Spring 5-4-2022

THE USE OF TIME-LAPSE AND STILL PHOTOGRAPHS TO DOCUMENT THE EFFECTS OF SEASONALITY ON DUNE MORPHODYNAMIC EVOLUTION IN COROLLA, NC.

Briar Ownby-Connolly
Coastal Carolina University, bcownbyc@coastal.edu

Recommended Citation

Ownby-Connolly, Briar, "THE USE OF TIME-LAPSE AND STILL PHOTOGRAPHS TO DOCUMENT THE EFFECTS OF SEASONALITY ON DUNE MORPHODYNAMIC EVOLUTION IN COROLLA, NC." (2022). *Honors Theses*. 443.
https://digitalcommons.coastal.edu/honors-theses/443

THE USE OF TIME-LAPSE AND STILL PHOTOGRAPHS TO DOCUMENT THE EFFECTS OF SEASONALITY ON DUNE MORPHODYNAMIC EVOLUTION IN COROLLA, NC.

By

Briar Ownby-Connolly

Department of Marine Science

Submitted in Partial Fulfillment of the
Requirements for the Degree of Bachelor of Marine Science
In the HTC Honors College at
Coastal Carolina University

2021-2022

Dr. Louis E. Keiner
Director of Honors
HTC Honors College

Dr. Till J.J. Hanebuth
Associate Professor, Coastal Geosystems Research Lab
Department of Marine Science
Gupta College of Science

ABSTRACT

With climate change altering established seasonal and weather phenomena, understanding the physical behavior of barrier islands and the processes driving such physical changes, specifically within their dune zones, is crucial in promoting their resiliency. With ecosystem services provided by dunes to coastal economies and wildlife habitat, promoting dune conservation serves to advance the benefits of these systems, within a changing climate. Current findings by the Army Corps of Engineers Field Research Facility in Duck, NC, suggest the significance of local aeolian sediment transport in interplay with storm intensity in effecting dune stability, and that anthropogenic impacts, like the installment of wooden beach accesses versus paved walkways can either aid or harm the strength of these natural systems, falling on the decisions of local communities. In this study, Time-Lapse and Still Photography was used to monitor and document the morphodynamic evolution of 45m and 20m wide dune sections in Corolla, NC, within a one-year timescale. Monthly dune topography elevation measurements were established to quantitatively emphasize effects of physical processes being illustrated within the footage and photographs captured. It was found that Scarping recovery time took 6.9 months, aligning with the collision regime established by Sallenger (2000), and that summer and winter profiles matched understandings of seasonal variations: stronger wind and wave energy in the winter, with the Time-Lapse qualitatively illustrating these concepts. Vegetation dwindled in the winter, as expected, and sand fences were effective in accumulating sediment, showing net growth. The findings in this study support modern dune studies, providing visual demonstrations of subtleties within dune dynamics so to provide future guidance to coastal homeowners

INTRODUCTION

Barrier islands are dynamic systems found along coastlines, representing only ~ 10-15% of global shorelines with nearly 30% found along the east coast of the U.S. (Zinnert et al. 2018). Unique to barrier islands are the ways in which wave energy and sediment transport can shape their morphology. The Outer Banks represents a wave-dominated barrier island system off the coast of North Carolina. In which, it is characterized by long and linear features, with few tidal inlets and estuaries present behind it; Currituck, Albemarle, and Pamlico Sound. Significant to the coastal processes and ecosystem services of barrier islands are the coastal dunes. With the majority of barrier islands belonging to heavily developed areas along the Atlantic and Gulf coastlines, the management and understanding of dunes are paramount to the continuation and protection of coastal communities (Zinnert et al., 2018). Especially in consideration of storms and dune erosional processes, measuring dune resiliency is crucial (Conery et al., 2019).

For most coastal areas, dunes represent the first line of defense when it comes to storms, and therefore are critical natural systems that provide stability in the realm of economics and infrastructure (Conery, et al., 2019). Studying the morphodynamic and evolutionary behaviors of dunes on sandy coastlines holds great significance to the stability of these coastal communities, enabling the continuation of growth and tourism, while furthering our understanding of their responses to anthropogenic impacts. Especially since relative sea level trends have been rising alongside the Mid-Atlantic shoreline regions (Zinnert et al., 2018).

Interactions with dunes presents a multifaceted arena of factors to consider in their growth and strength along coastlines. Dunes are continuously reacting to the dynamics of beach environmental stressors and, as a result, endlessly evolve and adapt (Conery et al., 2019). The primary force contributing to the morphology of dune shape and structure is aeolian transport, making storms and heavy winds crucial in recognizing impacts to dunes especially when considering intense storm surge.

Not only are dunes important in protecting coastal communities from inundation and flooding pressures but they also serve as vital habitat for various vegetation, a variety of vertebrates and invertebrates, and they sustain nesting for sea turtles and provide feeding locations for shore birds (Schlacher, de Jager & Nielsen., 2011). Because of the functionality of dunes and their relationship with the shoreline, sediment deposition contributes to the replenishment of the beach face on a seasonal basis, allowing for the continuation of habitat area for marine animals.

For example, one study found that sea turtles tend to nest around the dune area, suggesting that a loss of dune could disrupt turtle nesting (Bouchard & Bjorndal, 2000). Another study found that dunes play important roles when it comes to orientation signaling for hatchlings on beaches and their success in finding the sea (Hirama et al., 2021). Similarly, it was found that ghost crabs inhabited the complete foredune area, with 95% of their samples containing burrows (Schlacher, de Jager & Nielsen., 2011).

Emphasis on the ecological support from dunes, demonstrates their part in a much larger role then what's commonly assumed. They influence tourism, attributing economically to coastal communities, they're responsible for the continuation of our sandy shorelines, serve as habitat for flora, fauna, and humans alike, and they protect coastlines from storms and flooding pressures by dissipating wave energy. In essence, dunes are the keystone to myriad positive coastal feedback loops: enabling coastal economies, geophysical dynamics, and ecological processes. The diverse importance of dunes is highlighted so to deepen and build on the common understanding of their seasonal dynamics.

Within this study, the dynamics of dunes within various seasons was examined via photographs and Time-Lapse to aid in understanding the timeframe of dune stability and resiliency. Vegetation cover and wind differences in winter and summer months were monitored, along with sediment loss and deposition throughout a one-year timescale. Scarping recovery time in relation to hurricanes was also documented. Elevation measurements were also established on a monthly basis to analytically support the efforts illustrated in the photographs and Time-Lapse.

There is thought to be a gap in information surrounding sandy shoreline evolution, particularly in reference to storms and recovery, but video and other forms of imagery are believed to be the mechanism to close this gap (Biausque & Senechal, 2018). With that, the objective of this study was to provide qualitative as well as quantitative understandings of dune evolution and morphology to assist in our knowledge of its role in adaptative measures to coastal climate change impacts and indications for homeowners and coastal communities in an anthropomorphized climate.

We hypothesized that dune scarping recovery time would take between 3-6 months, given that it was a lower energy storm, the Time-Lapse footage would be able to qualitatively show us the winter and summertime distinctions that dunes experience, and the elevation measurement would quantitatively compliment what the Time-Lapse was demonstrating.

METHODS

Site location

This study took place at two separate locations within Corolla, North Carolina. The site where still photographs were taken was established to the right of the Tuna public beach access (Figure 01). The site where the Time-Lapse was mounted and recorded daily Time-Lapse videos was on a private beach access on Schoolhouse Lane (Figure 02). The dune measured and monitored throughout our project was located in front of 1101 Schoolhouse Lane, Corolla NC. Survey control points were set, 1 to 1A for our project (Figure 03), and control Points 2 and 3 were set for redundancy in case points 1 and 1A were compromised.

Figure 01. Satellite image of the project site where weekly photographs were taken to qualitatively support the storm impact scale established by (Asbury & Sallenger, 2000). *Source: Google Earth*

Figure 02. Satellite image of the project site where the Afidus Time-Lapse camera was mounted and the dune section that was monitored. *Source: Google Earth*

Figure 03. Study site set-up showing control baseline and profile sections. *Source: Google Earth*

Still photograph

The use of still photographs aided in the visual documentation of the process dunes undergo as described by Ashbery and Sallenger (2000). For this project site, a section of dune that had been scarped by Hurricane Teddy on September 20th, 2020, was qualitatively examined. The documentation via pictures started one week after Hurricane Teddy made landfall in the Outer Banks (Figure 04), with the first picture being dated on September 27th, 2020. Photographs were then taken every Sunday at the same location until the dune recovered. These photographs were downloaded and collectively stored on a document, labeled with the date and time.

