COASTAL SAND DUNE PROTECTION: INFLUENCE AND OPTIMIZATION OF VEGETATION PARAMETERS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Coastal Sand Dune Protection: Influence and Optimization of Vegetation

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Sand dunes protect coastal areas by absorbing wave energy generated by storms. However, during wave impact the dunes can be eroded heavily. Restoring native vegetation and placing plant biomass on dunes may decrease erosion by dissipating wave energy and adding substrate strength. This experiment tested this process by using various instruments such as capacitance wave gauges and Nortek Vectrino Acoustic Doppler Velocimeter (ADV) to measure the hydrodynamics associated with waves that hit a physical model of a coastline cross-section before and after the introduction of vegetation. Furthermore, this experiment tested different densities of plant material to determine the correlation between vegetation density and erosion reduction. The results of the experiment indicate that sparse, immature vegetation on dunes may increase erosion, but a significant increase in mature vegetation reduces erosion.

DEDICATION

This Undergraduate Thesis is dedicated to my parents, who have supplied for me an unlimited amount of love and patience, and my grandfather, who has been a faithful friend during both happy and difficult times. Without their constant love and support, I would hardly have time to focus on my goals.

ACKNOWLEDGMENTS

I would like to thank Jacob Sigren for his constant presence and guidance throughout the creation of this thesis. His dedication, professionalism, and integrity as both a mentor and a friend have made this project a delight to undertake.

I would like to thank Dr. Jens Figlus for providing me with this opportunity to gain valuable research experience. Through his intuition, patience, and encouragement, I have gained a clear mental image of what professionalism looks and acts like.

I would like to thank the Texas Institute of Oceanography for supporting this project via the TIO Research Fellowship.

NOMENCLATURE

ADV	Acoustic Doppler Velocimeter
MBWF	Moveable-Bed Wave Flume
SPV	*Sporobolus virginicus*
WG#	Wave Gauge
JONSWAP	Joint North Sea Wave Project
CT#	Control Trial
VT#	Vegetation Trial
WR#	Wave Run
SWL	Still Water Level

CHAPTER I

INTRODUCTION

Sand dunes and their purpose

Sand dunes are natural features used throughout the world to help protect and beautify coastal zones whether the coastline is being used for residential or recreational functions. By reducing the amount of wave energy that impacts sensitive coastal infrastructure, sand dunes play an essential role in minimizing the amount of damage done to coastal environments and structures (Sigren 5). Sand dunes are also host to many species of animals due to their ability to serve as a breeding ground.

Erosion and its influence

Sand dunes erode due to wave impact. Since sand dunes are constantly subjected to erosion, the infrastructure and ecosystems protected by the dunes are constantly at risk. As an effect of this erosion, some dunes must be frequently restored and rejuvenated through costly dune restoration projects.

Thesis goal

With the intermittent, natural destruction of dunes comes the question of whether or not there are cheaper and more sustainable ways to make sand dunes stronger and more effective in resisting wave-induced erosion. One method that produces desirable results is the adding of vegetation to sand dunes. The goal of this experiment is to find whether or not there are certain arrangements and densities of vegetation that provide optimal protection from erosion (7).

CHAPTER II

METHODS

Primary equipment utilized during this experiment

Moveable bed wave flume

The moveable bed wave flume (MBWF), seen in Figure 1, is used for this experiment. It consists of a 15 meter long steel and glass flume with a mechanized paddle for creating waves. Sand is arranged on top of a plywood platform to simulate a coastline, river bed, or lakefront. Waves generated at the left side of the flume initially travel to the right until they dissipate or reflect. Conditions near the swash zone can be altered in order to study erosion in depth.

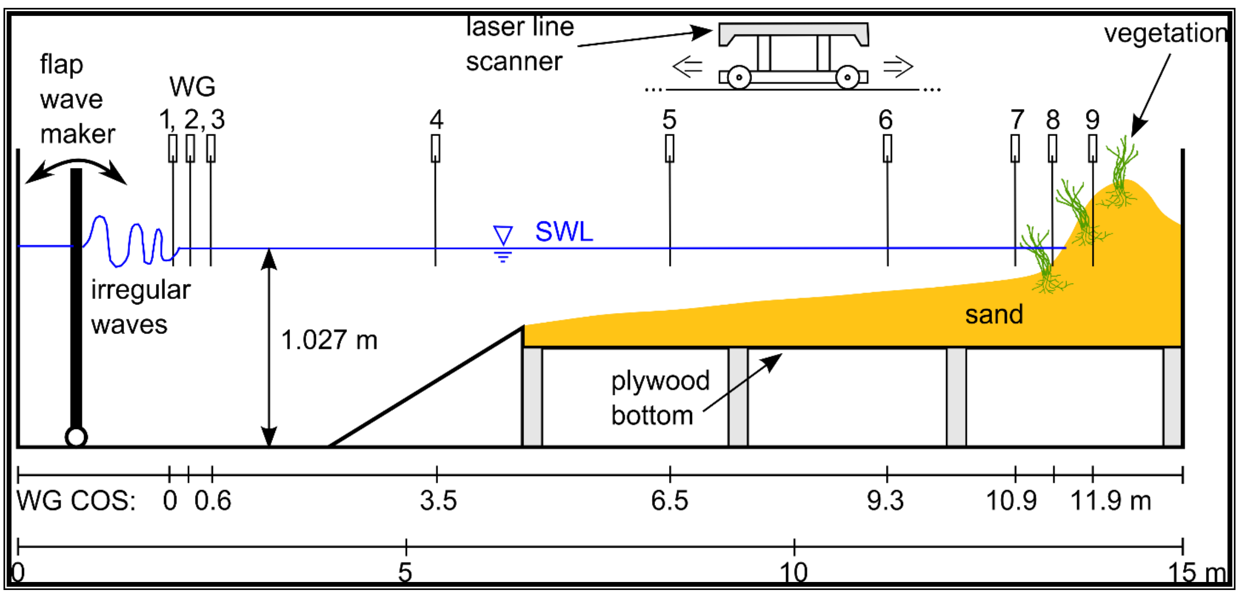

FIGURE 1: Moveable Bed Wave Flume.

Vectrino sensors: what they detect and how they do it

Vectrino sensors measure water velocity by analyzing the motion of suspended particles within the water. They accomplish this by pinging a measurement volume a few centimeters away from the probe head. Flow velocities at that point are determined based on the Doppler shift in the acoustic return signal produced by particles moving with the fluid. Table 1 and Figure 2 provide examples of wave data measured by Vectrino sensors.

TABLE 1: Sample Matlab Vectrino Data. This table shows an example of data retrieved by a Vectrino sensor. The highlighted cells represent particle velocity in the x, y, and z directions respectively.

	A	B	C	D	E	F	G	H
	VarName1	VarName2	VarName3	VarName4	VarName5	VarName6	VarNa...	VarNa...
	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NU...	NU...
1	1	00000011	-0.6320	0.3670	4.2130	0.0000	163	175
2	2	00000011	-0.8640	-0.1720	-3.1910	0.0000	162	173
3	3	00000011	-0.8150	-0.1680	-3.8970	0.0000	165	172
4	4	00000011	0.3280	0.6360	5.4050	0.0000	167	173
5	5	00000011	-0.8510	-0.2030	-5.3840	0.0000	162	177
6	6	00000011	0.1110	0.0670	0.4710	0.0000	165	175

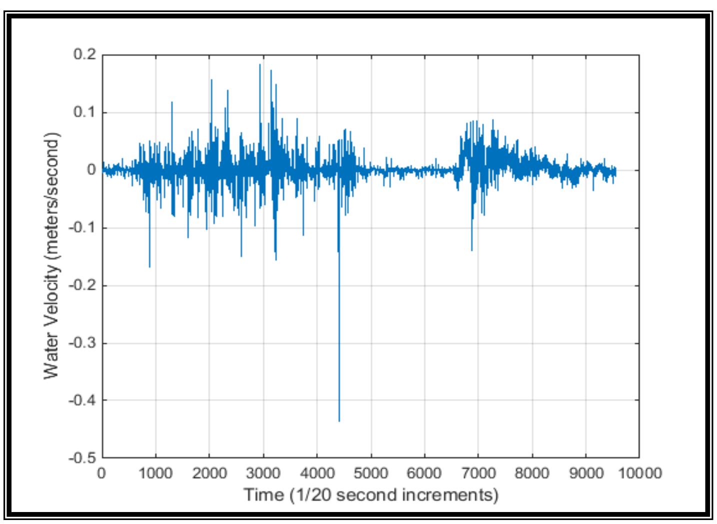

FIGURE 2: Vectrino Data Example. This is an example of data retrieved from the Vectrino sensors. The Y axis represents water velocity while the X axis represents elapsed time.

