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Executive Summary

Barrier island systems contain some of the most naturally dynamic landscapes on earth. Shoreline stability within these systems often varies dramatically and results from a relatively small set of physical parameters. Along the mid-Atlantic coast, winter storms are the principal source of disturbance and may create landscape pattern by producing a patch mosaic of successional stages. Barrier islands contain unique habitats that are critical to the persistence of many colonial and beach-nesting bird populations. Many of these species occupy a range of disturbance/successional niches that are defined by the relationship between beach erosion (due to storms) and beach recovery (via succession). Over the past 25 years, populations of several waterbird species have declined dramatically within the Virginia barrier island chain. These declines represent not only a reduction in the number of pairs but also a reduction in the distribution of breeding sites. The underlying factors causing these population changes are poorly understood. In order to reverse recent population trends, it is essential that the relative influence of abiotic (e.g. disturbance-driven habitat change) and biotic (e.g. predation) factors be separated within this system.

We characterized temporal and spatial patterns of beach habitats within the Virginia barrier island landscape and to quantify the relationship between landscape change and the distribution of avian breeding sites. Seven years of aerial photos were scanned, orthorectified, and placed in a Geographic Information System. Physical features of the active beach zone were digitized from processed aerial photographs. Data were compiled at island and sub-island level and used to delineate and compare habitat use patterns of 4 colonial beach nesting species and 2 solitary nesters.

We compared values and coefficients of variation for active beach area, beach width, distance to nearest wetland, habitat of beach-landward margins, within and between islands over 7 decades to characterize the frequency and spatial distribution of disturbance. Both colonial and solitary nesting birds exhibited similar patterns of habitat use that included the use of wide beaches that were close to mudflats and other wetlands, and that had fewer stable dunes. The amount of habitat under these conditions was then projected to examine availability over time. In general, the amount of habitat for these disturbance-prone species has fluctuated widely with time and has increased in recent years. The recent declines of beach-nesting birds are probably better explained by factors other than habitat availability. Nest predation by ground predators, are among the leading alternative factors.

BACKGROUND

Barrier Island Morphology

Although the morphology of barrier islands often appears complex, their distribution and dynamics are determined by a relatively small set of physical parameters. Worldwide, barrier islands occur primarily along coastal plains located on the trailing edges of continents (Inman and Nordstrom 1971, Hayes 1979). Within these coastal plains, barriers are restricted to those areas with tidal ranges less than approximately 4 m (Price 1955, Hayes 1979). In fact, only 10% of the world's barrier islands are present along coastlines where tidal ranges are in excess of 3 m (Glaeser 1978).

Within appropriate coastal shorelines, the most important determinant of island geomorphology is the type and amount of hydrologic energy expended within the area of interest (Price 1955). Island morphology is primarily controlled by the relative magnitude of tidal and wave energies and is usually classified according to the continuum between wave-dominated and tide-dominated islands (Hayes 1979). The morphological difference between tide-dominated and wave-dominated coastlines reflects the relative sediment transport capacity of the tidal currents verses the wave-generated long-shore currents. Along wave-dominated coasts the long-shore currents dominate the sediment dispersal pattern. The result of this long-shore dominance is that the islands become long and narrow with only a few small tidal inlets. These "microtidal" barriers are typified by North Carolina's outer banks. Along tide-dominated shorelines, tidal energy is strong enough to maintain open tidal inlets and ebb-tidal deltas (seaward shoals) against the destructive force of waves. These shoals then provide sediment to the down drift barrier beaches. The result of this tide dominance is that coastlines support short, stubby barriers separated by frequent inlets. Individual mesotidal barriers often have the typical "drumstick" shape caused by the continual welding of shoals to the up drift ends. These tide-dominated barrier chains are typified by the islands along the Delmarva Peninsula.

Although the plan form of barriers is primarily determined by the relationship between tidal and wave energies, the continual reshaping and subsequent dynamics of these islands is caused primarily by storm energies (Hayden 1975, Dolan et al. 1988). Tides along the Atlantic coast range from 1 to 3 m and average wave heights range from 0.5 to 1 m. Storms generate larger waves and are the primary agents of change. The Atlantic coast is subjected to 35 to 40 extratropical and tropical storms annually and winter storms may produce deepwater waves of 5 to 10 m with storm surges of 1 to 2 m (Bosserman and Dolan 1968, Dolan et al. 1988). The strong waves and surges associated with these storms often overtop primary dunes and drive water and beach stands to the landward edge of the island. These washover events often break the dune line and transform the shape of the island. Although all islands respond to the overwash process, because of spatial variation in sediment sources and currents there are often locations within an island where these overwash events occur with regularity. Within mesotidal islands, differences in sediment budgets between updrift and downdrift ends make washovers more frequent near the downdrift end. In addition to variations in washover frequencies within islands, there are also predictable differences between regions. For example, in the Northeast where large tide ranges have formed high dunes and cliffs, washover events are much less frequent than along the mid-Atlantic coast where the tide ranges are lower (Fisher 1968, Godfrey et al. 1979).

Virginia Barrier Island Morphology

The Virginia barrier islands located along the seaward margin of the Delmarva Peninsula is the most pristine chain of barriers remaining along the Atlantic coast. The chain contains 14 primary barriers and numerous bars, spits and shoals from Assateague National Seashore south to Fisherman Island National Wildlife Refuge. The island complex took its present form during the late Holocene rise in sea level (Newman and Munsart 1968, Oertel et al. 1989). The islands have changed rapidly over the past few thousand years, migrating westward across the continental slope at a rate as great as 1 km per thousand years. The modern islands exhibit a dynamic shoreline characterized by local deposition and erosion (Hayden et. al. 1991). These barriers are subjected to an average of 38 extratropical storms annually with enough intensity to rework beach sand and, as a result, have the highest beach erosion rate of any location along the Atlantic coast (Hayden 1976, 1981, Dolan et al. 1987, 1988).

The Virginia chain of barrier islands has long been known for its extraordinary ecological value. The site has been designated as a "Man and the Biosphere" reserve by the United Nations. Biosphere reserves are large, multipurpose areas intended to protect functioning natural ecosystems and conserve species. The Western Hemisphere Shorebird Reserve Network has designated the system as an "International Shorebird Reserve" for hosting the second highest number of migrating shorebirds along the Atlantic Flyway during the spring migration. The site is also a National Science Foundation Long-term Ecological Research site. Nearly all properties within the chain are currently owned and protected by various federal, state, and private organizations. Major land owners include The Nature Conservancy, the U.S. Fish and Wildlife Service, the Commonwealth of Virginia, and the National Atmospheric and Space Administration.

Beach-nesting Birds

The importance of the Virginia barrier islands to beach-nesting waterbirds has been recognized for generations. The islands attracted bird collectors from all over the world (e.g., Bailey 1876, Pearson 1892) and later were the focus of one of the first conservation projects of the National Audubon Society to protect waterbird populations (Dutcher 1901, 1902). Surveys by early ornithologists provide glimpses of what populations were like in earlier times (e.g., Chapman 1903, Bent 1907, Howell 1911, Hadley 1930). However, it is only in recent decades that we have been able to place the islands in the appropriate regional context and to evaluate population trends. Williams et al. (1990, 2005) have conducted annual surveys of colonial waterbirds along the island chain since 1975 documenting the location, size, and composition of individual colonies. Annual surveys of Piping Plovers (*Charadrius melodus*) were initiated in 1986 and Wilson's Plovers (*C. wilsonia*) in 1989 (Watts et al. 1995). Annual surveys of American Oystercatcher (*Haematopus palliatus*) were initiated in 2000 (Terwilliger and Cross 2000).

In recent years it has become evident that the Virginia barrier islands are the most important chain of barrier islands to colonial and beach-nesting birds in the mid-Atlantic region. A survey conducted in 1993 revealed that the site supported nearly 70.000 pairs of colonial waterbirds including 23 different species (Watts and Byrd 1998). The site supported more than 50% of the known Virginia population for 18 of these species and over 80% for 11 species. Seven of these species have been proposed for a status of "special concern" and 4 have been proposed for a status of "threatened" in Virginia. In addition to the colonial waterbirds, the site supports significant populations of the federally threatened Piping Plover, state endangered Wilson's Plover (Williams et al. 1990, Watts et al. 1996, Boettcher et al. In Press), and the largest breeding population of American Oystercatchers known (Wilke et al. 2005).