Time-Lapse Photography

On February 1st, 2021, an Afidus 200T Time-Lapse camera was mounted onto the railing of a private beach access five minutes north of the first study site. The camera was directed towards the south span of the Corolla, NC coastline. Filming times were established based on sunrise and sunset and were frequently adjusted. The Time-Lapse interval was set for ten seconds and the frames per second (FPS) was set to 30. The videos were extracted from the camera on site after 5-7 days of recording and after the set filming duration had been completed. Extracted footage was saved to two alternative modes of USB. The camera finished recording on February 1st, 2022.

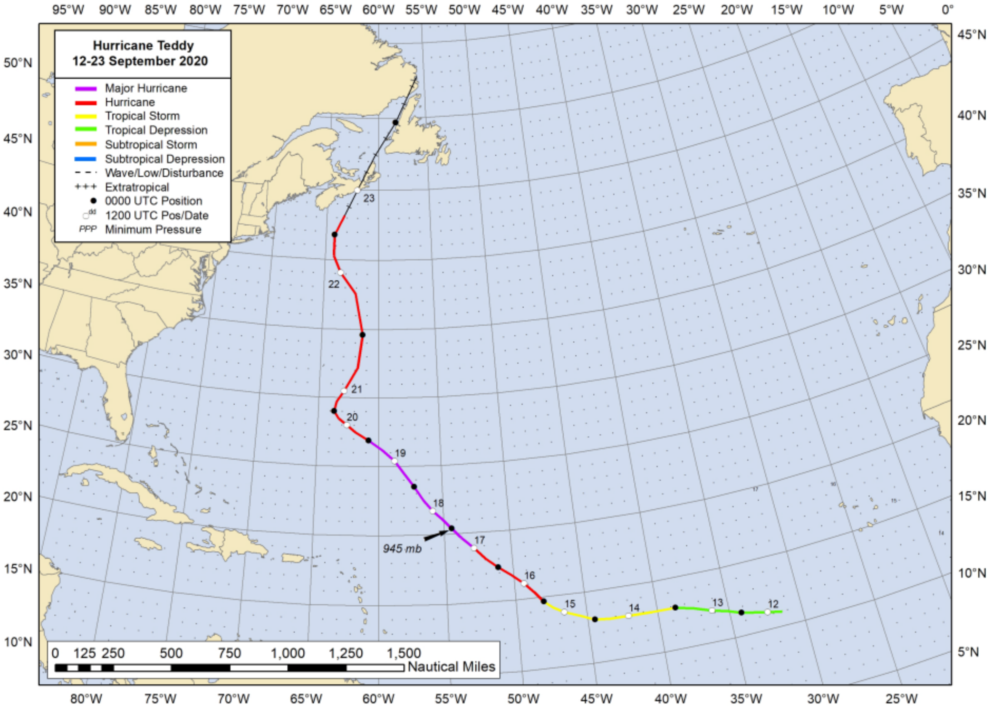


Figure 04. Hurricane Teddy track chart provided by NOAA and the National Hurricane Center in their Tropical Cyclone Report in September of 2020. *Source: NOAA*

Control baseline

Horizontal datum

Four control points were set in order to obtain measurements and the local coordinate system was assumed for our baseline, taking a magnetic compass reading to establish our north orientation.

Vertical datum NAVD 88

Differential leveling is a commonly used tool to establish measurements of elevation and height, a process that involves measuring differences in elevation between points (Cole, 2021, Ghilani, 2018). Because of this, differential leveling was used in our project to establish our control baseline. Determining the elevation of a series of points was based on point measurements and a benchmark, an object, usually permanent, that has a set elevation (Cole, 2021). For this project, a vertical datum using the Light House Benchmark P261 and the North American Vertical Datum, 1988 (NAVD88) was established (Figure 05).

A self-leveling level and graduated leveling rod were used for this process (Figure 06). An initial reading was made where the backsight (BS) added with the elevation of the Lighthouse benchmark equated to the height of our instrument (HI), giving us our line of sight elevation (1). Moving our graduated leveling rod to our first point established a foresight (FS), where subtracting FS from our instrument height gave us the elevation of our Point, as represented by equation (2). These equations (1) and (2) were used repeatedly from the benchmark to Point 2 of our project site and continuing back to the Lighthouse benchmark to ensure mathematical closure. The vertical measurements were acquired within ± 0.1 inches. These equations and their subsequent values were recorded in a field book (Table 01).

$$\mathbf{HI = elev + BS} \tag{1}$$

$$\mathbf{elev = HI - FS} \tag{2}$$

Figure 05. Photographs of the benchmark used to set vertical and horizontal datum for control baseline. Reference for differential level run.

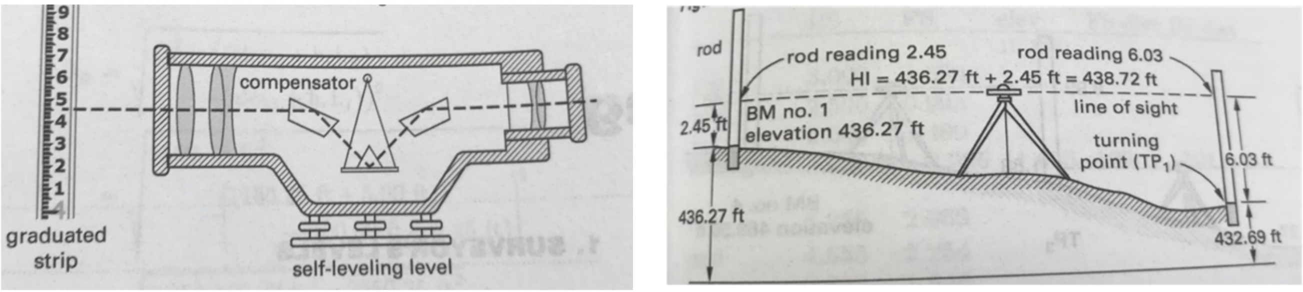
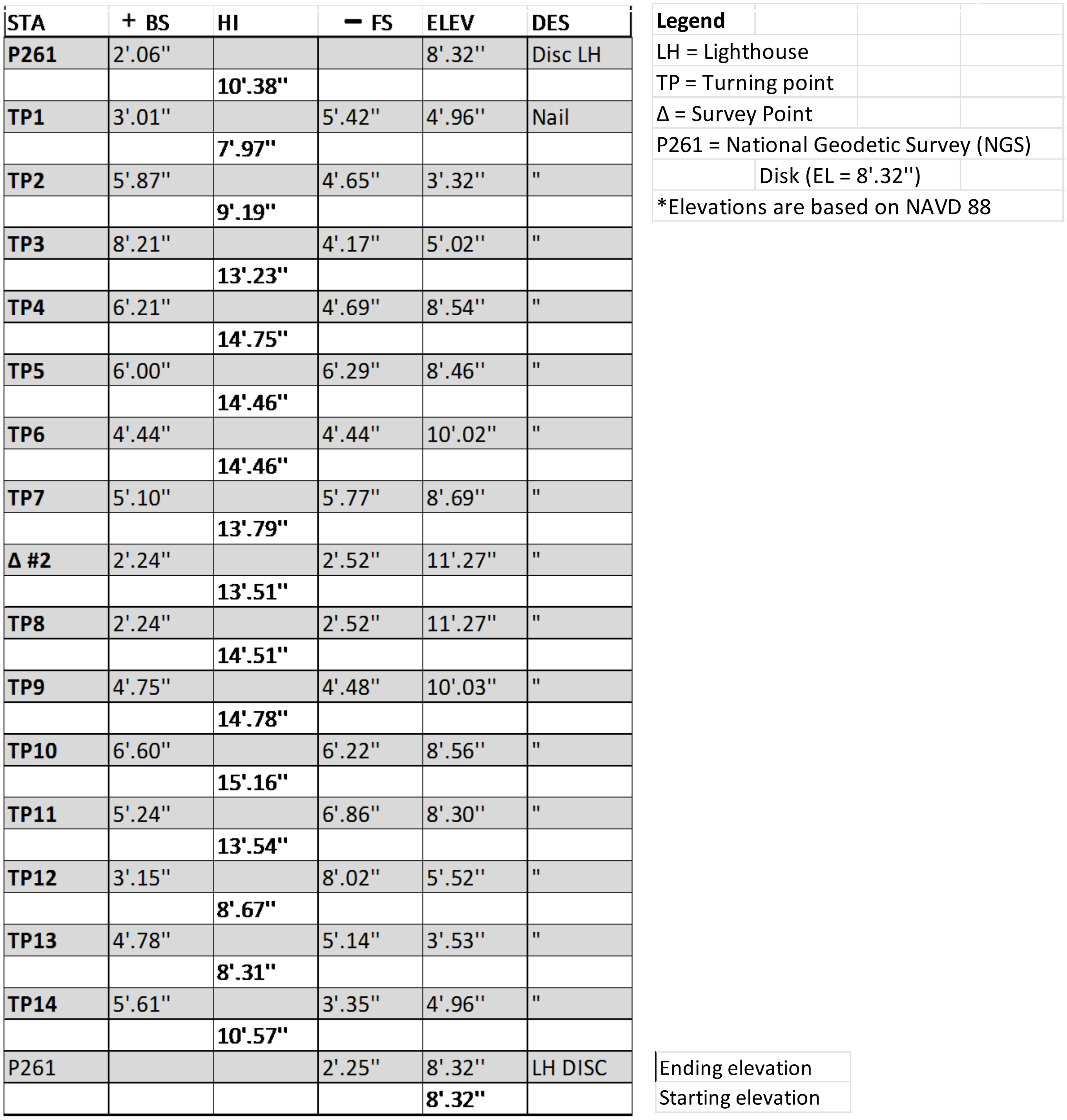


