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Using XBeach to Describe the Performance of an Intertidal Vegetation Shoreline Stabilization Treatment

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THE UNIVERSITY OF SOUTH ALABAMA
COLLEGE OF ENGINEERING

USING XBEACH TO DESCRIBE THE PERFORMANCE OF AN INTERTIDAL VEGETATION SHORELINE STABILIZATION TREATMENT

BY

Elizabeth Winter

A Thesis

Submitted to the Graduate Faculty of the
University of South Alabama
in partial fulfillment of the
requirements for the degree of

Master of Science

in

Civil Engineering

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LIST OF ABBERVIATIONS

ALDOT CORS = Alabama Department of Transportation Continuously Operating Reference System

CERC = Coastal Engineering Research Center

CRS = coordinate reference system

GNSS = global navigation satellite system

LST = longshore sediment transport

NOAA = National Oceanic and Atmospheric Administration

RTK = real-time kinematic

SLR = sea level rise

ABSTRACT

Winter, Elizabeth, M. S. Civil Engineering, University of South Alabama, December 2022. Using XBeach to Describe the Performance of an Intertidal Vegetation Shoreline Stabilization Treatment. Chair of Committee: Bret Webb, Ph.D.

The purpose of this project is to predict the hydrodynamic and morphodynamics of an engineered vegetation-only shoreline restoration project in Little Lagoon, Alabama under different storm and sea level rise scenarios. Little Lagoon is a shallow, single-inlet lagoon located in Baldwin County, Alabama that has been experiencing shoreline erosion for the past 28 years. A living shoreline using vegetation only (*Spartina alterniflora*) was implemented in the southwest corner of the lagoon, located within Bon Secour National Wildlife Refuge, to create habitat, improve water quality, and prevent future erosion. This research compares “with-project” and “without-project” hydrodynamics and morphodynamics using XBeach in a one-dimensional transect-based mode to assess potential project performance. This was done using four storm scenarios and five sea level rise scenarios. The with-project and without-project scenarios were compared using profile shape, gross sediment change, and wave height behind the vegetation. Results from this project indicate that the emergent marsh vegetation shoreline contributions to overall shoreline stability are negligible, likely due to the already stable nature of the shoreline. The results from this project will aid practitioners in the future design and implementation of vegetation only shoreline restoration projects along stable shorelines.

CHAPTER I

INTRODUCTION

The purpose of this project is to predict the behavior of a vegetation only shoreline restoration project under different storm and sea level rise scenarios. This project will compare “with-project” and “without-project” hydrodynamics and morphodynamics using XBeach in a one-dimensional (1D) transect mode using five sea level rise scenarios and four storm scenarios. This project will predict the performance of a vegetation only living shoreline, under the effects of increasing storm severity and increasing sea level rise. The results from this project will aid practitioners in the future design and implementation of vegetation only shoreline restoration projects along stable shorelines.

Little Lagoon is a shallow, single-inlet lagoon located in Baldwin County, Alabama. The lagoon is approximately 12.5 kilometers long (east to west), and 1 kilometer across (north to south) at its widest point, with a total area of approximately 10,000 km^2 (Gibson et al. 2009). The average tidal range within the lagoon is approximately 0.12 meters (Groza 2016). The primary freshwater contribution to the lagoon comes from groundwater, through highly porous and hydraulically conductive soils and aquifers in the surrounding Baldwin County (Groza 2016). Some small surface water contributions come from nearby Gator Lake and Shelby Lake, and nearby freshwater springs. According to a study from 2009, Little Lagoon experienced erosion along the southern shore between 1957 and 2009, especially near tidal inlets and areas of human development (Gibson et al. 2009). The total increase in lagoon area during this time period was approximately 38.3 km^2 (Gibson et al. 2009). Much of the lagoon's shores are developed, with the exception of the western end, which borders Bon Scour National Wildlife Refuge (Gibson et al. 2009). A living shoreline using vegetation only (*Spartina alterniflora*) was implemented in November 2019 in the southwest corner of the lagoon, located within Bon Secour National Wildlife Refuge, to contribute to habitat restoration and prevent future erosion.

1.1 Vegetation Use in Living Shorelines

As population increases, shoreline infrastructure must increase to support growing demand. In the United States, as of 2013, 52% of the country's population lived in a coastal watershed county (Crossett et al. 2013). This percentage has been steadily increasing for decades and is expected to continue increasing (Crossett et al. 2013). Historically, the response to growing coastal populations was to implement shoreline hardening structures, such as seawalls or bulkheads, to combat coastal erosion, reduce flooding, and mitigate storm risk (Gittman et al. 2016). While hard structures can be effective at stabilizing shorelines, they may have detrimental effects on the local ecology (Bozek and Burdick 2005; Gittman et al. 2016). Bozek and Burdick (2005) discuss seawalls in the Great Bay Estuary in New Hampshire and conclude that the seawalls in that region are negatively affecting the vegetative biodiversity in coastal marshes. A similar conclusion is reached by Gittman et al. (2016), finding that seawalls support 23% less biodiversity and 45% fewer organisms than natural shorelines. While vegetated living shorelines may benefit local ecology and biodiversity, their effectiveness at mitigating erosion is dependent on the wave energy along the shoreline being considered (Davis et al. 2015). Living shorelines tend to be most beneficial in areas with low wave energy (Davis et al. 2015). Under appropriate wave conditions, living shorelines utilizing shoreline vegetation can be an effective and ecologically ideal alternative to hardened shoreline structures.

Vegetation can be an effective tool for mitigating shoreline erosion when applied correctly. Roland and Douglass (2005) described the ideal wave conditions for *Spartina alterniflora. S. alterniflora* is a marsh plant native to North America commonly used in living shoreline projects. S. alterniflora thrives in low energy wave conditions, where 50% of the waves are less than 0.13 meters, and 80% of the waves do not exceed 0.2 meters (Roland and Douglass 2005).

1.2 Site History and Living Shoreline Design

Little Lagoon is located along Alabama's Gulf Coast, east of the mouth of Mobile Bay. The lagoon is connected to the Gulf of Mexico by a single, engineered tidal inlet (Figure 1 & 2)The site is approximately 200 meters of east-facing shoreline, and has been relatively stable for the last 27 years, so a modest restoration plan, focused on habitat creation and ecological improvement, has been implemented (AITG 2018). The proposed restoration plan for this site is planting *Spartina alterniflora* at 50% density in alternating stretches of shoreline, ultimately planting approximately 150 meters of shoreline (ATIG 2018).

Figure 1. Satellite imagery of Southern Alabama(A) and Little Lagoon (B). The yellow box (A) indicates the location of Little Lagoon. The red box indicates the shoreline used in this project. The green arrow indicates the engineered inlet. (Google Earth 2020).

Figure 2. Satellite imagery of project site. The red bracket indicates the stretch of shoreline studied in this project (Google Earth 2020).

The purpose of this living shoreline is to provide shoreline stabilization, while also providing ecological benefits. These long-term benefits will likely include water quality improvement, habitat creation, and aesthetic and visual resources (AITG 2018). The water quality would improve through providing a natural nutrient sink, reducing eutrophication, and by preventing erosion of pollutants and sediments (AITG 2018). The habitats created through this living shoreline include habitat for fish, shellfish, wading birds, and shorebirds (AITG 2018). This project is considered low risk to the environment, with only a few short-term adverse effects during construction, including wildlife and exiting vegetation disturbances (AITG 2018).

1.3 XBeach Model

XBeach is a numerical model originally developed to simulate hydrodynamics and morphodynamics along sandy beaches. However, it has been extended and applied to urbanized and dune coasts, reefs, and vegetated coasts (Roelvink et al. 2015). For this project, the XBeach model will be used in a 1D transect mode. In this mode, XBeach functions by solving the non-linear shallow water equations at points along a transect (Roelvink et al. 2015). Many of the studies that utilize XBeach are focused on modeling short term morphodynamics due to storm events. For example, van der Lugt et al. (2019) used XBeach to model how two different Atlantic barrier islands respond to hurricane forcing. In that study, XBeach predicted dune erosion, deposition, and breach formation well, with only the onshore sediment transport parameter calibrated (van der Lugt et al. 2019). Rooijen et al. (2015) analyzed XBeach's accuracy predicting wave attenuation through vegetation. The vegetation was simulated by adding in a vegetated layer (Rooijen et al. 2015). The modeled wave heights were compared to measured wave heights to determine the model accuracy. They found the vegetation layer accurately simulated the damping effects with little calibration (Rooijen et al. 2015).

XBeach has also been used to predict the performance of shoreline protection methods. Brandes (2020) used XBeach in a two-dimensional hydrostatic mode to determine the optimal shape, dimension, and location of an artificial reef to minimize energy transmission and shoreline erosion. XBeach proved useful for testing the site designs for short-term simulations, but was unable to produce some of the short waves needed to accurately model the wave climate at the study location (Brandes 2020). Another study on modeling shoreline protection strategies was performed for three recommended living shoreline erosion mitigation methods for a Rhode Island barrier island (Hayward et al. 2018). XBeach was coupled with the already coupled ADCIRC and SWAN models to determine offshore sea levels, wave conditions, and simulate nearshore sediment transport and erosion (Hayward et al. 2018). They found that the designs that reinforced dunes, and the beach face were more effective at mitigating erosion than those that reduce wave action and that XBeach was able to estimate eroded volume along beach transects within 8% to 39% (Hayward et al. 2018).

CHAPTER II

METHODS

The purpose of this project is to predict the behavior of a vegetation only living shoreline project under different storm and sea level rise scenarios. In order to predict the behavior, real-time kinematic (RTK) measurement were collected to establish multiple cross shore transects. These transects were used to create the 1D grid that was then used in the XBeach model. Two grids were created: one with vegetation, and one without vegetation to simulate the with-project and without-project scenarios. Five sea level rise scenarios were selected, along with four storm conditions of increasing severities, and these were used to inform the tide and wave forcing within the model. The model was run on the Alabama State Supercomputer. The outputs were extracted and analyzed in Matlab.

2.1 Wind, Wave, and Longshore Sediment Transport Conditions Analysis

A wind, wave, and longshore sediment transport (LST) conditions analysis was performed for the project site. The fetches were delineated at 15-degree intervals. The fetch lengths were measured from a reference point in the middle of the project site, to the adjacent shore every 15 degrees using Google Earth (Google 2022). This resulted in eleven, non-zero length fetches. Zero length fetches are those that occur over land. The average depth along each non-zero fetch length was determined using QGIS (QGIS Development Team 2020). The depth data used to determine the average depth was taken from a dataset titled “Mobile, Alabama 1/3-arc second NAVD 88 Coastal Digital Elevation Model” found on the NOAA National Centers for Environmental Information website (NOAA National Geophysical Data Center 2009). Figure 3 shows the delineated fetches and elevations in Little Lagoon. Table 1 lists the fetch angles, lengths, and average depths. The wind climate data, including hourly wind speed, hourly wind direction, and hourly wind gust speeds, used in this conditions analysis were sourced from the NOAA Tides and Currents’ Fort Morgan Station (8734673) (NOAA 2020). The wind data from years 2008 to 2019 excluding 2016 were used to develop the wind climate analysis in Matlab (“Matlab” 2019). Data for the year 2016 were omitted because it had little usable data. The wind data were then used in the wave climate, and LST climate analysis also generated using Matlab (“Matlab” 2019).

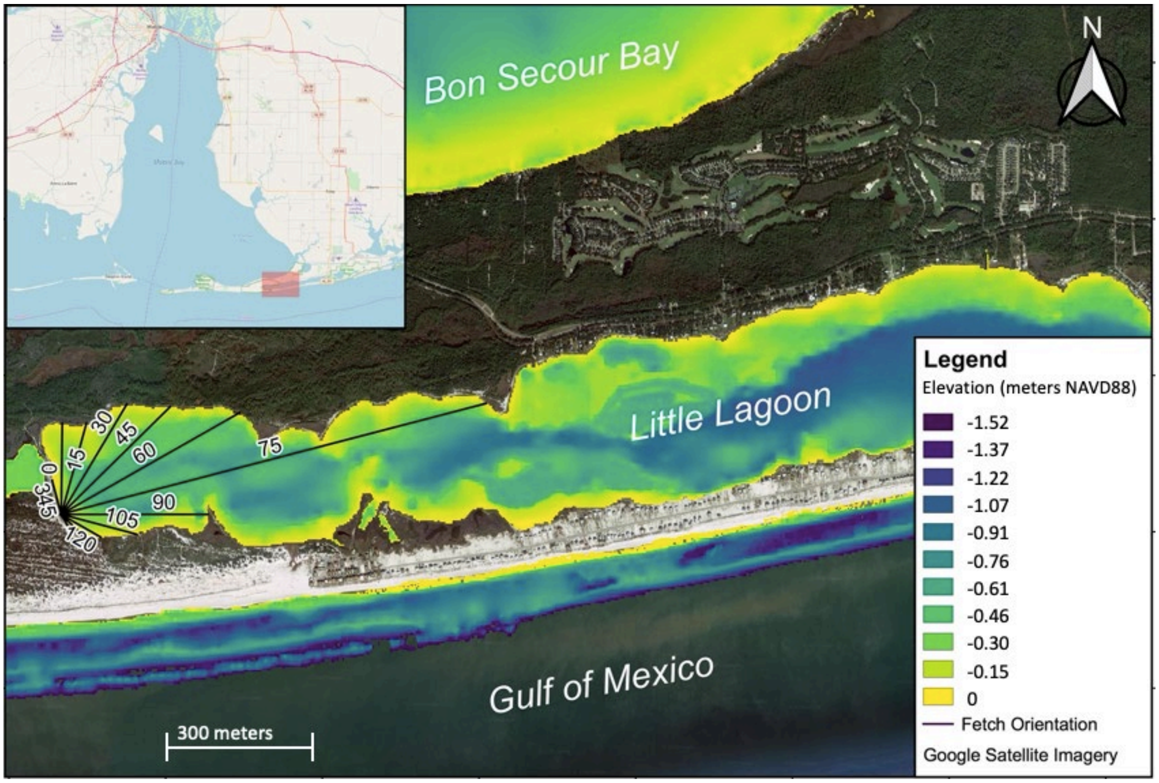

Figure 3. Fetches used in wind, wave and LST conditions analysis. Cooler colors denote deeper depth, and warmer colors denote shallower depth. The black lines represent the fetches used. The black number located along each fetch line denotes the angle of the fetch, relative to north.

Table 1. Fetch depth table. Fetch direction is in degrees from north, distance is the distance from midpoint on the project site to the adjacent shoreline, and depth is the average depth along the fetch in meters, using NAVD88 as the datum.

Direction (degrees)	Distance (m)	Depth (m)
0	579.4	1.8
15	594.3	3.0
30	805.0	3.3
45	974.6	4.2
60	1305.3	4.8
75	2795.9	4.6
90	927.0	3.4
105	502.6	1.7
120	292.8	1.1
135	199.3	0.4
150	0.0	0.0
165	0.0	0.0
180	0.0	0.0
195	0.0	0.0
210	0.0	0.0
225	0.0	0.0
240	0.0	0.0
255	0.0	0.0
270	0.0	0.0
285	0.0	0.0
300	0.0	0.0
315	0.0	0.0
330	0.0	0.0
345	217.5	0.4

The wave climate developed from the wind data, and the fetch and depth data, include the hourly wave height, and hourly wave period by direction and frequency. The Matlab code used to generate this data makes a few assumptions, including waves are generated only by local winds, waves are fetch limited, the sea state is fully arisen, depth contours are straight and parallel, and the offshore profile slopes are mild. The wave climate data was be used to estimate LST at the project site.

