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UNDERSTANDING THE EFFECTS OF SAND FENCE USAGE AND THE RESULTING LANDSCAPE, LANDFORMS AND VEGETATION PATTERNS: A NEW JERSEY EXAMPLE

by

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ABSTRACT OF THE DISSERTATION

UNDERSTANDING THE EFFECTS OF SAND FENCE USAGE AND THE RESULTING LANDSCAPE, LANDFORMS AND VEGETATION PATTERNS: A NEW JERSEY EXAMPLE

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Dissertation Director:

Karl F. Nordstrom

Sand fences are important human adjustments modifying the morphology of developed shores because they are inexpensive, easy to build and permitted seaward of dunes. The effects of sand fences on sediment transport and deposition in the early stage of their use are well known, but little is known about the significance of sand fences as instruments of landscape change and the effect of their late stages when they have deteriorated into weathered remnants and potential low scale barriers benefiting dune vegetation growth. This study identifies the role of sand fences in modifying coastal dunes. Effects of fence usage were evaluated in 29 municipalities of the developed coast of New Jersey over a 6-year period through a video inventory, interviews with municipal officers and field reconnaissance. Data on vegetation, topography and fence characteristics were gathered at four dune sites within Stone Harbor and Ocean City, New Jersey during September 2007 and March 2008. Variables include: vegetation diversity and density, distance of vegetation quadrat landward of dune toe, degree of sheltering, sediment deposition and erosion, presence of remnant fence, and distance of vegetation quadrat landward and seaward of fence. Results reveal that sand fence characteristics define the coastal landscape and communicate management goals which presently are not based on restoring landforms and habitats; use of fences can be made more compatible with natural processes and biota if careful consideration is given to their initial placement, sand fences remain visible when deployed at locations of low sediment transport; vegetation diversity does not increase near remnant fences but accretion caused by fences in the past may result in topographic diversity which benefits the development of specific vegetation communities.

Dedication and Acknowledgement

I dedicate this dissertation to my family who even from far away did everything they could to help me, unconditionally support me and encourage me to persevere. To my sister who came and rescued me when I was sick and every time I needed her. To my boyfriend who's support has gone from help in the field, to making me laugh, to providing a crying shoulder and words of encouragement.

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Table of Contents

Lists of tables

List of illustrations

Chapter 1: Research background, statement and purpose

1.1Introduction

Geographic science is interactively linking human and physical dimensions by seeking to understand human-environmental relations (Golledge 2002). As a consequence of the processes of interaction between these relations, a spatial arrangement or pattern develops. The knowledge of geographic space represents the connection between the pattern-process dynamic which creates landforms and landscapes.

Biogeographic patterns across a landscape reflect the interplay of disturbance dynamics and gradient zonation (Stallins and Parker 2003). This interplay establishes a network of feedbacks among vegetation, landforms and sediment mobility which characterizes biogeomorphic environments (Parker and Berdix 1996). The characteristics of these environments will be modified in time and space, having specific occurrence periods and spatial extensions.

The biogeomorphological characteristics of a coastal dune environment depend on four main factors: (1) beach morphology and shoreline dynamics, which influence the rate of sand supply, grain size, and area of sand exposed to wind action; (2) wind characteristics; (3) the extent and growth form of vegetation cover (density, distribution and height); and (4) human activities, such as sand fence building (Pye 1990, Hesp 1991). The relationships among these factors have consequences for pattern formation depending on zonation and disturbance dynamics. The relative importance of disturbance and zonation as structuring agents is scale dependent, varying in time across geographic space (Peet 1992). Dune gradational zones have distinctive processes and disturbance factors which create heterogeneous environments that can be explained through spatial interactions and scale differences. The characteristics of each zone on the dune gradient are greatly affected by physical and human barriers to sediment transport such as vegetation, topography and sand trapping fences.

Sand fences are important human adjustments affecting the morphology and vegetation on sandy coasts because they are one of the few structures permitted seaward of the dune crest; they are inexpensive, easy to emplace; and they are usually deployed on the dynamic backshore (Nordstrom 2000). Sand fences are physical boundaries which limit the movement and occurrence of fauna and flora. Human impact, such as that caused by fences, can sharpen natural ecological boundaries (Correl et al. 1991) and halt natural flows of organisms and non organic material (Harris 1991). Fences delimit a space; they are frontiers determining the difference between two spaces and their purposes. Fences are perceived as barriers; they show people the space they can occupy and the space that is out of their reach. Once a fence is built, each space on opposite sides of it obtains a meaning and an importance which depends on the presence of the fence. Meaning can be attributed to the fence itself as a result of history and cultural heritage (Eley and Northon 2003). In the case of New Jersey, wooden fences contribute to the creation of a landscape and characterize and build on a coastal heritage that speaks of the history of the shore. Fences are such crucial elements of developed coastal landscapes throughout the world that is often difficult to think about the coast without picturing them.

Developed shores are often characterized by other human-made shore parallel structures such as, boardwalks, and bulkheads. Sand fences are coastal structures that contribute to dune formation and are useful in controlling wind-blown sands preventing the inundation of cultural features (Nordstrom 2000, Sherman and Nordstrom 1994). Use of sand-trapping fences, hereafter termed sand fences, is documented as early as the 15^{th} Century in Europe (Cordshagen 1964; van der Laan et al. 1997), and they are now deployed all over the world (Bouaziz et al. 2003; Gómez-Pina et al. 2002; Hotta et al. 1987, 1991). Sand fences have not only transformed the morphology of the shore, they are now an accepted part of the coastal image. The geomorphic and engineering purposes of sand fences are well studied (e.g. Gares 1990; Hotta et al. 1987, 1991; Mendelssohn et al. 1991; Miller et al. 2001; Snyder and Pinet 1981).

Many of these studies have evaluated the early stages of sand fences and their effect on sediment transport and deposition. Nevertheless, little is known about the significance of sand fences as instruments of change in landscape characteristics and the effect of late stages of sand fences when they have deteriorated into remnants within the vegetated dune. This dissertation analyzes remnant fences as unintended outcomes of fence deployment and identifies the effect of their location in the dune gradient on the distribution of dune vegetation density and diversity.

1.2 Objectives

The objectives of this dissertation are: (1) analyze the significance of sand fences on coastal landscapes (Chapter 3); (2) describe and characterize the history of fence usage in New Jersey (Chapter 4); (3) evaluate the intended and unintended effects, and rationale of sand fence deployment (Chapter 5); (4) relate the presence of remnant fences within developed dunes to vegetation density and diversity (Chapter 6); and (5) identify the management implications (Chapter 7).

The first two objectives establish the context of this study through a review of the literature about fences as landscape boundaries and a more specific look at the significance of sand fence deployment on a representative developed coast. The third and fourth objectives involve the evaluation of data collected to understand the effect of fence usage in modifying the character of the coastal landscape and in the distribution of geomorphological and vegetation characteristics.

The third objective was accomplished through a sand fence inventory of fence usage at the municipal level, where most decisions about fence deployment are made, and the resulting landscape modifications. Steps involve (1) identifying the many purposes and effects of fences, including those not solely designed for use in the coastal zone; (2) conducting an inventory of sand fence characteristics on a representative developed coast; (3) identifying how these characteristics change over several years; (4) identifying reasons why municipal managers install fences and select the locations and configurations for fence construction; (5) identifying the unanticipated outcomes of fence construction; and (6) suggesting alternative methods for emplacing fences on beaches and dunes.

The fourth objective was accomplished through a detailed ground survey of dune morphology, fence and vegetation characteristics to analyze the local effects of remnant fences. Variables include: vegetation diversity, vegetation density, distance landward of dune toe, degree of sheltering, sediment erosion and deposition, presence of remnant fence, distance landward and seaward of fence, fence location and fence height. Data collection involved: (1) cross-shore topographic transects to relate the variables to their location in relation to distance landward of the dune toe and from fences and (2) an alongshore transect to evaluate variables directly landward and seaward of a single remnant fence.

1.3 Importance of vegetation on dune development and factors affecting community survival and evolution

Dune formation is a function of sediment grain size, characteristics of beach profile and wind regime. Once sediment transport is initiated by wind entrainment, deposition is controlled by topography, presence or obstructions (litter, tree trunks), and above all vegetation (Carter et al. 1990). Few plant species survive in the harsh beach/dune environment (CERC 1984). Much of the success of dune vegetation depends on their ability to tolerate stress such as sand burial, salt spray, sand salinity, sand blasting, high temperatures, exposure to full sunlight, desiccation, lack of moisture and nutrient deficiencies (Boyce 1954, Costa et al. 1996, Hesp 1991, Maun 2004, Ripley and Pammenter 2004, Wilson and Sykes 1999). The level of tolerance of each species to a specific stress depends on their individual adaptations (Table 1.1).

Onshore stresses (ie. sand burial depth, salt spray concentration, and wind velocity) decrease with distance from the shoreline creating different cross-shore habitats and eventually leading to the establishment of ecologically distinct zones that represent different stages in succession (Maun 2009). These dune zones are discrete and occur in parallel series with species composition related to the ability of each species to withstand the environmental factors prevailing in that zone (Doing 1985).

Table 1.1: Stresses and corresponding adaptations of dune vegetation species (Costa et al 1996, Hesp 1991, Maun 2004, Wilson and Sykes 1999)

Stress	Adaptation
Sand transport	Thick stems, broad and hairy leaves, 35 cm height
Sand burial	Increased seed, root, and shoot development, growing, up through deposited sand and remaining alive in the dark until deposited sand is blown away
Salt spray	Salt resistance or salt preferring/tolerance, enlargement of cells leading to thicker leaves
Sand salinity	Salt resistance, high requirement for salt, salt bladders
Lack of moisture, dryness, high light intensity and temperature, wind exposure	Leaf rolling, leaf orientation , leaf hairiness to trap moisture and reduce evaporation, leaf loss, deep roots, heat tolerance, succulence, efficient water use

Sediment transport is one of the primary factors controlling dune vegetation types and the structure of plant communities because it has direct mechanical effects on burial and erosion (McLachlan 1990, Moreno-Casasola 1986). Burial in sand alters all aspects of the plant and the soil micro environment including soil temperature, soil moisture, bulk density, nutrient status, soil pH and oxygen levels (Maun 2004). Individual plant species may respond differently to varying degrees and rates of sand inundation and burial (Hesp 1991).

Amounts of burial specific to a species are beneficial and stimulate plant growth but, above a certain threshold level specific to each species, burial becomes a stress (Maun 2004). These different reactions have been classified into three plant response categories including positive, negative and neutral responses (Table 1.2). The differential tolerance of sand dune species to burial may be one of the principal causes of zonation of plant species on coastal foredunes (Maun and Perumal 1999).

Dune zones where high sand transport and deposition take place, such as the primary foredune, are colonized by pioneer vegetation species (ie. Ammophila), which

Table 1.2: Plant responses to burial (Maun 2004)

Positive stimulatory	Plant exhibits enhancement of growth following a certain threshold level of burial
Negative inhibitory	Plant is unable to withstand burial and dies
Neutral and then negative	Plant shows little or no visible response initially because burial depth is within its limits of tolerance, but as sand accretion increases the response becomes negative and the plant eventually dies

contribute to dune initiation and stabilization of the sandy substrate (Cheplick 2005, Hesp 1991). Previous studies in natural dunes on New Jersey have demonstrated that Ammophila breviligulata, a common pioneer dunegrass species in the northeastern United States, can be especially vigorous in zones with an average sand deposition of 17-28 cm (Martin 1959). Ammophila decreases in vigor as deposition decreases landward and is eventually replaced by successional species landward of the seaward ridge as the dune grows seaward and soil nutrients increase or stress levels decrease (Hesp 1991). Examples of such successional species include Hudsonia tomentosa and Juniperus virginiana (Table 1.3).

Stress decreases landward of the seaward ridge, as a consequence of topographic sheltering, but topographic variability can create either sheltered or exposed locations on the dune surface. Sediment transport rates vary along the dune gradient; decreasing with distance from the oceanic source during onshore winds (Arens 1996) due to an increase in obstacles provided by vegetation and topography. Remnant sand fences are additional obstacles that may shelter vegetation from onshore stresses or trap seeds creating local micro-environments within the dune.

Table 1.3: Description of vegetation zones corresponding to dune succession stages in the natural dune complex of Island Beach State Park, NJ (Martin 1959)

Vegetation community	Dune zone	Stresses	Species
Dunegrass	Seaward slope, crest and backslope of primary foredune or seaward ridge	High exposure to windborne salt spray, marked deflation (wind erosion) and deposition, low moisture content, and extreme temperature fluctuations	Ammophila breviligulata, Cakile edentula, Euphorbia polygonifolia
Heather	Seaward slopes of secondary foredunes	Less exposed to sand movement and windborne salt spray than dunegrass	Hudsonia tomentosa, Panicum amarum
Ticket or shrubs	Backslopes and swales	Exposed, at canopy height, to considerable amounts of salt spray, but they are not generally exposed to burial by sand	Myrica Pensylvanica, Prunus serotina, Juniperus virginiana
Woodland	Landward of secondary foredune (300 m landward of shoreline)	High intensity of salt spray only at canopy height	Juniperus virginiana, Ilex opaca, Prunus serotina

1.4 Conceptual model of sand fence effect on dune vegetation distribution

Sand fences increase the rate of sand accumulation during the initial stage of the dune building process (Mendelssohn et al. 1991, Miller et al. 2001, Nordstrom et al. 2007) causing greater deposition over a shorter period of time than any dune vegetation species. They are used as primary dune building barriers controlling sand transport by wind (Hotta et al. 1987) and affect dune formation by concentrating sediment deposition which prevents sediment transport to landward dune locations (Gares 1990). Since even burial-tolerant plants will be negatively affected by burial that exceeds their stimulus threshold (Maun 2004), dune building is faster and more reliable through fence deployment.

Sand fences become buried with time when they are deployed at locations where sediment transport is sufficient for them to cause enough deposition, such as at the dune toe. Sand fences may not become completely buried, remaining partially visible if they are deployed at locations with low rates of sediment transport. This condition occurs if sediment transport is obstructed by a seaward barrier such as when multiple fence rows are deployed simultaneously. The seaward-most fence will trap most of the onshore sediment transport, preventing landward transport and the burial of the landward fences.

The effectiveness of fences at reducing wind speeds and causing deposition has made fencing a cost-effective method for sand stabilization (Bofah and Ahmad 1985). Further benefits of fencing are the protection of vegetation against sand blast, the promotion of a microclimate conducive to vegetation growth, the contribution to plant diversity by trapping seeds, and the creation of distinctive vegetation patterns by providing local scale boundaries that influence rates of sand transport (Bofah and Ahmad 1985, Nordstrom et al. 2007). These fence benefits are possible once the fence has caused sufficient deposition to become partially buried, the dune has grown seaward, and fence position has changed from a high to a low sediment transport zone (ie. from dune toe to backslope).

Most of the issues related to sand fences reported in the literature are illustrated in the ways fences are deployed on the ocean shore of New Jersey. Sand fences have been employed for building dunes at the New Jersey shore for decades and especially since the 1980's when the New Jersey Shore Protection Master Plan was implemented (NJDEP 1984).

1.5 Relevance of sand fences for coastal management

This study addresses the long-term unintended consequences on vegetation growth once they are incorporated into the dunes as remnants. The results obtained will facilitate the understanding of the underlying effects of remnant fences on vegetation distribution and the development of management alternatives for fences that currently exist within the dunes and fences deployed in the future. Recommendations, such as using vegetation plantings rather than fences to build dunes or building organic biodegradable fences (Miller et al. 2001) have been suggested to allow dunes in developed shorelines to evolve naturally and contribute to restoration purposes, but other alternatives are possible. This dissertation examines these alternatives: reduction of remnant fence height based on vegetation height and restriction of fence deployment seaward of the dune toe. The suggestions developed through this study should be a useful educational tool for coastal communities to learn about the consequences of their decisions and actions on their coastal dune resources and for managers to apply a restorative approach to their municipal dunes.

Chapter 2: Methods

The methods presented here address the four main objectives of this study including: 1) significance of sand fences, 2) history of fence usage in New Jersey, 3) sand fence inventory and rationale of deployment, 4) relationship of fences to morphology and vegetation at four sample sites.

2.1. Review of significance of sand fences and history of their usage in New Jersey

Previous literature on sand fences and their historical usage in New Jersey was reviewed with the purpose of providing a broad framework of landscape studies and management actions. This framework gives the context for the analysis of results from the data gathered during the sand fence inventory and ground survey of dune vegetation and fence characteristics.

2.2 Sand fence inventory and rationale for fence deployment

Data was collected in two phases: 1) conducting an inventory of sand fence configuration to analyze the general characteristics of sand fences along the ocean shore of New Jersey; 2) identifying the intended and unintended effects of sand fence deployment. The inventory and classification of the overall characteristics of sand fences was done using an existing video of 29 municipalities along the ocean shoreline of New Jersey (Figure 2.1) taken from a light airplane in August 2002 (Mitteager 2005). Inexpensive video records provide managers with massive amounts of data over large areas within a limited time and budget (Leatherman et al. 1995). The variables evaluated are identified in Table 2.1. Municipalities selected for the sand fence inventory represent all coastal counties and the three physiographic regions of New Jersey. The shorelines of eight municipalities were not recorded in the video and were excluded from the inventory.

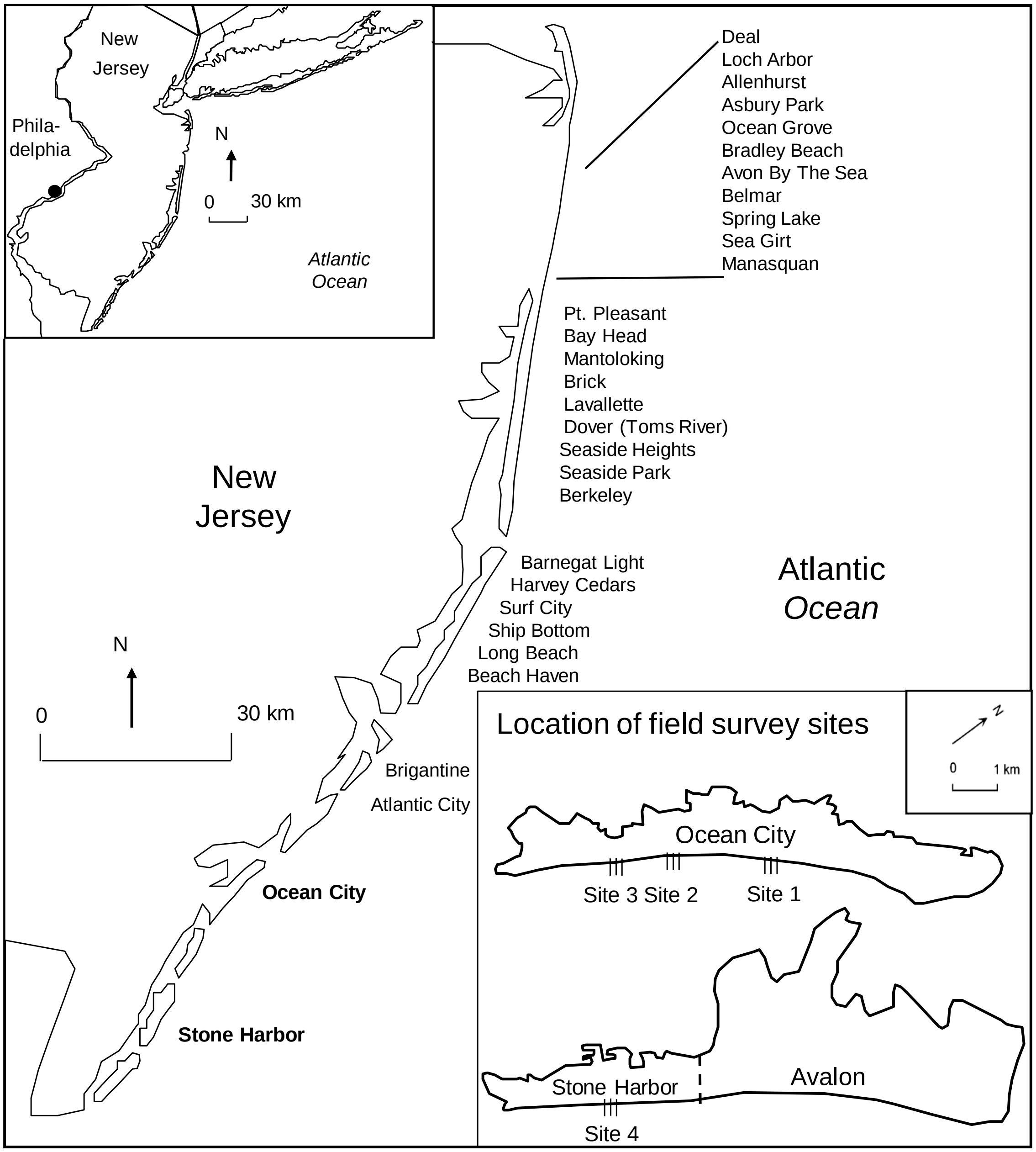


Figure 2.1: Ocean shore of New Jersey and developed coastal municipalities evaluated in sand fence inventory. Ocean City and Stone Harbor are the study areas for the field survey.

