OFF-ROAD VEHICLE IMPACT ON SEDIMENT DISPLACEMENT AND DISRUPTION AT ASSATEAGUE ISLAND NATIONAL SEASHORE, MARYLAND

A Thesis

by

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ABSTRACT

The National Park Service (NPS) monitors off-road vehicle (ORV) use in National Seashores across the United States. The sediment disturbance that is caused by ORVs is believed to have a large impact on erosion (by wind or waves), which there by affects the morphology of the foredunes. With greater knowledge of ORV impacts, the NPS can better manage ORV use and minimize anthropogenic affects to the coastal environment. There remains considerable uncertainty about the disturbance and its larger-scale impact.

This study quantifies the sediment disturbance made by tire tracks, as well as the tire track form, width, depth, and evolution with relation to the number of vehicle passes and location on the beach at Assateague Island National Seashore (ASIS), Maryland. To measure ORV impact, ground-based LiDAR was used to collect detailed profiles across a three by three meter test plot at each site. Based on the quantification of the displaced sediment and redistribution of that sediment from the tracks, a recommendation to the NPS can be made as to where along the beach traffic should be limited to, in order to minimize impact to the physical environment at ASIS.

Tire tracks were found to widen after the first pass, as a result of the imperfections of driving. Compaction of the sediment in the center of the tire track accounts for only a minimal amount of the sediment lost from the tire tracks. Sediment removal accounted for greater than 75% of the sediment lost from the tire tracks at all sites. It was concluded that sediment removal is the most dominant factor in the creation and evolution of a tire track. The width, depth, and evolution of a tire track were also found to be controlled by the imperfections of driving.

Despite the amount of sediment disturbance, it is found that there is no net downslope displacement of sediment. This conclusion counters previous ORV impact studies and suggests that ORVs are not directly responsible for beach erosion. It is also recommended that to minimize the impact of OVRs on the beach at ASIS, the NPS should limit driving to the backshore.

DEDICATION

This thesis is dedicated to the entire Labude family, from which the skills necessary to complete this research were instilled in me: hard work, patience, ingenuity, creativity, will power, and courage. If it was not for the love and patience my family had with me growing up, I do not know where I would be today.

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NOMENCLATURE

ASIS	Assateague Island National Seashore
CHIS	Cape Hatteras National Seashore
cm	Centimeter
D	Volume of Mound Downslope
DEM	Digital Elevation Model
FIIS	Fire Island National Seashore
g	Grams
GPS	Global Positioning System
IDW	Inverse-Distance Weighted
kg	Kilograms
km	Kilometer
kPa	Kilopascal
LiDAR	Light Detection and Ranging
m	Meter
mm	Milimeter
mph	Miles per Hour
MTP	Microtopography Profiler
NARA	National Archives and Records Administration
nm	Nanometer
NOAA	National Oceanic and Atmospheric Administration

NPS	National Park Service
ORV	Off-Road Vehicle
OSV	Oversand Vehicle
PSI	Pound Per Square Inch
T1	Landward Mound
T2	Seaward Mound
U	Volume of Upslope Mound
UTM	Universal Transverse Mercator
UNWTO	World Tourism Organization
YR	Year

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CHAPTER I

INTRODUCTION

Off-road vehicles (ORVs) and their impact to beaches and dunes are important to the management of coastal areas by the National Park Service, U.S. Fish and Wildlife Service, and Department of Natural Resources. These government agencies along with state run Coastal Zone Management programs, manage 153,594 kilometers (95,439 miles) of coastline in the United States (Millhouser et al. 1998). Within their management portfolio are national seashores such as Assateague Island National Seashore in Maryland (Millhouser et al. 1998). The Unites States government has given these agencies the task of protecting natural resources, managing any coastal development in order to minimize the impacts of natural hazards, restoring and protecting the water quality along the coast, providing access to the coast for the general public, planning for the events of land subsidence and sea level rise, and also protecting the physical environment from being impacted by humans (NPS). With ORVs being perceived as an instrument humans use to create impact along the coasts, it is important that their impacts are fully understood.

ORVs have been studied with respect to behavior, administration, environment, economic, safety, resource, technology, and land use (McCool 1981). However, ORVs have not been studied in as great detail with respect to their impacts on beaches. The only extensive studies that have been conducted were by Anders and Leatherman (1987a), Carlson (2007), Schlacher and Morrison (2008), and Schlacher and Thompson

(2008). In each of these studies, the authors present evidence (to varying degrees of strength and confidence) that ORVs cause significant erosion to the various beach sections (foreshore, backshore, and dune), but do not provide any specific link between sediment disturbance and sediment erosion.

Anders and Leatherman (1987a) quantified the displacement of sediment caused by ORVs at Fire Island National Seashore (FIIS), New York. The authors calculated the net displacement of sediment using the simple formula:

$$\text{Net Displacement} = D - U$$

where, D represents the area of the downslope mound and U represents the area of the upslope mound. Their field observations suggested a net downslope movement of sediment in the foreshore was approximately 200 cm^3, and the backshore ranged from approximately 50 cm^3 to 75 cm^3. The net downslope displacement increased with higher slope angles, meaning that on a steeper beachface, a larger volume of sediment is displaced seaward. Based on the volume of vehicle traffic on Fire Island, the authors estimated that the amount of sediment eroded from the island was 119,300 m^3/yr, based on 100 vehicle passes per day (36,500 vehicle passes per year). Based on FIIS erosion rates of 176,000 m^3/yr, calculated by Rosati and Gravens (1995), and the amount of sediment eroded at FIIS from ORVs, it can be inferred that 69 % of the sediment erosion is a direct result of ORVs. It is important to note, however, that the authors provide no mechanism for beach and dune erosion, other than the net downslope/seaward displacement of sediment by the vehicles. The most practical mechanism would be the swash. However, the actual amount of sediment that the swash can move offshore is dependent on the beach slope and varies from beach to beach (Houser and Barrett 2010).

Schlacher and Morrison (2008) examined ORV impact on two ocean-exposed beaches along North Stradbroke Island in Queensland, Australia. Based on the area and width of tire tracks, as well as the number of tire tracks present on the beach, the authors concluded that the greater sediment disturbances are caused by higher number of vehicles. The authors further speculate that this sediment disturbance can cause beach erosion, although they could not determine whether or not ORVs cause direct beach erosion.

Schlacher and Thompson (2008) quantified sediment disturbance caused by ORVs in regards to the depth, position, and width of every vehicle rut found along five beaches on North Stradbroke Island in Queensland, Australia. They examined the backshore of a beach and found that the largest displacements of sediment occurred there, as opposed to the foreshore. The authors concluded that the backshore has favorable conditions that allow deeper ruts to form, compared to the foreshore. The foreshore had more highly compacted sediment, as well as higher moisture content that prevents the sediment from being compacted or ejected by a passing vehicle. The deeper ruts lead to approximately 155 % more sediment displaced in the backshore compared to the foreshore. This is only relevant to the sediment budget of the beach and dune system if a mechanism for how sediment on the backshore is transported off the beach can be given. If there is no mechanism that can remove the displaced sediment in the backshore then the sediment is just being transported locally on that section of beach and has no direct impact on the beach-dune morphology. Rather, the authors merely concluded that up to 90 % of the beach face is disturbed by vehicles and there appeared to be significant compaction and displacement of sediment by ORVs that (based on Anders and Leatherman (1987a)) will lead to the erosion of the beach.

Carlson (2007) took the Anders and Leatherman (1987a) study a little further by trying to correlate ORVs with erosion at Assateague Island, Maryland. Carlson (2007) looked at the vehicle traffic in the Oversand Vehicle (OSV) Zone and LiDAR data to determine if there was any correlation between erosion/accretion and ORV use. The author found that ORVs were spatially correlated with beach erosion on the island and that areas of greater erosion had more ORVs. However, the same relationship can be generated if a frontal or tropical storm moves over the island just before or between the dates that the LiDAR images were taken or if that section of island was naturally sensitive to erosion (Stockdon et al. 2007). The relationship can also be seen in the natural variability of the beach-dune system (Bentes 2003). Over the span of a year, the shape, size, and volume of a beach can drastically change or not change at all (Bentes 2003). If Assateague Island went through a large change, than the results from Carlson (2007) would be the result of the natural morphological change of the beach and not the result of ORVs. The beach erosion observed could also have been artifact of having LiDAR images from different times of the year or at different times of the day. If the LiDAR images were taken at different times of the year, than the changing offshore bathymetry and bar movement could alter/change the beach face. If the beach is reflective in the winter and dissipative in the summer (assuming the images were taken then) the beach face could have a steeper slope in the winter than the summer. This fact will drastically affect the results of Carlson (2007), because the cut/fill tool is based on the digital elevation models (DEMs) being used. The tool subtracts the elevation at one location from the elevation of the same location in another DEM. This would mean that if the beach changed states between winter and summer than the accretion/erosion results based on the cut/fill tool in ArcGIS would be an artifact of the changing beach states and not ORVs. The area with a positive correlation between ORVs and erosion may be because the author just looked at areas that had high volumes of ORVs and not at the entire island. As with the other studies that examine ORVs and their impacts on beaches, the physical relationship and the physical mechanism for long-term erosion was not considered or even discussed by Carlson (2007).

In summary, the studies described above that have been conducted on the physical disturbance by ORVs have not provided mechanisms or explanations as to how ORVs cause beach erosion, with the exception of net downslope/seaward movement of sediment identified by Anders and Leatherman (1987a). However, the estimates of Anders and Leatherman (1987a) are unrealistic in that it represents 68 % of the entire sediment loss for one year. If it were true, we would expect driving to be the leading cause of erosion at FIIS. In other words, there is no conclusive evidence to suggest ORVs are a direct cause to beach erosion, or where and what happens to the sand displaced from a tire track (i.e. where does it go and how far is it moved). The purpose of this study is to determine the impact of ORVs to the various beach sections at ASIS and to inform the NPS of better management practices that can be undertaken to ensure that the natural resource and physical environment of the seashore is not impeded upon by humans.

The specific objectives of this study are:

- To quantify the disturbance and redistribution of sediment in relation to vehicle location cross-shore and the number of passes.
- To determine if there is a net downslope displacement of sediment at ASIS
- To quantify the level of sediment disturbance at ASIS

From these findings, the National Park Service at ASIS can be informed of better management practices that they can implement to ensure that their goals of managing the seashore are met and achieved in the most efficient manner possible. It is also important to note, that once the full level of sediment disturbance caused by ORVs is known, then further studies can be conducted to determine what the full physical impact ORVs have on coastlines.

CHAPTER II

LITERATURE REVIEW

2.1 Off-Road Vehicle Recreation and Tourism

Tourism is an ever-growing and expanding industry with seemingly unlimited growth potential. According to Goodwin (1996) tourism is the world's largest industry and will continue to grow with every passing year. In 2010 there were 940 million international tourist arrivals worldwide, with North America seeing 99.2 million international tourist arrivals (Goodwin, 1996; UNWTO). Many of the international tourists that visit North America include a national park or protected area in their trip (Goodwin, 1996; UNWTO).

Nature-based tourism has evolved to include coastal tourism, which was first seen in the 1700's, when doctors began promoting salt-water bathing as a cure for a multitude of ailments (Meyer-Arendt 2008). Although coastal tourism can be traced back to the 1700's, the concept exploded into huge popularity in the 1800's and has since expanded exponentially (Davenport and Davenport 2006). The rapid increase seen in tourism over the past two centuries can be attributed to motorized mass transport and the introduction of personal vehicles to the mainstream public (Davenport and Davenport 2006).

With the ever expanding tourism industry comes, a large profit to those who work and live in areas that meet the needs of coastal tourists around the world. According to Davenport and Davenport (2006), the travel and tourism industry worldwide was worth $3.5 trillion annually and responsible for employing 200 million people by the end of the 20th Century. Due to the wide range of activities that tourists partake in along the coast (swimming, sunbathing, surfing, snorkeling, SCUBA diving, yachting, personal watercraft vehicles, and off-roading by way of off-road vehicles), the management of coastal areas (primary destinations for tourists) are vital to the tourism industry and rely heavily on government agencies such as the National Park Service, the Department of Natural Resources, and the U.S. Fish and Wildlife Service (Davenport and Davenport 2006). Meyer-Arendt (2008) found that there are four major factors that influence the effects tourism has on the environment in which the localized tourism activities are conducted. The four factors are the type of tourist attracted, the time perspective of the developers, the intensity of the tourism, and most importantly the resiliency of the environment (Meyer-Arendt 2008). Ultimately tourism and the environment have an unique relationship: tourism is dependent upon the environment, but at the same time the environment is vulnerable to the impacts of tourism (Wong 1993)

The impacts of tourism can be seen in a variety of ways. Houston (2008) found that beach erosion was the main concern for beachgoers in the United States. Many people come to the beach to enjoy the aesthetic beauty it offers, as well as to build homes and hotels. The United States coastlines are highly developed and the few areas that are not are quickly being integrated into the already developed infrastructure that exists. Beach erosion directly affects all of these aspects, as well as many others. With ORVs being contributed to beach disturbance and erosion (Anders and Leatherman

1987a, Schlacher and Morrison 2008, Schlacher and Thompson 2008, Carlson 2007) it is vital to manage the use of ORVs in National Parks and protected areas along the coastlines of the United States. However, as noted, there is no conclusive link between beach erosion and ORVs.

Gunter, Ditton, and Olson (1987) examined ORV use and management on Galveston Island, Texas. The authors found that driving ORVs along Galveston Beach was a cultural norm dating back generations and was even the only means of transportation at one point in time. In the 1800's there were no roads for landowners to access their homes, so they used the beaches as their roads (Gunter, Ditton, and Olson 1987). Many of the land owners would drive their horse-drawn buggies along the beaches to their homes, thus the beaches became the public road system on Galveston Island (Gunter, Ditton, and Olson 1987). In 1959 the Texas Legislature passed the Texas Open Beaches Act that gave the public the legal right to ingress and egress to the sandy Gulf-coast beaches (Gunter, Ditton, and Olson 1987). The act was passed by using the argument that the beaches in fact were a public road system that had long been established and used constantly over the past two centuries (Gunter, Ditton, and Olson 1987). The Texas Open Beaches Act was passed to combat the actions taken by many of the landowners on Galveston Island, Texas. By early 1959, over one-third of the of 32 miles of beaches on Galveston Island were barricaded and blocked off to such a degree that the public could no longer access the beaches and waterfronts that attracted them to the island (Gunter, Ditton, and Olson 1987). In the late 1970's, the Galveston City Council decided to ban all ORVs from the beaches on the island due to the traffic problems they were creating (Gunter, Ditton and Olson 1987). The city council claimed pedestrian safety, passenger safety, obstruction of law enforcement and emergency responders, and aesthetic damages as reasons why the beaches were closed to all ORVs (Gunter, Ditton, and Olson 1987). Many lawsuits have taken place since this decision without resolve (Gunter, Ditton, and Olson 1987).

In South Africa, a new policy was passed in 2002 that bans all ORVs from beaches except for in marked recreational use areas (Celliers et al. 2004). This new policy came as a result of the inadequate implementation and enforcement of a policy to protect sensitive areas along the coast. Before the new policy was enacted in 2002, much of South Africa’s coastlines were open to ORVs (Celliers et al. 2004). A number of agencies were given the task of preventing ORVs from driving in environmentally sensible areas, although these agencies failed because ORVs continued to drive in some of the most environmentally sensible areas located in South Africa (Celliers et al. 2004). However effective the management and enforcement of laws and policies regarding ORVs can be, at times they may be to large to comply with. Thus ORVs, at times, can traverse beaches and inadvertently cause erosion and destruction of fauna.

2.2 Off-Road Vehicle Regulation and Legislation

With ORVs still in use in the United Sates, the need to regulate and monitor the effects and use of ORVs is also increasing (McCool 1981). ORVs are regulated and monitored by way of Presidential Executive Order 11644 and amended by Presidential Executive Order 11989 (McCool 1981, NARA, accessed April 28, 2011). These two

Presidential Orders gave federal land management agencies the authority to regulate and monitor ORVs and their impacts on any land deemed "public" (McCool 1981, NARA, accessed April 28, 2011). The term "public land" meant any land that the Secretary of Agriculture, Secretary of the Interior, Secretary of Defense and the Tennessee Valley Authority has custody and control of, except Indian controlled land (NARA, accessed April 28, 2011). The two Presidential Executive Orders also required federal land management agencies to: 1) create and enact management plans that would protect the natural resources located on those lands, 2) minimize conflicts between the people that use the land, and 3) promote the safety and well-being of those users (NARA, accessed April 28, 2011). When the Carter Administration first proposed to amend Presidential Executive Order 11644 there was a public outcry and 80,000 letters were sent to the federal government from companies in the ORV industry, ORV organizations, and ORV enthusiasts in protest of the order (McCool 1981). Although a significant number of people were against the amendment, the Carter Administration pushed forward and amended Presidential Executive Order 11644 with Presidential Executive Order 11989 (McCool 1981).

Most of the opposition and protest came as a result of the monitoring and regulation of ORV use in national parks, as well as national seashores (McCool 1981). This was because many enthusiasts travel to national parks and seashores to enjoy the vegetation, wildlife, topography, and scenery through the use of their ORVs (McCool 1981). While there was opposition against the Presidential Executive Order, the Defenders of Wildlife and the National Audubon Society took the National Park Service

(NPS), the U.S. Fish and Wildlife Service, and the U.S. Department of the Interior to court in an attempt to place an injunction on the use of ORVs in Cape Hatteras National Seashore (CHIS) (Defenders of Wildlife, accessed April 28, 2011). Ultimately, the parties involved, negotiated an agreement (consent decre) that was approved by the court and enacted in April 2008 (Defenders of Wildlife, accessed April 28, 2011). In the consent decre, both parties agreed that the NPS would monitor and provide protection for waterbirds and shorebirds during their breeding and nesting seasons (Defenders of Wildlife, accessed April 28, 2011). The NPS would also monitor and protect the threatened and endangered sea turtles which call CHIS home (Defenders of Wildlife, accessed April 28, 2011). The agreement also called for the education of the public on driving on the beach and compliance with new regulations (Defenders of Wildlife, accessed April 28, 2011).

Even though the federal government is monitoring and regulating ORV usage, by restricting the number of vehicles allowed on beaches at any one time, many of the governmental agencies admit that further research is needed with regards to ORV use (McCool 1981). In a survey conducted by McCool (1981), 87 % of the National Recreation Areas, National Seashores, and Lakeshores said that more information and further research is needed on the impacts of ORVs on the environment. 60 % of those same organizations surveyed stated that there is also a need for further research and monitoring of the effects of ORVs, as well as 73 % acknowledged that the rehabilitation of area impacted by ORVs needed to be studied further (McCool 1981).

2.3 Tire Mechanics

Tire mechanics are the most important factor when looking at sediment disturbance by ORVs. As a vehicle drives along a surface, in this case a beach, the tires act directly on the surface through 1) the compaction of sediment based on the weight of the vehicle, 2) ejection of sediment from its path, 3) pushing of sediment to the side, and 4) by any combination of these three methods. A schematic showing the affects that a tire can have on sediment can be seen in Figure 1. These tire track characteristics, as they relate to beach erosion were looked at by Schlacher and Morrision (2008) and Schlacher and Thompson (2008). In both studies, the authors looked at the distribution of tire tracks across the shore, as well as their depth, and width. The authors found that greater than 90 % of a beach face can be covered by tire tracks with varying depths and widths based on what zone the tracks were found in. The foreshore experiences shallower and thinner tracks, while the backshore experiences deeper and wider tracks. This is because the moisture content of the foreshore is more than that of the backshore. The higher moisture content of the foreshore limits the compaction, ejection, and pushing of sediment by tires. This is because the force required to compact, eject, and push wet sediment is much greater than dry sediment.

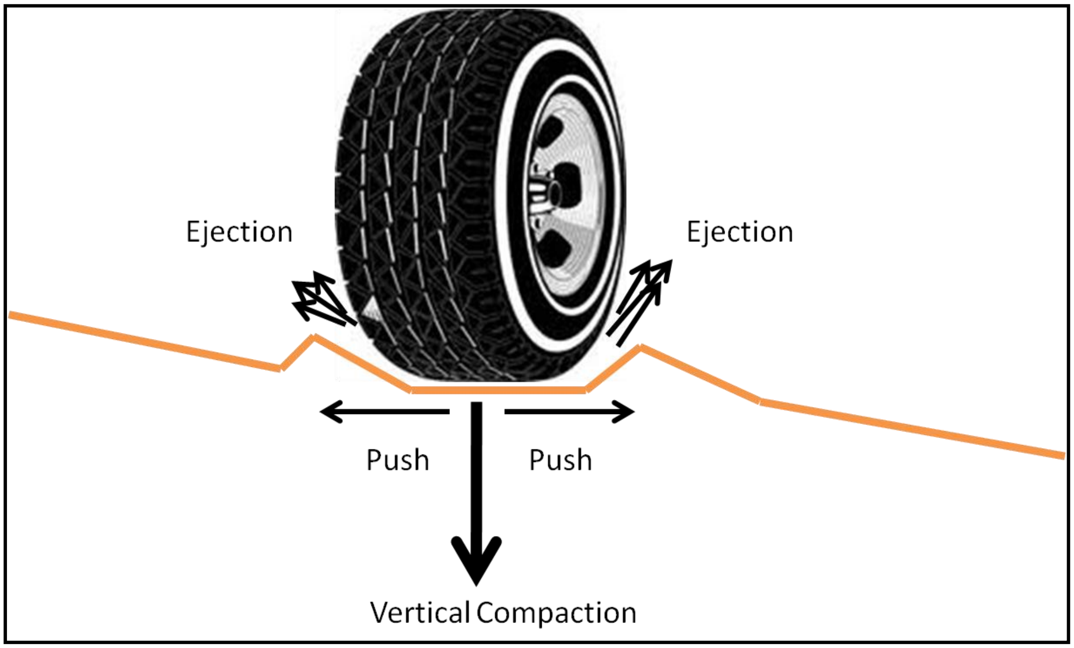


Figure 1. A schematic showing the direct affects that tire's have on sediment.

Raper et al. (1995) looked at the impact of tire pressure on the creation of tire tracks. The authors discovered that tire pressure is the key component in tire-soil interaction. They found that the lower the tire pressure, the less the amount of stress at the center of a tire. If the tire pressure increases, the the amount of stress on the center of a tire is also increased, causing more compaction and sediment disturbance (ejection, compaction, and push) by a tire. This would mean that to minimize sediment disturbance and compaction resulting from ORVs, lowering the tire pressure of ORVs can have a large impact.

Raghavan et al. (1976) found that larger tires were able to spread their weight out more evenly, thus reducing the amount of force at one point and causing less disturbance to sediment. The authors also found that lower tire pressure results in increased traction and better handling of an ORV and that the best traction and control of a vehicle occurred when the tire pressure was at 200 kPa (29 psi). Based on the conclusions drawn by Raper et al. (1995), Raghavan et al. (1976), and Pytka et al. (2006), the best way to minimize compaction and disturbance of sediment by tires is to have large tires with tire pressures less than 29 psi. The NPS recommends that ORVs on beaches have tire pressure of 20 psi. The reduction of tire pressure does reduce the number of vehicles getting stuck, as well as the depth of the tire tracks. However, it does not diminish the ecological damage caused by ORVs.

Schlacher, Thompson, and Price (2007) looked at the crushing capabilities of ORVs and their impacts on ghost crab. The authors found that ORVs can crush ghost crabs that have burrowed up to 30 cm below the surface. In their study they used a 4x4 Nissan Patrol that weighed 3080 kg. The authors looked at the depths of crushed ghost crab and concluded that the tire pressure of an ordinary 4x4 ORV can affect sediment up to 30 cm below the surface. This is key in looking at beach disturbance by ORVs, because the deeper a vehicle can impact, the larger the volume of sediment that can be affected by the tire. Based on the findings of the studies noted above, the lowering of the tire pressure will reduce the crushing capabilities of ORVs, because the tires would be unable to compact sediment up to the depths that ghost crabs burrow.

2.4 Off-Road Vehicle Impacts and Erosion

Only a few studies have looked at ORVs and their impact to the beach (Anders and Leatherman 1987a, Anders and Leatherman 1987b, Schlacher and Morrison 2008, Schlacher and Thompson 2008, Carlson 2007). In each of these studies the authors suggest, with little supplementary evidence, that ORVs cause significant erosion to the various beach sections and need to be monitored and controlled in order to effectively reduce and minimize erosion. Off-road vehicles (ORV) are used for recreation at National Seashores and beaches in the United States (Table 1) and across the world.

Table 1
Selected locations where ORV driving is permitted in the United States

National Seashores (# of visitors)	Other Locations
Assateague Island, Maryland (2,106,090)	Galveston Island, Texas
Cape Cod, Massachusetts (4,653,706)	Matagorda Island, Texas
Cape Hatteras, North Carolina (2,193,292)	South Padre Island, Texas
Fire Island, New York (613,057)	Daytona Beach, Florida
Padre Island, Texas (612,716)	Oregon Dunes National Recreation Area

The impacts of ORVs to vegetation have been thoroughly studied, as well as their impacts on the mortality of different species such as varying types of plover, ghost crab, and lizards. Table 2 shows a small selection of studies that have looked at the impacts of ORVs on different animal species, plant species, and physical effects.