Examination of survey data over the past few decades has shown that several waterbird species have declined dramatically within the Virginia barrier island chain (Williams et al. 2005, Watts and Byrd, In press). These declines represent not only a reduction in the number of pairs but also a reduction in the distribution of breeding sites. The underlying factors causing these population changes are poorly understood. Some recent evidence strongly suggests that biotic factors such as mammalian and avian predators have played a role in declines and distribution shifts (Erwin et al. 2001, Keiss 2001, Watts et al. 2006). However, because the barrier island landscape is so naturally dynamic, it is difficult to eliminate possible shifts in habitat availability as a driving force. In order to reverse recent population trends, it is essential that the relative influence of abiotic (e.g. disturbance-driven habitat change) and biotic (e.g. predation) factors be separated within this system.

Objectives

Our objectives for this project are to characterize temporal and spatial patterns of beach habitats within the Virginia barrier island landscape and to quantify the relationship between landscape change and changes in the distribution of avian breeding sites. It is hoped that understanding these relationships will lead to more informed, long-term management strategies.

METHODS

Barrier Island Dynamics

Aerial Photographs

Aerial Photographs and Satellite Imagery

A broad approach was used to identify and locate sources of aerial photographs or satellite imagery that could have useful information regarding the Virginia barrier islands at specific points in time. A portfolio of materials was developed that contained 1,068 entries of materials that spanned from 1936 to 2004 (Wilson 2005). Complete aerial photo sets that depict the entire island chain are available for many years. These include the years 1938, 1949, 1955, 1957, 1960-1963, 1966-1968, 1973, 1977, 1980, 1982, 1983, 1985, 1987-1991, 1994, 2000-

2004. These photo archives are the most useful in the analysis of shoreline change because the entire photographic set was collected within a narrow time frame.

Image sets were chosen for inclusion in this study based on resolution, condition, completeness, and date. The scale of available aerial photos ranged from 1:5,000 to 1:131,000. Finer scale images provide better resolution for analyzing landscape change, particularly when summarizing changes in beach width. Sets with a resolution of less than 1:30,000 were deemed unsuitable for quantifying fine-scale habitat details and were not used. Sets that were in good condition and that were complete or nearly so were given preference in the selection process. Sets were chosen to provide coverage on approximately 8-10-yr intervals from the late 1940s to the early 2000s. Seven years were chosen over a 53-yr period for inclusion (Table 1).

Table 1. Summary of aerial photography sets used in this study with a listing of gaps in coverage.

Island	1949	1955	1962	1977	1985	1994	2002
Fisherman	all	all	all	all	W Side	all	all
Smith	all	all	all	all	all	all	all
Myrtle	all	all	None	all	all	all	all
Ship Shoal	all	all	N End	all	all	all	all
Wreck	all	all	N End	all	all	all	all
Cobb	all	all	N End	all	all	all	all
Hog	S End	None	N End	all	all	all	all
Parramore	NE Corner	NW End	NW Corner	all	all	all	all
Cedar	all	all	all	all	all	all	all
Metompkin	all	all	all	all	all	all	all
Assawoman	all	all	N End	all	all	all	all
Wallops	all	None	None	all	all	all	all
Assateague	None	None	all	all	all	all	all

Photo Processing

Scanning - Aerial photographs were scanned with a high-resolution scanner as a TIFF image file at 600 dpi. This resolution was chosen because it represents the best tradeoff between resolution and storage requirement. A 600 dpi TIFF image generally represents 67 megabytes of information. Image memory increases exponentially with selection of higher dpi but without providing appreciably better image quality than that achieved with the 600 dpi. Image color and brightness were manipulated in Adobe Photoshop to increase their contrast and resolution. Images were then cropped to remove blank or unusable portions (such as open water) to reduce storage requirements and archived on DVDs.

Ortho-rectification - TIFF images were ortho-rectified with ERDAS Imagine 8.5 software (Copyright 2001, ERDAS Inc.) using a “non-metric camera” model. This model was used because it offers the greatest flexibility and least amount of photo information. This was a necessary choice because of the wide range of aerial photos that needed to be rectified. The conditions in which aerial photographs were originally taken vary greatly between photo sets and years. A non-metric camera model allows for the reduction in the strength of camera variables (e.g., camera focal length, fiduccial marks, etc.) that need to be included for ortho-rectification. The TIFF images were georeferenced using Virginia Digital Orthophoto Quads (DOQQs) in UTM GRS 1980 NAD83 North and UTM Zone 18 (Range 78W - 72W) projection. Reference units were set to meters and no rotation system was used in the process. Images were then processed through two series of tie-points. Tie-points provide the georeference between the image being processed and a reference image such as the DOQQs chosen. A first trial of ortho-rectification was conducted using a range of 6- 14 control points per attempt. This process was repeated several times or until the root mean square error was reduced to an acceptable value (generally below 1.6). The resulting image was then ortho-resampled, a process used by ERDAS to complete a final rectified image. The output image file is an ERDAS formatted Imagine file (.img suffix) that can be viewed with ERDAS or GIS software (supported by both ArcView 3.x and ArcMap products). Individual images were stitched together using Adobe Photoshop to form a mosaic of each island then geo-referenced using ArcGis 8.3.

Island Measurements

Physical features of the active beach zone were digitized from processed aerial photographs using ArcView 3.2 and ArcGIS 8.3 software. The active beach zone was considered to be the area between the high-tide line along the ocean-beach interface and where the landward edge transitions to a different habitat (e.g. dune, mudflat, wetland). Both the ocean edge (high tide line) and landward edge (other habitat) were digitized for the length of each island. The landward edge of the beach zone was segmented according to the adjacent habitat. Adjacent habitats were either upland (dune, grass, woody vegetation, hardened surface) or wetland (water, mudflat, marsh). The active beach was subdivided into 100-m segments by establishing a transect perpendicular to the high tide line and extending landward to the adjacent habitat. For each segment the distance between the landward edge and the closest wetland feature (water, mudflat, marsh) was measured.

Island measurements were compiled within approximately 1.5 km segments to create a number of habitat variables including 1) beach width, 2) dune stability – defined as the % of dune length intact, 3) beach-margin interface – subdivided into 3 categories; mudflat, vegetated, open water, and defined as the % of each composing the border with the landward edge, 4) distance to wetland habitat, and 5) active beach area.

Bird Data

We investigated the habitat use patterns of six species of beach nesting birds including four colonial waterbirds; Black Skimmer (*Rynchops niger*), Common Tern (*Sterna hirundo*), Gull-billed Tern (*Sterna nilotica*), Least Tern (*Sterna antillarum*), and two solitary nesting species; Piping Plover (*Charadriius melodus*), and American Oystercatcher (*Haematopus palliatus*). Data on colonial waterbirds were obtained from 30 yr of ground surveys on the Barrier Islands (Williams et al. 1990). We specifically examined 5 yr of data for each decadal period that matched aerial photography sets. This included the period from the years 1976-1980, 1984-1988, 1993-1997, and 2001-2005. Data on Piping Plovers were obtained for the year 1986 and 1995 (Watts et al. 1996)and used to match aerial photography sets for 1984 and 1994, respectively. Finally, data collected from surveys of American Oystercatchers in 2002 (Wilke et al. 2005) were obtained for matching with photo sets of the same year.

Data Analysis

We compiled data extracted from aerial photography at the scale of islands and individual segments. Data for variables repeatedly measured within segments (e.g., beach width, distance to wetland) were averaged at the level of individual islands across all variates. However, these variables were also average at the level of individual segments to represent a single value. Other values such as beach interface and dune stability have only one measure per island segment so could only be averaged across islands or across years. Trends and variation in beach area and width were examined using multiple regression. Comparisons for beach width for individual islands were conducted using Two-way ANOVA with year and segments as main factors. We also estimated variance in habitat variables within islands and across time by capturing island-level temporal variance, within-island temporal variance (variation of island segments over time), and within-island spatial variance (variability between segments of island) with each defined by the Coefficient of Variation ($CV = \bar{x} / SD * 100$).

Bird data were summarized within island segments for each year examined. Data for colonial waterbirds were aggregated across 5 yr of each decade to identify and enumerate used and unused beach segments. Habitat occupation was examined using non-parametric statistics.