Table 2.1: Inventory of fence characteristics based on percentage of shoreline length

shoreline with fences
shoreline without fences
shoreline with dunes
shoreline without dunes
shoreline with fences and dunes (fences within dunes)
shoreline with fences but no dunes (fences on backshore)
straight fence configuration
zigzag fence configuration
straight/diagonal/perpendicular fence configuration
number of fence rows

Variables were measured based on length of shoreline characterized by each variable and their location within the dune or on the backshore. Only alongshore measurements were taken. Fences could be located within dunes or on the backbeach landward of a boardwalk or bulkhead. Dunes could be located landward or seaward of boardwalks. Shore perpendicular walkways at street ends or within the dunes were not measured because of lack of alongshore fence continuity to calculate shoreline length. The beginning and end points of each shoreline segment with a specific fence characteristic were marked relative to human features, which were then located on a map to measure length.

Dunes were identified using vegetation cover and difference in height observable by the shadow they cast. Fenced segments that had no vegetation cover or were not high enough to create a shadow were not identified as dunes, although dune building could have been in an incipient stage. Dune width was not measured because the video was taken at an oblique angle and the scale was uncertain. Fences were revealed as linear, narrow, dark features. The fence at the seaward base of the dune where the beach ends and the dune begins is termed the dune toe fence. The fence on the landward side of the dune, or backdune fence, could not always be identified because the shadow of the dune obscured the details.

Phone or personal interviews with municipal officers were conducted to identify the rationale for deploying fences and their specific locations and configurations. Two thirds of the responses were obtained from officials involved with fence deployment in the Departments of Public Works or Beach and Recreation. Other officials willing to share their insights include former environmental commission members, dune inspectors, and officials who worked and lived in the municipality for decades. Three of the municipalities never used sand fences, and one municipality provided no information. Questions asked are included in Table 2.2. A qualitative table summarizing the responses provided by municipal officers and environmental commission members along with the number of municipalities that gave each response was created from the information gathered in the interviews.

Table 2.2 : Questions asked to municipal officers

What is the purpose of using sand fences?
When are sand fences built? Why?
Where are sand fences built? Why?
How or in what configuration are sand fences built? Why?
How many rows of fences are deployed at a time?

The 2002 video record was compared with field reconnaissance in 2008 to identify (1) the way fence configurations, row numbers, locations and the associated landforms and habitats changed over a 6-year period and (2) the characteristics of shore-perpendicular fences and backdune fences that could not be derived from the video. At least two locations were visited in each municipality. The site visits followed the interviews so that the outcomes of fence construction could be compared to the rationale identified by municipal managers.

2.3 Relationship of fences to dune morphology and vegetation

2.3.1 Field methods

Data were gathered in the field on four sites in two municipalities (three in Ocean City and one in Stone Harbor, Figure 2.1) to quantify and relate vegetation density and diversity to fence and dune variables. The data were collected during the period of September 8th to October 6th 2007 to account for maximum vegetation growth during months that were warm but less crowded by tourists. 1m^2 quadrats were used to collect data on vegetation variables and to record distance from fences. Data was gathered on the following variables: vegetation diversity, vegetation density, sediment deposition, dune height, dune width, distance of quadrat landward of dune toe, distance of quadrat from fence, fence presence, and fence height. Data collection was done along cross-shore transects and an alongshore transect. The cross-shore transects account for onshore disturbance and relate the variables to their location in relation to distance landward of the dune toe and from each remnant fence. The alongshore transect evaluates variables landward and seaward of a remnant fence. Both transects were integrated to compare vegetation diversity and density at different distances landward and seaward of the alongshore transect.

Cross-shore topographic data was collected every 3m on transects that extended from the upper limit of swash (ULS) to the landward most sand fence or seaward most bulkhead. Three transects were located on each of four dune sites by measuring the alongshore length of the dune (measured by counting steps from the southern break in the surface of the dune at the street-end walkway to the northern break at the street-end walkway (1 step = 0.8m) and dividing it by four. The resulting number was the distance between transects on that dune. The angle of dune orientation in relation to the shore was obtained for each site using a compass. Dune elevation and width were measured using rod and transit at 3m intervals, which allows for the identification of most topographic and vegetation differences within the different sub-environments across the dune. Visible remnant fences were identified and located within the dune gradient along the transects. Their height and distance from edge of closest quadrat were determined using a measuring tape.

Erosion pins were located on each transect every 3m to calculate deposition or erosion throughout the dune. The exposed height of the pins was measured on October 4th 2007; March 2nd 2008 and May 24th 2008. Most sediment transport in the New Jersey coast occurs during these months. Many of the pins had been removed by May 2008, possibly by curious beach/ dune wanderers. Therefore, only the measurements of October (initial) and March (final), the months with most active sediment transport, were considered in the data analysis. The difference between the initial and final measurement represent the net change in surface elevation which describes where on the dune erosion or accretion occurred. Because data collected with the pins represents deposition or erosion occurring after data on vegetation was gathered, deposition data was not used here to explain specific vegetation patterns but to identify depositional and erosional zones.

Replicated ordered sampling was used to measure vegetation characteristics. 1 m^2 quadrats (Figure 2.2) were placed every 3 m on each of the topographical transects from the landward most fence or bulkhead to the seaward most vegetation. The 1 m^2 quadrat size was chosen because it is sufficiently detailed to evaluate fine scale patterns of vegetation and their relation to topography (Nordstrom et al. in 2007). Replicates were located 1m north and 1m south of the middle quadrat and the values for each group of quadrats every 3m was averaged. Locating the replicates at a distance greater than 1m from the middle quadrat could have caused quadrat overlapping. Ten to 27 lines of quadrats with replicates were located in each transect depending on the width of the dune. Using replicates provides more accurate information on the variability of vegetation characteristics every 3 m.

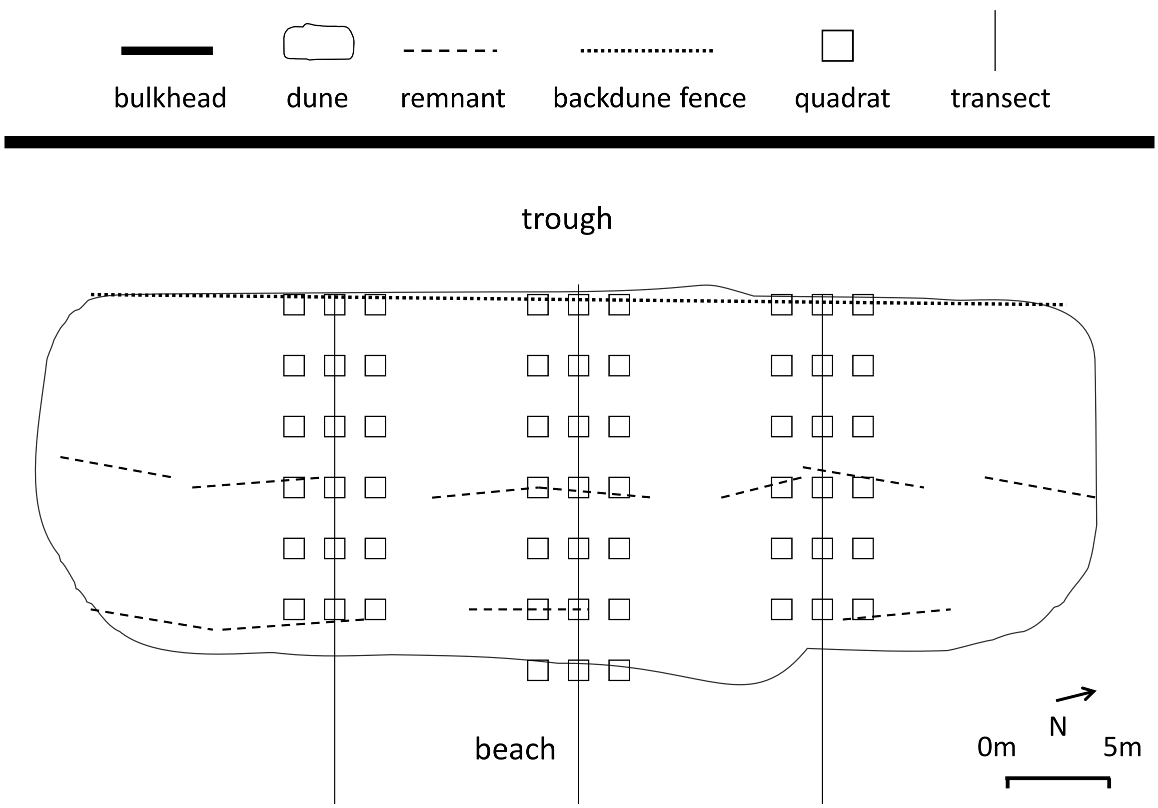


Figure 2.2: Cross-shore data collection methods

Species were identified and counted in each quadrat. Vegetation diversity was calculated using Simpson's diversity index (Lubke 2004) which considers the number of species and the number of individuals per species for each quadrat. To account for vegetation density, number of individuals per species was approximated by manually counting small clusters (5-10 individuals) and visually estimating the number of individuals in larger clusters. An additional density measure was vegetation cover, determined by using the diameter of the vegetation clusters in each quadrat and calculating their area. The sum of the areas represented square meters covered by the clusters which were then multiplied by a hundred to obtain percentage cover. This measurement was not used in the final analysis because some percentages were higher than a hundred. Inaccuracies in gathering the data, such as measuring portions of clusters outside the quadrat, may have led to this error.

An along-shore topographic survey was conducted on a transect running parallel to an intermittently visible remnant fence at Site 2 (Figure 2.1) to study the effect of the remnant fence on vegetation next to it. Vegetation was counted and identified using $1m^2$ quadrats located every meter landward and seaward of the transect for a total of 26 quadrats on each side starting at the northern walkway (where the fence started) and ending 3 m from the southern walkway where the fence was no longer visible. An erosion pin was set in the middle of each quadrat to account for change in sediment volume. The height of the remnant fence was measured with a measuring tape in the 15 quadrats where it was visible.

Vegetation distribution patterns may be affected by other variables such as soil moisture, salt spray, sand blasting, sand abrasion, swash erosion, swash inundation, salinity, scarcity of water and mineral nutrients, high wind velocities, high temperature, high light intensity and heat stress, overwash, soil pH levels, sand texture, organic matter, presence of houses and presence of street ends, and trampling (Hesp 1991, Nordstrom 2007). Data for these variables was not collected in the field, but cross-shore position on transects accounts for the decreasing intensity of most of the physical stresses and increases in the conditions favoring growth landward of the beach. Previous studies on the effects of these variables on coastal dune vegetation density and diversity were evaluated and considered qualitatively when examining the effects of remnant fences on vegetation distribution.

2.3.2 Statistical analysis

Quadrat replicates and transect were aggregated per site to create a correlation coefficient matrix and identify significant relationships between variables at a 95% confidence level. The correlation coefficient matrix included the variables in Table 2.3. Only quadrats 0-7m landward or seaward of remnant fences were considered when evaluating variables of distance landward and seaward of fence because fences affect sediment mobility the most between 3-7 times their fence height (CERC 1984). An initial fence height of approximately 1m was considered when determining these measurements to account for original and current fence height.

Table 2.3: Correlation coefficient matrix variables

fence presence
distance landward of remnant fence to a maximum of 7m
distance seaward of remnant fence to a maximum of 7m
distance landward of dune toe
degree of sheltering (absolute value of square root of plot depth by highest elevation seaward by distance landward of dune toe)
deposition (October 2007-March 2008)
diversity (Simpson’s diversity index)
density (number of individuals)
Ammophila breviligulata (beachgrass) density
Hypericum gentianoides (pineweed) density)
Triplasis purpurea (purple sandgrass) density
Chamaesyce polygonifolia (seaside spurge) density
Eragrostis spectabilis (purple lovegrass) density
Solidago sempervirens (seaside golden rod) density

Cenchrus tribuloides (sandbur) density
Panicum amarum (seaside panicum) density
Cakile edentula (sea rocket) density
Hudsonia tomentosa (beach heather) density
Heterotheca subaxillaris (camphorweed) density
Carex kobomugi (Japanese sedge) density
Clitoria marinara L. (butterfly pea) density
Uniola paniculata (sea oats) density
Myrica pensylvanica (bayberry) density
Andropogon longiberbis (sand broomsedge) density
Xanthium strumarium (cocklebur) density
Juniperus virginiana (red cedar) density

Multiple regression analysis was conducted per site using diversity as the dependent variable and distance landward of fence, degree of sheltering and sediment deposition as independent variables. This analysis provides four models to predict which independent variables affect vegetation diversity variability the most in each site. Some independent variables used in the correlation coefficient matrix were dropped from the analysis because they were correlated with the chosen variables (ie. fence presence and distance landward of fence, distance from dune toe and sheltering).

A t-test was conducted to compare the means of the variables on the quadrats landward and seaward of the alongshore transect. The t-test was chosen over the F test because the sample size was less than 30. The t-test was chosen over the ANOVA because there were only two locations (landward and seaward) to be compared, and the sample size varied for each location to be evaluated. The variables analyzed include: vegetation diversity, vegetation density, deposition, and density of specific species most common along the transect (beachgrass, seaside spurge, sandbur and purple lovegrass). Locations compared in relation to the alongshore transect include : 1m landward and 1m seaward (Figure 2.3 A), 1m landward with fence and 1m landward without fence (Figure

2.3 B), 1m seaward with fence and 1m seaward without fence (Figure 2.3 C), 1m landward with fence and 1m seaward with fence (Figure 2.3 D), 1m landward without fence and 1m seaward without fence (Figure 2.3 E), 1m landward and seaward aggregated and 3-6m landward (Figure 2.3 F), 1m landward and 3-6m landward (Figure 2.3 G) 1m seaward and 3-6m seaward Figure 2.3 H).

2.3.3 Study Areas

The relatively long history of fence usage in New Jersey, especially Ocean City and Stone Harbor, and the deployment of several fence rows through time, make them ideal places to study remnant fence rows with different heights and within different dune zones.

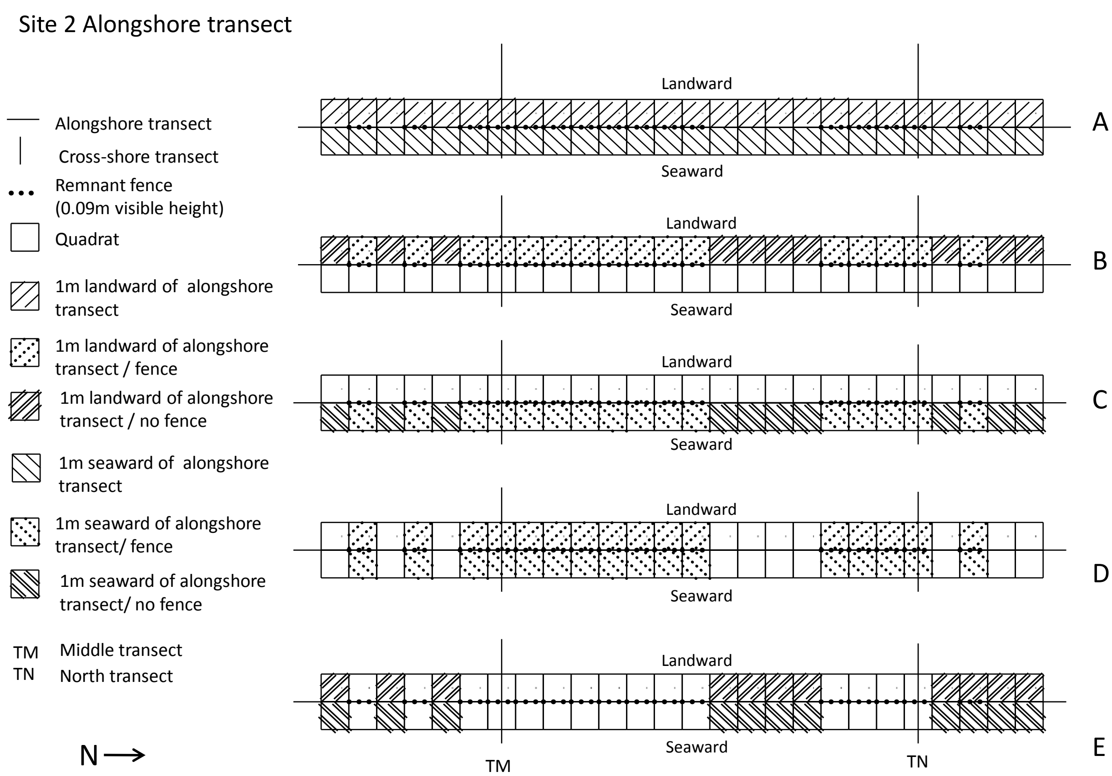


Figure 2.3: Alongshore transect quadrat comparison

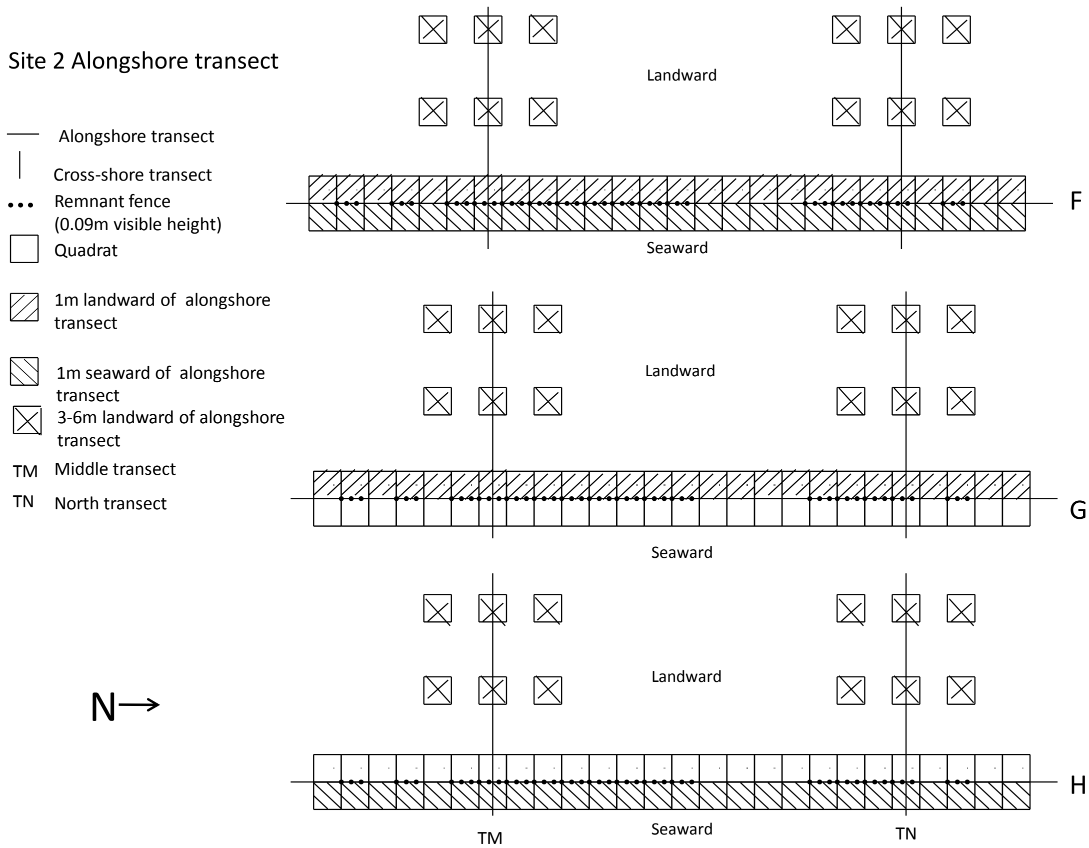


Figure 2.3: Alongshore transect quadrat comparison, continuation

Ocean City is a developed barrier island in Cape May County characterized by shorefront houses, bulkheads, boardwalks, and sand fences. The un-vegetated beach is 60m wide at low tide (Nordstrom et al. 2007). The dune is approximately 35m wide and 2-3m above the backshore with a landward un-vegetated trough 4-12m wide (Nordstrom et al. 2006). Beach nourished in 1990 was followed by foredune construction through fence deployment in 1995 (Nordstrom et al. 2007). Seaward of the bulkhead (located a few meters seaward of the first row of houses) the municipality placed two rows of 1.2m high wooden-slat sand fences with 50% initial porosity (Nordstrom et al. 2007). In the 5m space between the fences, *Ammophila breviligulata* was planted. Subsequent plantings occur annually as needed (Freestone and Nordstrom 2001).