For this experiment, a single, side-facing Vectrino sensor is used. This Vectrino is composed of four prongs that use acoustic waves to track the velocity of suspended soil particles in the water [Fig 3]. The Vectrino sensor is placed into the area that becomes the swash zone [Fig 4].

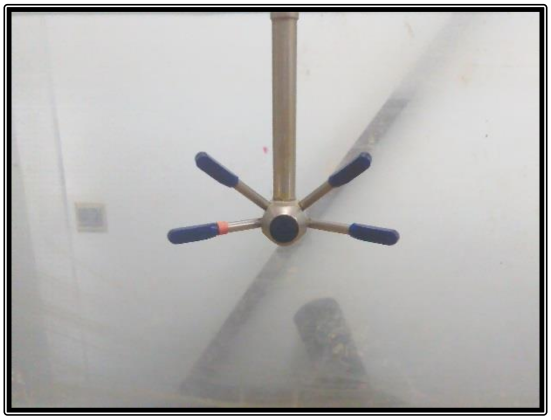

FIGURE 3: Vectrino Sensor. This side facing Vectrino sensor is placed in the swash zone of the shore profile to record swash velocity.

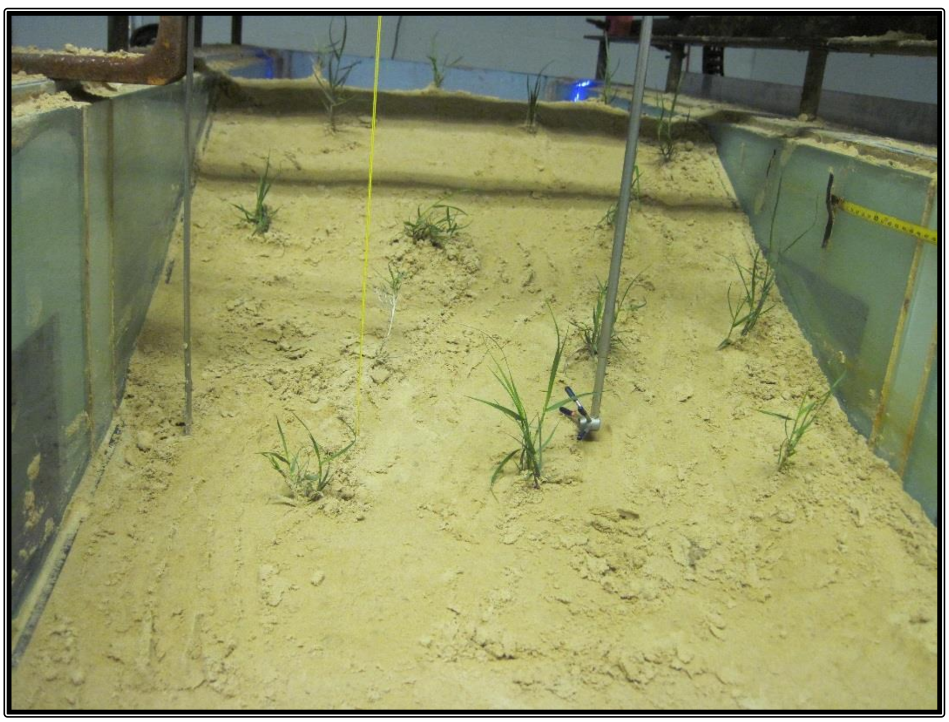

FIGURE 4: Vectrino Sensor Near Vegetation. This figure shows the placement of the Vectrino sensor on the shore for each trial.

Water height tracking with wave gauges

Wave gauges (WG) track the total water height at any moment during a wave run (WR). They also record the still water level. There are nine WGs located throughout the moveable bed wave flume (labeled WG1-9). Figure 5 provides an example of data retrieved by a WG. The location of WG4 is set as the beginning of the sand profile.

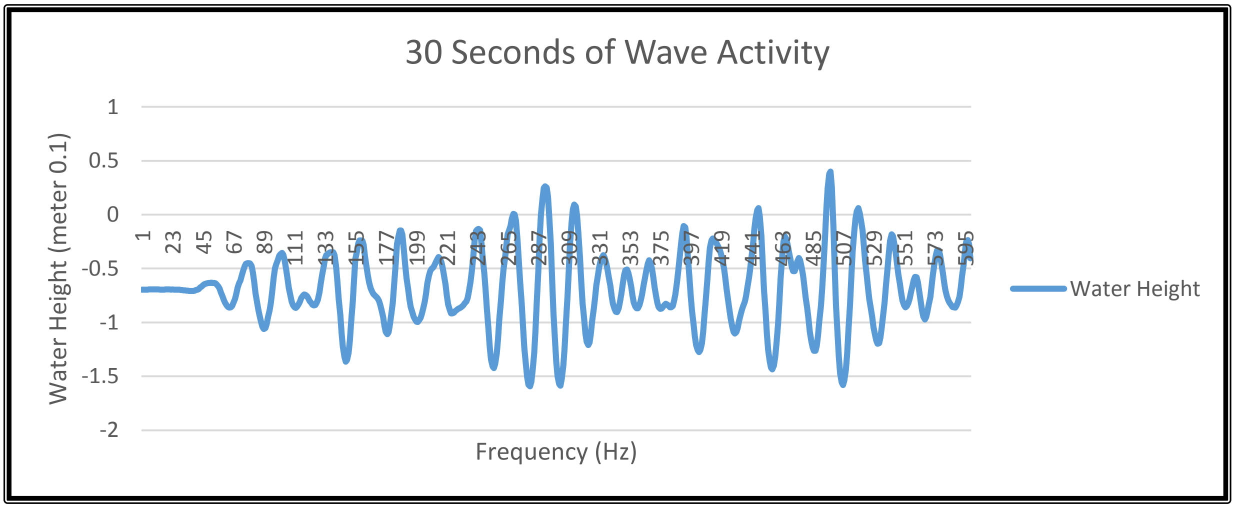

FIGURE 5: Wave Gauge Data. This is an example of the data retrieved by a wave gauge during a wave simulation. The X axis represents elapsed time. The Y axis represents water height.

Measuring sand profile changes with a laser profiler

By using a laser profiler [Fig 6] the depth of sand can be scanned throughout the flume. The laser profiler is used before and after each WR to find the change in sand elevation due to the influence of wave energy. The changes in sand elevation without vegetation are compared to the changes in sand elevation with vegetation to show how much erosion occurred. When plotted, the data retrieved by the laser profiler appears as in Figure 7.

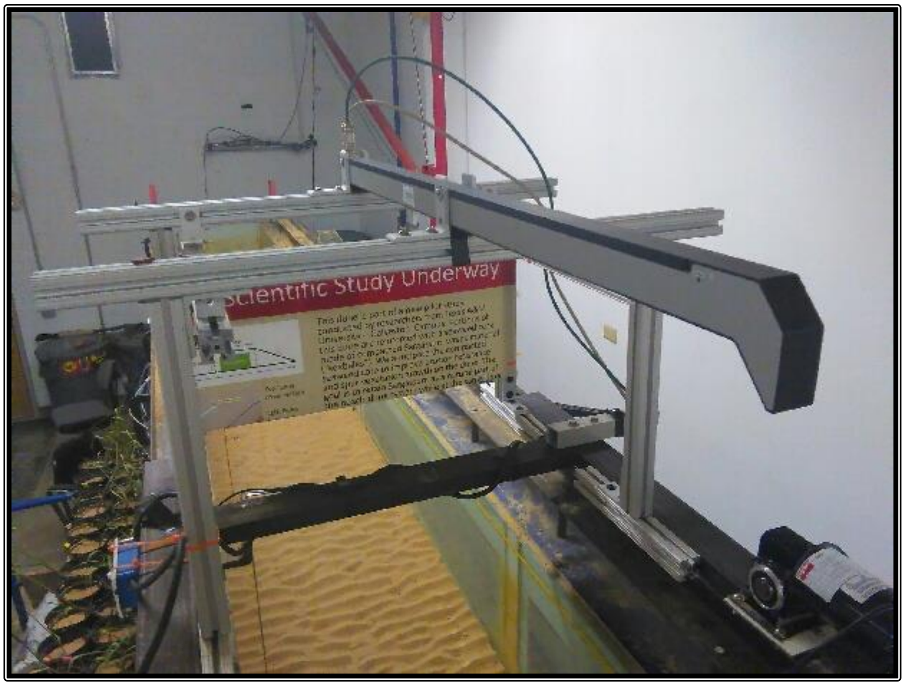

FIGURE 6: Laser Profiler. This figure shows the laser profiler mounted onto a moveable cart atop the MBWF.

