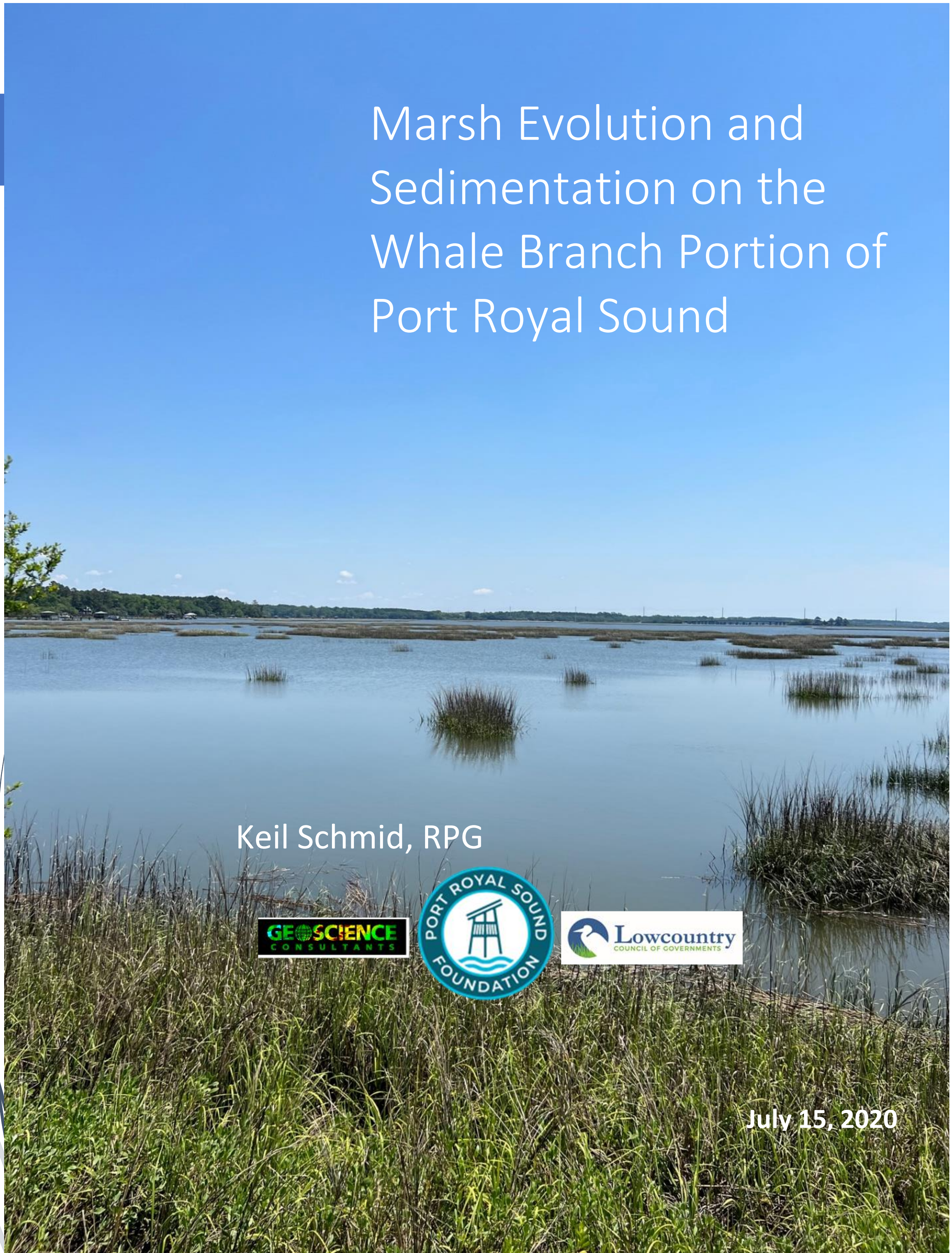

Marsh Evolution and Sedimentation on the Whale Branch Portion of Port Royal Sound

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Table of Contents

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Introduction

This project is intended to be Phase I in a multi-phase effort in so much as the results can be used in the future to expedite restoration goals. The Phase I project/pilot used a small marsh island on the Whale Branch creek to model processes that control marsh health and evolution in the larger Broad River/Port Royal Sound habitats. This historic island and the marshes surrounding it tell a larger story of the role that sediment accumulation, erosion, and sea level rise has in the marshes throughout the area. By studying the habitats (Figure 1) and their history and relationship to marsh evolution and elevation trends this phase I project has provided information for the development of restoration techniques tailored to the wide variety of marsh conditions found within the Port Royal Sound.

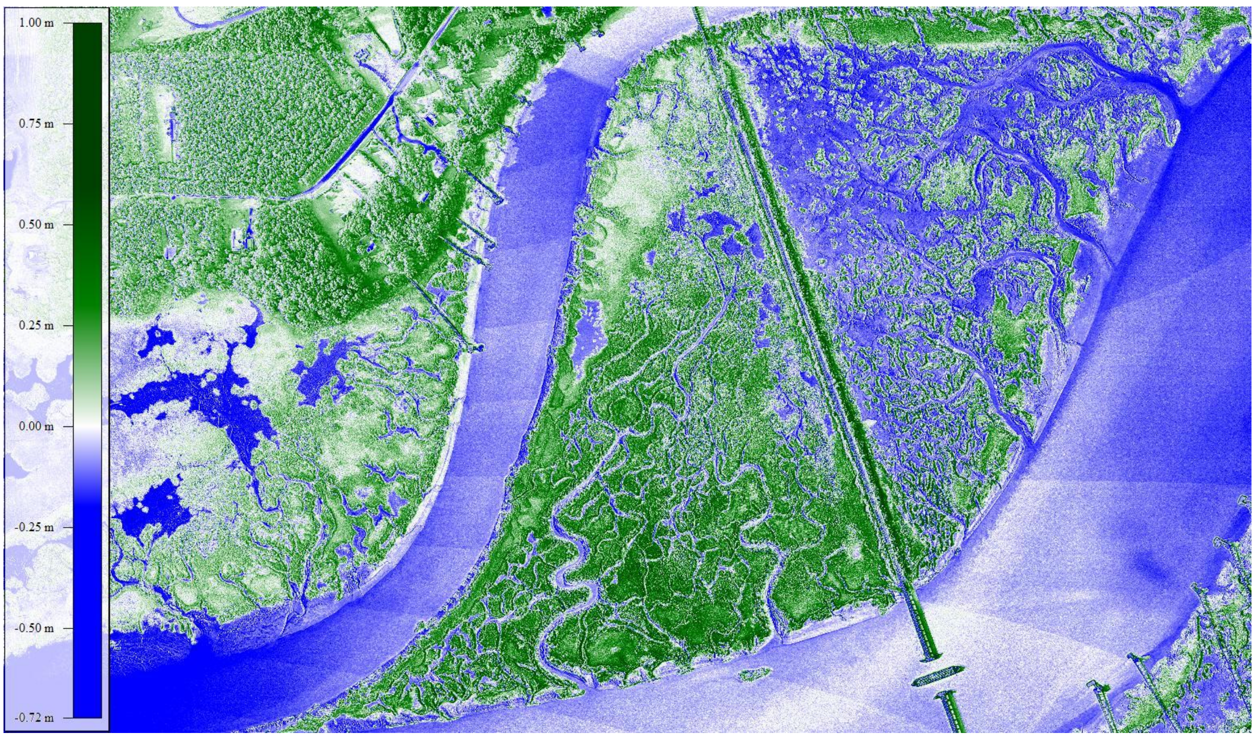

Figure 1. 2003 NDVI highlighting the two separate sides of the island. Green is indicative of healthy vegetation and blue highlights water or a lack of vegetation.