Table 2
Selected studies on the various types of impacts that ORVs have

Vegetation	Piping Plover	Ghost Crab	Lizards	Macroinvertebrates	Erosion
Brodhead and Godfrey (1977)	Melvin, Hecht, and Griffin (1994)	Barros (2001)	Luckenbach and Bury (1983)	Wolcott and Wolcott (1984)	Anders and Leatherman (1987a)
Hosier and Eaton (1980)	Patterson, Fraser, and Roggenbuck (1991)	Schlacher, Thompson, and Price (2007)			Carlson (2007)
Luckenbach and Bury (1983)	Buick and Paton (1989)	Moss and McPhee (2006)			Schlacher and Morrison (2008)
Schlacher, Richardson, and Mclean (2008)	Watson, Kerley, and Anton (1997)	Steiner and Leatherman (1981)			
Anders and Leatherman (1987b)					

Each column heading represents the impact ORVs have on that particular topic

Of all of the types of studies conducted on the effects of ORVs, their impacts on vegetation is the most widely focused upon topic. Brodhead and Godfrey (1977) examined the dune system on Cape Cod National Seashore, Massachusetts and found that beach grass growing on the dunes were being destroyed, because of the tire tracks left in the sand. The authors concluded that the tire tracks disrupted fresh sand from replenishing the older sand around the beach grass, ultimately starving the beach grass. This disruption of fresh sand was due to the compacting of the sand by ORVs driving along the beach. Luckenbach and Bury (1983) examined the biota of the Algodones Dunes in California and discovered that ORVs are directly causing herbaceous and shrubby perennial vegetation to be greatly reduced, as well as the diminishing the numbers of fringe-toe lizards and kangaroo rats through direct crushing.

Moss and McPhee (2006) observed ghost crab on beaches in Australia and found that four-wheeling on the beaches at dusk greatly reduced the number of crab by direct crushing. With both Moss and McPhee (2006) and Schlacher, Thompson, and Price (2007) coming to the same conclusions it helps to increase scientific knowledge of the impacts that can be caused by ORVs and indicates the importance of tire pressure in sand displacement. The population of Hooded Plover on Australian beaches have been decreasing rapidly due to ORVs (Buick and Paton 1989). The authors found that 81% of the Hooded Plover nests were being runover during the incubation period, resulting in an overall decrease in the successful reproduction rates of the Hooded Plover.

As previously noted, Anders and Leatherman (1987a) examined the physical effects of ORVs on the environment by studying the tire tracks of ORVs on a beach in

Fire Island, New York. The authors used a microtopography profiler (MTP) to measure the amount of sand displaced by a passing of a 4x4, 1600 kg, ORV with LR78X15 tires. The authors measured a number of variables at each of their sites (Table 3). The authors calculated the net displacement of sediment using the simple formula D – U, where D represents the area of the downslope mound size, while U represents the area of the upslope mound. They found that net downslope displacement increased with higher slope angles. Another conclusion that Anders and Leatherman (1987a) found was that ORV impact directly on dunes resulted in the greatest net downslope displacement. They determined that high volumes of vehicle traffic are associated with high volumes of sand migrating towards the ocean or sea, thus leading to their conclusion that 119,300 m^3/yr of sediment is eroded from Fire Island, New York (Anders and Leatherman 1987a). The authors also looked at the relationship between various independent variables in trying to calculate various dependent variables (Table 3), most notably: 1) the net downslope displacement, 2) track displacement, and 3) net disruption. They used a means of regression analysis to determine the most influential factors in determining the statistics mentioned above. They used data from 89 field tests in their means of regression analysis and calculated the coefficient of determination (r^2) for all of their results. They found that in determining the amount of net downslope displacement, slope is the most influential factor (explaining 29.5 % of the variance). The other most influential factors were the number of passes, vertical compaction and horizontal compaction. These variables explained 10, 3.8 and 1.1 % of the variance in net downslope displacement. In determining the other two statistics (track displacement and net disruption) the number of passes explained 23 and 7.7 % of the variances respectively. With no variable explaining more than 29.5 % of the variance, there must be another variable unaccounted for by Anders and Leatherman (1987a) that can better explain net downslope displacement, track displacement, and net disruption. However, the values for equality of variance (a statistic for determining significance) were highly significant for the results of the means of regression analysis, which would suggest that the overall results are significant despite the low r^2 values (Anders and Leatherman 1987a).

Table 3
Independent and dependent variables measured and used by Anders and Leatherman (1987a) in their means of regression analysis

Independent Variables	Dependent Variables
Place	Upslope Displacement
Slope Angle	Downslope Displacement
Vertical Compaction	Net Downslope Displacement
Horizontal Compaction	Track Displacement
Speed	Net Disruption
Moisture	
Tire Pressure	
Number of Passes	

Schlacher and Thompson (2008) quantified the spatial distribution of tire tracks on two Australian beaches during the peak holiday season, in order to determine the physical disturbance of sand caused by ORVs. The authors mapped the position, width, and depth of any and all vehicle ruts that were visible between the foredune and the upper swash zone. The authors found that 61 % and 54 % of the beach surface was visibly disturbed by ORVs at two different beaches. They also found that the mean depth of the tire tracks for both beaches was 5.86 cm, with 57 % of the tire tracks having a depth greater than 5 cm and 21 % had a depth greater than 10 cm; the largest tire track had a depth of 28 cm. Schlacher and Thompson (2008) also found that the upper shore had larger displacements of sand, 0.051 m^3 per meter of beachface as opposed to 0.020 m^3 per meter of beachface in the lower shore, due to significantly deeper vehicle ruts. The vehicle ruts had a mean depth of 9.103 cm on the upper shore and 3.922 cm on the lower shore (Schlacher and Thompson 2008). The deeper vehicle ruts were due to the softer, drier, less compact sand found in the backshore. This type of sand makes it easier for tires to displace and transport downslope. Conversely, Schlacher and Thompson (2008) concluded that on the lower shore, vehicle ruts were wider and shallower than on the upper shore.

As stated before, ORVs cause disturbance in sand and move it in a generally net downslope direction, but at this time there exists no direct linkage or mechanism for the erosion of the loosened sand. Carlson (2007) used LiDAR to determine if ORVs can be linked to higher levels of dune and beach erosion. The study by Carlson (2007) concluded that three study sites located on Assateague Island had eroded due to ORVs.

The author also found that the area called “The Bullpen” (where vehicles can spend the night) had in fact dropped in elevation by one meter over a four year span. Also, the dunes along the island were found to have eroded in the same four year time span, with the northern portion of the island experiencing the most pronounced erosion (Carlson 2007). However, there is only a correlation of erosion and ORV use. The author found that at all three of the dune crossings experienced greater than -75,000 m^3 of volume change (erosion) from 2000 to 2004. The author also found that the bullpen area in the Over Sand Vehicle (OSV) zone of ASIS experienced the most volume change of any location that was looked at, -869,940 m^3 (erosion). However, the author found that on both sides of the Maryland/Virginia border there was a volume change of 18,135 and 2,700 m^3 (accretion) respectively. With the author examining only locations in which vehicles traversed, there is insufficient data for the author to suggest that erosion has a positive correlation with ORV use, because there was no control site for the author to compare their results too.

2.5 Measuring Off-Road Vehicle Impacts

Many of the studies that have looked at ORV impact on beaches use various methodologies and techniques for data collection. Anders and Leatherman (1987a) used a microtopography profiler (MTP) to measure the amount of sand displaced by the passing of an ORV during controlled experiments. The problem with their technique is with the amount of time that it took to collect, manipulate and analyze their data, as well as the increasing chance that human error plays factors into their profiles, since they were hand drawn with the aid of the MTP. The positive aspect of the authors' technique for data collection was that it allows for accurate measurements down to the cm scale.

Schlacher and Morrison (2008) also conducted controlled field experiments, they used digital photographs to determine the area that was disturbed by ORVs, and they also measured the widths of every tire track with a measuring tape. The downfalls of using these methods are that human error, again, can influence their measurements. Also, the authors could only produce a count of the number of tire tracks and an area estimate based on the digital photographs. However, digital photographs do allow for a wider range of data to be collected from their experiments, such as the number of vehicle passes and the volume of sediment disturbed by ORVs.

Schlacher and Thompson (2008) used uncontrolled field experiments and standard theodolite surveying techniques to measure the amount of sand displaced by ORVs. As with the previously mentioned techniques, standard theodolite surveying has the potential of human error affecting the results and is also very time consuming. However, the technique did allow the authors to calculate volume and area change down to the cm scale. With all of these studies having some type of human error involved, a new technique (ground-based LiDAR) has been developed and introduced into coastal studies that drastically reduces human errors and increases the resolution and accuracy of the data being collected.

Caldara et al. (2006) explored the usefulness and accuracy of ground-based laser scanning technology in the monitoring of coastal defenses in the Apulian region of Italy. Caldara et al. (2006) used ground laser scanning on a coast which contains various types of coastal defenses (gabions, hook-shaped groynes, T-shaped groynes, and rectangular groynes). The error of the scanner is 6 mm, much less than the 15 cm error of airborne LiDAR. The study found some advantages and disadvantages of using the ground laser scanner. Some of the advantages are the speed and time it took to complete the scan, amount of points surveyed, mm precision in the accuracy of the points. The disadvantages were the frailty of the laser scanner, the size and weight of the instrument, and the dependency on weather conditions. Ultimately the authors found that ground laser scanning can be used to monitor coastal defenses. This finding is relevant to all coastal monitoring, including erosion/accretion, and allows for the application of ground laser scanning to all coastal research (Caldara et al. 2006).

CHAPTER III

STUDY SITE

Assateague Island is a barrier island located on the east coast of the United States and is oriented from south to northeast in the states of Virginia and Maryland. According to Thornberry-Ehrlich (2005) the barrier island formed from a long chain of much smaller barrier islands. The barrier island is 60 km long, 7700 ha, ranges in width from 120 m to 5 km, and represents the eastern shore of the Delmarva Peninsula (Patterson, Fraser and Roggenbuck 1991, Steiner and Leatherman 1981). The island is separated from the mainland by Chincoteague and Sinepuxent Bays and is bounded to the north by the Ocean City Inlet (constructed in 1933), and the naturally formed Chincoteague Inlet (Thornberry-Ehrlich 2005). As a result of the construction of the Ocean City Inlet, the northern section of the island has receded at a rate ranging from 11 m/yr to 12.2 m/yr (Thornberry-Ehrlich 2005). The average elevation of the island is 2 m with the highest elevations (10 m) being located on some of the dunes (Thornberry-Ehrlich 2005). In the region, the most predominant types of storms to effect the island are Nor'easters and tropical storms (Thornberry-Ehrlich 2005). Local sea level rise along the island has been roughly 3 mm/yr and poses a major threat to low-lying areas and backbay wetlands, because of the low relief on the island (Thornberry-Ehrlich 2005).

Located on Assateague Island is the Assateague Island National Seashore (ASIS), the Chincoteague National Wildlife Refuge, and the Assateague State Park

(Patterson, Fraser and Roggenbuck 1991). ASIS was founded on September 21, 1965 during President Lyndon B. Johnson's administration (Thornberry-Ehrlich 2005). The National Seashore covers the Coastal Plain area between Chincoteague, Virginia and Ocean City, Maryland, an area that covers 39,727 acres (Thornberry-Ehrlich 2005). The National Park Service (NPS), the U.S. Fish and Wildlife Service, and the Department of Natural Resources all manage the island in various ways. ORVs are permitted to drive on both sides of the state line (as a result of Presidential Executive Order 11644 and 11989), although the Virginia side of the island closes sections of the beach to allow Piping Plover to breed during the summer months (NPS). Year round, the Maryland portion of the island restricts ORVs to 145 at any one time for the overall visual experience (aesthetics) to each visitor to the park.

From 1967 to 2010 the park received 85,085,278 visitors with an average of 1,933,756 each year (NPS). Tourist activity peaked at ASIS in 1987 (Figure 2) when 2,648,892 people visited the park (NPS). From 2006 to 2010 there were 202,275 vehicles that drove in the OSV zone (112 vehicles each day), with the peak months occurring between May and September each year, Figure 3 (NPS). During the month that this study was conducted (June 2010) 5,297 vehicles drove in the OSV zone.

The OSV zone begins at kilometer marker 16 and extends south for 19 kilometers, ending at kilometer marker 35 at the state line between Maryland and Virginia. The controlled experiments were set up between kilometer marker 24 and kilometer marker 35, the state line (Figure 4 and 5). In 2010, the entire stretch of the OSV zone was open to the public up until June 23, 2010, when the Piping Plover nest south of kilometer marker 24 hatched and forced the park to close this area to the public. From June 23th to the end of the field work, only a few vehicles would drive through the area used for the controlled experiments.

The beach along the OSV zone is characterized as having a distinct foreshore and backshore, with a sharp contrast between them. The 19 kilometers of the OSV zone has varying widths of the foreshore and backshore, as well as drastically different sizes of foredunes, which can be attributed to the fact that much of them are artificially created (Leatherman 1979b). Figure 6 shows a photograph of a typical foreshore section of beach at ASIS. The profile is steep, indicative of a reflective beach state. Beach cusps and sharp escarpments are present along the foreshore zone. They are created when incident waves create a surge of swash that is large enough to impact the beachface (Inman and Guza 1982).

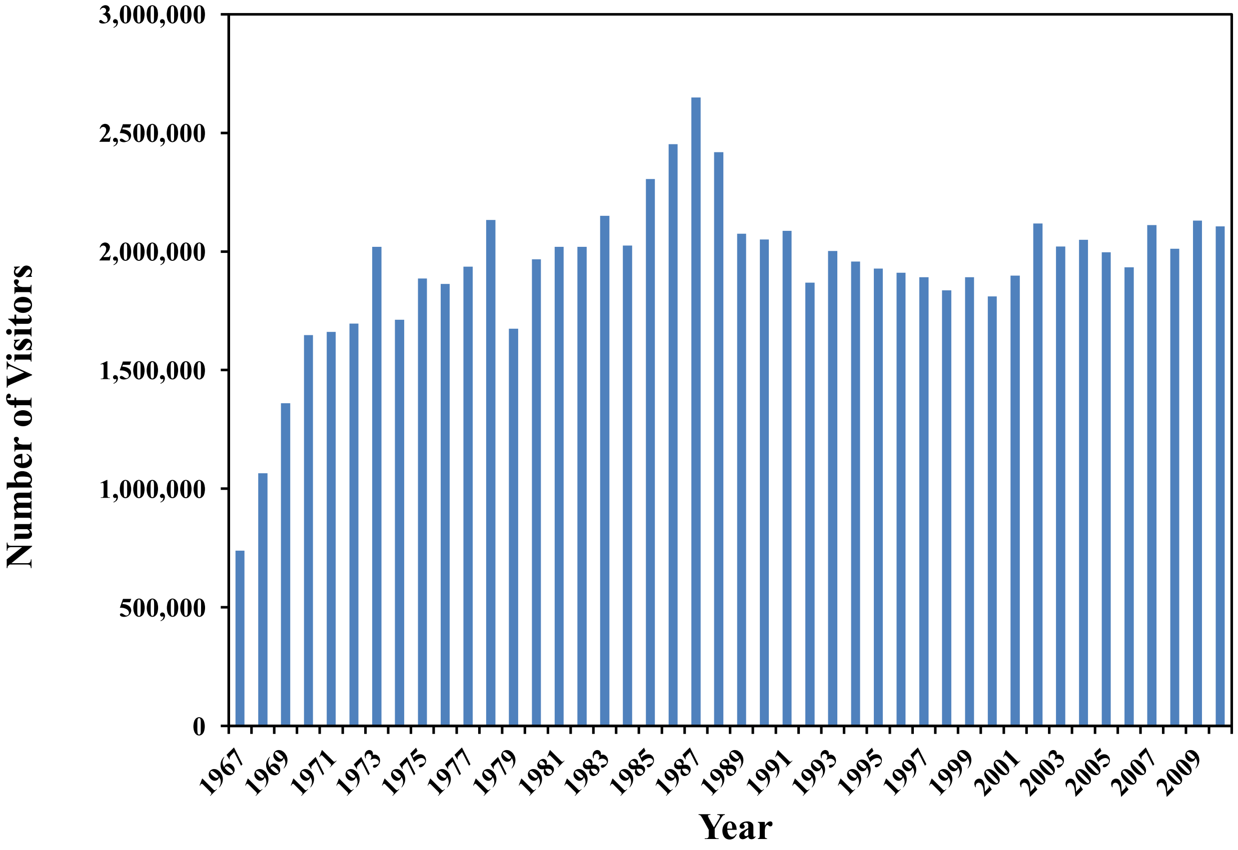


Figure 2. Number of park visitors to Assateague Island National Seashore from 1967-2010 (NPS). With a maximum of 145 vehicles at any one time allowed in the OSV zone.

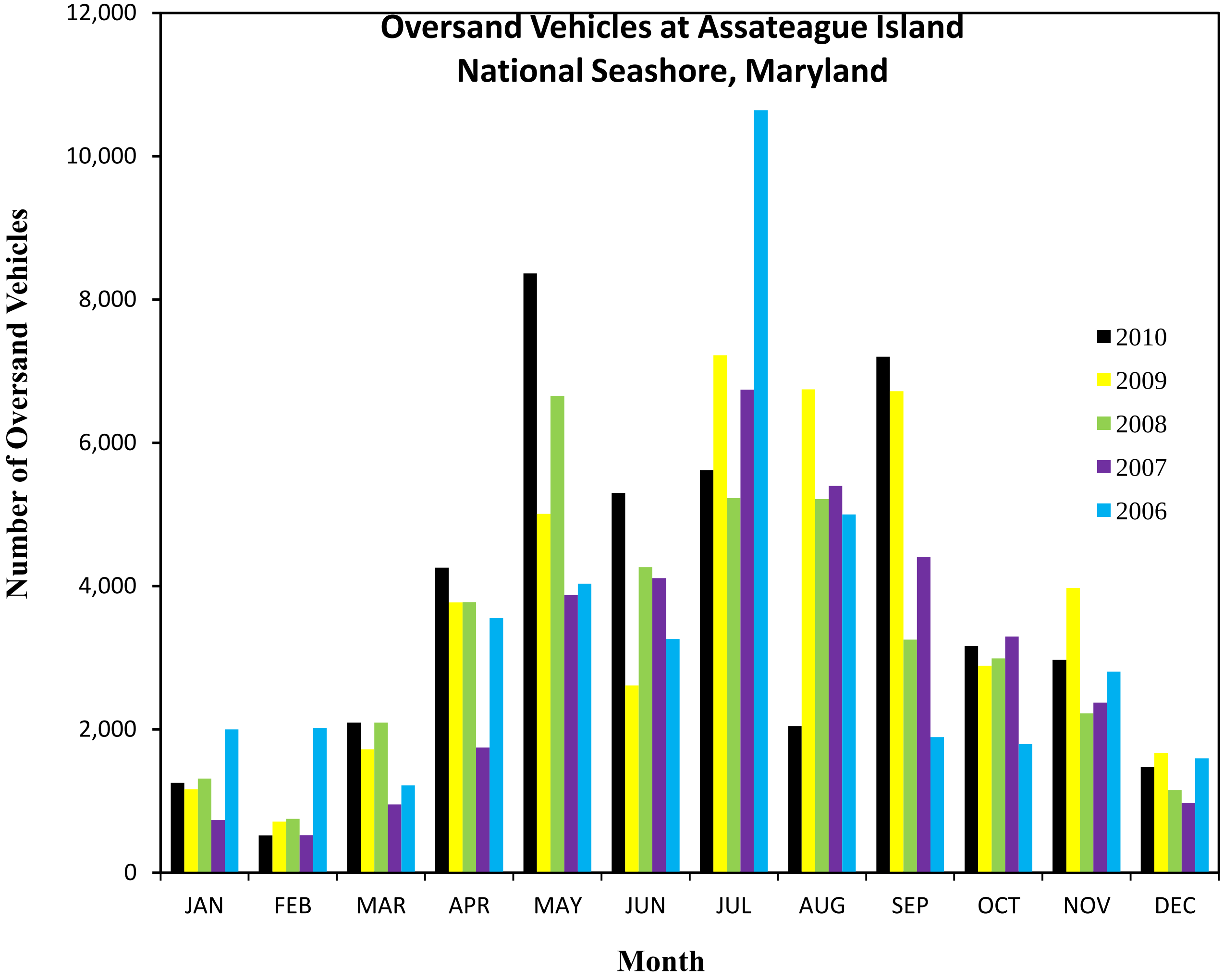


Figure 3. Oversand vehicles on Assateague Island National Seashore from 2006-2010 (NPS).

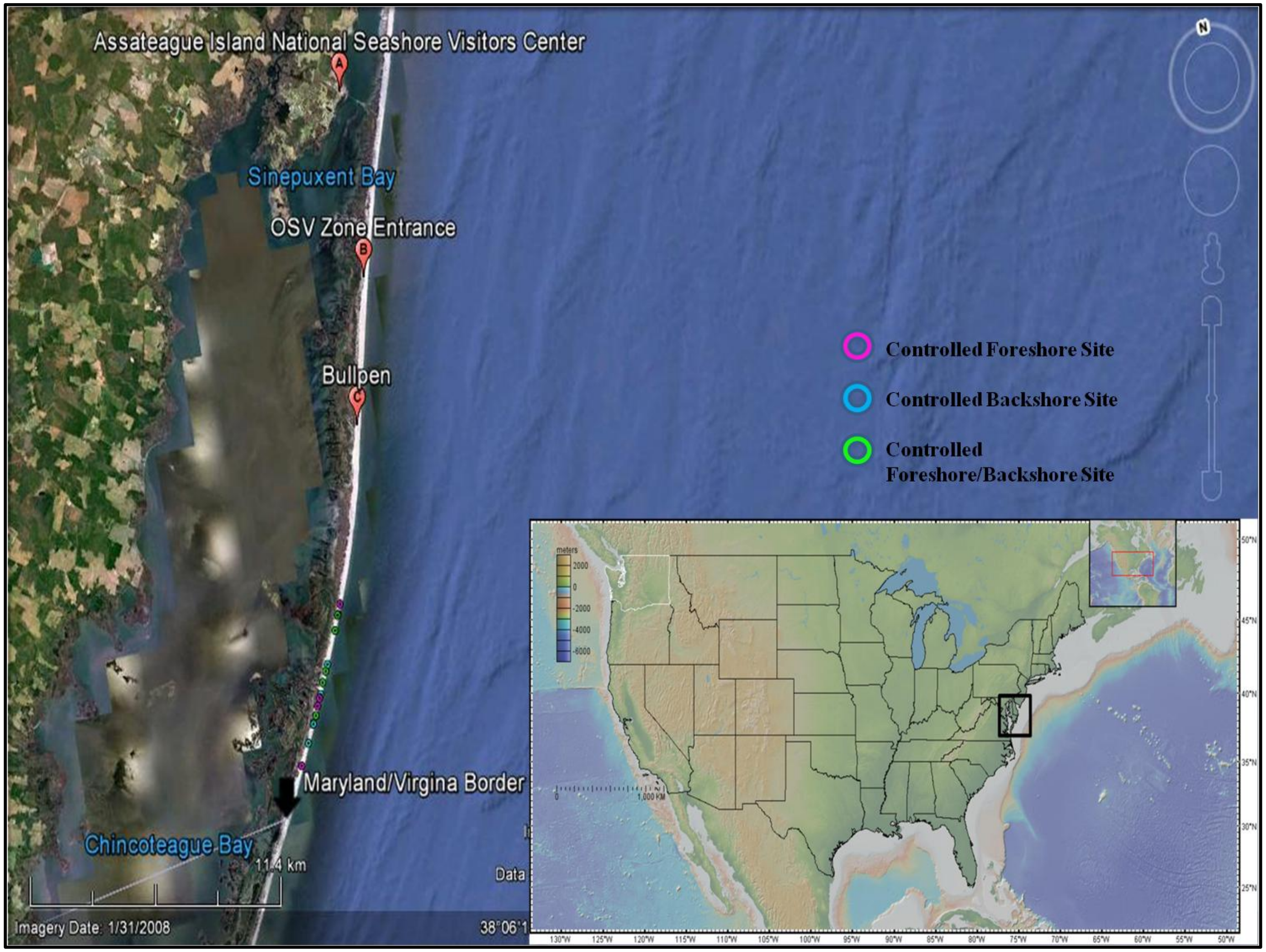


Figure 4. Map of Assateague Island, Maryland and the locations of the controlled ORV experiments.