Figure 06. Schematic from (Cole, 2021) illustrating the self-leveling level used in the project and how it works.

Table 01. Field notes taken on March 6th, 2021, using equations (1) and (2) to establish control baseline and create vertical datum.



STA	+ BS	HI	− FS	ELEV	DES
P261	2'.06''			8'.32''	Disc LH
		10'.38"			
TP1	3'.01''		5'.42''	4'.96''	Nail
		7'.97"			
TP2	5'.87''		4'.65''	3'.32''	"
		9'.19"			
TP3	8'.21''		4'.17''	5'.02''	"
		13'.23"			
TP4	6'.21''		4'.69''	8'.54''	"
		14'.75"			
TP5	6'.00''		6'.29''	8'.46''	"
		14'.46"			
TP6	4'.44''		4'.44''	10'.02''	"
		14'.46"			
TP7	5'.10''		5'.77''	8'.69''	"
		13'.79"			
Δ #2	2'.24''		2'.52''	11'.27''	"
		13'.51"			
TP8	2'.24''		2'.52''	11'.27''	"
		14'.51"			
TP9	4'.75''		4'.48''	10'.03''	"
		14'.78"			
TP10	6'.60''		6'.22''	8'.56''	"
		15'.16"			
TP11	5'.24''		6'.86''	8'.30''	"
		13'.54"			
TP12	3'.15''		8'.02''	5'.52''	"
		8'.67"			
TP13	4'.78''		5'.14''	3'.53''	"
		8'.31"			
TP14	5'.61''		3'.35''	4'.96''	"
		10'.57"			
P261			2'.25''	8'.32''	LH DISC
				8'.32"	

Legend
LH = Lighthouse
TP = Turning point
Δ = Survey Point
P261 = National Geodetic Survey (NGS)
Disk (EL = 8'.32'')
*Elevations are based on NAVD 88

Ending elevation
Starting elevation

Study site setup

The initial topographic survey data was collected for Profiles (1-5) from baseline control Points 1-1A. The topographic data was acquired using Leica total stations. Conventional Electronic Distance Measuring (EDM) data collection was performed with a prism pole from the ocean to the toe of slope of the dune. The laser function of the total station was utilized for dune measurements to avoid traversing up and down the dune.

Profile analysis

The topographic data was post processed in Carlson surveying software with AutoCAD using basic coordinate geometry; northings, eastings, elevations, (x, y, z). This software was used to graph the five profiles by plotting the elevation data for February 2021, May 2021, August 2021, November 2021, and February 2022, resulting in five elevation graphs with five months shown.

The data was graphed in this way so to avoid graphical clutter and to help underline any changes visible between the months. The profiles were then compared with the Time-Lapse photography footage to observe qualitative and quantitative data side by side, providing visual demonstrations of the measurements and vice versa

.

RESULTS & INTERPRETATION

Dune hurricane recovery time

Scarping recovery time took 6.9 months (Figure 07). Examination of the weekly photographs alluded to the paired work of failure of the angle of repose, the steepest angle at which a slope can maintain loose sediment, and aeolian transport. Meaning that, sections of the scarped dune would surpass the 30-40° angle of repose established for compact and loose sand, filling in the base of the dune and wind would act as a dispersal mechanism, distributing the sand further.

Figure 07. Comparison of the first and last photographs taken. The magnitude of scarping in this figure represents a collision regime, a storm impact level 2.

Using the study by Asbury and Sallenger, the storm impact level was determined to be of a collision regime, in which the initial storm surge from Hurricane Teddy collided with the base of the dune, causing erosion to occur, but over the course of months was re-established (Asbury

& Sallenger, 2000). Our study qualitatively matched descriptions put forth by Ashbury and Sallenger (2000).

Vegetation cover across seasons

Vegetation at the crest of the dune was more abundant and taller in the summertime and sparse during the winter season. Vegetation also thrived on the face and base of the dune during the summer and dwindled during winter (Figure 08).

The differences in vegetation abundance throughout seasons is visibly noticeable in the Time-Lapse videos, matching results found in a similar 2019 study from the Army Corps of Engineer's Field Research Facility in Duck, NC. They reported increases in dune spatial coverage by various dune plants as well as reporting taller vegetation during the summer season (Conery et al., 2019). Vegetation is considered a main factor in trapping wind-blown sediment, meaning that the increased vegetative cover in their study better accumulated sediment. Therefore, increasing vegetation spatial coverage connects with growth and dune height (Conery et al., 2019).

Aeolian transport

Wind played a dominate role of moving sediment across seasons. Analyzing the Time-Lapse footage illustrated this role, particularly its impact in the winter versus the summer, where stronger winds were noticed in the winter, with the movement of sand visibly noticeable. Strong winds, however, were not the prevalent in the summertime, indicating a more impactful role of wind in the winter, perhaps more erosional attributes, and a less energetic role in the summer, important in distributing sediment for dune growth.

Seasonal morphologic distinctions

In the winter, there was a loss of sediment and vegetation, a narrower beach face, and a steeper dune. In the summer, the beach face was wider with fuller vegetation, and the dune was fuller. The differences in these features could be distinguished in the Time-Lapse videos and support common knowledge surrounding seasonal dune dynamics (Conery et al., 2019).

In a study by Biausque and Senechal (2018), they described beaches in temperate climates as demonstrating two different types of seasonal cycles that relate to winter and summertime changes in beach and dune morphology. They acknowledged that beaches in the wintertime will experience erosion while the summer season represents recovery, resulting in sediment accretion. This is congruent with the fundamentals of dune seasonal behavior (Figure 09). The same was found be true in this study.

Dune elevation profiles

The elevation profiles quantitatively showed loss of sediment in the winter with growth occurring in the summer, as was previously described qualitatively (Figure 10). Overall, the crest of the dune fluctuated within an average range of one foot throughout the year and across all five profiles. In addition, net growth was established around the sand fences present at the base of the dune, with an approximated average of a foot and a half of sediment accumulation visible along the sand fences throughout the year. Most of the dynamics on the dune occurred at the crest and the base, where in the summer the crest experienced growth, as illustrated by our blue and yellow profile lines, and a loss of sediment was experienced in the winter, as shown by our pink, red, and dark blue profile lines. The face of the dune did not display as much change throughout the year. All profiles showed similar trends, which small variability present between them.

Figure 08. Visual comparison of vegetation cover in winter vs. summer. Circles highlight visible areas of change in vegetation on the dune between winter and summer.