Two more rows of fences were added seaward of the initial ones after they where partially buried. At the time of this field study, these remnant fences had weathered and missing slats, which provides them with much higher porosity levels than when first placed (Nordstrom et al. 2007). Data were gathered at the developed dune found at 38th and 41st street (Site 2 and 3) where multiple remnant fences are visible along the dune gradient and at 21st street (Site 1), where there is a naturally evolving dune and remnant fences are farther landward.

Stone Harbor is a developed coastal town on the southern side of Seven Mile Island in Cape May County. The beach was intensively nourished in the past due to severe erosion problems related to mid-latitude cyclones. The dunes at Stone Harbor are narrow and young, and conspicuous sediment transport and instability predominates on the seaward ridge. The landward dune ridge was built using bulldozing after a 1998 beach nourishment project (Sheeran, 1999; Stockton 2008). Beach grass was planted over the bulldozed sediment to protect it from wind erosion and help reduce wave erosion (Sheeran 1999). Sand fencing was installed along the dune toe of the bulldozed ridge to produce a larger and wider dune system (Stockton 2008). Data were gathered at the developed dune found at 102nd street (Site 4), where multiple fences including a fence at the dune toe and various remnants landward of it are visible along the dune gradient.

2.4 Conclusions

The two data collection techniques provide general and more detailed information that will be discussed next. The following two chapters present the literature review on the significance of sand fences (Chapter 3) and history of fence usage in New Jersey

(Chapter 4). Chapters 5 and 6 present the results from the data collection for the fence inventory and the ground survey of vegetation, topography and fence characteristics.

Chapter 3: Significance of sand fences

Sand fences, like other fences, walls and their vegetative equivalents (windbreaks and shelterbelts) are human-created physical boundaries that differentiate spaces and their purposes and constrain natural physical and biotic processes and human actions. These boundaries, hereafter termed fences, may be constructed to many designs using a variety of construction materials, including concrete, iron, wood, wire, plastic, stone, sod, and vegetation (Martin 1888; Hewes 1981; Pickard 2005, 2007; Raitz 1995; VerCauteren et al.2006). They can extend for tens to thousands of kilometers regionally (Hewes 1981; Price 1993) and over a million kilometers on a national scale (Hewes and Jung 1981; Pickard 2007). The presence of fences influences the spatial structure and image of a landscape and imparts historical meaning, making fences a manifestation of culture and index of landscape character (Eley and Northon 2003; Hart and Mather 1957; Pickard 2007; Price 1993). Fences can be evaluated economically, politically, or in terms of sustainability of resources (Centner 2000). They are often built to accomplish a specific purpose, but they can cause many alterations to a landscape. Like many other human structures, little thought is often given to designing or constructing fences to address the unanticipated effects they create (Grafals and Nordstrom 2009).

3.1 Purposes and effects of fences

Fences are commonly used to control the flows of air, water, sediments, people and animals (Table 3.1). This barrier effect can allow some elements to pass it, or it can stop or even repel flows or activity, causing accumulation or dispersion of the controlled item. The barrier effect can be due to the structure itself or a change in landform or vegetation induced by the structure, which can persist even when the fence is buried or obscured. Land cover and land use can evolve on different trajectories on both sides of the fence or the resulting landform that is created from it as a primary or secondary effect (Minnich and Bahre 1995). Many physically-based studies of fences for controlling wind effects exist (e.g. Bates 1911; Burke 1998; Caborn 1965; Grant and Nickling 1998; Sturrock 1988; Tinus 1976; Wang and Takle 1995; Wilson 1997), with emphasis on soil loss and suspension of particulates. The landforms created in the process are often of lesser interest.

Table 3.1. Purposes and effects of fences in the landscape. Purposes and effects are not mutually exclusive (Grafals and Nordstrom 2009).

Purpose

- Control processes (impede, reduce or redirect flows of wind, water or sediment)
- Control sediment
    - Retain sedimentary resource within an area
    - Prevent inundation outside area
    - Cause accretion (build landforms)
- Control animal access
    - Keep domesticated animals within managed properties
    - Keep wild animals out of populated areas, agricultural lands, pastures.
    - Keep wild animals from transportation corridors.
- Control human access
    - Crowd control
    - Prevent human access to territory owned by another owner or jurisdiction
    - Prevent human access to vulnerable habitat or valued public resources
    - Provide safety barriers from hazards or self-inflicted damage
- Create privacy
- Demarcate territory
- Differentiate land use
- Change landscape image
- Dispose of unwanted items

Effects

- Habitat change
    - Physical effect of fence itself
    - Effect of sediment accretion (new landform)
- Economic
- Psychological

Political
Cultural icon
Aesthetic

The literature on use of fences to control animal access is vast (Anthony 2007; Cole et al. 2007; Dodd et al. 2004; Gallacher and Hill 2008; Jackson et al. 2005; Matsumasa and Murai 2005; Melvin et al. 1991; Melvin et al. 1992; Miller et al., 2001; Moseby and Read 2006; Patterson 1977; Rimmer and Deblinger 1990; Spooner and Biggs 2008) and focuses on impact of fences on access to nesting sites and feeding. Control of human access is often motivated by social, political or economic reasons. Fences may also be used to keep people out of valued public resources or sensitive or hazardous environments (Holloway 2002). Fences can have important psychological as well as physical effects (Cohen 2006; Edmonds 1979; Lagerquist 2004; Litz 2000; Schnell and Mishal 2008). Control of access for people or animals can be considered in their best interests when the barrier is designed for safety (Bateman et al. 2007; Dodd et al. 2004; Pelletier 2007) or against their interests when the barrier unnecessarily restricts their freedom or access to resources that affect their livelihood (Mosely and Read 2006; Olsson et al. 2008).

Fences may be deployed to differentiate land uses, without regard to their effect on flows of air or water or movement of fauna, such as when managers wish to make a statement of ownership. Fences may also be constructed as evocative symbols to change the landscape image (Price 1993), sometimes without having any intended barrier effect (Harrod 1991). Once in the landscape, fences become objects of aesthetic interest. The aesthetic effect may be to invite or guide vision rather than obscure or interrupt it. Fences take on many meanings in artistic portrayals as objects of beauty, nostalgia or social comment (Doherty 2001; Gomez 2003).

Fences may be created by disposing of unwanted materials, such as where boulders are placed to the side of a cleared field. These disposal fences provide dramatic evidence of the way unanticipated effects of fence construction can transform the landscape and define its character. Once in the landscape, fences can become cultural icons and targeted for preservation or restoration because of their heritage value (Pickard 2005, 2007).

Fences are often used to control wind-blown sand in the coastal zone. One of the most ubiquitous fence types is the permeable wooden slat fence that is also used to prevent inundation by snow (Dong et al. 2004; Skidmore et al. 1972; Zaghloul 1997). Other common fencing materials used at the coast are commercially-produced plastic mesh or saplings and branches placed close together in a vertical array. These fences reduce wind speed, trap sand and create dunes that provide protection against flooding, overwash and sand inundation, often in locations where dunes would not occur under natural conditions.

3.2 Sand fence characteristics

There are a few characteristics that apply to all sand fences. The amount of sand trapped and deposited landward of a sand fence depends on wind conditions, fence porosity, height (Hotta et al. 1991), location and the number of fence rows. Porosity levels determine the sand trapping effectiveness of the fence and the steepness of the dune slope upwind and downwind of the fence (Hotta et al. 1987). Sediment entrapment is greatest leeward of fences at distances of 3 to 6 times the height of the fence (CERC

1984). The location of the sand fence on a specific zone of the dune gradient determines the intensity of sediment transport; the closer to the relatively flat beach the greater the transport. The number of sand fences affects the mobility of the deposited sediment. Multiple fences reduce the quantity of sediment blown off the new deposit and transported downwind (Hotta et al. 1991). The distance between multiple sand fences influences the amount of deposited sediment, with wider separations tending to collect greater sediment volume (Hotta et al. 1991).

Newly built sand fences in the USA commonly have a height of 1.2m and porosity of 50% (Mendelssohn et al. 1991), which is the most effective porosity for sand trapping (Hotta et al. 1987). Sediment deposition occurs just downwind of the sand fence creating a steep slope. The initial location of sand fences is usually at the dynamic boundary between beach and dune (Nordstrom 2000), where great amounts of sediment are transported.

Sand fences are arranged in various ways including a straight line parallel to the shore (Figure 3.1), in zigzag configurations (Figure 3.2), or straight with perpendicular side spur configurations (CERC 1984). Throughout three years of study, Mendelssohn et al. (1991) observed that a straight fence with perpendicular side spurs accumulated the most sand during the first year; during the second year the zigzag and straight fences both accumulated more sand and yielded greater vertical dune growth than the straight fence with side spurs. The greatest sediment loss throughout the three years was observed at the zigzag fence. The configuration of a dune-building fence could be selected based on the short term or long term objective of its use.

Figure 3.1: Straight wooden slat sand trapping fence at the dune toe. Manasquan, NJ

Figure 3.2: Zig-zag fence at the dune toe/foreslope and remnant fence at the dune crest. Stone Harbor, NJ.

The ability of sand fences to trap sediment changes as they become remnants. Weathering increases their porosity (Nordstrom 2000), and sand burial decreases their exposed height. Higher porosity and lower exposed height allow for more sediment transport and deposition farther landward (Hotta et al. 1991). The construction of new seaward fences changes the fence location from the beach/dune boundary to a landward and less dynamic position within the dune (Figure 3.3). Fences remaining within the dune become small-scale barriers that influence local sediment transport rates and create distinctive vegetation patterns (Nordstrom et al. 2007).

Figure 3.3: Remnant fence located landward of the foredune crest at the less dynamic swale at Stone Harbor, NJ.

Although sand fences are commonly used for dune building, they are also used to prevent sand from inundating cultural features like boardwalks, residential home backyards and roads. In this case, the fences are positioned parallel to the shore landward of the dune crest and backslope between the dune and the cultural feature. The fence does not get buried as a consequence of placement in the backdune where sediment transport is limited (Figure 3.4).

Figure 3.4: Backdune fence, trough, and houses Ocean City, NJ

Municipalities use sand fences to control pedestrians and prevent inundation of beach access pathways. Pathway sand fences are positioned in a straight line sub-perpendicular to the shore from the back of the dune to the dune toe, creating a pathway that shows visitors their way to the beach and prevents dune trampling (Figure 3.5). Pedestrian-control sand fences parallel to dunes on their landward or seaward side also prevent sand inundation on boardwalks (Figure 3.6). Vegetation may be planted between the fence and the boardwalk for dune building, aesthetic and/or pedestrian control purposes (Figure 3.6).

Sand fences obstruct free passage of organisms through the dune such as grazing rabbits. The steep seaward dune slope created by sand fences may affect certain birds (ie. piping plover) and other species nesting and surviving strategies (Melvin et al. 1991).

Figure 3.5: Walkway fence arrangement perpendicular to the shore, NJ.

Figure 3.6: Fence placed to prevent sand inundation and control pedestrian access to the beach through boardwalk, Belmar, NJ.

3.3 Remnant fence characteristics

Remnant fences are partially buried, weathered sand fences that have become local barriers within the dune. Sand fences are not intended to remain within the landscape but they will if limited sediment reaches them. Remnant fences are a consequence of inappropriate placement for building dunes or deployment for purposes that are not intended for dune building such as pedestrian control. If the purpose is dune building, sand fences will remain when their location in relation to the dune toe changes to a less active dune zone, for example if a new fence is deployed seaward. Sand fences will also remain if they are the landward-most fences in multiple and simultaneous fence row deployments.

Fences located at highly dynamic dune zones are considered remnants if their height makes them vulnerable to complete burial. Fences intentionally located at the backdune to prevent landward sediment transport, inundation of cultural features and trampling are not considered remnants because they were intentionally deployed at the presently static landward portion of the backdune, their location stays constant and they are still useful for their intended management purposes (Figure 3.4).

3.4 Conclusion

Because sand fences increase the rate of sand deposition and successfully build dunes, especially if they are placed in conjunction with vegetative plantings (Mendelssohn et al. 1991), their placement is an essential short-term solution to protection problems. Nevertheless, sand fences and their partially buried remnants have additional intended and unintended effects that may or may not relate to dune building. Identifying and differentiating these effects may facilitate the development of management guidelines that anticipate the consequences of fence deployment in the functioning of dune systems.

Chapter 4: History of sand fence usage in NJ

Most of the issues related to sand fences reported in the literature are applicable in some way to sand fences at the coast and are readily illustrated in the ways fences are deployed on the ocean shore of New Jersey. The 205 km long ocean shore of New Jersey (Figure 1.1) consists of sandy barrier spits and barrier islands and low headlands composed of unconsolidated sediment. Before the mid 19th Century, multiple dune ridges were common in portions of several barrier islands, and large portions of most of the islands were characterized by isolated hummocky dunes (Nordstrom 1994). Human modifications included grading dunes and destroying natural vegetation to facilitate construction of buildings and roads. Much of the ocean shore was developed in residential properties by 1962, when a mid-latitude cyclone in March damaged thousands of residences and destroyed nearly all of the remaining dunes along entire barrier islands (USACOE 1962; 1963). Restoration of dunes using artificial fill, sand fences and vegetation plantings was one of the many post-storm reconstruction activities (Nordstrom and Mauriello 2001).

A renewed state focus on building dunes followed damaging storms in 1977-78 and development of the New Jersey Shore Protection Master Plan in 1981 that encouraged use of non-structural approaches to shore protection (NJDEP 1984). The state then adopted a formal Hazard Mitigation Plan recommending dune creation and enhancement as a primary hazard mitigation effort. Federal funds were passed through to municipalities to make vegetation and sand fence materials available. The state required municipalities to agree to dune building as a condition of receiving aid to rebuild damaged structures, resulting in construction of new dunes in municipalities that accepted this funding (Nordstrom and Mauriello 2001). Legislative amendments to the State Coastal Area Facilities Review Act in 1993/94 allow for construction of sand trapping fences but prohibit direct disturbance to dunes that would increase their mobility or reduce their dimensions, including removal of existing sand fences or pedestrian trampling of the vegetation. Most municipalities now have regulations that restrict access to dunes except along designated cross-shore walkways to the beach. The state regulation against removing fences helped curtail a former practice of creating dunes in the fall to provide protection against winter storms and flattening the structures prior to the summer tourist season.

The fences employed throughout the state are similar to fences used to build dunes in other parts of the USA (Savage and Woodhouse 1968; CERC 1984; Mendelssohn et al. 1991) and are 1.2 m high, with 35 mm wide wooden slats joined together by horizontal strands of wire strung along vertical wood or commercially produced iron poles (Figure 3.1). The fences have a porosity of about 50% initially, although they often weather to a porosity close to 65%. Some municipalities provide fence materials for use on private properties, but fence materials are so inexpensive that residents do not need this incentive to use them.

Dunes in areas where beaches are narrow are usually a single ridge, with vegetation characterized by species commonly found on the active beach and seaward portions of natural dunes. American beachgrass (*Ammophila breviligulata*) usually dominates because it is planted. Dunes that have crests high enough to reduce the impact of wind, salt spray and blowing sand may have a more complete environmental gradient perpendicular to the shore, with shrubs, such as bayberry (*Myrica pennsylvanica*) and rugosa rose (*Rosa rugosa*) landward of the crest.

Many beaches in New Jersey are artificially nourished (Nordstrom and Mauriello 2001). Where there is ample space on the backshores of these beaches, municipalities often progressively place sand fences on the seaward side of the dune to encourage horizontal growth rather than upward growth that would restrict views of the sea. This practice creates small dune fields with multiple low ridges.

4.1 Characteristics of field sites in Ocean City and Stone Harbor

The dunes in Ocean City are approximately 35m wide and 2-3m above the dune toe; the un-vegetated beach is 60m wide on average at low tide (Nordstrom et al. 2006). The beach was nourished in 1990 followed by foredune construction in 1995 (Nordstrom et al. 2007). To build the dunes the municipality placed two rows of 1.2m high wooden-slat sand fences with 50% initial porosity 4-12m seaward of the bulkhead creating an unvegetated trough between the dune and the shorefront properties landward of the bulkhead (Nordstrom et al. 2007). In the 5m space between the fences, *Ammophila breviligulata* was planted. Two more rows of fences were added seaward of the initial ones after they were partially buried. The slats of these remnant fences are weathered or missing, which provides them with much higher porosity levels than when first placed (Nordstrom et al. 2007). According to the Ocean City Chamber of Commerce, beach re-nourishment is scheduled for winter of 2010. Data was gathered at the dunes found at 21st (Site 1), 38th (Site 2), 41st (Site 3) street ends.

Stone Harbor, located in Seven Mile Island, has a 45m wide dune approximately 2m above the dune toe, and a 30m wide beach at low tide. A bulkhead divides the dune from the shorefront properties, and there is no intervening trough, boardwalk or backdune fence. Severe erosion problems related to mid-latitude cyclones, led to several nourishment projects. Two winter storms in 1998 caused great erosion and, in some areas, the complete removal of sediment from the beach and dune system. Nourishment was completed soon after the storms to create a 66m wide beach and an 18m wide bulldozed dune (Stockton 2008). Sand fences were used to stabilize the freshly placed sand, prevent pedestrian traffic on dunes, reduce wind damage and define a path over the dunes to the beach (Sheeran, 1999; Stockton 2008). Beach grass was planted over the newly created dune system to protect it from wind erosion and help reduce wave erosion (Sheeran 1999). Sand fencing installed along the seaward toe of the bulldozed ridge produced a larger, 33m wide dune system (Stockton 2008). Reports do not indicate the number of fence rows deployed at a time, but 15m seaward of the bulldozed dune toe (where the new seaward ridge is), 3 to 4 fence rows are noticeable every 3m. Fences with more than 50% of their original height are in the seaward ridge. They were probably deployed on the already formed crest to increase the dune height and compensate for the narrow beach. A follow up nourishment project was completed in 2003 to enhance the beach and dune built in 1998. There is a conspicuous linear patch of sea oats at the backslope of the bulldozed ridge 3m seaward of the bulkhead which was possibly planted as an experiment to test its viability near the northern limit of its natural range. Field data was gathered at the dune found at 102nd street (Site 4).

Each of the selected sites represents fence usage common in New Jersey where the resulting sediment deposition is responsible for the current dune structure and where remnant fences exist in the dunes. Site 1 in Ocean City is considered the control site because the seaward portion is an example of a naturally forming dune gradient. Fences and vegetation plantings were only used to build the landward ridge, where fence remnants are visible at the foreslope and at the former dune toe (Figure 4.1). These fences remain as a consequence of a rapidly widened nourished beach and the natural development of a new foredune that prevented landward sediment transport and fence burial.

Figure 4.1: Remnant fences at former dune toe and foreslope of landward ridge in Site 1, Ocean City, NJ (looking seaward, east)

The dunes at Site 2 and Site 3 in Ocean City were built through fence deployment and vegetation plantings. They both formed on narrower beaches and represent compressed dune gradients. Most fences at Site 2 are completely buried and only one remnant fence row is visible in the swale between two dune ridges. At Site 3, three visible remnant fence rows are located at the foreslope of the landward ridge, foreslope of the seaward ridge and in the swale between these ridges.

The topography and shape of the dune at Site 4 in Stone Harbor is different from all other sites because it was built by a combination of bulldozing, fence deployment and vegetation plantings. Indications of bulldozing are the linear dike-like shape of the landward ridge and the presence of coarse sediment which the wind is unable to transport. The seaward ridge was built with fences deployed 3m apart. New fences were deployed on top of completely buried ones at the crest, creating a high seaward ridge instead of a wide one. There are two remnant fence rows at the swale, and two active fence rows at the seaward crest and dune toe.

4.2 Conclusions

The history of fence usage in New Jersey reveals the evolution of fences from a tool to build protective structures to a multiple-use structure that is now considered indispensable to managers. The diverse practices of sand fence deployment have intended effects that communicate the different initial purposes and management priorities and unintended effects that reveal the deeper significance of fences in determining the character of the coastal landscape and its value.

Chapter 5: Sand fence inventory and rationale for deployment

Sand fence deployment has multiple purposes that depend on the priorities established by each municipality to fulfill their economic and coastal protection needs. The intended effects on the landscape include the accumulation of sediment landward of the fences to build a dune or seaward of the fence to prevent the inundation of cultural features. Unintended consequences include creation of topographic diversity and microhabitats. The unintended effects of sand fence usage may be positive or negative for the functioning of the dune system. Intended and unintended sand fence effects are identified and analyzed here to develop management alternatives that will enhance the functional value of the dune systems on developed coasts using data collected through the 2002 video inventory, interviews with municipal officers in 2007-08 and field reconnaissance in 2008.