The LST was estimated using a Matlab code, which utilizes the wave climate results, and the Coastal Engineering Research Center (CERC) equation:

$$Q = k\sqrt{\frac{g}{kappa}}\, H_b^{5/2} \sin 2\theta \, \frac{1}{16\,(S-1)(1-p)} \qquad (1)$$

where Q is the volume transport rate of sediment, k is the CERC coefficient value, *kappa* is the wave constant, g is gravity, H_b is the breaking wave height, θ is the breaking wave angle, S is the sediment specific gravity, and p is sediment porosity (Coastal Engineering Research Center 1984). The Matlab code used produced LST rate for each wind/wave data point, resulting in an hourly rate of LST. This hourly rate was converted into volume by year which is a more usable metric. A few assumptions were made to calculate LST. The constant (k) in the CERC equation is assumed to be 0.32, and sediment specific gravity is assumed to be 2.65 and the sediment porosity (p) is assumed to be 0.4.

2.2 RTK Measurements and Grid Creation

Real-time kinematic elevation surveys (RTK) were performed at the project site in November 2019 and April 2022. Location and elevation data were collected at each point, using a global navigation satellite system (GNSS) receiving RTK corrections from the Alabama Department of Transportation’s Continuously Operating Reference System (ALDOT CORS) Network. The elevation data were recorded using the North American Vertical Datum of 1988 (NAVD88), and the location data were recorded using the Alabama State Plane West (FIPS 0102, Feet) horizontal coordinate reference system (CRS). The original, 2019 survey consisted of four cross shore transects each approximately 50 meters in length, spaced approximately 40 meters apart. Each transect was comprised of about 15 unevenly spaced points. Points were taken approximately every 20 feet, or more frequently if there was notable change in the profile. Particular attention was given to the area near the water line and dune toe. One transect was chosen as a representative transect for the project site. In April 2022, the site was surveyed again along the same transects, but the representative transect was extended in both the onshore and offshore directions, resulting in a 73 meter transect. The extended transect consisted of 32 unevenly spaced points. The representative transect was used to create the XBeach transect. In order to increase resolution, five additional points were added near the waterline. The values for these points were determined using linear interpolation.

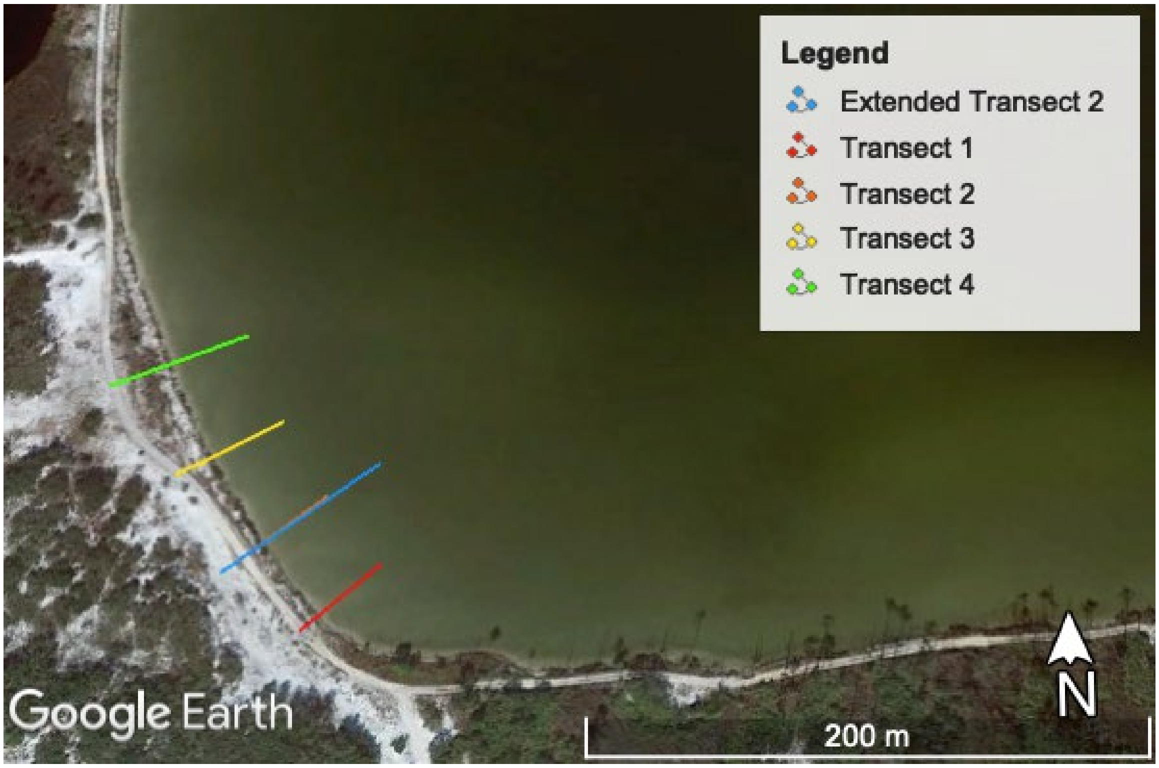

Figure 4. Map of transects over satellite imagery of Little Lagoon project site. Transects 1, 2, 3, and 4 were measured in November 2019, and Extended Transect 2 was measured April 2022.

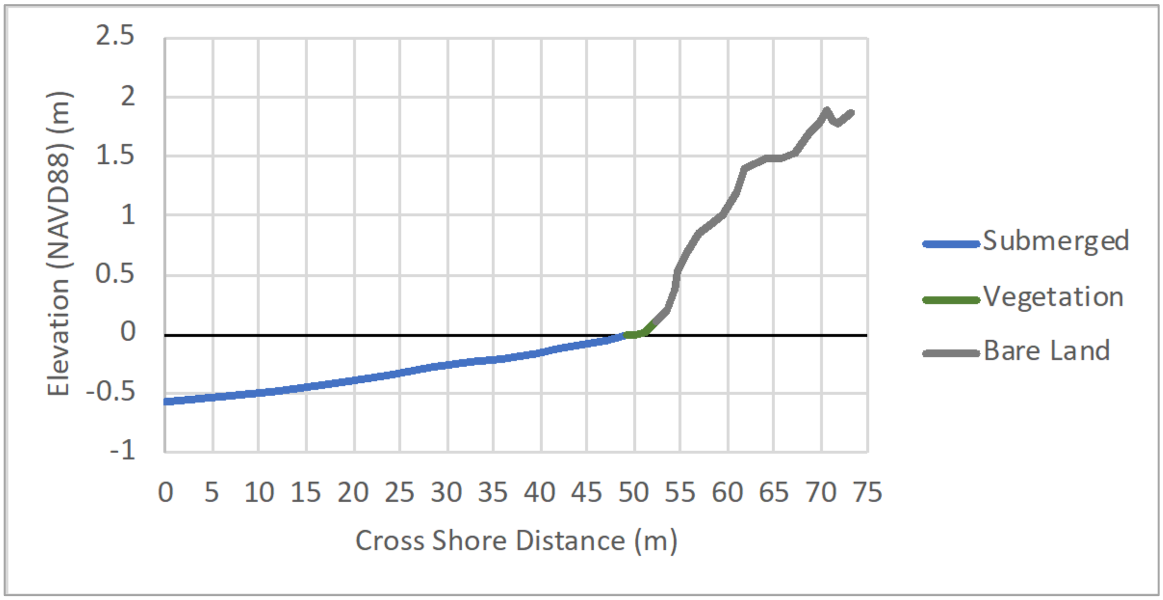

Figure 5. Cross shore distance and elevation of representative transect. This transect corresponds to Extended Transect 2 shown in Figure 4. The zero cross shore point corresponds to furthest offshore point along the transect. The blue line is the submerged portion of the profile, the green line is the vegetated portion of the profile, and the gray line is the bare land portion of the profile. For the without-project runs where no vegetation is included, the submerged portion extends to the zero-elevation line, and the bare land portion begins above the zero-elevation line.

When run in 1D mode, XBeach requires three different transect input files. The first, x.grd, contains the cross-shore distance information. The most offshore point is the zero point, and the values increase in the onshore direction. The next file required is the y.grd file. In the 1D mode, this file contains all zero values, coordinating to the number of points in the x.grd file. The last required file is the bed.dep file. This file contains the elevation data that coincides with the x.grd points. Each of these files were created using the RTK elevation measurements. However, the data was first converted to meters, and distance calculated between each survey point, for the x coordinates.

In addition to these three required files, a Manning's n file, and a vegetation map file were also incorporated into this project. The Manning's n file assigned a roughness coefficient to each point along the transect. Separate Manning’s n files were created for the with and without project scenarios. The vegetation map was simply omitted for the without project model runs. The values used in the Manning’s n grid creation were previously established values from open water, emergent marsh vegetation, and bare land (Passeri et al. 2018). The open water value used was 0.022, the emergent marsh vegetation value used was 0.05, and the bare land value used was 0.03. Two separate Manning’s n files were created with these values for with and without project model runs.

A vegetation map file was created for the with-project model. While XBeach allows for more than one vegetation type to be incorporated into the model, only *Spartina alterniflora* was used in this project. In order to generate the vegetation map file for this project a value of one was placed everywhere the vegetation occurred along the transect, and a zero was placed at all the points that vegetation did not exist. This one value then referenced a vegetation type file. Within the vegetation type file, a vegetation characteristics file was referenced. This vegetation characteristics file contained four descriptive values, specific to *Spartina alterniflora*. These values included height (ah), drag coefficient (cd), the stem diameter at base (bv), and the number of stems per meter squared (N). The values used came from previously established values for *Spartina alterniflora*. The height used was 1.5 m, the stem diameter used was 0.00762 m, and the stem density used was 300 stems per square meter (Anderson and Smith 2014; Bush and Houck 2002). The drag coefficient used was 1.5 (Anderson and Smith 2014).

2.3 Sea Level Rise and Storm Scenarios

In this project, five sea level rise scenarios, and four storm forcing scenarios were used, and run both with and without project, resulting in a total of forty unique runs. The sea level rise scenarios and storm scenarios were used to create the tide and wave files for XBeach. The sea level rise scenarios consisted of zero sea level rise, low sea level rise, low-intermediate sea level rise, intermediate sea level rise, and intermediate-high sea level rise. Higher sea level rise scenarios were not modeled because the project would be completely inundated, reducing the likelihood of any usable results. The magnitude of each of these scenarios were sourced from the US Army Corps' Sea Level Change Curve Calculator, using Dauphin Island as the location, and 2050 as the year (USACE 2022). The sea level rise values were recorded in NAVD88, using NOAA's 2017 vertical land movement study as the data source, and the results were adjusted to local mean sea level (MSL) (NOAA et al. 2017; USACE 2022). The resulting sea level rise increments are shown in Table 2.

Table 2. Sea level rise scenarios used to inform XBeach model forcing. All values are in meters, using NAVD88 the reference datum, and in mean sea level (MSL). Predictions are for the year 2050.

Scenario	Mean Sea Level (meters)
Current Conditions	0.016
Low	0.300
Intermediate-Low	0.350
Intermediate	0.490
Intermediate-High	0.650

For the storm conditions, four scenarios were used, consisting of average, mild, moderate, and severe conditions. The current conditions were derived from the wind, wave, and longshore sediment analysis described in Section 1.2. The three storm scenarios were chosen based on data from the Coastal Hazards System, using the South Atlantic Coastal Study data set, and ADCIRC save point 28721 (Coastal and Hydraulics Laboratory 2021). The average spectrally significant wave height (H_{m0}), average peak period (T_p) and storm surge were recorded for mild (2-yr return period), moderate (5-yr return period), and severe (10-yr return period) storms. The storm conditions are summarized in Table 3. In order to generate the wave and tide files for the XBeach model, the five sea level rise scenarios, and four forcing conditions were combined, resulting in twenty unique tide and wave conditions.

Table 3. Forcing condition scenarios used to inform XBeach model forcing. Surge, tide, and wave height values are in meters. Period values are in seconds. Average conditions are from the wind, wave, and LST conditions analysis performed. Storm conditions are from the Coastal Hazards System (Coastal and Hydraulics Laboratory 2021).

Forcing Conditions	Return Period (T_r) (years)	Surge (m)	H_{m0} (m)	T_p (s)
Average	n/a	0	0.17	1.49
Mild Storm	2	0.85	0.26	2.13
Moderate Storm	5	1.33	0.34	2.22
Severe Storm	10	1.77	0.43	2.29

The tidal forcing used for this project was a three-day time period, with a base range of 0.12 meters, a typical tide range for Little Lagoon (Groza 2016). Storm surge and sea level rise were incorporated into this tidal pattern to create the tidal forcing files. In order to create the wave forcing files, the spectrally significant wave height, and the average peak period were used to create a three-day, time varying wave forcing file. Examples of the tide and wave forcing files can be found in Appendix A, Table A 1 and Table A 2, respectfully. Figure 6 shows the tide forcing hydrographs for each sea level rise and forcing conditions scenario. The wave forcing used in this model utilizes a non-spectral, stationary wave boundary condition mode in XBeach. This means that the wave conditions are defined without wave groups and time series (Roelvink et al. 2015). Instead, a constant wave energy is specified using H_{m0} and T_p (Roelvink et al. 2015). Each of these specified constant wave energies is considered a sea state. The keyword "stat_table" was used, which allows the users to specify a series of sea states. For this model, a series of sea states was defined using the data from the forcing conditions in Table 3.