RESULTS

<u>General Island Trends</u>

The total beach area of each island varied greatly between years (Table 2). Coefficients of variation (CV =) for average beach area across the entire time series indicate that Fisherman Island had the greatest relative variation and Cobb Island had the least amount of variation. The CV for average beach area was relatively similar between most other islands. There was no universal pattern for gains and losses in beach area between sequential decades. Some islands increased from one decade to the next at the same time that other islands decreased. For many individual islands, increases in beach area across its time series included gains in one decade followed by losses in the next decade. Only Smith Island showed a significant linear trend by declining over time (Table 3). The patterns of gain and loss between decades were too variable for other islands to yield a statistically significant linear trend.

Table 2. Trends in active beach area (ha) for the Virginia Barrier Islands between 1949 and 2002.

Island	Beach Area (ha) by Year							x̄ ± SD	CV
	1949	1955	1962	1977	1985	1994	2002	for all years	
Northern									
Assateague	**n/a**	**n/a**	383.0	140.2	267.1	171.9	245.9	241.6 ± 94.59	39.1
Wallops	41.7	**n/a**	**n/a**	22.4	19.9	21.2	23.1	25.6 ± 9.05	38.4
Assawoman	20.6	42.9	54.1	13.7	**n/a**	51.4	68.2	41.8 ± 20.86	49.9
Metompkin	68.3	75.9	98.3	22.2	102.6	164.3	113.8	92.2 ± 43.88	47.6
Cedar	74.5	108.4	56.0	36.1	84.7	135.5	127.1	88.9 ± 37.76	41.4
Southern									
Parramore	102.2	**n/a**	124.8	66.1	60.3	92.9	31.1	79.6 ± 33.57	42.1
Hog	**n/a**	**n/a**	150.5	174.4	171.4	84.9	115.4	139.4 ± 38.44	27.6
Cobb	70.7	54.0	56.9	61.5	63.7	90.2	54.1	64.4 ± 12.86	19.9
Wreck	52.9	36.1	**n/a**	11.3	15.0	31.1	34.6	30.2 ± 15.22	50.4
Ship Shoal	47.1	36.2	**n/a**	15.5	23.8	19.9	25.1	27.9 ± 11.67	41.8
Myrtle	47.0	47.2	30.5	6.6	23.3	34.2	19.4	29.7 ± 14.78	49.7
Smith	101.0	91.2	87.0	58.9	55.2	49.0	71.2	73.3 ± 20.00	27.3
Fisherman	35.3	48.8	**n/a**	11.9	**n/a**	69.1	97.9	52.6 ± 32.74	62.2

Table 3. Regression results for the change in beach area between 1949 and 2002 on the Virginia Barrier Islands where y = beach area and x = year.

Island	Regression Equation	R	R^2	P
Northern				
Assateague	y = 362.9 – 24.3x	0.40	0.16	> 0.10
Wallops	y = 40.9 – 3.3x	0.85	0.72	> 0.05
Assawoman	y = 20.7 + 5.4x	0.61	0.37	> 0.10
Metompkin	y = 46.8 + 11.3x	0.55	0.31	> 0.10
Cedar	y = 54.5 + 8.6x	0.50	0.25	> 0.10
Southern				
Parramore	y = 126.2 – 10.7x	0.69	0.47	> 0.10
Hog	y = 219.2 – 15.9x	0.65	0.43	> 0.10
Cobb	y = 60.2 + 1.04x	0.17	0.03	> 0.50
Wreck	y = 42.6 – 2.9 x	0.45	0.21	> 0.10
Ship Shoal	y = 63.47 – 6.3x	0.45	0.21	> 0.10
Myrtle	y = 46.3 – 4.1x	0.60	0.37	> 0.10
Smith	y = 102.6 – 7.33	.79	0.63	< 0.05
Fisherman	y = 33.8 + 7.0x	0.45	0.21	> 0.10

Average beach area among all islands and all time series was significantly and positively correlated with average beach width ($r^2 = 0.93$, $P < 0.05$) but negatively and not significantly correlated with overall shoreline length ($r^2 = -0.35$, $P > 0.05$). These results explain that changes in beach area were a result of variation in width rather than length. Average beach width varied between all islands and all years (Table 4). Beach width of Wallops Island and Cobb Island varied the most across time while other the variance was relatively uniform between other islands. Some islands showed positive linear trends while others showed negative linear trends but only Wallops and Smith islands showed statistically significant trends by declining over time (Table 5). Gains and losses in average beach width for all other islands contributed too much variation to yield a significantly significant linear trend.

In turn, average beach width for each island was significantly and negatively correlated with the dune stability ($r = -0.71$, $P < 0.05$). This result explains that variation in beach width is related, to some degree, spatially and temporally to washover disturbance. However, changes in dune stability do not account for the total variation in beach width. Portions of some islands in some years are naturally wide even in the absence of washover.

Average dune stability for all islands over time had a strong negative correlation with its temporal variance ($r = -0.91$, $P < 0.05$) (Table 6). This result explains that islands with the most stable dunes had the least amount of variation over the time and conversely, islands with low dune stability had high variation over time. In general, it appears as if there are 3 functional groups based on this disturbance relationship; 1) Stable Islands – high dune stability, low temporal variance, 2) Dynamically Stable – low dune stability, high temporal variance. For instance, Assateague, Wallops, Hog, Fisherman, and Cobb remain relatively stable through time and were characterized by high dune stability and low temporal variance. By comparison, islands such as Metompkin and Ship Shoal would be considered chronically disturbed by having low dune stability coupled with high temporal variance.

Table 4. Average beach width for the Virginia Barrier Islands.

Island	Beach Width (m) by Year							CV for all years
	1949	1955	1962	1977	1985	1994	2002	
Northern Islands								
Assateague	**n/a**	**n/a**	153.9 ± 99.69	54.6 ± 35.82	69.3 ± 49.48	79.2 ± 37.2	101.4 ± 86.33	48.3
Wallops	49.1± 66.65	**n/a**	**n/a**	19.6 ± 12.31	19.9 ± 13.09	16.4 ± 12.8	13.3 ± 11.17	64.9
Assawoman	34.5 ± 32.4	78.6 ± 29.83	132.3 ± 32.91	29.1 ± 25.95	**n/a**	110.2 ± 99.27	124.8 ± 79.08	53.5
Metompkin	64.5 ± 21.99	74.2± 21.17	110.5 ± 28.33	24.4 ± 19.93	95.5 ± 32.52	153.2 ± 59.41	107.9 ± 47.86	48.6
Cedar	71.3 ± 25.06	110.2 ± 54.52	56.1 ± 25.97	36.9 ± 21.52	68.4 ± 33.19	4.5 ± 2.45	104.3 ± 30.49	55.0
Southern Islands								
Parramore	93.6 ± 36.29	**n/a**	98.4 ± 66.11	51.5 ± 54.58	42.9 ± 17.96	85.5 ± 74.5	23.7 ± 11.38	38.5
Hog	**n/a**	**n/a**	154.4 ± 60.15	141 ± 85.77	145.1 ± 98.86	69.6 ± 80.65	89.6 ± 72.68	32.5
Cobb	68.5 ± 29.27	57.4 ± 28.91	61.5 ± 32.47	61.1 ± 44.85	71.4 ± 36.3	103.1 ± 35.54	66.2 ± 29.94	24.1
Wreck	87.9 ± 25.14	65.5± 21.35	**n/a**	18.6 ± 5.94	25.7 ± 15.04	43.5 ± 27.51	58.6 ± 14.59	57.3
Ship Shoal	131.1 ± 17.49	111.7 ± 17.55	**n/a**	44.5 ± 33.05	65.4 ± 3.16	61.1 ± 0.01	65.3 ± 27.01	46.2
Myrtle	109.7 ± 37.72	100.2 ± 47.66	78.2 ± 17.93	15.2 ± 9.13	60.2 ± 19.84	89.1 ± 49.56	57.2 ± 31.13	47.0
Smith	78.6 ± 3.58	84.5 ± 70.41	76.2 ± 35.35	51.3 ± 36.59	46.9 ± 22.79	42.2 ± 23.78	56.2 ± 24.97	29.7
Fisherman	67.3 ± 22.35	88.7± 38.86	**n/a**	20.5 ± 16.34	**n/a**	105.3 ± 90.84	130.9 ± 60.07	44.5

Table 5. Regression results for the change in average beach width between 1949 and 2002 where y = beach width and x = year.