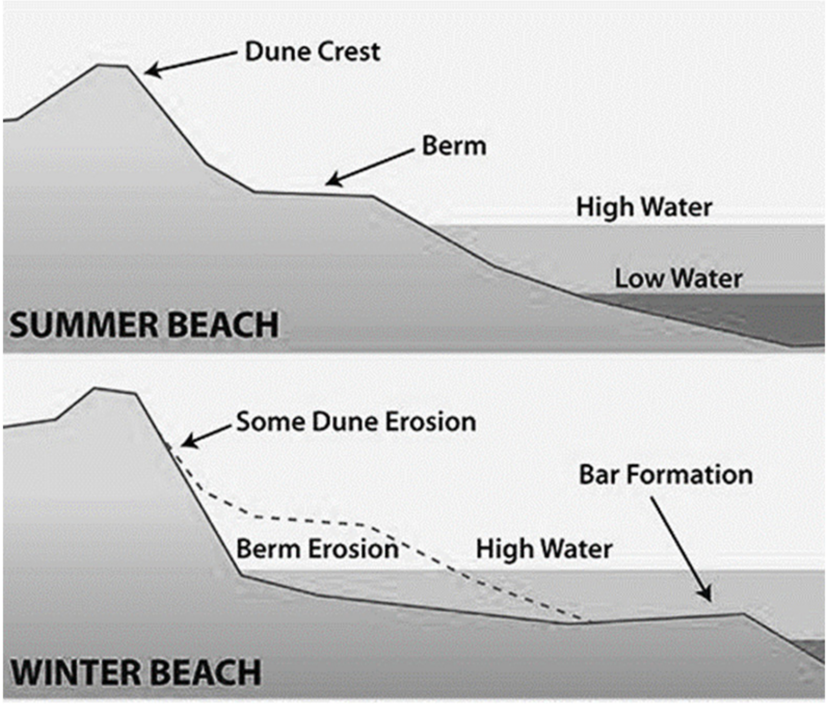
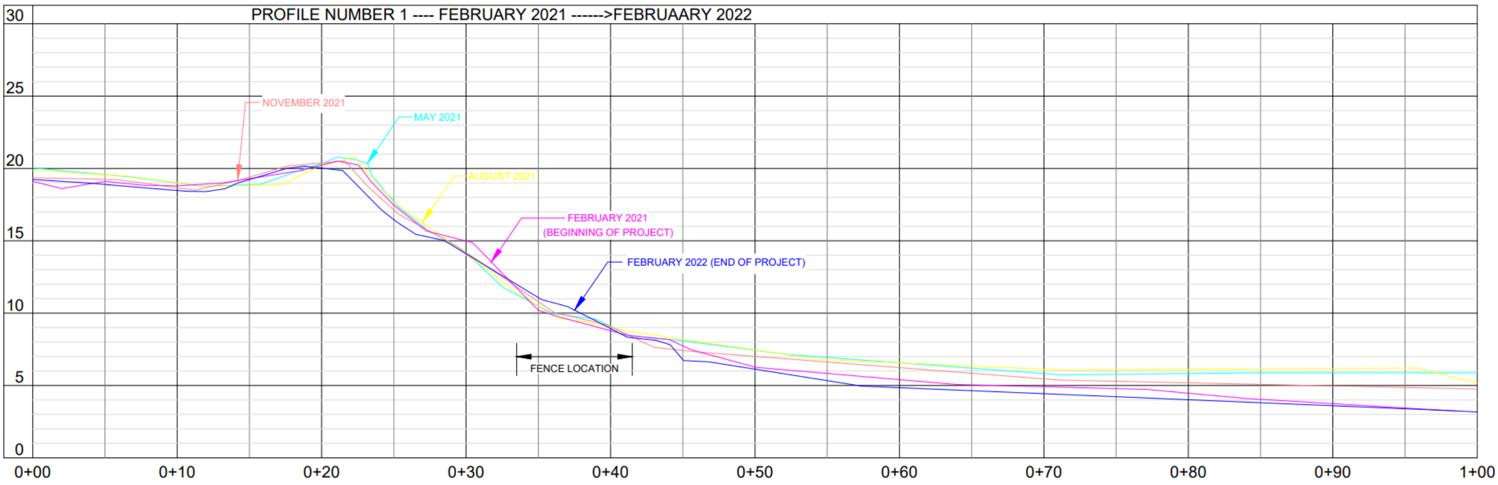
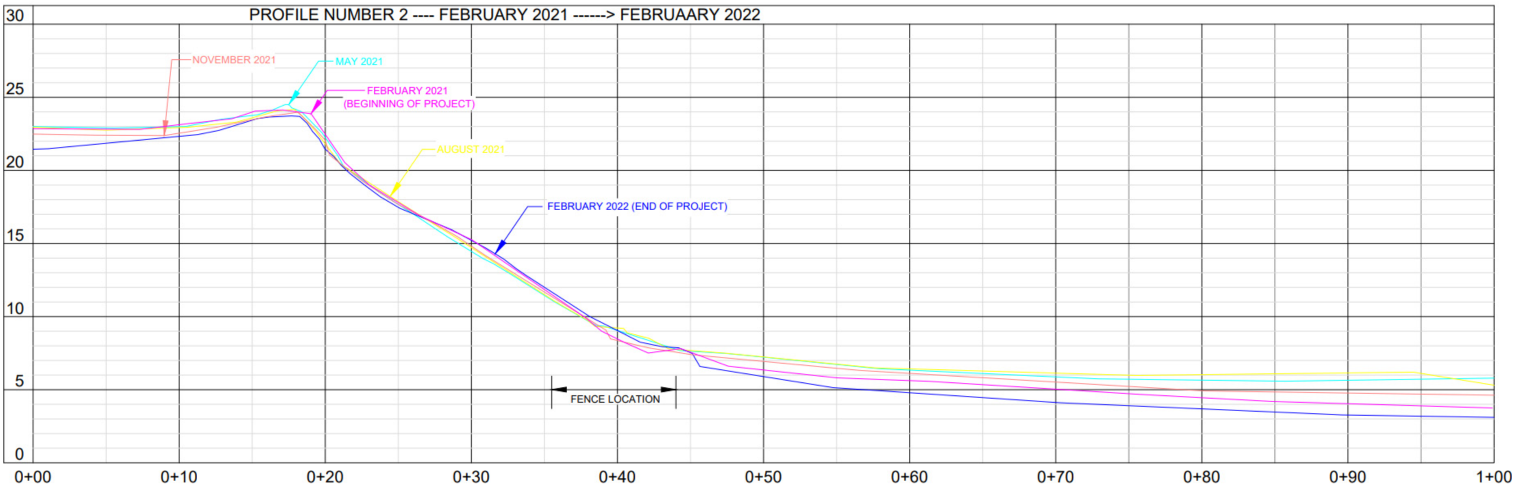
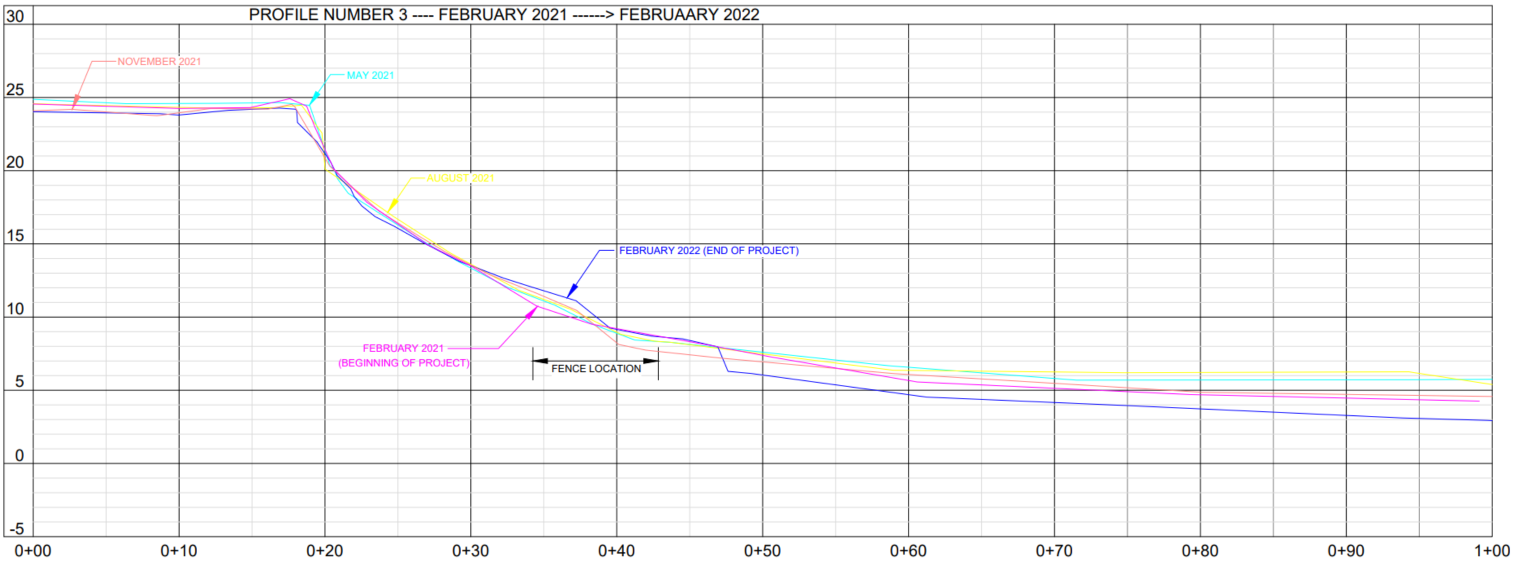
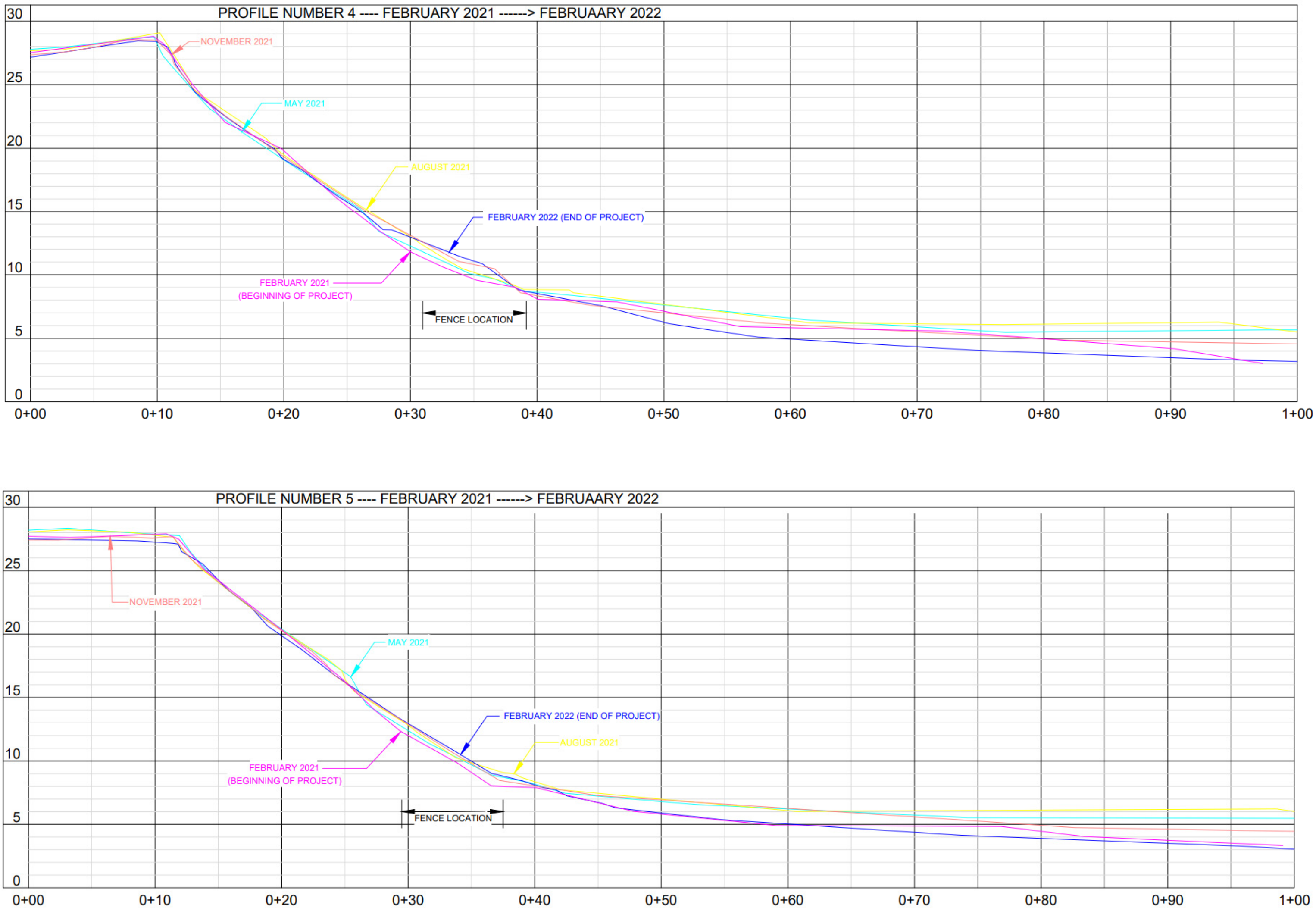