Pilot Area Extents

The island lying off the Whale Branch fishing pier between Coosaw and Seabrook is the site of a railroad bridge and causeway built in ca. 1870; it was the first railway to and from Beaufort (Figure 2 and 3). The rail line is no longer in use and what remains are the causeway and some bridge sections. The result of the existing infrastructure is a tale of two islands. There are no indications that the island was different from one side to the other prior to the construction; however, the Normalized Difference Vegetation Index (NDVI) image derived from the color infrared image (Figure 1) highlights the evolution of the island with two distinct results. NDVI is a comparison of the reflected infrared and red-light wavelengths that are captured by aerial imagery (or satellites); it can be used to highlight vegetation and its health.

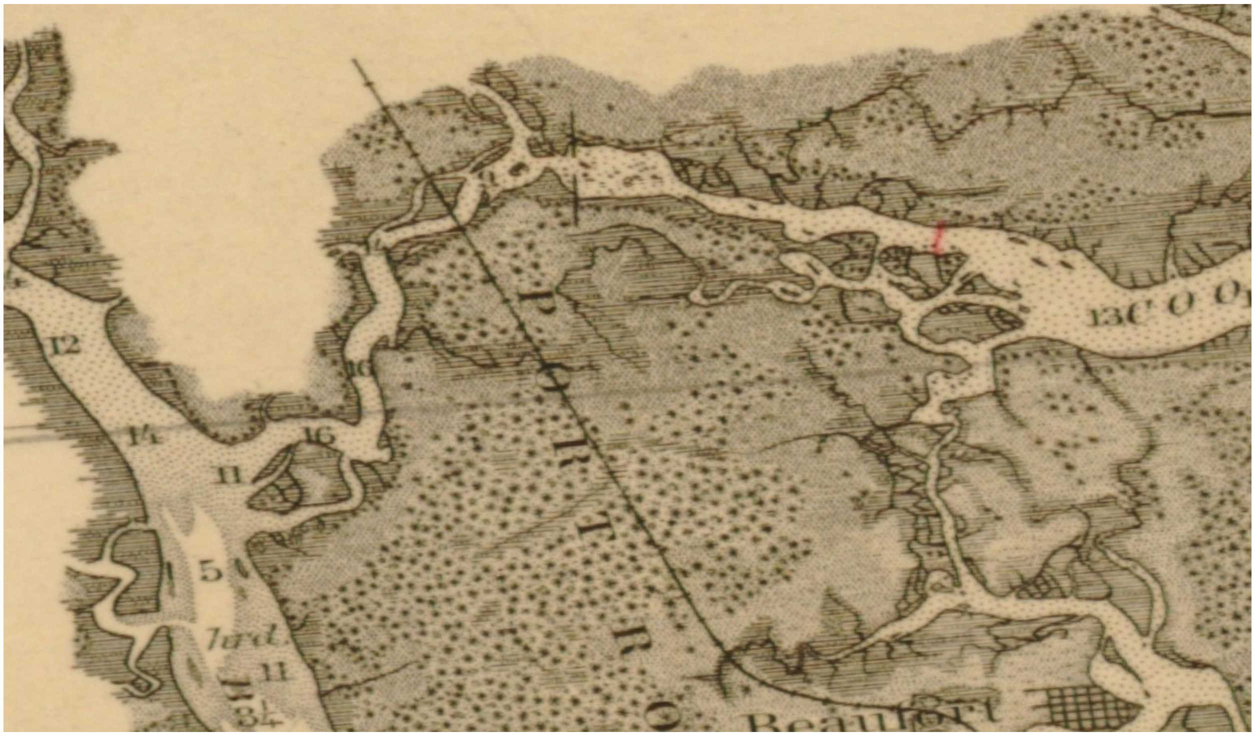

Figure 2. Map from 1870's showing the railway from Beaufort running across the island

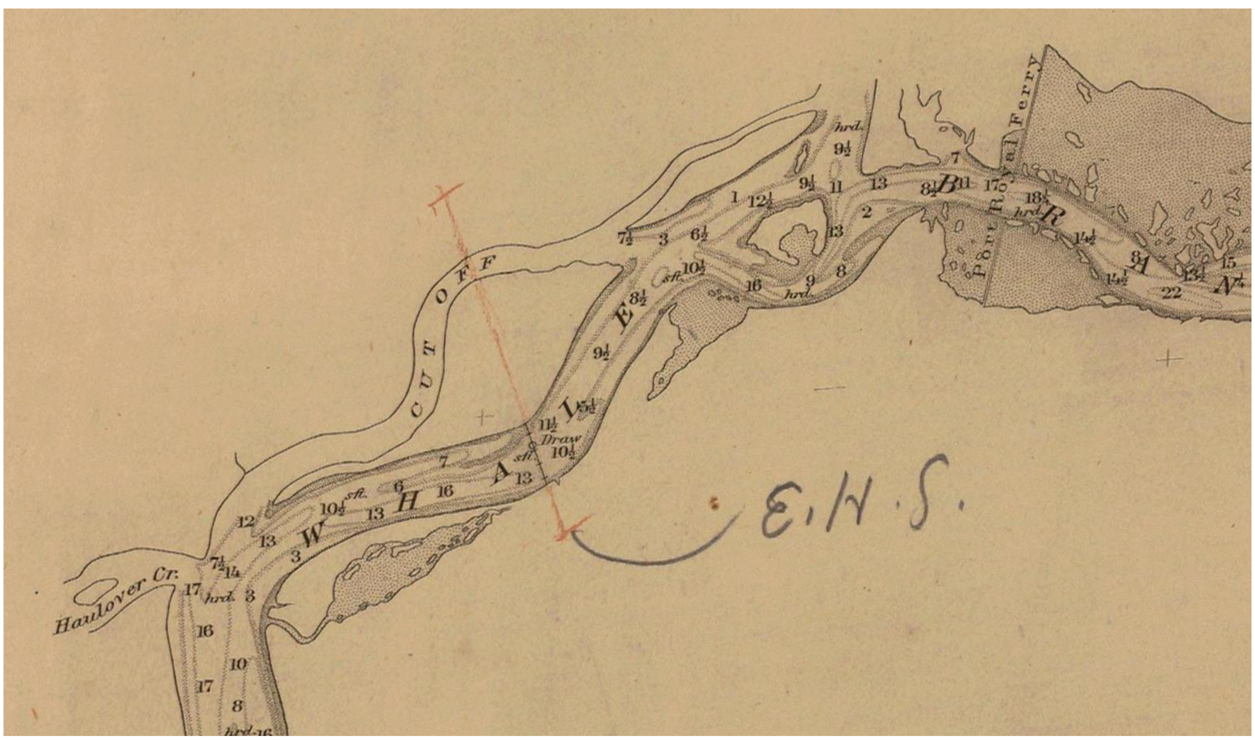

Figure 3. 1875 Nautical chart of the area showing the island and location of railway.

Methods/Background

One of this study's intents is to examine the techniques and processes for use over a much larger area than the 130-acre island. To facilitate the potential to scale several orders of magnitude the study drew heavily on existing information to drive site specific findings that inform restoration decisions. Remote sensing data from both active and passive sensors is widely available and covers the entire Port Royal Sound from the 1950's to present. This includes aerial imagery and high-resolution elevation data (lidar[1]) from 2002 to 2019/20.

The process included selecting specific definitive aerial imagery sources to define the historical marsh vegetation evolution over the past 60-plus years. This helped generate a matrix of different beginning and ending morphologies, which were further binned into specific coastal habitat typologies. The three primary habitats being used to look at patterns are: mud/sand, healthy marsh, and variable cover including a mix of mud and sparse marsh vegetation. Oyster colonies are harder to discern since they are neither flora nor sediment; the existing South Carolina Department of Natural Resources (SCDNR) map of oyster mounds was used. There are very few on the island.

Shoreline change is a tidally defined boundary shift. It is more difficult to assess at the site with the imagery and elevation as much of the area is below mean high water (MHW), which is a common tidal level associated with shorelines. The shorelines in this study do not consist of sand, so any mapped shoreline really is more of an indicator of vegetation and the change represents either a loss or a gain of vegetation. Change in the shoreline for this study will be evident in the elevation changes of the marsh surface (sedimentation vs. loss of sediment) as opposed to a 'line' moving inland or offshore.