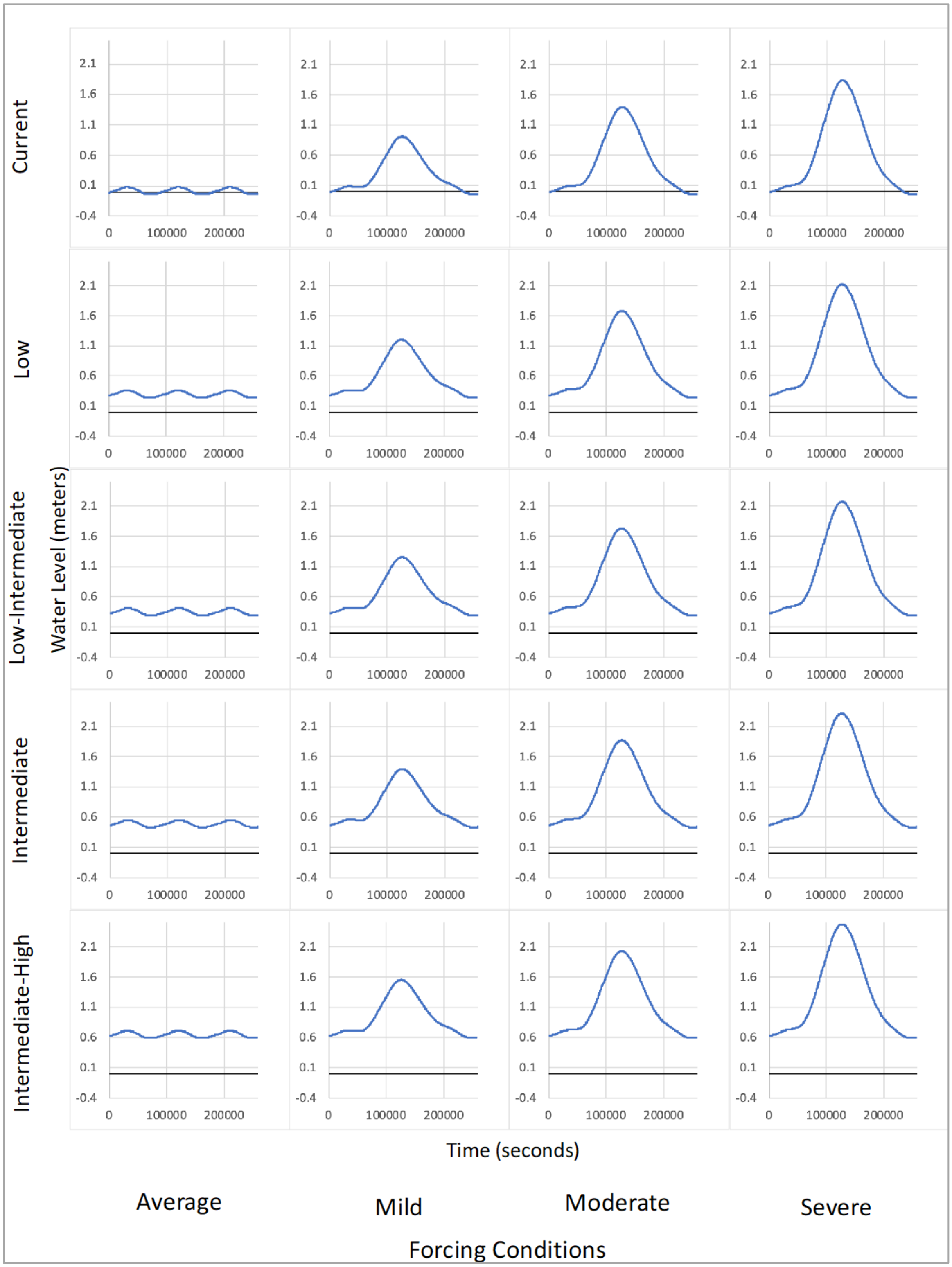

Figure 6. Water Levels for each sea level and forcing scenario. Sea level scenarios are in rows and forcing conditions are in columns.

2.4 Model Configuration

In addition to the grid files, XBeach also requires a configuration file called params.txt. This file contains grid file information, bathymetry information, wave input, morphological inputs, and more (Rooijen et al. 2015). Within the params.txt file, there is the option to toggle on the vegetation function. This was turned on for the with-project model runs, but left off for the without-project runs. Apart from this, the rest of the params.txt file was left identical for the with and without-project model runs. Within this params.txt file, there are many parameters than can specified, but if nothing is denoted, the model runs a default setting or value. The params.txt file contents can be found in Appendix A, Figure A 1 and Figure A 2.

2.5 Model Runs and Matlab Analysis

The XBeach model in this project was run using the Alabama State Supercomputer. The grid files, the tide and wave forcing files, and the configuration params.txt file were uploaded to the supercomputer for each individual run. The files for each run were divided up into individual directories. The model was run, and the resulting output files were exported for analysis in Matlab ("Matlab" 2019). After the model runs were completed, Matlab was used to extract and analyze the results. The model results were in Fortran binary, with separate files for all the outputs, including profile (zb), water level (zs), and wave height (H). Matlab was used to convert these files into usable data. The profile figures were produced within Matlab, comparing initial, final with-project, and final without-project profiles for each scenario. Gross sediment change was also calculated using the profile data in Matlab. However, the data was exported to Microsoft Excel for further analysis and figure generation (Microsoft 2018).

To quantitatively compare the with-project and without-project profiles, the gross sediment change for each model run was calculated, shown in Figure 15 through Figure 19. Gross sediment change was calculated by subtracting the final profile from the initial profile, integrating the difference over the cross shore profile, summing the negative values to get erosion, summing the positive values to get depositions, then adding the absolute values of erosion and deposition. Then the with-project gross sediment change was subtracted from the without-project gross sediment change, in order to determine the difference the presence of the project made. A similar method was used to analyze the wave results. The average and maximum wave heights at the point immediately shoreward of the vegetated layer were determined for each scenario, shown in Figure 25 through Figure 29. The with-project wave heights were subtracted from the without-project wave heights to determine if the vegetated layer induced wave attenuation.

CHAPTER III

RESULTS

The results from the model runs were extracted and analyzed for each sea level rise and storm scenario using Matlab. This section details the results from the model run. The overall profile change was analyzed by comparing initial profile, final with-project profile, and final-without project profile for each scenario. The with and without project gross sediment differences were analyzed, allowing for a quantitative profile comparison. Finally, the wave heights behind the vegetation were estimated.

3.1 Wind, Wave and Longshore Sediment Transport Conditions Results

Figure 7 is a wave rose, displaying the results of this wind-wave climate analysis. Each wedge is a 15 degree directional bin, and contains the wave height and frequency of occurrence from that direction. Figure 7 shows that the majority of the waves at the project site come from either the north east, or from the south east, with a small number of waves coming directly from the east. The largest waves are from the north east, and the waves become increasingly smaller as they begin coming from the south. Figure 8 shows both the net and gross LST for each year of data. While the results in Figure 8 are more qualitative, they do show that net transport tends to be positive, which is south in this case.

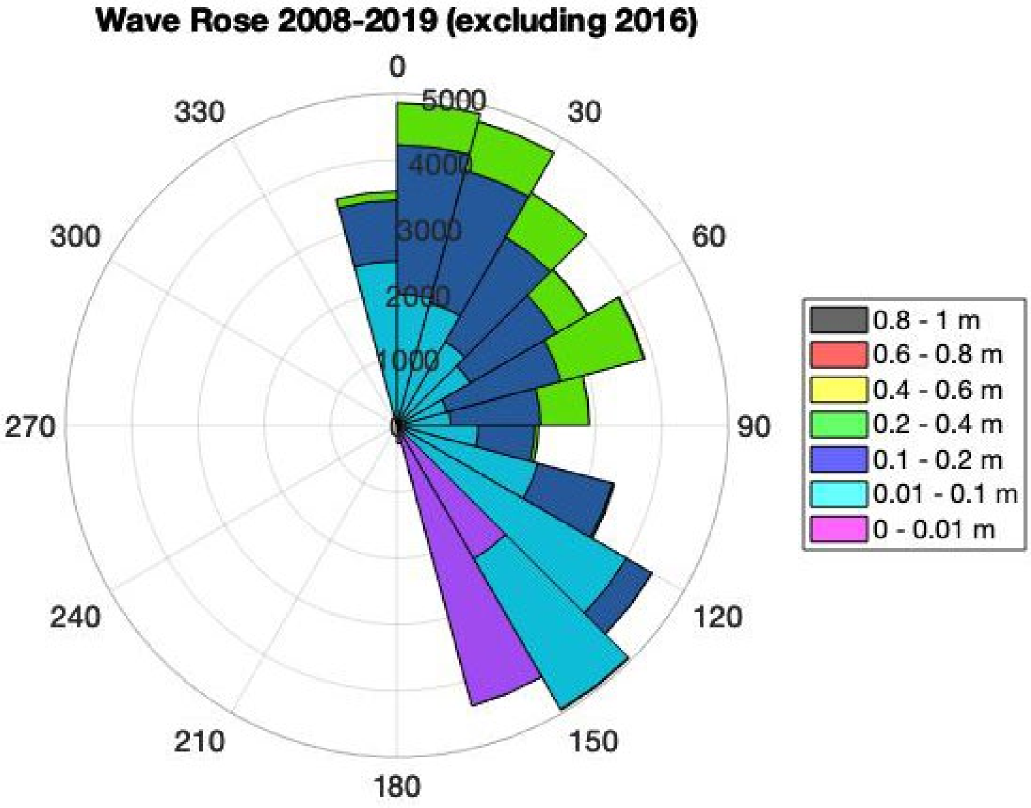

Figure 7. Wave Rose for 2008 to 2019 (excluding 2016). Waves are sorted into bins based on wave direction. Each wedge is a 15 degree directional bin, and contains the wave height and frequency of occurrence from that direction. All directions are with respect to degrees north. The numbers ascending up the radius correspond to the number of waves. Generated using Matlab (Matlab 2019).

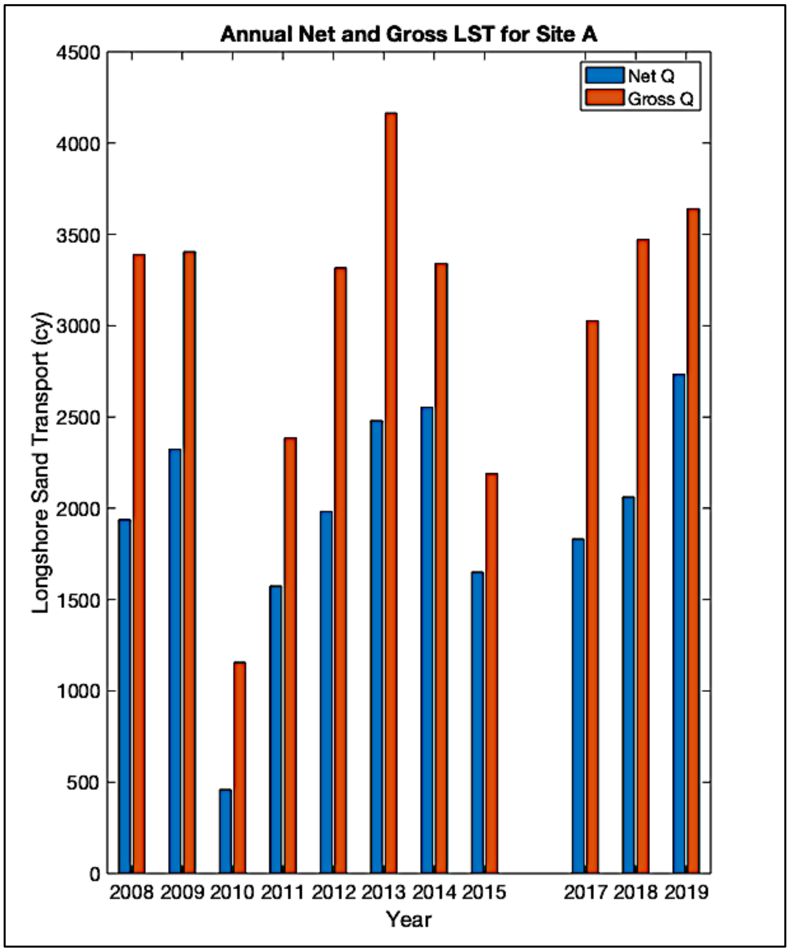

Figure 8. Annual longshore sediment transport in cubic yards for Little Lagoon site from 2008 to 2019 (excluding 2016) calculated from wind and wave conditions analysis. Red indicates gross sediment flow and blue represents net sediment flow. Generated using Matlab (Matlab 2019).

3.2 Profile Change

This section describes the differences between the initial and final profile elevations for each model run, and the differences between the with and without-project conditions. The following figures, Figure 9 through Figure 12, compare initial profile, final with-project profile, and final without-project profile. They are separated by sea level scenario, progressing from current sea level to intermediate-high sea level rise in number order.

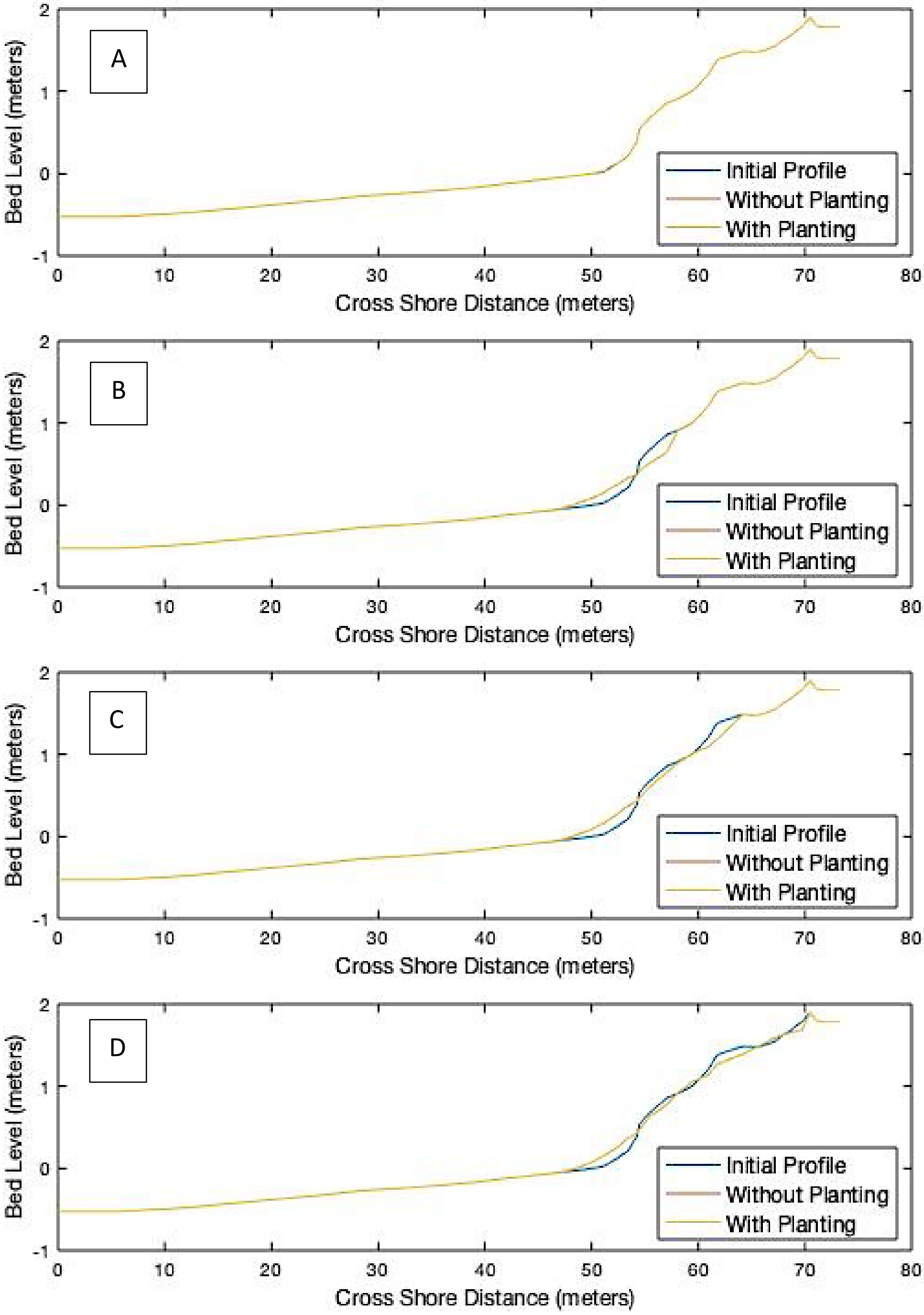

Figure 9. Pre-project profile, with-project final profile, and without-project final profile for current sea level, for (A) average conditions, (B) mild storm conditions, (C) moderate storm conditions, and (D) severe storm conditions.