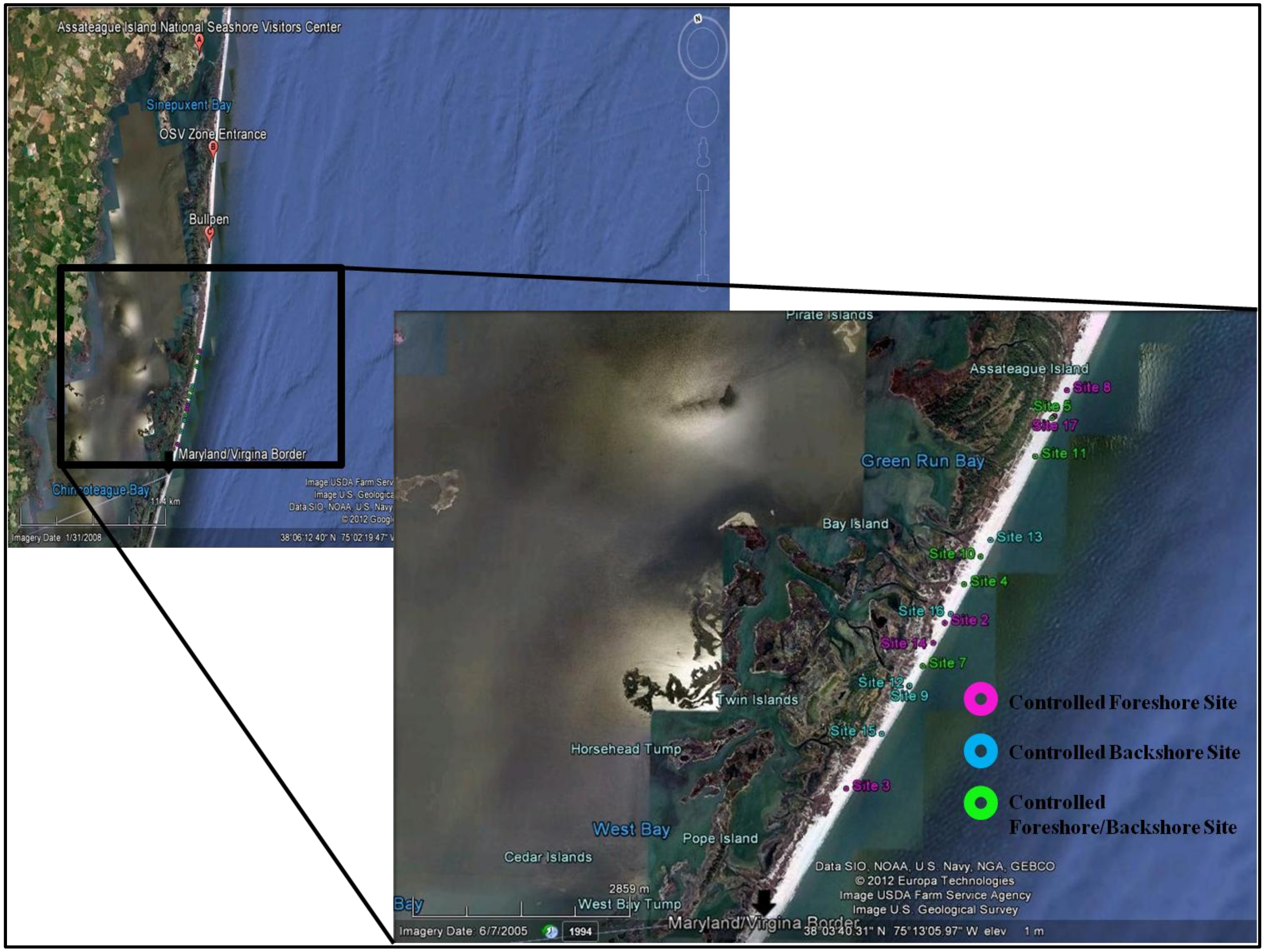


Figure 5. Map showing the locations of the controlled sites, in relation to the entire island.

Figure 6. A photograph of the foreshore at ASIS.

CHAPTER IV

METHODS

4.1 Data Collection

To quantify the disturbance of sediment caused by off-road vehicles (ORVs), controlled experiments were conducted along the Oversand Vehicle (OSV) zone at Assateague Island National Seashore, Maryland. The controlled experiments were conducted to allow for the control of variables such as vehicle type, speed, number of passes, tire pressure, location across-shore, and it allowed for the control of unwanted vehicle passes by the public. The controlled experiments were conducted south of kilometer marker 24 (Figures 4 and 5 above) and took place in two different zones: the foreshore (the shore side of the mean high tide line) and the backshore (between the mean high tide line and the dunes). Within each zone a three meter by three meter plot was marked by use of survey flags (Figure 7). This plot was the target area that the vehicle would drive though for every pass of the experiment. The plot remained undisturbed by human activity throughout the experiment, no vehicles drove through the test plot (except the test vehicle) and no one walked inside the test plot. The driver would drive through this test plot after it was set up, thus the tracks could not be centered inside the test plot.

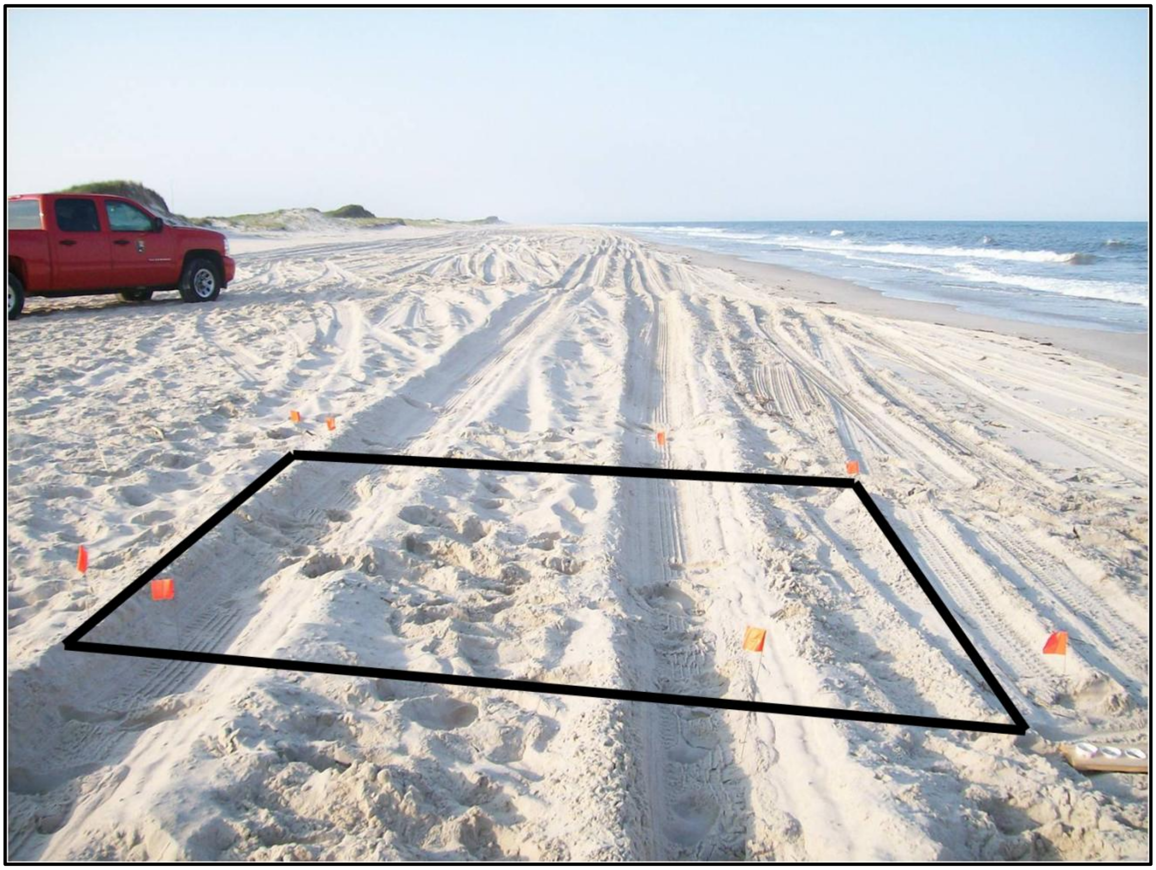


Figure 7. Three meter by three meter plot that was marked off (the lines) for the controlled experiments.

Adjacent to the test plot, an instrument designed to catch the sediment ejected from the tire tracks (sediment traps spaced every 8.89 cm) was placed perpendicular to the plot but downwind of the dominant wind direction (Figure 8). If the wind was predominately coming from the west, than the sediment trap was placed on the shore side of the test plot and if the wind was predominately coming from the east, the sediment trap was placed on the landward side of the test plot. The placement of the sediment trap was to collect sand that was ejected from the truck as it passed through the plot and allows for the determination of the direction and distance that sand in thrown out of a tire track.

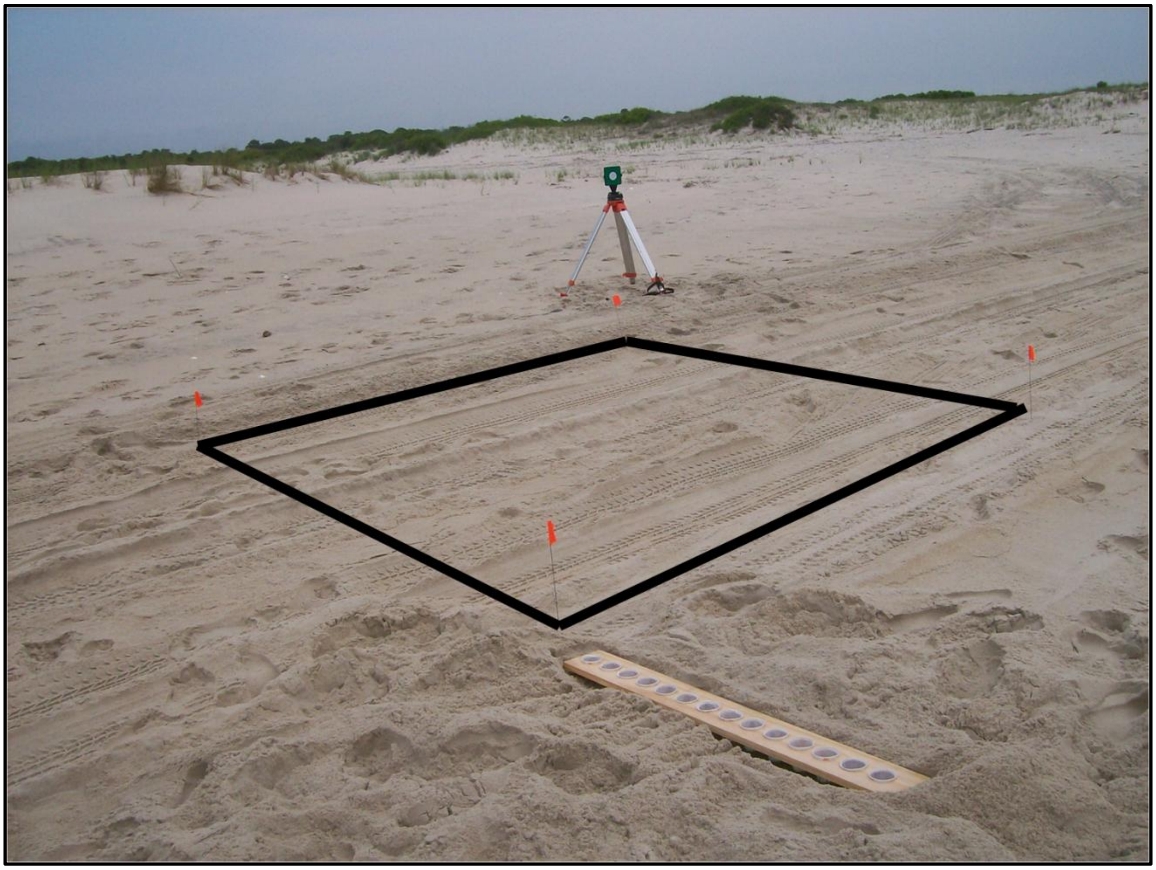


Figure 8. Layout of the test plot with the sediment trap placed into position (The lines represent the test plot).

The ground-based LiDAR (Trimble GX 3D Scanner) was set up directly south of the test plot at a distance ranging from ten to thirty meters (Figure 9). The scanner uses a Class 2 pulsed 532 nm laser and has a range of up to 250 m (Hanke et al. 2006). The scanner can scan up to 5000 points per second and has an error of only 8 mm (Hanke et al. 2006).

Figure 9. A typical placement of the Trimble GX 3D Scanner in relation to the test plot. The box represents the test plot.

After the scanner was set up, two targets were placed west of the test plot, near the dunes (Figure 10). The targets were placed at a distance ranging from ten to fifty meters apart from each other, and placed near the dunes to keep the targets at a safe distance away from passing vehicles.

Figure 10. Location of targets in relation to the test plot and the Trimble GX 3D Scanner (The lines represent the test plot).

Sand samples were taken using a specially designed sampling container and placed into a small baggie that was taped shut. Penetrometer measurements were taken and recorded from within the test plot. After all of the measurements had been taken and the equipment set up, the ground-based LiDAR was turned on and the Pointscape 4.0 program used to collect the data was set up.

Information entered into the Pointscape program included the measurements of the scanner itself. The GPS coordinate and height of scanner was recorded into the program in the UTM coordinate system and meters respectively. A scan of each of the two targets that were set up near the dunes was also taken in order for the scanner itself to become calibrated. A GPS coordinate was entered for each of the two targets in the UTM coordinate system. The height of each target was also measured and entered into the program before each target was scanned separately from each other. The test plot was framed and the distance from the scanner to the end of the plot was measured and input into the program along with the resolution of the scan, 5 mm by 5 mm. When the required settings had been input and selected, the scan of the undisturbed pre-test plot was conducted (Figure 11). The pre-test scans usually lasted around ten minutes and proved to be the most valuable data collected, as each of the scans thereafter were rectified using the pre-test scan.

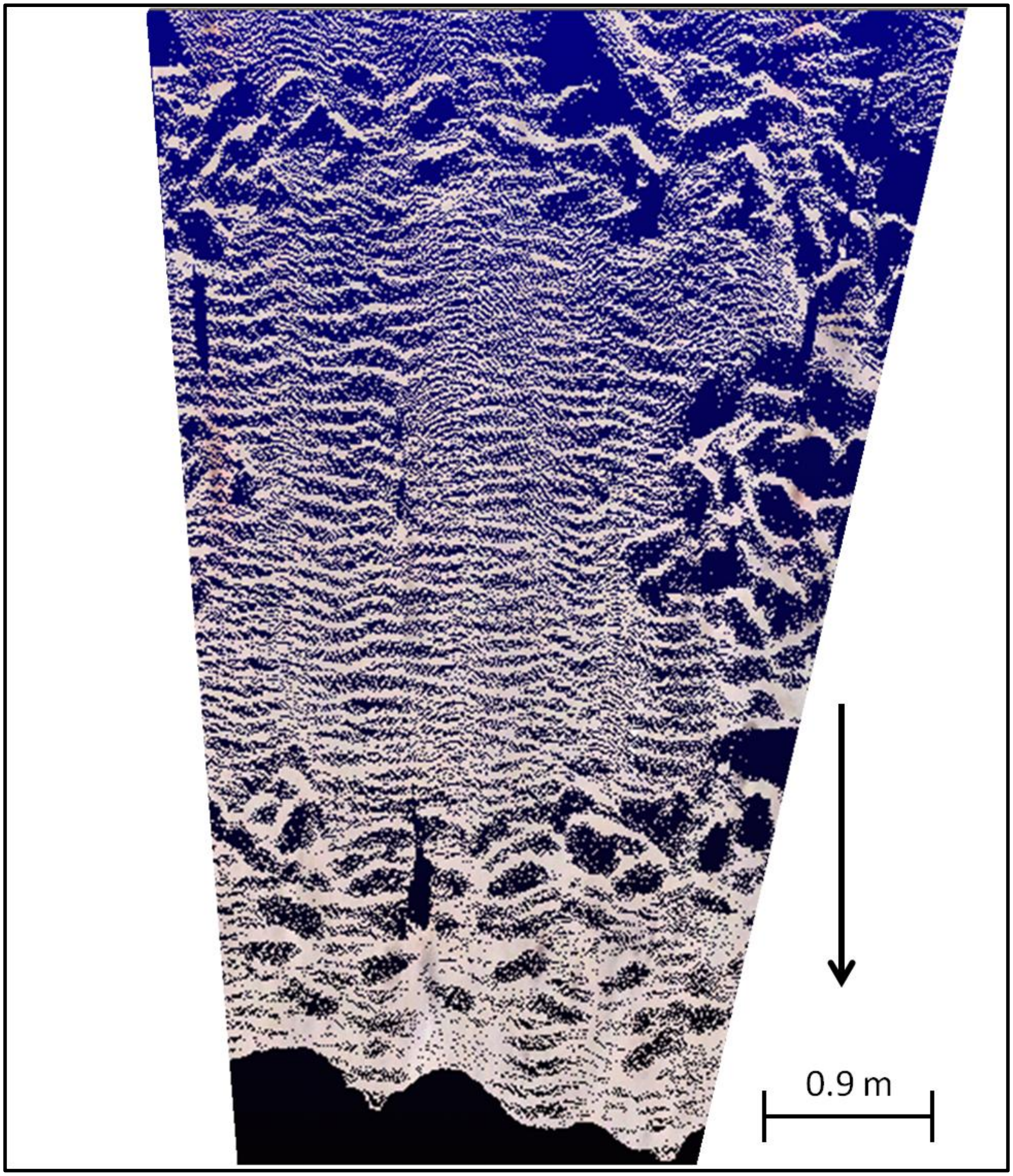


Figure 11. Pre-test scan of a backshore site (Site 17), the arrow represents the direction in which the vehicle would drive through the test plot.

Immediately after the pre-test scan was complete, the ground-based LiDAR was moved either towards the shore or dunes, far enough that it would remain safe as the vehicle drove through the test plot. Next, the vehicle being used for the controlled experiments, a Chevrolet Silverado 4x4 truck (Figure 12) with a tire pressure of 20 psi (recommended for all ORVs by the National Park Service), would drive once through the test plot at the posted speed limit of 25 mph. The Chevrolet Silverado was considerably larger than the test vehicle used by Anders and Leatherman (1987a). In their study the authors used a vehicle weighing only 1600 kg, while the Chevrolet Silverado weighed in around 2900 kg. A comparison of some of the variables (independent and dependent) used in Anders and Leatherman (1987a) and this study are shown in Table 4. After the truck passed through the test plot the ground-based LiDAR equipment would be moved back into its original place, directly south of the test plot. Once the ground-based LiDAR was set back up, each of the two stationary targets were rescanned into the program as well as the new information for the scanner (GPS coordinate and height).

Table 4

Comparison of independent and dependent variables from Anders and Leatherman (1987a) and this study

Variable	Anders and Leatherman (1987a)	This Study
Vehicle Type	Truck	Chevrolet Silverado 4x4
Vehicle Weight (Kg)	1600	2900
Vehicle Speed (mph)	Varied	25
Tire Pressure (psi)	Varied	20
Orientation to the natural slope of the beach (degrees)	90	90
Number of Passes at each site	5, 10, 15, 20, 25, 30, 40, 50, 75	1, 2, 4, 8, 16, 32

Figure 12. The Chevrolet 4x4 truck used in the controlled experiments.

The test plot was framed and the resolution and distance to the plot was reentered into the program. Once the scan was complete, penetrometer measurements were taken from the seaward tire track. Five penetrometer measurements were taken (Figure 13), the first being from the mound that formed on the seaward side of the tire track. The second penetrometer measurement coming from the dune side mound of the tire, the third from the center of the track, and the fourth and fifth measurements from outside the tire track on the seaward and dune sides of the tack respectively.

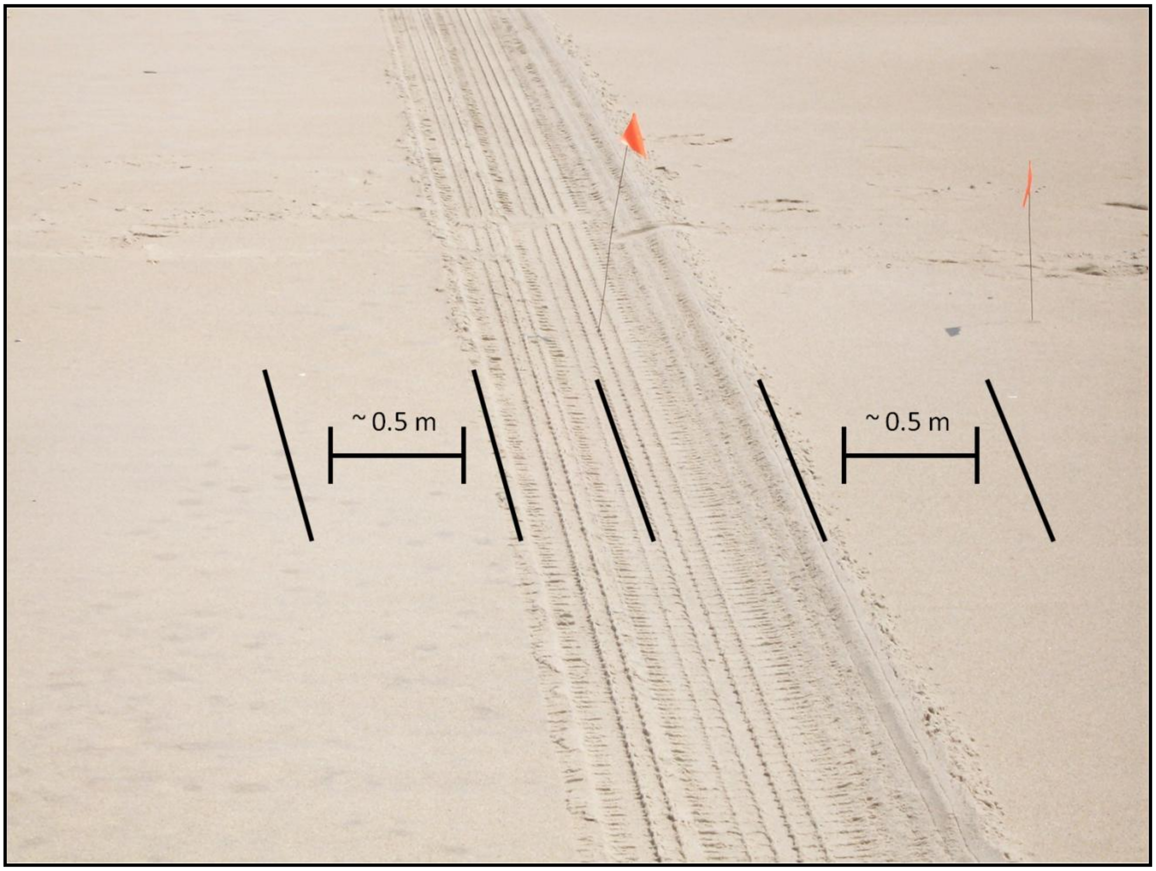


Figure 13. Locations (the five vertical lines) along the controlled test plot where each of the five penetrometer measurements were taken.

Afterwards the plot was scanned and the same process was repeated with the truck driving through the test plot at different increments (1, 2, 4, 8, and 16 times). The scans were then taken after total passes of 1, 2, 4, 8, 16, and 32.

After the last scan was completed, sand samples from the same locations that the five penetrometer measurements were taken. After each of the sand samples were stored away, the sand in each of the sediment traps were carefully placed into zip-lock baggies and weighed to determine how much sand was thrown out of the tire track and how far.

This same process was conducted for each of the nine foreshore and nine backshore sites.

4.2 Data Processing of the Ground-Based LiDAR

The point cloud data that resulted from each of the scans had to be processed and rectified in order for the data to prove useful. First, each scan taken from each site had to be separated, as did the point cloud data for each of the associated target scans. After every set of point cloud data (for the scans and targets) had been separated, the X, Y, and Z data for the targets were averaged. Once averaged, the point cloud data from the scans of one site were entered into a Microsoft Excel program. Because the targets remained stationary throughout the scans at each site, all of the scans can be rectified to the coordinates of the pre-test scan. This entails entering the average of the two targets for the pre-test scan and then the first scan. The program was run using the Microsoft Excel solver. The output was then placed into the conversion equation for the point cloud data for the corresponding target, in this case the first scan. The point cloud data was then transformed or rectified into the same coordinate system as the pre-test scan and can be overlaid and analyzed.

The point cloud data cannot be analyzed directly, even if the data has been rectified. The rectification mentioned above, just places each of the scans in the same coordinate system as their corresponding pre-test scans, however the rectification process does not correct for the change in the height of the scanner each time it was moved. Since the targets remained stationary for each of the sites, the difference in the average Z values from the pre-test scan and each of the other scans was added to their respective point cloud association. So, if for example, the difference in average Z values for the targets of the pre-test scan and the scan after the first pass was -25.5, then -25.5 was added to the Z values of the point cloud data for the scan after the first pass.

After the point cloud data for all of the scans had been rectified, both the X, Y coordinates and the Z values, then the point cloud data was converted into a feature class using ArcCatalog. Then, using the 3D Analyst tool in the ArcToolbox, the feature classes were converted to Digital Elevation Models (DEM's) using an Inverse Distance Weighted (IDW) interpolation method (Figure 14). This interpolation method calculates unmeasured values based on the distances measured values are away from the value that is trying to be predicted. This method assumes that the closer a measured value is to an unmeasured value, the more alike it is. The IDW interpolation method was chosen based on the data acquired in the field. Since the point cloud data retrieved from the 3D Scanner is uniform throughout the image, the best possible interpolation method is an IDW.