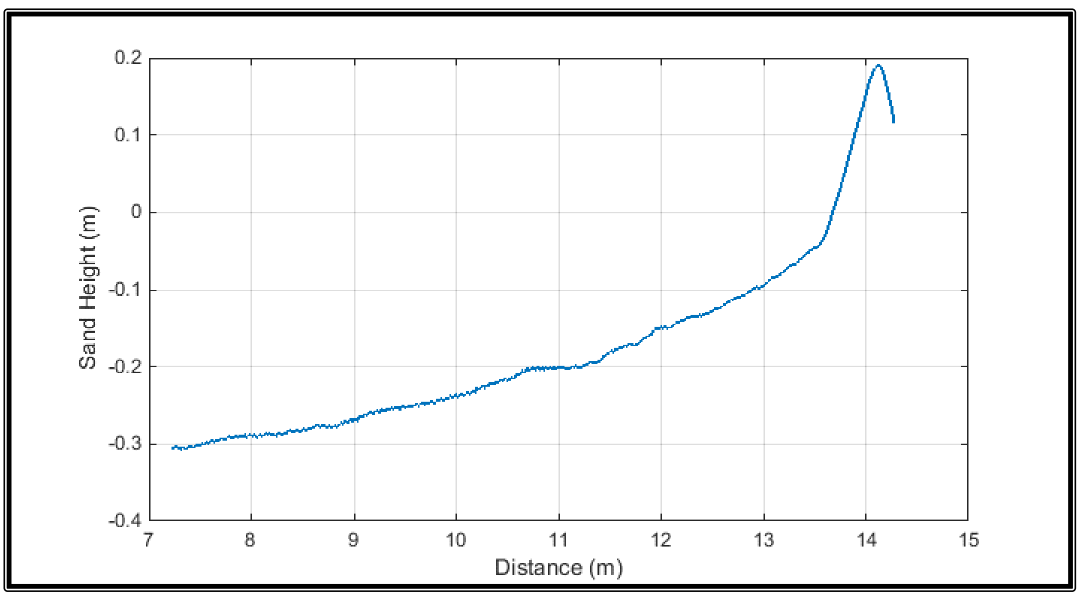

FIGURE 7: Sand Profile. This graph displays the profile elevetion measured by the laster profiler (vertical zero is the still water level).

Dune retention due to increased vegetation

Control and vegetation trials

In order to properly analyze the effects of erosion, a total of four trials are performed. For this research project, a trial is defined as a series of 12 wave runs accompanied by specific, preset conditions within the swash zone. The four trials are as follows:

CT1: *Control Trial 1.* This trial consists of the dune shape that will be used for every trial. No vegetation was supplanted into the swash zone for this trial.

CT2: *Control Trial 2.* The conditions for CT2 were the same as in CT1.

VT1: *Vegetation Trial 1.* The only difference between this trial and the previous two was the addition of sparse, immature vegetation to the swash zone.

VT2: *Vegetation Trial 2.* Like VT1, the difference between this trial and the control trials was the addition of vegetation to the swash zone. However, the vegetation introduced for this trial was denser and more mature than the vegetation in VT1.

The process of erosion

Erosion happens when energy from the breaking of waves and running of swash disturbs sediments within the swash zone, then pulls the particles seaward as the swash recedes. The disturbance in the particles is due to shear stresses that develop due to the viscosity of the water. A moving fluid creates a shear stress through the following relationship:

$$\tau(y) = \mu \frac{\partial u}{\partial y} \qquad \{EQ\ 1\}$$

Where $\tau(y)$ is shear stress with respect to water height, y. μ is the dynamic viscosity of the water, and $\frac{\partial u}{\partial y}$ is the change in the water velocity component parallel to the sea floor, u, with respect to its distance from the surface. For the purpose of this experiment, the velocity in the along shore direction was not considered.

Any sediment particles removed from the dune face were deposited in the surf zone or further offshore. Therefore, the amount of beach mass lost due to erosion was equal to the mass deposited elsewhere along the profile. This relationship is represented by Equation 2

$m\ erosion = m\ deposition$ {EQ 2}

The mass of the sediment is represented by the symbol m.

Supplanted vegetation

Sporobolus virginicus (SPV) is a short dune grass that is native to many coastal areas throughout the world [Fig 8]. This vegetation formed the basis for this experiment. Different increments of growth of this plant were transplanted into the swash zone of the simulated coastline for VT1 and VT2.

FIGURE 8: Sporobolus Virginicus. The native dune grass used for this experiment. Different increments of growth are transplanted into the swash zone of the wave flume (Figlus 4).

Generation of waves, the JONSWAP wave spectrum

The wave profile utilized in this experiment for inducing erosion was created by the Joint North Sea Wave Project (JONSWAP) experiment (Hasselmann 13). Running a JONSWAP wave run for 50 seconds in the MBWF produces the wave profile seen in Figure 9.

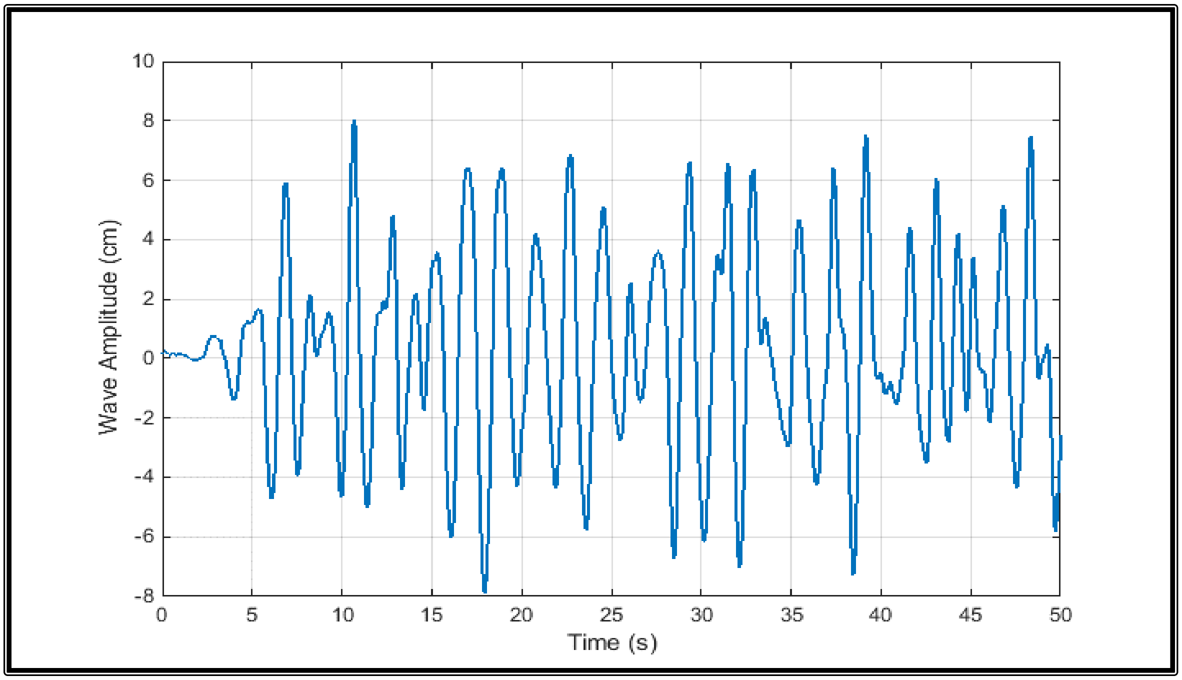

FIGURE 9: JONSWAP Profile. This is the wave profile produced by generating JONSWAP waves for fifty seconds.

Waves of this profile are based on conditions recorded in the North Sea off the coast of Denmark. Those seas have a relatively smooth seafloor and moderate tidal currents. The water depth was deep enough so that any changes in the wave profile caused by the sea floor were negligible. The waves were recorded on and offshore in the location shown by Figure 10. More information regarding JONSWAP wave profiles can be found in *Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project* (Barnett Hasselmann).