Aerial Imagery

Aerial imagery is a 'passive' form of remote sensing with the camera/sensor capturing the sun's reflected visible light and non-visible (e.g., near infrared) wavelengths in some cases. Aerial imagery span from the mid 1950's to present, a total of almost 70 years. Each data set is unique and not all are useful for habitat mapping. Many images were collected at higher tides and the earlier data was either grayscale or lacked the near-infrared channel. The more contemporary data included 4-band data (red, green, blue, and infrared) that helped define the vegetation using the NDVI (Figure 1). Unfortunately, some of the most recent 4-band data was collected during mid to high tides and could not be used. The result is that a mix of 3-band and 4-band data was utilized. The vegetation in the grayscale or 3-band data was mapped using a combination of band information; the specific vegetation mapping algorithm was image-dependent and developed using small test areas. As a result, habitat delineation was done using the most appropriate technique for each data set.

Lidar Data

High-resolution lidar point-elevation data from 2002, 2013, and 2019/20 was obtained from the Beaufort County GIS Department (2002) and the NOAA Office For Coastal Management (2013, 2019/20). The point data was re-classified by Geoscience to increase the amount of 'bare-earth' points and represent different tidal regimes. Normal processing can remove many of the 'high-points' during normal classification in this environment from rapid changes in elevation (e.g., oyster or marsh mounds on mud/sand flats – see right side of Figure 4). The points were also assigned color-infrared values from low-tide imagery taken at the same time-period. The 2002 and 2013 data were captured near low-tide while the 2019/20 data were captured near mid-tide; the result being that some of the lower elevations were not captured in 2019/20 data.

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[1] See https://oceanservice.noaa.gov/facts/lidar.html for more information on lidar.

There are limitations of single lidar datasets to define absolute ground elevations in marsh habitats. This study tries to avoid these known pitfalls by using relative values in each of the typologies and the statistics available with many data points per typology. Since there is commonly a difference of several cm in lidar collections due to different GPS and IMU configurations[2] during capture the data were calibrated using the 2002 data as the base. Ground-class point data from the strip of land along the railway was used to adjust each data set to 2002. The correction difference was on the order of 5 cm for the 2013 and 2019/20 data, which is within the error[3] of the data.

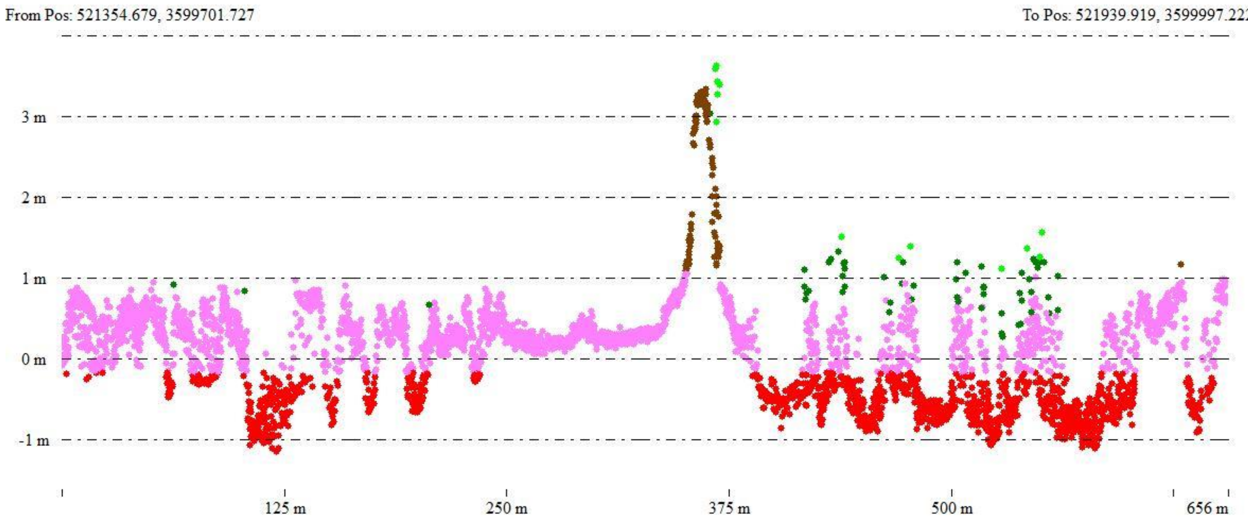

Figure 4. Lidar data along a profile across the island. The rail line is the high area around 350m. The red dots represent mud flats, the purple represent marsh, green represent vegetation, and the brown are upland areas.

The goal of realigning the data is to allow them to be compared in each coastal habitat typology to help define the sedimentation patterns. The sedimentation patterns were then assessed in terms of the measured changes in sea level (Ft Pulaski) to provide a corrected measure of the time the marsh surface is inundated. This value can then be used to look at the level of sedimentation needed to maintain a healthy marsh in the future, what the tipping points are, and how those tipping points express themselves.

Fieldwork

Fieldwork consisted of a site visit on May 16, 2022. Water levels were above mid-tide so direct measurement of the surface sediment was not possible. The field team used stand-up paddleboards to move around, and the surface was probed with paddles. It turned out that the substrate was very soft mud in most places and walking would not have been possible. No oyster mounds were probed, nor were any shells seen along the causeway shoreline.

[2] There are many spatial and measurement variables that affect the accuracy of the lidar data. See the sidebar in https://oceanservice.noaa.gov/facts/lidar.html for more information.

[3] Root mean squared error is commonly used to calculate the error or confidence in lidar elevation values. It is approximately equal to 1 standard deviation from the 'correct value'.

Analysis

The goal of the analysis was to marry the changes in habitat with trends in elevation and sedimentation. The primary period of analysis was 2002 to 2019/20 where the two data types overlapped. Longer-term analysis was undertaken for the imagery to document the overall patterns of change.

Imagery

The imagery was used, primarily, to define the changes in vegetation through time (Figure 5). The end points of the record are 1957 and 2021 and highlight the overall pattern of marsh loss on the eastern side of the railway line. The west side has kept up and may have even seen a bit more marsh vegetation growth between 1957 and 2021. The east side has had the opposite trend and has lost a significant amount of marsh habitat. These trends, using the same exact technique on the same exact imagery, highlight the conditions that spurred the analysis on this island in the first place.

Table 1. Changes in habitats through time on the east and west side of the rail line.

	1957			2021		
	Mud (acres)	Marsh & Sparse Veg (acres)	Water (acres)	Mud (acres)	Marsh & Sparse Veg (acres)	Water (acres)
West	17.7	33.6	7.4	10.5	41.6	7.4
East	23.3	24.5	7.5	38.7	10.5	7.6

Habitat Change 1957 to 2021

	Mud (%)	Marsh & Sparse Veg (%)	Water (%)
West	-41%	24%	0%
East	66%	-57%	1%

These dates capture the overall changes, but do not highlight the variability that occurs here. There are dye-off and regrowth cycles that occur on both sides of the rail line. These cycles are common and may be caused by many different processes and include changes in drainage, precipitation, predation, storms, or patterns of wrack deposition. An overall map of the change between 1957 and 2021 (Figure 6) using 10 m x 10 m cells (100 sq m) highlights marsh loss on the island's eastern point. The greatest area of marsh growth is in the middle part of the western side of the island. Little change occurs on the northern boundary of the island. It should also be noted that, although not part of the study area, the western adjacent marsh has also been accreting and has had marsh development (Figure 5). The central portion of the eastern side of the island lost a significant amount of marsh in the time between the rail line construction and 1957 (about 75 years). Why that loss was concentrated there is not entirely clear; it is possible it was related to wave interactions with the causeway acting like a seawall. Seawalls have commonly been associated with increased erosion in front of them from wave reflection and offshore dominated currents. Or it could be from a lack of sediment-laden water moving across the island from west to east.

