.G., Ergul, Ayhan, Zhang, Ouya, Zichichi, J.L., and Thieler, E.R. (2021). Digital Shoreline Analysis System version 5.1: U.S. Geological Survey software release, https://code.usgs.gov/ cch/dsas.

Klee, G. A. (1999). The coastal environment: Toward integrated coastal and marine sanctuary management. Prentice-Hall, Inc., 113 Sylvan Ave. Englewood Cliffs NJ 07632 USA.

Li, R., Di, K., & Ma, R. (2001). A comparative study of shoreline mapping techniques. GIS for coastal zone management, 53-60.

Morton, R. A., Miller, T., & Moore, L. (2005). Historical shoreline changes along the US Gulf of Mexico: a summary of recent shoreline comparisons and analyses. Journal of Coastal Research, 21(4 (214)), 704-709.

Morton, R. A. (2008). Historical changes in the Mississippi-Alabama barrier-island chain and the roles of extreme storms, sea level, and human activities. Journal of Coastal Research, 24(6 (246)), 1587-1600.

Nicu, I. C. (2021). Is digital shoreline analysis system “fit” for gully erosion assessment? Catena, 203, 105307.

NOAA OCM (2022). Office of Coastal Management: Mississippi. https://coast.noaa.gov/states/mississippi.html Date accessed: 03/15/2022.

Nummedal, D., S. Penland, R. Gerdes, W. Schramm, J. Kahn, and H. Roberts, 1980, Geologic response to hurricane impacts on low-profile gulf coast barriers: Gulf Coast Association of Geological Societies Transactions, v. 30, p. 183-195.

Oyedotun, T. D. (2014). Shoreline geometry: DSAS as a tool for historical trend analysis. Geomorphological Techniques, 3(2.2), 1-12.

Paris, P., Starek, M. J., Hardin, E., Kurum, O., Overton, M., & Mitasova, H. (2013). Lines in the sand: Geomorphic and Geospatial characterization and interpretation of sandy shorelines and beaches. Geography Compass, 7(5), 315-343.

Schmid, K., 1999, Geomorphic expression of erosion on the Mississippi Gulf Coast islands caused by Hurricane Georges [abs]: Journal of the Mississippi Academy of Sciences, Abstract with Programs, v. 44, n. 1, p 43.

Schmid, K. (2001). West Ship Island Evolution, Morphology, and Hurricane Response--1995 to 2000. Mississippi Department of Environmental Quality, Office of Geology, Coastal Section, Energy and Coastal Geology Division.

Schmid, K. (2003). East Ship Island Evolution, Morphology, and Hurricane Response--1994 to 2001. Mississippi Department of Environmental Quality, Office of Geology, Coastal Section, Energy and Coastal Geology Division.

Stockdon, H. F., Sallenger Jr, A. H., List, J. H., & Holman, R. A. (2002). Estimation of shoreline position and change using airborne topographic lidar data. Journal of Coastal Research, 502-513.

U.S. Climate Resilience Toolkit (2021). Coastal Erosion. April, 2021. https://toolkit.climate.gov/topics/coastal-flood-risk/coastal-erosion