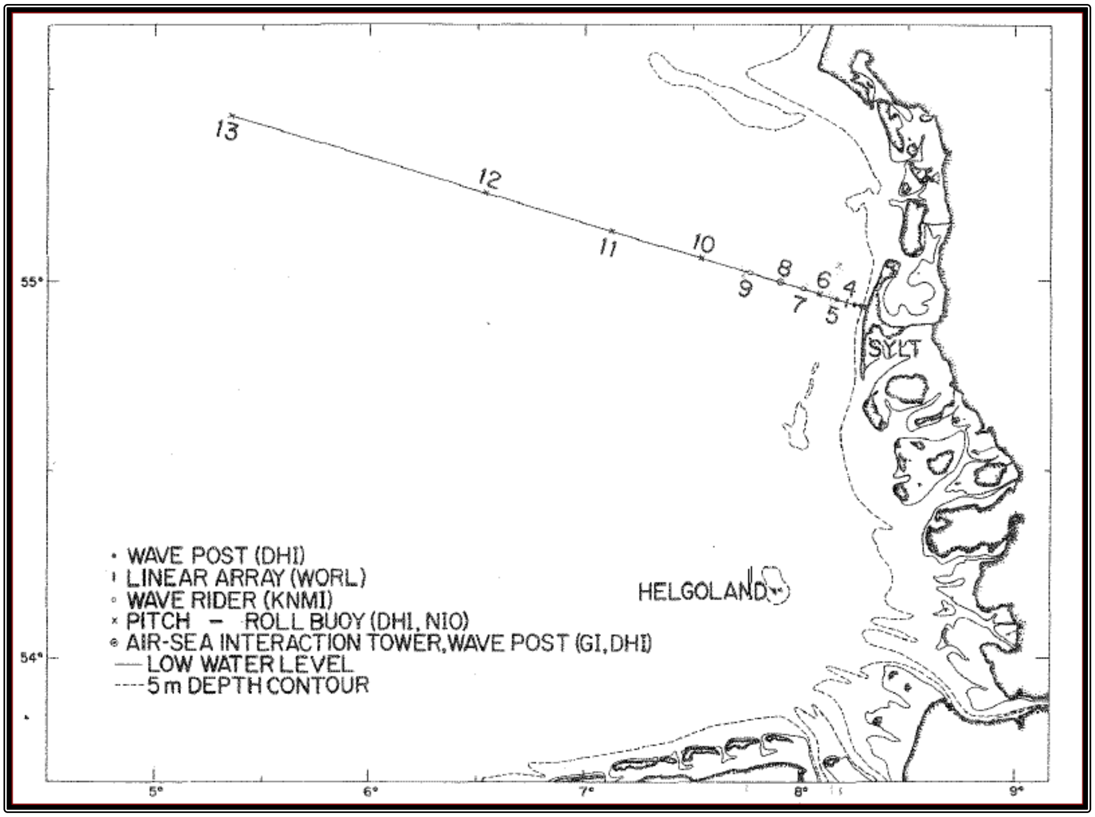

FIGURE 10: JONSWAP Recording Area. The location of recording for JONSWAP waves is off the coast of the German barrier island, Sylt. The waves used in this experiment are based on waves generated in this area (13).

Recording and interpreting profile data

To begin the experiment, a specific profile is created manually within the moveable bed wave flume. This same profile is restored for reuse in every control trial and vegetation trial. Before the first wave run, the laser profiler scans the sand height in the flume from WG4 at 7.22 meters to the end of the dune at 14.28 meters as seen in Figure 11.

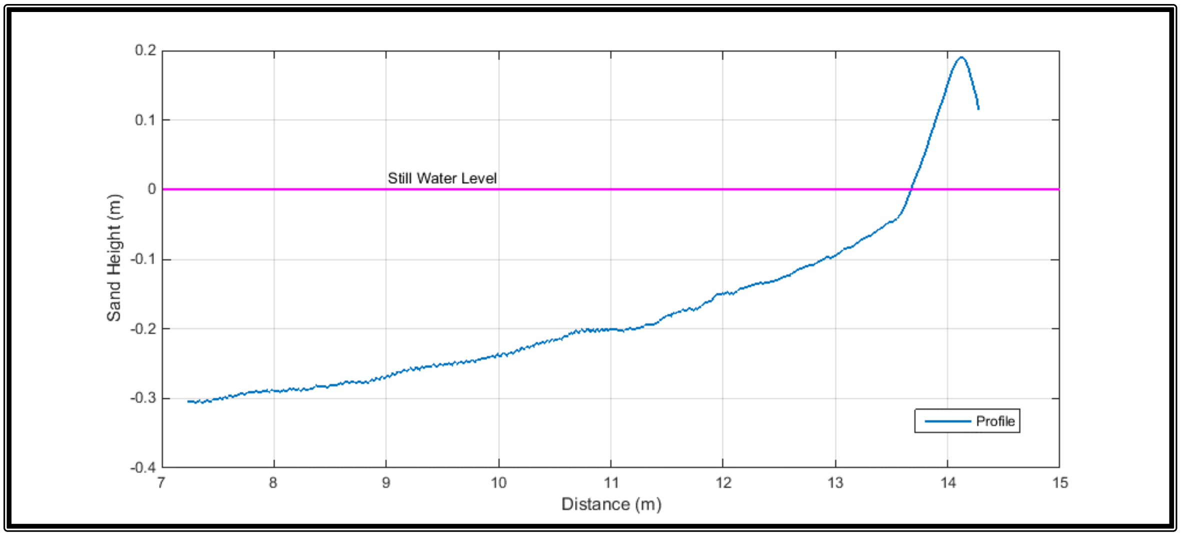

FIGURE 11: Basic Dune Profile. This is the dune profile prior to WR1. It is approximately regenerated for reuse in each trial.

After filling the flume to its still water line (SWL), wave gauges measured the stillness of the water to ensure that waves were not propagating prior to a wave run. The paddle device then produces the first wave run of JONSWAP waves. Once the wave run was complete, the flume was drained, and the laser profiler rescanned the profile. This process was repeated for twelve wave runs. The resulting profile after twelve wave runs is shown in Figure 12.

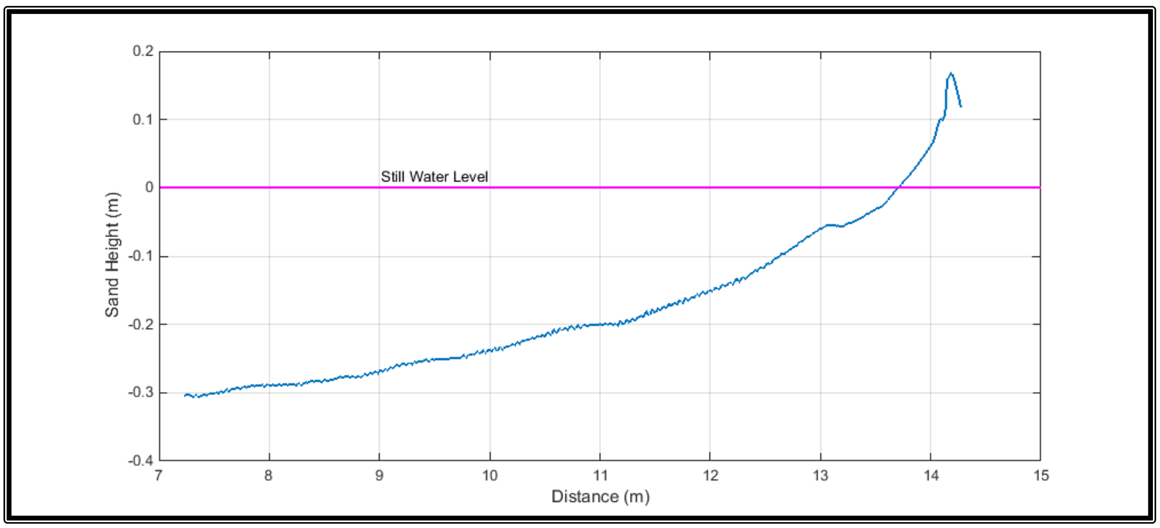

FIGURE 12: Eroded Profile. This is the profile after 12 wave runs for CT1.

A plot of the erosion that took place during the 12 wave runs is found by using the following equation:

$$Change\ in\ Profile = Final\ Profile - First\ Profile \qquad \{EQ\ 3\}$$

By subtracting the initial profile (measured prior to WR1) from the final profile (measured after WR12), the total change in profile was found. Figure 13 shows an example of the erosion of CT1.