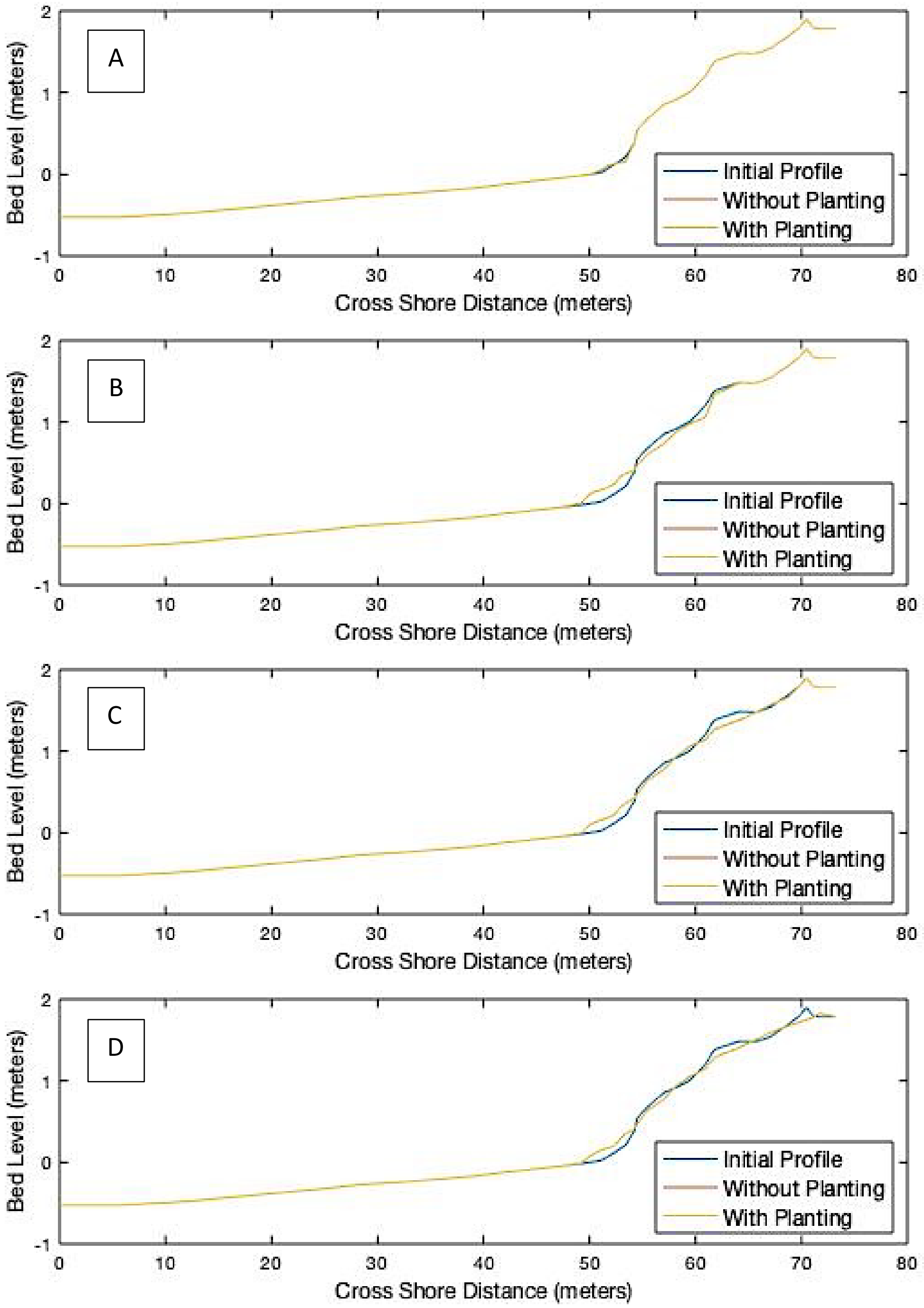

Figure 10. Pre-project profile, with-project final profile, and without-project final profile for Low Sea Level Rise Scenario, for (A) average storm conditions, (B) mild storm conditions, (C) moderate storm conditions, and (D) severe storm conditions.

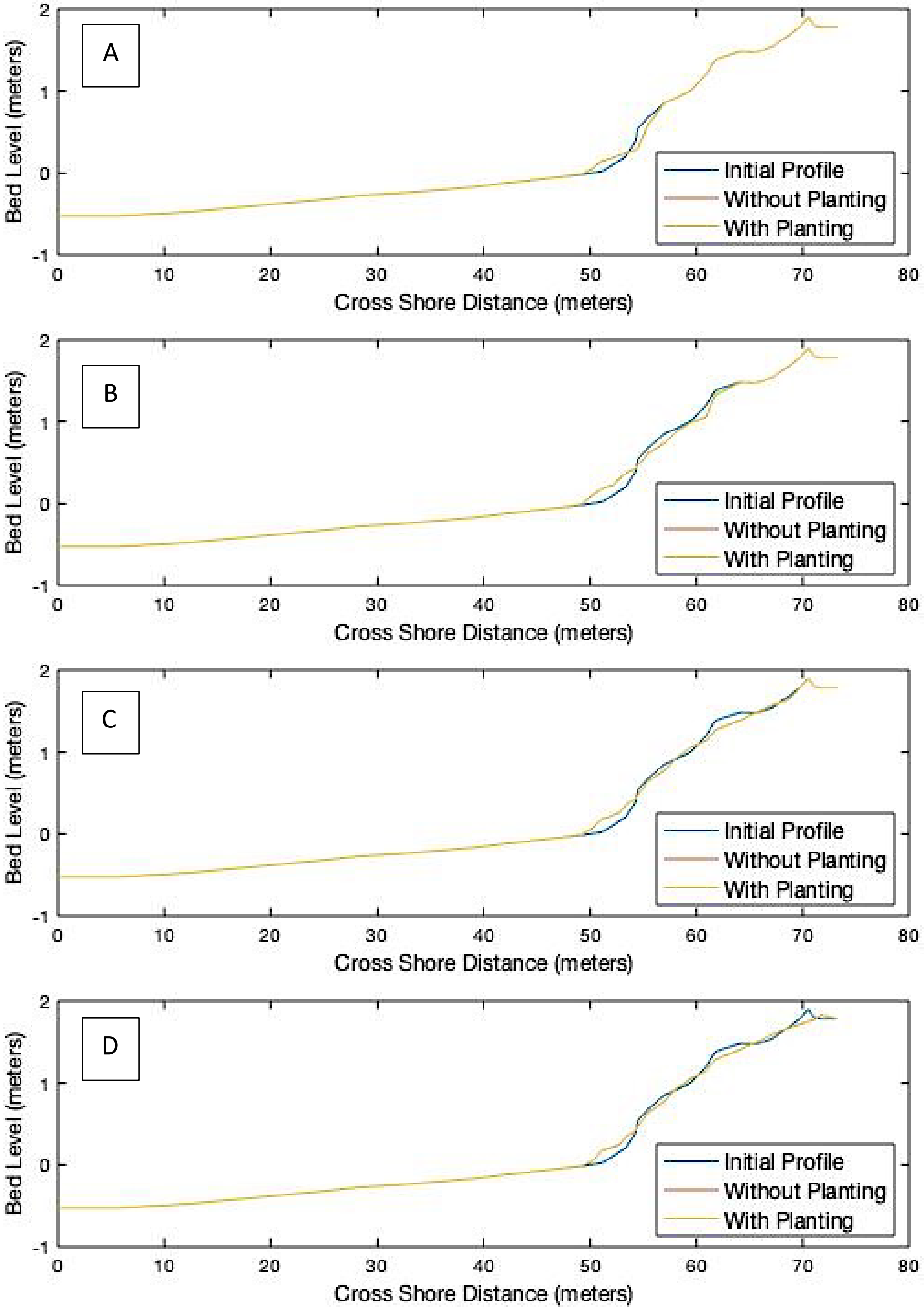

Figure 11. Pre-project profile, with-project final profile, and without-project final profile for Low-Intermediate Sea Level Rise Scenario, for (A) average storm conditions, (B) mild storm conditions, (C) moderate storm conditions, and (D) severe storm conditions.

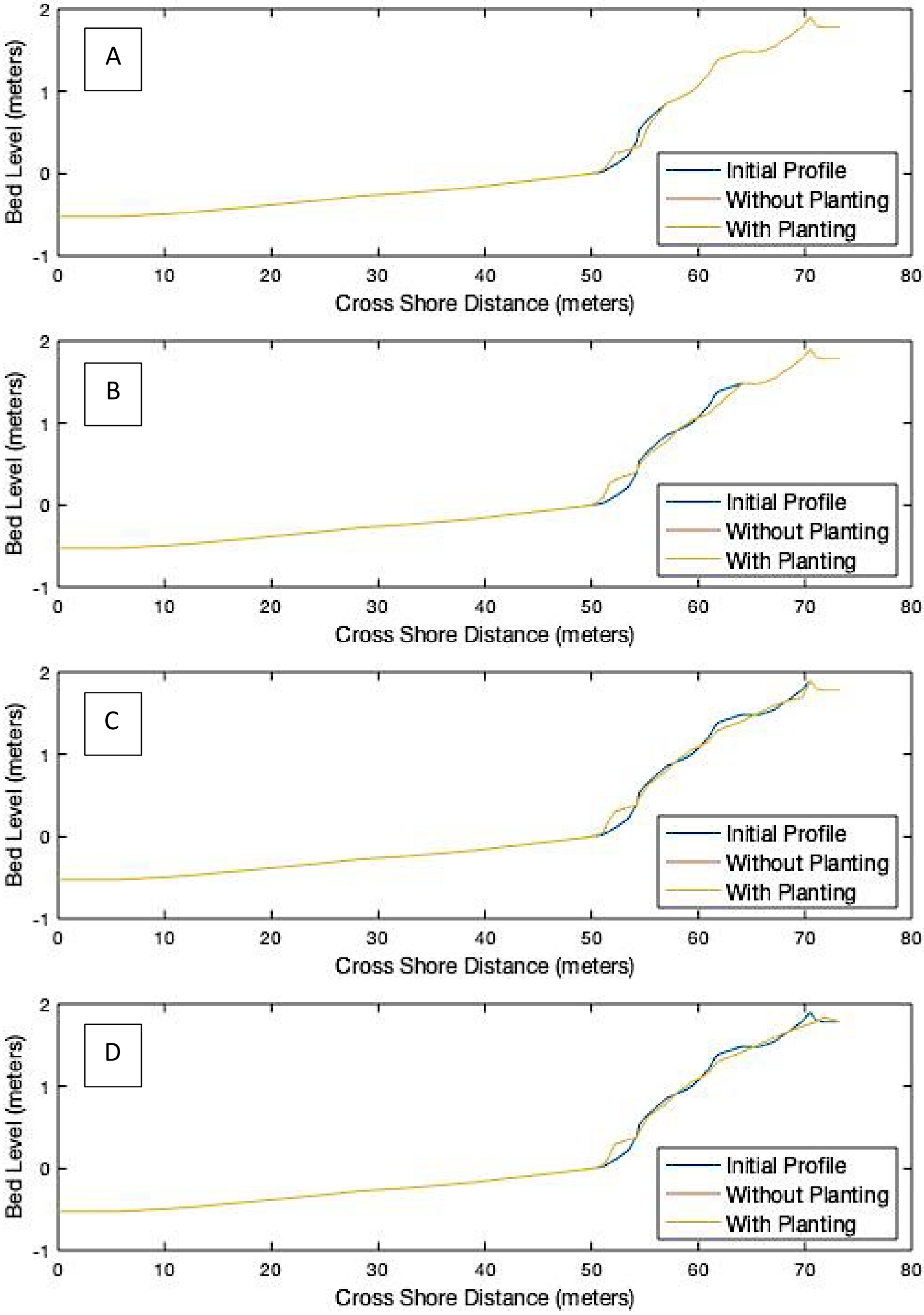

Figure 12. Pre-project profile, with-project final profile, and without-project final profile for Intermediate Sea Level Rise Scenario, for (A) average storm conditions, (B) mild storm conditions, (C) moderate storm conditions, and (D) severe storm conditions.

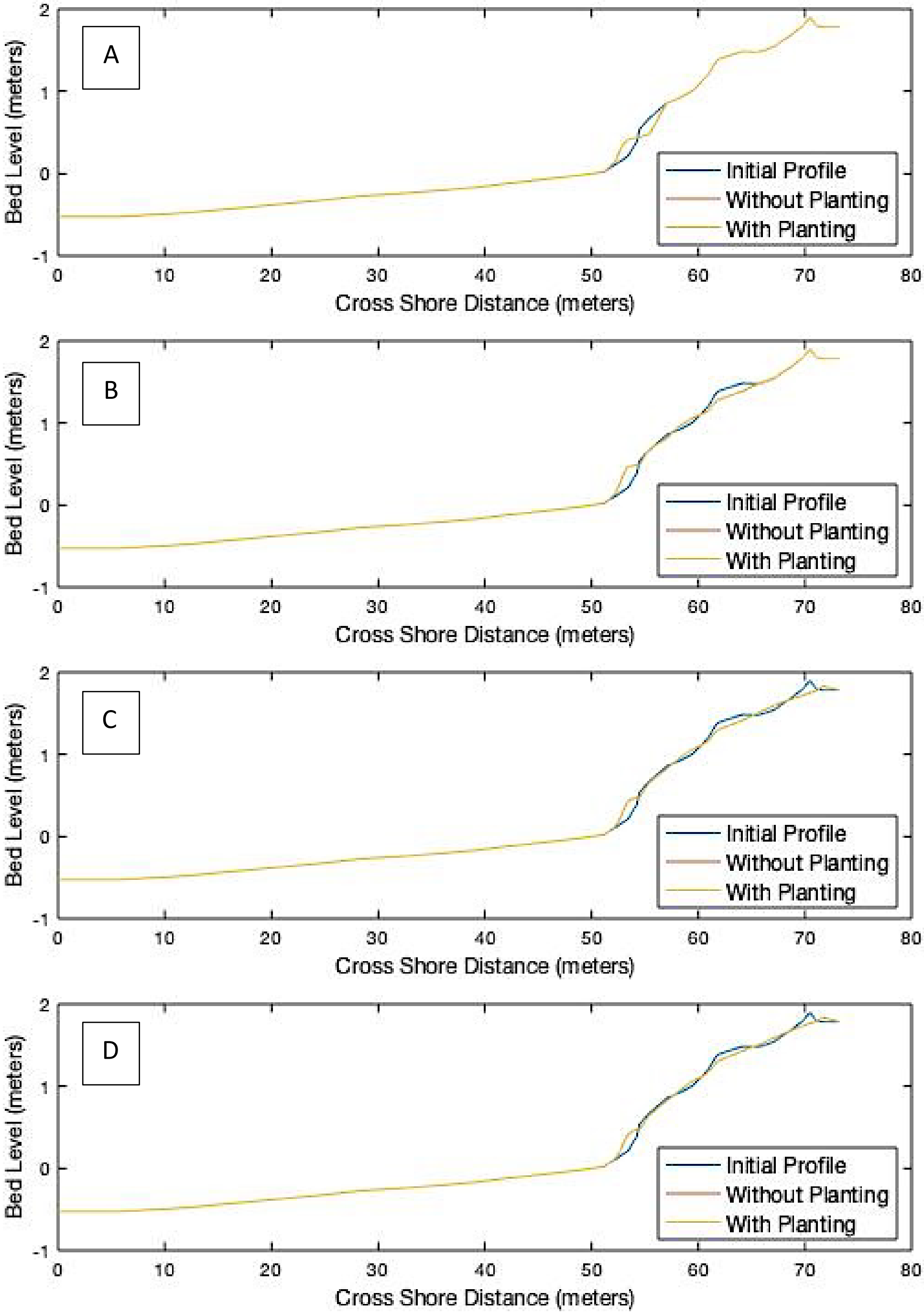

Figure 13. Pre-project profile, with-project final profile, and without-project final profile for Intermediate-High Sea Level Rise Scenario, for (A) average storm conditions, (B) mild storm conditions, (C) moderate storm conditions, and (D) severe storm conditions.