Island	Regression Equation	R	R^2	P
Northern				
Assateague	y = 131.9 – 8.0x	0.33	0.10	> 0.10
Wallops	y = 31.0 – 5.9x	0.94	0.89	< 0.05
Assawoman	y = 43.9 + 10.6x	0.54	0.30	> 0.10
Metompkin	y = 51.0 + 9.7x	0.51	0.27	> 0.10
Cedar	y = 78.7 – 3.5x	0.21	0.04	> 0.10
Southern				
Parramore	y = 107.9 – 9.7x	0.68	0.46	> 0.10
Hog	y = 270.3 – 20.1x	0.84	0.70	> 0.05
Cobb	y = 56.4 + 3.4x	0.47	0.22	> 0.10
Wreck	y = 74.2 – 5.8 x	0.52	0.27	> 0.10
Ship Shoal	y = 63.47 – 6.3x	0.45	0.21	> 0.10
Myrtle	y = 101.1 – 7.1x	0.47	0.23	> 0.10
Smith	y = 88.1 – 6.4x	0.82	0.67	< 0.05
Fisherman	y = 48.1 + 8.6x	0.52	0.27	> 0.10

Table 6. Trends in the dune stability (% of stable dune per island) across all years.

Island	Percent of Stable Dune by Year							$\bar{x}$ ±SD for all years	CV
	1949	1955	1962	1977	1985	1994	2002		
Northern Islands									
Assateague	**n/a**	**n/a**	87.9	73.1	81.6	67.6	78.7	77.8 ± 7.82	10.1
Wallops	80.8	**n/a**	**n/a**	100.0	100.0	100.0	100.0	96.2 ± 8.57	8.9
Assawoman	82.0	19.8	**n/a**	100.0	**n/a**	67.5	45.5	63.0± 31.32	49.8
Metompkin	48.2	33.2	13.7	76.0	29.3	16.9	45.3	37.5 ± 21.34	56.9
Cedar	74.4	31.4	49.0	100.0	79.2	57.6	51.2	63.2 ± 22.81	36.1
Southern Islands									
Parramore	51.3	**n/a**	70.4	100.0	82.1	59.3	94.6	76.3 ± 19.39	25.4
Hog	**n/a**	**n/a**	80.2	97.6	94.0	100.0	100.0	94.4 ± 8.28	8.8
Cobb	68.4	65.4	62.5	71.8	87.2	85.0	68.5	72.7 ± 9.63	13.3
Wreck	47.9	63.0	**n/a**	100.0	100.0	71.1	52.6	72.4 ± 22.83	31.5
Ship Shoal	45.8	100.0	**n/a**	47.4	47.5	44.5	33.5	53.1 ± 23.55	44.3
Myrtle	31.1	55.3	60.2	100.0	100.0	88.1	43.0	68.2 ± 27.89	40.9
Smith	51.3	78.7	41.4	99.8	85.9	71.5	89.1	74.0 ± 20.98	28.4
Fisherman	90.2	100.0	**n/a**	100.0	**n/a**	100.0	90.9	96.2 ± 5.18	5.4

Patterns Within and Between Islands

Relationships Between Habitat Variables

When data were compiled among all island beach segments and all time series, significant correlations between habitat variables indicated a suite of conditions related to disturbance by storm overwash (Table 4). Dune stability was negatively correlated with beach width, the amount of beach-mud interface, the amount of beach-water interface, and positively correlated with the distance to nearest wetland and the amount of beach-vegetation interface. These relationships are expected when storm energy washes out a portion of dune, disturbs the vegetation, and drives the active beach zone across land towards mudflats and other wetlands. Likewise, beach width was positively correlated with the amount of beach-mud interface, amount of beach-water interface, and negatively correlated with amount of beach-vegetation interface. Finally, the amount of beach-mud interface was negatively correlated with the amount of beach-vegetation interface. Because each of these variables is standardized by the total length of beach-land margin, this result simply indicates the inverse relationship between these two variables. Mudflats and vegetation were the dominant cover bordering the landward edge of the beach. So this relationship also explains why other variables that have a positive correlation for the amount of beach-mud have an automatic negative relationship with the amount of beach-vegetation.

Table 4. Correlation coefficients between habitat variables. Values in boldface are significant at the $P < 0.05$ level. All other values are not statistically significant.

	Beach Width	**Beach-Mud Interface**	**Beach-Veg. Interface**	**Beach-Water Interface**	**Dune Stability**
Distance to Wetland	-0.02	**-0.15**	0.04	-0.06	**0.31**
Beach Width		**0.33**	**-0.35**	**0.11**	**-0.29**
Beach-Mud Interface			**-0.73**	0.02	**-0.43**
Beach-Veg. Interface				**-0.47**	**0.43**
Beach-Water Interface					**-0.34**

Dune Stability

Dune stability varied greatly between individual beach segments and years (Appendix I). Only 13 of the 90 (14%) segments had dunes remain undisturbed across all decades. Dune recovery after disturbance was common. There were no beach segments where dunes remained completely disturbed (i.e., 0% dune stability). Eighty-five of the 90 beach segments had completely stable dune lines in at least one decade examined with many of these segments having 100% intact dune lines after earlier disturbances.

When individual beach segments were used as replicates, dune stability had a strong negative correlation with its temporal variance ($r = -0.89$, $P < 0.05$). This pattern suggests that there are stable segments of islands that receive less or are more resistant to storm disturbance and other segments of islands that are more susceptible to disturbance.

The spatial variance of dune stability (Table 5) suggests that there is a shifting mosaic of patches at different places along the disturbance-return interval continuum. Individual segments on each island rotate through different periods of disturbance and succession to produce periods of relative uniformity (low spatial variance) and relative disparity (high spatial variance) between years. This is particularly true for islands that receive higher levels of disturbance such as Metompkin or Ship Shoal. In general, this pattern suggests that individual segments of islands either undergo disturbance at different magnitudes, different rates, or at different times.

Table 5. Within-island spatial variance (CV) of dune stability by year.

	Spatial CV by Year						
Island	**1949**	**1955**	**1962**	**1977**	**1985**	**1994**	**2002**
Northern Islands							
Assateague	**n/a**	**n/a**	30.5	48.3	30.9	47.4	31.2
Wallops	31.1	**n/a**	**n/a**	0.0	0.0	0.0	0.0
Assawoman	38.3	66.9	**n/a**	0.0	**n/a**	50.3	90.7
Metompkin	57.9	55.6	263.7	44.9	99.2	185.5	47.3
Cedar	23.4	138.4	72.5	0.0	53.5	75.8	57.9
Southern Islands							
Parramore	94.9	**n/a**	82.8	0.0	31.5	99.6	14.1
Hog	**n/a**	**n/a**	43.6	7.6	13.4	0.0	0.0
Cobb	49.2	58.4	56.1	63.8	26.2	28.3	57.3
Wreck	88.6	73.2	**n/a**	0.0	0.0	53.4	65.0
Ship Shoal	94.1	0.0	**n/a**	64.8	23.3	10.8	75.6
Myrtle	154.9	101.2	67.9	0.0	0.0	22.9	90.1
Smith	78.7	42.0	102.0	0.7	27.6	49.8	18.1
Fisherman	18.2	0.0	**n/a**	0.0	**n/a**	0.0	28.9

Beach Width

When islands were examined individually, average beach width was significantly different between beach segments and years for 12 of 13 islands (Two-way ANOVA results for each island, all P values < 0.001). A significant year *x* beach segment interaction term (P < 0.001) in all of these comparisons indicates that differences in beach width between segments of an island were dependent on the year examined. The only exception to this general pattern was Ship Shoal Island. Average beach width of Ship Shoal Island was significantly different across years ($F_5 = 31.5$, $P < 0.001$) but was not significantly different between beach segments (F1 = 1.9, P < 0.001). One explanation for this result was that Ship Shoal was only divided into two segments so had less variation to contribute to a significant ANOVA result compared to an island with 3 or more segments. However, a significant year *x* beach segment interaction term for Ship Shoal Island ($F_4 = 3.1$, $P < 0.01$) indicated that differences in beach width between segments were dependent on the year examined. Post-hoc tests revealed that segments were statistically similar in the years of 1949 and 1955 but statistically different in later years (Tukey's HSD test, P > 0.05 between 1949 and 1955, and P < 0.05 for all years thereafter).