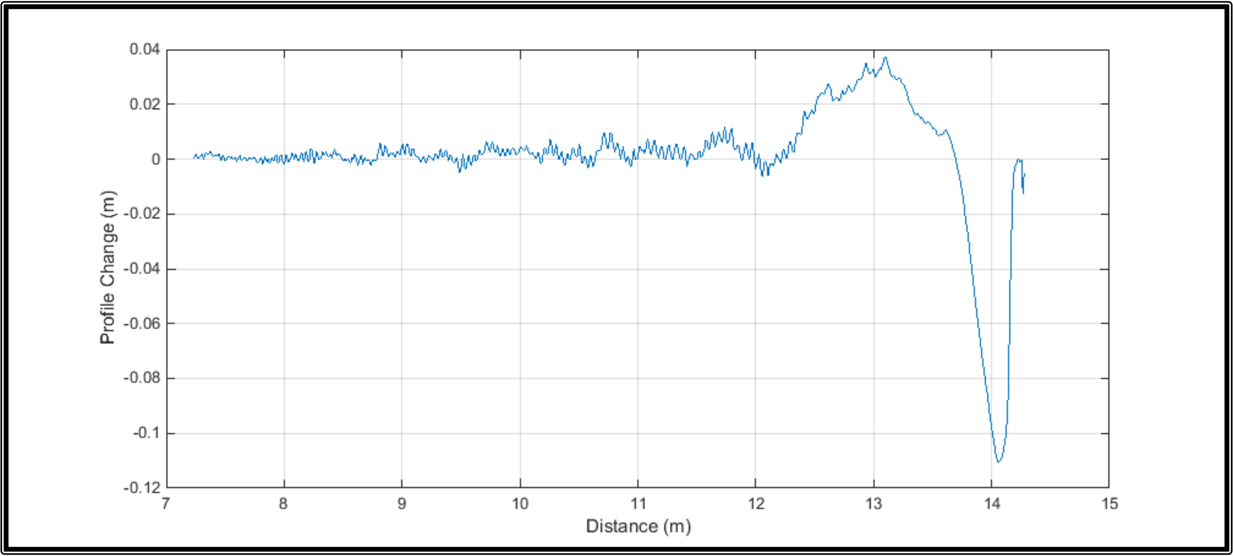

FIGURE 13: Change in Profile. This figure represents the total change in sand profile after 12 wave runs for CT1.

The vast majority of the erosion and sand deposition took place between 11.5 meters and 14.5 meters, so the plots are limited to that range. In order to obtain a quantitative value of the erosion from this plot, the percentage of total erosion was obtained from the following equation:

$$Erosion\ \% = \frac{WR12\ Dune\ Profile - WR0\ Dune\ Profile}{WR0\ Dune\ Profile} * 100\% \qquad \{EQ\ 4\}$$

WR0 indicates that no wave runs have been performed, and WR12 indicates that all 12 wave runs have already occurred. The phrase *Dune Profile* indicates that the area considered by this equation is the dune, which typically ranged from $13.7\ m$ to $14.2\ m$.

These calculations were repeated for each CT and VT.

Recording and interpreting Vectrino data

Vectrino sensors measure the velocity of particles suspended in the water. For this experiment, a single Vectrino sensor measured the swash velocity [Fig 14]. Only the water velocity in the cross shore direction is analyzed. A sample of typical Vectrino data is shown in Figure 15.

FIGURE 14: Vectrino Sensor Recording Swash Velocity.

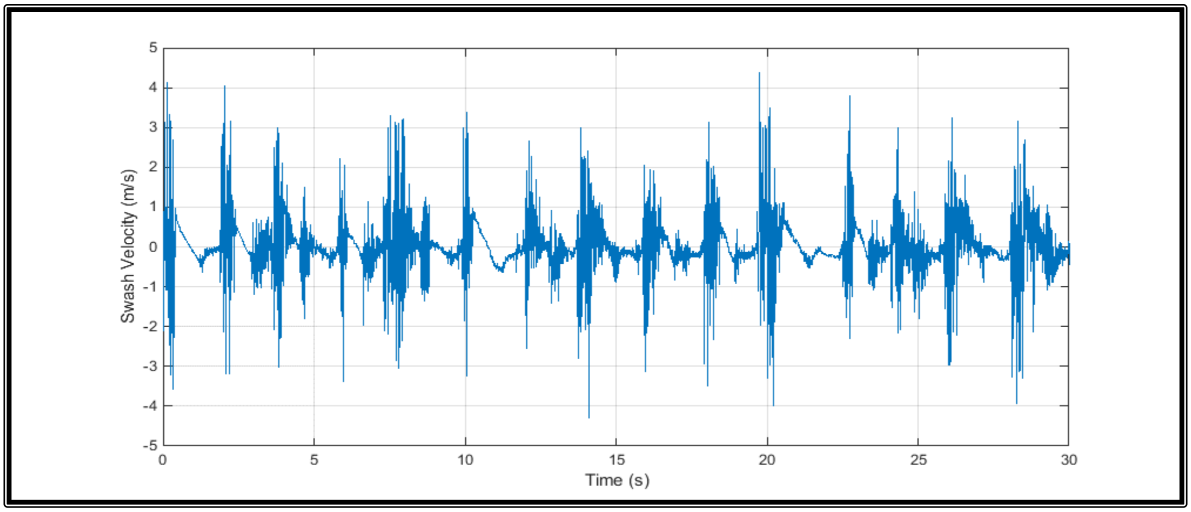

FIGURE 15: Vectrino Data. This figure shows the plot of swash velocity vs elapsed time.

Because the Vectrino sensor cannot analyze velocity while it is not fully submerged, spikes and sudden drops appear throughout the data once the swash had receded. These spikes and drops were shown in Figure 15. To account for this, specific segments of time where the Vectrino sensor was fully submerged were chosen for data analysis [Fig 16]. A best fit line was plotted in addition to the actual Vectrino data. The slope of this line is equal to the average acceleration of the swash.

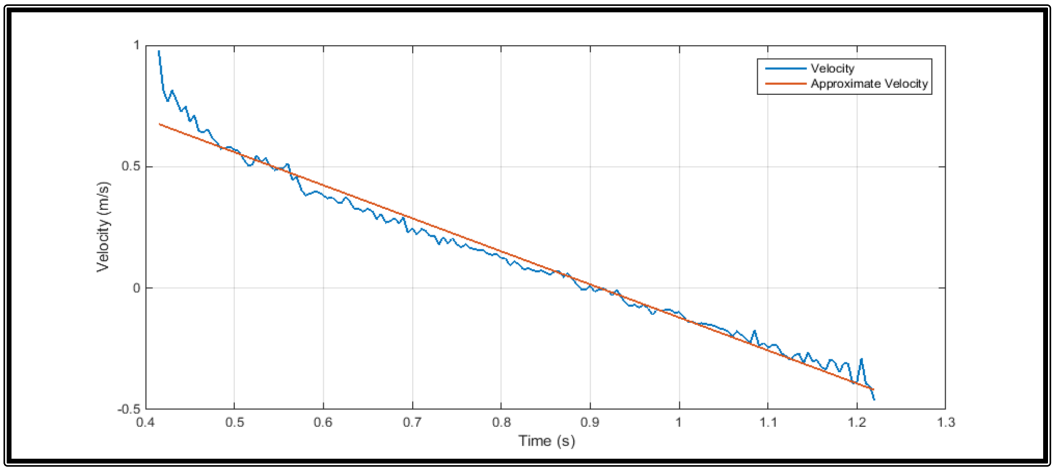

FIGURE 16: Revised Vectrino Data. This specific range of data includes no points where the Vectrino sensor came out of the water. Thus, the data is reliable.

Selecting Vectrino Data

To compare Vectrino data from one trial to another, a specific time range that encapsulated comparable data across each trial was chosen. This range consisted of specific times at which the same JONSWAP wave hit each profile. For example, if ten waves were generated during a WR, and one wanted to compare the effects of this WR across each trial, one specific wave out of the ten would be chosen for analysis. One wave from WR1 of CT1 would be compared to the same wave of WR1 for CT2, VT1, and VT2. The same process was repeated for WR4 and WR12.

CHAPTER III

RESULTS

Shore profile changes due to wave action

Profiles: before and after wave runs

Before and after each WR, the sand profile was scanned by the laser profiler. The sand profiles before the first wave run and after the final wave run are shown in Figures 17-20.