5.1 Fence characteristics from video inventory

Individual fenced segments varied from 32 to 2,000 m alongshore in 2002. A total of 82% of the shoreline had fences and 72% had dunes. Most municipalities (18) had dunes and fences (Table 5.1). Dunes are frequently isolated from each other by walkways at backbeach elevation. Portions of shoreline with dunes but no conspicuous fences may have had dunes that were bulldozed or created by fences and subsequently buried. Straight fences occurred in at least a portion of all but one of the municipalities with fences (Table 5.2). Fence configurations seaward of boardwalks on the backshore include straight (Figure 5.1D), zigzag (Figure 5.1.E), straight/zigzag (Figure 5.1 F), and straight/diagonal/perpendicular (Figure 5.1. G). Single and double fence rows

Table 5.1. Video inventory of shoreline and fence characteristics in dunes in 2002 in the 29 municipalities analyzed. Characteristics are not mutually exclusive for number of municipalities.

Characteristics of entire shoreline	Number of municipalities	Mean length of shoreline with these characteristics (%)
Along total shoreline length		
Dunes, no fences	11	9
Fences, no dunes	12	15
No dunes, no fences	13	10
Dunes and fences	18	65
Total		100
Characteristic of shoreline with fences		
Fence configuration		
Straight fences	23	79
Zigzag fences	5	15
Straight/zigzag	6	5
Straight/diagonal/perpendicular	3	2
Total		100
Number of rows		
Single	21	35
Double	19	33
Three	14	19
Four	12	11
Five	4	2
Six	2	0.30
Total		100

The mean length of shoreline with each characteristic was calculated by adding the shoreline segments with a specific characteristic and dividing this sum by the entire shoreline length (90.7 km) for characteristics along total shoreline length, or dividing the sum by the shoreline with fences (74 km).

predominate (Table 5.1). The maximum number of fence rows seen on the video was six, not counting any backdune fence.

It is common for adjacent municipalities to have dissimilar fence usage and distribution (e.g. straight vs zigzag fence (Bayhead and Mantoloking, Table 5.2), no dune no fence v.s. dune with fence (Seaside Heights and Seaside Park, Table 5.3, Figure 5.2).

The greatest similarity is in the northernmost municipalities where no dunes and single, straight fences predominate and create the least topographically diverse backshore landscape (Table 5.3).

Table 5.2: Configuration of sand fences, NJ (2002)

Municipalities	**Shoreline with fences (km)**	**Straight (%)**	**Zigzag (%)**	**Straight/ zigzag (%)**	**Straight/ diagonal/ perpendicular (%)**
Monmouth County					
Ocean Grove	1	0	62	0	38
Bradley Beach	1.5	100	0	0	0
Avon by the Sea	0.6	100	0	0	0
Belmar	2.1	100	0	0	0
Spring Lake	0.5	100	0	0	0
Sea Girt	0.1	100	0	0	0
Manasquan	1.6	100	0	0	0
Ocean County					
Point Pleasant	2.5	56	0	8	36
Bay Head	1.8	81	0	19	0
Mantoloking	3.5	30	29	41	0
Brick	2.5	82	0	18	0
Lavallette	2.2	100	0	0	0
Dover	3.5	63	0	37	6
Seaside Park	2.8	100	0	0	0
Berkeley	0.5	100	0	0	0
Barnegat Light	1	100	0	0	0
Harvey Cedars	3.6	100	0	0	0
Surf City	2	100	0	0	0
Ship Bottom	2.4	100	0	0	0
Beach Haven	2.3	100	0	0	0
Long Beach	11.2	90		4	0
Atlantic County					
Brigantine	6.2	90	10	0	0
Atlantic City	3.8	100	0	0	0
Cape May County					
Ocean City	16	48	52	0	0

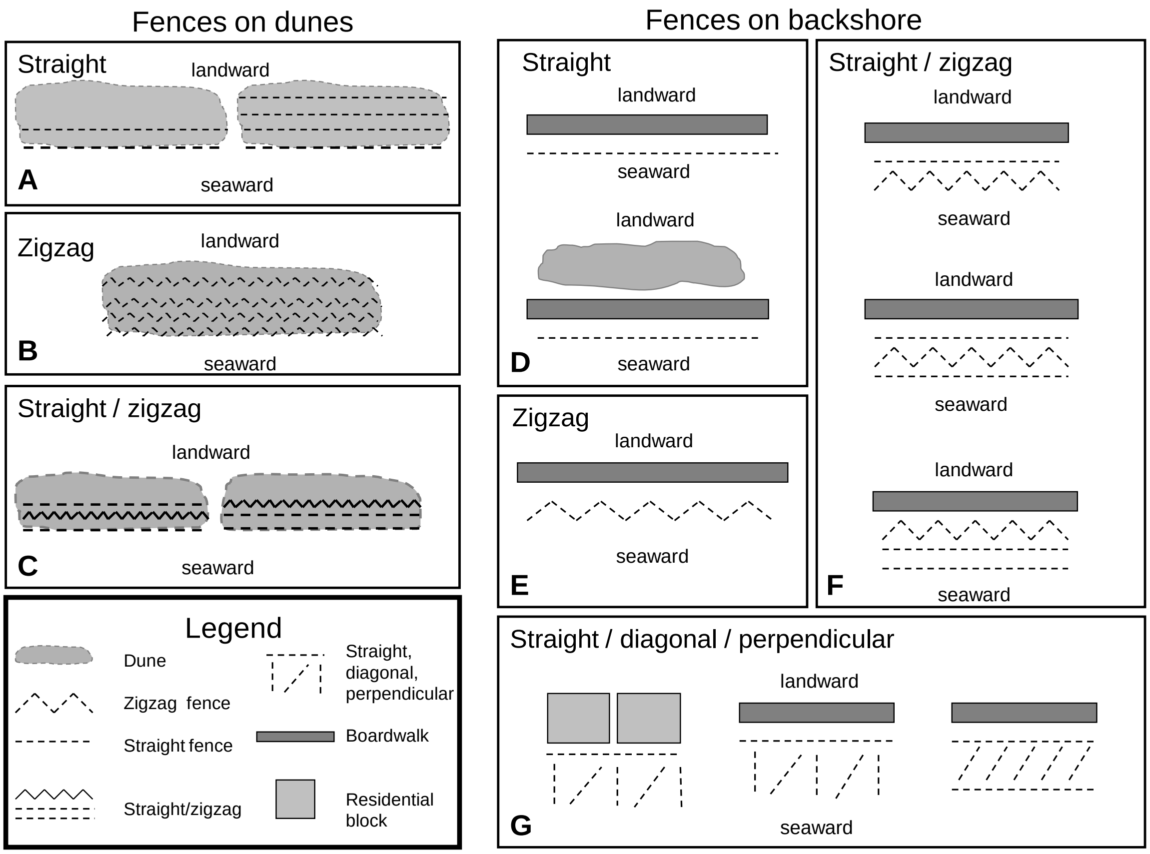


Figure 5.1 Fence configurations within dunes and on backshore

5.1.1 Fence location

Most municipalities have dunes and/or fences (Table 5.1). Fifteen municipalities have all or at least half their shoreline with fences within the dunes (Table 5.3). Six municipalities have all or most of their shoreline with fences at the backshore but no dunes (Table 5.3). Four municipalities have no dunes or fences on their shoreline (Table 5.3).

Figure 5.2: Seaside Park (left) and Seaside Heights (right) have dissimilar fence usage and distribution (images taken from 2002 video)

Table 5.3: Shoreline with dunes and/or sand fences (2002)

Municipality	Length of municipality (km)	No dunes, no fences (%)	Fences, no dunes (%)	Dunes, no fences (%)	Fences and dunes (%)
Monmouth County					
Deal	2.6	100	0	0	0
Loch Arbor	0.3	100	0	0	0
Allenhurst	0.5	100	0	0	0
Asbury Park	1.5	100	0	0	0
Ocean Grove	1	0	100	0	0
Bradley Beach	1.5	0	100	0	0
Avon by the Sea	0.6	0	100	0	0
Belmar	2.4	0	91	9	0
Spring Lake	3.2	33	6	61	0
Sea Girt	2.3	36	8	56	0
Manasquan	1.6	0	0	0	100
Ocean County					
Point Pleasant	2.9	7	61	8	24
Bay Head	1.8	0	0	0	100
Mantoloking	3.5	0	0	0	100
Brick	2.6	4	0	0	96
Lavallette	2.25	0	27	0	73
Dover	3.7	5.4	64.2	0	30.5
Seaside Heights	1.3	100	0	0	0
Seaside Park	2.8	0	0	0	100
Berkeley	0.7	0	0	29	71
Barnegat Light	3	0	0	65	35
Harvey Cedars	3.5	0	0	0	100
Surf City	2.7	0	0	27	73

Ship Bottom	2.4	0	0	0	100
Beach Haven	2.5	0	8	8	84
Long Beach	11.5	2	23	1	74
Atlantic County					
Brigantine	6.2	5.4	8	13.4	73
Atlantic City	3.8	0	0	0	100
Cape May County					
Ocean City	16	1.6	0	2.5	96

5.1.2 Fence configuration

Most municipalities with fences have straight fences (Table 5.1) which is the most common configuration both in dunes and on the backshore. Straight and zigzag fences can be found anywhere within the dune (dune toe, foreslope, crest, backslope, backdune) or two to three meters seaward of boardwalks where there are no dunes (Figure 5.1D, 5.1E).

The percentage of shoreline with zigzag fences and straight/zigzag fences is greater within dunes than on the backshore. Straight/zigzag fences are present on the backshore only in two municipalities. Straight, diagonal and perpendicular fences are the most uncommon fence configuration, present only on the privately managed backshore of three municipalities (Table 5.2)

5.1.3 Number of fence rows

One (single) and two (double) fence rows are most commonly used on the Jersey shore (Table 5.1). A greater percentage of shoreline has single fences on the backshore (53%) than on the dunes (47%). Municipalities with more than 70% of shoreline with single fences (Table 5.4) have them on a flat beach. Two municipalities have bulldozed dunes without fences landward of the boardwalk and single fences on a flat beach seaward of the boardwalk. Single fences can be located anywhere on the dune but are most common at the dune toe and foreslope.

Eight municipalities have no more than two fence rows (Table 5.4). Most municipalities with double fence rows have all of them on dunes. Three municipalities are the exception with most or all of their double fence rows on a flat beach. A greater percentage of shoreline with dunes has double fence rows than single.

Eight municipalities have less than 25% of their fenced shoreline with three fence rows (Table 5.4). Four municipalities have no more than three fence rows on their fenced shoreline (Table 5.4). Most municipalities with three fence rows have them on dunes.

Table 5.4: Number of sand fences, NJ (2002)

Municipalities	**Shoreline with fences (km)**	**one**	**two**	**three**	**four**	**five**	**six**
Monmouth County							
Ocean Grove	1	57	43	0	0	0	0
Bradley Beach	1.5	100	0	0	0	0	0
Avon by the Sea	0.6	100	0	0	0	0	0
Belmar	2.1	81	19	0	0	0	0
Spring Lake	0.5	100	0	0	0	0	0
Sea Girt	0.15	100	0	0	0	0	0
Manasquan	1.6	100	0	0	0	0	0
Ocean County							
Point Pleasant	2.5	52	36	4	8.0	0	0
Bay Head	1.8	0	33	56	11	0	0
Mantoloking	3.5	17	46	21	16	0	0
Brick	2.5	4	23	20	33	14	6
Lavallette	2.25	56	44	0	0	0	0
Dover	3.5	21	31	31	17	0	0
Seaside Park	2.8	68	7	0	25	0	0
Berkeley	0.5	0	100	0	0	0	0
Barnegat Light	1	0	22	67	11	0	0
Harvey Cedars	3.6	13	36	30	14	7	0
Surf City	2.0	45	40	15	0	0	0
Ship Bottom	2.44	6	8	14	51	18	3
Beach Haven	2.35	37.5	37.5	17	8	0	0
Long Beach	11.2	32	40	26	2	0	0
Atlantic County							
Brigantine	6.2	29	40	31	0	0	0

Atlantic City	3.8	29	60	11	0	0	0
Cape May County							
Ocean City	16	31	30	19	17	3	0

Most municipalities with fences have no more than four fence rows (Table 5.1) Nine municipalities have less than 20% of their fenced shoreline with four fences rows (Table 5.4). Six fence rows is the least common fence number only found in two municipalities (Table 5.1). Four, five and six fence rows are only visible on dunes. Numerous fences are evidence of a history of fence building and dune stabilizing.

5.2 Rationale for fence locations and configurations obtained from interviews of municipal officers

The main stated purpose of installing fences is to create wider dunes for shore protection, followed by the need to keep people off dunes (Table 5.5). Preventing inundation of infrastructure is frequently mentioned, especially in municipalities with no dunes. Managers are aware of some of the adverse effects caused by fences (especially loss of views when dunes become too high), but they consider most of them acceptable, given the importance of the primary purpose.

The location where fences are initially placed is usually the dune toe to create a wider dune, but placing fences on the foreslope of an existing dune landward of the dune toe fence to create a higher dune or placing them 2-3 m seaward of a boardwalk to prevent inundation were mentioned several times (Table 5.5). Fences are deployed when they are perceived to be needed, often at intervals of one year or less. They are installed primarily in the fall to build dunes to protect against wave uprush during winter storms and prevent inundation of cultural features by wind-blown sand or in the spring to repair dunes and fences damaged by winter storms and prepare for control of visitors in the summer.

The fence configuration mentioned most frequently is straight (Table 5.5) because it requires less fence per shoreline length, can be built quickly, requires fewer people to build it, is easier to clean and remove the sand that builds up against it on the side used by people, and is easy to repair or to dig out if its removal is necessary. Zigzag fences are frequently mentioned because they trap sand coming from different directions. The sand trapping function is the overriding reason for constructing this type of fence. Zigzag fences are more commonly used in the beginning stages of dune construction.

Table 5.5: Summary table of responses of municipal officers or environmental commission members (N = 29). Number of municipalities that answered is in parenthesis. Some municipalities gave more than one answer for the same question.

Purpose of installing fences
- Create wider dunes (14), higher dunes (4) or keep the dune in place (2) for shore protection
- Keep people from entering the dunes (9), the beach (2) or private property (1)
- Prevent inundation of infrastructure (7)
- Keep sand on the beach (1)

Location of fence
- Dune toe, for a wider dune (12)
- Foreslope, for a higher dune (4)
- Seaward of boardwalk, to prevent inundation (5)
- Backdune, to prevent inundation (1)
- Around the dune, for control of access and for stabilization (4)
- Create walkways (2)

Season when installed
- Late spring to repair dune (11) or control access (10)
- Fall, to build dune (7), keep sand on beach or prevent inundation (5), control access (3)

Fence configuration related to purpose
- Straight
  - Control access (11)
  - Dune building (10)
  - Prevent inundation of infrastructure (7)

Fix dunes (2)
Keep sand on beach (1)
Create walkways (1)
Zigzag
Dune building (9)
Number of fences built at one time
One (13)
One or two (7)

Fences are built as single rows or pairs (Table 5.5). Double zigzag fence rows deployed at the backshore to initiate dune formation are often followed by placing a single straight fence row at the new dune toe to continue building the dune seaward and keep people out of the dune. Straight single fence rows may be used to fix eroded dunes originally built with zigzag fences, resulting in a straight/zigzag configuration (Figure 5.1 C). Straight fences are more commonly employed than zigzag fences now that most dunes have been built to heights and widths considered acceptable for shore protection. Some municipalities have not deployed fences recently.

5.3 Change of sand fence characteristics over several years

Site visits in 2008 reveal that five municipalities that had fences with no dunes in 2002 have dunes; one that had fences and no dune has neither fences nor dunes; two that had fences and dunes have no conspicuous fences; seven have more fence rows; three have fewer fence rows because of burial; eight have different fence configurations; and eight have no change in numbers of fence rows or configurations. Backdune fences occur in 11 municipalities, more than would be expected, given responses in the interviews (Table 5.5). Shore-perpendicular fences are common. Twelve municipalities have fences to control pedestrian access to the beach, and property owners in eight municipalities use shore-perpendicular fences as their private paths to the beach or along cross-shore property lines. Many fences also demarcate property lines alongshore. The only fence configuration seen on the ground in 2008 and not on the video is a double line of shore-parallel straight fences partitioned into rectangular compartments by numerous cross shore fences placed between them (Figure 5.3).

The impact of fences in organizing and compartmentalizing space is conspicuous when viewed from the ground as well as from the air. Even damaged and decaying fences provide conspicuous reminders of this compartmentalization (Figure 5.4).

Figure 5.3: Fence configuration observed in 2008 field reconnaissance but not in 2002 video inventory, double line of shore-parallel straight fences partitioned into rectangular compartments (Loveladies Beach, Long Beach Township, NJ)

The numbers, locations and configurations of sand fences and the dunes they create change through time. Fences may deteriorate, be destroyed by wave uprush, buried by aeolian accretion, repaired, removed or replaced. The number of fences increases as new ones are built to replace those that are weathered or end up far from the original zone of active sand transport. Some fences are repaired, but there is often no local consistency in where repairs are made. Many fences deployed on the backshore in 2002 are now within dunes as sediment has accumulated around them. The number of fence rows within dunes can range from 8 to 10 between completely buried, partially buried weathered remnants and new fences. Zigzag fences, common in the past, now often only occur within the dunes and are partially or completely buried. Many old fences in the dune remain conspicuous, especially when new fences were placed in locations that were already well vegetated and little subsequent burial occurred.

Figure 5.4: Damaged or decaying fences still important in organizing and compartmentalizing space (Brick Township, NJ)

The wooden slat fences revealed in the dune in the video record at Manasquan had been replaced by a symbolic rope fence on the seaward side (Figure 5.5) because local residents thought that sand-trapping fences would build the dune higher and obstruct their views. The municipality asked for, and obtained, a permit from the state to install a sand-trapping fence seaward of the dune toe at the beginning of the winter storm season and remove the fence prior to the summer season and bulldoze the accumulation onto the backshore. This practice mimics the former practice of seasonal dune grading that had been eliminated by state regulations, but it is considered acceptable because a protective foredune now remains landward of the temporary accretion. The overriding concern is the value of the dune as a protection structure. The symbolic fence was created by simply removing the wooden slats and attaching a rope to the remaining fence posts. The alternative fence types used to control access at Manasquan are easy to repair, and less physically and visually intrusive than the previous sand fences and thus provide a more compatible image of the dune as a natural component of the landscape, but the seasonal placement and removal of the seaward sand fence and accumulated sediment to maintain views of the sea is an unfortunate byproduct of the new policy.

Figure 5.5: Sand fence slats replaced by rope on the seaward side of the dune to control access to the dune (Manasquan, NJ)

Fence configurations revealed in the video at Ocean Grove were unusual in their orientation and location on the middle of the backshore. In 2008, a vegetated protective dune had formed along the landward-most shore parallel fence, and zigzag fences had been deployed on the backshore. These backshore fences and the unvegetated ridges they created are conspicuous human intrusions on the beach (Figure 5.6).

Figure 5.6: Zigzag fences on the middle of the backshore are human intrusions on the beach that form unvegetated dune ridges (Ocean Grove, NJ)

5.4 Conclusions

The temporal and spatial characteristics of sand fences help define the coastal landscape and communicate the history of management goals and priorities, which presently are not based on restoring a natural image or function. Decisions for fence deployment made at the municipal level result in considerable longshore variety in numbers and configurations of fences and the landforms they create. Sand fences may have to be accepted as necessary human adjustments to developed coasts because of their value in creating dunes to provide protection against coastal hazards, but use of fences can be made more compatible with natural processes and biota. Sand fences impede movement of fauna and are physically and psychologically exclusionary. These detrimental aspects worsen with over-use of fences. New fences or fences placed in locations where little sand can be trapped are conspicuous. More careful consideration should be given to the initial placement of sand fences where regulations prevent their removal. They should not be placed where a dune of adequate size already exists, where they would trap sand in unnatural configurations, or where they cannot be buried, such as in vegetated portions of the dune or on narrow beaches where sources of wind blown sand are restricted. The presence of fences that remain partially buried within the dunes is conspicuous and should be further analyzed to identify their impacts on topographic variability and the distribution of vegetation density and diversity. These aspects are addressed in the following chapter.

Chapter 6: Relationship of remnant fences to dune vegetation and morphology

It was initially assumed that vegetation density and diversity would be higher near remnant fences because the fences may provide shelter, trap seeds and/or create microhabitats. Based on this possibility, an analysis of field survey variables was conducted to evaluate the effect of remnant fences on dune vegetation distribution. Field variables are divided in three categories and include: geomorphic (distance landward of dune toe, degree of sheltering and sediment deposition), vegetation (diversity and density) and fence variables (fence presence, distance landward and seaward of fence). Cross-shore field data are used to evaluate the effect of remnant fences of different heights and locations on vegetation distribution within different dune zones. An alongshore transect was evaluated to analyze the local distribution of vegetation directly landward and seaward of a fence. These analyses are used in Chapter 7 to facilitate the development of guidelines that consider the effect of remnant fences on vegetation in future dune building projects.