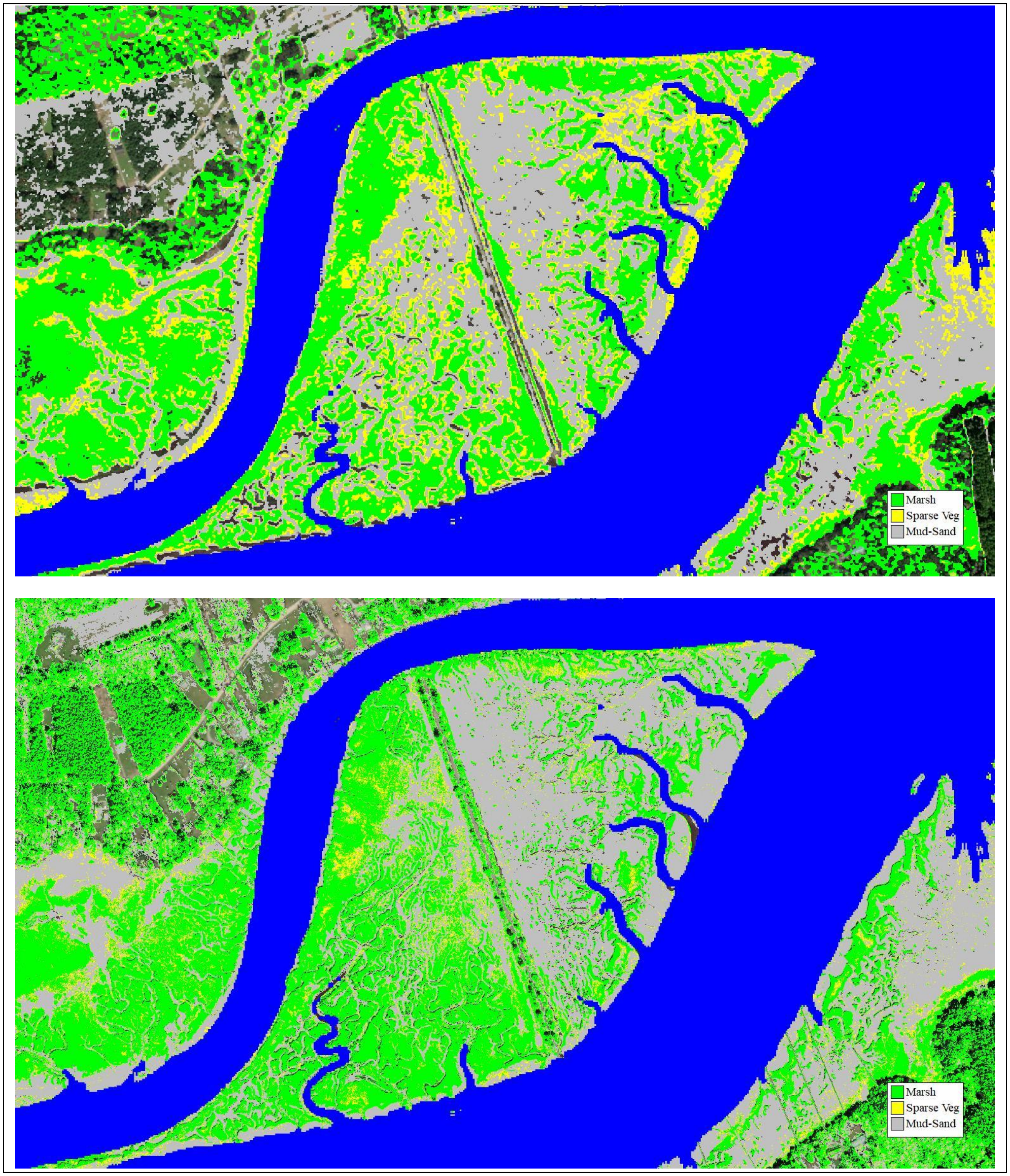

Figure 5. 3-band classifications from grayscale 1957 imagery (top) and color 2012 imagery (bottom); north is up.

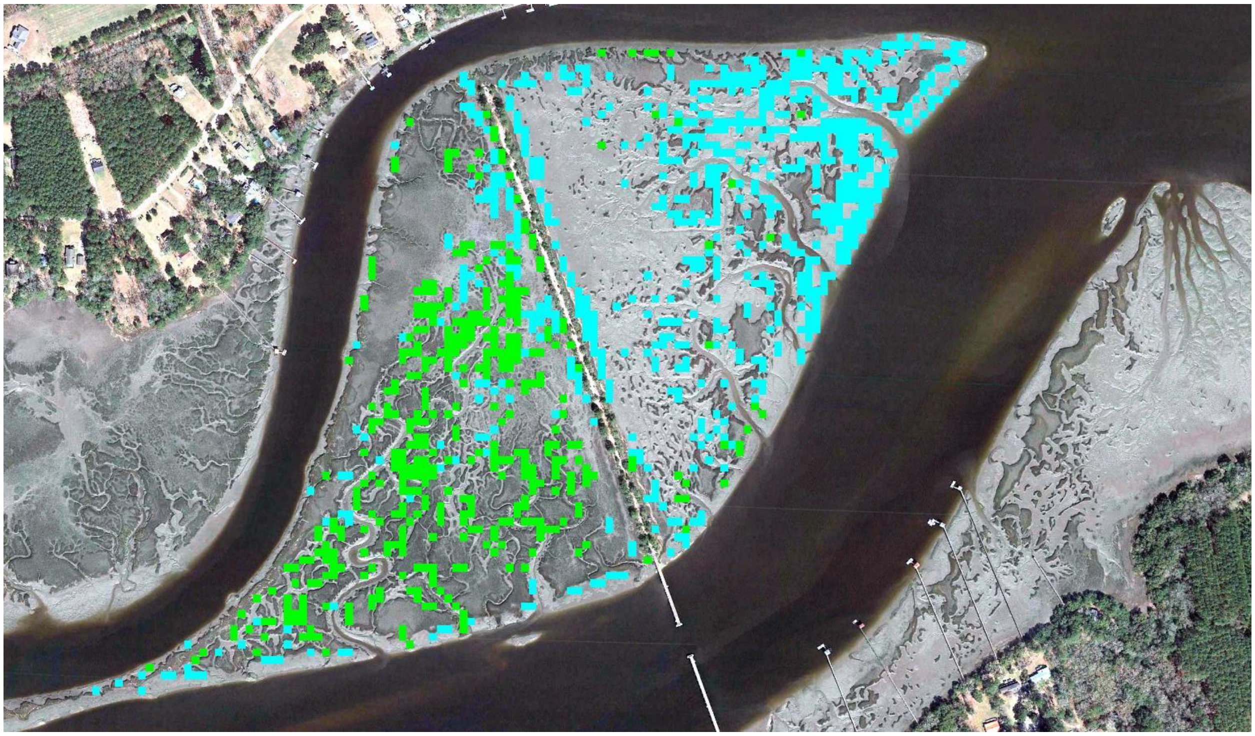

Figure 6. Location of change from vegetation to mud (blue) and mud to vegetation (green) between 1957 and 2021.

Lidar

The imagery provides powerful evidence of the trends but does not really capture the processes that are driving the two very different evolutions. The railway line is an important component in the difference, that is evident. The physical changes it created, however, require further examination. One of the ways is to measure (via lidar) how the marsh surface has responded to the presence of the impenetrable barrier to water and sediment flow across the island. This can provide some answers, like how the elevation of the substrate is decreasing in some areas through time, which can cause stress on marsh vegetation. It does not, however, define the process. For example, the lidar cannot tell us whether lower sedimentation rates are from a lack of sediment from the west or, that the east is open to NE winds driving resuspension and erosion and the west is protected from them. For this we must infer from the data, and it may be a combination of processes.