The average value of beach width for each segment across the time series was not significantly correlated with its CV (r = -0.17, P > 0.10) (Appendix II). This result explains the variance of relatively narrow segments over time was no different than wider segments. It further explains that narrow beaches remain relatively narrow through time and wider beaches remain relatively wide through time.

When all islands and all years were compiled, average beach width was greater at end segments (N = 144) of islands compared to middle segments (N = 375) of islands (F_1=3.57, P < 0.05) ($\bar{x} \pm SD$ = 83.4 m ± 58.37, and 72.6 m ± 59.37, respectively) (Ship Shoal Island not included in this comparison). However, the average difference between end and middle segments was only 10 m. The disparity in beach width was more pronounced when penultimate segments near the ends of islands that had 5 or more total segments were reclassified from the middle to the end group. The average difference between end (N = 252) and middle (N = 257) segments was nearly 20 m for this comparison (F_1=13.6, P < 0.001) ($\bar{x} \pm SD$ = 85.2 m ± 61.82 and 66.5 m ± 55.06, respectively). The CV for average beach width was 73 and 82 % for end and middle beach segments, respectively. The similarity of these values indicates that temporal variation in beach width was relatively consistent between end and middle segments. There was no statistically significant difference in average beach width among segments between northern and southern islands (t-test, $t_{88} = 0.22$, P > 0.50) ($\bar{x} \pm SD$ = 75.8 ± 34.94 and 77.6 ± 43.00, respectively) or between combinations of northern and southern islands with end and middle segments (Two-way ANOVA results, all P values > 0.10)

Island and Habitat Use by Birds

Colonial Beach Nesting Birds

General Island Use

Black Skimmers – Black Skimmers used 42 of the 75 (56%) different beach segments over the 20 years selected for study. The total number of beach segments used by Black Skimmers steadily declined over time. This included 34 segments in the 1977 period, 24 in the 1985 period, 17 in the1994 period, and 7 in the 2002 period. Turnover rates between segments within and between decade groups were relatively high. Only two beach segments were used in all years of any one decadal period and only 1 beach segments was used at least one time in each decade. Metompkin, Myrtle, and Ship Shoal islands had the greatest overall use in regards to the proportion of segments occupied (Table 6).

Table 6. Maximum number of years that individual beach segments were used by Black Skimmers over a 20 yr period.

Island	Total # of segments	# Never used	# Segments Used for Maximum of									
			1 yr	2 yr	3 yr	4yr	5 yr	6yr	7yr	8 yr	9yr	10yr
Assawoman	5	4	0	0	0	1	0	0	0	0	0	0
Cedar	8	4	2	1	0	0	0	0	0	0	1	0
Cobb	6	3	0	1	0	0	0	1	0	1	0	0
Fisherman	5	1	1	3	0	0	0	0	0	0	0	0
Hog	10	4	0	0	0	0	0	0	4	2	0	0
Metompkin	8	0	0	1	3	0	1	0	1	2	0	0
Myrtle	3	0	1	0	0	1	0	1	0	0	0	0
Parramore	8	7	0	0	1	0	0	0	0	0	0	0
Ship Shoal	2	0	0	0	0	1	0	0	0	0	0	1
Smith	10	3	2	1	2	0	0	2	0	0	0	0
Wallops	5	5	0	0	0	0	0	0	0	0	0	0
Wreck	5	2	0	0	1	1	0	0	1	0	0	0

Common Tern - Common Terns used 44 of the 75 (59%) different beach segments over the 20 years selected for study. The total number of beach segments that were used steadily declined over time. This included 32 segments in the 1977 period, 30 in the 1985 period, 23 in the1994 period, and 10 in the 2002 period. Turnover rates between segments within and between decade groups were relatively high. No beach segments were used in all years of any one decadal period and only 5 beach segments (7% of all) were used at least one time in each decade. Metompkin Island had the greatest overall use in regard to the proportion of segments occupied and the length of time those segments were occupied (Table 7). All segments on Metompkin Island were occupied for ≥ 5 yr. Parramore Island had the lowest overall use. Only 1 of 8 segments on Parramore Island was ever occupied and that segment was occupied for 4 yr.

Table 7. Maximum number of years that individual beach segments were used by Common Terns over a 20 yr period.

Island	Total # of segments	# Never used	# Segments Used for a Maximum of									
			1 yr	2 yr	3 yr	4yr	5 yr	6yr	7yr	8 yr	9yr	10yr
Assawoman	5	3	1	0	0	0	0	1	0	0	0	0
Cedar	8	2	3	2	0	0	0	0	0	0	1	0
Cobb	6	3	1	0	0	0	1	0	1	0	0	0
Fisherman	5	1	1	1	1	0	1	0	0	0	0	0
Hog	10	4	0	0	0	0	1	1	2	1	1	0
Metompkin	8	0	0	0	0	0	1	1	1	1	2	2
Myrtle	3	1	0	0	0	0	1	0	1	0	0	0
Parramore	8	7	0	0	0	1	0	0	0	0	0	0
Ship Shoal	2	0	0	0	0	0	0	0	1	0	1	0
Smith	10	4	1	0	1	2	1	1	0	0	0	0
Wallops	5	4	1	0	0	0	0	0	0	0	0	0
Wreck	5	1	1	0	1	0	0	0	0	2	0	0

Gull-billed Tern - Gull-billed Terns used 32 of 75 (43%) different beach segments over the 20 years selected for study. The total number of occupied segments steadily declined over time with 32 segments used during the 1977 period, 23 in the 1985 period, 16 in the 1994 period, and 4 in the 2002 period. Turnover rates between segments both within and between decade groups were high. No beach segments were used in all 20 years and only 2 segments were used in at least one year in all 4 decades. Metompkin, Myrtle and Ship Shoal islands ranked high in terms of the proportion of segments occupied (Table 8).

Least Tern - Least Terns used 48 of 75 (64%) different beach segments over the 20 yr selected for study. The total number of used beach segments slightly declined over time with 31 segments used in the 1977 period, 33 in the 1985 period, 20 in the 1994 period, and 24 in the 2002 period. Least Terns used individual beach segments more consistently than other colonial beach nesting species. One explanation for this is that the number of breeding sites of Least Terns has not declined as much as these other species. However, turnover rates were still relatively high. Least Terns occupied only 4 segments in all decades and only 2 segments in all 5 years of one decade. Cobb, Metompkin, Myrtle, and Ship Shoal islands had the greatest overall use in terms of the proportion of segments occupied (Table 9).

Table 8. Maximum number of years that individual beach segments were used by Gull-billed Terns over a 20 yr period.

Island	Total # of segments	# Never used	# Segments Used for Maximum of									
			1 yr	2 yr	3 yr	4yr	5 yr	6yr	7yr	8 yr	9yr	10yr
Assawoman	5	2	2	1	0	0	0	0	0	0	0	0
Cedar	8	4	2	1	0	0	0	0	0	0	0	1
Cobb	6	2	1	1	0	0	0	1	1	0	0	1
Fisherman	5	4	1	0	0	0	0	0	0	0	0	0
Hog	10	4	0	1	1	0	1	3	0	0	0	3
Metompkin	8	0	2	0	2	1	0	1	1	0	1	1
Myrtle	3	0	0	1	1	0	0	1	0	0	0	1
Parramore	8	7	0	0	1	0	0	0	0	0	0	0
Ship Shoal	2	0	0	0	0	1	0	0	0	1	0	0
Smith	10	3	2	2	1	0	1	0	1	0	0	0
Wallops	5	4	1	0	0	0	0	0	0	0	0	0
Wreck	5	2	0	1	0	1	0	1	0	0	0	1

Table 9. Maximum number of years that individual beach segments were used by Least Terns over a 20 yr period.