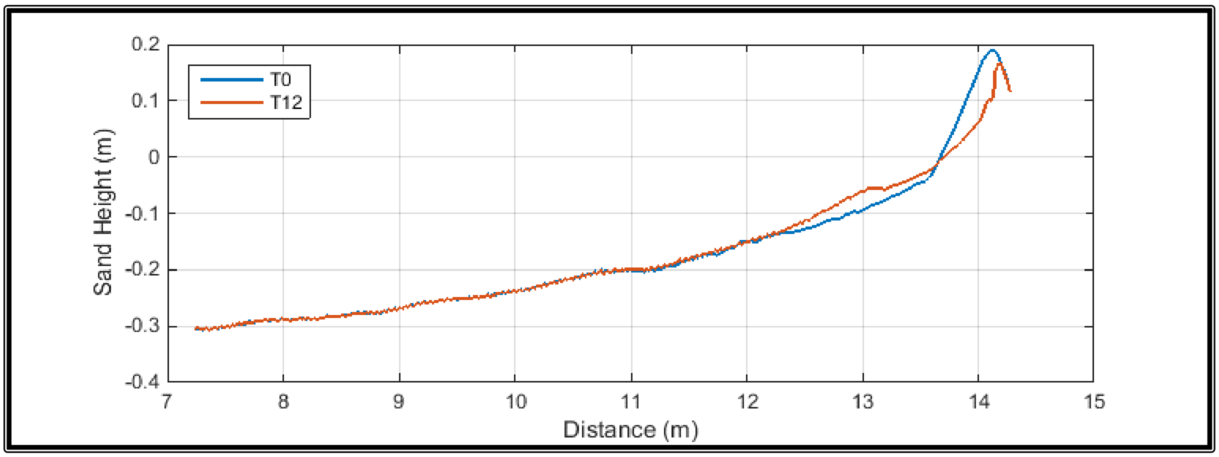

FIGURE 17: Initial and Final Profiles of CT1. This plot shows the initial (T0) and final (T12) profiles of the trial CT1.

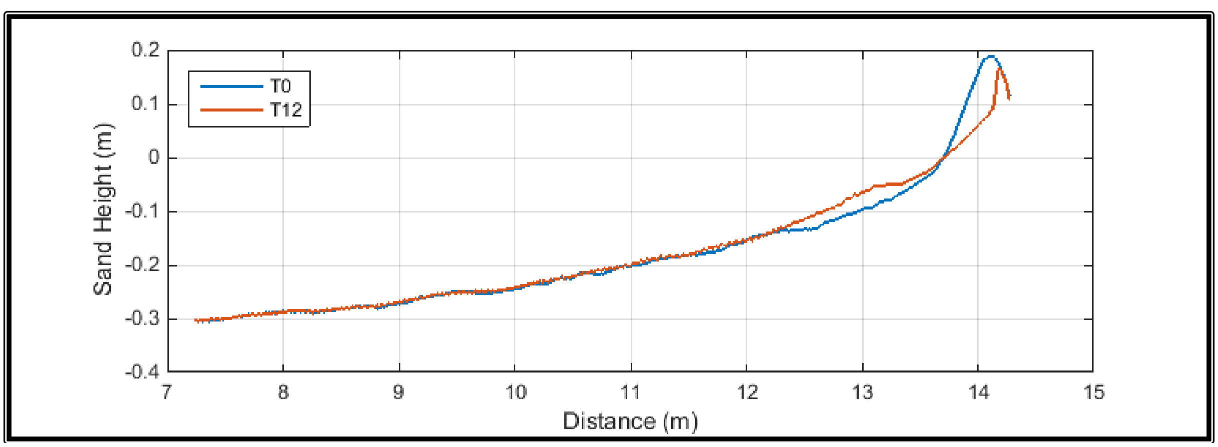

FIGURE 18: Initial and Final Profiles of CT2. These are the initial and final profile plots of CT2.

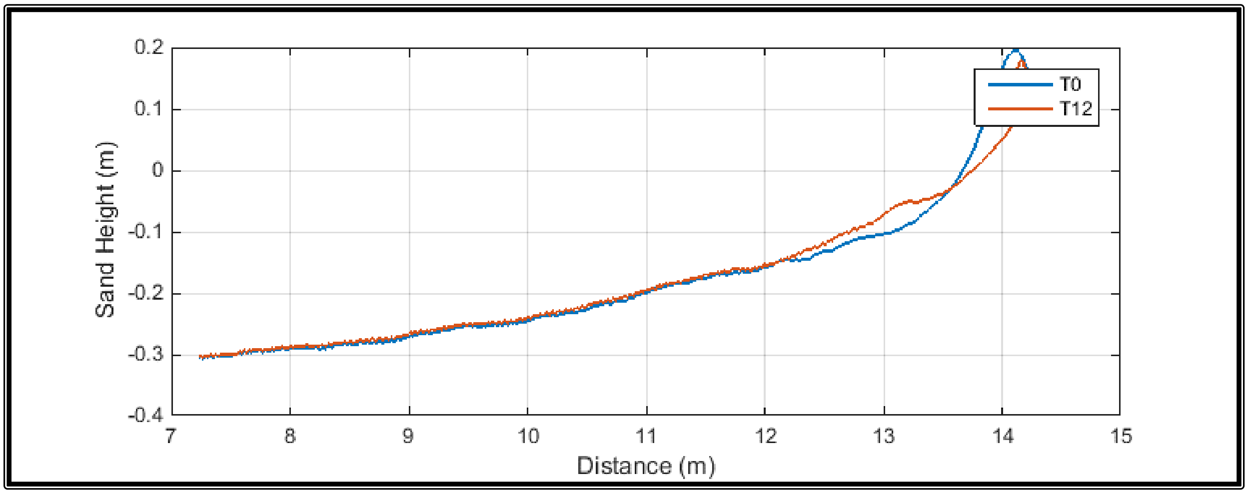

FIGURE 19: Initial and Final Profiles of VT1. This plot shows the initial and final profiles of the trial VT1.

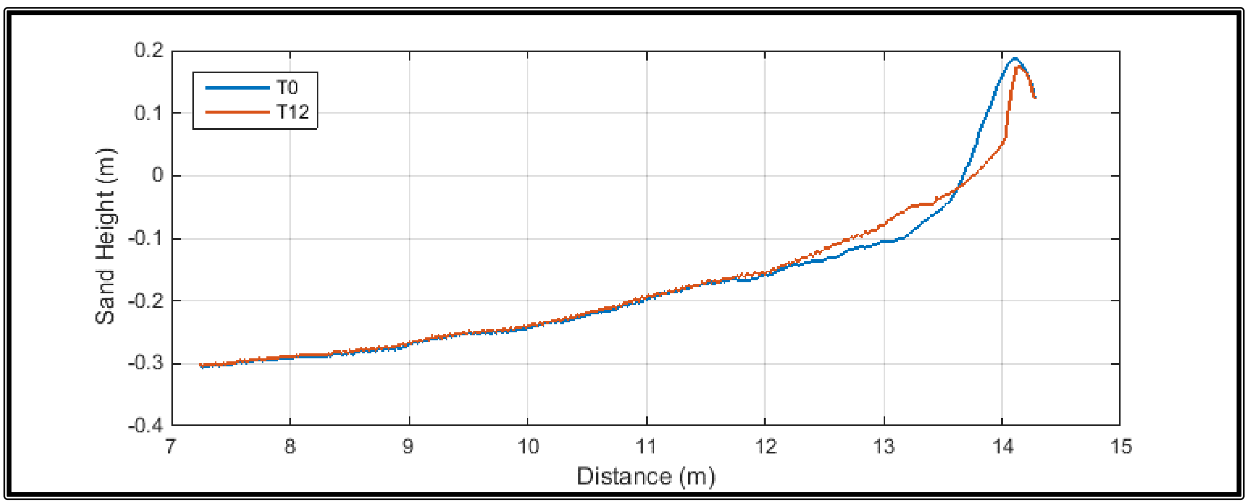

FIGURE 20: Initial and Final Profiles of VT2. This plot shows the initial and final profiles of the trial VT2.

Profile change: erosion and deposition

The total change in the dune profile was found by subtracting the old profile from the new profile. This difference is shown in Figure 21 for both control trials and vegetation trials.