Habitat Elevations

Using the NDVI (Figure 1) and classification (Figure 4) attributes from all the lidar points the average elevation (NAVD 88[4]) for those defined as marsh was 0.43 m in 2002, 0.46 m in 2013, and 0.40 m in 2019/20. Looking at just a sample of the areas that contained marsh in all three periods the average elevation was 0.43 m. The average of the constant tidal mud flat areas was -0.34 m with a maximum of 0.29 m. Areas that changed from mud to marsh (it does occur) had an average elevation of 0.29 m. The standard deviation in most cases was about 0.27 m. On average the marsh vegetation is found between 0.15m and 0.7 m which is about the middle range of mean sea level (MSL) and MHW and tidal flats are generally around MSL (-0.033 m NAVD 88) or below. Areas between MSL and 0.3 m (about 1 ft above MSL) are where the primary change appears to be occurring.

[4] North American Vertical Datum of 1988

Elevation Trends: 2002-2020

The primary elevation changes were computed from three Digital Elevation Models (DEM) between 2002 and 2020 (See Figure 7 as an example). The change rates in mm/yr between 2002 – 2013 and 2013 – 2020 (11 and 7 years) were calculated and then averaged (Figure 8) to define the overall change in mm/yr. Over the entire island, the average sedimentation rate in marsh and tidal flats was 0.7 mm/yr; the eastern side had an average of about 1.25 mm/yr and the west side had 0.15 mm/yr. This may seem counter intuitive given that the east side is obviously lower on average (Figure 7).

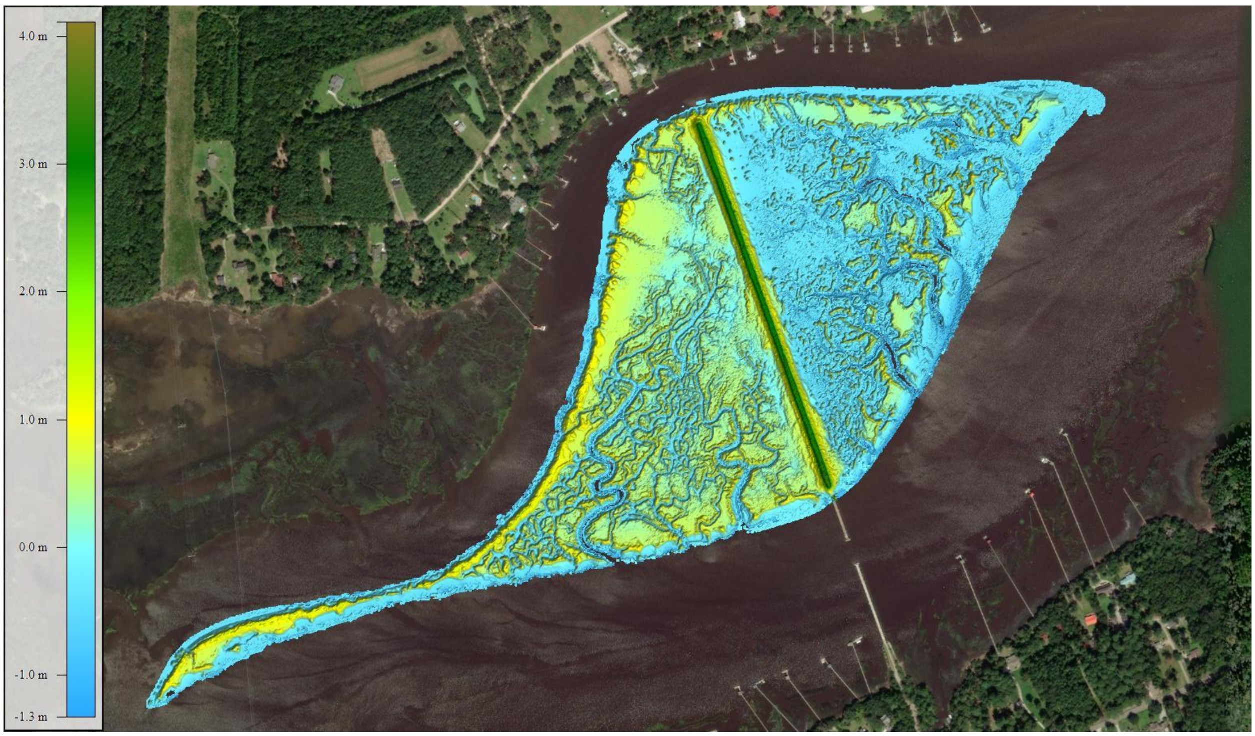

Figure 7.Example of DEM (2020) used to define the sedimentation rates.

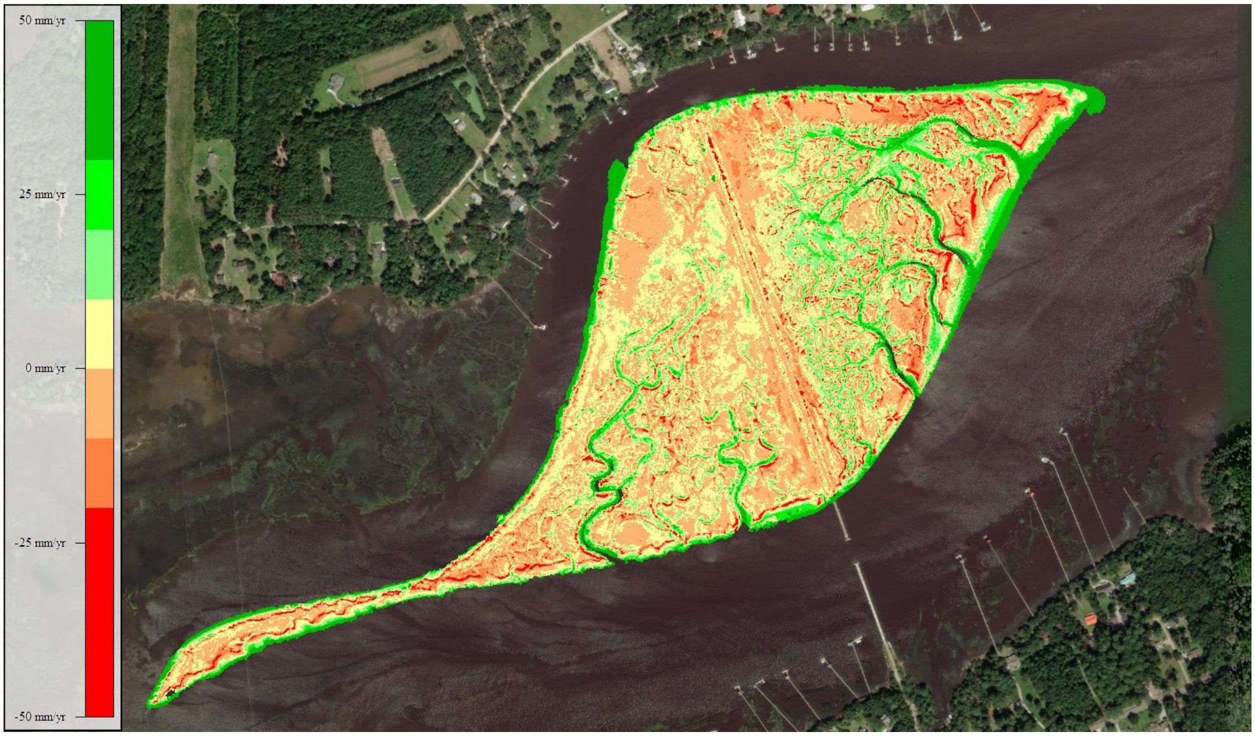

Figure 8. Average sedimentation rates in mm/yr between 2002 and 2020.

When the area is broken down by habitat, i.e., mud flat or marsh, the sedimentation rates are more telling. The sedimentation rate for marsh areas is -3.4 mm/yr (erosion) on the east and 0.24 mm/yr on the west and highlights the trend that is affecting the loss of marsh at present. The tidal mud flats have a different trend and are accreting by 2.5 mm/yr on the east and eroding at -0.2 mm/yr on the west. Again, this may seem contrary to the overall long-term change, however another aspect is the time the water (with suspended sediment) is above the substrate. The tidal mud flats on the west are covered with water about 53% of the time; those on the east are covered, on average, 68% of the time. Based on the overall population of tidal flat points (Figure 9) the 15% difference in time of inundation is equal to about 4 mm/yr, which is consistent, but slightly higher than the observed difference (2.7 mm) in sedimentation rates. This suggests, despite the lower average rate, that the west is receiving a higher level of sediment.