6.1 Effect of fences at all sites: cross-shore characteristics

The cross-shore transects are used to provide information on topographic variability, vegetation distribution and depositional patterns with increasing distance landward of the dune toe and remnant fences. These transects consider cross-shore dune vegetation variability with increasing distance landward of the beach, which is the main effect on factors determining the spatial distribution of dune species such as sediment transport and burial (Moreno-Casasola 1989, Maun 2004).

Topography and fence locations are identified in all sites and transects in Figure 6.1. The other figures (Figure 6.2-6.5) display the cross-shore distribution of variables in the middle transect of each site. The middle transect was selected as the most representative of each site because its location is less affected by the presence of walkways. The variables in the figures include topography, deposition from October 2007 to March 2008, degree of sheltering (absolute value of square root of plot depth by highest elevation seaward by distance landward of dune toe), vegetation diversity (Simpson's diversity index accounts for number of species and number of individuals per species), vegetation density (number of individuals), and density of the densest species (each site has different species with highest density). Correlation coefficients were calculated by aggregating data from all transects per site to establish statistical relationships between variables.

6.1.1 Fence, morphology and vegetation characteristics in all sites

Fences are considered remnants when located at low sediment transport dune zones and/or when their height is lower than average vegetation height (0.25m). A fence is considered active if it is located at a high sediment transport zone and it is higher than average vegetation height. The combination of location and height makes active fences effective and useful barriers to onshore sediment transport.

Remnant fences were found at different dune zones including: foreslope of landward ridge, swale, and backslope and foreslope of seaward ridge (Figure 6.1, Table 6.1). Average remnant fence height is 0.3 m; highest remnant fence is 0.9m (Site 1) and lowest 0.04m (Site 3) (Figure 6.1, Table 6.1). Low fences found at high sediment transport dune zones (crest of Site 4, Figure 6.1) are considered remnants because their height limits their effectiveness in causing deposition. Most transects (seven of twelve) have three fences at different dune zones, one transect has four remnant fences, three transects have one remnant fence and one transect has no remnant fence (Figure 6.1). 61 of the 630 quadrats studied had remnant fences within them or within 1.5m of the edge of the quadrat. Site 4 is the only site with active fences, found at the seaward crest of the middle and north transects, and at the dune toe of the south transect (Figure 6.1, Table 6.1).

Dune width ranges from 33m to 88m, and beach width from 30m to 80m (Figure 6.1). The highest dune is 3.2 m (Site 1) above the dune toe, while the lowest is 1.2m at its highest point (Site 3) (Figure 6.1). Vegetation diversity is high in the backslope of the landward ridge (Figure 6.2-6.5), and in the sheltered swales of sites with high topographic variability (Figure 6.3, 6.5) which is expected (Miller et al. 2010, Doing 1985, Stallins 2002). Site 4 is the only site with high topographic variability but low diversity at the swale. Site 2 has the lowest topographic variability and low diversity at the high swale (Figure 6.3). High vegetation density occurs at the seaward ridge of each sites (Figure 6.2-6.4) where the growth of beachgrass, the most abundant species in most sites, is stimulated by deposition.

Eighteen vegetation species were identified in at least one of 12 transects (Table 6.2). Beachgrass, pineweed, seaside spurge, dune sandbur and purple sandgrass were found in all sites. Beachgrass is the most common and abundant species which is often artificially planted during early dune building stages to help build and stabilize the dunes (Mauriello and Halsey 1987, Nordstrom 2000). Japanese sedge was the only invasive species found occurring in the backslope of three sites. According to the Monmouth County Planning Board, this species is sometimes used to stabilize the dune because it is tolerant to salt and sand blasting. A dense linear pattern of sea oats was artificially planted in the backslope of Site 4 possibly as an experiment to test its viability near the northern limit of its natural range. Quadrats lacking vegetation occurred at all sites in locations such as the dune toe, foreslope, seaward ridge, and seaward backslope. In most cases, these bare patches were found in locations where erosion occurred (Figures 6.2-6.5). Two species found in three sites were unidentifiable. Twelve vegetation species occurred at Site 1, thirteen at Site 2, nine at Site 3 and eleven at Site 4 (Table 6.2).

6.1.2 Fences, morphology and vegetation characteristics per site

6.1.2.1 Site 1

Site 1 was used as a control site because the landward ridge was created with fences but the topography seaward of the seaward-most fence and former dune toe was not restricted by fence deployment and was allowed to evolve naturally on a beach artificially widened by nourishment. As a result, this dune is the highest and widest of all sites (Figure 6.1). Its average width is 85m and its average highest point is 2.7m above the dune toe at the crest of the landward ridge. This is the only site where the lowest elevation within the dune field is lower than the dune toe (Figure 6.1). The beach is approximately 66m wide at low tide.

After beach nourishment, a new foredune developed 60m seaward of the fenced landward ridge, trapping most sediment blown onshore and preventing transport farther landward. As a consequence, fences at the foreslope of the landward ridge and at the former dune toe, 0.3m and 0.9m high respectively (Figure 6.1) remained visible within the ridge. The height of the remnant fence at the former dune toe is evidence of the effectiveness of the sand-trapping capability of the incipient foredune that developed far seaward of it.

Site 1 provides the greatest degree of sheltering of all sites at the landward edge of the dune because it has the widest dune and the highest landward ridge (Figure 6.2). Although it is expected that more sheltering leads to greater diversity, Site 1 has the lowest overall diversity of all sites (Figure 6.2). The limited sediment transport landward of the natural seaward ridge prevented natural succession from occurring. The establishment of successional species depends on the richness of the soil resulting from healthy growth of beachgrass in windblown sand (Maun 1993). Pioneer plants should be replaced by others as soil nutrients increase and/or stress levels decrease landward of the dune toe (Hesp 1991). Pioneer species are established in the dune if there is enough sediment deposition to stimulate their growth. Once established, beachgrass stabilizes the dune surface and facilitates the recruitment, growth or fecundity of other species (De Lillis et al. 2004, Nordstrom et al. 2007). Lack of transport and deposition landward of the seaward ridge, prevented the establishment and later decay of dense strands of beachgrass in the landward ridge and in the space between the ridges, restricting the organic content of the soil and the establishment of a diverse successional vegetation community.

Site 1 has the highest vegetation density at the seaward ridge of all sites (Figure 6.2). This ridge developed at a slower rate because it was not restricted by fence deployment. Fences can alter the temporal sequence of dunes by accelerating depositional rates and exceeding the positive stimulus threshold of beachgrass growth. Dense beachgrass developed on the seaward ridge because the rates of burial stimulated its growth as deposition was not restricted to a location directly landward of a fence.

6.1.2.2 Site 2

Site 2 has a 45m wide dune and a 62m wide beach (Figure 6.1). The highest point at the crest of the seaward ridge averages 2.3m above the dune toe. A 0.10m high remnant fence row is barely noticeable at the vegetated swale. The highest sediment deposition at Site 2 averages 24, cm which is the highest of all sites because of the effectiveness of the high and well vegetated seaward ridge in trapping and preventing landward sediment transport (Figure 6.3). Vegetation has a key role in controlling local sediment transport by modifying the velocity of the near surface wind, enhancing deposition of grains in transit and anchoring local deposits (Sherman and Hotta 1990).

6.1.2.3 Site 3

Site 3 has the narrowest (38 m on average) and lowest dune (1.2m above the dune toe at highest point) and widest beach (75m) of all sites (Figure 6.1). The narrow dune and wide beach may be a consequence of boats on the beach which are only present at this site. The boats trap onshore sediment transport on their seaward side during the winter months preventing sediment from reaching the dune.

The lowest remnant fence of all sites (0.04m) is found at this site. The remnant fences are 0.3m high or less which is 25% or less of their initial height (1.2m) (Figure 6.1). The past deposition caused by these fences has created a variable topography consisting of two ridges and a swale within a space of approximately 38m (Figure 6.4).

Figure 6.1: Topography and fences of all transects at Site 1 and Site 2

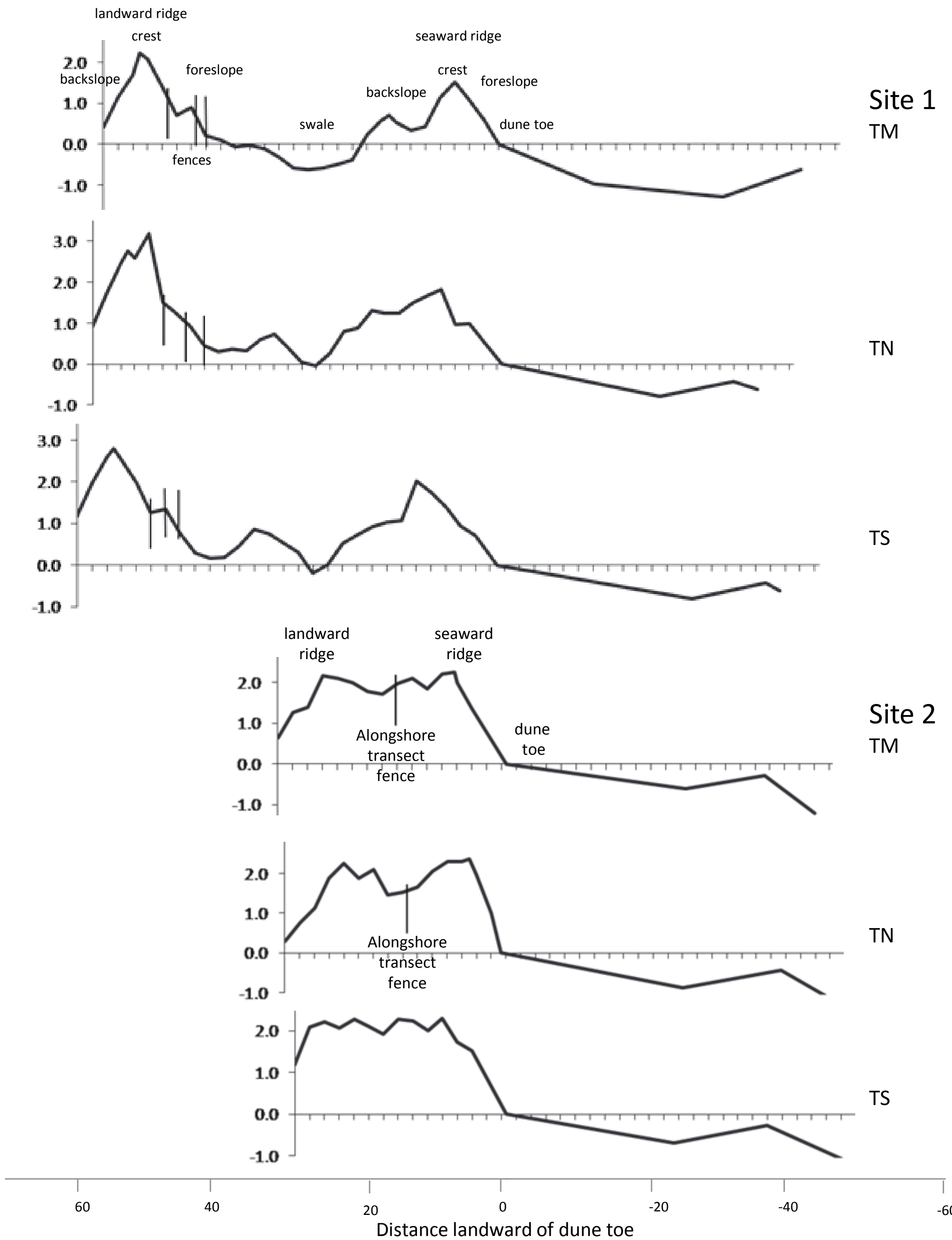


Figure 6.1: Topography and fences of all transects at Site 3 and Site 4

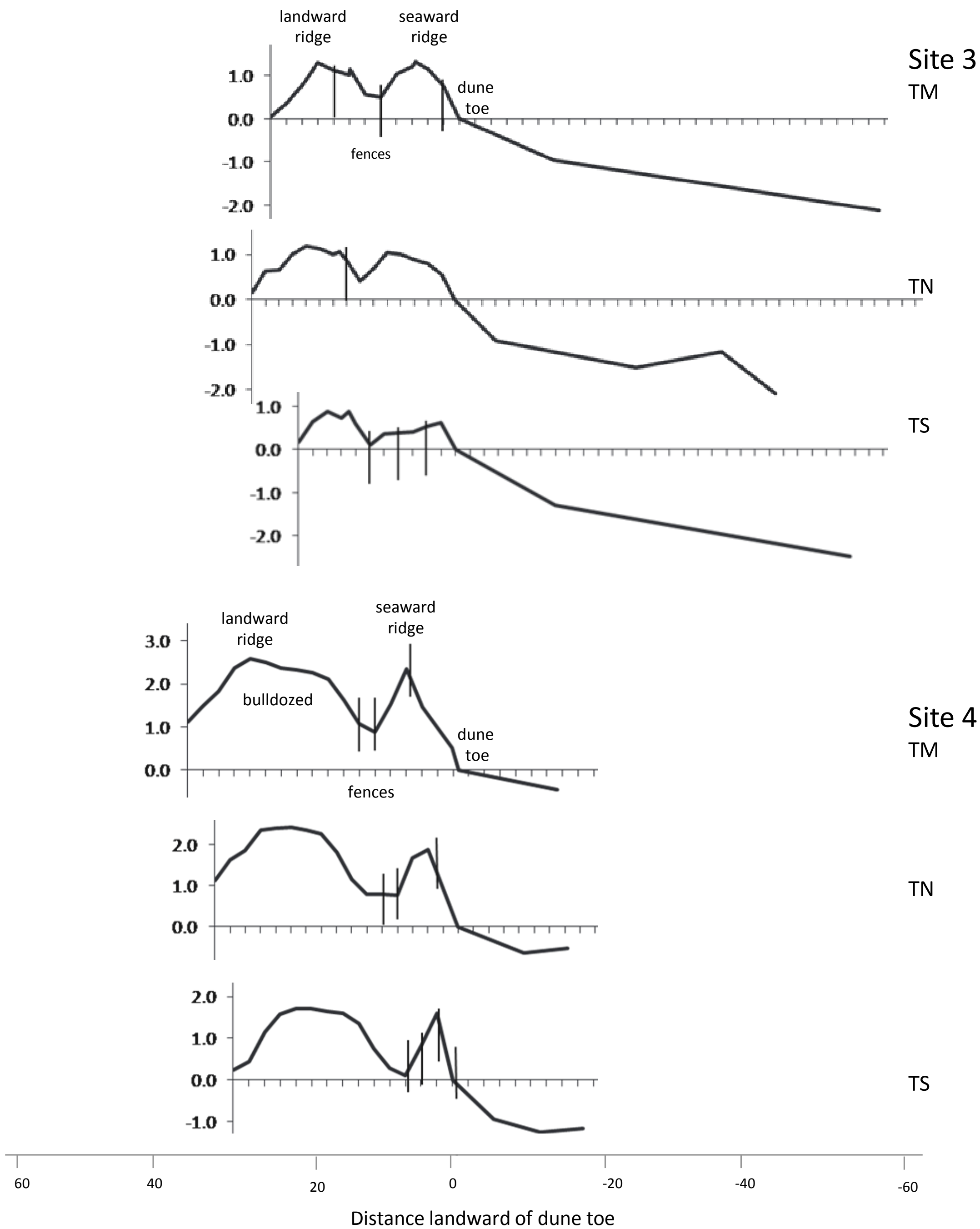


Table 6.1: Location of active and remnant fences within the dune and fence height

Site	Transect	dist landward of dune toe (m)	dune zone	average fence height (m)
1	TM	69	foreslope landward ridge	0.23
1	TM	63	foreslope landward ridge	0.27
1	TM	60	foreslope landward ridge	0.91
1	TN	76	foreslope landward ridge	0.12
1	TN	73	foreslope landward ridge	0.24
1	TN	70	foreslope landward ridge	0.54
1	TS	74	foreslope landward ridge	0.17
1	TS	68	foreslope landward ridge	0.47
1	TS	65	foreslope landward ridge	0.92
2	TM	25	swale	0.18
2	TN	26	swale	0.05
3	TM	24	foreslope landward ridge	0.04
3	TM	15	swale	0.27
3	TM	3	foreslope seaward ridge	0.05
3	TN	24	foreslope landward ridge	0.32
3	TS	18	swale	0.20
3	TS	12	backslope seaward ridge	0.09
3	TS	6	backslope seaward ridge	0.06
4	TM	18	swale	0.55
4	TM	15	swale	0.80
4	TM	9	seaward crest*	0.84
4	TN	15	swale	0.48
4	TN	12	swale	0.61
4	TN	9	seaward crest*	0.80
4	TS	9	swale	0.40
4	TS	6	backslope seaward ridge	0.65
4	TS	3	seaward crest	0.08
4	TS	0	dune toe*	0.73

6.1.2.4 Site 4

Site 4 has a 47m wide dune and the narrowest beach of all sites (32m wide) (Figure 6.1). This is the only site with a 2.25m high bulldozed landward ridge. All fences are within 18m landward the dune toe. Two rows of remnant fences with an approximate height of 0.6m are conspicuous at the swale. Active fences with average heights of 0.75m occur at the crest and dune toe (Figure 6.1).

Table 6.2: Vegetation species present per transect

		Site 1			Site 2			Site 3			Site 4		
Common name	**Scientific name**	**TS**	**TM**	**TN**	**TS**	**TM**	**TN**	**TS**	**TM**	**TN**	**TS**	**TM**	**TN**
beachgrass	Ammophila breviligulata	x	x	x	x	x	x	x	x	x	x	x	x
pineweed	Hypericum gentianoides	x	x	x	x	x	x	x	x	x	x	x	x
seaside spurge	Chamaesyce polygonifolia	x	x	x	x	x	x	x	x	x	x	x	
purple sandgrass	Triplasis purpurea	x	x	x	x	x	x	x	x	x	x		x
dune sandbur	Cenchrus tribuloides	x	x		x	x	x	x	x	x		x	
purple lovegrass	Eragrostis spectabilis	x	x	x	x	x	x	x	x	x			
seaside golden rod	Solidago sempervirens	x	x	x	x	x	x				x	x	x
seaside panicum	Panicum amarum		x		x	x	x	x	x	x			
beach heather	Hudsonia tomentosa		x		x	x		x	x	x			
sea rocket	Cakile edentula					x	x	x	x	x			
japanese sedge	Carex kobomugi			x	x	x	x			x			
camphorweed	Heterotheca subaxillaris	x			x						x	x	x
butterfly-pea	Clitoria marinara L.		x	x								x	x
sea oats	Uniola paniculata										x	x	x
bayberry	Myrica pensylvanica											x	
sand broomsedge	Andropogon longiberbis				x								
coclebur	Xanthium strumarium		x										
red-cedar	Juniperus virginiana												x
unidentified				x	x					x			
no vegetation		x	x	x	x	x	x	x			x	x	x

Site 4 is the only site with active fences within the seaward ridge, and it was expected that excessive and localized deposition would occur landward of them. Deposition at Site 4 is actually the lowest of all sites (Figure 6.5) because the narrow beach provides an insufficient sediment source.

Site 4 has the lowest overall vegetation density and relatively low diversity at the swale considering the high topographic variability. These characteristics may be a consequence of a rapidly formed bulldozed landward ridge immediately followed by the emplacement of multiple rows of seaward fences that prevented landward sediment transport, growth and later decay of beachgrass, and species succession. Low vegetation density at the seaward ridge may be a consequence of low sediment available at the beach to be transported and deposited at that ridge to stimulate beachgrass growth. High diversity at high dune elevations, such as the landward ridge, is unusual and may be related to vegetation plantings of beachgrass and sea oats (Figure 6.5).