Island	Total # of segments	# Never used	# Segments Used for Maximum of									
			1 yr	2 yr	3 yr	4yr	5 yr	6yr	7yr	8 yr	9yr	10-14yr
Assawoman	5	2	1	0	0	0	0	0	1	1	0	0
Cedar	8	1	0	0	2	1	1	1	0	1	0	1
Cobb	6	0	0	0	4	1	0	0	0	0	1	0
Fisherman	5	4	0	1	0	0	0	0	0	0	0	0
Hog	10	2	3	1	1	0	1	1	0	1	0	0
Metompkin	8	0	0	1	1	0	1	3	1	0	1	0
Myrtle	3	0	0	0	0	0	2	1	0	0	0	0
Parramore	8	7	0	1	0	0	0	0	0	0	0	0
Ship Shoal	2	0	0	0	0	0	0	0	0	0	0	2
Smith	10	4	0	1	1	2	1	1	0	0	0	0
Wallops	5	4	1	0	0	0	0	0	0	0	0	0
Wreck	5	0	1	2	0	0	1	1	0	0	0	0

Habitat Use by Colonial Beach-nesting Waterbirds

The habitat use patterns of the Colonial Beach-nesting Waterbirds were highly consistent between species and years examined (Tables 10-13). When data were compiled over all decades, occupied beach segments were significantly different from unoccupied segments for at least 5 of 6 habitat variables among all species. In general, used segments for Black Skimmers, Common Terns, Gull-billed Terns, and Least Terns tended to have wider beaches, fewer stable dunes, greater access to adjacent mudflats, and to be closer in proximity to wetland habitats compared to unused segments. The level of statistical significance between occupied and unoccupied segments for individual decades had mixed results between species. However in each of these comparisons, the relative positive or negative difference in average value of habitat variables between occupied and unoccupied segments remained consistent between every comparison.

The relative difference between statistically significant values for habitat variables varied widely. For example, differences in beach width between occupied and occupied were sometimes by orders of magnitude in one year and less than that in others. The fact that overall difference between groups as well as that the level of significance varied between decades and species for certain variables is not surprising since the characteristics of the overall islands are changing with time (including those re-used) and the location of breeding sites are moving between segments in different decades. Moreover, the fact that there was such close consistency between species is not surprising since we are often sampling the same breeding sites for multiple species. All four of these species regularly form mixed species colonies with each other as well as exclusive single species colonies.

Text continues after tables on page 23

Table 10. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by Black Skimmers. Data were compiled from the use of beach segments for all years (N = 20) and for a 5 years sets around each selected year of 1977, 1985, 1994, and 2002.

Habitat Variable	Occupied $\bar{x} \pm SD$	Unoccupied $\bar{x} \pm SD$	U	P
All Years	**N = 42**	**N = 33**		
Distance to Wetland (m)	181.6 ± 141.89	304.3 ± 249.01	469.0	**< 0.01**
Beach Width (m)	80.6 ± 50.23	51.2 ± 33.38	381.0	**< 0.01**
Beach-Mud Interface (%)	19.43 ± 19.33	8.5 ± 14.20	427.0	**< 0.01**
Beach-Vegetation Interface (%)	74.9 ± 23.02	86.8 ± 17.24	458.0	**< 0.01**
Beach-Open Water Interface (%)	5.7 ± 9.73	2.0 ± 4.61	506.5	**< 0.05**
Stable Dune (%)	68.7± 24.36	84.9 ± 19.17	428.0	**< 0.01**
1977	**N = 34**	**N = 41**		
Distance to Wetland (m)	369.9 ± 355.25	355.3 ± 319.55	636.0	> 0.10
Beach Width (m)	58.2 ± 67.02	43.6 ± 44.36	562.0	> 0.10
Beach-Mud Interface (%)	16.3 ± 27.42	5.7 ± 2.56	451.5	**< 0.05**
Beach-Vegetation Interface (%)	78.5 ± 33.67	92.1 ± 21.19	533.5	> 0.10
Beach-Open Water Interface (%)	5.2 ± 16.44	1.8 ± 6.49	659.5	> 0.10
Stable Dune (%)	87.3 ± 27.40	96.6 ± 12.65	547.0	> 0.10
1985	**N = 24**	**N = 41**		
Distance to Wetland (m)	273.5 ± 359.33	318.1 ± 303.03	361.0	> 0.10
Beach Width (m)	108.1 ± 73.73	47.4 ± 29.04	161.0	**< 0.01**
Beach-Mud Interface (%)	28.13 ± 30.65	5.23 ± 15.65	275.0	**< 0.01**
Beach-Vegetation Interface (%)	66.5 ± 35.34	90.1 ± 20.09	318.0	**< 0.01**
Beach-Open Water Interface (%)	5.3 ± 13.82	3.5 ± 12.41	468.0	> 0.10
Stable Dune (%)	64.5 ± 39.07	88.05 ± 20.64	333.0	**< 0.05**
1994	**N = 17**	**N = 58**		
Distance to Wetland (m)	55.23 ± 54.65	146.5 ± 175.03	371.0	> 0.10
Beach Width (m)	78.4 ± 70.53	70.9 ± 69.08	453.0	> 0.10
Beach-Mud Interface (%)	11.4 ± 20.44	24.87 ± 35.09	423.5	> 0.10
Beach-Vegetation Interface (%)	77.9 ± 31.61	72.7 ± 37.32	461.0	> 0.10
Beach-Open Water Interface (%)	10.7 ± 17.53	1.7 ± 5.98	334.0	**< 0.05**
Stable Dune (%)	73.2 ± 40.70	69.1 ± 40.70	477.5	> 0.10
2002	**N = 7**	**N = 68**		
Distance to Wetland (m)	27.59 ± 30.86	183.02 ± 191.97	69.0	**< 0.01**
Beach Width (m)	95.0 ± 47.06	73.8 ± 55.14	160.0	> 0.10
Beach-Mud Interface (%)	44.3 ± 29.36	11.4 ± 22.40	85.5	**< 0.01**
Beach-Vegetation Interface (%)	41.4 ± 30.56	83.3 ± 27.28	63.5	**< 0.01**
Beach-Open Water Interface (%)	14.2 ± 27.04	4.6 ± 14.09	147.5	> 0.10
Stable Dune (%)	40.7 ± 28.18	77.4 ± 31.04	100.0	**< 0.01**

Table 11. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by Common Terns. Data were compiled from the use of beach segments for all years (N = 20) and for a 5 years sets around each selected year of 1977, 1985, 1994, and 2002.

Habitat Variable	Occupied $\bar{x} \pm SD$	Unoccupied $\bar{x} \pm SD$	U	P
All Years	**N = 44**	**N = 31**		
Distance to Wetland (m)	189.3 ± 151.51	301.3 ± 249.90	487.0	**< 0.05**
Beach Width (m)	77.6± 51.51	53.6±31.92	462.0	**< 0.05**
Beach-Mud Interface (%)	20.6± 18.9	6.1 ± 12.4	330.5	**< 0.01**
Beach-Vegetation Interface (%)	73.7 ± 22.13	89.2± 16.17	347.0	**< 0.01**
Beach-Open Water Interface (%)	5.3 ± 9.53	2.3 ± 5.06	507.0	> 0.05
Stable Dune (%)	69.2 ± 24.72	85.3 ± 18.23	418.0	**< 0.01**
1977	**N = 32**	**N = 43**		
Distance to Wetland (m)	363.7.3 ± 357.76	401.5 ± 327.34	519.0	> 0.10
Beach Width (m)	56.9± 69.26	47.3 ± 45.19	566.0	> 0.10
Beach-Mud Interface (%)	17.6 ± 27.82	0.3 ± 2.02	352.0	**< 0.01**
Beach-Vegetation Interface (%)	74.8 ± 34.6	94.49 ± 19.16	376.5	**< 0.01**
Beach-Open Water Interface (%)	5.5 ± 16.91	0.9 ± 3.5	557.5	> 0.10
Stable Dune (%)	88.1 ± 24.01	97.4 ± 11.80	434.0	> 0.10
1985	**N = 30**	**N = 35**		
Distance to Wetland (m)	269.9 ± 337.99	328.8 ± 311.73	519.0	> 0.05
Beach Width (m)	96.8 ± 70.61	46.7 ± 29.4	566.0	**< 0.01**
Beach-Mud Interface (%)	26.3 ± 30.98	2.8 ± 8.89	352.0	**< 0.01**
Beach-Vegetation Interface (%)	68.3 ± 34.49	92.3 ± 16.47	376.5	**< 0.01**
Beach-Open Water Interface (%)	545 ± 13.25	3.14 ± 12.6	557.5	> 0.10
Stable Dune (%)	69.2 ± 35.34	90.2 ± 18.75	434.0	**< 0.01**
1994	**N = 23**	**N = 52**		
Distance to Wetland (m)	42.7 ± 61.18	162.8 ± 178.42	279.0	**< 0.01**
Beach Width (m)	115.4 ± 79.97	52.9 ± 54.66	311.0	**< 0.01**
Beach-Mud Interface (%)	34.9 ± 38.48	16.3 ± 28.56	399.0	**< 0.05**
Beach-Vegetation Interface (%)	55.0 ± 41.45	81.8 ± 30.27	365.0	**< 0.05**
Beach-Open Water Interface (%)	10.1 ± 15.97	0.89 ± 4.7	392.0	**< 0.05**
Stable Dune (%)	67.9 ± 41.10	72.9 ± 37.98	472.5	> 0.10
2002	**N = 10**	**N = 65**		
Distance to Wetland (m)	29.7 ± 28.98	185.3 ± 194.91	92.0	**< 0.01**
Beach Width (m)	97.0 ± 40.45	73.29 ± 56.37	194.0	> 0.05
Beach-Mud Interface (%)	37.1 ± 27.19	11.2 ± 22.89	118.0	**< 0.01**
Beach-Vegetation Interface (%)	43.7 ± 32.16	84.7 ± 25.87	83.0	**< 0.01**
Beach-Open Water Interface (%)	19.2 ± 34.5	3.4 ± 9.03	210.0	> 0.10
Stable Dune (%)	37.8 ± 23.89	79.7 ± 30.22	107.5	**< 0.01**