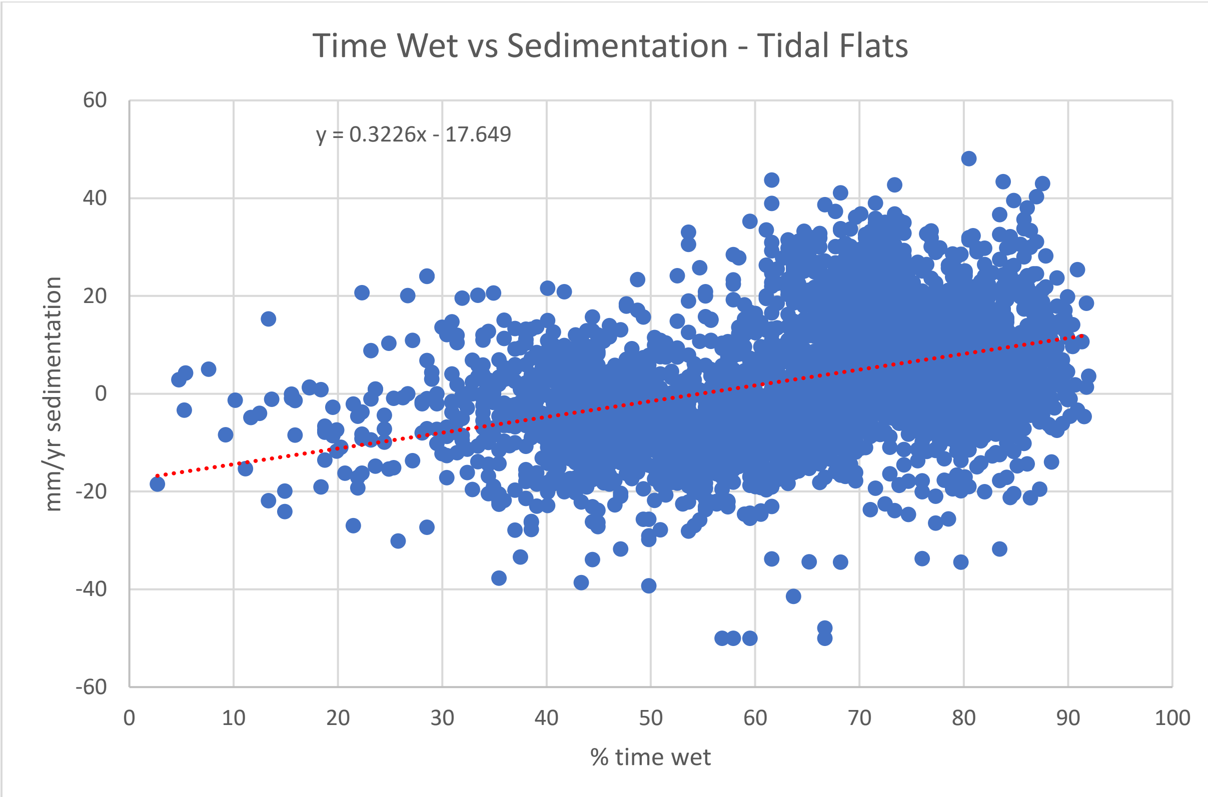

Figure 9. Sedimentation vs total time wet in the tidal flat habitats. Trend is about 0.3 mm/yr per percent increase in the time wet.

Time of Submergence: Marsh

An important aspect of the growth conditions for a marsh are how long the plants are inundated[5]. Morris found that the overall growth range varies between MSL and MHW which roughly translates to a range of total inundation time of 10% (MHW) to 50% (MSL). The data from this site are consistent with those in the Morris study; the marsh areas at the site are inundated an average of 31% of the time and have a standard deviation of 14%. So, 68% of the areas supporting marsh are inundated between 17% and 45% of the time.

The site elevations (2020) were used along with the April to May 2022 predicted water levels at Beaufort to calculate the % of inundation for the island (Figure 10). Areas with inundation levels within the growth range of Morris are highlighted in Figure 11; areas in green highlight the optimal growth range.

[5] MORRIS, JAMES T., et al. "Salt Marsh Primary Production and Its Responses to Relative Sea Level and Nutrients in Estuaries at Plum Island, Massachusetts, and North Inlet, South Carolina, USA." *Oceanography*, vol. 26, no. 3, 2013, pp. 78–84. *JSTOR*, http://www.jstor.org/stable/24862067. Accessed 20 Jun. 2022.

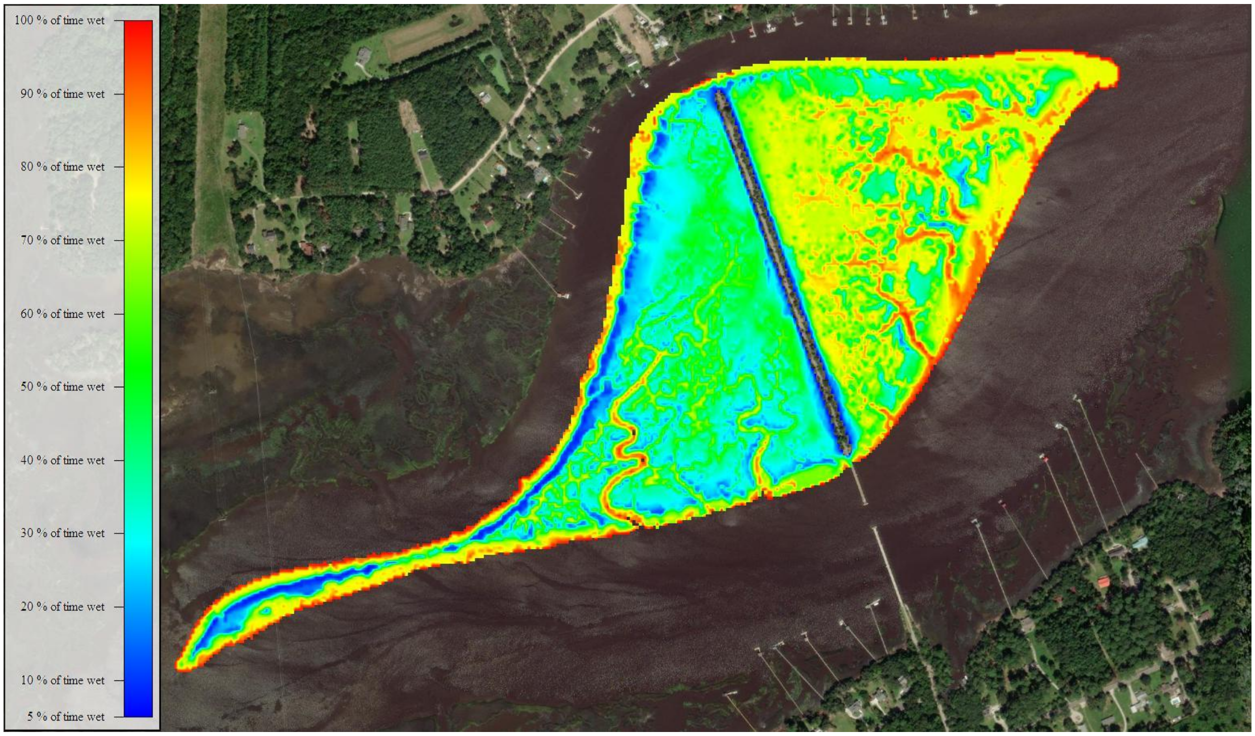

Figure 10. Calculation of the time the marsh island is wet (inundated).