Figure 6.2: Cross-shore distribution of variables: Site 1 middle transect
(landward of the dune toe)

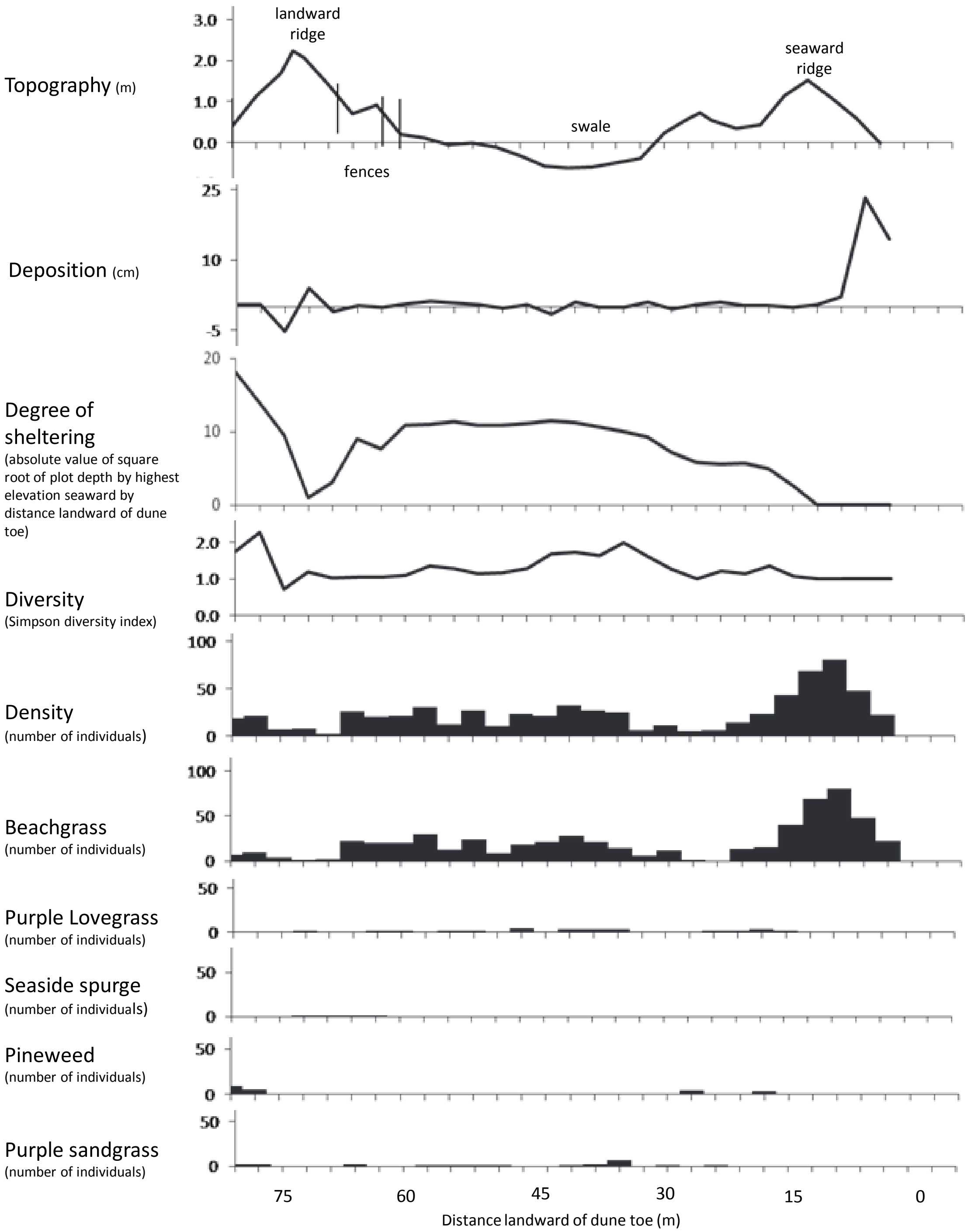


Figure 6.3: Cross-shore distribution of variables: Site 2 middle transect
(landward of the dune toe)

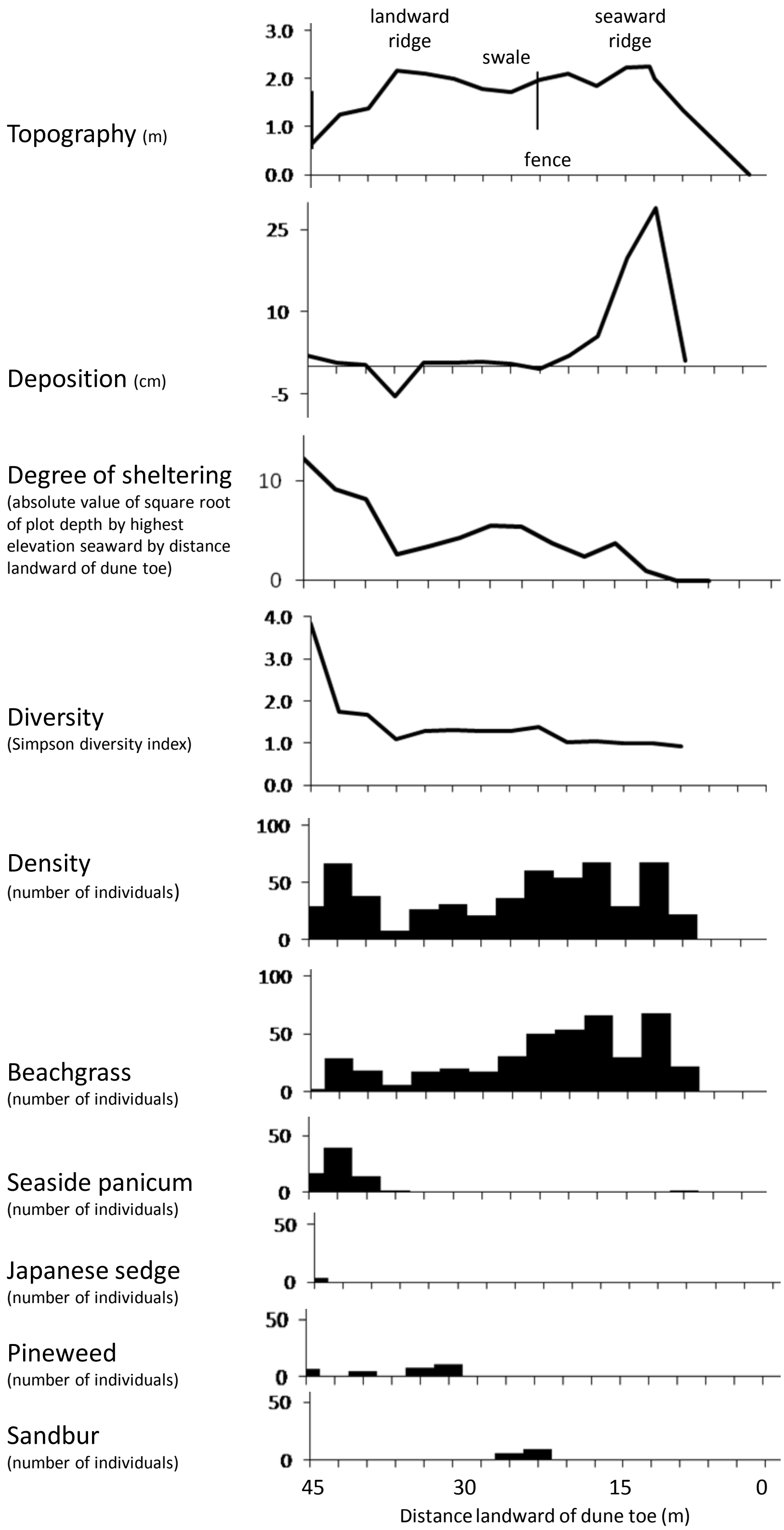


Figure 6.4: Cross-shore distribution of variables: Site 3 middle transect
(landward of the dune toe)

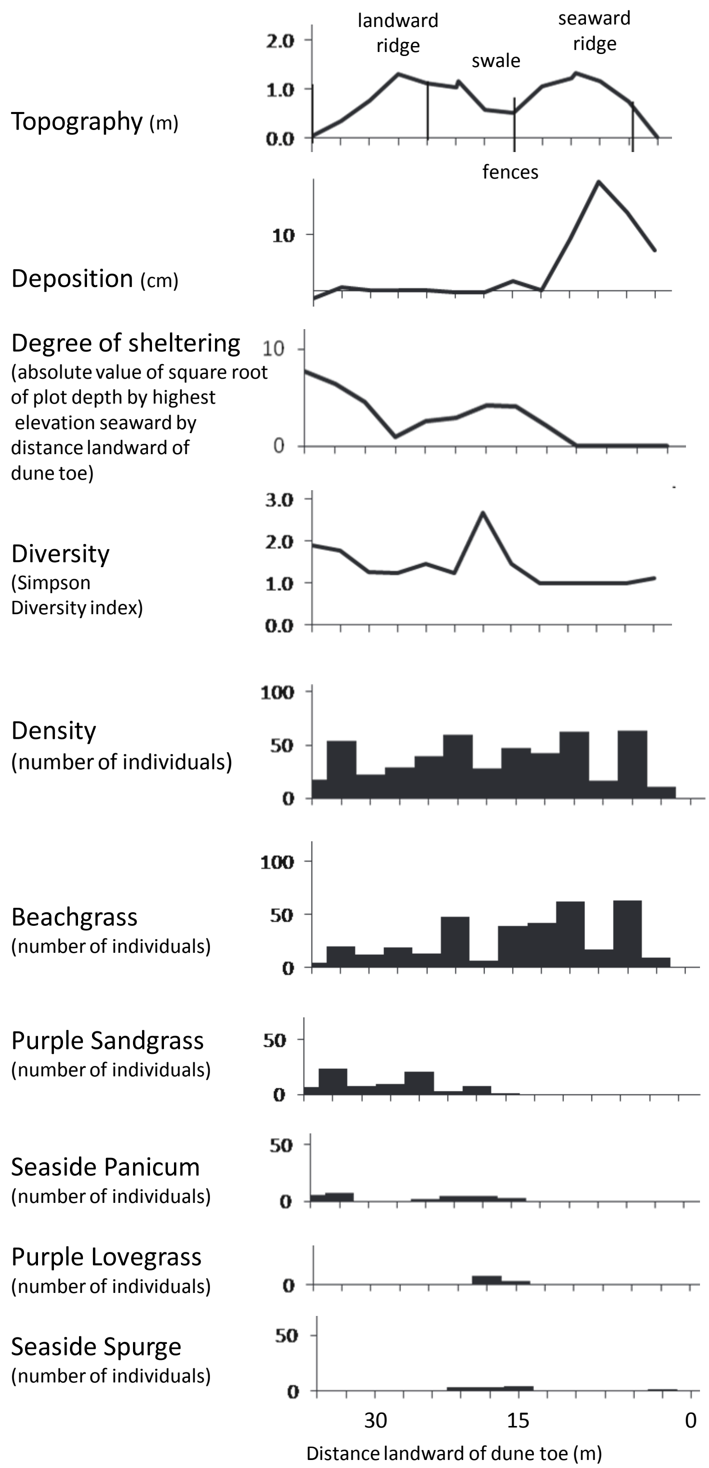
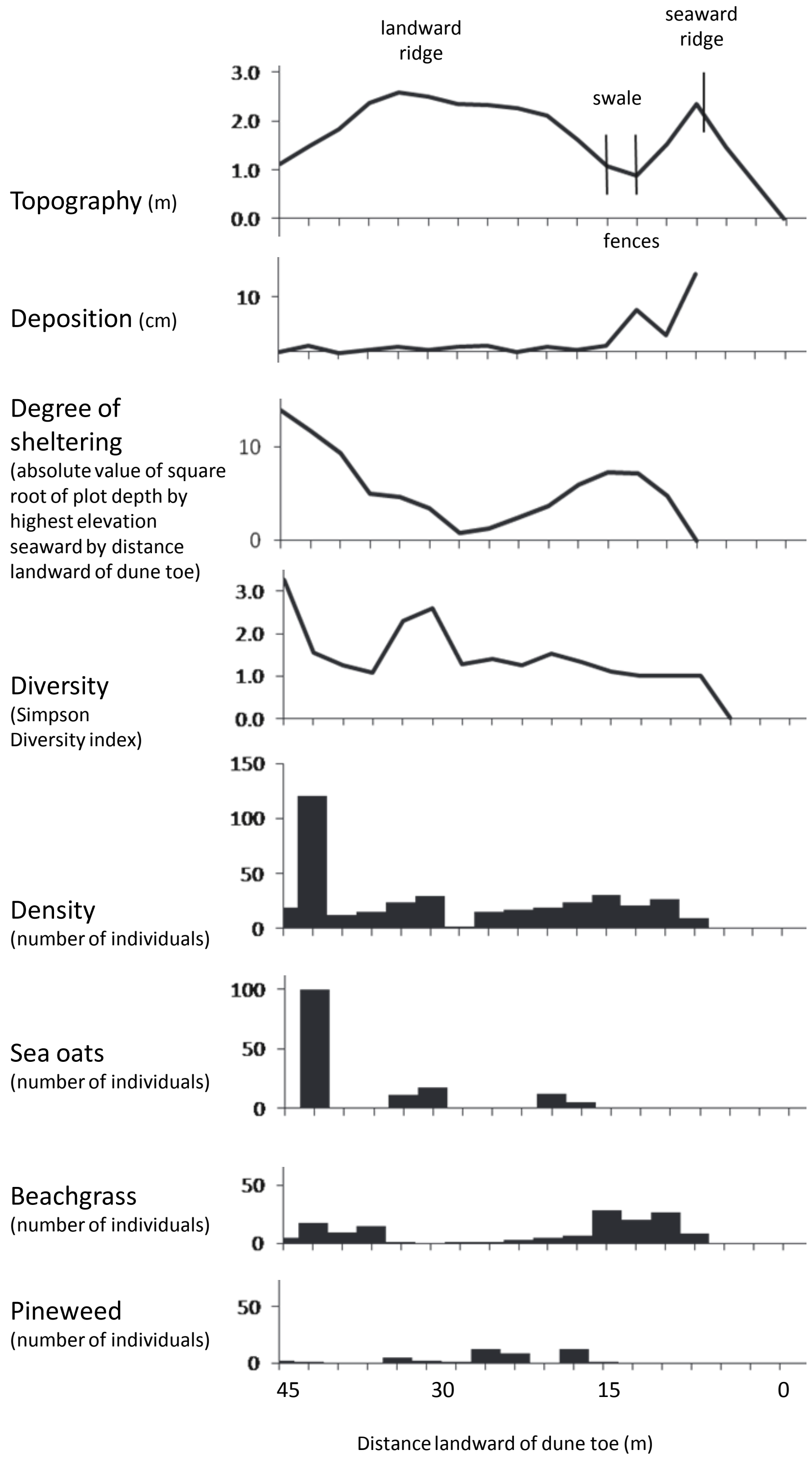


Figure 6.5: Cross-shore distribution of variables: Site 4 middle transect
(landward of the dune toe)



6.1.3 Variable interrelationships in all sites

Correlations that apply to all sites are identified here. Correlations of site specific interest are explained in the following section 6.1.4.

6.1.3.1 Geomorphic and fence variables

There is a high positive relationship between degree of sheltering and distance landward of the dune toe (Tables 6.3-6.6) because the seaward ridge blocks most onshore stress including sediment transport. Stress decreases landward of the dune toe as distance from the source of stress, topographic barriers and degree of sheltering increase (Figure 6.2-6.5). This correlation is higher than others (Tables 6.3-6.6) because one variable is used to calculate the other.

The negative correlations between deposition and distance landward of dune toe and between deposition and degree of sheltering (Tables 6.3-6.6) are expected. Landward sediment transport into sheltered dune locations is prevented by the seaward ridge (Figure 6.3-6.5). This relationship is strongest at Site 2 (Table 6.4).

Correlation coefficients show significant relationships between fence variables and geomorphologic variables at Site 4, where fence presence is positively related to deposition (Table 6.6).

6.1.3.2 Vegetation variables and fence variables

There is a positive correlation between vegetation diversity and distance landward of the dune toe (Tables 6.3-6.6) because only a few vegetation species can withstand the high levels of onshore stresses at the seaward ridge. The seaward ridge is the feature that

Table 6.3: Correlation coefficients Site 1

Site 1	lw. F	sw. f	F	lw. dt	sheltering	deposition
distance landward of fence (lw. f)	1.000					
distance seaward of fence (sw. f)	0.598	1.000				
fence presence (F)	-0.866	-0.182	1.000			
distance landward of dune toe (lw. dt)	0.621	-0.286	0.312	1.000		
sheltering	0.094	-0.179	0.013	0.729	1.000	
deposition: oct/march	-0.241	-0.342	-0.076	-0.345	-0.333	1.000
diversity	-0.175	-0.284	-0.004	0.384	0.523	-0.098
density	-0.043	0.050	-0.158	-0.406	-0.353	0.202
Beachgrass (Bgrass)	0.046	0.238	-0.175	-0.486	-0.450	0.222
Pineweed (Pweed)	-0.021	0.039	-0.100	0.062	0.223	-0.088
Sandgrass (Sgrass)	0.019	-0.321	-0.070	0.134	0.227	-0.046
Seaside Spurge (Spurge)	-0.152	-0.151	0.269	0.210	-0.046	-0.011
Lovegrass (Lgrass)	-0.270	-0.081	0.209	0.162	0.219	-0.056
Seaside Goldenrod (Goldenrod)	0.100	0.226	-0.050	0.185	-0.006	-0.037
Sandbur	0.189	-0.220	-0.048	0.250	0.184	-0.025
Seaside Panicum (Panicum)	0.000	0.000	-0.020	0.009	0.027	-0.018
Sea rocket (Rocket)	0.000	0.000	0.000	0.000	0.000	0.000
Beach heather (Heather)	0.000	-0.091	-0.035	0.157	0.099	0.037
camphor weed (Cweed)	0.000	0.000	-0.020	-0.032	0.015	-0.041
Japanese sedge (Sedge)	0.000	-0.159	-0.020	0.112	0.199	0.013
Butterfly pea (Pea)	0.000	0.045	-0.028	0.136	0.139	-0.025
Sea oats	0.000	0.000	0.000	0.000	0.000	0.000
Bayberry	0.000	0.000	0.000	0.000	0.000	0.000
Sand broomsedge (Broomsedge)	0.000	0.000	0.000	0.000	0.000	0.000
Coclebur	0.000	0.032	-0.020	0.087	0.062	-0.018
Red cedar	0.000	0.000	0.000	0.000	0.000	0.000
n= 251	n=49	n=58				
r citical= 0.126	rcrit=0.285	r crit= 0.263				

diversity	density	Bgrass	Pweed	Sgrass	Spurge	Lgrass	Goldenrod	Sandbur	Panicum
1.000									
-0.113	1.000								
-0.287	0.956	1.000							
0.408	-0.055	-0.119	1.000						
0.339	-0.059	-0.154	0.188	1.000					
-0.017	-0.121	-0.128	-0.089	-0.049	1.000				
0.435	0.053	-0.142	0.023	0.030	0.066	1.000			
0.086	-0.085	-0.138	-0.028	-0.035	-0.012	-0.019	1.000		
0.246	-0.027	-0.121	-0.026	0.031	-0.019	0.022	0.354	1.000	
-0.037	-0.067	-0.056	0.144	-0.014	-0.013	-0.024	-0.011	-0.011	1.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.097	-0.022	-0.065	-0.051	0.107	0.156	-0.041	0.021	0.132	-0.007
-0.029	-0.062	-0.049	-0.029	-0.014	-0.013	-0.024	-0.011	-0.011	-0.004
0.184	0.000	-0.056	-0.029	0.214	-0.013	-0.024	-0.011	0.134	-0.004
0.207	-0.066	-0.087	0.006	0.037	-0.019	-0.034	0.050	-0.015	-0.006
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.139	-0.030	-0.061	0.024	0.039	-0.013	-0.024	-0.011	-0.011	-0.004
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Rocket	Heather	Cweed	Jsedge	Pea	Sea oats	Bayberry	Bsedge	Coclebur	Red cedar
1.000									
0.000	1.000								
0.000	-0.007	1.000							
0.000	0.575	-0.004	1.000						
0.000	-0.010	-0.006	-0.006	1.000					
0.000	0.000	0.000	0.000	0.000	1.000				
0.000	0.000	0.000	0.000	0.000	0.000	1.000			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000		
0.000	-0.007	-0.004	-0.004	0.706	0.000	0.000	0.000	1.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 6.4: Correlation coefficients Site 2