After all of the DEMs were created, all DEMs for one site were loaded into ArcMap (Figure 15), where with the aid of the 3D Analyst toolbar (Figure 16), a cross-section/profile was taken across the middle of the three by three meter plot and exported to Microsoft Excel (Figure 17). A natural effect of the 3D Analyst tool in ArcMap is that each individual profile originates from the same exact point in space, but the profiles do not have evenly spaced points ranging out from the origin. It is ideal in this situation to have evenly spaced data points along the profile in order to calculate the volumetric changes from one set of passes to the next.

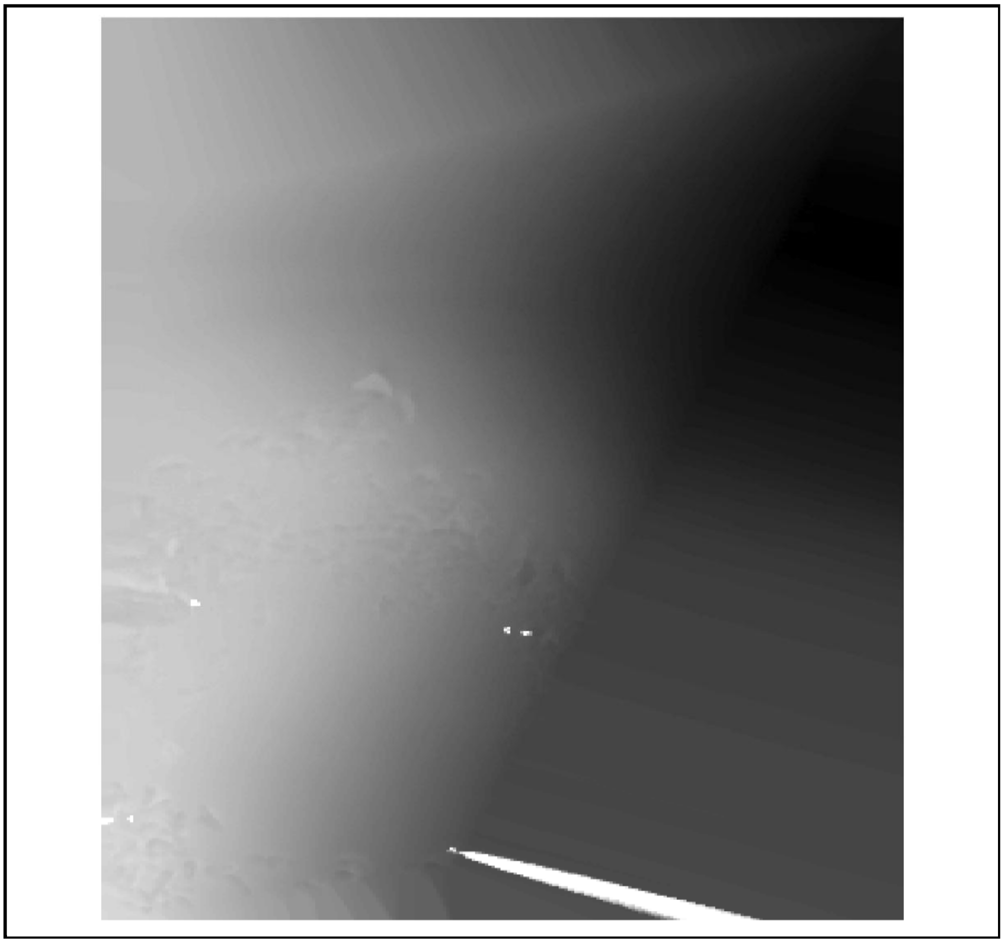
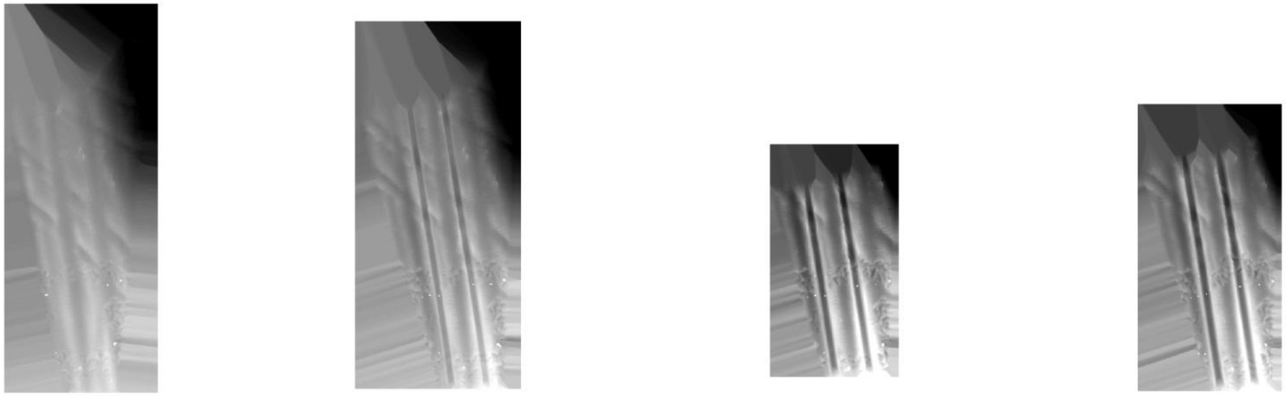
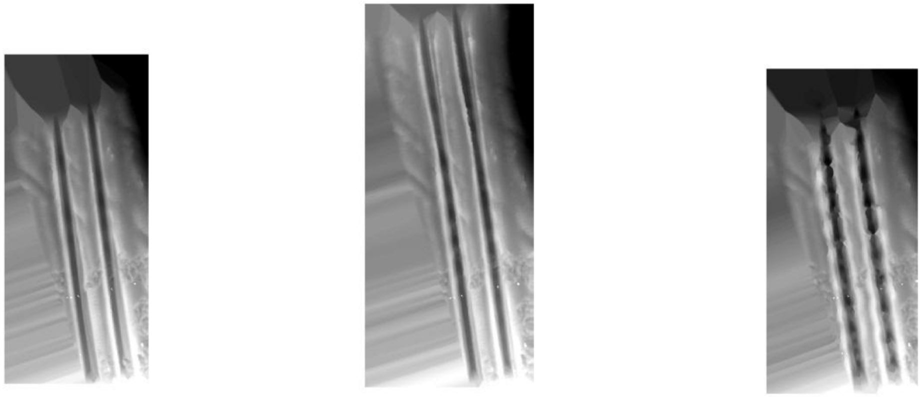


Figure 14. IDW interpolated digital elevation model of the pre-test scan at site 10-2. The white spots on the image are the survey flags that were used to mark the three by three meter test plot. The rest of the image is uniform because the test plot has not been disturbed by any vehicle passes.



A) Pre-test B) 1 Pass C) 2 Passes D) 4 Passes



E) 8 Passes F) 16 Passes G) 32 Passes

Figure 15. A-E, IDW interpolated digital elevation models from site 17.

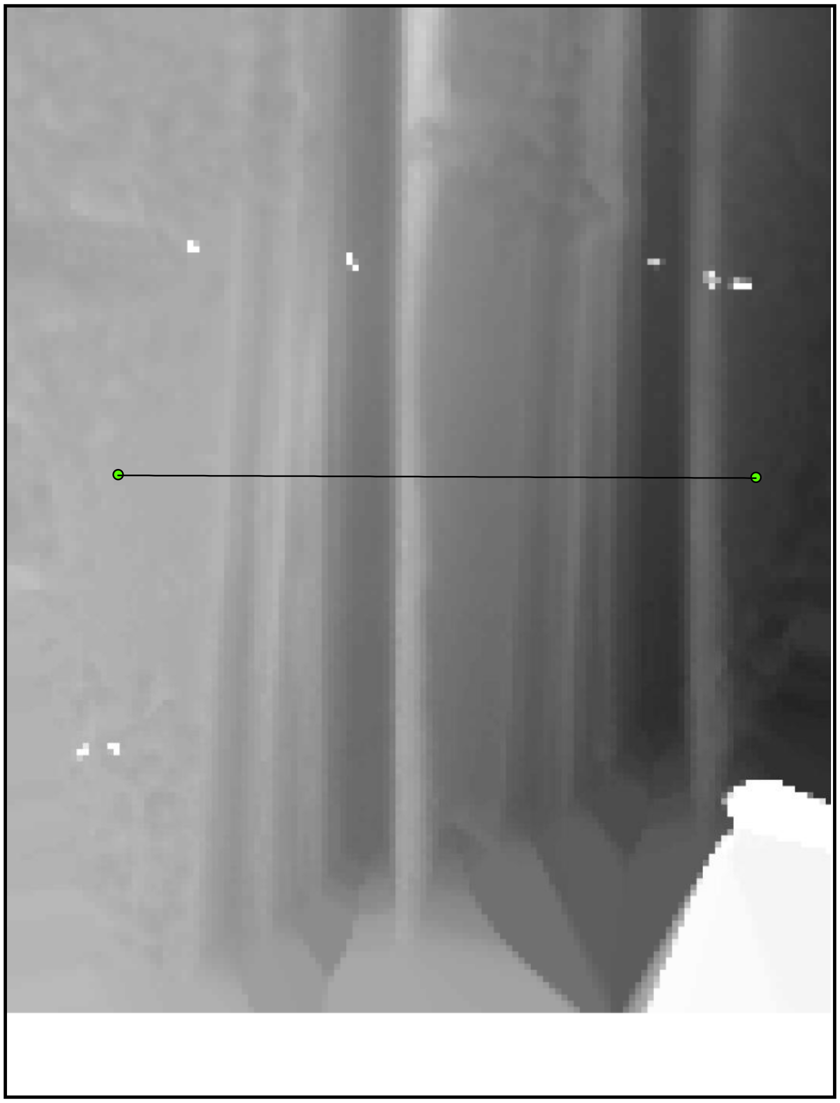


Figure 16. 3D analyst tool to interpret a cross-section across the three by three meter plot. The cross-sectional profile is provided in Figure 19.

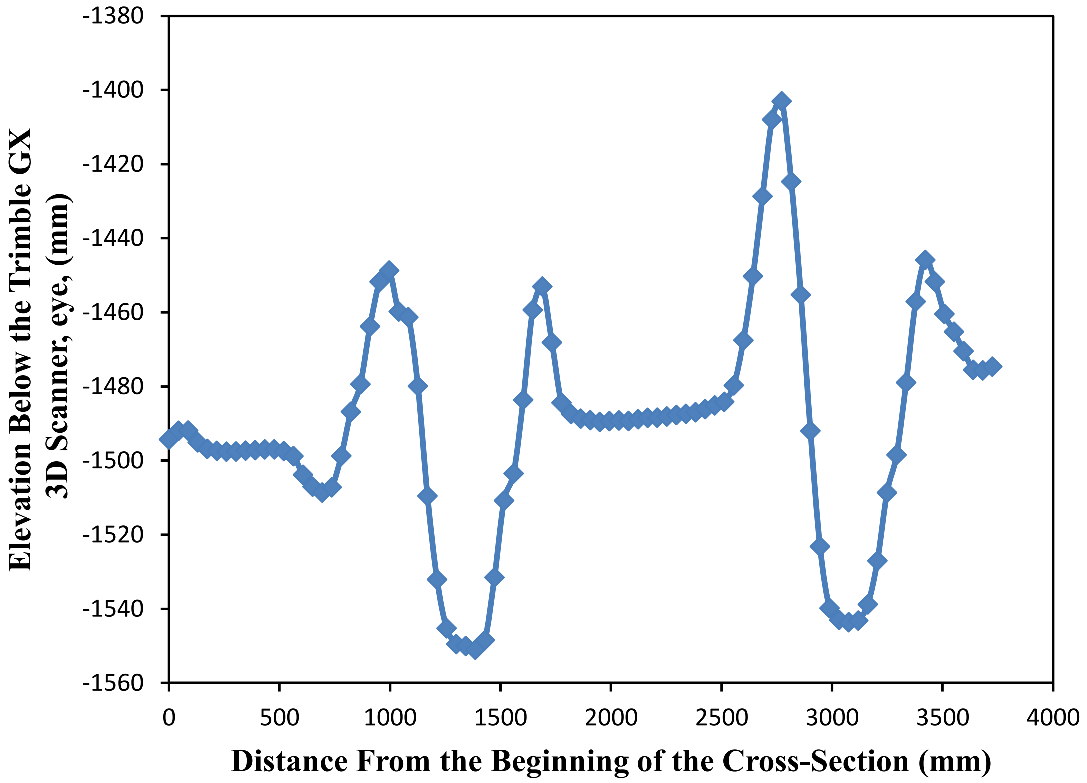


Figure 17. Interpreted cross-sectional profile across the three by three meter plot.

Needing evenly spaced data points along each of the profiles, another interpolation was performed. To do this, each profile and its associated data points were loaded into Microsoft Excel. From this point forward, all interpolations and calculation were done using Microsoft Excel. To begin the interpolation and manipulation of the profile data, the slope (m) and Y-intercept (b) each point along a single profile was calculated. This was accomplished by calculating the slope between two consecutive points along the profile, for example the slope between the first point on the profile and the second point on the profile was calculated along with its associated Y-intercept.

These two individual calculations can be combined to create an equation for a line that intersects both points (Figure 18).

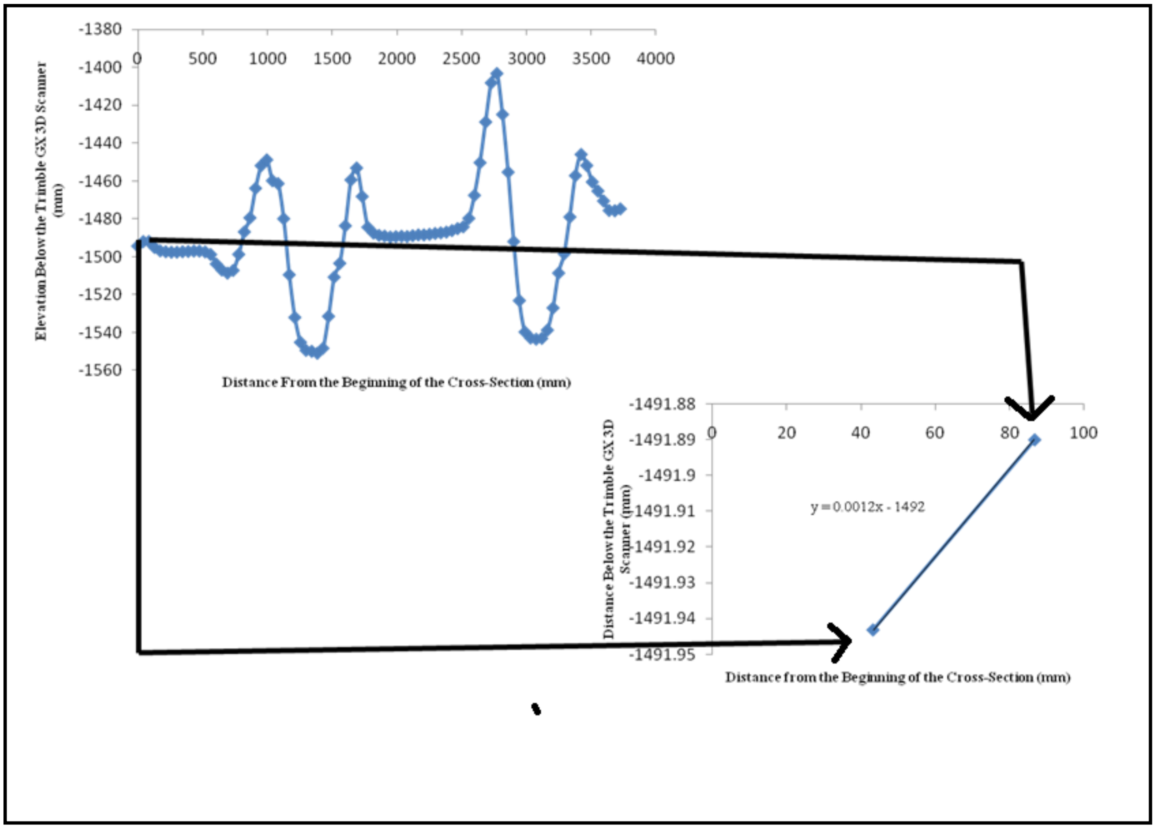


Figure 18. Two consecutive points along the original cross-sectional profile with an interpolated line between them.

$$Y = mx + b$$

Once an equation has been estimated for every point on the profile taken from the IDW, interpolated DEM, then new points along the profile were interpolated at 20 mm intervals. 20 mm intervals were chosen, because most of the profiles that were originally generated were 4000 mm long and 20 mm spacing would give roughly 200 data points along the profile. Each data point at 20 mm spacing was created by looking at the original points along the profile. If one of the new evenly spaced data points were to fall along a particular line created from the equations, then the equation associated with that line was used to create the new data point. For example, since all of the profiles originate from the same location (for a given site), the next point to be interpolated would be 20 mm from the origin, to do this you would need to look at the points on the original profile. If it turns out that the first point along the original profile occurred 30.27 mm from the origin, then the equation that was created for those two points are used to interpolate what the height of a point that is 20 mm from the origin.

4.3. Measurements

Once all of the profiles were interpolated and a new profile with evenly spaced data points generated, each profile was analyzed for the width of the tire tracks, the depth of the tire tracks, the volume of the mounds on either side of the tire tracks, and the volume of sand removed from the tire tracks.

4.3.a Width of Tire Tracks

The widths of the tire tracks came from the individual profiles created after each set of passes. This was done by using a simple definition for the width of a tire track, the distance from the crest of the mound furthest from the shore to the crest of the mound closest to the shore (Figure 19). The profile in Figure 19 shows five distinct tire tracks (each dip in the profile), in order to determine which tracks were made by the test vehicle the pre-test scan was used. The profile was compared to the original pre-test scan where two of the tracks are nonexistent. It is the two tracks that are not observed in the pre-test scan that are the tire tracks created by the vehicle passing through the test plot. The X-component of the data point at the crest of the mound furthest from the shore was subtracted from the X-component of the data point at the crest of the mound closest to the shore. This was done for every tire track, until all of the tire tracks had a width measurement associated with them.

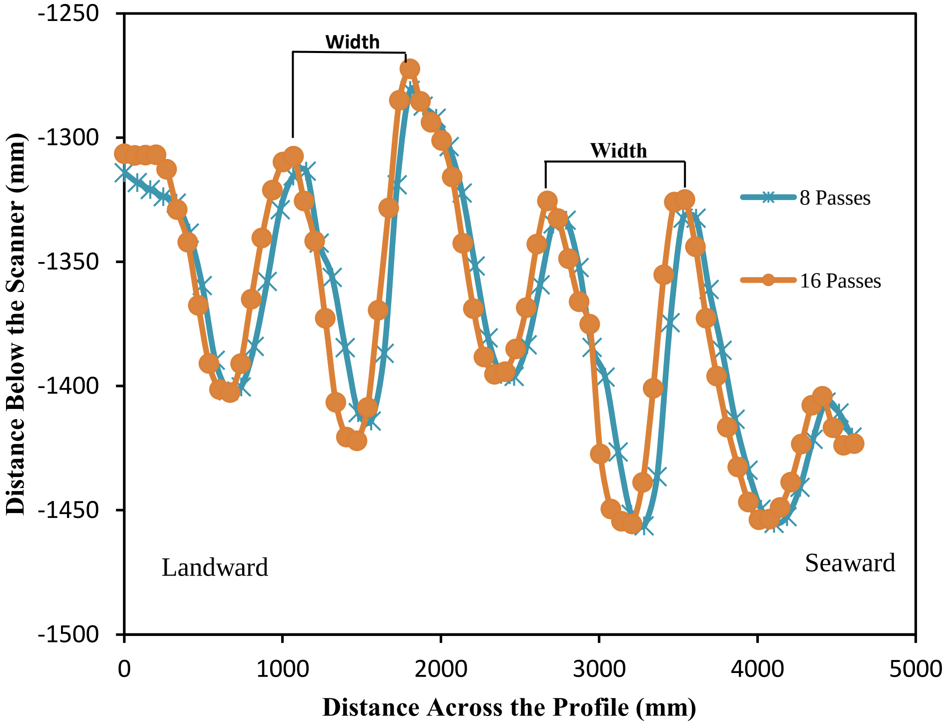


Figure 19. Cross-sectional profile of the three by three meter plot after 8 and 16 passes at site 11-2 with the definition of width.

4.3.b Change in the Depth of Tire Tracks

The next measurement that was taken from the profiles of the tire tracks were the changes in the depths of the tire tracks. The change in depth of a tire track was measured based upon the previous set of passes before it. Thus, the tire tracks generated after one pass were measured based upon what roughly appeared to be the center of the track before the pass began. This leads to the definition of the change in depth of a tire track as the difference between the lowest point of the tire track generated from the previous set of pass(es) and the lowest point of the tire track generated from the current set of pass(es) that is in question (Figure 20). For example, to calculate the change in depth of a tire track generated after 32 passes, the lowest Y-value along the profile of the track after 16 passes was subtracted from the lowest Y-value along the profile of the track after 32 passes. This type of calculation was repeated for every tire track from every set of passes for each site until all of the tire tracks had an associated depth with them. The shift in the profiles that can be seen in Figure 21 is an artifact of the vehicle failing to drive perfectly straight in the track for every pass. If the shift in the profiles were a result of a rectification error than all of the profiles would see the same exact shift, since all of the profiles were rectified in the same manner. However, Figure 21 shows that some of the profiles are not offset, some are offset landward, and some are offset seaward. This confirms that the offsets seen in the profiles are a result of the imperfections of driving on sand. While driving on sand (through a previously formed tire track), the tendency is to slide back and forth within the tire track. However, if driving through untouched sand, the vehicle will not slide but rather eject the sediment from in front of the tires in order to create a track to drive through.

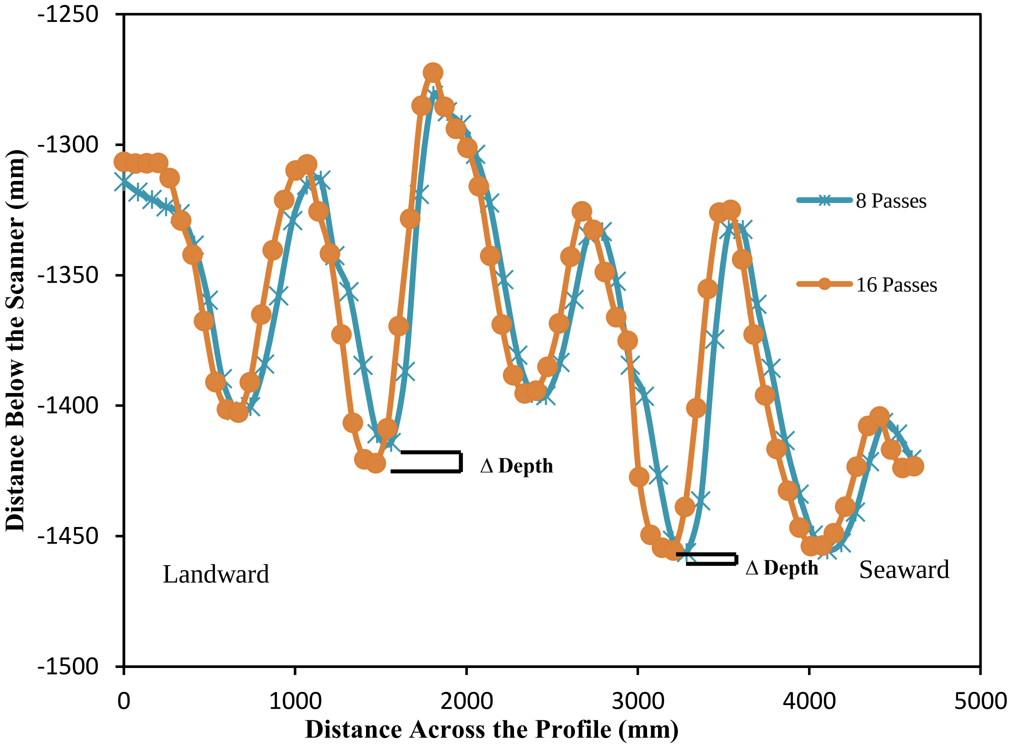
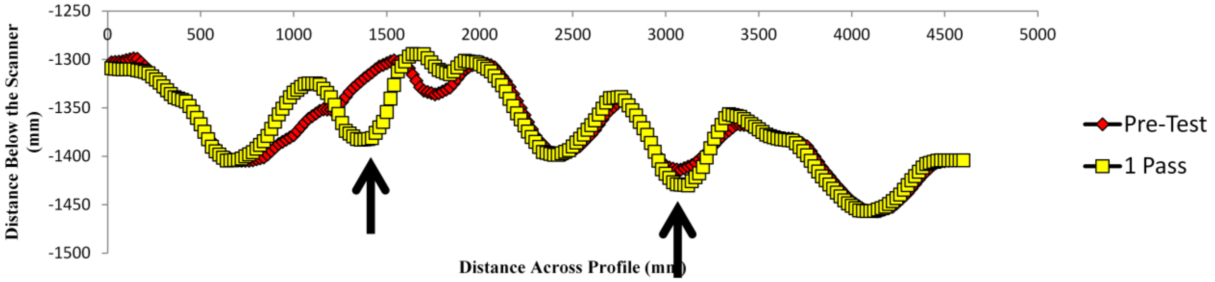
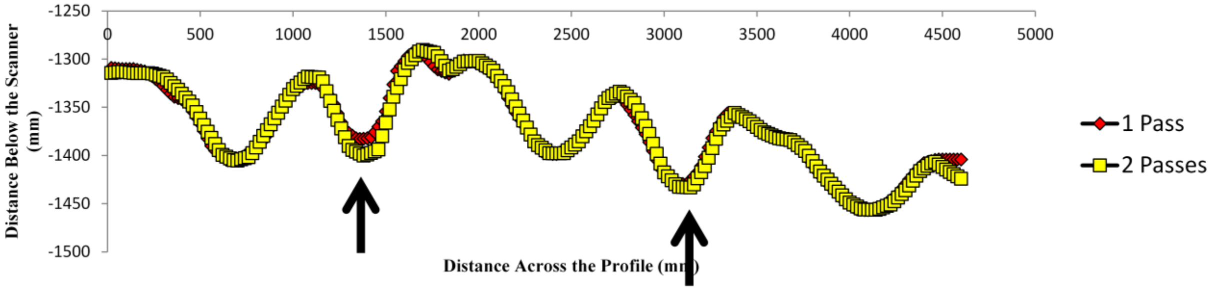


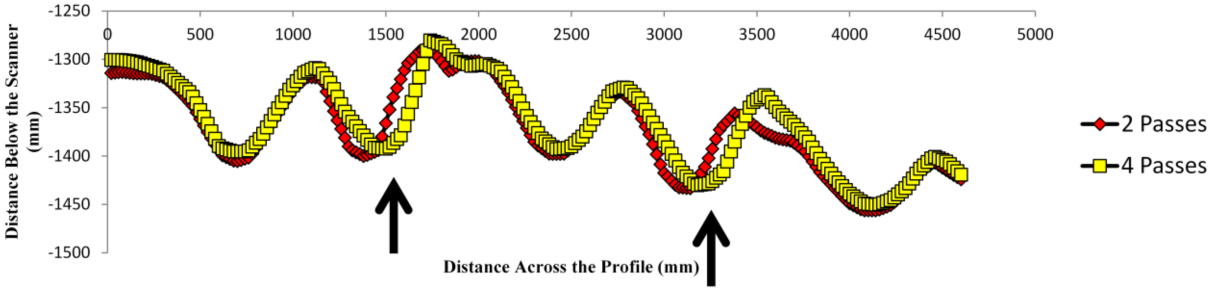
Figure 20. Cross-sectional profiles of the three by three meter plot after 8 and 16 passes at site 11-2 with the definition of depth.



a) Cross-sectional profiles for 0 and 1 passes.