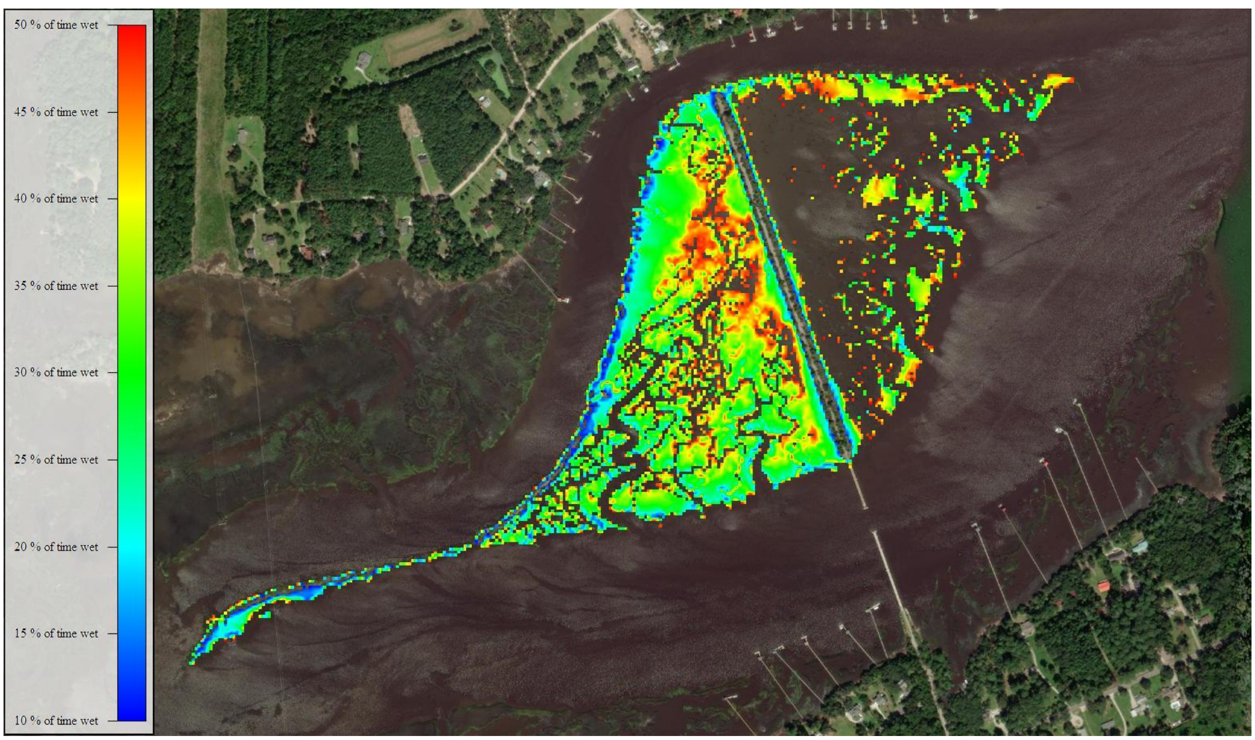

Figure 11. Areas of the island with inundation levels between 10 and 50%

The optimal growth range is skewed highly towards the western portion of the island (Figure 11). The void in the optimal growth range just east of the rail line suggests that sediment has been re-routed from reaching the area during times of higher water – above MSL. This may be from blocking water flow or creating higher flow on the back side during flooding (in-coming tide) from a longer flow path (like a wing where higher velocities are on the 'long' side). Higher flows could reduce deposition and increase re-suspension.

Erosion

Wave driven erosion is likely occurring on the exposed shorelines of the island and is indicated by the darker reds in Figure 8. The primary areas of erosion are on northeast facing shorelines which have slightly longer fetches (more open water) suggesting that winter storms or cold fronts bringing North to Northeast winds are causing the bulk of erosion. The impact from erosion, however, appears to be a secondary process in reducing marsh coverage. The greater impact is from a lack of sediment deposition within the interior of the island.

Sea Level Rise

The earlier sedimentation rate map (Figure 8) was generated assuming the sea level was constant between 2002 and 2020, which we know is not the case. If the average rate of SLR over the period (7 mm/yr) is included in the calculation the net result is more concerning (Figure 12) and it is likely that the entire island will begin to resemble the present condition of the eastern side. This is not a unique situation in the Port Royal Sound and an increase in tidal flats and loss of marsh is expected.

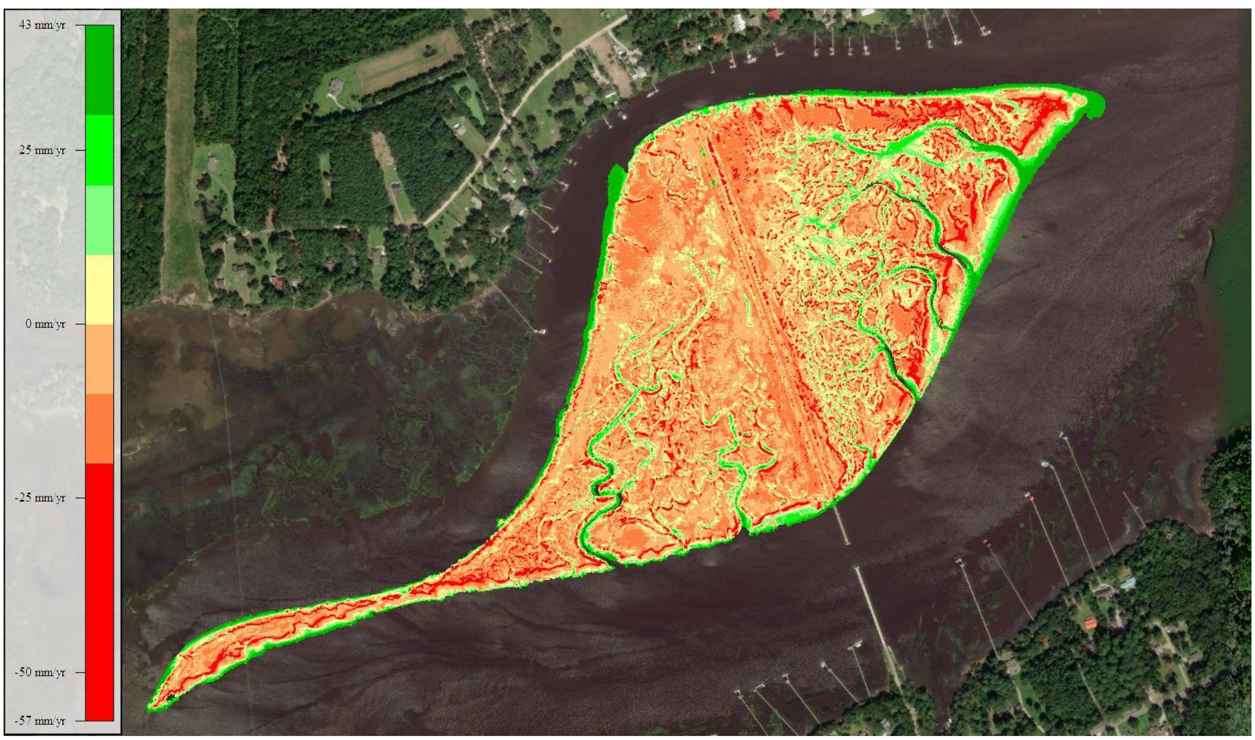

Figure 12. Net sedimentation rates with SLR included

Tidal Flats as an Opportunity

The presence of tidal flats on the island and potential for increased coverage is common in the Port Royal Sound (Figure 13). In the sound, tidal flats represent more than 1/3 of the estuarine wetlands at present. This will likely approach 50% in the future given the lack of space for the wetlands to migrate upwards if development patterns do not change (e.g., increases in bulkheads). At present there are about 4,000 acres of tidal flats in Port Royal Sound based on the NOAA C-CAP landcover.