Site 2	lw. F	sw. f	F	lw. dt	sheltering	deposition
distance landward of fence (lw. f)	1.000					
distance seaward of fence (sw. f)	0.000	1.000				
fence presence (F)	-0.856	-0.373	1.000			
distance landward of dune toe (lw. dt)	0.999	-0.189	-0.007	1.000		
sheltering	-0.468	-0.463	0.078	0.793	1.000	
deposition: oct/march	0.413	-0.086	-0.086	-0.536	-0.422	1.000
diversity	-0.464	-0.572	0.056	0.584	0.646	-0.152
density	-0.389	0.198	0.000	-0.266	-0.140	0.410
Beachgrass (Bgrass)	-0.340	0.351	-0.023	-0.514	-0.389	0.531
Pineweed (Pweed)	0.586	0.060	-0.064	0.360	0.194	-0.194
Sandgrass (Sgrass)	-0.352	-0.483	-0.024	0.184	0.097	-0.057
Seaside Spurge (Spurge)	0.162	0.132	-0.037	0.216	0.079	-0.201
Lovegrass (Lgrass)	0.000	-0.031	-0.028	0.150	0.057	-0.067
Seaside Goldenrod (Goldenrod)	-0.466	0.185	0.085	0.183	0.113	-0.078
Sandbur	-0.621	-0.232	0.187	-0.014	0.123	-0.102
Seaside Panicum (Panicum)	0.000	0.146	-0.056	0.456	0.490	-0.145
Sea rocket (Rocket)	0.000	-0.037	-0.024	-0.041	0.061	-0.062
Beach heather (Heather)	-0.054	0.000	-0.023	0.061	0.020	-0.063
camphor weed (Cweed)	0.000	0.222	-0.020	0.116	-0.070	-0.024
Japanese sedge (Sedge)	0.000	-0.328	-0.025	0.252	0.337	-0.010
Butterfly pea (Pea)	0.000	0.000	0.000	0.000	0.000	0.000
Sea oats	0.000	0.000	0.000	0.000	0.000	0.000
Bayberry	0.000	0.000	0.000	0.000	0.000	0.000
Sand broomsedge (Broomsedge)	0.000	-0.222	-0.014	0.148	0.195	-0.024
Coclebur	0.000	0.000	0.000	0.000	0.000	0.000
Red cedar	0.000	0.000	0.000	0.000	0.000	0.000
n =125	n = 9	n = 8				
r = 0.179	r = 0.667	r crt=0.667				

diversity	density	Bgrass	Pweed	Sgrass	Spurge	Lgrass	Goldenrod	Sandbur	Panicum
1.000									
-0.021	1.000								
-0.324	0.884	1.000							
0.245	-0.154	-0.257	1.000						
0.451	0.090	-0.160	-0.035	1.000					
0.197	-0.136	-0.246	0.110	0.319	1.000				
0.159	0.004	-0.096	0.065	0.074	0.059	1.000			
-0.027	0.010	-0.008	-0.015	-0.035	-0.065	-0.034	1.000		
0.162	0.316	0.061	-0.096	0.139	0.037	-0.049	-0.024	1.000	
0.295	0.064	-0.179	0.155	-0.022	-0.057	0.018	0.196	-0.097	1.000
0.019	0.254	0.116	-0.064	-0.035	-0.073	-0.028	-0.030	0.645	-0.056
-0.008	-0.119	-0.101	-0.059	-0.017	0.000	0.005	-0.028	-0.018	-0.026
0.090	-0.049	-0.147	-0.052	0.515	0.074	-0.023	-0.024	0.059	-0.045
0.501	-0.101	-0.183	-0.049	0.146	0.153	-0.013	-0.030	-0.035	0.080
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.434	-0.020	-0.113	0.165	0.152	-0.042	0.178	-0.017	-0.024	0.107
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Rocket	Heather	Cweed	Jsedge	Pea	Sea oats	Bayberry	Bsedge	Coclebur	Red cedar
1.000									
-0.023	1.000								
-0.020	-0.018	1.000							
-0.025	-0.023	-0.020	1.000						
0.000	0.000	0.000	0.000	1.000					
0.000	0.000	0.000	0.000	0.000	1.000				
0.000	0.000	0.000	0.000	0.000	0.000	1.000			
-0.014	-0.013	-0.011	0.064	0.000	0.000	0.000	1.000		
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 6.5: Correlation coefficients Site 3

Site 3	lw. F	sw. f	F	lw. dt	sheltering	deposition
distance landward of fence (lw. f)	1.000					
distance seaward of fence (sw. f)	0.327	1.000				
fence presence (F)	-0.866	-0.022	1.000			
distance landward of dune toe (lw. dt)	0.337	-0.084	-0.119	1.000		
sheltering	-0.006	-0.361	-0.063	0.773	1.000	
deposition: oct/march	-0.192	0.050	0.152	-0.369	-0.276	1.000
diversity	0.207	0.126	-0.073	0.320	0.242	0.009
density	0.142	0.037	0.052	0.045	0.017	0.160
Beachgrass (Bgrass)	0.048	0.074	0.113	-0.329	-0.225	0.288
Pineweed (Pweed)	-0.030	-0.146	0.103	0.295	0.119	-0.170
Sandgrass (Sgrass)	0.100	-0.199	-0.066	0.215	0.156	-0.123
Seaside Spurge (Spurge)	0.158	-0.058	-0.034	0.009	0.122	-0.097
Lovegrass (Lgrass)	0.194	0.190	-0.017	0.177	-0.041	-0.123
Seaside Goldenrod (Goldenrod)	0.000	0.000	0.000	0.000	0.000	0.000
Sandbur	-0.183	-0.175	-0.054	-0.220	-0.131	0.000
Seaside Panicum (Panicum)	0.213	-0.163	-0.118	0.288	0.512	-0.137
Sea rocket (Rocket)	-0.377	-0.077	0.002	-0.174	-0.097	0.147
Beach heather (Heather)	-0.193	-0.189	0.066	0.165	0.230	-0.076
camphor weed (Cweed)	0.000	0.000	0.000	0.000	0.000	0.000
Japanese sedge (Sedge)	0.000	-0.074	-0.071	0.419	0.395	-0.095
Butterfly pea (Pea)	0.000	0.000	0.000	0.000	0.000	0.000
Sea oats	0.000	0.000	0.000	0.000	0.000	0.000
Bayberry	0.300	0.202	-0.029	0.077	0.105	-0.031
Sand broomsedge (Broomsedge)	0.000	0.000	0.000	0.000	0.000	0.000
Coclebur	0.000	0.000	0.000	0.000	0.000	0.000
Red cedar	0.000	0.000	0.000	0.000	0.000	0.000
n = 120	n = 29	n = 45				
r critical = 0.183	r = 0.372	r = 0.298				

diversity	density	Bgrass	Pweed	Sgrass	Spurge	Lgrass	Goldenrod	Sandbur	Panicum
1.000									
0.304	1.000								
-0.247	0.629	1.000							
0.240	0.122	-0.090	1.000						
0.363	0.445	-0.225	0.219	1.000					
0.269	0.133	0.009	-0.012	0.096	1.000				
0.362	0.108	-0.163	0.037	0.021	0.063	1.000			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000		
0.017	-0.102	-0.047	-0.088	-0.073	-0.019	-0.081	0.000	1.000	
0.359	0.069	-0.090	-0.008	0.037	0.047	-0.045	0.000	-0.009	1.000
0.240	-0.017	0.052	-0.039	-0.048	-0.023	-0.041	0.000	0.024	-0.022
0.161	-0.022	-0.061	0.062	0.053	-0.064	-0.015	0.000	-0.042	0.322
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.121	0.105	-0.142	0.089	-0.075	-0.069	-0.063	0.000	-0.053	0.197
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-0.053	-0.087	-0.040	-0.037	-0.032	-0.034	-0.032	0.000	-0.022	-0.034
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Rocket	Heather	Cweed	Jsedge	Pea	Sea oats	Bayberry	Bsedge	Coclebur	Red cedar
1.000									
-0.005	1.000								
0.000	0.000	1.000							
-0.031	-0.039	0.000	1.000						
0.000	0.000	0.000	0.000	1.000					
0.000	0.000	0.000	0.000	0.000	1.000				
-0.013	-0.016	0.000	-0.021	0.000	0.000	1.000			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000		
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 6.6: Correlation coefficients Site 4

Site 4	lw. F	sw. f	F	lw. dt	sheltering	deposition
distance landward of fence (lw. f)	1.000					
distance seaward of fence (sw. f)	0.400	1.000				
fence presence (F)	-0.799	-0.183	1.000			
distance landward of dune toe (lw. dt)	0.338	-0.258	-0.474	1.000		
sheltering	0.181	-0.248	-0.166	0.595	1.000	
deposition: oct/march	-0.235	-0.064	0.271	-0.276	-0.154	1.000
diversity	0.381	-0.074	-0.293	0.437	0.301	-0.149
density	0.140	-0.004	-0.086	0.248	0.367	0.037
Beachgrass (Bgrass)	-0.142	0.021	0.223	-0.232	0.110	0.241
Pineweed (Pweed)	0.211	-0.268	-0.171	0.179	-0.077	-0.100
Sandgrass (Sgrass)	0.000	0.000	-0.041	0.156	0.211	-0.033
Seaside Spurge (Spurge)	-0.138	-0.177	0.093	-0.131	0.075	-0.010
Lovegrass (Lgrass)	0.000	0.000	0.000	0.000	0.000	0.000
Seaside Goldenrod (Goldenrod)	0.305	-0.177	-0.177	0.201	-0.009	-0.108
Sandbur	0.000	0.000	-0.034	0.161	0.237	-0.026
Seaside Panicum (Panicum)	0.000	0.000	0.000	0.000	0.000	0.000
Sea rocket (Rocket)	0.000	0.000	0.000	0.000	0.000	0.000
Beach heather (Heather)	0.000	0.000	0.000	0.000	0.000	0.000
camphor weed (Cweed)	0.000	0.000	-0.069	0.243	0.340	-0.043
Japanese sedge (Sedge)	0.000	0.000	0.000	0.000	0.000	0.000
Butterfly pea (Pea)	0.000	0.000	-0.080	0.343	0.451	-0.037
Sea oats	0.012	-0.185	-0.032	0.282	0.295	-0.027
Bayberry	0.000	0.000	-0.034	0.161	0.237	-0.026
Sand broomsedge (Broomsedge)	0.000	0.000	0.000	0.000	0.000	0.000
Coclebur	0.000	0.000	0.000	0.000	0.000	0.000
Red cedar	0.000	0.000	-0.034	0.142	0.194	0.011
n = 131	n = 44	n = 27				
r = 0.175	r = 0.302	r = 0.385				

diversity	density	Bgrass	Pweed	Sgrass	Spurge	Lgrass	Goldenrod	Sandbur	Panicum
1.000									
0.245	1.000								
-0.245	0.417	1.000							
0.315	0.059	-0.203	1.000						
0.212	-0.009	0.035	-0.030	1.000					
-0.085	-0.003	0.143	-0.071	-0.016	1.000				
0.000	0.000	0.000	0.000	0.000	0.000	1.000			
0.406	0.063	-0.268	0.032	-0.004	-0.071	0.000	1.000		
0.421	0.002	0.006	-0.029	-0.009	-0.013	0.000	-0.005	1.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.235	0.001	-0.029	-0.047	0.675	-0.027	0.000	0.102	0.218	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.348	-0.029	-0.080	-0.071	-0.022	-0.032	0.000	0.011	0.665	0.000
0.098	0.652	0.152	-0.097	-0.047	-0.074	0.000	0.027	-0.042	0.000
0.086	-0.037	-0.058	-0.043	-0.009	-0.013	0.000	0.022	-0.008	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-0.051	0.025	-0.058	-0.043	-0.009	-0.013	0.000	-0.041	-0.008	0.000

Rocket	Heather	Cweed	Jsedge	Pea	Sea oats	Bayberry	Bsedge	Coclebur	Red cedar
1.000									
0.000	1.000								
0.000	0.000	1.000							
0.000	0.000	0.000	1.000						
0.000	0.000	0.153	0.000	1.000					
0.000	0.000	-0.025	0.000	-0.038	1.000				
0.000	0.000	-0.016	0.000	-0.018	-0.042	1.000			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000		
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	
0.000	0.000	-0.016	0.000	0.324	-0.042	-0.008	0.000	0.000	1.000

causes the positive relationship between degree of sheltering and diversity. This relationship is strongest at Site 2 and weakest at Site 3 (Tables 6.4 and 6.5).

Beachgrass density relates negatively to distance landward of the dune toe and positively to deposition in all sites because as a pioneer, sediment trapping, dune building species, its growth is positively stimulated by high deposition (17-28cm) occurring at the seaward ridge (Martin 1959). Beachgrass density negatively correlates with sheltering in all sites but Site 4. Beachgrass density and vegetation density are highly correlated because beachgrass is the most (Figures 6.2-6.4) or second most (Figure 6.5) abundant species. This relationship is lowest at Site 4 where sea oats is the most abundant species.

Site 1 and Site 4 are the only sites with significant relationships between fence and vegetation variables, which are discussed in detail in the following sections.

6.1.4 Explanation of variable interrelationship at each site

6.1.4.1 Site 1

Correlation coefficients show significant positive relationships between fence presence and density of seaside spurge and purple lovegrass (Table 6.2). Seaside spurge occurs in relatively undisturbed dune zones (Duncan and Duncan 1987) similar to the characteristics of the foreslope of the landward ridge at Site 1 where the remnant fences are. Seaside spurge is much lower than the remnant fences (0.1m) and may benefit from sheltering provided by them. Purple lovegrass is common at stable dune areas and at locations where there are fences (Duncan and Duncan 1987).

Vegetation density and beachgrass density are negatively correlated with distance landward of the dune toe and sheltering and positively to deposition (Table 6.3). Pioneer plants germinate in a region where maximum sand transport and deposition take place (Hesp 1991). When sand deposition is greatest, plant growth is encouraged, resulting in an increased aerodynamic roughness and higher deposition (Hesp 1989). As soon as deposition ceases landward of the seaward ridge, there is a marked decline in vigor and density of foredune populations (Maun 2004). Therefore, highly sheltered, low deposition dune zones landward of the seaward ridge will have the lowest density of beachgrass growth. These factors explain why vegetation density and beachgrass density negatively relate to remnant fence presence (Table 6.2); all fences are located at the landward ridge where sediment deposition is minimal (Figure 6.2).

6.1.4.2 Site 2

Site 2 has the highest positive correlation between vegetation diversity and degree of sheltering (Table 6.4) because conspicuously high diversity occurs at the backslope (Figure 6.3). The swale is usually a low and sheltered high diversity dune zone protected by the higher seaward crest (Doing 1985, Stallins 2002), but the swale at Site 2 is abnormally high with limited increase in sheltering (Figure 6.3). It is 0.5m lower than the seaward crest which is much higher than the swale at the control site (2m lower than the seaward crest, Figure 6.2). Low topographic variability and sheltering expose the swale to onshore stresses causing low diversity at this zone.

6.1.4.3 Site 3

Site 3 has the highest number of positive correlations between vegetation diversity and the density of specific species occurring in the swale including pineweed, purple sandgrass, seaside spurge and purple lovegrass (Table 6.5, Figure 6.4). The high diversity at the swale of this site is possibly a consequence of sheltering and topographic variability. Although the increase in sheltering at the swale is slight, as a consequence of the overall low height and narrow width of this dune, the low swale height may bring vegetation closer to the water table increasing the availability of moisture and providing an additional benefit to vegetation growth.

6.1.4.4 Site 4

Site 4 has the greatest number of significant correlations between fence variables and geomorphic and vegetation variables. There is a positive relationship between fence presence and deposition (Table 6.6), but it is possible that deposition is being caused by the seaward ridge than by the fences, because deposition is less than would be expected from fences deployed so close to the backshore. Fence presence negatively relates to diversity (Table 6.6) because fences are on or close to the highly exposed seaward ridge.

Unlike Site 1, there is a positive relationship between vegetation density and distance landward of the dune toe (Table 6.6) because highest density occurs at the stable backslope where sea oats were planted. This is the only site where vegetation density has no relationship with deposition (Table 6.6).

6.1.5 Vegetation diversity variability prediction models

The multiple correlation site models show no significant correlations between diversity and distance landward of fence (Table 6.7). Degree of sheltering shows a significant positive correlation with diversity in all sites but Site 3. Sediment deposition has a positive significant correlation with diversity only at Site 1. Adjusted R^2 values of 0.37 for Site 1 and 0.43 for Site 2 (significant at 0.05 level), indicate that the combination of these variables accounts for approximately 40% of the variability in vegetation diversity in these sites. Adjusted R^2 values at Site 3 and 4 are not significant.

Table: 6.7 Individual Site models to predict vegetation diversity variability

	Site 1		Site 2	
Dependent variable: Vegetation diversity	Estimated coefficient	Prob> t	Estimated coefficient	Prob> t
Dist. landw. fence	0.0009	0.9533	0.0056	0.8310
Sheltering	0.0554	0.0001	0.1477	0.0105
Deposition	0.0823	0.0017	0.0795	0.5185
Observations	68		23	
F	14.36		6.70	
Prob >F	0.0000		0.0026	
Adjusted R^2	0.3708		0.4265	
	Site 3		**Site 4**	
Dependent variable: Vegetation diversity	Estimated coefficient	Prob> t	Estimated coefficient	Prob> t
Dist. landw. fence	0.0086	0.6532	0.0149	0.5896
Sheltering	0.0033	0.9535	0.0445	0.0374
Deposition	-0.0139	0.2198	0.0091	0.1667
Observations	46		25	
F	1.06		2.16	
Prob >F	0.3751		0.1215	
Adjusted R^2	0.0040		0.1222	

Critical values used for models were calculated at a 0.05 confidence level

Based on this model, sheltering is an significant variable in predicting the variability in the distribution of dune vegetation in all sites but Site 3. The low height and narrow width of the dune at this site leads to low overall sheltering, but diversity still increases at the slightly sheltered dune zones (Figure 6.4). Other variables, such as topographic variability and nearness to the water table, may be of greater importance than sheltering in determining the variability of vegetation diversity at Site 3.

The low significance of the adjusted R^2 in Site 4 is possibly a consequence of other variables having greater importance in the variability of dune vegetation diversity. These variables may include human factors such as limited succession due to accelerated building of the landward ridge through bulldozing and vegetation plantings.

6.2 Vegetation distribution along the remnant fence at Site 2

The alongshore transect was used to evaluate vegetation distribution 1m seaward, 1m landward, and 3 and 6m landward of the intermittently visible remnant fence located at the swale of Site 2 (Figure 6.1). Quadrat replicates along both sides of the fence were compared based on presence or absence of remnant fence.

6.2.1 Sediment deposition and vegetation characteristics 1m landward and seaward

The t test of comparison of means showed no significant difference in deposition, vegetation diversity and vegetation density when the following quadrat categories were compared: 1m landward and 1m seaward of alongshore transect (Figure 2.3 A), 1m landward with and without a remnant fence (Figure 2.3 B), 1m seaward with and without remnant fence (Figure 2.3 C), 1m landward and 1m seaward with a remnant fence (Figure 2.3 D), 1m landward and 1m seaward without remnant fence (Figure 2.3 E). The remnant fence does not cause sediment deposition because sediment is trapped by the seaward ridge and does not reach the swale. Vegetation diversity and density are not affected by a remnant fence within 1m because the height of the remnant fence (0.09m) is lower than average vegetation height (0.25m). The fence does not provide more shade or sheltering than the vegetation.

Seaside spurge is significantly denser in quadrats 1m seaward of the alongshore transect where no fence occurs than in quadrats 1m seaward of an existing fence remnant (Figure 2.3 C). It is also significantly denser 1m landward of the alongshore transect where there is a remnant fence than 1m seaward of the fence (Figure 2.3 D). Seaside spurge on the landward side of the remnant fence may be benefit from additional shelter provided by the fence because the average seaside spurge height (0.1m) is less than average remnant height (0.3m). When located on the seaward side of the transect where there is no fence, this low species may benefit from the slightly lower elevations (Figure 6.1) at the swale and slight shelter provided by the seaward crest.

6.2.2 Sediment deposition and vegetation characteristics 1, 3, and 6m landward

All variables in quadrats 1m landward and seaward of the alongshore transect were compared to quadrats 3m and 6m landward. Mean deposition and vegetation density showed no significant difference when the following quadrat categories were compared with quadrats 3m and 6m landward of the alongshore transect: 1m landward and seaward (Figure 2.3 F), 1m landward (Figure 2.3 G) and 1m seaward (Figure 2.3 H). Mean vegetation diversity is significantly greater 1m landward and seaward (Figure 2.3 F, T stat 4.6, T critical 2.0), 1m landward (Figure 2.3 G, T stat 4.1) and 1m seaward (Figure 2.3 H, T stat 2.8) of the alongshore transect than 3m and 6m landward. Diversity is higher within 1m of the alongshore transect than 3 and 6m landward because the seaward ridge provides slightly more sheltering to the vegetation closer to the alongshore transect than to the quadrats farther landward. The average difference in height between the alongshore transect and the seaward crest is 0.5m, while for the quadrats 3m and 6m landward it is 0.4m. This slight local difference in relief may be important in determining local vegetation distribution. Additionally, the fence may have provided sheltering or trapped seeds 1m landward in the past because the T statistic for vegetation diversity is greater when comparing quadrats 1m landward to quadrats 3m and 6m landward (T stat 4.1, Figure 2.3 G) than when comparing quadrats 1m seaward to quadrats 3m and 6m landward (T stat 2.8, Figure 2.3 H).

Sandbur is denser 1m landward and seaward (Figure 2.3 F, T stat 4.9, T critical 2.0), 1m landward (Figure 2.3 G, T stat 3.6), 1m seaward (Figure 2.3 H, T stat 3.5) of the alongshore transect than 3-6m landward. Sandbur may benefit from the stability provided by the relatively lower swale (Figure 6.1) and not by the fence because it is greater on both sides of the alongshore transect and showed no significant difference based on presence of remnant fence.