Table 12. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by Gull-billed Terns. Data were compiled from the use of beach segments for all years (N = 20) and for a 5 years sets around each selected year of 1977, 1985, 1994, and 2002.

Habitat Variable	Occupied $\bar{x} \pm SD$	Unoccupied $\bar{x} \pm SD$	U	P
All Years	**N = 43**	**N = 32**		
Distance to Wetland (m)	181.6 ± 145.51	308.10 ± 247.95	438.0	**< 0.01**
Beach Width (m)	82.1 ± 52.29	48.2 ± 24.86	371.0	**< 0.01**
Beach-Mud Interface (%)	21.5 ± 19.67	5.3 ± 9.72	320.5	**< 0.01**
Beach-Vegetation Interface (%)	72.2 ± 22.90	90.8 ± 13.30	316.0	**< 0.01**
Beach-Open Water Interface (%)	5.9 ± 9.72	1.6± 4.02	448.0	**< 0.01**
Stable Dune (%)	67.2± 23.52	87.5 ± 18.11	339.0	**< 0.01**
1977	**N = 32**	**N = 43**		
Distance to Wetland (m)	318.4 ± 315.58	407.6 ± 347.83	526.0	> 0.10
Beach Width (m)	61.4 ± 69.49	42.8 ± 43.34	524.0	> 0.10
Beach-Mud Interface (%)	12.4 ± 23.18	4.5 ± 17.16	522.5	**< 0.01**
Beach-Vegetation Interface (%)	78.6 ± 32.46	90.9 ± 24.04	515.0	**< 0.01**
Beach-Open Water Interface (%)	6.8 ± 17.97	0.9 ± 3.5	579.0	> 0.10
Stable Dune (%)	89.9 ± 23.64	94.5 ± 19.30	577.5	> 0.10
1985	**N = 23**	**N = 42**		
Distance to Wetland (m)	300.5 ± 373.3	302.3 ± 296.55	399.0	> 0.10
Beach Width (m)	100.4 ± 62.24	53.3 ± 48.42	184.0	**< 0.01**
Beach-Mud Interface (%)	31.9 ± 32.26	3.7 ± 10.69	220.0	**< 0.01**
Beach-Vegetation Interface (%)	62.4 ± 36.22	91.9 ± 16.75	262.0	**< 0.01**
Beach-Open Water Interface (%)	5.8 ± 14.03	3.3 ± 12.27	425.0	> 0.10
Stable Dune (%)	63.3 ± 39.16	88.3 ± 20.56	313.0	**< 0.01**
1994	**N = 16**	**N = 59**		
Distance to Wetland (m)	35.5± 50.34	150.3 ± 172.68	240.0	**< 0.05**
Beach Width (m)	106.5 ± 76.11	62.9 ± 65.06	305.0	**< 0.05**
Beach-Mud Interface (%)	32.9 ± 37.86	19.2 ± 31.05	351.5	> 0.10
Beach-Vegetation Interface (%)	56.9 ± 38.00	78.1± 34.46	323.0	**< 0.05**
Beach-Water Interface (%)	10.29 ± 17.13	1.9 ± 6.94	307.0	**< 0.05**
Stable Dune (%)	53.7 ± 42.03	73.8 ± 37.45	317.0	> 0.10
2002	**N = 4**	**N = 71**		
Distance to Wetland (m)	13.7 ± 19.13	177.2 ± 189.93	31.0	**< 0.01**
Beach Width (m)	90.9 ± 50.73	74.9 ± 54.93	194.0	> 0.05
Beach-Mud Interface (%)	60.4 ± 24.13	11.9 ± 22.36	118.0	**< 0.01**
Beach-Vegetation Interface (%)	20.0 ± 15.85	82.7 ± 26.97	83.0	**< 0.01**
Beach-Open Water Interface (%)	19.6 ± 36.34	4.8 ± 36.34	210.0	> 0.10
Stable Dune (%)	34.1 ± 31.82	76.2 ± 31.82	107.5	**< 0.01**

Table 13. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by Least Terns. Data were compiled from the use of beach segments for all years (N = 20) and for a 5 years sets around each selected year of 1977, 1985, 1994, and 2002.

Habitat Variable	Occupied $\bar{x} \pm SD$	Unoccupied $\bar{x} \pm SD$	U	P
All Years	**N = 48**	**N = 27**		
Distance to Wetland (m)	182.3 ± 145.86	330.2 ± 256.54	394.0	**< 0.01**
Beach Width (m)	78.6 ± 48.94	48.2 ± 31.98	342.0	**< 0.01**
Beach-Mud Interface (%)	20.4 ± 18.82	4.3 ± 10.53	266.5	**< 0.01**
Beach-Vegetation Interface (%)	73.7 ± 22.15	91.6 ± 14.19	276.5	**< 0.01**
Beach-Open Water Interface (%)	5.6 ± 9.29	1.3± 4.08	404.5	**< 0.01**
Stable Dune (%)	68.7± 23.91	88.6 ± 16.75	342.0	**< 0.01**
1977	**N = 31**	**N = 44**		
Distance to Wetland (m)	288.1 ± 291.35	429.45 ± 356.59	455.0	**< 0.05**
Beach Width (m)	59.1 ± 59.67	44.5 ± 53.31	546.0	> 0.10
Beach-Mud Interface (%)	11.5 ± 22.81	5.1 ± 17.77	533.5	**< 0.05**
Beach-Vegetation Interface (%)	82.4 ± 28.82	88.2 ± 28.06	541.5	> 0.10
Beach-Open Water Interface (%)	3.9 ± 12.81	2.9 ± 11.82	622.0	> 0.10
Stable Dune (%)	89.4 ± 23.44	94.4 ± 19.40	545.5	> 0.10
1985	**N = 33**	**N = 32**		
Distance to Wetland (m)	268.6 ± 326.37	335.7± 320.84	394.0	> 0.10
Beach Width (m)	100.6 ± 65.67	38.1 ± 20.60	112.0	**< 0.01**
Beach-Mud Interface (%)	24.2 ± 30.31	2.9 ± 9.17	295.5	**< 0.01**
Beach-Vegetation Interface (%)	69.8 ± 33.25	93.4 ± 16.9	289.0	**< 0.01**
Beach-Open Water Interface (%)	6.0 ± 12.90	2.3 ± 12.75	401.0	> 0.10
Stable Dune (%)	69.5 ± 36.10	89.8 ± 19.67	351.0	**< 0.01**
1994	**N = 20**	**N = 55**		
Distance to Wetland (m)	37.1 ± 48.00	158.2 ± 176.18	279.0	**< 0.05**
Beach Width (m)	85.5 ± 60.49	67.5 ± 60.67	395.0	**< 0.05**
Beach-Mud Interface (%)	28.4 ± 33.32	19.8 ± 32.68	411.0	> 0.10
Beach-Vegetation Interface (%)	64.5 ± 36.79	76.8 ± 35.58	404.5	> 0.10
Beach-Open Water Interface (%)	7.1 ± 12.18	2.5 ± 12.18	441.0	> 0.10
Stable Dune (%)	66.5 ± 37.67	70.8 ± 39.74	468.0	> 0.10
2002	**N = 24**	**N = 51**		
Distance to Wetland (m)	62.1 ± 97.54	219.28 ± 200.60	187.0	**< 0.01**
Beach Width (m)	89.8 ± 36.67	69.12 ± 60.44	362.0	**< 0.01**
Beach-Mud Interface (%)	30.6 ± 27.77	7.2 ± 19.76	248.0	**< 0.01**
Beach-Vegetation Interface (%)	58.4 ± 34.53	88.9 ± 22.23	272.0	**< 0.01**
Beach-Open Water Interface (%)	11.1 ± 24.82	3.0 ± 8.20	502.0	> 0.10
Stable Dune (%)	40.1 ± 25.30	89.5 ± 21.82	119.0	**< 0.01**