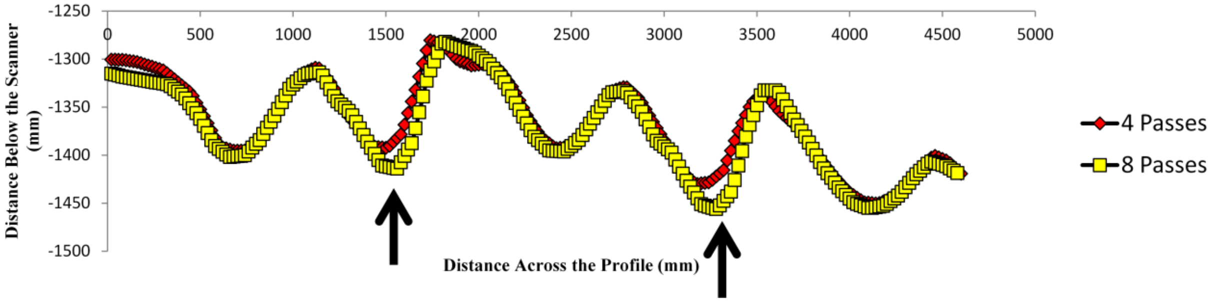


b) Cross-sectional profiles for 1 and 2 passes.

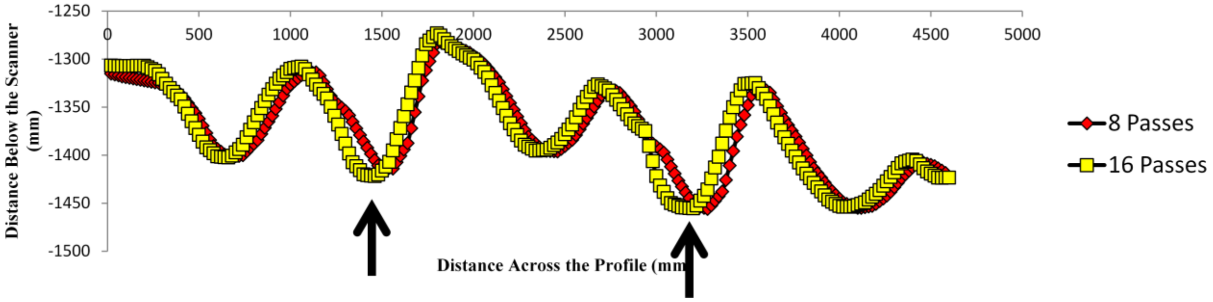


c) Cross-sectional profiles for 2 and 4 passes.

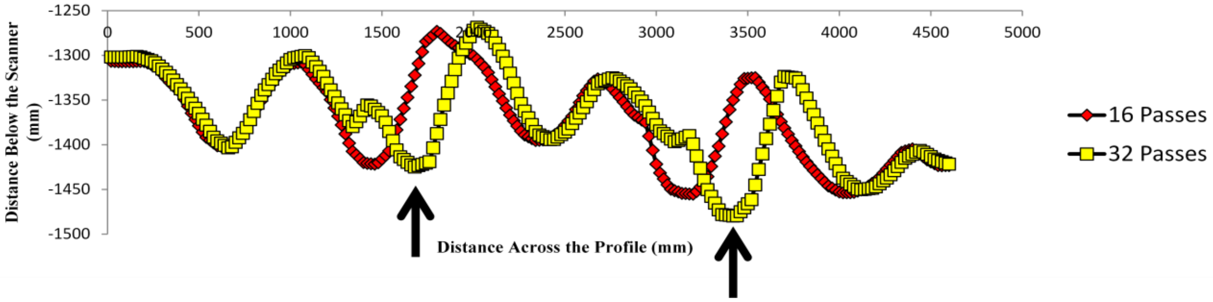
Figure 21. Profiles from site 11-2, the arrows show the two new tire tracks created. Shown are a) surface profiles for 0 and 1 passes, b) surface profiles for 1 and 2 passes, c) surface profiles for 2 and 4 passes, d) surface profiles for 4 and 8 passes, e) surface profiles for 8 and 16 passes, f) surface profiles for 16 and 32 passes.



d) Cross-sectional profiles for 4 and 8 passes.



e) Cross-sectional profiles for 8 and 16 passes.



f) Cross-sectional profiles for 16 and 32 passes.

Figure 21 cont.

4.3.c Volume

Volume measurements of the mounds of sand that are created from the sand removed from the tire tracks were calculated from the profiles. To calculate the volumes of each of the mounds it was first important to determine the definition of a mound, a mound begins where the current tire track profile crosses the previous tire tracks profile and ends when the resulting arc begins to flatten out and drastically change slope away from the track (Figure 22). This definition of a mound was used for three reasons: 1) because it allowed for the easy identification of a mound, 2) there were no other reasonable definitions, and 3) it most accurately resembles what is seen in the field. Using this definition, the data points where each of the mounds, associated with the tire tracks, begin and end were identified. Then using the Y-values of the profile for the set of pass(es) in question can be used in conjunction with the Y-values of the profile for the set of pass(es) prior to the one in question. This is done by using the equation below that calculates the volume of a mound.

$$\text{Volume (mm}^3\text{)} = \Sigma\ (Y_2 - Y_1) * 20$$

Y_2 is the Y-value associated with the profile in question, Y_1 is the Y-value associated with the previous pass(es) profile, and 20 is the distance between each of the data points. Each Y-value between the beginning and end of the mound is put into the equation above to calculate the volume.

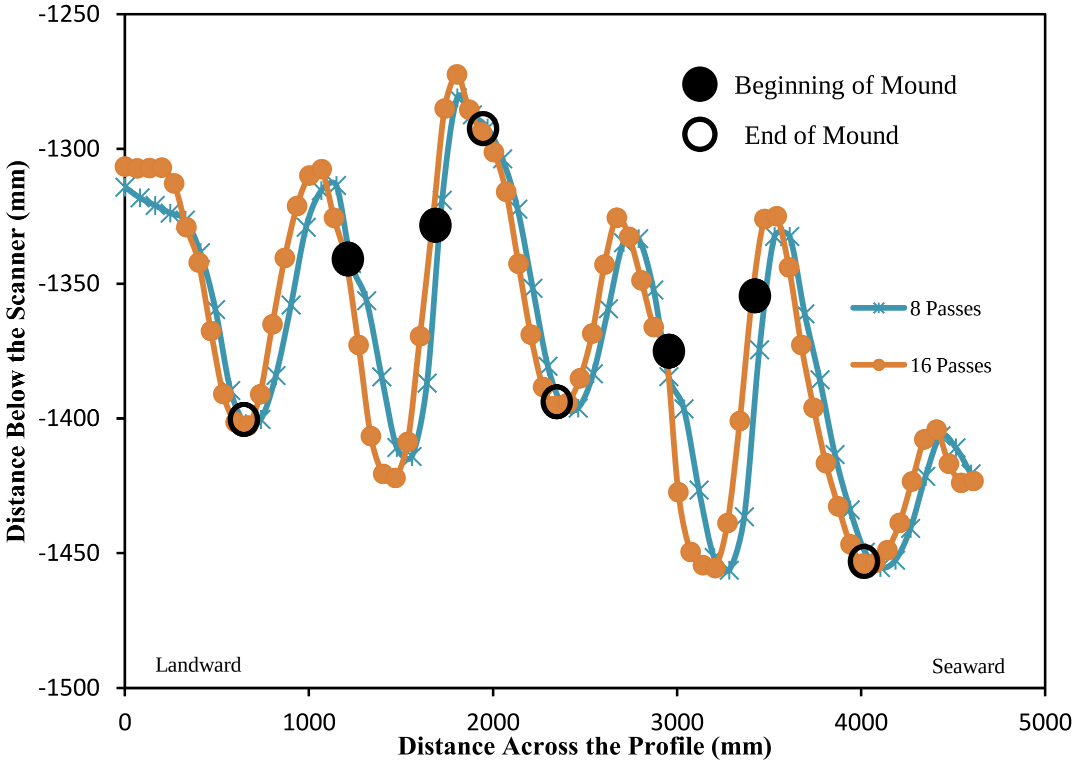


Figure 22. Cross-sectional profiles of the three by three meter plot after 8 and 16 passes at site 11-2 with the start and end of each mound marked.

The volume of sand removed from each of the tire tracks was considered to be the void space between the beginnings of the mound furthest from the shore and the beginnings of the mound closest to the shore (Figure 23). As with calculating the volume of the mounds, the same equation and process was used to calculate the volume of sand displaced by each tire track.

The volume change of the entire profile was also calculated. As with the previous two volume measurements, the total volume change was calculated using the same equation as noted before.

$$\text{Volume (mm}^3\text{)} = \sum(Y_2 - Y_1) * 20$$

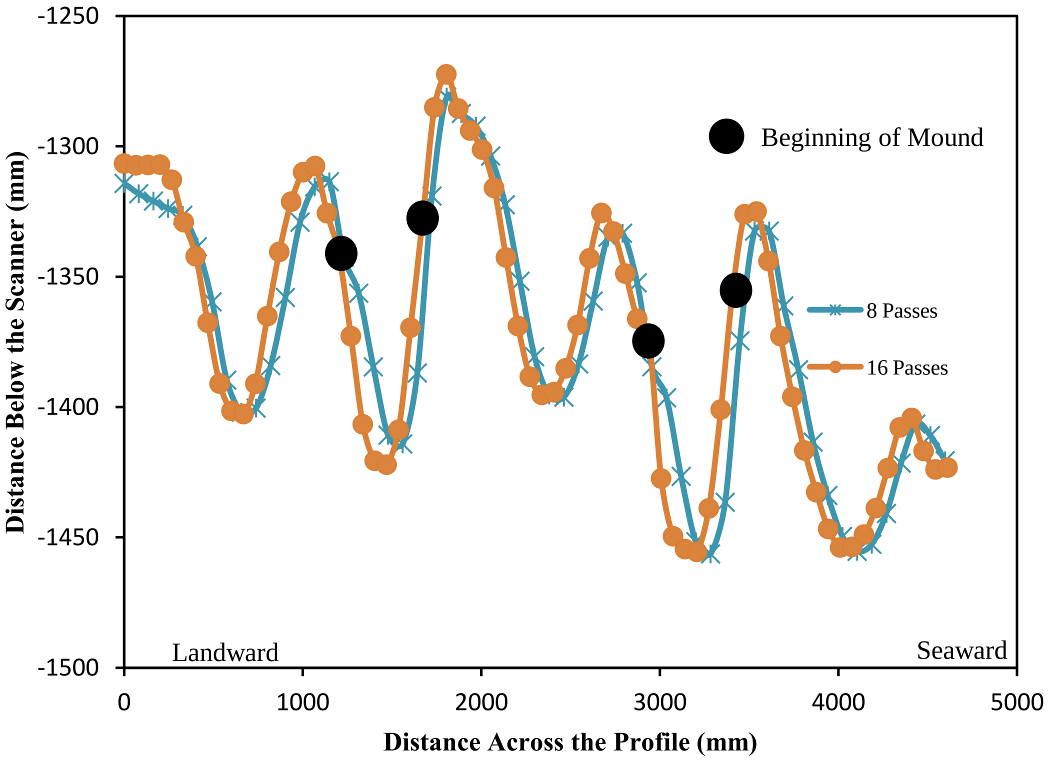


Figure 23. Cross-sectional profiles of the three by three meter plot after 8 and 16 passes at site 11-2 with the start of each mound marked.

4.3.d Displacement

The net displacement was calculated for each of the eighteen controlled sites. The displacement was calculated based off of Anders and Leatherman (1987a). In their study they calculated the displacement of sediment from the tire track as the area of the downslope mound subtracted from the area of the upslope mound. In this study, however, the net displacement was calculated as the volume of the downslope mound (D) subtracted from the volume of the upslope mound (U).

$$\text{Displacement (mm}^3\text{)} = D - U$$

The net displacement was calculated in a similar manner to Anders and Leatherman (1987a), the sum of all of the displacement measurements at one site.

$$\text{Net Displacement (mm}^3\text{)} = \sum \mathrm{D} - \mathrm{U}$$

The net displacement will allow for conclusions to be made as to whether sediment displaced from the tire tracks has a net shoreward movement or a net landwards movement.

CHAPTER V

RESULTS

5.1 Aesthetic Impact by Off-Road Vehicles

While the width and depth of tire tracks are the measureable effects of ORVs on beaches, there is also the damge that tire tracks do to the asthetic beauty of the beach. After only a few minutes of vehicles driving in cicles (doughnuts) and criss-crossing the beach, the entire asthetics of the beach is destroyed. Figure 24 shows how much disturbance can be caused to the beach. The top photograph shows the area of the beach closed to ORVs, while the bottom photograph shows the area of the beach that is open for ORVs to drive on. The Natoinal Park Service tries to protect the asthetic qualities that the beach offers, however these photos show how destructive uncontolled driving can be.

Figure 24. Two photographs showing the beach at ASIS where no ORVs are permitted (top) and the OSV zone,where ORVs are permitted (bottom)

5.2 Dynamics of Sediment Disturbance

When a vehicle drives on a beach it creates and leaves behind tire tracks. To create these tire tracks, sediment in the path of a vehicle is either compacted, ejected out of the vehicles path, or both. The result of the forces of the vehicle acting on the sediment and the opposite and equal forces of the sediment acting on the vehicle work to create unique, individual tire tracks (Figure 25) depending on the type of vehicle, vehicle speed, orientation of the vehicle to the shore, tire pressure, tire size, and the weight of the vehicle (Anders and Leatherman 1987a). All tire tracks have the same basic form, a main track and two mounds on either side of the track. The basic form of a tire track can also be seen in Figure 25.

Figure 25. Images of various types of tire tracks along the beach at Assateague Island National Seashore, Maryland (ASIS).

5.3 Tire Track Creation and Evolution

Using the cross-sectional data obtained from the digital elevation models that were created from each of the scans, the width and depth of each tire track were calculated. The graphs (Figure 26 and 27) below show the average widths of each of the two tire tracks (created by the vehicle) for the entirety of the study. Throughout the duration of the study, both the landward (T1) and seaward (T2) tire tracks exhibited the same relationship in regards to the width of the tire tracks generated from driving a vehicle through the three by three meter test plot. Each track experiences a sharp increase in the width (as a result of the tire track being created), then a steady increase as the number of passes amplifies. This steady increase is most likely a result of the imperfections of driving. If a vehicle has more passes to slide back and forth within a tire track, than a vehicle can unknowingly concentrate the tires on one side of the track or the other. This concentration of the vehicle's force on one side of the track will actually widen the track in that direction. The more passes that are concentrated, the wider the track can become.

Tables 5 and 6 show how the widths of each set of passes compare with each other. The widths after the first pass were compared to the widths after the second pass; this was done by using a t-test. A t-test compares the means of two groups and can determine whether or not the two groups are statistically different from each other. The results of the t-test are in the form of a p-value, if the p-value is less than 0.05 than the two groups are statistically different from each other at a 95 % confidence level. When examining the foreshore sites, there is a statistically significant difference between the width of a tire track after 1 pass and the width of a tire track after 2, 4, 8, 16, and 32 passes. There is also a statistically significant difference between the width of a tire track after 2 passes and the width after 4, 8, 16, and 32 passes. However, when comparing the other sets of passes with each other, there is no statistically significant difference between them. This would suggest that after 4 passes, there is no statistically significant change in the width of a tire track. For the backshore sites, there is no statistically significant change in the width of a tire track after 8 passes. This means that between 0 and 8 passes there is a statistically significant change in the widths of tire tracks, but after 8 passes there is no significant change.

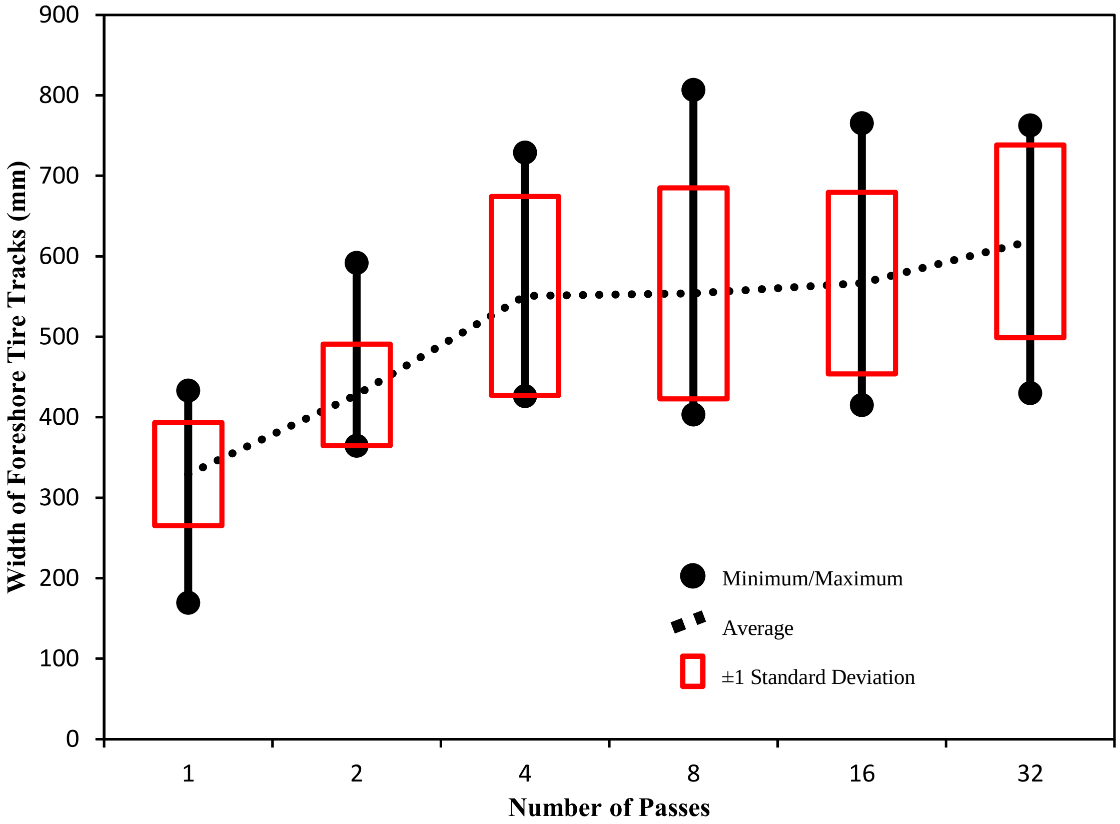


Figure 26. The average width of foreshore tire tracks, across all sites, after each set of passes. The graph also shows the minimum and maximum values across all foreshore sites.

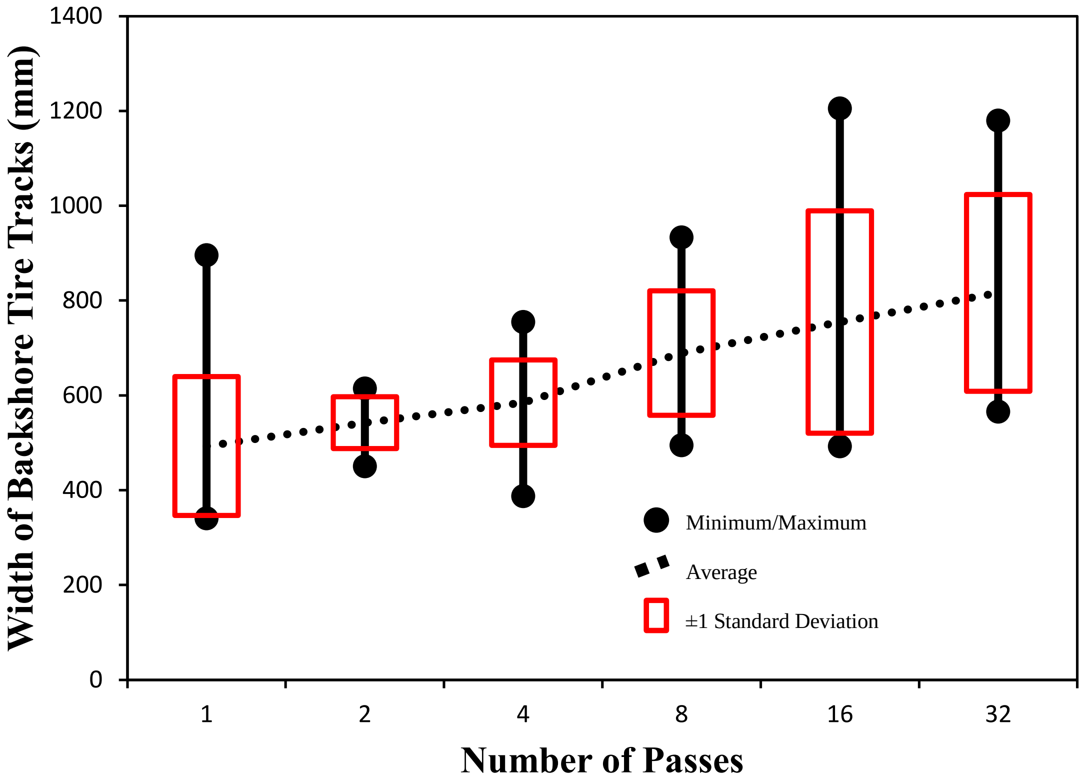


Figure 27. The average width of backshore tire tracks, across all sites, after each set of passes. The graph also shows the minimum and maximum values across all backshore sites.

Table 5

P-values associated with t-tests that compare the widths of each set of passes of the foreshore sites

	1	2	4	8	16	32
1		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
2			**0.01**	**0.01**	**0.00**	**0.00**
4				0.95	0.75	0.16
8					0.81	0.19
16						0.25
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

Table 6

P-values associated with t-tests that compare the widths of each set of passes of the backshore sites

	1	2	4	8	16	32
1		0.24	0.06	**0.00**	**0.00**	**0.00**
2			0.22	**0.01**	**0.01**	**0.00**
4				0.05	**0.04**	**0.00**
8					0.47	0.09
16						0.48
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

As a result of both tracks exhibiting inconsistencies with regards to the increase or decrease in the width and with the imperfections of driving (i.e. sliding), the increase in the width after the initial pass is most likely the result of the tire tracks migrating either landward or seaward. The compaction of the sediment, as a result of the vehicle passes can be seen in Figures 28 and 29. Tables 7 and 8 are tables that compare the compaction of the tire tracks after each set of passes with each other. Figures 28 and 29 show that the compaction of sediment within the tracks increases as the width of the tire tracks increase. After the initial pass, every set of passes experience a very small, but slight increase in the compaction of the sediment within the tire tracks. If the width of the tire tracks increases with the number of passes, the expected observation would be that the compaction continues to decrease as a result of the loosening of sediment to be expelled and thrown out and away from the tire tracks. This is however not the case. The compaction of the sediment within the tire tracks actually increases with the increased number of passes through the test plots. It is also important to note that the sediment on the foreshore is almost twice as compact as the sediment on backshore. This is because the foreshore sediment has a higher moisture content than the sediment on the backshore. The higher moisture content binds the sediment together and fills in the void spaces, making the sediment more compact than the sediment on the backshore.