At current sea level rise, the difference in initial and final profile progressively becomes more severe with the increase in storm severity (Figure 9). There is minimal profile change with the average conditions, but by the severe storm, it appears that the toe of the dune has begun to be reshaped. Similar to the current sea level rise scenario, the low sea level rise scenario shows a progressively larger profile change as storm severity increases (Figure 10). However, with this scenario, the profile change in the severe storm conditions reaches the dune and begins to affect it. With this sea level rise scenario, the average condition profile change, Figure 10A, begins to show more profile change when compared to the previous figure. Similar to the low sea level rise scenario the low-intermediate scenario (Figure 11) shows profile change up to the dune with the severe storm scenario (Figure 11D). Similar to the low and intermediate-low, the intermediate storm scenario (Figure 12) generates profile change up to the dune with the severe storm conditions. However, in the moderate storm conditions (Figure 12C) there was also some profile change at the toe of the dune, similar to the profile change in the current sea level rise, severe storm forcing scenario. Similar to the lower sea level scenarios, the difference in initial and final profile progressively becomes more severe with the increase in storm severity for the intermediate-high sea level rise scenario (Figure 13). However, dune profile change occurred at both the moderate and severe storm scenarios (Figure 13A and Figure 13B).

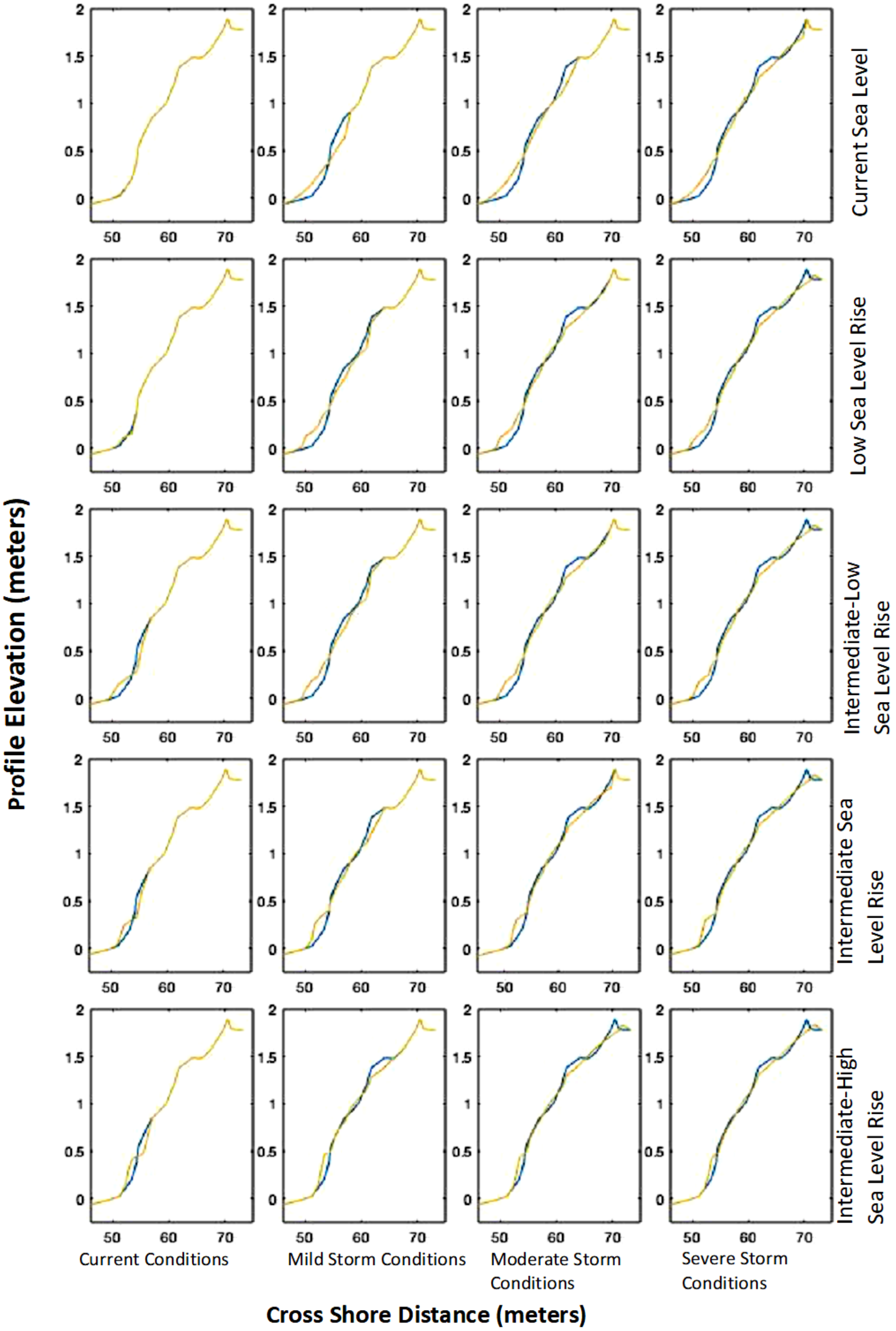

Figure 14. Pre-project profile (blue), with-project final profile (yellow), and without-project final profile (orange) for all scenarios. Sea level rise scenarios are grouped in rows, and forcing conditions are grouped by columns. The x-axis shows cross shore distance in meters, and the y-axis shows the profile elevation in meters.

Overall, with increasing storm severity, and increasing sea level rise, the impact on the profile becomes more noticeable. This trend is shown in Figure 14, which shows the initial, final with-project, and final without-project profiles. It appears that at larger sea level rise scenarios and more extreme storm events, the profile became smoother and sediment moved lower on the profile. Figure 12 shows sediment accreting around zero on the y-axis, which in this case was at, or just below the water line, depending on the storm scenario.

Figure 9 through Figure 14 show initial profile, final with-project profile, and final without-project profile. However, the difference is negligible between the final with-project profile and the final without-project profile in every figure, due both to the scale of the figures, and the similarity of the two profiles. Another method was used to compare the two final profiles quantitatively. The gross and net sediment transport for each scenario allows for a more quantitative approach to comparing the with and without project scenarios.

3.3 Gross Sediment Change

This section describes the gross sediment change for each model run and compares with and without project gross sediment change differences. The with and without project gross sediment change is shown in Figure 15 through Figure 19. The differences in gross sediment change are shown in Figure 20 through Figure 24. Units are in two-dimensions due to the 1D nature of the transect.

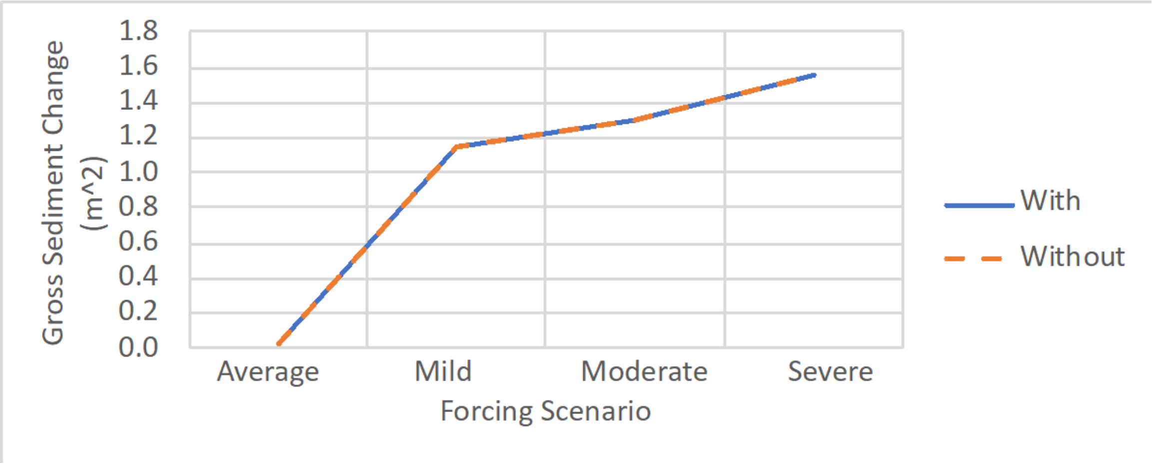

Figure 15. Gross sediment change for current sea level scenario. The orange line denotes the without-project data, and the blue line denotes the with-project data.

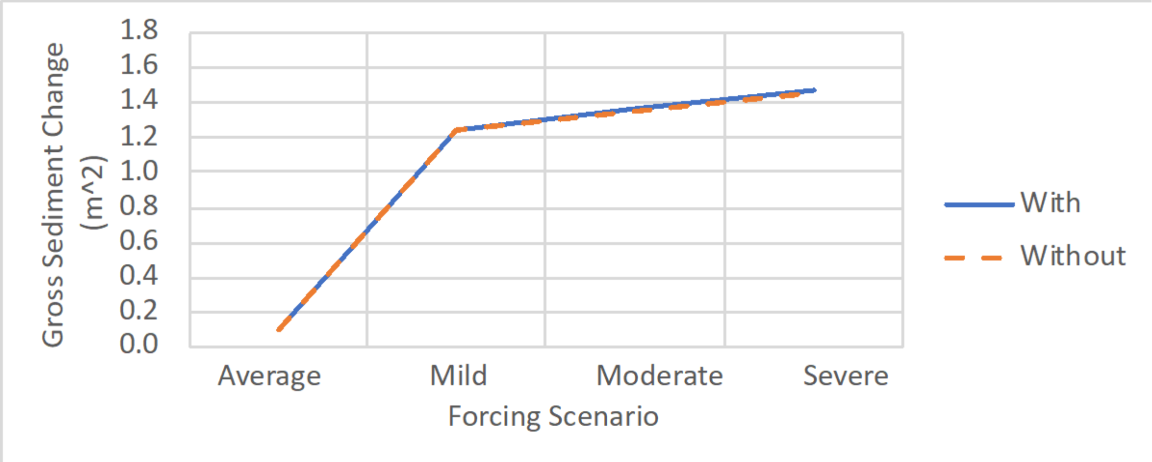

Figure 16. Gross sediment change for low sea level rise scenario. The orange line denotes the without-project data, and the blue line denotes the with-project data.

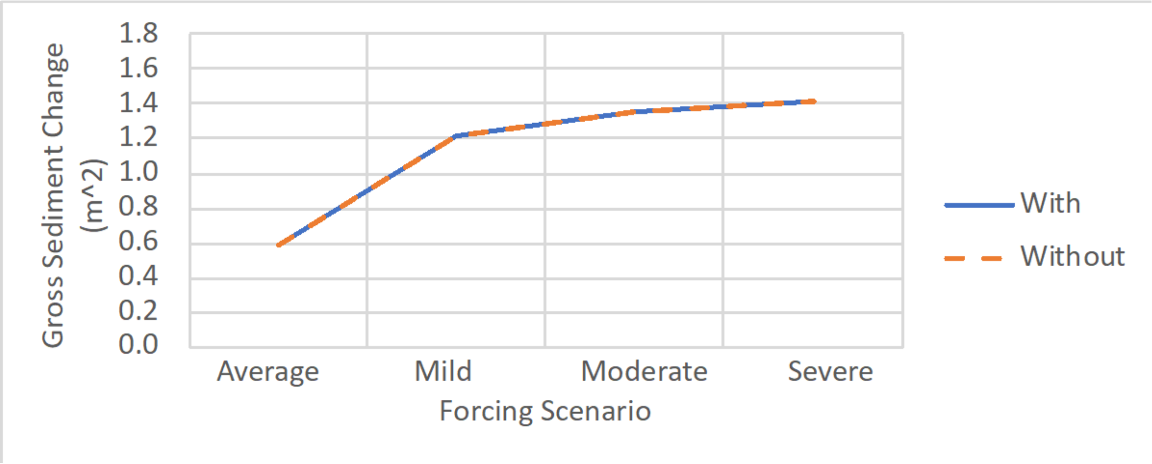

Figure 17. Gross sediment change for low-intermediate sea level rise scenario. The orange line denotes the without-project data, and the blue line denotes the with-project data.

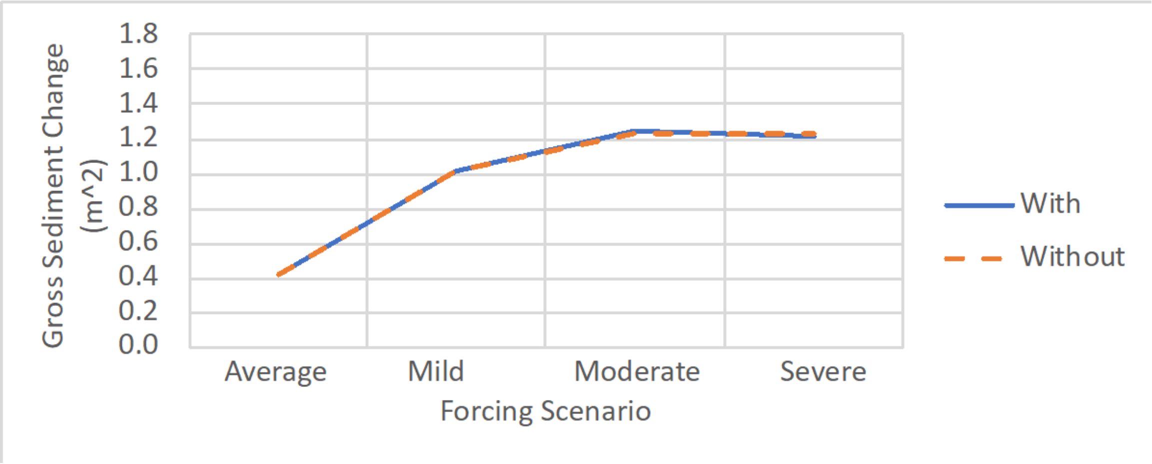

Figure 18. Gross sediment change for intermediate sea level rise scenario. The orange line denotes the without-project data, and the blue line denotes the with-project data.