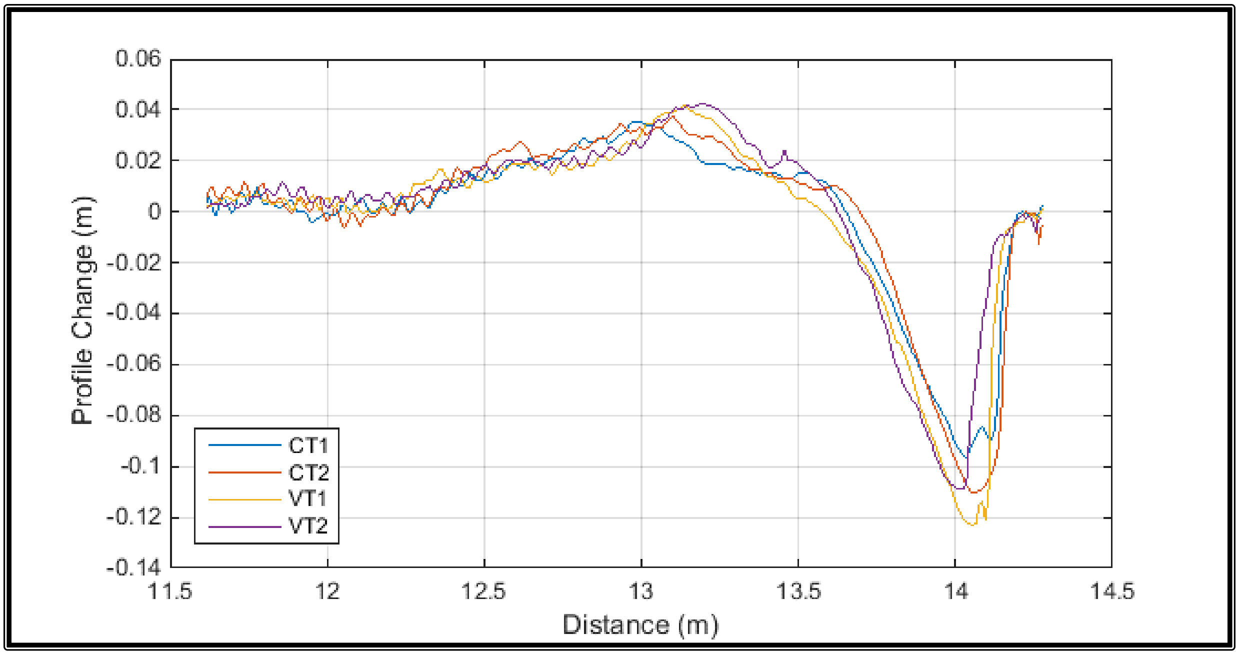

FIGURE 21: Dune Profile Change. This plot shows the change in the dune profile (located from 11.5 m to 14.3 m) for each control and vegetation trial. Negative values indicate erosion while positive values indicate deposition.

The percentage of erosion that occurred due to wave action for each control trial and vegetation trial are shown in Table 2:

TABLE 2: Total Erosion of Sand Dunes. This table shows the percentage of erosion that occurred after 12 wave runs for each trial.

	CT1	*CT2*	*VT1*	*VT2*
Dune Erosion	47.6%	48.9%	51.5%	41.9%

The percent of erosion for the first vegetation trial was 3.25% higher than the average erosion of both control trials. Because this trial consisted of sparse, immature vegetation, the additional erosion could be due to loosening of soil occurring when the poorly rooted vegetation was torn away by wave action. In VT2 the amount of erosion was 6.35% less than the average erosion of the control trials. The vegetation supplanted into the MBWF for this trial was more mature and less sparse than the vegetation from VT1. Its deeper roots and higher volume likely held the soil particles together more rigidly than the immature vegetation from VT1.

Changes in swash velocity

Velocity plots

The cross shore velocity for specific time ranges during WR1, WR4, and WR12 was plotted for each CT and VT. Different time ranges were selected for each plot. The plots of swash velocity vs time are shown in Figures 22-24, where "Raw" indicates the data is in its original form, and "Fit" indicates a best fit line to represent the trend of the velocity.

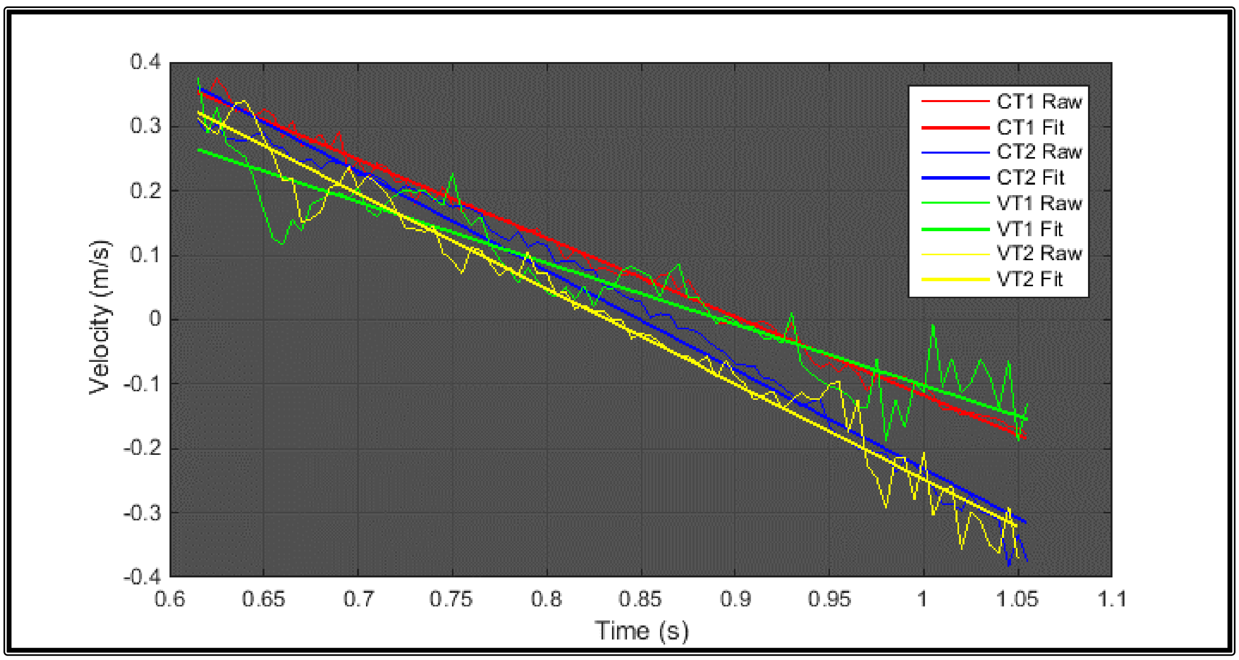

FIGURE 22: Swash Velocity during WR1. The recording range for this plot is 0.615 – 1.055 seconds.

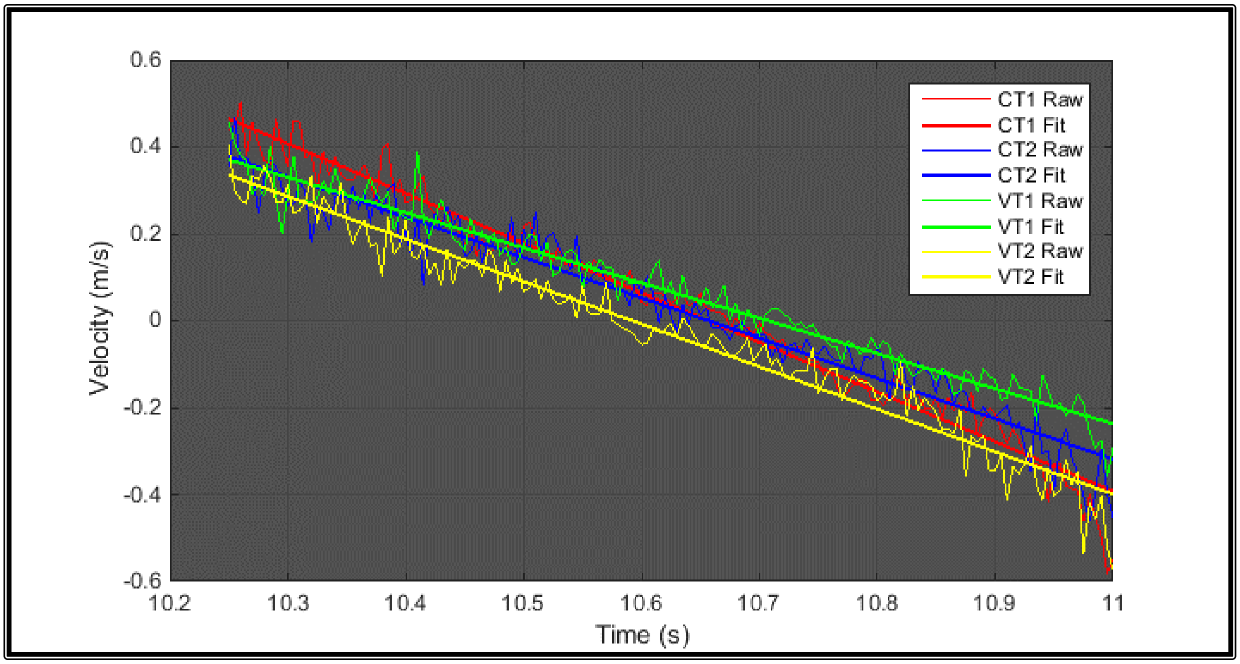

FIGURE 23: Swash Velocity during WR4. The recording range for this plot is 10.25 – 11.00 seconds.