Figure 09. Schematic illustrating foundational differences in beach and dune morphology between winter and summertime profiles (Source: Science of the Shore – A Tale of Two Beaches: Winter & Summer Beach Profiles, n.d.).


PROFILE NUMBER 1 ---- FEBRUARY 2021 ------>FEBRUAARY 2022
30
25
20
15
10
5
0
NOVEMBER 2021
MAY 2021
AUGUST 2021
FEBRUARY 2021
(BEGINNING OF PROJECT)
FEBRUARY 2022 (END OF PROJECT)
FENCE LOCATION
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+80
0+90
1+00


PROFILE NUMBER 2 ---- FEBRUARY 2021 ------> FEBRUAARY 2022
30
25
20
15
10
5
0
NOVEMBER 2021
MAY 2021
FEBRUARY 2021
(BEGINNING OF PROJECT)
AUGUST 2021
FEBRUARY 2022 (END OF PROJECT)
FENCE LOCATION
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+80
0+90
1+00


PROFILE NUMBER 3 ---- FEBRUARY 2021 ------> FEBRUAARY 2022
30
25
20
15
10
5
0
-5
NOVEMBER 2021
MAY 2021
AUGUST 2021
FEBRUARY 2022 (END OF PROJECT)
FEBRUARY 2021
(BEGINNING OF PROJECT)
FENCE LOCATION
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+80
0+90
1+00



SHEET: 1 OF 2
DRAWN BY: BOC/MHC
DATE: 03-21-2022
SCALE: 1" = 5'