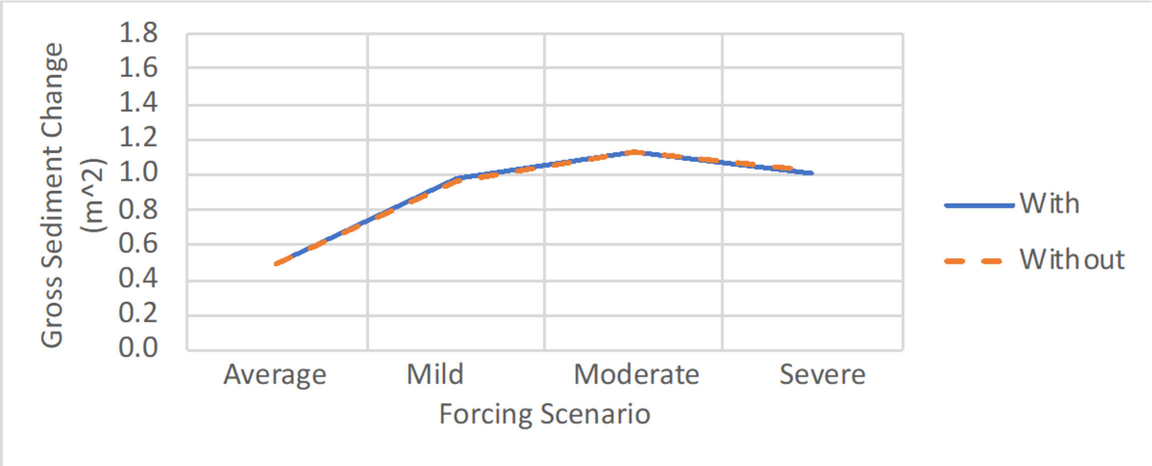

Figure 19. Gross sediment change for intermediate-high sea level rise scenario. The orange line denotes the without-project data, and the blue line denotes the with-project data.

The above figures display gross sediment change for each storm scenario. The gross sediment change is greatest at current sea level (Figure 15) and severe storm conditions. The gross sediment change is the lowest at current sea level (Figure 15) and average conditions. The low sea level rise scenario (Figure 16) follows the same overall pattern as the current sea level rise scenario, with slightly elevated values for gross sediment change. For low-intermediate sea level rise (Figure 17), the values are very similar to those found for the low and low-intermediate scenarios, with the exception of the average condition gross sediment change. At intermediate sea level (Figure 18), average conditions experience a notable increase in gross sediment change from the previous values found for current, low, and low-intermediate scenarios. The intermediate sea level rise scenario generates no change in gross sediment change between the moderate and severe storm scenarios. The intermediate-high sea level rise scenario (Figure 19) shows a similar trend, with the moderate storm producing greater gross sediment change than the severe storm.

Based on Figure 15 through Figure 19, it appears that the greatest amount of gross sediment change occurs during severe storm conditions, at lower sea levels, and at moderate storm conditions for higher sea levels. The largest gross sediment change occurred in the current sea level scenario, and with the severe storm conditions. However, there was more consistently elevated gross sediment change at the higher sea level rise scenarios. This is evident when considering the average conditions scenario. The gross sediment change at the current sea level is approximately zero, but it increases through as sea level increases. Figure 15 through Figure 19 are useful in interpreting the overall gross sediment trends between sea level rise and forcing scenarios, but the with and without project values are still difficult to differentiate. Figure 20 through Figure 24 show the difference in gross sediment change between with-project and without-project.

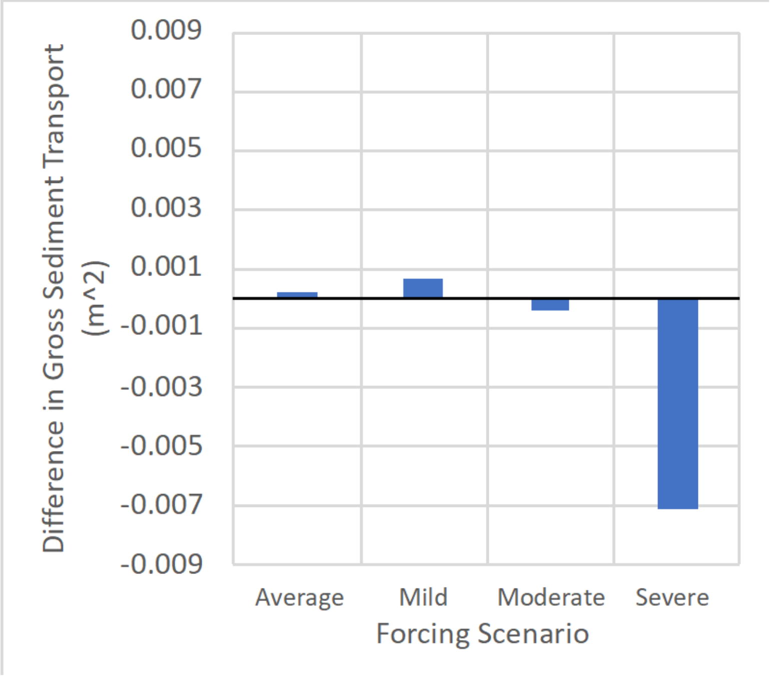

Figure 20. Current sea level: difference in gross sediment change from without-project to with-project. The negative values denote where the presence of the project reduced the total gross sediment change.

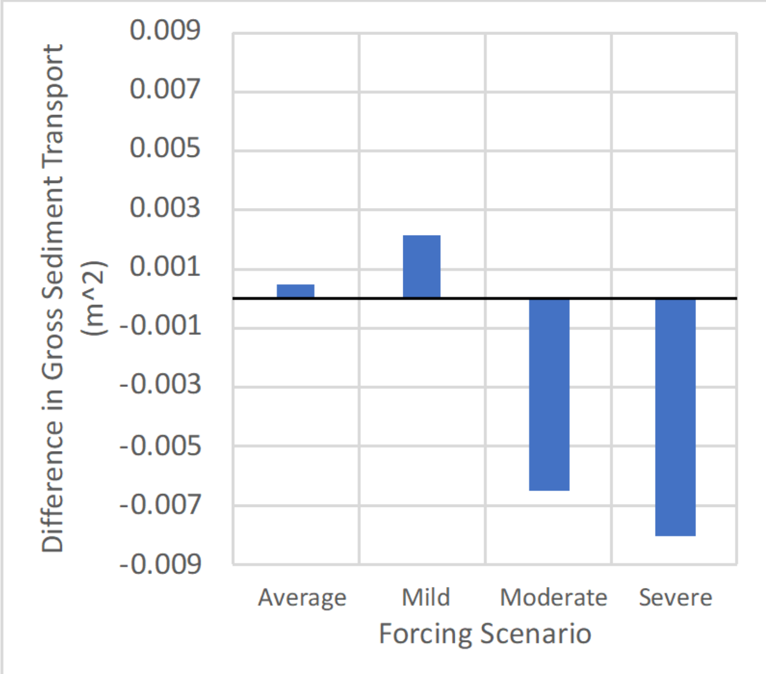

Figure 21. Low sea level rise: difference in gross sediment change from without-project to with-project. The negative values denote where the presence of the project reduced the total gross sediment change.

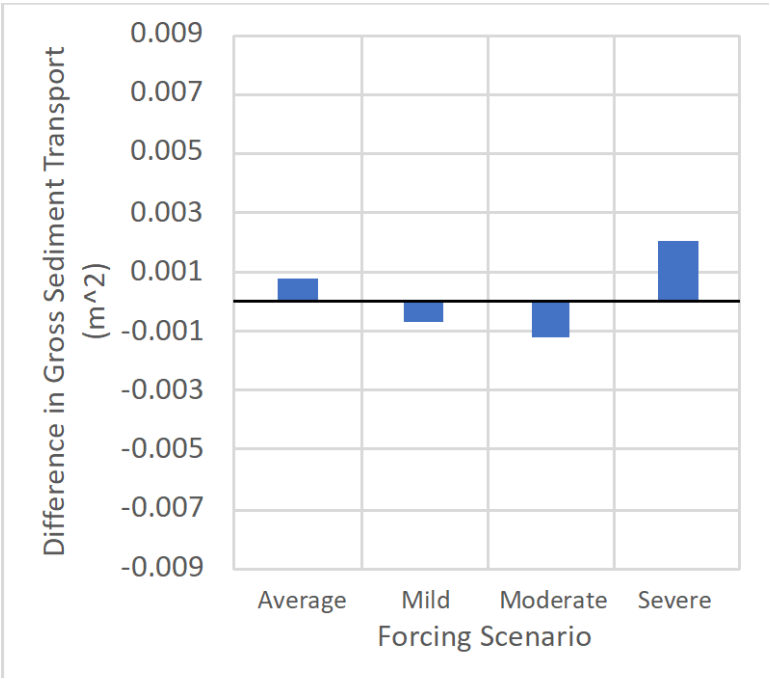

Figure 22. Low-intermediate sea level rise: difference in gross sediment change from without-project to with-project. The negative values denote where the presence of the project reduced the total gross sediment change.

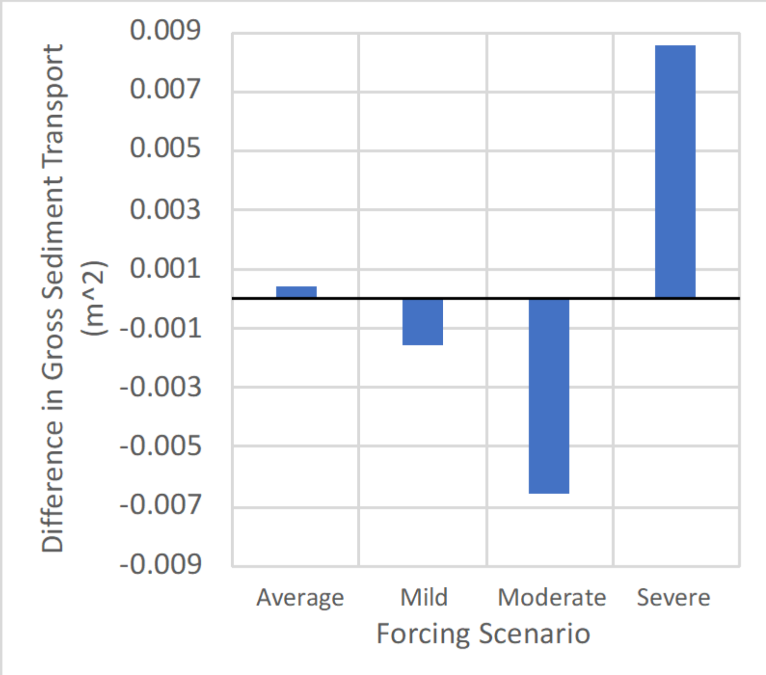

Figure 23. Intermediate sea level rise: difference in gross sediment change from without-project to with-project. The negative values denote where the presence of the project reduced the total gross sediment change.

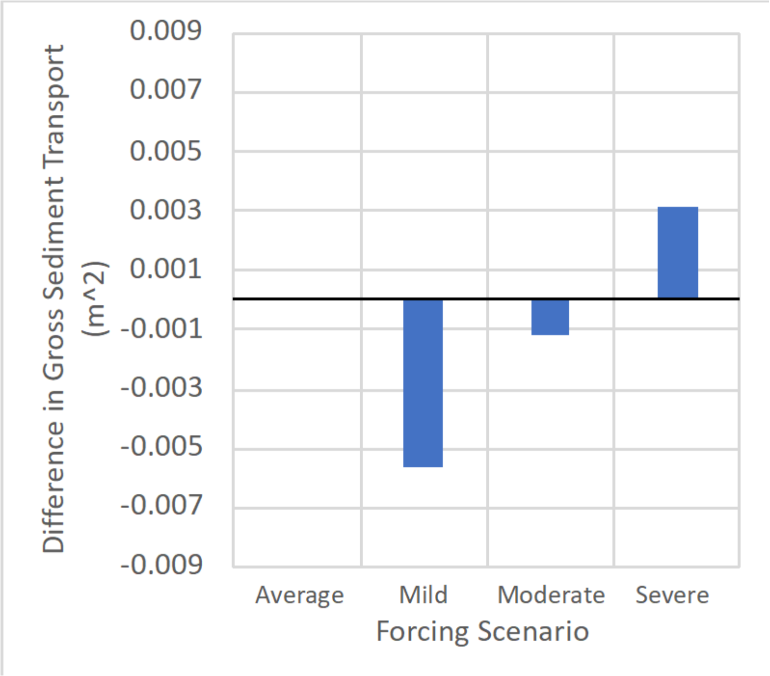

Figure 24. Intermediate sea level rise difference in gross sediment change from without-project to with-project. The negative values denote where the presence of the project reduced the total gross sediment change.

Figure 20 through Figure 24 display the differences in gross sediment change between with and without-project scenarios. Since the with-project was subtracted from the without project, scenarios with positive values indicate that the gross sediment change was reduced as a result of the project. The gross sediment change is displayed in terms of square meters of sediment, due to the 1D nature of the profiles.

For current sea level both average conditions and mild storm conditions have relatively small positive values, and the moderate and severe storm conditions have negative values (Figure 20). The low sea level rise scenario (Figure 21) follows a similar pattern, showing positive values for average and mild storm conditions, and negative values for moderate and severe storm conditions. However, the magnitude of each of these values increased from current sea level to low sea level. Low-intermediate sea level rise (Figure 22) shows a different pattern than the one seen in current and low sea level scenarios. For low-intermediate sea level the average conditions and the severe storm conditions are positive, while the mild and moderate storm conditions are negative. This same pattern is repeated for this intermediate sea level rise scenario. The intermediate sea level rise scenario (Figure 23) has positive values for both average conditions, and severe storm condition, and negative values for both mild and moderate storm conditions. Intermediate-high sea level rise (Figure 24), follows the same pattern as low-intermediate and intermediate, with positive values for average conditions and severe storm conditions, and negative values for both mild and moderate storm conditions.

While the gross sediment change data does show some interesting trends, it is notable that the scale of difference is small. The largest absolute value of gross sediment change difference is -0.0080 m^2, or approximately 80 cm^2. Many of the values are much smaller than this, with the smallest absolute value of 0.0001, or approximately 1 cm^2. This scale is very small relative to the overall size of the profile.

3.4 Wave Height Behind Project

Matlab was used to extract and determine the wave height at the first data point behind the vegetation on the grid. The data was then graphed in Microsoft Excel. Both average and maximum wave height were compared. The wave heights found were consistent with those found in the wind, wave, LST conditions analysis. The wave heights are suitable for *Spartina alterniflora* based on the thresholds determined in Roland and Douglass (2005). Figure 25 through Figure 29 show the maximum and average wave height for increasing storm conditions, at each sea level rise interval. Then, similar to the gross sediment change, the with-project were subtracted from the without-project values, in order to understand the effect the project had on the wave height. However, for all scenarios, there was zero change in wave height, for both average and maximum wave heights.

