Task 3: Barrier Beach Vulnerability YR 1

Many of the state's shorelines are protected by barrier islands and/or barrier beaches. The data and analyses perform for this task will provide site-specific data for this project as well as easily transferable techniques and methods to other areas of the state. The Nauset Barrier Beach system was mapped in the fall of 2022 and the spring of 2023 using Uncrewed Aerial Systems (UAS), or drones. This represents two out of the three surveys to be completed for this project and as such this report is focused on preliminary results from the first two surveys. Analysis is ongoing but initial results confirm the efficacy of the methods used and show quantifiable seasonal change in the areas mapped.

Understanding how barrier islands evolve annually and seasonally can better inform management decisions when changes occur. Managers may mistakenly believe that, for example, a large erosional event in response to a storm is anomalous and signaling a change in the system requiring steps to be taken when, in reality, the erosion and subsequent deposition is a typical response. These types of data provide quantitative evidence, rather than anecdotal, of the natural variability seen in coastal landforms and thus can better inform short medium- and long-term decisions.

Other past studies of Pleasant Bay show a dynamic barrier island/tidal inlet system that Has shown a 140-year cycle of inlet formation, inlet migration/barrier elongation and new inlet formation (Giese, et al, 2009). Recent studies also show that the 140-year cycle, as well as the present inlet evolution, are likely being affected by sea level rise (Borrelli, et al., 2016) and coastal engineering structures in Chatham Harbor (Giese, et al, 2020).

Field Surveys

The FireFLY6 PRO is a fixed wing vertical takeoff and landing (VTOL) UAS that provides long-range flight capability, large area coverage, and the flexibility to launch and land in most places. Weighing 8.4lbs, the FireFLY6 is equipped with six motors that power the aircraft to carry a payload of 1.5lbs for up to 40 mins, giving it the ability to map ≈ 600 acres per flight under ideal conditions. The FireFLY6 is a professional mapping drone that uses a real time kinematic (RTK) GPS that has been documented to achieve spatial accuracies of 3.4cm in the horizontal (x,y) dimensions and 5.3cm in the vertical (z) dimension (Birdseyeview Aerobotics, 2019). Mapping missions are carried out with an integrated Sony a6000 24-megapixel sensor, resulting in orthophoto resolutions as fine as 3cm when flown at 400ft above ground level (AGL). This setup results in an average ground sampling distance (GSD) of 2.75cm.

Since receiving permission to fly on 10/4/2022, the Center for Coastal Studies spent 11 survey days completing 17 unoccupied aerial system (UAS) flights over the Pleasant Bay barrier island between the dates of 10/18/22 and 04/13/2023, nine in the fall of 2022, and 8 in the spring of 2023. The total survey area is approximately 2,100 acres stretching along a 9-mile length of coast. We collected 11,047 images and 161 ground control points to create topographic surface models and orthomosaics for each survey timeframe (Fall and Spring) to detect seasonal changes on the barrier (Table 1).

Table 1. Data collected via UAS

Survey	Flights	Images	Area (ac)	GCPs	Survey Days
Fall 2022	9	6,683	2,100	91	6
Spring 2023	8	4,364	1,618	70	5
TOTALS	**17**	**11,047**	**3,718**	**161**	**11**

Data Processing and Analysis

Processing - Structure from Motion (SfM)

The method for surface creation is a process called structure-from-motion (SfM), which is photogrammetric process by which 3-dimensional topographic models are created from a series of 2-dimensional images. Pictures taken by the UAS are run through a specialized mapping and photogrammetry software that uses features identified in overlapping scenes from different angles to triangulate that feature's position and elevation, then records it in a point cloud. After an initial round of processing, ground control points (GCPs) collected in the field at the time of the survey are added to the model and their positions are marked in all images in which they appear. This is known as georeferencing, and is an essential step for increasing the accuracy of the model. Once georeferencing is complete, the point cloud goes through another round of processing to increase the point density. Denser point clouds allow for finer resolution of the final raster products, and is one of the primary advantages of SfM method compared to other remote sensing methods. Processing the point cloud is computationally expensive, as point clouds typically contain many millions of points. Before any surfaces are created, noise is removed from the point cloud through a series of automated and manual processes. This step is critical because the cleaned point cloud is the basis for products such as orthophotos, digital surface models (DSM), and digital terrain models (DTM), and any artifacts in the point cloud will be reflected in the final products. After cleaning the point cloud, points are projected onto a grid with a user-defined resolution, thus creating the elevation surface. This surface is then used to orthorectify the aerial mosaic, creating a geometrically correct orthomosaic from which accurate measurements can be made.

GIS-Based spatial analysis

Topographic surfaces of the barrier were created for both the Fall 2022 and the Spring 2023 UAS surveys. These raster products (25cm grid cell size) were used to calculate the area and volume for areas of significant erosion and deposition, defined in this report as any difference greater or less than 15 cm in elevation between the two survey periods. No change (< 15cm of difference) area is also reported without associated volume.