Tables 7 and 8 show that for both the foreshore and backshore sites, there is no statistically significant difference between the compaction of sediment after any of the sets of passes examined. This would suggest that with the increase in the number of passes, there is not a statistically significant difference in the amount of compaction seen at the center of the tire track.

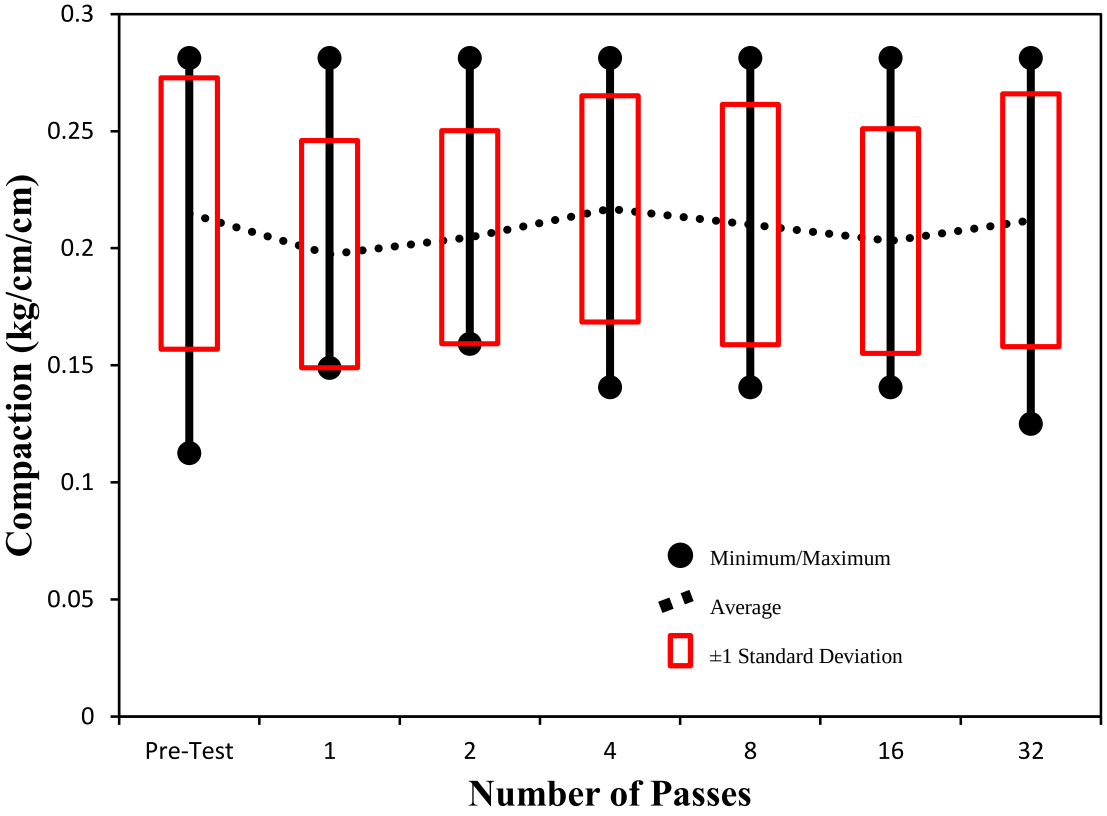


Figure 28. Average compaction of the center of the tire tracks at the foreshore sites, as well as the minimum and maximum compaction observed.

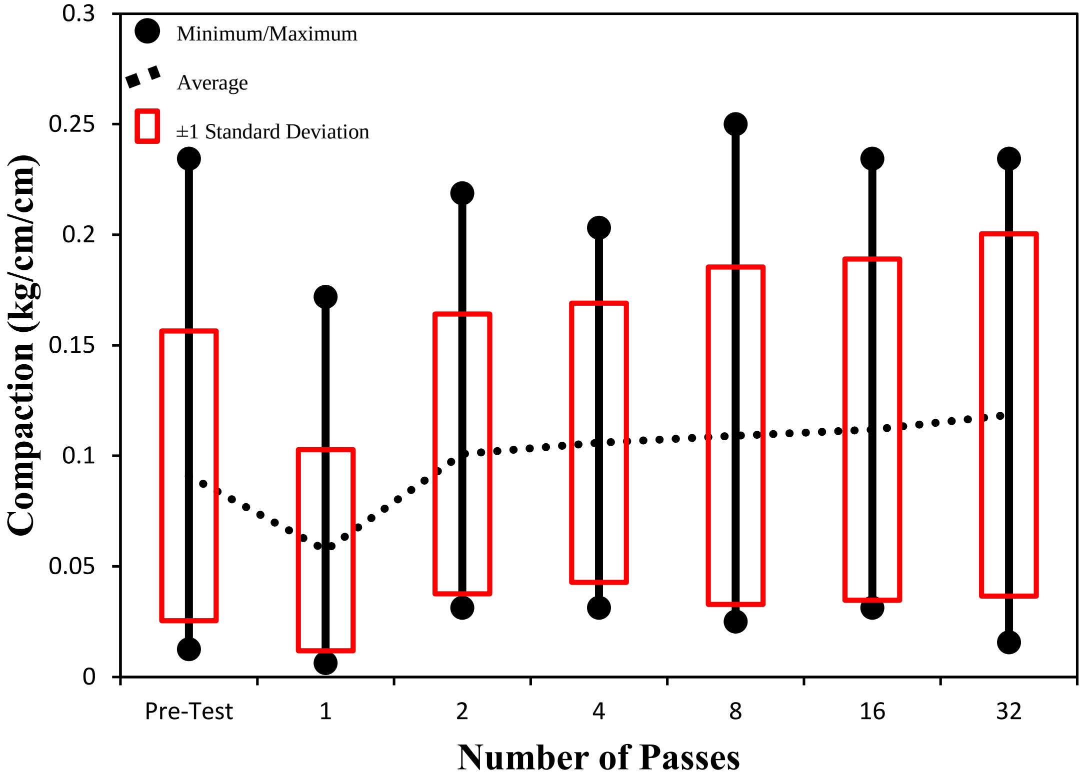


Figure 29. Average compaction of the center of the tire tracks at the backshore sites, as well as the minimum and maximum compaction observed.

Table 7

P-values associated with t-tests that compares the compaction of the sediment after each set of passes with each other (foreshore sites)

	0	1	2	4	8	16	32
0		0.46	0.68	0.93	0.85	0.64	0.91
1			0.74	0.4	0.58	0.8	0.52
2				0.61	0.82	0.95	0.76
4					0.78	0.58	0.84
8						0.78	0.94
16							0.71
32							

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

Table 8

P-values associated with t-tests that compares the compaction of the sediment after each set of passes with each other (backshore sites)

	0	1	2	4	8	16	32
0		0.16	0.74	0.62	0.56	0.52	0.37
1			0.12	0.09	0.08	0.08	0.04
2				0.87	0.80	0.75	0.59
4					0.92	0.86	0.70
8						0.94	0.78
16							0.85
32							

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

The depth of the tire tracks varied by the zone in which the test was being conducted (only in the measurements not the relationship) and the amount of compaction seen after each of the passes. Figures 30 and 31 show the change in the depth that both tire tracks had. When examining Figures 28, 29, 30, 31, the increase in the change in the depth of the tracks after the first pass also corresponds to a decrease in the compaction of the tire tracks after the first pass as well. The decrease in compaction suggests that removal/ejection of the sediment is the primary source that creates the initial tire track. This phenomenon can be seen in Figures 26 and 27. Also, when looking at Figures 28, 29, 30, and 31 it can been seen that the sediment is loosened and ejected from the path of the tires, which widens the tire track. If the compaction of the tire tracks were to increase as dramatically as it decreases after the first pass, then the depth of the tire track could be the result of compaction. All sites experienced the same decrease in the compaction of the tire tracks after the first pass and a steady increase in the compaction after the other sets of passes. Looking at Tables 9 and 10, it can be seen that with the foreshore sites, there is no statistically significant change in the depth between 1 pass all the way through 32 passes. This suggests that with increasing the number of passes there is no real increase in the depths of the tire tracks. However, in the backshore sites, there is a statically significant difference between 1 pass and 4 and 16 passes. Also there is a significant difference between 4 and 8 passes. This would suggest that between 0 and 8 passes there is a statistically significant change in the depth that each pass creates. After 8 passes however, there is no statistically significant change in the depth from increasing passes. Thus no change can be seen after 8 passes. As a result of compaction not changing with increased passes, compaction is not the main or even the primary cause for the depth of a tire track.

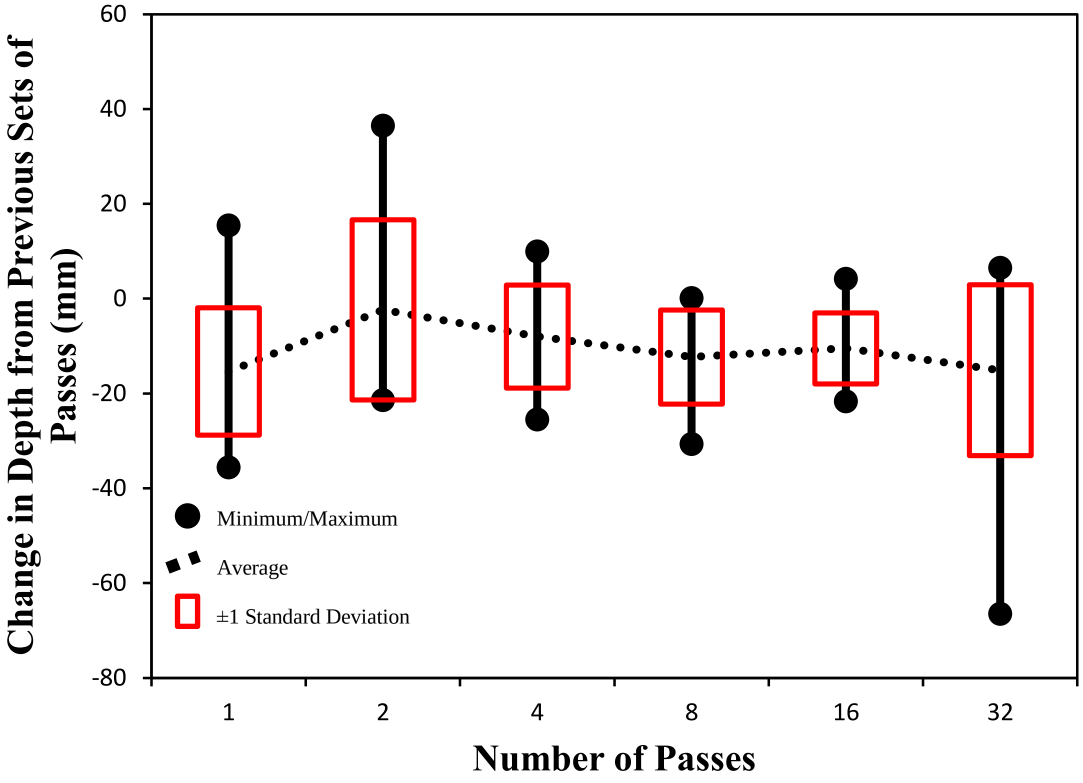


Figure 30. The average change in the depth of the tire tracks at the foreshore sites with respects to the previous set of passes before it, meaning that the values represent the change in depth from the 1st set of passes to the 2nd. Also shown on the graph are the maximum and minimum changes in depth.

Table 9

P-values associated with t-tests that compare the change in depths of the tire tracks of each set of passes with each other (foreshore sites)

	1	2	4	8	16	32
1		0.06	0.12	0.50	0.23	0.96
2			0.39	0.13	0.19	0.09
4				0.32	0.52	0.21
8					0.62	0.61
16						0.37
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

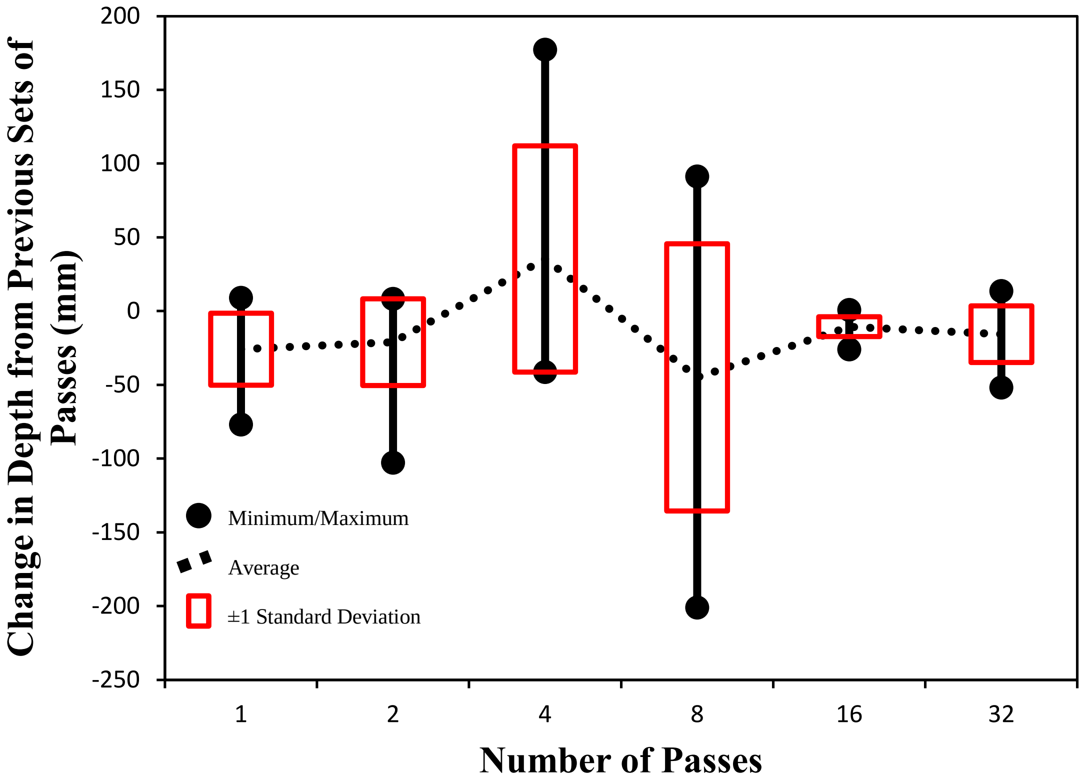


Figure 31. The average change in the depth of the tire tracks at the backshore sites with respects to the previous set of passes before it, meaning that the values represent the change in depth from the 1st set of passes to the 2nd. Also shown on the graph are the maximum and minimum changes in depth.

Table 10

P-values associated with t-tests that compare the change in depths of the tire tracks of each set of passes with each other (backshore sites)

	1	2	4	8	16	32
1		0.67	**0.03**	0.55	**0.03**	0.20
2			0.05	0.45	0.29	0.61
4				**0.04**	0.09	0.07
8					0.23	0.32
16						0.34
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

Once the track has been created, compaction does not play an important role with regards to the evolution of a tire track. Sediment removal, however, has the most important role in the evolution and deepening of a tire track. This can be seen in Figure 32, a graph showing the compaction of the sediment after each set of passes with the volume of sediment lost from each of the tire tracks after each set of passes, based on the set of passes before it. Figure 32 shows that with each set of passes, the amount of sediment lost from the tire track steadily increases. The sediment lost from the tire tracks is defined as the volume of the tire track (the void space created), thus the compaction of sediment and sediment being ejected from the track all account for the loss of sediment. Figure 32 also shows that compaction does not increase with the increase in sediment lost. Thus, compaction does not have a large impact on the deepening and evolution of a tire track. However, sediment removal does play a large role in a tire tracks evolution. Figures 33 and 34 show the relationship between the sediment removed from the tire tracks and the actual sediment lost from the tire tracks. The sediment removed from a tire track is defined as the volume of the mounds that form at the sides of a tire track. The increase in the amount of sediment removed from the tire tracks after the first pass is again a result of the creation of the tire tracks and is directly related to the compaction of the sediment that forms the tire tracks. The volume of the sediment removed from the tire track increases directly with the amount of sediment lost from the tire track, thus leading to the conclusion that the sediment removed from the tire track actually is the main mechanism responsible for the evolution of a tire track. Figures 33 and 34 reveal that the volume of the sediment removed from tire track 1 (T1, landward track) after the first pass is roughly 91.36 % of the entire amount of sediment lost from the landward tire tracks at the foreshore sites. While the seaward tire tracks (T2) have only 159.18 % of the sediment lost coming from direct sediment removal at the foreshore sites. This would mean that after the first pass, 8.64 and 0 % of the sediment loss respectively can be attributed to the compaction of the tire tracks (T1 and T2 respectively) at the foreshore sites. A possible reason that the seaward track experienced sediment removal greater than 100 % of the sediment lost is that some of the sediment ejected from the landward tire track could have landed on the landward mound of the seaward tire track. After 1 pass at the backshore sites, sediment removal accounted for 66.08 and 47.47 % of the sediment lost. Compaction accounted for 33.92 and 52.22 % of the sediment lost from the tire track. The reason that compaction plays a larger role in the evolution of sediment at the backshore sites is that the sediment is much less compact than on the foreshore, allowing the vehicle to compact the sediment.

On average, at the foreshore sites, sediment removal accounted for 93.74 and 104.19 % of sediment removal for the landward and seaward tire tracks respectively. For the backshore sites, sediment removal accounted for, on average, 75.98 and 85.05 % of the sediment lost for the landward and seaward tire tracks respectively. This suggests that sediment removal is the largest impact that can be measured from ORV driving on Assateague Island National Seashore, Maryland.

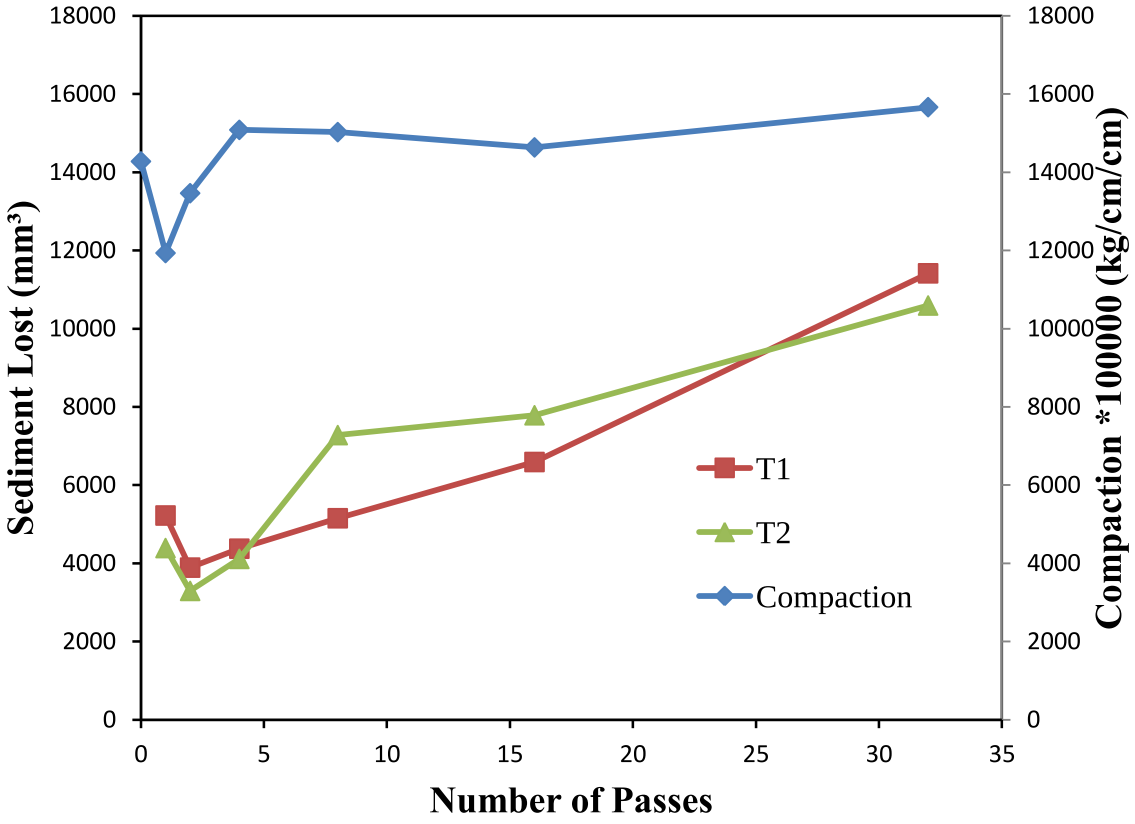


Figure 32. Sediment lost from both of the tire tracks after each of the set of passes and the average compaction across all sites.

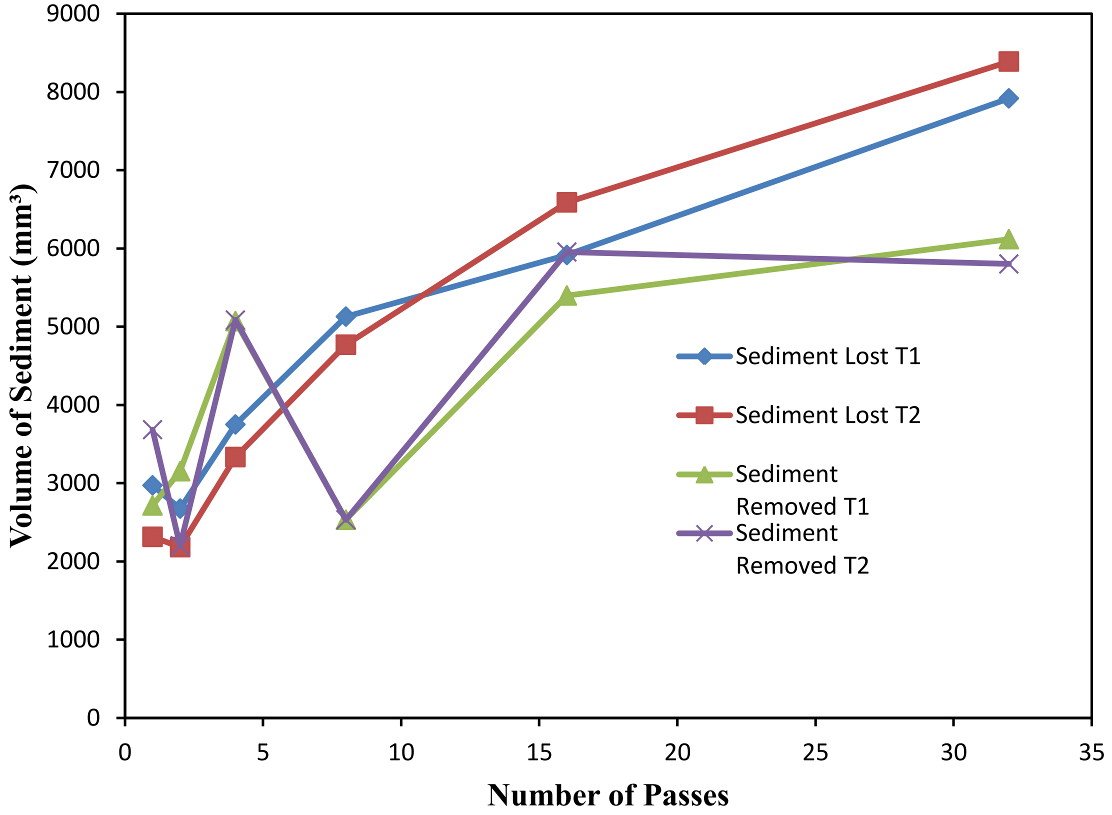


Figure 33. The amount of sediment lost from the tire tracks, along with the physical amount of sediment removed (Foreshore Sites).