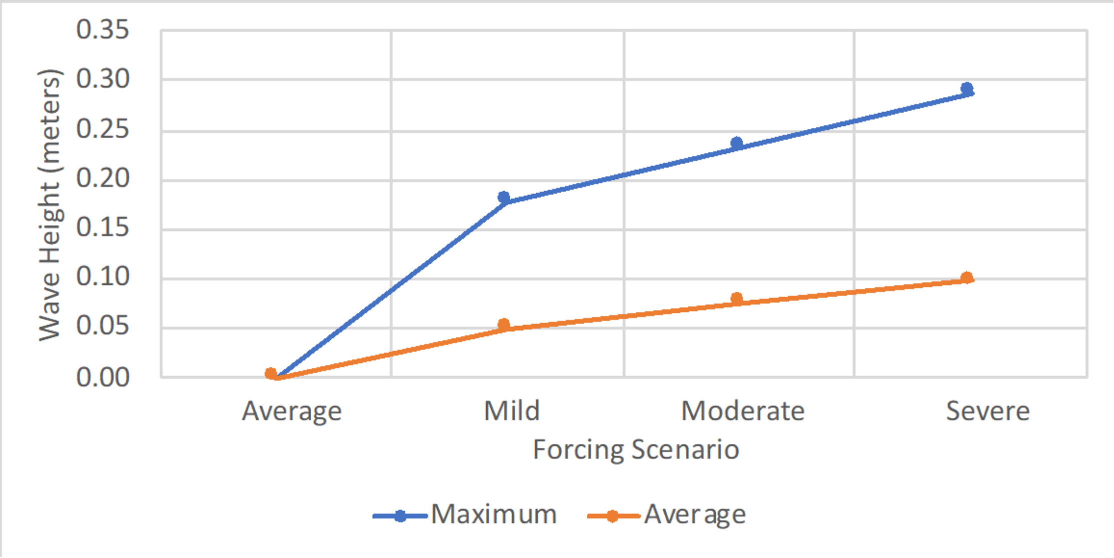

Figure 25. Maximum and average wave height in meters for current sea level scenario. The orange line shows the average wave height, and the blue line shows the maximum wave height.

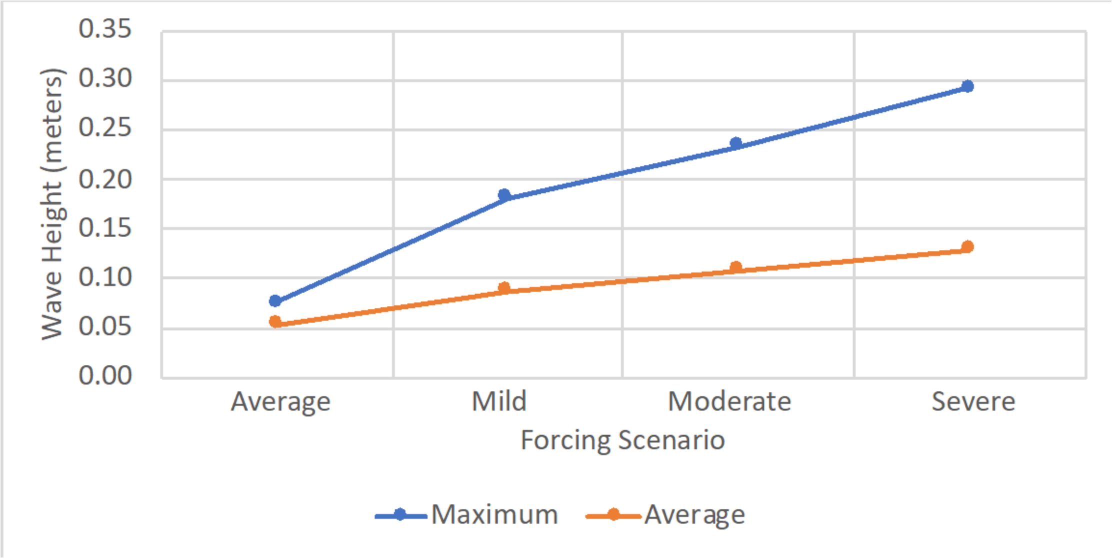

Figure 26. Maximum and average wave height in meters for low sea level rise scenario. The orange line shows the average wave height, and the blue line shows the maximum wave height.

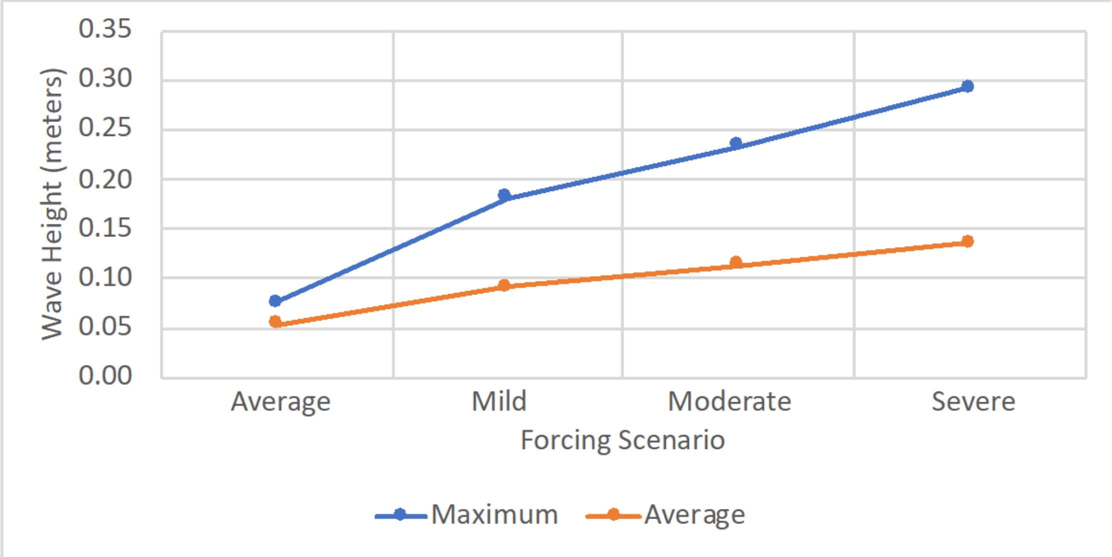

Figure 27. Maximum and average wave height in meters for low-intermediate sea level rise scenario. The orange line shows the average wave height, and the blue line shows the maximum wave height.

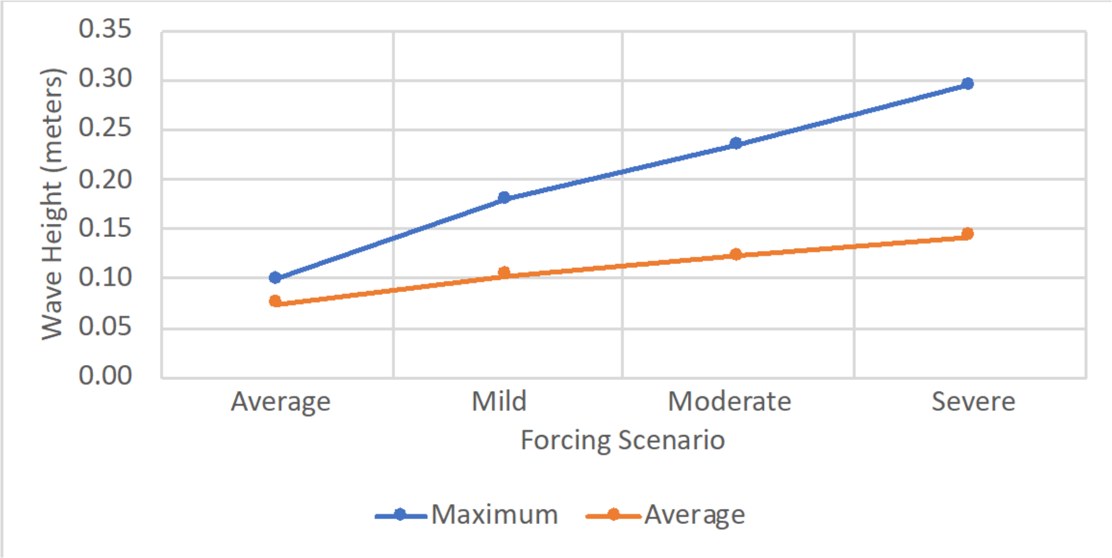

Figure 28. Maximum and average wave height in meters for intermediate sea level rise scenario. The orange line shows the average wave height, and the blue line shows the maximum wave height.

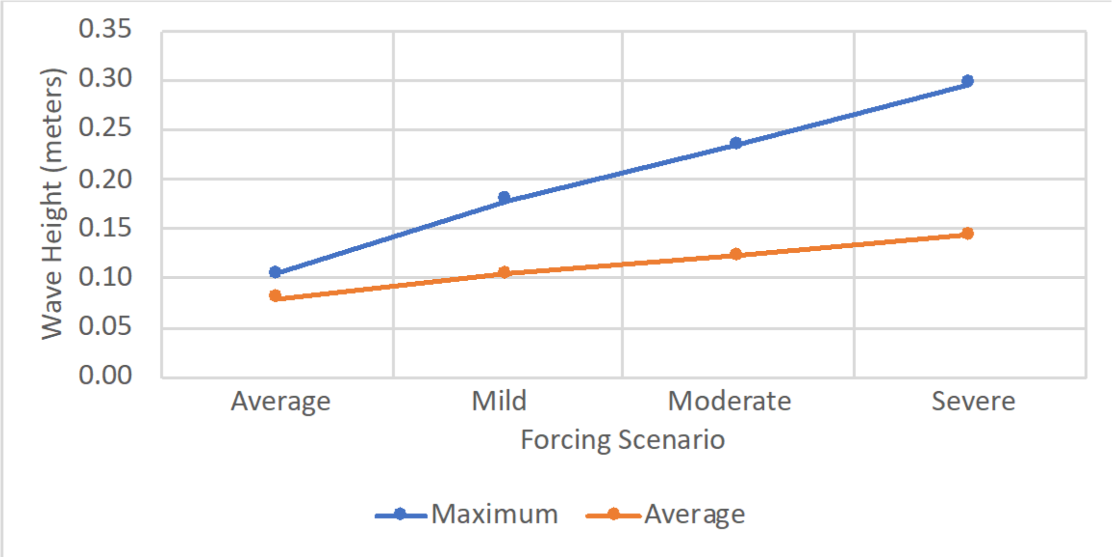

Figure 29. Maximum and average wave height in meters for intermediate-high sea level rise scenario. The orange line shows the average wave height, and the blue line shows the maximum wave height.

Figure 25 through Figure 29 show the average and maximum wave heights at the first grid point behind the vegetation. Figure 25 shows the current sea level scenario, and it displays the only instance of zero wave height throughout the whole analysis. The no storm scenario features a wave height of zero. In the subsequent figures, the no storm scenario wave height steadily increases for both average and maximum wave height. The severe storm scenario follows a different trend throughout the sea level increase, with no notable increase or decrease with sea level rise. The overall trend in wave height is an increase in wave height with increasing storm severity, but as sea level rise increases, the wave heights tend to stay constant for more severe storm scenarios.

CHAPTER IV

DISCUSSION

This section discusses the results presented in Chapter 3. The profile changes observed throughout this project follow a few trends, including an increase in gross sediment change with storm severity, and a decrease in gross sediment change for mild and moderate storms as sea level increases. This section also discusses the possible reasons behind the lack of wave height reduction behind the vegetation, and how that may have affected the overall project.

4.1 Wind, Wave and LST Conditions Discussion

The wind, wave, and LST conditions analysis was used throughout the project to better understand the existing project site conditions, and to inform the average forcing conditions used in the model. The assumptions made for this analysis include that waves are generated only by local winds, waves are fetch limited, the sea state is fully arisen, depth contours are straight and parallel, and the offshore profile slopes are mild. All of these are reasonable assumptions for this project site, given the site morphology, the fetch lengths, and the wind climate. However, limitations of these conditions analysis come from the wind data source. The wind data were from NOAA's Tides and Currents' Fort Morgan Station, where the wind sensor is approximately 38 meters above mean sea level

(NOAA 2020). At this elevation, the wind speeds would be much higher than wind speeds at the water surface. This could contribute to slightly elevated wind speeds, wave heights, and LST estimates. Future studies could adjust windspeed to altitude using a long wind profile model to account for the difference in elevation.

Figure 30 shows the wave height frequency of occurrence for the Little Lagoon site, based on a wind-wave conditions analysis, along with the Spartina alterniflora thresholds established by Roland and Douglass (2005). Based on the wave height thresholds from Roland and Douglas (2005), and the wind-wave conditions analysis performed for this study site, *Spartina alterniflora* should thrive, without any additional wave attenuation structures.

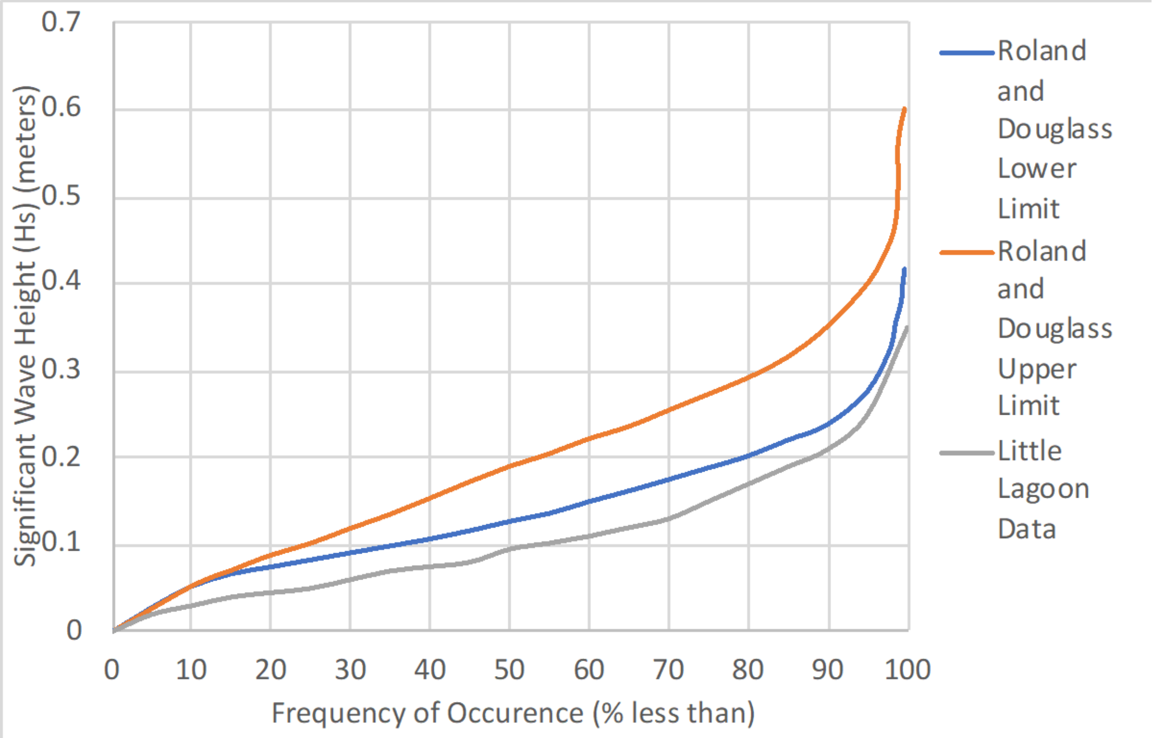

Figure 30. Significant wave height frequency distributions. The orange and blue lines are the upper and lower limits respectively from Roland and Douglass (2005). The gray line is the significant wave height frequency distribution at the Little Lagoon site from the wind-wave conditions analysis.