COASTAL CAROLINA
UNIVERSITY®

HONOR THESIS - BRIAR OWNBY-CONNOLLY
DUNE PROFILES
1101 SCHOOLHOUSE LANE
COROLLA, NORTH CAROLINA

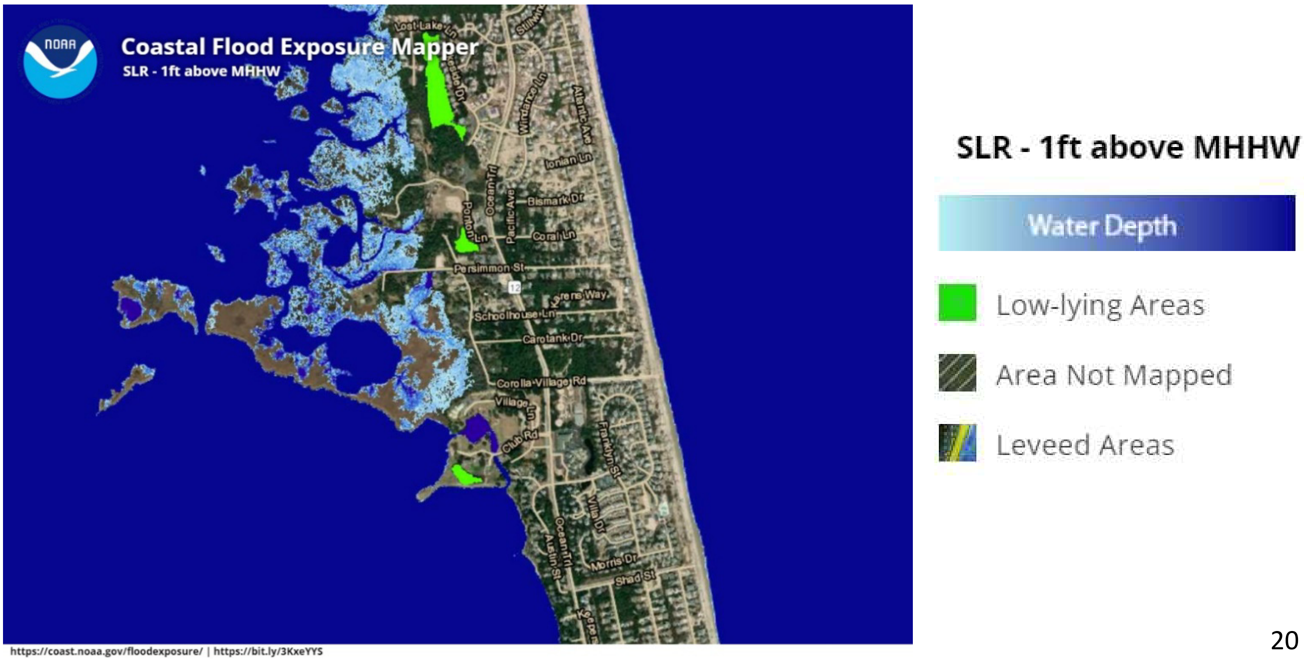
Figure 10. The five profiles from south to north (see Figure 03) showing dune elevation over the course of a year, represented by the start of the project February 2021 (pink), May 2021 (light blue), August 2021 (yellow), November 2021 (red), and the end of the project February 2022 (dark blue) Scale: 1” = 5’ – each horizontal line represents 1ft and each vertical line represents 5 ft.

DISCUSSION

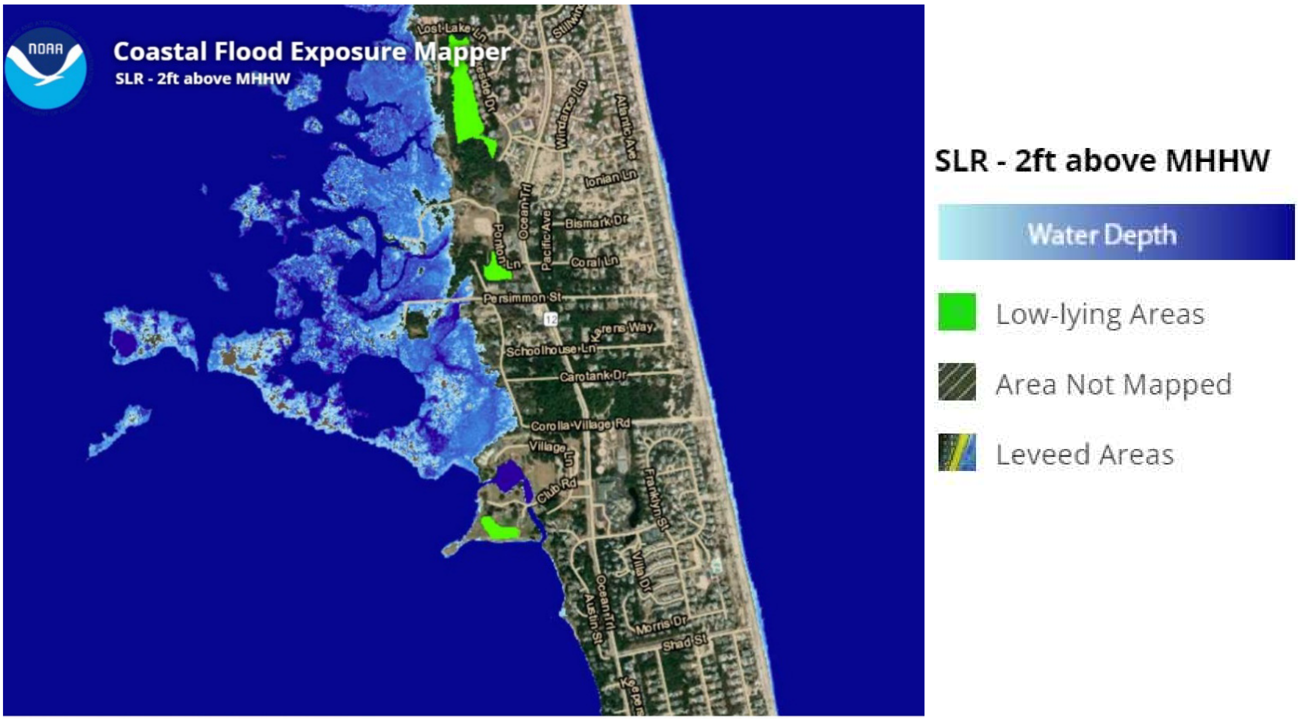
Sea level rise implications for barrier islands

By 2100, sea level is expected to rise by at least 2 feet, with the next 30 years showing us an increase of 1 foot or more (Sweet, et al., 2022). For the east coast, it is estimated to gain between 10 and 14 inches of sea level rise by 2050 (Sweet, et al., 2022). While somewhat conservative estimates, NOAA’s Coastal Flood Exposure Mapper was used, as pictured in Figure 11, to help conceptualize what 1-2 feet of sea level rise would mean for our study site, understanding that these projections do not take into account sediment movement over decades.

With the beach face becoming narrower, less area suggests that the winter beach profile may experience more scarping due to high tides and more flooding and inundation pressures from storms. This raises questions of availability of sediment to be transported by aeolian forces. A narrowing beach face implies less dry sand area open to dispersal via wind, since wet areas cannot be picked up by this mechanism (Grotzinger & Jordan, 2014). This may impact aeolian sediment transport, slowing down aspects of sediment deposition crucial to the dune and beach maintenance and growth dynamics.



https://coast.noaa.gov/floodexposure/ | https://bit.ly/3KxeYYS



tps://coast.noaa.gov/floodexposure/ | https://bit.ly/3pOFG7G

Figure 11. Corolla, NC NOAA sea level rise modeling projections based on 1-2 feet of predicted rise. The white star represents our study site.

The impact of sea level rise on coastal homeowners is already a pressing issue along the Outer Banks, with multiple communities along the east coast facing pressures. Sea level rise and increases in storm intensities threaten the sandy shorelines and the infrastructure behind them (Biausque & Senechal, 2018). For instance, the DeBordieu community in South Carolina is currently battling sea level rise and beach erosion, prompting them to appeal to the South Carolina Department of Health and Environmental Control (SCDHEC) to allow for the use of hard structures on the beach to protect their homes (Fretwell, 2021).

The residents in DeBordieu, without state approval, fixed sandbags in front of their homes in hopes of mitigating sea level and flooding pressures and are pleading to keep them (Fretwell, 2021). This situation brings in legal issues between state approval and residential property owners but is merely a prediction of the battle coastal communities will continue to face. With this in mind, having qualitatively and quantitatively watched the behavior of dunes over the course of a year, current mitigation and management solutions were looked at and theoretically applied to this study site.

Impact of hard structures on sandy shorelines

Figure 12 illustrates the hard structures discussed, where, for the most part, negative impacts are seen from using hard structures to stabilize beach and dune systems. Seawalls are associated with adverse impacts, among them are narrowing of the beach face, reducing accessibility to the beach, and decreasing aesthetic characteristics (Hall & Pilkey, 1990). Seawalls interfere with the dune's ability to participate in the natural processes of sediment deposition and loss, preventing sediment from replenishing the beach and causing the beach face to disappear (Grotzinger & Jordan, 2014).

Figure 12. Example of the different hard structures implemented on coastlines as a means of stabilization.

The main attribute of seawalls is that it protects coastal buildings and infrastructure, other than that, it does nothing to support the dynamics of coastal ecosystems and are not recommended for mitigation efforts. Groins disrupt shoreline equilibrium and sediment transport, causing the beach system to change in response (Mishra & Patra, 2012). When groins are built it disrupts sediment transportation, often building up the beach in one area while eroding it in another (Grotzinger & Jordan, 2014). For similar reasons groins are also not recommended and other methods are suggested.