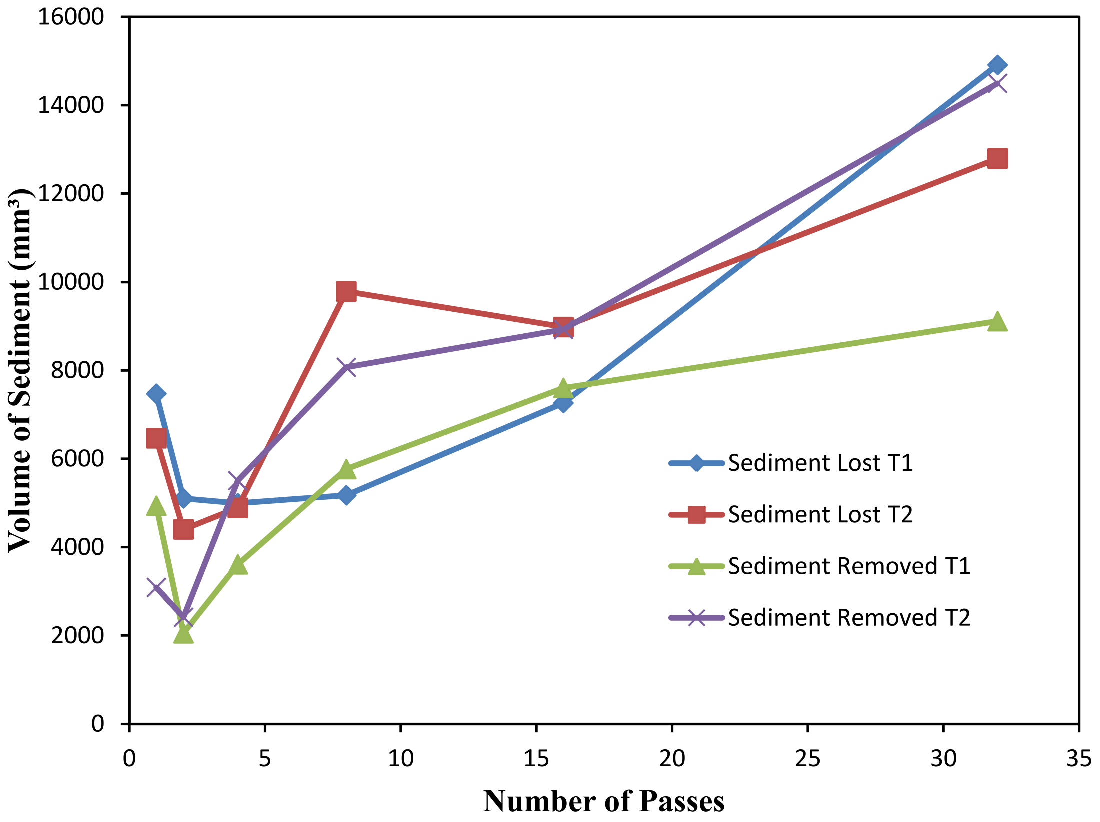


Figure 34. The amount of sediment lost from the tire tracks, along with the physical amount of sediment removed (Backshore Sites).

5.4 Sediment Removal and Calculations

While using the volume of the mounds of the tire tracks as a measurement for net displacement appears to be relatively accurate (Anders and Leatherman 1987a), it is important to remember how a tire track is created. Most of the sediment that is removed from a tire track is done after the first pass by way of the vehicle ejecting sediment away from its path. The question here is whether or not it is important to consider the amount of sediment that is thrown outside of the mounds. The average weights (g) of the sediment collected in each of the dixie cups, along with the average distance away from the tire tracks (Figure 35) shows that only a very small fraction (on average 0.9 %) of the amount of sediment that is thrown from the tire tracks actually makes it outside of the mounds located on either side of the tracks. Figure 36 shows the minumim and maximum values (range) of the sediment ejected from the tire tracks. The figure reveals that the sediment ejected closer to the track has a larger range of variablility than does sediment ejected futher away. Sediment ejected from the tire track was observered at a maximum of 147 g as far awat from the track as 0.5 m. However, once the sediment reached a distance of 1 m away from the track the ranges were consistently at 2 g with only two of the distances having ranges at 3 g. The max standard deviation was with the first observation in the backshore (0.50 m away from the track), in which the standard deviation was 57.98 g. 25 of the 28 observations (14 foreshore and 14 backshore), had the closest distance to the track being 0.66 m and the longest distance being 1.73 m all had standard deviations less than 4 g. With 0.9 % of the sediment removed from the tire track traveling outside of the mounds proving to be negligible and the values used to calculate the weight having a small range of variability, means that the calculation of net displacement is valid without using the volume of sediment that is ejected outside of the mounds.

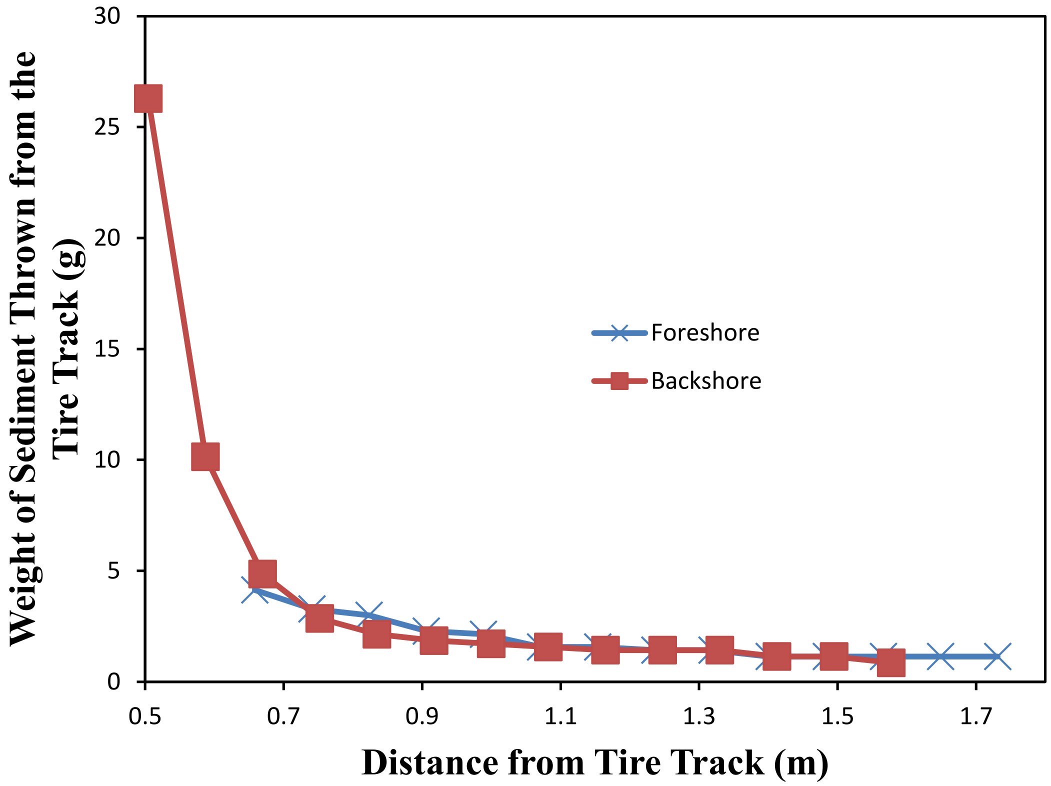


Figure 35. The weight (g) of the sediment that was thrown outside of the mounds and caught by the sediment trap placed perpindicular to the tire tracks. The values are the average from all of the foreshore sites (Foreshore) and backshore sites (Backshore).

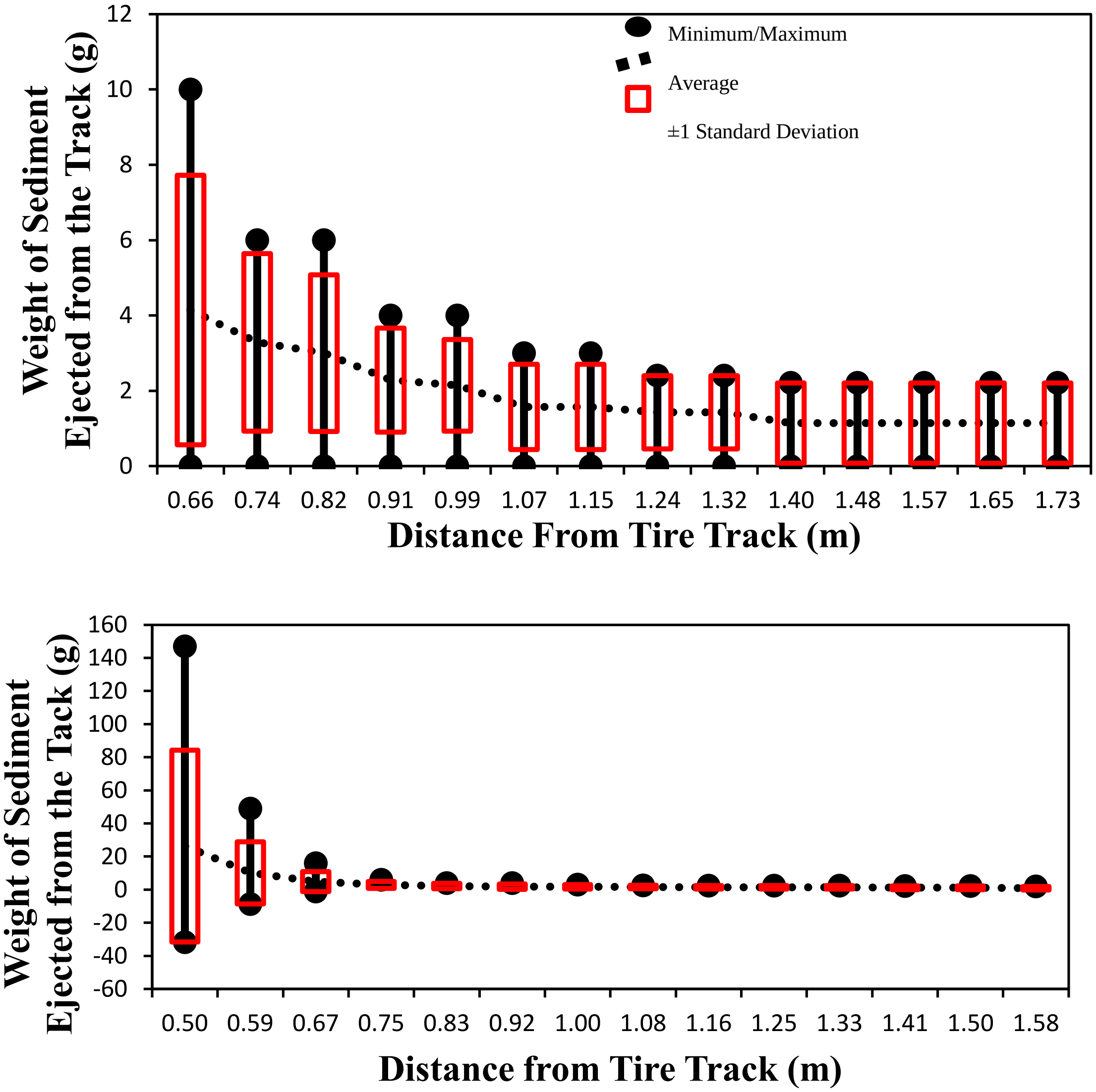


Figure 36. The minimum and maximum values for the weight of sediment ejected from the tire track, as well as the distance it was thrown. The graph also has the averages and ±1 standard deviation for each distance overlaid on it.

Along with sediment removal, it is also important to note that Anders and Leatherman (1987a) examined how slope influenced sediment displacement. Figures 37 and 38 show how the slope of the orginal test surface compared to the net displacement after the experiment was conducted. Figure 37 shows that on the foreshore, the direction of net sediment displacement is directly related to the direction of the slope. If the slope of the original surface sloped landward (positive slope), than the net displacement of sediment was landward. However, if the original surface sloped seaward (negative slope), than the net displacement of sediment was seaward. The direct relationship between the slope of the original surface and the direction of sediment displacement is likely the result of the higher slope angles on the forshore. The higher slope angles causes gravity to impact the direction of the sediment displacement. If the slope of the orginal surface is steeply sloped, than a vehicle will naturally concentrate its driving along the downslope side of a tire track. This is because the vehcile cannot fight gravity's force that brings the vehcile downslope. Figure 37 also shows that on the foreshore, the magnitude of net sediment displacement does not directly relate to the slope of the original surface. Figure 38 shows that on the backshore, the direction of net sediment displacement is not directly related to the slope of the original surface. Two of the study sites that sloped landward experienced a net seaward displacment of sediment while one of the study sites that slope seaward experienced a net landward displacement of sediment. Figure 38, as with Figure 37, shows that the magnitude of the net sediment displacment does not directly relate with slope. Thus, larger slopes does not necessarily mean that there will be larger magnitudes of sediment displaced.

The average slope of the study sites located in the foreshore zone of the beach was -1.45, meaning that the foreshore sites sloped seaward. The sites in the backshore zone had an average slope of -0.01, meaning that the sites did not slope in either a landward or seaward direction. The fact that the direction of net sediment displacement in the backshore does not directly relate to the slope of the orginal surface can be explained by the slope itself. Because the slope is roughly 0, the direction of net sediment displacment will be influenced more by chance, wind direction, and the imperfections of driving. As noted previously, the imperfections of driving on sand (i.e. sliding back and forth within the tire track) will casue sediment to be displaced unevenly. This would result in the direction of sediment displacment being directly related to which side (landward or seaward) of the track was driven on. However, on the foreshore, where driving is less eradic, because of the compaction of the sediment, the slope of the orginal surface will determine the direction of sediment displacment.

Figures 39 and 40 show a diagram of a set of tire tracks along with how much each meachanism that creates a tire track accounts for, in regards to the amount of sediment lost from each tire track. The total percentage does not equal 0 for either track on the foreshore or the backshore because the amount of sediment ejected from the tire tracks outside of the mounds were negligible. However, their exact values were less than 0.1 % of the sediment lost from each of the tire tracks. The seaward track for the foreshore sites had sediment removal account for greater than 100 % of the sediment lost. One way this could occur is if some of the sediment ejected from the landward could have land in the mound or even inside the seaward track. Also, sediment from the mounds could have slid off the mound and back into the track, causing sediment lost values to be scewed towards a lower value. Another explanation of this phenomena is that after the tracks on the foreshore were created, the extensive amount of moisture in the sediment caused the sediment around the tracks to act as a fluid and fill in part of the tracks. Again, this could cause the sediment lost values to actually be less than the amount of sediment removed.

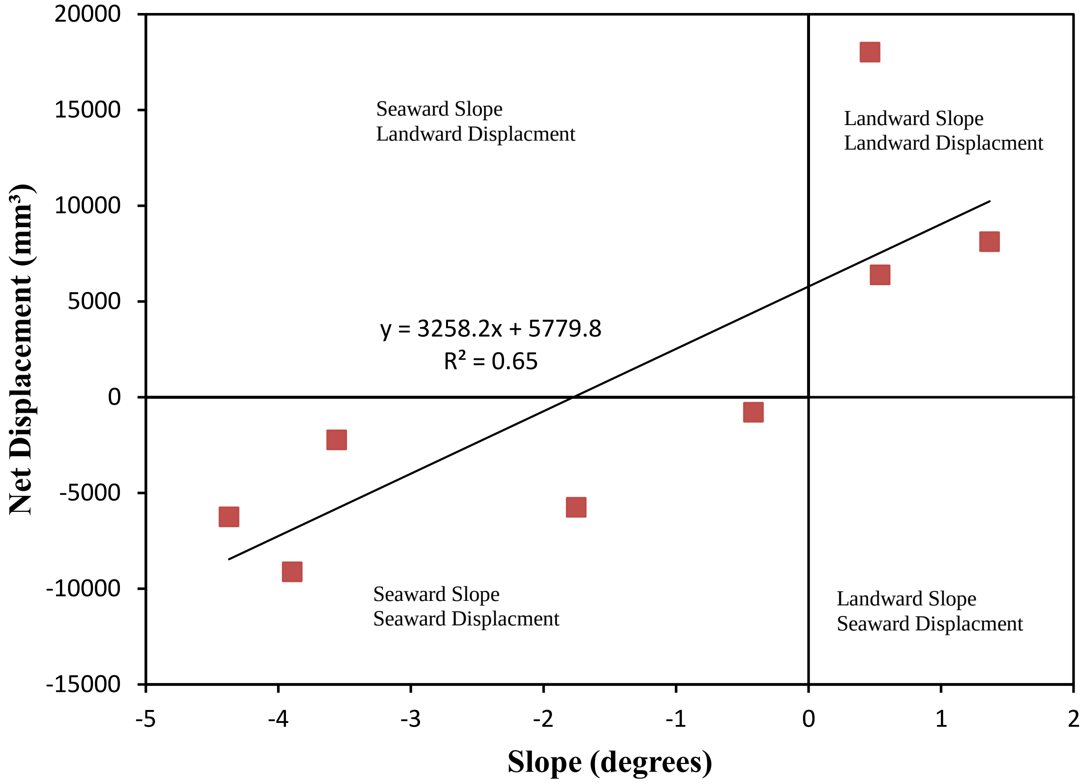


Figure 37. Graph showing the slope of the study sites conducted in the foreshore, along with the net sediment displacment for each study site. The negative slopes correspond to seaward dipping slopes, while the negative net displacments also correspond to a seaward direction of displacment.

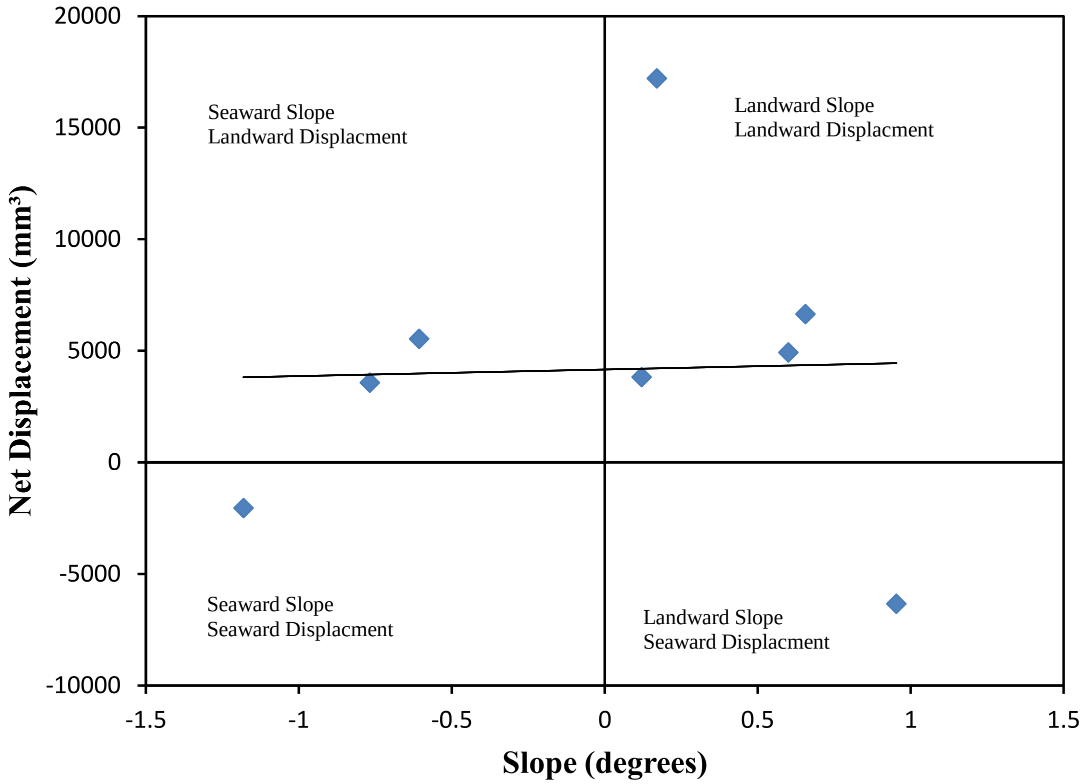


Figure 38. Graph showing the slope of the study sites conducted in the backshore, along with the net sediment displacment for each study site. The negative slopes correspond to seaward dipping slopes, while the negative net displacments also correspond to a seaward direction of displacment.

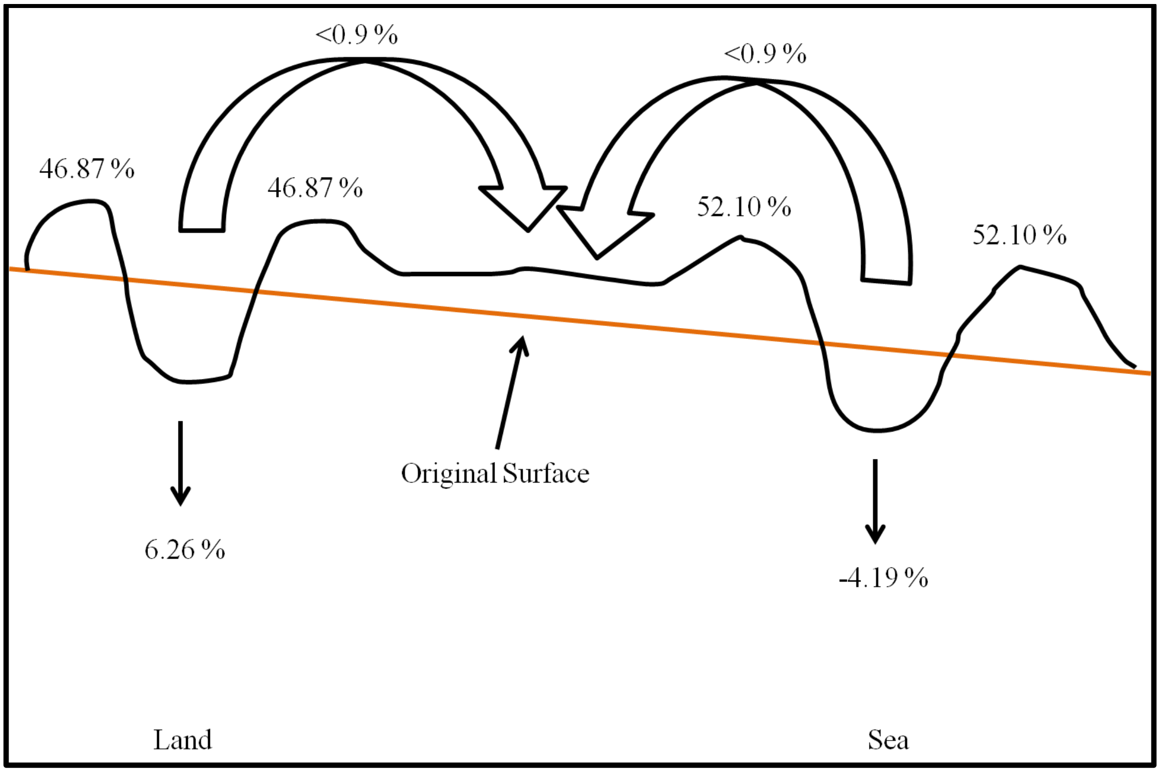


Figure 39. A diagram showing each mechanism responsible for the evolution of a tire track (compaction, sediment removal, and sediment ejection) along with how much of the sediment lost that can be attributed to each. This diagram is for the foreshore sites.

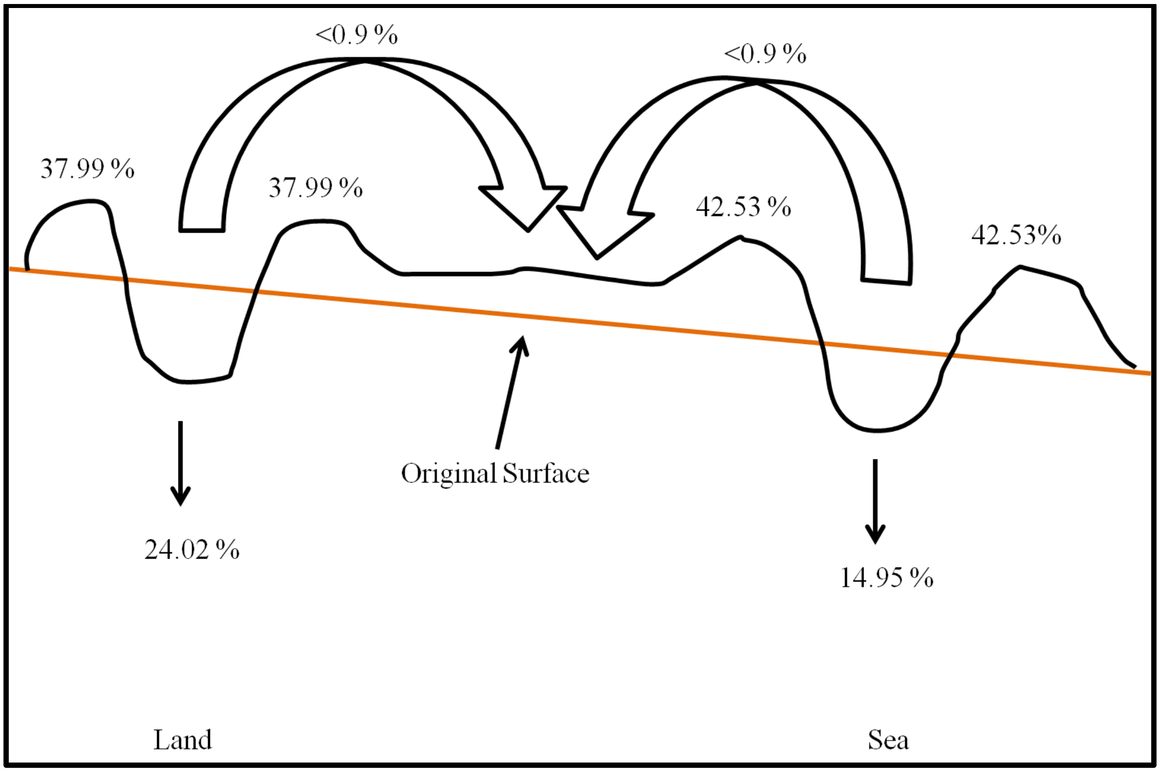


Figure 40. A diagram showing each mechanism responsible for the evolution of a tire track (compaction, sediment removal, and sediment ejection) along with how much of the sediment lost that can be attributed to each. This diagram is for the backshore sites.