The small difference in height between the swale and the seaward crest at the alongshore transect in Site 2 appears to be enough to affect overall vegetation diversity at a local scale and the density of specific species such as sandbur. Topography has greater importance in the distribution of vegetation density and diversity than remnant fence presence. Remnant fence presence may provide additional sheltering when its height is greater than average vegetation height, such as in the case of seaside spurge.

6.3 Conclusions

Vegetation is not denser or more diverse near remnant fences because most remnant fences are lower than average vegetation height and do not provide sheltering or create microhabitats in most cases. Remnant fences may provide shelter to specific vegetation species that are known to occur at fenced locations, (ie. purple lovegrass), or to species that are lower than the fence (ie. seaside spurge).

Dune vegetation is denser at the seaward ridges and more diverse at sheltered swales and backslopes (Doing 1985, Freestone and Nordstrom 2001, Miller et al. 2010). The distribution of dune vegetation density and diversity is a function of topographic variability resulting from sheltered and exposed dune zones that create vegetation communities differentiated by their tolerance to onshore stress. Different plant species will dominate ridges and swales (Stallins and Parker 2003). The location and extent of different dune zones and the general morphology of the dune that determines the distribution of the vegetation is a function of the past deposition caused by fences, some of which currently remain as remnants. Fence deployment may lead to high (Figure 6.4) or low (Figure 6.3) morphological and vegetation diversity, depending on placement.

The morphology of developed dunes and the resulting vegetation cannot be attributed to one or two observable fence rows. Morphology is determined by the combination of all fences, including completely buried fences, and to bulldozing, and beach nourishment which often occur simultaneously. All of these methods allow dune environments to grow but change their temporal sequences by accelerating the dune building process (Nordstrom 2008). Rapid dune formation often hinders natural processes of vegetation growth, such as succession of species, which is necessary for an ecologically diverse dune to develop. Because sand fences determine the topographic diversity and the distribution of dune vegetation, they are more than instruments of dune building, they can be used to create alternative types of dune environments. Suggestions about using remnant fences to evaluate the creation of diverse developed dunes are made in the following chapter.

Chapter 7: Implications of fence presence within developed dunes

The following discussion focuses on the sand fence inventory and vegetation field surveys (Chapters 5 and 6), which involved collection and analysis of original data. The sand fence significance and sand fence history (Chapters 3 and 4) are not included in this discussion because their purpose was to establish the background and context of the thesis. A section on the effect of beach nourishment on dune vegetation distribution is included in this chapter because findings in Chapter 6 indicate that over-nourishment of a beach may result in lack of succession and low vegetation diversity.

Previous studies indicate that artificially creating and maintaining a dune for protection of human facilities against flooding, salt spray and wind-blown sand also provides protection to landward vegetation, resulting in greater species richness than would be possible in the restricted space available on developed coasts and allowing more natural cross-shore gradients of processes and vegetation types to occur (Nordstrom 2008). This dissertation research elaborates on the role of sand fences in this process. Results reveal that 1) sand fence characteristics define the coastal landscape and communicate management goals, 2) present management goals are not based on restoring landforms and habitats, 3) use of fences can be made more compatible with natural processes and biota, 4) careful consideration should be given to the initial placement of sand fences emphasizing on their long term effects on dune morphology and vegetation, 5) sand fences remain visible when deployed at locations of low sediment transport, 6) vegetation diversity does not increase near remnant fences because most remnants are lower than average vegetation height, 7) accretion caused by fences in the past may result in topographic diversity which benefits the development of specific vegetation communities. The implications of results 1-4 were previously published in Grafals-Soto and Nordstrom 2009 and are included here in Section 7.1. Implication of results 5-7 are discussed in terms of remnant fence presence and are included in Section 7.2.

7.1 Implications of sand fences in defining the coastal landscape and its use

The main intended effect of sand fences to build protective dunes obscures their great significance in providing habitat. The value of fences in creating habitat was not mentioned by a single manager (Table 5.5), underscoring the emphasis on the utilitarian function of the dune as a protection structure. Despite a high level of development, the value of the natural capital of New Jersey is great (NJDEP 2007). Conserving or restoring the natural values and functions of the shore are becoming increasingly important as more coastline is converted to human use (Breton and Esteban 1995; Dauvin et al. 2004; Nordstrom 2008), requiring evaluation of use of fences in these other contexts.

The height of sand fences when initially deployed and the narrow spacing between vertical slats make them effective barriers to control human access and differentiate land use. Because fences are effective at trapping sand, their use for these purposes creates landforms with shapes related to access corridors that are often oriented across the shore rather than alongshore like natural dune ridges.

The effects of a sand fence change through time as the initial structure becomes integrated into the environment it helps create (Figure 7.1). The trapping efficiency of the fence is greatest when it is initially emplaced and decreases as sediment accumulates around it, creating a new landform. The effect of the fence as a barrier to faunal movement also diminishes as its height above the surrounding surface decreases and as the fence degrades and wooden slats abrade and break. The effect of the fence as a political statement diminishes as it becomes a less conspicuous intrusion into the landscape. Accretion caused by the fence increases topographic variability, which creates greater variety of microhabitats. Natural habitat value is also increased as the fence is obscured by subsequent growth of vegetation.

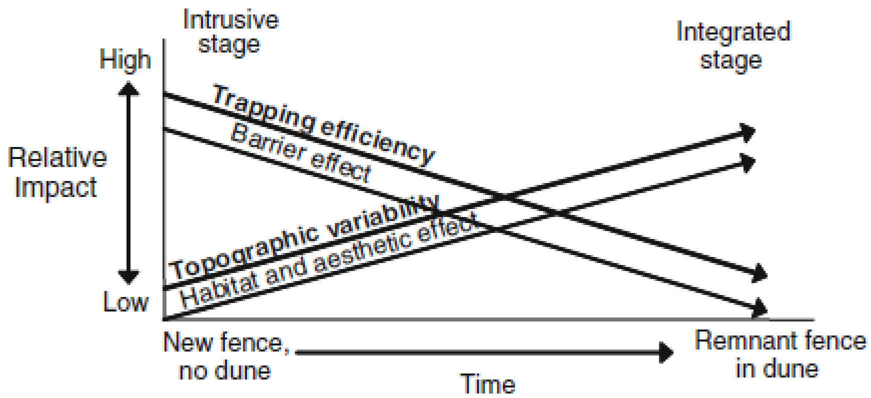


Figure 7.1: Diagram of the impact of sand-trapping fences in the coastal zone though time. This scenario may be reinitiated, truncated, or prevented by ongoing human actions (Grafals-Soto and Nordstrom 2009)

Sand fences can be considered unattractive or attractive, depending on the way they are deployed. A wide range of indicators for assessing the visual image of a landscape exists (Ode et al. 2008; Tveit et al. 2006), making simple decisions about aesthetic values difficult. Nevertheless, it is difficult to argue that a sand fence newly placed in an environment prized for its natural beauty has positive aesthetic value. The aesthetic value can increase through time as the rationale for fence construction as an aid to natural processes becomes clearer, the size of the exposed parts of the fence decreases, and the remaining components create an element of mystery or nostalgia. These characteristics will improve if the fence is placed in a location where the delivery of sediment is sufficient to bury it.

Sand fence locations and configurations vary, depending on the management decisions established in each municipality. The method of emplacement of sand fences is often according to the whim of local managers (Nordstrom 2008), despite the existence of technical assessments and guidelines for their use for shore protection (e.g. Coastal Engineering Research Center 1984; Hotta et al. 1987, 1991; Ranwell and Boar 1986). The result is a heterogeneous coastal landscape, with fences appearing as conspicuous intrusions and reminders of the artifactual nature of the landforms. The frequency at which new fences are deployed and the changing location of their placement create a highly variable human-influenced topography through both time and space.

Zigzag fences create wider dunes with more undulating crestlines and more gently sloping dune faces than straight alignments, resulting in a closer approximation to the shapes of natural dunes (Snyder and Pinet 1981). This greater compatibility with natural dune forms was not mentioned by managers as a rationale for use of zigzag fences, but it makes them more useful than straight fences for constructing dunes landward of narrow beaches, where sand supply is limited and dunes are not expected to grow beyond the initial ridge. If space for additional rows of fences to accumulate sand exists, straight fences could be used to create the multiple ridges more common to natural dune fields.

Adding rows of fences on the foreslopes of dunes built with fences can create higher dunes with much greater volume and have greater value as protection structures (CERC 1984; Mendelssohn et al. 1991; Miller 2001; Savage and Woodhouse 1968). Dune toe fences are more commonly deployed in the New Jersey dunes than foreslope fences (Table 5.5), in part because management decisions have strong input from property owners who want lower dunes for views of the water from shorefront homes. Placing additional fences on the foreslope or dune toe may be unnecessary in any case.

The location of the contact between the foredune and backshore is determined by erosion of the foredune during storms and dune accretion following storms. Storm wave uprush may eliminate the seaward portion of the dune and create an erosional scarp, but post-storm deposition on the beach creates a new source of sand to be blown to the foredune, reestablishing the dune sediment budget. Once established, the dune form becomes the obstacle that traps sand. Adding sand fences on the seaward side of a dune that can function as a barrier to transport onshore has little value from the standpoint of shore protection. Sand fences tend to create steep dune faces that are incompatible with plover nesting (Melvin et al. 1993), providing an additional reason to restrict the use of sand fences on the seaward side.

Human structures can be visually acceptable in landscapes if they are in harmony with natural features (Kearney et al. 2008). Sand fences will not represent the best practice in environmental management or communicate good environmental goals if they are used out of context. In some cases, they do not serve as proper guides for controlling human traffic nor are the linear over-stabilized landforms they create examples of the kinds of dynamic nature that can be achieved in the state (Nordstrom et al. 2007). Fences and walls, like other boundaries (Newman and Paasi 1998) can have significance as metaphors (Cohen 2006), but the messages to managers and users of the landscape must be clear to have value in this context. The purposes of some configurations, such as straight/diagonal/perpendicular fences and isolated fenced enclaves on the backshore

(Figure 5.5) are unclear to beach users, providing little insight into the relationship between management actions and use of the backshore and dune environments.

The coast is an important geographical symbol and a landscape that manifests communal ideals of inclusiveness and belonging (Davidson and Entrikin 2005). Human structures should reinforce these attributes to the extent possible. Sand-trapping fences used for controlling access in locations sheltered from the wind or in locations where the amount of sand in transport is insufficient to generate new landforms will remain visually intrusive and function as psychological barriers and impediments to faunal movement. Those constructed on or near the beach often create unnatural shore-normal shapes and extend seaward of the normal dune toe.

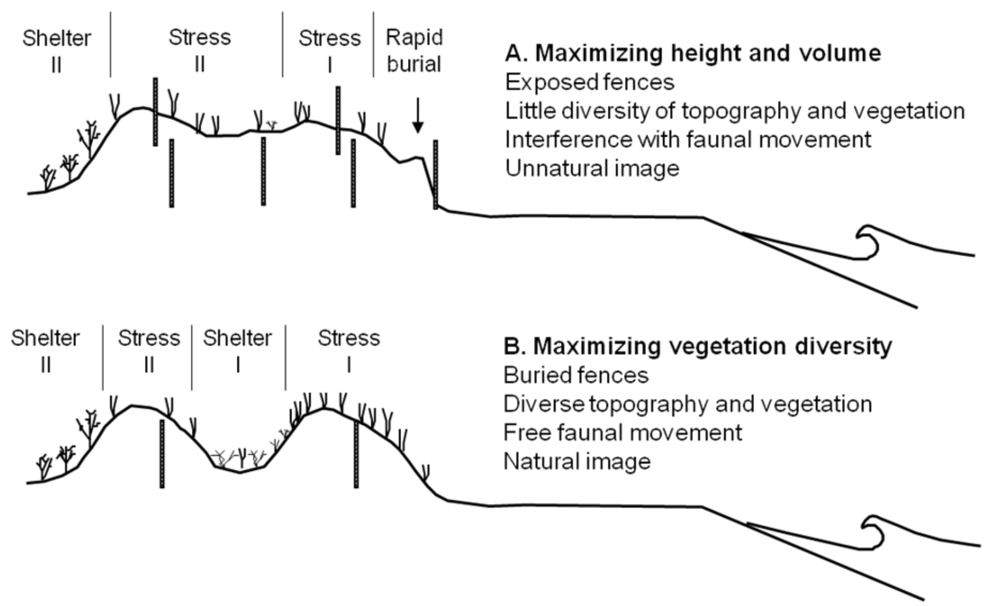
There appears to be little advantage in using sand-trapping fences over symbolic fences for controlling pedestrian access. The replacement of slat fences with wooden post and rail and rope fences in Manasquan represents an effective way of separating the incompatible sand trapping and crowd control functions. These fences convey the message that the dune is a protected environment but do not exclude that environment from the visual landscape the way sand-trapping fences do. Post and rail, and rope fences are not a barrier to fauna and are less visually intrusive than sand fences. Rope fences are more easily constructed, more expendable, easy to replace if damaged and less intrusive than sand fences and are better placed on the more dynamic and more naturally-functioning seaward side. Wooden rail fences are better placed on the landward side of the dune, which is less dynamic. This type of fence was almost universally adopted by settlers in timbered parts of the USA in the past (Martin 1888) and is more appropriate closer to human structures, where historic and nostalgic considerations are more important. Symbolic fences that are less expensive or less visually intrusive and allow for free movement of biota should be used for controlling pedestrian access. Many of these suggestions are not based on controlled experiments, and some may need to be tested before being implemented as formal guidelines.

7.2 Implication of remnant fence presence for the management of developed dunes

Remnant fences indirectly affect vegetation because the sediment deposition they caused created the current dune topography which defines topographic diversity and sheltering. Most remnant fences caused at least some deposition in the past which contributed to the topographic variability of the dune.

The effect that remnant fences have on topography is a function of the amount of sediment transport that reached their initial deployment location which depends on the amount of time that the fence was allowed to be the seaward-most barrier to sediment transport. Dune shape, width and height; and location and distance between ridges and swales are determined by the initial deployment. Topographic variability determines the degree of protection against onshore stress that the swale and backdune can provide. The ridge and swale topography resulting from this variability creates small-scale differences in sheltering that enhance the variety of habitats over short distances across the shore (Nordstrom et al. 2007). Dunes with high topographic variability have lower swales (ie. Figure 6.4) that may provide additional benefits, such as nearness to the water table, than dunes with low topographic variability cannot provide (ie. Figure 6.3). Highest dune diversity is found on the low swales and protected backdunes, which have a more stable morphology (Miller et al. 2010).

The purpose of sand fence deployment determines the locations, numbers of rows and distance between them which create a high or low topographic variability (Figure 7.2). Multiple fence rows placed a short distance apart or above one another, create a protective dune with low topographic variability that maximizes dune height and volume but sacrifices geomorphic and vegetation diversity (Figure 7.2 A). Fewer fence rows placed a slightly greater distance apart create a dune that better represents the high topographic variability of natural dunes and has greater potential of developing diverse vegetation communities within a narrow space (Figure 7.2 B). Greater topographic variability and vegetation diversity can significantly increase the value of dunes built primarily to protect human facilities (Nordstrom 2008).



Stress I: seaward foreslope and crest exposed to highest wind speeds, salt spray, sediment transport, sand burial and soil salinity
Stress II:: landward crest and abnormally high swale exposed to moderate wind speeds, and salt spray
Shelter I: low swale protected from high wind speeds, sand transport, sand burial, salt spray
Shelter II: backdune protected from moderate and high wind speed, sand movement, sand burial and salt spray
(Sources to identify stress and shelter zones: Maun 2009, Acosta et al 2007, Wilson and Sykes 1999)

Figure 7.2: Dune geomorphic model based on purpose of sand fence deployment

Remnant fence height of 0.25m or less is an indicator of initial fence deployment at a relatively high sediment transport zone. Remnant fences with visible heights greater than 0.25m remain conspicuous in the landscape and indicate that not enough sediment was transported to their location. Because remnant fence height is an indicator of deployment effectiveness, managers can use this criterion to evaluate and improve decisions affecting their use. Fences higher than 0.25m represent ineffective or unnecessary deployments that are aesthetically unpleasant and may obstruct the movement of fauna within the dune. Large mammals, such as rabbits can jump over fences of this height, and small mammals and invertebrates can pass through the slats. Fences should not be deployed seaward of partially buried fences with heights greater than 0.25m until most of the original height (1.2m) of the landward fence is buried.

Legislative amendments to the State Coastal Area Facilities Review Act in 1993/94 allow for construction of sand trapping fences but prohibit their removal. Managers should consider cutting high remnant fences to make them lower than average vegetation height, facilitate faunal movement and provide an image of the dune that is more compatible with natural dune functions. Reducing the height of remnant fences that are less than 0.25m high is unnecessary because low remnant fences blend into the landscape and are not obstructions to faunal movement. Fence deployment that prioritizes the creation of high relief dunes within a restricted space may enhance their morphological and vegetation diversity allowing the dune to be better able to adapt to change and disturbance.

7.3. Implications of beach nourishment as a potential dune restoration alternative

Beach nourishment is designed to reduce threats to buildings but it has the potential for restoring dune landforms and habitats by widening beaches and creating space for foredunes to evolve naturally (Nordstrom 2008) and has proven its effectiveness at specific locations when integrated with vegetation plantings (De Lillis et al. 2004). Nevertheless, the creation of an excessively wide beach solely for protection or recreation will not necessarily result in a well vegetated dune system. Beach nourishment can be a tool for restoration, but the development of a diverse dune system has to be integrated as one of the main nourishment objectives.

Site 1 is an example of a rapid beach widening that resulted in limited succession and low vegetation diversity after the natural formation of a new foredune prevented landward sediment transport and the establishment of pioneer species. Adequate beach width is viewed as necessary for incipient dunes to develop into a naturally functioning dune (McLean and Shen 2006), but an overly wide beach may not be key to success.

Smaller scale nourishment projects have been suggested to avoid creating exotic environments and detrimental effects on benthic habitats (Bilodeau and Bourgeois 2004, Nordstrom et al. in press). If the beach at Site 1 was nourished at a narrower width or in several installments to allow the natural foredune to form closer to the original fenced foredune, sediment transport would have buried the fences, and beachgrass would have colonized the original foredune and the space between ridges. A dune forming on a narrower nourished beach would better reflect nature and allow for the establishment of pioneer species along the entire available space, leading to succession and higher vegetation diversity.

7.4 Future research

Seaside spurge and purple lovegrass showed significant correlations with fence presence (Table 6.3). A study that specifically targets these species should be conducted to determine how remnant fences alter other factors that affect dune vegetation growth such as, salt spray, sand blasting, light intensity, temperature, nutrient content in sediment, pH levels, and wind speed.

Methodology for this type of research should include: 1) identification of all dune locations where these species occur whether there is a fence or not, 2) description of the characteristics of their locations related to distance landward of the dune toe, topographic variability, distance landward or seaward of fence and of other vegetation species within a $1m^2$, 3) deployment of anemometers and thermometers to measure wind speed and temperature at locations with and without fences, and 4) collection of sediment samples to document nutrient, salt content and sediment grain size.

7.5 Concluding statement

Linking human and physical dimensions by seeking to understand human-environmental relations is an important goal for geographers (Golledge 2002). This dissertation attempts to relate the human and physical aspects of coastal dune systems in developed shores. Including human structures in the study of coastal environments is essential because as it is becoming increasingly difficult to find these environments unchanged by human actions (Nordstrom 2000; Defeo et al. 2009). Landscape scenery is the product of the interaction between humans and the natural environment, and the coastal landforms and habitats communicate the social priorities of landscape usage. The essential characteristic of a truly coherent landscape is a state where all functions and processes are irreplaceable parts of its internal unity (Krause 2001). It is our responsibility to acknowledge that our actions on the landscape are a fundamental part of its functionality. The decisions we make determine whether the interaction between our actions towards the natural environment and nature's response will express coherence or contradiction. These decisions and their results apply to structures as small and seemingly benign as sand fences as well as to larger structures.

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Honors and Awards

2003	**Thalia Véve Award.** Thalia Véve Foundation, Geography Deparment. University of Puerto Rico.
2003	**Dissertation Research Grant**. Graduate School of New Brunswick.
2003 - 2008	**Ford Foundation Pre-Doctoral Fellowship for Minorities**. The National Academies.
2008 - 2009	**Bunting Cobb Graduate Mentor Fellowship**. The Douglass Project for Rutgers Women in Math, Science and Engineering.
2010 - 2011	**Lyman T. Johnson Post Doctoral Fellowship**. Office of the Vice President for Research, University of Kentucky

Work Experience: Teaching

2005	**Teaching Assistant** for Dr. Roger Balm. Introduction to Geography, Geography Department, Rutgers University, New Jersey.
2006	**Teaching Assistant** Co-taught Cultural Geography with Monalisa Chatterjee, Geography Department, Rutgers University, New Jersey.
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Publications

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