Certain hard structures on the beach, however, can aid in sediment accretion and stabilization. For example, the Army Corps of Engineers Field Research Facility in Duck, NC found that wooden walkways, sand fencing, and plants all aided in faster growth rates for their managed dune, resulting in a growth rate 1.7 times faster than the unmanaged dune in their study (Conery, et al. 2019). In reference to sand fences, similar results were found in this study, with the sand fences successful in accumulating sediment at the base of the dune. On the other hand, bulldozed walkways lost sediment and presented easier access for overwash during high tides or storm surge in the study by Conery, et al (2019). With this, the continuation of sand fences is suggested, along with wooden walkways that traverse over the dune, allowing access to the beach by pedestrians, since walkways are a magnified version of sand fences. Bulldozed walkways should be kept to a minimum.

Beach renourishment pros and cons

With the loss of beach area from the installment of seawalls and groins, beach renourishment has gained popularity (Pilkey & Cooper, 2014). Beach renourishment involves dredging sand from a different location and added it to the subject beach to increase its width. Beach renourishment works as a short-term solution, but with the threat of sea level rise, the cost of maintaining nourished beaches will rise along with the ocean (Figure 13) (Pilkey & Cooper, 2014). Along with this process being economically intrusive and energy intensive, many people against this concept argue that any form of habitat alteration should be avoided, though better mechanisms for extending the lives of our sandy shorelines, outside of retreating, can’t seem to be found. So, beach renourishments continue as coastal communities face threats. DeBordieu, South Carolina is going through with a beach renourishment in the spring of 2022 and Avon, North Carolina has a beach renourishment project scheduled for the summer of 2022.

Figure 13. Example of a beach renourishment project that occurred in Rodanthe, NC.

Hurricanes intensity effects on potential dune recovery time

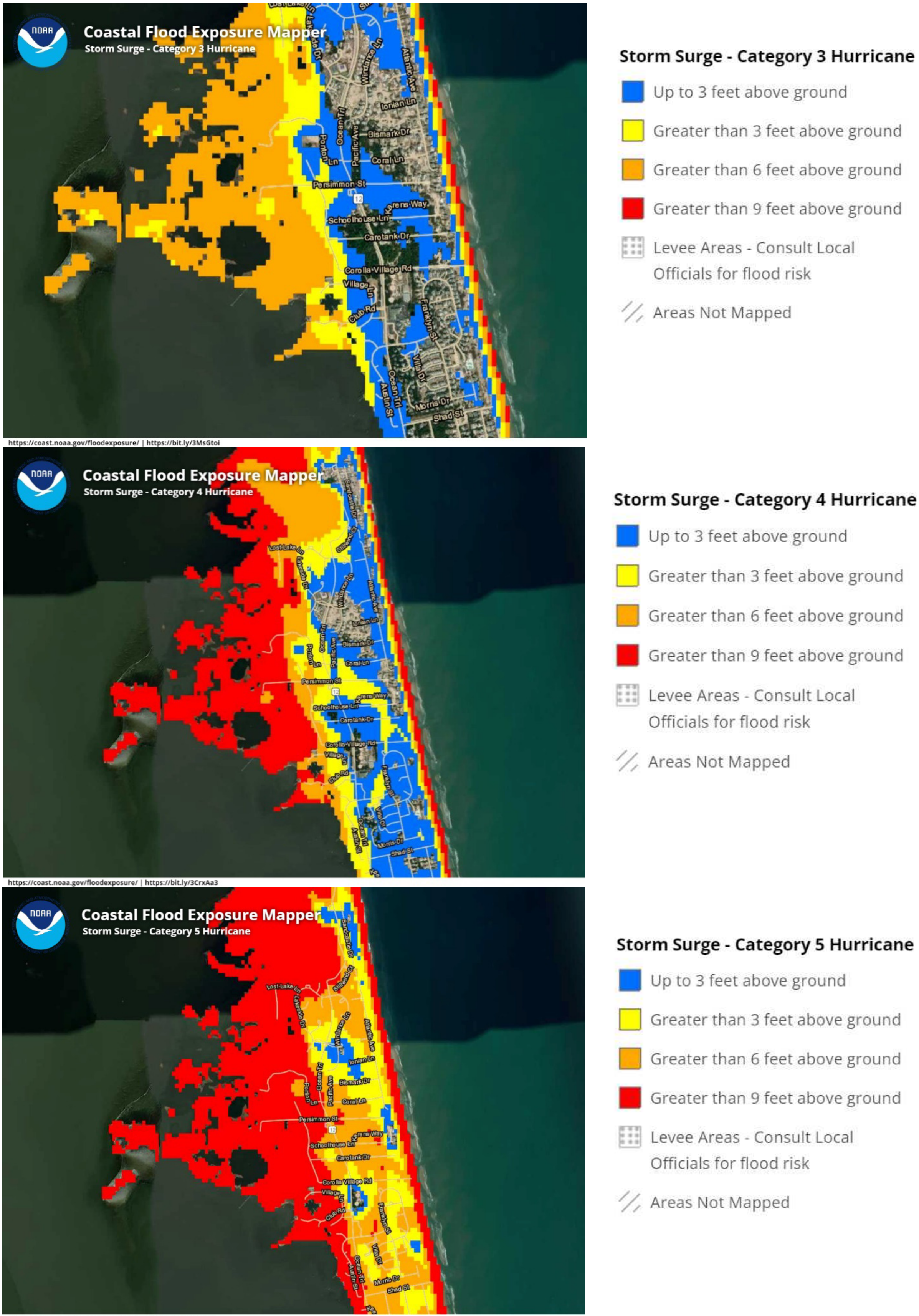
From what has been documented by the Army Corps of Engineers Field Research Facility in Duck, NC, sand fences and certain hard structures are beneficial structurally, economically, and are less intrusive coastal management options. Sand fences, wooden walkways, and vegetation, as mentioned previously, prove to be successful, though the question is, are they enough?

The sand fences were successful in accreting sediment at the base of the dune, though storm surge, from a hurricane or even an unusually high tide can quickly erode it away, causing varying degrees of scarping. As this study outlines, this recovery process has been recorded to take nearly seven months, and that was at a low energy storm level; a tropical cyclone (Blake, 2020). Increasing hurricane intensity, as projected to occur with exacerbated climate change, will only lengthen dune recovering time, possibly to the detriment of these systems. If hurricane intensity and possibly frequency are increased, this raises questions of the ability of dunes to effectively utilize these tools in enough time for recovery, potentially establishing these methods as obsolete.

As can be seen in Figure 14, the utilization of NOAA modeling shows our study site hit with between 3-9 ft or above of storm surge from category 3, 4, and 5 hurricanes. As previously stated, hurricane intensity is expected to increase and become more unpredictable in the coming years due to climate change (Knutson, et al., 2021). With this, sand fences, wooden walkways, and vegetation are not seen as the singular solutions to dune stabilization, nor are they enough.

It's also the case that hurricanes themselves are not the most intrusive, rather their storm surge is the most destructive, responsible for widespread damage to coastal infrastructure and the coastline (Grotzinger & Jordan, 2014). In the case of Hurricane Katrina in 2005, this tragedy was not so much the direct result of the hurricane, but instead the storm surge that followed, which caused sections of their levee system to fail (Grotzinger & Jordan, 2014). Similarly, Hurricane Sandy in 2012 was not a particularly strong storm. In fact, it was only a category 3 hurricane while Katrina was a category 5.

The significance was that Hurricane Sandy had an unusually wide diameter and hit New York City at high tide (Hurricane Sandy, 2013). These characteristics caused rises in water levels



https://coast.noaa.gov/floodexposure/ | https://bit.ly/3MsGtoi

https://coast.noaa.gov/floodexposure/ | https://bit.ly/3CrxAa3

https://coast.noaa.gov/floodexposure/ | https://bit.ly/3Cq678E

Figure 14. Corolla, NC NOAA storm surge impact modeling projections based on differing hurricane magnitudes. The white star represents the location of our study site.

and catastrophic storm surge, flooding the New York City subway (New York City Subway Timeline, 2013). Therefore, storm surge presents itself as a serious concern for coastal barrier islands. Especially since storm surge height is directly related to hurricane wind strength and the atmospheric pressure inside the eye, increasing hurricane intensity will only amplify storm surge on the coast to critical levels (Grotzinger & Jordan, 2014).