Change *area* is measured by first differencing the rasters from the two survey campaigns. Using a sequence of Time_2 -Time_1 creates a new raster, a surface difference layer, with negative values indicating areas of sediment loss (erosion) and positive values indicating areas of sediment gain (deposition). Thresholds are then added to the symbolization of the layer to delineate varying degrees of gain or loss. These threshold maps are the change layers that visualize to what extent the barrier has changed between surveys. The surface difference layer is then reclassified to reflect the types of change and converted into polygons. A dissolve operation is run to consolidate many polygons into one for each type of change. The areas of these polygons are calculated and recorded in the table.

Change *volume* is calculated using a cut/fill operation in ArcMap. The surface rasters from each survey are added as inputs in the software, and a raster is output with net gain, net loss, or unchanged categories. Volumes are calculated using ‘select by attribute’ in the raster’s attribute table, selecting all cells that equate to the desired change type, then running stats on those cells. Once complete, the operation is performed for the opposite cells.

A coarse scale, GIS-based analysis was conducted to place annual and seasonal change in the system into both spatial and temporal context. Using lidar data available from 2014 to 2021 change was quantified in the areas of overlapping data between those two time periods. The techniques used were similar to those discussed above. It should be noted that the footprints for the 2014 and 2021 lidar data sets as well as the 2022 and 2023 data sets are not identical and some variation occurs but the comparisons discussed below are in areas where both data sets (2014-2021 or 2022-2023) overlap.

Preliminary Findings

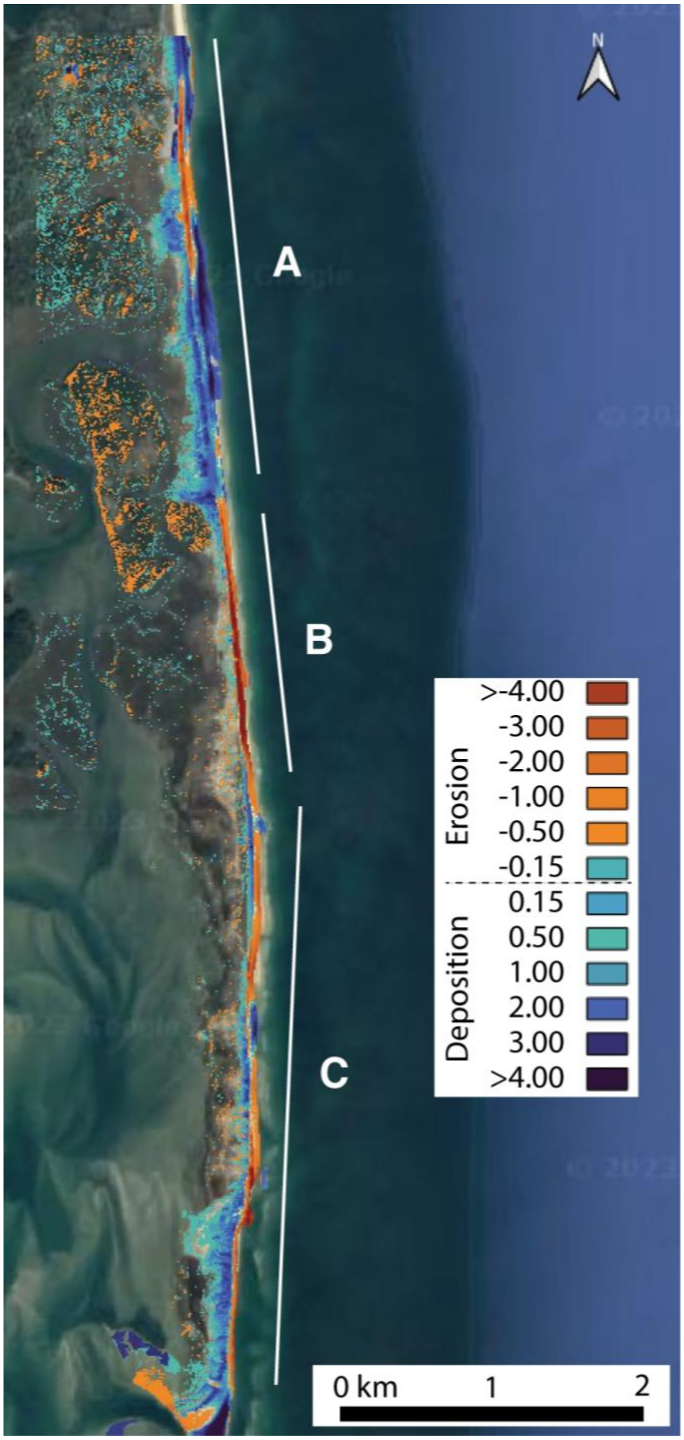

Figure 1. Surface difference between 2014 - 2021

Changes seen between the 2014 and 2021 lidar data sets can be roughly broken down into 3 coastal compartments (Figure 1). The northernmost section (A) sees mostly deposition with some erosion starting from Nauset Beach in Orleans down to the southern part of Pochet Island. There is considerable deposition in the backbarrier areas which is a positive trait for barrier islands within a regime of sea level rise. This increase in elevation is caused by the deposition of sediment between 2014 - 2021. This is likely due to either overwatch occurring during high water level events, such as during storms, carrying sediment and ocean water across the barrier and depositing in low-lying areas along the backbarrier shoreline, and/or wind-blown sand. Deposition in this area of the barrier is an indicator that the barrier is, at least during this time-period, keeping pace with sea level rise.