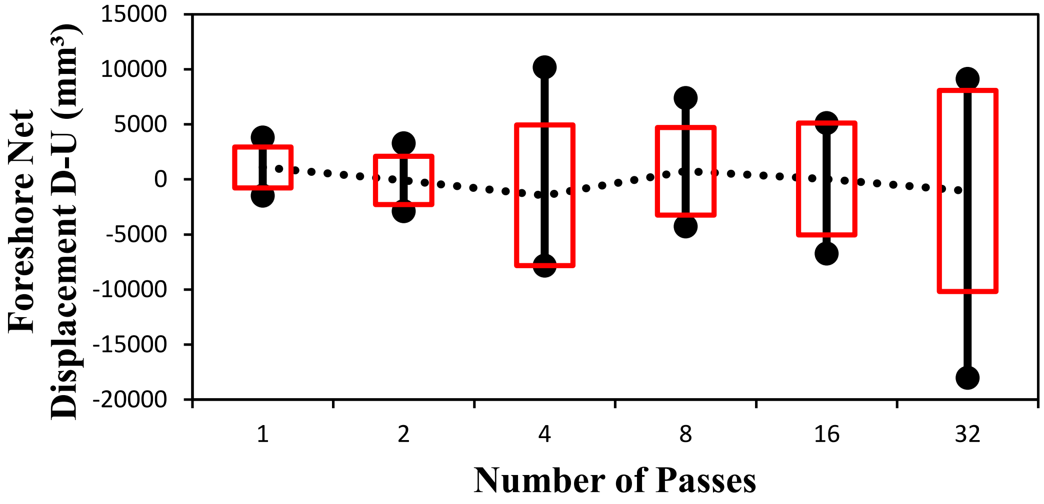
5.5 Sediment Displacement

Anders and Leatherman (1987a) found that the mounds of the tire tracks can reveal the net movement of sediment (downslope or upslope). Figure 25 (above) shows typical tire track at ASIS. The downslope/seaward mound is the right mound in Figure 25 and the upslope/landward mound is the left mound in Figure 25. Using this reference, the net seaward movement of displaced sediment can be calculated. Each zone of the beach will affect the amount of sediment displacement differently and thus the foreshore and backshore of the beach were looked at separately in regards to the tire track dynamics. The volume of the mounds for each of the tire tracks were calculated and put into the equation same equation used by Anders and Leatherman (1987a)

$$\text{Net Displacement } (\text{mm}^3) = \sum \text{D} - \text{U}$$

to determine the average net displacement after each set of passes. The graph below shows the average net displacement after each set of passes for the foreshore and the backshore (Figures 41). The positive values represent a seaward displacement of sediment, while negative values represent a net landward displacement of sediment. The graph shows that of the six sets of passes, three of them result in a net seaward displacement and three of them result in a net landward displacement of sediment. This same result can be seen in the graphs for both the foreshore and the backshore; the only difference is in the magnitude of the displacements. The average net displacement (shown in Figure 41) can also be seen in Table 11, along with the standard deviations after each set of passes. The large standard deviations for average net displacements suggest that the values are not closely grouped together but rather over a broad range of values. The minimum and maximum values shown in Figure 41 also show the wide range of values that make up each average. Although the standard deviations for the net displacements are large, when the values are converted to a more standard unit of measure (m^3) all of the values are less than $1.42 * 10^{-5}$ m^3. This would mean that based solely on displacement measurements (using the mounds of the tire tracks) there is no significant net displacement in one direction or the other.

a)



b)

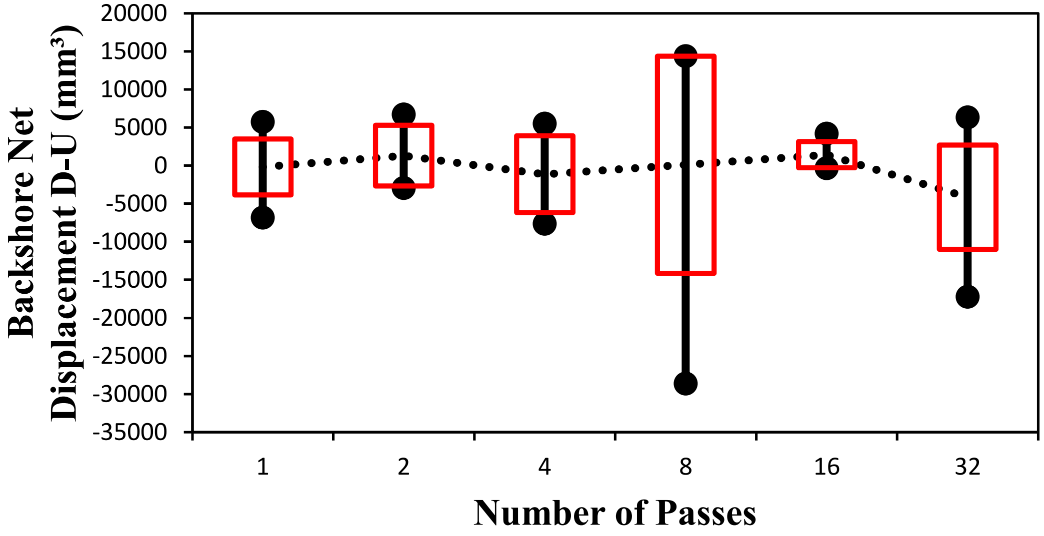


Figure 41. The average net displacement after each set of passes (postive values represent a net downslope/seaward displacement, while negative values represents a net upslope/landward displacement). The graph also shows the minimum and maximum net displacement for each set of passes. Shown are a) Foreshore and b) Backshore.

Table 11

Standard deviations for the net displacement after each set of passes (both foreshore and backshore), along with the average net displacement for each set of passes.

	Foreshore		Backshore	
Number of Passes	Average	Standard Deviation	Average	Standard Deviation
1	1091.70	1853.05	-192.25	3660.37
2	-89.44	2184.96	1292.64	3978.90
4	-1445.54	6385.73	-1139.94	5025.28
8	737.02	3967.01	122.81	14252.97
16	36.20	5078.05	1424.25	1731.06
32	-1043.59	9130.53	-4163.96	6846.65

Both Average and Standard Deviation are measured in mm^3

Tables 12 and 13 also look at the net displacements after each set of passes, but the tables compare the net displacements with each other. By comparing the net displacements after each set of passes with each other, it can be concluded as to the impact of adding additional passes. Both Tables 12 and 13 show that there is no statistically significant difference between any of the sets of passes. This suggests that the same results are observed after 1 pass as is observed after 32 passes. This conclusion is expected, because there is no net displacement of sediment observed at Assateague Island National Seashore, Maryland.

Table 12

P-values associated with t-tests that compare the net displacements after each set of passes with each other (foreshore sites)

	1	2	4	8	16	32
1		0.31	0.38	0.84	0.64	0.53
2			0.64	0.67	0.96	0.78
4				0.50	0.67	0.92
8					0.80	0.63
16						0.78
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

Table 13

P-values associated with t-tests that compare the net displacements after each set of passes with each other (backshore sites)

	1	2	4	8	16	32
1		0.52	0.73	0.96	0.30	0.18
2			0.42	0.85	0.95	0.10
4				0.85	0.33	0.38
8					0.83	0.52
16						0.06
32						

P-value < 0.05 (bold values) means that the two sets of passes are statistically significant from each other

CHAPTER VI

DISCUSSION

Off-road vehicle (ORV) driving at Assateague Island National Seashore (ASIS), Maryland is one of the most popular tourist activities on the island. As such, ORV impacts are closely monitored and managed by the National Park Service (NPS), the U.S. Fish and Wildlife Service, and the Department of Natural Resources. The various management agencies monitor the impacts that ORVs have on animals and the physical environment. They also control the number of vehicles allowed to drive on the beach at any one time. Anders and Leatherman (1987a) have put forth that driving at Fire Island National Seashore, New York directly results in the net seaward movement of 119,300 m^3 of sediment each year. The authors also concluded that vehicles driving on beaches move sediment downslope, which on Fire Island is almost always in a seaward direction unless near the berm (Anders and Leatherman 1987a). From this study, direct sediment disturbance and net seaward displacement has been exhaustively examined in order to determine if there is a net seaward/downslope displacement of sediment and to quantify the level of sediment disturbance at Assateague Island National Seashore (ASIS), Maryland.

This study looked at how a track is created, as well as the morphology of its evolution with the addition of vehicle passes. A tire track was found to be mostly created by the first vehicle pass and then any widening of the track thereafter was a result of the imperfections of driving (i.e. sliding back and forth). It was also found that tire tracks in the backshore were on average 29 % wider than that of tire tracks on the foreshore. This finding is in concurrence with that of Schlacher and Thompson (2008), the backshore zone is more favorable to wider ruts. This result is evident at ASIS, because the less compact sediment in the backshore is already loosened and can be impacted more by the act of driving over it. The sediment on the foreshore is much more compact than the sediment on the backshore and as a result is not disturbed as much.

Schlacher and Thompson (2008) also found that the backshore zone was more favorable for the formation of deeper ruts than was the foreshore. This study also found that the tire tracks in the backshore exhibited deeper ruts, on average 97 % deeper. This finding is also most likely the result of the sediment in the backshore being much less compact (lack of moisture content) than the foreshore. Another finding that was similar to that of Schlacher and Thompson (2008) was that the foreshore experienced the greatest amount of sediment compaction. The foreshore experienced 120 % more sediment compaction that did the backshore. Schlacher and Thompson (2008) also found that the backshore experienced 155 % more sediment displacement than the foreshore. However, this study found that at ASIS, the foreshore experienced (on average) 13 % more sediment displacement than the backshore. The fact that the foreshore experienced more sediment displacement than the backshore is directly attributed to the slope of the beach at ASIS. The study sites for the foreshore at ASIS had an average slope of -1.45 (seaward dipping slope), while the backshore had an average slope of -0.01(seaward dipping slope). Because the slope of the backshore was almost perfectly planar, the sediment was displaced more evenly between the land and the sea. Although the foreshore experienced 13 % more sediment displacement, both net displacement values were 0. This would mean that there really is no difference between the foreshore and the backshore, in terms of sediment displacement at ASIS.

Anders and Leatherman (1987a) only included the sediment located within the mounds on either side of tire tracks in their calculations of the net seaward movement of sediment. The sediment ejected beyond the mounds was taken into consideration for this study. However, only 0.9 % of the sediment ejected from a tire track reached beyond the mounds. This led to the decision to leave out those measurements, because they were negligible when calculating net seaward displacement.

Ander and Leatherman (1987a) found that the greater the slope of the beach, the greater the magnitude of sediment that is displaced. They also found that the direction of sediment displacement (i.e. land or seaward) is directly related to the original slope of the surface. However, this study found that ASIS the magnitude of sediment displacement is not directly related to the slope of the original surface. It was also found that only on the foreshore was the direction of sediment displacement directly related to the slope of the original surface. The direction of sediment displacement on the backshore at ASIS is not directly related to the slope of the original surface. On the backshore, 38% of the sites had the direction of sediment displacement indirectly related to the surface of the original slope. One reason that these findings are drastically different is that the shorelines are different. Anders and Leatherman (1987a) conducted their reasearch along a beach which had seaward dipping slopes between 1.5 and 2.5

degrees, with no slope smaller than 1°. The average slope of the test sites on ASIS were 1.45° for the foreshore and 0.01° for the backshore (both the foreshore and backshore slopes at ASIS sloped seaward). With the backshore slopes being close to planar, the sediment displaced can be influenced more by outside forces (such as wind). These outside forces can cause the sediment displaced on the backshore at ASIS to periodically be displaced landward even though the slope of the beach is in fact seaward. As noted previously, some of the seaward sloped sections examined at ASIS exhibited a net landward movement of sediment, which is in contrary to what Anders and Leatherman (1987a) concluded.

This study also determined how much sediment loss that can be attributed to each mechanism of creating a tire track. Along the foreshore, compaction accounts for 6.26 and 0 % (T1 and T2 respectively) of the sediment lost from a tire track. Sediment removal accounted for 93.76 and 104.19 % (T1 and T2 respecively) of the sediment lost. This leads to the conclusion that sediment removal is the largest impact ORVs have at ASIS. One reason why sediment removal accounts for greater than 100% of the sediment lost for T2 on the foreshore is that the high moisture content of the sediment in the foreshore causes that sediment to become fluid and try and fill in the void space left from the removal of sediment. If the void left from the removal of sediment is decreased by sediment filling it in, than the amount of seidment removed from the tire track will be greater than 100% of the sediment lost. On the backshore, compaction accounts for 24.02 and 14.95 % (T1 and T2 respectively) of the sediment lost. This means that sediment removal accounts for 75.98 and 85.05 % (T1 and T2 resectively) of the sediment lost. As with the foreshore, sediment removal is the main mechanism that creates and allows the tire track to evolve with increasing passes.

Based on this study, it can be concluded that at ASIS there is no net seaward displacement of sediment directly caused by vehicles and their tire tracks and as such no net erosion offshore. Although there appears to be no direct erosion evident in the offshore direction, it cannot be concluded that there is no indirect erosion as a result of ORV driving. This is because it is not known if the loosened sediment that results from OVR driving is impacted by the prevailing winds in the region. In other words, it is not known as to how or if the wind regime at ASIS affects the loosened sediment (i.e. transports the sediment landward, seaward, or has no affect). A further study would need to be conducted to determine if the loosened sediment is eroded from the beachface landward towards the dune, or if the wind regime has some other affect on the loosened sediment.

Both Schlacher and Morrison (2008) and Schlacher and Thompson (2008) found that sediment displacement was greater in magnitude in the backshore, as well as was larger in magnitude with larger vehicle volumes. This was also observed at ASIS, the backshore experienced 82 % more sediment displacement than did the foreshore. Also the largest amounts of sediment displacement occurred with the largest number of vehicle passes.

The large net downslope displacement values that Anders and Leatherman found might have been influenced by the seaward sloping beachface (1.5 to 2.5 degrees) at Fire Island National Seashore, New York. However, their conclusion that sediment is displaced downslope (in a seaward direction) is not a valid or accurate statement when it comes to other beaches around the world. This is because the results showed that at ASIS 38 % of the sites on the backshore had an indirect relationship between slope and the direction of displacment.

The results of this study also show that optimal (maximum reduction in downslope displacement of sediment) location to drive along the beach at ASIS is on the backshore. This is because displaced more evenly between the landward and seaward. However, driving on either location will result in no net displacment, landward or seaward. This study aslo shows that driving in the foreshore does not lead to beach erosion/loss of sediment as was concluded by Anders and Leatherman (1987a).

This study looked at the impacts that ORVs have at ASIS during the peak summer months (tourist activity and vehicle volume all peak during the summer) and replicated the normal driving conditions seen in the OSV zone. Also, the weather conditions (i.e. the wind speed, wind direction, rainfall, and storm activity) that can influence the results are specific to the timeframe of the summer months at ASIS. With the average grain size at ASIS being on average 0.30 mm (Leatherman 1979a), the wind direction and speed can scew the results of this study. With the threshold velocity to initiate motion being 0.4 m/s (Dong et al. 2002) and the average wind speed during the months of this study being 3.82 m/s, it is conceivable that sediment was blown from outside of the tire track to within the tire track and vice versa. However, the amount of sediment that could be transported into and out of the controlled field experiements is minimal. This is because the amount of time between tests were kept to round 10-15 minutes.

When comparing the results of this study to those conducted by Anders and Leatherman (1987a), Schlacher and Thompson (2008), and Schlacher and Morrison (2008), it is important to note that their studies took place during different timeframes. Anders and Leatherman (1987a) conducted their experiements over two field seasons, while Schlacher and Morrison (2008) conducted theirs during a one month period in the summer (peak season). Schlacher and Thompson also conducted their experiments during the peak season. With all of these studies, including this one, it is imnportant to cautiously compare the results.

A further direction that this study may take is in looking at how ORV driving is affecting the dune system at ASIS, as well as how it is changing the beach-dune interaction system that supplies the sediment necessary for dunes to grow and evolve through time. If further studies can show that there is no considerable impact to the beach-dune system, than it can be concluded that driving ORVs on the beaches of ASIS and other beaches of similar profile will cause no erosion or damage to the complex systems that create them. Another aspect to ORVs impact on dunes, is their impact on the vegatation that stabalizes the dune complexes at ASIS and other beaches in the United States. If the sediment suply to the dunes are disrupted by ORVs, than how does that impact the vegetation. As with the possible impact of ORVs on the vegatation, ORVs may indeed have a much larger impact on the wildlife and habitat of many of the animal species that call ASIS home. Further research into the crushing force and impacts that ORVs have would be essential to the NPS protecting the habitat of certain species such as ghost crabs. Other research that could help ensure that the NPS protects endagered species would be on the effects ORVs have on the reproducing and early lives of piping plovers on the island or even the feral horses. However, superficial and physical the impacts of ORVs are, the biggest impact they can have are on the tourist that enjoy ASIS and other national seashores.

With many tourists coming to national seashores for the asethetic beauty of the untouched shorelines, a study on the impact ORVs and how they impact the asethetic beauty of a beach might help to better inform the NPS at to how to manage ORV traffic at ASIS, as well as at other national seahores around the United States. Each and every vehicle that travels outside of already established tire tracks, creates a new set of tire tracks that may never disapear (depending on where future vehicles drive). Figure 42 shows a semi-permanent set of tire tracks at ASIS. This set of tire tracks remains permanent almost year round, because of the constant flow of NPS and Law Enforcement vehicles through those specific tire tracks. Tourists that do drive in the Oversand vehicle zone also are more prone to cause damage to the asthetic qualities of the prestine untouched beach. Figure 43 shows how careless tourists can leave a lasting mark on the asthetic beach of the beach. This type of driving has not been studied, with regard to its effects on tourists perception of the asthetic qualities of the beach or how it effects sediment displacement, erosion, or beach-dune sediment supply. Other than a decrease in the asthetic beauty of beaches, there is no need to restrict or curtail the driving of ORVs at ASIS and other beaches of similar makeup.

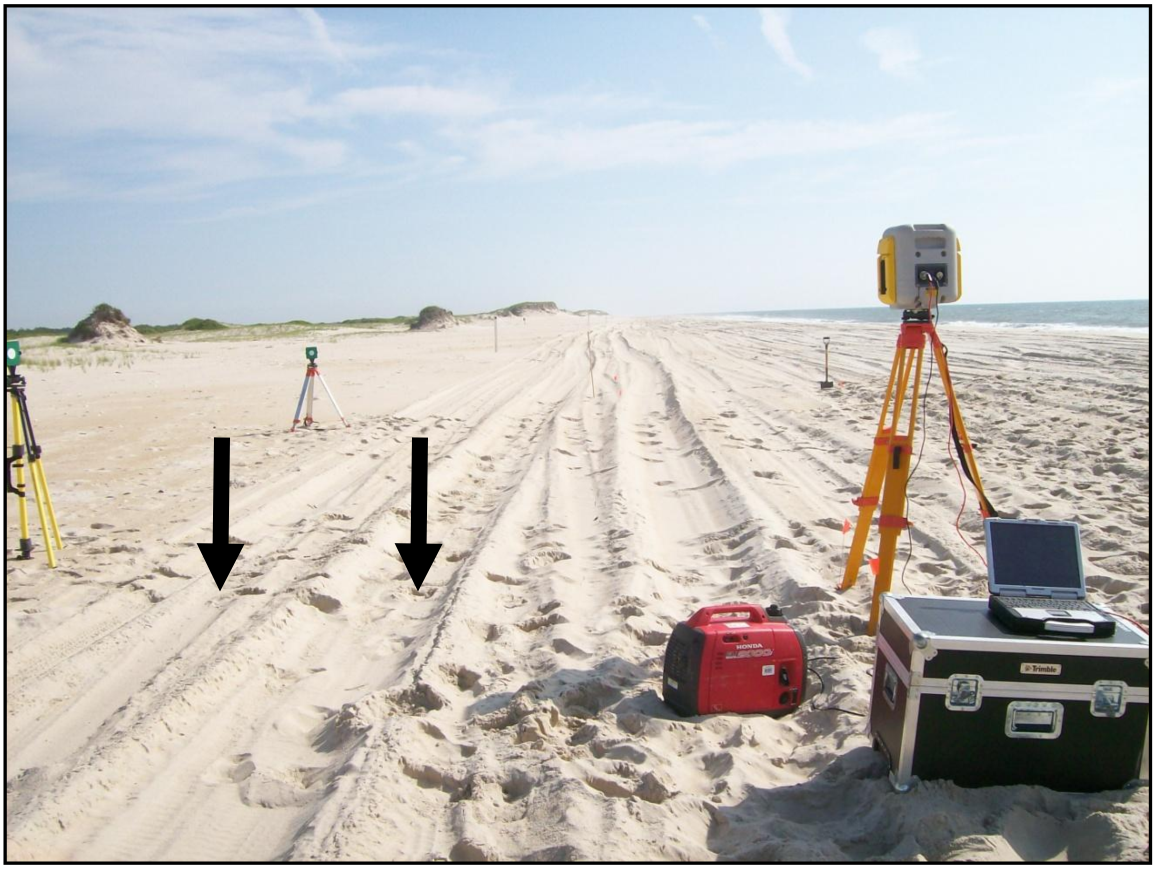


Figure 42. Semi-permanent tire tracks in the backshore of the beach at ASIS. The tire tracks are marked with the arrows.

Figure 43. An image of deep ruts across the beach caused by tourists at ASIS.

CHAPTER VII

CONCLUSION

This study has looked at the various ways in which ORVs affect the physical environment of Assateague Island National Seashore (ASIS), Maryland. ORVs create deep tracks in the sediment along beaches and do so by ejecting sediment from its path, by compacting the sediment, by pushing the sediment aside, or by a combination of these methods. The results of this study reflect normal driving conditions during the high vehicle volume months at ASIS. The ejection of sediment is one of the two primary mechanisms that create the initial tire tracks, as well as influences the morphology of the tire tracks. Along with the ejection of sediment, the vertical compaction of sediment also plays a minor role in the morphology of tire tracks. Vertical compaction plays a minor role in the creation and evolution of a tire track, while sediment removal attributes to greater than 75 % of the sediment lost from the tire tracks. This leads to the conclusion that the most important and influential mechanism to the creation and morphology of tire tracks is the sediment removal generated from the vehicles driving over the sediment.

The width of the tire tracks changes randomly from the act of inconsistent driving (i.e. sliding around within the tire track). This means that the width of the tire tracks will increase and decrease as a result of a driver driving slightly off of the center of the track, either filling the track up and decreasing the width, or ejecting more material and widening the track.

Ultimately this research was conducted to determine if ORVs driving along the beach at ASIS are causing a net downslope/seaward displacement of sediment. It is concluded that there is no net downslope/seaward displacement of sediment from ORVs driving on the beach. However, it also is concluded that there is no net upslope/landward displacement of sediment either.

While these conclusions look at the small scale processes involved with ORVs at ASIS, there are larger scale processes and influencing factors that can control how ORVs impact the coastal environment. The natural variability of the beach-dune system can actually cause different results to be experienced along a beach. As a beach progresses through the various beach states and sediment is transported into, out of, and throughout the beach-dune system, the affects of ORVs become minimal at best (Wright and Short 1984).

7.1 Management Practices

The National Park Service (NPS) at Assateague Island National Seashore (ASIS) is responsible for preventing humans from impeding upon and damaging the physical environment. With the aforementioned conclusions about the impacts ORVs have on the physical environment, specifically the beach, at ASIS, a number of management practices can be recommended to the NPS to help ensure their goals are met.

The most important recommendation would be that the backshore section of the beach is the best location to drive along the Oversand Vehicle (OSV) zone. Driving on the backshore would limit the amount of sediment being displaced seaward and prevent any erosion that could take place in the swash zone. The flat slope of the backshore will actually allow sediment to be displaced landward and seaward equally. The second recommendation would be to not limit the number of vehicles that can drive along the OSV zone. The number of vehicle passes does not cause the volume of sediment displacement to increase. The volume of sediment displacement is controlled by how people drive, where people drive, and other unknown factors. The NPS should also know that at ASIS there cannot be direct beach erosion caused by ORVs. If there is no net downslope displacement of sediment by ORVs, which is the case at ASIS, than there cannot be erosion of that sediment in the swash zone. The flat slope of the backshore will actually allow sediment to be displaced landward and seaward equally. The management practices and recommendations mentioned above should however not be immediately considered by other management organizations. It is important to remember that this study was conducted during a two month period at ASIS. The results, conclusions, and recommendations are specifically for ASIS and during the high vehicle volume summer months. A multiple year study would need to be conducted in order to determine how weather conditions (i.e. wind, rainfall, storms, etc.) might affect or change these results. Some results that are transferable from this study to locations across the United States, is that driving on the backshore will limit the most amount of direct impact to the physical environment (on relatively planar backshores). Similar beaches to that at ASIS can use these management practices, each beach is unique and individualized, thus each beach will see different results.

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