The ability of the tidal flats to survive through increased sedimentation (via longer inundation times) provides a potential long-lasting substrate/habitat for offsetting the natural loss of marsh. Simply put, adding sediment to these habitats, which will largely maintain themselves in the interim, may be an easier way to begin restoring lost marsh acreage than procuring and managing upland areas for marsh migration given the present development patterns. Changes in future development and planning could help provide space for upward marsh migration to offset some of the future loss.

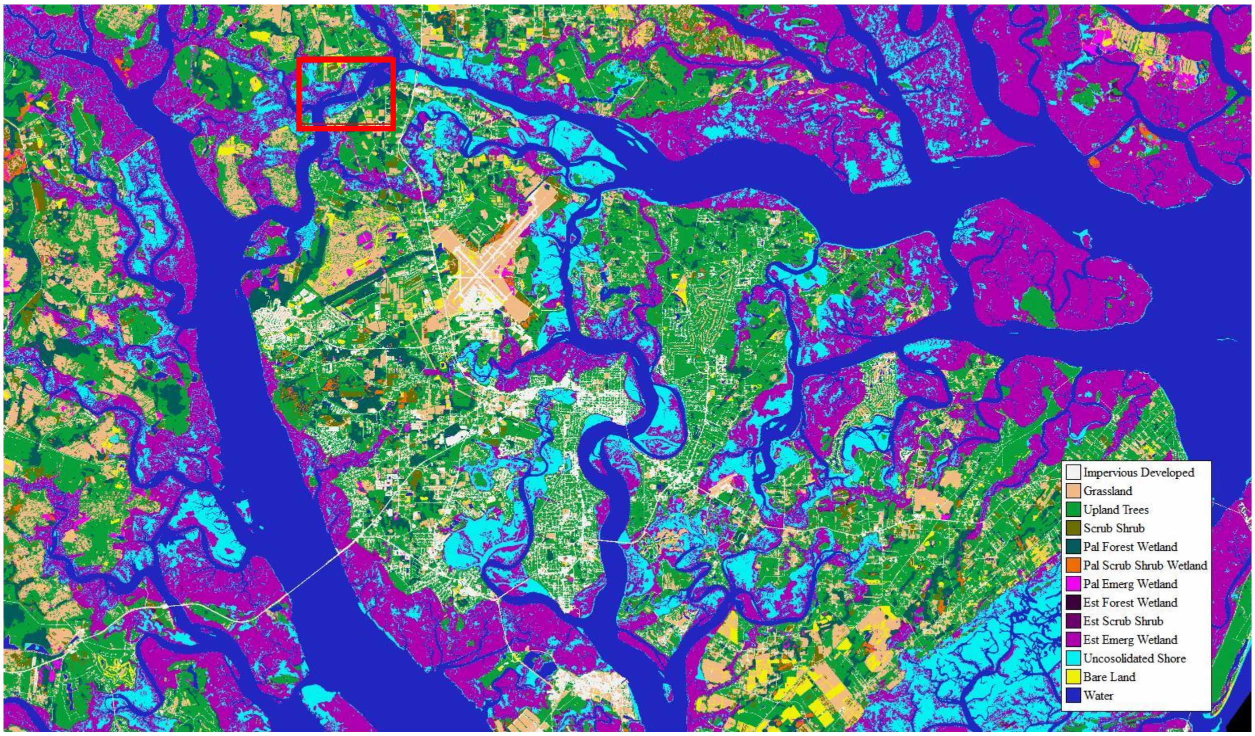

Figure 13. NOAA C-CAP landcover map of the area. Tidal flats are shown as a teal color and marshes as purple. The study site is shown in a red box near the upper left.

Thin layer deposition is being used and studied at a nearby location in Georgia at Jekyll Creek[6] by the US Army Corps of Engineers to add sediment to tidal flats/low marsh. The setting is a bit different as it is on the backside of a barrier island and a sandy location, but it has the same low elevation, sparsely vegetated tidal flat appearance as the Whale Branch Study area. The source of sediment was from dredging of the Intracoastal Waterway, which also passes through the Port Royal Sound, although not the Whale Branch area. The USACE study is part of the recent and timely push for the beneficial use of dredge material in coastal habitats within the coastal areas of NC, SC, and GA.

Initial Conclusions

Although the study location is small it contained a variety of environments that were created by both natural and anthropogenic (human activity) variables. It is a unique site and at the same time provides a good summation of the processes going on in the greater Port Royal Sound. The sum of environments and variables helped to highlight the following take-aways.

1. Sediment deposition may not necessarily follow the common estuarine model of inland sources and an estuarine turbidity maximum where sediment deposition is concentrated. In the area of

[6] https://budm.el.erdc.dren.mil/jekyllcreek-georgia.html

interest (AOI) the trends point to deposition from seaward sediment sources more than upland areas.

2. Sedimentation rates are related to elevation and, thus, time of inundation.

3. Most of the areas supporting marsh had an inundation time of 31% +/- 14%. Areas below about 50% will likely become tidal flats if not so already.

4. Tidal flats have higher sedimentation rates than marsh areas because they are inundated longer than the marsh.

5. Nearly the entire island has a negative net sedimentation rate when sea level rise is included in the calculation of rates.

6. Man-made structures cutting across marshes (e.g., causeways) can interrupt sediment deposition and create conditions that lead to marsh loss.

7. The vast acreage of tidal flats in Port Royal Sound provides a framework for development of future marsh if the correct elevations can be achieved. The likelihood of upland land becoming marsh, the natural cycle, is being curtailed by current development trends in the area.

8. Thin layer deposition and the beneficial use of dredge material provides an avenue towards re-establishment of areas that used to be marsh. The beneficial use of dredge material program within the US Army Corps of Engineers should be a valuable source of information and potential funding.

9. The use of existing remote-sensing data, especially lidar, provides an avenue for high accuracy measurements. The existence of several decades of data facilitates the capture of yearly trends on the sub-centimeter scale. The techniques described and presented in this study can be used in many other marsh sites around the US to define trends and document changes.

Next Steps and Recommendations

Tidal flats are an important resource and one that will become more common. If they are to be used in the restoration and maintenance of the Port Royal Sound marshes, they, along with the marshes, should be mapped and categorized. It will be important to know what trends are occurring at the different locations and what critical habitats are present (e.g., oysters) so that when sediment resources are available, they can be used effectively. This effort should include/will require the generation of a beneficial use plan that incorporates the source areas (e.g., dredging needs) with destination areas (e.g., tidal flats or marshes with high negative sedimentation rates). Cost considerations have heretofore been an impediment to BU, but as the value of coastal sediments becomes more apparent the recognized benefit to cost ratio should help drive more responsible use of the resource.

An aspect of the responsible use of coastal sediments includes developing an understanding of the engineering required to maximize the effectiveness of adding sediment to these habitats. Various techniques are available to ‘spread’ the sediments on these habitats and some will work better in the distribution than others depending on the specific area and physical conditions, which may be able to be modified. Living shorelines are an aspect of this as are the use of plantings, geotextiles, temporary earthwork, and natural materials (e.g., coir logs).

The present study is intended to be Phase I in a multi-phase project. Phase II can build on the data that has been gathered, some of which has been included in this report. The engineering and material aspects mentioned above can be linked to the trends and physical conditions presented within the report and documented with additional information that was not presented. Phase II will require a multi-discipline (e.g., geology, biology, ecology, and engineering) approach to marry the appropriate techniques and infrastructure to the overriding issues that are driving the loss of marsh habitat at the site and in the Port Royal Sound in general. The logical completion of the project, i.e., a Phase III effort, could help to facilitate the use of the Phase I and II studies to tackle the policy, legal, planning, environmental, and funding aspects of the tremendous effort required to advance the existing techniques used in contemporary dredging practices.

The project site provides a good pilot area to look at the different technologies and engineering requirements as it has a stable high area to stage from (the old railway line). This is not likely to be a short-term pilot as marsh growth – or die off – is not an overnight occurrence. The existing infrastructure will help facilitate monitoring activities that will be required to maximize the process of using tidal flats to help reestablish marsh habitat lost to climate change and other stressors.