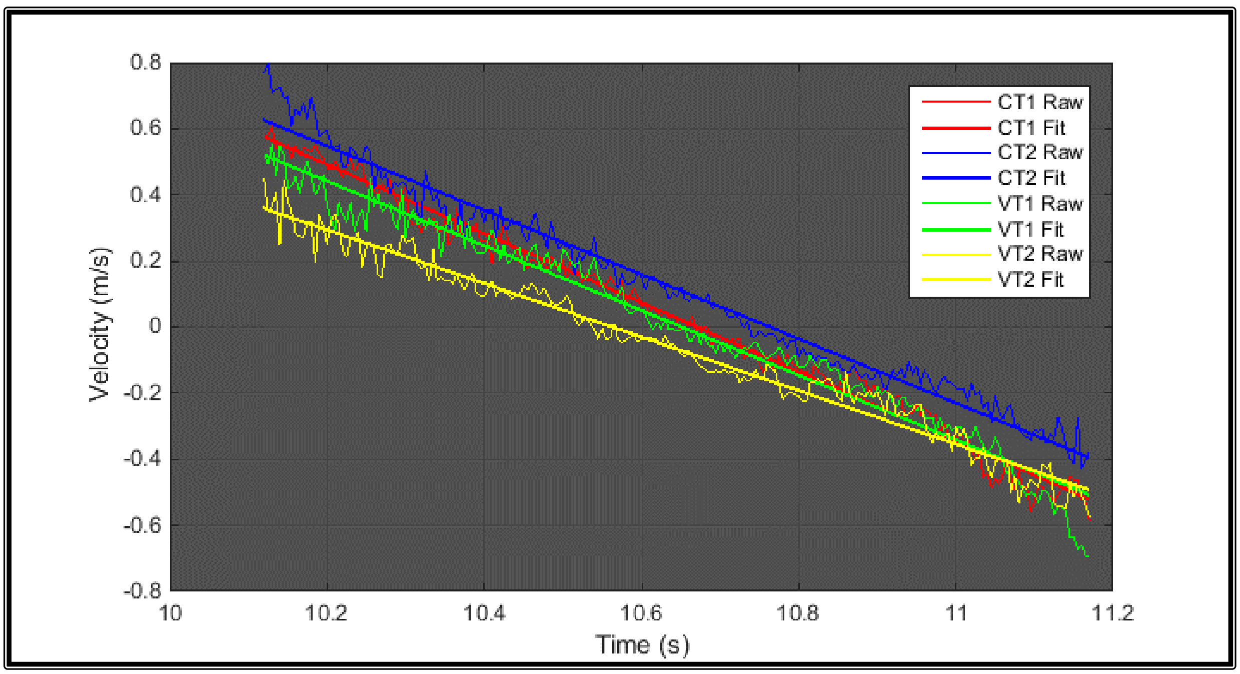

FIGURE 24: Swash Velocity during WR12. The recording range for this plot is 10.12 – 11.17 seconds.

The velocity values obtained from these plots contain error due to the method used for selecting data. Because not all data collection started at the same time, the reference point for each time series is the moment the first wave hits the Vectrino sensor. Because of inaccuracies when finding this moment, each data range is slightly offset. This affects the max and min magnitudes of the velocity. The effects of this are shown in Figure 25. This error, however, does not affect the slope of the best fit line since the downward trend of the velocity does not change significantly during the time range.

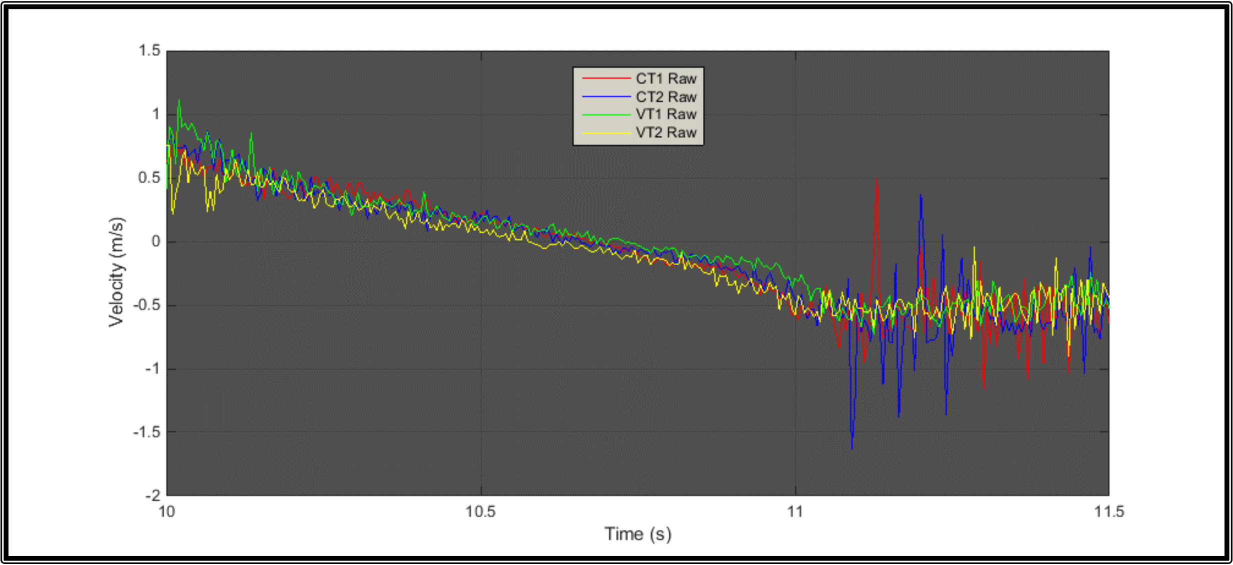

FIGURE 25: Difference in Velocity Due to Range Shifts in WR4. In this figure, VT1 appears to have larger velocity values than the other trials merely because its range is offset to the right, which is in favor of higher velocity values.

Figure 25 also shows that, in between 11.00 and 11.5 seconds, the sensor emerged from the water for each trial. This is indicated by the sudden jumps and drops in velocity. The range for each trial was selected to exclude points where the sensor emerged from the water.

Acceleration of swash

The average accelerations of the swash for each trial are shown in Table 3. The average acceleration of the vegetative trials were lower than that of the CT1, and nearly the same as in

CT2, thus indicating that there could be a correlation between an increase in vegetation and a decrease particle velocity. If vegetation decreases the acceleration of water flow, then the velocity of the swash theoretically cannot attain as high of velocities. According to Equation 1, shear stresses on the surface of the sand are directly influenced swash velocity. Therefore, if the vegetation inhibits this velocity from increasing, the shear stresses on the sand may be lower, thus reducing erosion.

TABLE 3: Average Swash Acceleration. The average swash accelerations from each CT and VT are shown in the table below.

	$CT1\ \frac{m}{s^2}$	$CT2\ \frac{m}{s^2}$	$VT1\ \frac{m}{s^2}$	$VT2\ \frac{m}{s^2}$
WR1	**-1.222**	**-1.539**	**-0.951**	**-1.479**
WR4	**-1.143**	**-0.929**	**-0.811**	**-0.980**
WR12	**-1.045**	**-0.972**	**-0.979**	**-0.811**

CHAPTER IV

CONCLUSIONS

After supplanting vegetation into the swash zone, the effects of erosion were changed by a notable amount. For sparse vegetation, there was a higher percentage of erosion than for either of the control trials. This indicates that vegetation in the swash zone may actually increase dune erosion if the vegetation is immature and poorly rooted. For moderately dense, mature vegetation, there was a noticeable decrease in total erosion, thus indicating that an increase of more mature vegetation reduces erosion. Overall, the acceleration of swash was reduced by the presence of vegetation regardless of whether it was sparse or dense. Because erosion occurs due to shear forces caused by swash passing over the sand, reduced swash acceleration implies that less erosion due to shear forces will occur.

In order to obtain more definitive results for these experiments, more trials with a wider range of vegetation densities and maturities should be performed.

REFERENCES

Figlus, Jens, Jacob Sigren, Anna Armitage, Robert Tyler. *Erosion of Vegetated Coastal Dunes*. (2014): 4-5. Digital.

Sigren, Jacob, Jens Figlus, and Anna Armitage. "Shore & Beach." *Coastal Sand Dunes and Dune Vegetation: Restoration, Erosion, and Storm Protection* 82.4 (2014): 5,7. Print.

Hasselmann, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K., ... & Meerburg, A. (1973). *Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP)*. Deutches Hydrographisches Institut.