The central section (B) is the only section where there is erosion with little to no deposition. This is not as problematic as one would initially assume because most of the barrier in this compartment has extensive salt marsh backing the barrier. Though attention should be paid, as over time deposition in this area would indicate that the barrier will be able to keep pace with sea level rise going forward and a lack of deposition could represent a shift in the evolution of the barrier.

The southernmost section sees erosion along most of the open ocean shoreline and deposition along most of the backbarrier shoreline. This also is indicative of a barrier that is able to keep pace with sea level rise. In fact, the areas closest to the inlet in this section are seeing some of the highest levels of deposition along the barrier. Overall, the barrier north of the 2007 inlet has seen deposition in backbarrier areas in the form of washover fans and other depositional features as well as erosion along much of the shoreline. The abrupt shifts in shoreline orientation between compartments B and C are a function of longer term processes such as sea level rise and changes in angles of wave approach, similar to those that led to a 2° counterclockwise shift in the orientation of the outer beach of Cape Cod from the 1880s through the early part of the 21st century (Giese, et al, 2007).

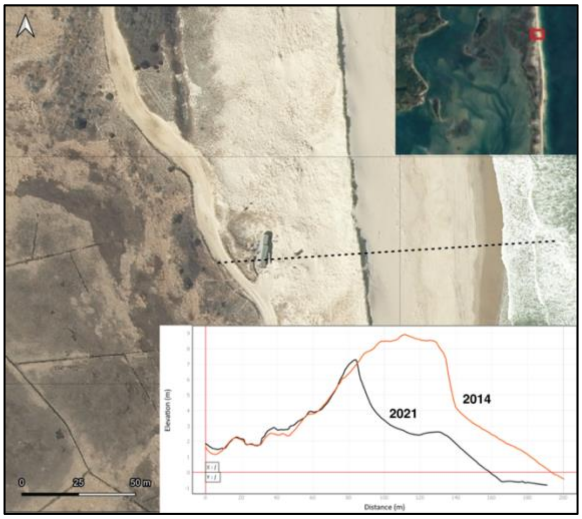

Figure 2. Erosion along a transect from 2014 -2021.

From 2014-2021 erosion occurred along much of the open ocean shoreline. This erosion occurred along the beach as well as the primary dune. This type of erosion is common along much of Cape Cod. Although approximately 30 m of erosion (Figure 2) over 7 years yields an annual rate of 4.3 m/yr rather than the typical long-term erosion rate of ~1 m / yr on the outer beach. Annual rates of erosion are only averages for a given period of time and 3-4 m of erosion per year is not unprecedented for short periods of time. However, if this trend were to continue it would constitute a regime shift for these barriers.

The trends of seasonal changes (erosion/deposition) along the study area are similar to that of the medium-term trends seen in the lidar data. From the fall of 2022 through to the spring of 2023 we see changes of 6-8 meters in the highwater line (Figure 3). This is common among open ocean beaches and indicates the natural variability expected in such environments. This appears to be more common in the Nauset Barrier spit, whereas North Beach island seems to be undergoing large amounts of deposition along the southernmost portions of the island from fall to spring.

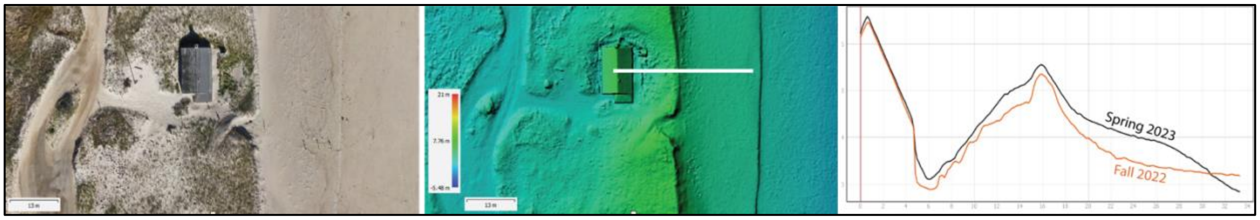

Figure 3. Seasonal changes along a transect. Left and Center: Orthophoto and surface from spring 2023 drone data. Right: changes in profile between Fall 2022 and Spring 2023.

This interim report was confirmation of the efficacy of the methods for mapping seasonal change in this environment using a drone. More analyses, both short and medium term, will be completed in the final project report.

References

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