The Outer Banks is expected to experience more intense storm events in the coming years (Lubofsky, 2022). Coastal areas are already population dense, but over the last few years real estate sales have hit record-breaking levels in the Outer Banks (Lubofsky, 2022). Storm impacts and a growing population intensifies the relevance and critical nature of issues associated with climate change, like storm surge. Currently, there is nothing in place for an instance where storm surge, high tide, heavy rainfall, and wind direction collide to create maximum damage. And thus, alludes to the themes within this paper, where innovative mitigation approaches are needed to address the complex issues of dynamic sandy shorelines under pressure.

Rights of Nature (RoN)

With the current state of the climate, an expanding union of people are urging for Rights of Nature (RoN), in which legal rights are established to the natural world, where ecosystems, habitats, and species alike hold inherent value and rights (Kauffman & Martin, 2021). The Earth has already warmed by around 1.2 °C (IPCC, 2022). We continue to hear and see the impacts of rising global temperatures on the environment, with new reports, like ones from the Intergovernmental Panel on Climate Change (IPCC), echoing this sentiment and pushing for change through transformative action throughout all sectors of our lives; political, social, and economic.

This change is crucial if we desire to avoid permanent environmental damage that will impact communities throughout the globe, especially if these issues are left unaddressed (Kauffman & Martin, 2021). RoN in essence, is the shift in mindset needed that would allow for us to legally coexist with nature in a way that puts the continuation of ecological and geophysical function of natural ecosystems, like dunes, at the forefront of our legislation (Kauffman & Martin, 2021). This is the pivot we need.

Sea level rise and coastal erosion are serious concerns, though the coast will not disappear, rather be forced inland as a result of these factors (Gasper de Freitas, 2019). So, while retreat policies should be codified and considered at great length, dune conservation efforts will still be needed, and this is where RoN has its place. As Joana Gasper de Freitas put it, "The most sustainable solution and management for coastal areas may well be: let the sea take it! But, that should not stop us from looking for and exploring other options." And doing so within the confines of RoN is the way we must move forward that accentuates sustainable development, particularly the 17 United Nations Sustainable Development Goals.

CONCLUSION

With an ever-pressing climate crisis, it is important to draw attention to the anthropogenic implications of shifting climate fluctuations as it relates to shorelines, especially barrier islands. Considering the geospatial location of barrier islands, at the border of land and sea, climate changes that effect atmospheric and oceanic conditions coincidentally effect these islands as well (Zinnert et al., 2018). As such, accelerating sea level rise and storm intensity pose a serious threat to the stability of these systems, upsetting their natural processes (Zinnert et al., 2018). There are current mitigation and adaptive strategies, but innovation and human ingenuity is needed to effectively ensure cooperation between humans and nature, but also to offer solutions for coastal communities that benefits both parties within a changing climate. It is believed that Rights of Nature (RoN) serves as the outlet to do such, paving the way towards sustainable development.

ACKNOWLEGEMENTS

We sincerely thank Dr. Till Hanebuth, Matthew Connolly, Liam Saffer, Dr. Patrick Limber, Bernie Mancuso, Phil Clayton, Luke Hurley, and the Carson Berry Marine Science Scholarship. Whether it was to aid in the initial push in getting this study off the ground or helping with dune photographs, the maintenance of the Time-Lapse camera, financial aspects, or insight into the surveying and data analysis methods used in this study, was a collective effort.

LITERATURE CITED

Sallenger Jr, Asbury H. "Storm impact scale for barrier islands." *Journal of coastal research* (2000): 890-895.

Biausque, M., & Senechal, N. (2019). Seasonal morphological response of an open sandy beach to winter wave conditions: The example of Biscarrosse beach, SW France. *Geomorphology*, *332*, 157-169.

Blake, E. S. (2020). *National Hurricane Center Tropical Cyclone Report Hurricane Teddy.* NOAA.

Bouchard, S. S., & Bjorndal, K. A. (2000). Sea turtles as biological transporters of nutrients and energy from marine to terrestrial ecosystems. *Ecology*, *81*(8), 2305-2313.

Cole, G. M. (2021). *Surveyor Reference Manual, Seventh Edition.* Kaplan, Inc: 492.

Conery, I., Brodie, K., Spore, N., & Walsh, J. (2020). Terrestrial LiDAR monitoring of coastal foredune evolution in managed and unmanaged systems. *Earth Surface Processes and Landforms*, *45*(4), 877-892.

Fretwell, S. (2021, December 22). *Affluent seaside landowners plead for help in SC's battle against rising ocean*. Retrieved from MSN: https://www.msn.com/en-us/news/us/affluent-seaside-landowners-plead-for-help-in-scs-battle-against-rising-ocean/ar-AAS3Sbx

Freitas, J. G. D. (2019). Between the land and the sea: dunes as natural and cultural heritage.

Ghilani, C. D. (2018). *Elementary Surveying An Introduction to Geomatics, Fifteenth Edition.* Hoboken New Jersey: Pearson: 960.

Grotzinger, J. P., & Jordan, T. H. (2014). *Understanding Earth, Seventh Edition.* New York, NY: W.H. Freeman and Company: 752.

Hall, M. J., & Pilkey, O. H. (1991). Effects of hard stabilization on dry beach width for New Jersey. *Journal of Coastal Research*, 771-785.

Hirama, S., Witherington, B., Hirsch, S., Leone, E., & Carthy, R. (2021). Accuracy and precision of hatchling sea-finding orientation relative to dune proximity in three species of sea turtles.

Hurricane Sandy (2013, October 28). Retrieved from NASA: https://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kauffman, C. M., & Martin, P. L. (2021). *The Politics of Rights of Nature: Strategies for Building a More Sustainable Future*. MIT Press.

Knutson, T. R., Chung, M. V., Vecchi, G., Sun, J., Hsieh, T. L., & Smith, A. J. (2021). Climate change is probably increasing the intensity of tropical cyclones. In *Critical issues in climate change science*. ScienceBrief Review.

Kunkel, K. E., Easterling, D. R., Ballinger, A., Bililign, S., Champion, S. M., Corbett, D. R., ... & Terando, A. J. (2020). North Carolina Climate Science Report. *North Carolina Institute for Climate Studies*, *233*.

Lubofsky, E. (2022, March 3). With Worsening Storms can the Outer Banks Protect its Shoreline? *Oceanus: The Journal of Our Ocean Planet*.

Mohanty, P. K., Patra, S. K., Bramha, S., Seth, B., Pradhan, U., Behera, B., ... & Panda, U. S. (2012). Impact of groins on beach morphology: a case study near Gopalpur Port, east coast of India. *Journal of Coastal Research*, *28*(1), 132-142.

New York City Subway Timeline. (2013, March 17). Retrieved from Shaping the Future of New York City: https://eportfolios.macaulay.cuny.edu/macbride13/research/timelines/new-york-city-subway-timeline/#:~:text=2007%20August%208%20The%20New%20York%20Subway%20floods%2C,Second%20Avenue%20Subway%20line%20begins%20again.%20%28Reis%202009%29

Pilkey, O. H., & Cooper, J. A. G. (2014). Are natural beaches facing extinction?. *Journal of Coastal Research*, (70 (10070)), 431-436.

Schlacher, T. A., De Jager, R., & Nielsen, T. (2011). Vegetation and ghost crabs in coastal dunes as indicators of putative stressors from tourism. *Ecological Indicators*, *11*(2), 284-294.

Science of the Shore – A Tale of Two Beaches: Winter & Summer Beach Profiles. (n.d.). Retrieved from Friends of Island Beach State Park: https://www.friendsofibsp.org/breaking-news/science-of-the-shore-a-tale-of-two-beaches-winter-summer-beach-profiles/

Sweet, W. V., Hamlington, B. D., Kopp, R. E., Weaver, C. P., Barnard, P. L., Bekaert, D., ... & Zuzak, C. (2022). *Global and Regional Sea Level Rise Scenarios for the United States: Up-dated Mean Projections and Extreme Water Level Probabilities Along US Coastlines* (No. 01). NOAA Technical Report.

Zinnert, J. C., Via, S. M., Nettleton, B. P., Tuley, P. A., Moore, L. J., & Stallins, J. A. (2019). Connectivity in coastal systems: Barrier island vegetation influences upland migration in a changing climate. *Global Change Biology*, *25*(7), 2419-2430.