4.2 Profile Change Discussion

The profile changes in Chapter 3 show increasing profile change with increasing storminess and increasing sea level rise. For current sea level, shown in Figure 15, there is almost no profile change, but the profile change increases with storminess. This trend continues as sea level rise increases. Figure 31 compares the gross sediment change for each storm condition, with increasing sea level rise. As sea level increases, there is actually less gross sediment change in stormy conditions, but greater gross sediment change in average conditions. While this chart shows overall trends in sediment change, it does not compare the with-project and without-project sediment change.

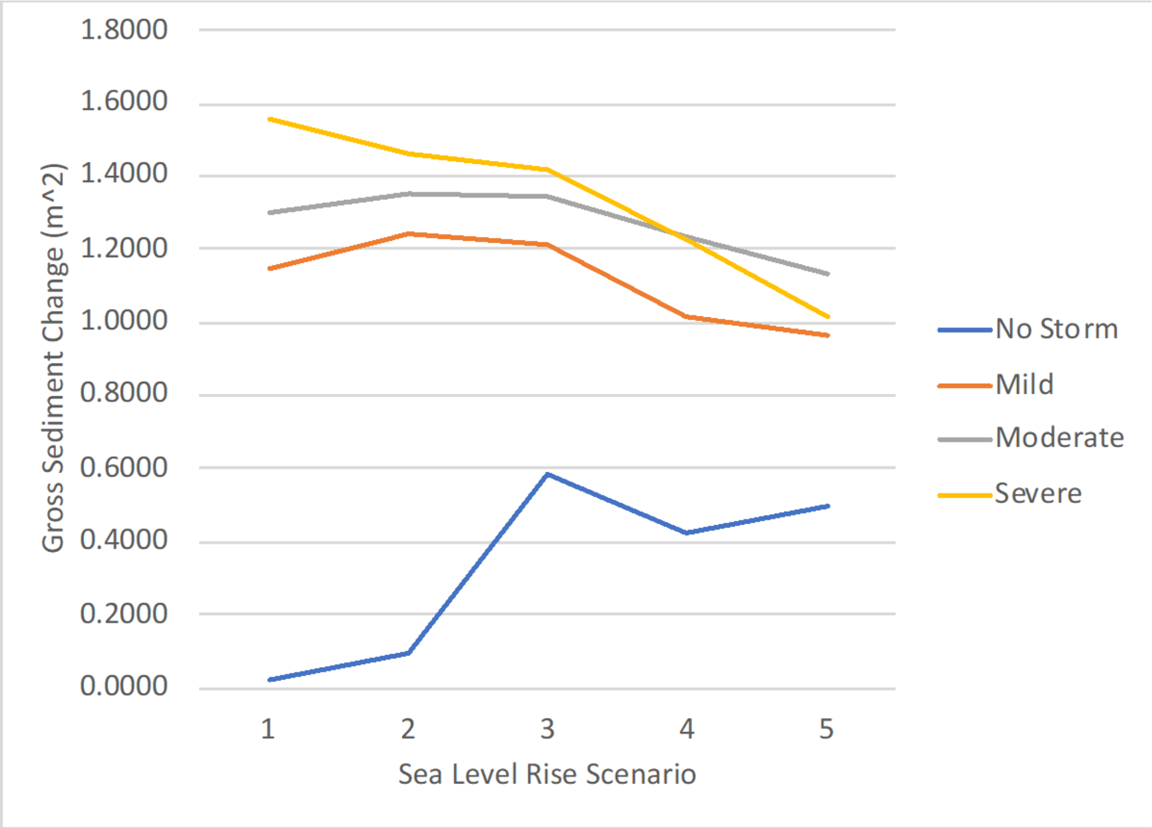

Figure 31. Gross sediment change comparison. Each line represents a storm scenario. Sea level rise scenario 1 is current sea level, sea level rise scenario 2 is low sea level rise, sea level scenario 3 is intermediate-low sea level rise, sea level rise scenario 4 is intermediate sea level rise, and sea level rise scenario 5 is intermediate-high sea level rise.

Figure 31 shows that for moderate and severe storm conditions, gross sediment change decreases with sea level rise. This is likely due to the profile becoming mostly or completely submerged. This prevents the waves from directly impacting the section of profile used in the model. For example in the case of severe storm conditions, and intermediate-high sea level rise, the combined water level is 2.42 meters, but the highest profile point included in the grid is 1.87 meters. This explains why the greatest change is observed at current sea level, but severe storm conditions. Under these conditions, the shore would not be sheltered from the high wave energy that the severe storm would bring.

The relatively small changes in profiles from without-project to with-project are expected, considering the shoreline was already stable before the project was implemented. The scale of the graphs in Figure 9 through Figure 13 makes it difficult to distinguish the profile differences. The gross sediment change differences were an effective way to quantitatively determine the profile change. However, the change was still very small in magnitude. The differences seen in gross sediment change for this project are small, with a maximum difference of 0.0060 m^2. This indicates that the shoreline restoration project had a negligible effect on the overall stability of the site.

4.3 Wave Height Discussion

There was no difference found in wave height behind the vegetation from without-project to with-project. There are a few possible explanations for this result. First, the vegetated layer in the model could be too weak to make any measurable impact on the wave height. Second, wave damping in XBeach could be relatively insensitive to vegetation. However, this is unlikely because according to the XBeach manual, the addition of a vegetated layer can induce wave damping for both short waves and infagravity waves. The vegetation inputs for this model were not calibrated, which is recommended by the developers, so the model could be underpredicting the wave damping effects as a result.

The lack of wave reduction could also provide further explanation to the small change in gross sediment change from without-project to with-project. One of the ways that vegetation aids in shoreline stabilization is through wave attenuation. If the waves were not attenuated, they are likely to still cause the same level of shoreline change despite the presence of the project. Increasing the effect of the vegetated layer could lead to a decrease in wave height behind the vegetation, and in turn lead to a larger difference in gross sediment change from without project to with-project.

CHAPTER V

CONCLUSIONS

Cross shore transects of a vegetation only living shoreline project site were taken using an RTK enabled GNSS device. One of these transects was chosen as a representative transect for the site and used to inform an XBeach model. Five sea level rise scenarios and four storm scenarios were used to inform the tide and wave inputs in order to predict the performance of the project through storms and sea level rise. A vegetated layer, representative of the *Spartina alterniflora* planted at the project site was incorporated into the with-project model. The with and without-project final profiles were compared to determine the effect of the project on the profile change.

The project site was already considered stable before the project implementation. The results on the XBeach model show very little, or no change between with-project and without-project gross sediment transport. The results of this project indicate that the planting of *Spartina alterniflora* provided very little difference in shoreline stability. However, the project may provide other benefits, including habitat creation, and water quality improvement.

In future studies, the values used for height, stem density, stem diameter, and drag coefficient could be adjusted to increase the effect of the vegetated layer. Although these values were taken from reliable sources, the exact vegetation conditions at the project site could be measured and used. The width of the vegetation could also be increased, as this would increase the wave damping within the model.

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APPENDICES

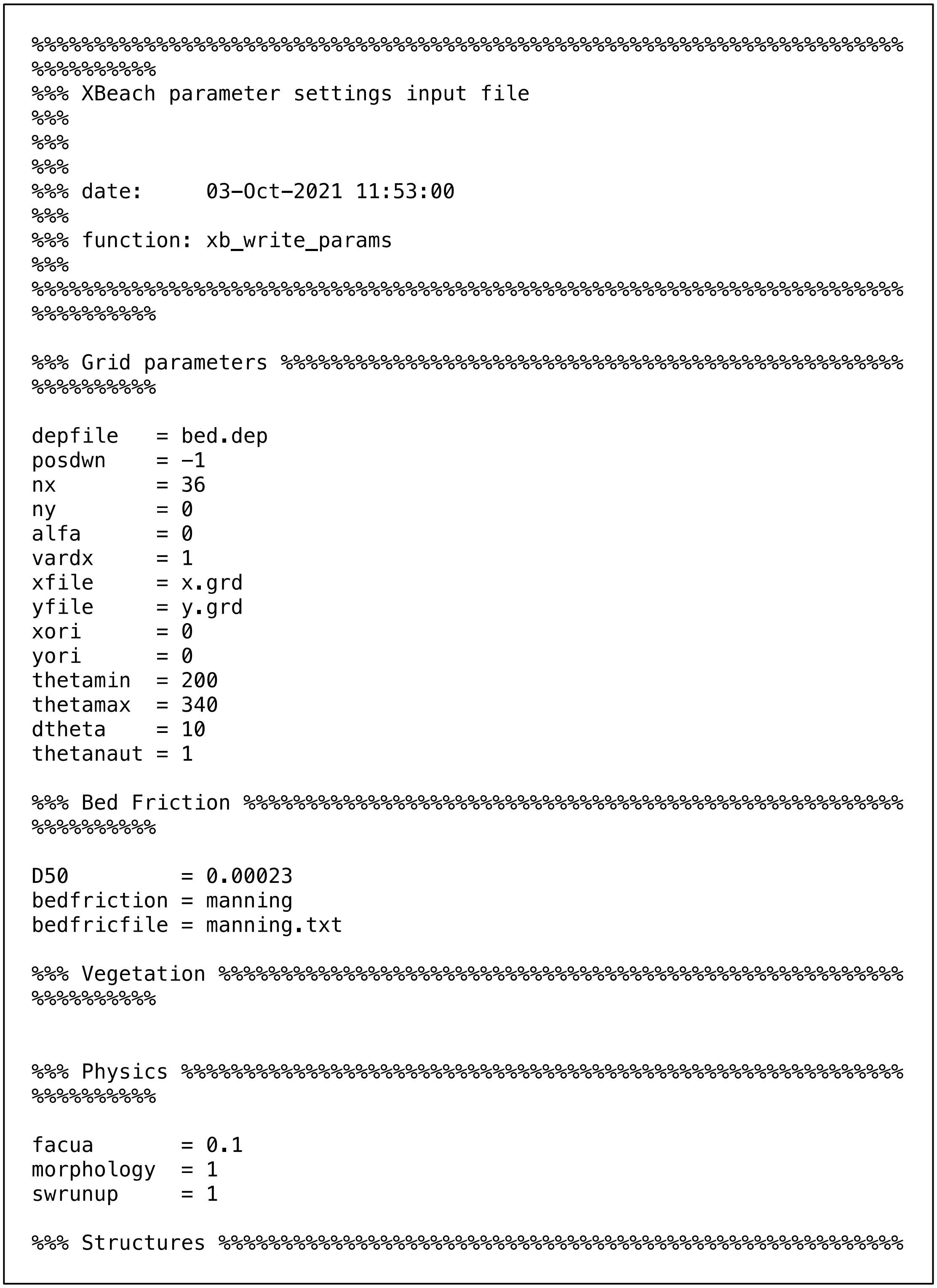
Appendix A: XBeach Input Files

Table A1. Tidal forcing file example. First ten lines of the low sea level rise, and mild storm conditions. The first column contains the time in seconds, and the second column contains the water level on meters, NAVD88. The full file goes up to 258300 seconds.

Time (s)	Tide (m NAVD88)
0	0.325
900	0.327
1800	0.329
2700	0.331
3600	0.336
4500	0.338
5400	0.340
6300	0.342
7200	0.344
8100	0.348

Table A2. Wave forcing file example. First ten lines of the low sea level rise and mild storm conditions. Each row defines a sea state, and corresponds to the timestep in the tide forcing file. The full wave file has the same number of rows as the tide forcing file.

Hs (m)	Tp (s)	Dir (deg)	Gamma	S	duration	dtbc
0.1	1.5	270	5	1000	900	1
0.1	1.5	270	5	1000	900	1
0.1	1.5	270	5	1000	900	1
0.10000001	1.50000002	270	5	1000	900	1
0.10000003	1.5000001	270	5	1000	900	1
0.10000008	1.50000031	270	5	1000	900	1
0.10000019	1.50000076	270	5	1000	900	1
0.10000042	1.50000164	270	5	1000	900	1
0.10000081	1.50000319	270	5	1000	900	1
0.10000147	1.50000573	270	5	1000	900	1



```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
%%% XBeach parameter settings input file
%%%
%%%
%%%
%%% date:     03-Oct-2021 11:53:00
%%%
%%% function: xb_write_params
%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

depfile   = bed.dep
posdwn    = -1
nx        = 36
ny        = 0
alfa      = 0
vardx     = 1
xfile     = x.grd
yfile     = y.grd
xori      = 0
yori      = 0
thetamin  = 200
thetamax  = 340
dtheta    = 10
thetanaut = 1

%%% Bed Friction %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

D50         = 0.00023
bedfriction = manning
bedfricfile = manning.txt

%%% Vegetation %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%



%%% Physics %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

facua       = 0.1
morphology  = 1
swrunup     = 1

%%% Structures %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Figure A 1. XBeach configuration file (params.txt) for without-project model runs

```
%%%%%%%%%%

struct    = 0

%%% Tide BC %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%

tideloc   = 1
zs0file   = tides.txt

%%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
tstop     = 258300

%%% Wave boundary condition parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

instat    = stat_table
random    = 0
bcfile    = waves.txt

%%% Output variables %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

tstart       = 0
tintg        = 3600
tintm        = 21600
outputformat = fortran
nglobalvar   = 6
zb
zs
H
Fx
Fy
runup
```

Figure A 1. Continued

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
%%% XBeach parameter settings input file
%%%
%%%
%%%
%%% date:     03-Oct-2021 11:53:00
%%%
%%% function: xb_write_params
%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

%%% Grid parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

depfile   = bed.dep
posdwn    = -1
nx        = 36
ny        = 0
alfa      = 0
vardx     = 1
xfile     = x.grd
yfile     = y.grd
xori      = 0
yori      = 0
thetamin  = 200
thetamax  = 340
dtheta    = 10
thetanaut = 1

%%% Bed Friction %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

D50         = 0.00023
bedfriction = manning
bedfricfile = manning.txt

%%% Vegetation %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
vegetation+
vegetation = 1
nveg = 1
veggiefile    = veggiefile.txt
veggiemapfile = veggiemapfile.txt

%%% Physics %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

facua       = 0.1
```

Figure A 2: XBeach configuration file (params.txt) for with-project model run. The changes from the without-project file are indicated by the yellow box.

```
morphology  = 1
swrunup     = 1

%%% Structures %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

struct    = 0

%%% Tide BC %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%

tideloc   = 1
zs0file   = tides.txt

%%% Model time %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
tstop     = 258300

%%% Wave boundary condition parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

instat    = stat_table
random    = 0
bcfile    = waves.txt

%%% Output variables %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

tstart       = 0
tintg        = 3600
tintm        = 21600
outputformat = fortran
nglobalvar   = 6
zb
zs
H
Fx
Fy
runup
```

Figure A 2. Continued

BIOGRAPHICAL SKETCH

Name of Author: Elizabeth Winter

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> University of South Alabama – Mobile, Alabama

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