Solitary Beach-nesting Birds

Piping Plover

Piping Plover used a total of 29 segments in 1986 and 21 segments in 1995. In 1986, Piping Plovers were distributed over most of the entire island chain except for Assawoman, Wreck, Ship Shoal, and Fisherman islands. In 1996, Piping Plovers were distributed on all islands except for Parramore, Hog, Cobb, and Hog islands. Metompkin Island had the greatest overall use with 100 % and 62 % of all segments in 1986 and 1995 respectively.

Used beach segments were significantly different from unused segments for 5 of 6 habitat variables in 1986 and 1995. In 1986, Piping Plovers used segments with wider beaches, greater access to mudflat habitats, lower relative amount of vegetation on the beach margin, and fewer stable dunes. Habitat use in 1995 was relatively similar, with the only differences being that Piping Plovers used segments significantly closer to wetlands but did not use wider beaches.

The difference in average values between occupied and unoccupied was sometimes by orders of magnitude. For instance, in 1986, beach width of occupied segments was more than twice as wide as occupied segments. The amount of beach-mud interface in occupied segments was almost 5 times that of unoccupied segments in 1996 and 2 times the percentage in 1995.

Table 14. Occupation patterns of Piping Plovers on the Virginia Barrier Islands in 1986 and 1995.

Island	Total # of Segments	# of Segments Occupied	
		1986	1995
Assawoman	5	0	1
Wallops	5	1	1
Metompkin	8	8	5
Cedar	8	5	5
Parramore	8	1	0
Hog	10	5	0
Cobb	6	4	0
Wreck	5	0	1
Ship Shoal	2	0	2
Myrtle	3	1	3
Smith	10	4	3
Fisherman	5	0	0

Table 15. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by Piping Plovers. Data were compiled from the use of beach segments in 1986 and 1995 and paired with habitat data measured in 1985 and 1994, respectively.

Habitat Variable	**Occupied** $\bar{x} \pm$ **SD**	**Unoccupied** $\bar{x} \pm$ **SD**	**U**	**P**
1985	**N = 29**	**N = 36**		
Distance to Wetland (m)	294.1 ± 364.44	307.7 ± 290.38	402.0	> 0.10
Beach Width (m)	97.3 ± 70.81	47.6 ± 31.36	228.0	**< 0.01**
Beach-Mud Interface (%)	24.3 ± 29.41	5.14 ± 16.25	310.5	**< 0.01**
Beach-Vegetation Interface (%)	71.0 ± 32.16	89.8 ± 32.16	327.5	**< 0.01**
Beach-Open Water Interface (%)	4.7 ± 9.52	3.8 ± 1.51	437.0	> 0.10
Stable Dune (%)	67.1± 36.86	89.4 ± 20.28	328.0	**< 0.01**
1994	**N = 21**	**N = 54**		
Distance to Wetland (m)	80.5 ± 162.52	143.3 ± 159.05	402.0	**< 0.01**
Beach Width (m)	75.2 ± 66.81	71.2 ± 71.03	228.0	> 0.10
Beach-Mud Interface (%)	39.2 ± 37.99	15.36 ± 28.23	310.5	**< 0.01**
Beach-Vegetation Interface (%)	53.20 ± 39.95	81.6 ± 31.32	327.5	**< 0.01**
Beach-Open Water Interface (%)	7.6 ± 11..36	2.21 ± 9.80	437.0	**< 0.05**
Stable Dune (%)	47.6 ± 42.09	78.6 ± 35.04	328.0	**< 0.01**

American Oystercatcher

American Oystercatchers used 54 of 75 (72 %) beach segments in 2002. These were distributed across all islands except for Parramore. Relative use of beach segments was high with at least 67% of all segments used on each occupied island.

Used beach segments were significantly different from unused segments for 3 of 6 habitat variables. In general, American Oystercatchers used segments that were closer to wetland habitats, had wider beaches, and fewer stable dunes. Average beach width of occupied segments was nearly 3 times greater than unoccupied segments. Distance to nearest wetland of occupied segments was less than half the distance of unoccupied segments.

Table 16. Occupation patterns of American Oystercatchers on the Virginia Barrier Islands in 2002.

Island	Total # of Segments	# of Segments Occupied
Assawoman	5	4
Fisherman	5	5
Metompkin	8	8
Parramore	8	0
Ship Shoal	2	2
Cedar	8	6
Cobb	6	4
Myrtle	3	3
Smith	10	7
Wallops	5	1
Wreck	5	5
Hog	10	9

Table 17. Average values and Mann-Whitney U test results for comparisons of habitat variables between beach segments occupied and unoccupied by American Oystercatchers. Data were compiled from the use of beach segments in 2002.

Habitat Variable	Occupied $\bar{x} \pm SD$ (N = 54)	Unoccupied $\bar{x} \pm SD$ (N = 21)	U	P
Distance to Wetland (m)	115.48 ± 116.05	339.8 ± 262.38	191.0	**< 0.01**
Beach Width (m)	89.15 ± 55.62	32.65 ± 21.87	141.0	**< 0.01**
Beach-Mud Interface (%)	16.9 ± 25.04	4.5 ± 16.91	330.0	> 0.10
Beach-Vegetation Interface (%)	75.8 ± 31.18	91.7 ± 19.69	341.0	> 0.10
Beach-Open Water Interface (%)	7.3 ± 18.03	1.1 ± 4.78	390.0	> 0.10
Stable Dune (%)	69.03± 33.95	93.4 ± 13.87	297.0	**< 0.01**

Generalized Habitat Availability for Birds over Time

Both colonial and solitary nesting birds exhibited similar patterns of habitat use that included the use of wide beaches that were close to mudflats and other wetlands, and that had fewer stable dunes. Values for habitat variables of occupied beach segments varied between species and even within species between years. Moreover, most average values were accompanied by a large quantity of variance. Because of this, it is difficult to draw a single value that best represents habitat use for any one species and creating a broad confidence interval to project habitat availability across time serves no better purpose than generalizing on a few dimensions of habitat use. Even so, addressing the availability of habitat over time is a powerful tool for conservation and management. So, in order to meet this objective, we used a generalized and conservative set of values that combined beach width, distance to wetland, beach-mud interface, and dune stability to yield the number and area of beach segments available to beach-nesting birds over time. Specifically we used the combination of following values; beach width > 50m, distance to wetland < 500m, beach interface > 9%, and dune stability < 80%. All of these values are within one SD unit from the average values for habitat variables of the species examined. We understand the conservative nature of these parameters because they ultimately yield fewer patches and area than actually occupied by birds in any single year.

Results of this projection indicate that habitat availability fluctuates both across islands and across years as can be expected (Table 18). However, there appear to be extreme 'crunches' such as the zero availability of habitat in 1977. Although we know this not to be accurate, it demonstrates how habitat can drop across the entire barrier island system only to be recycled in later years. In general, there is more habitat available based on our generalized parameters in the two most recent decades than that available on some islands dating back to 1949. Our exploration also demonstrates that some islands such as Asswoman, Metompkin, and Cedar currently contribute an overwhelming proportion to the entire balance of available habitat including providing more area now than prior decades. Better models of birds and habitat use are needed to provide more accurate estimates.

DISCUSSION

Both colonial and solitary beach-nesting birds exhibited similar patterns of habitat use that included the used of wide beaches that were close to mudflats and other wetlands, and that had fewer stable dunes. The combination of these habitat conditions are only found along barrier islands that are frequently disturbed by storm washover. Moreover, these conditions are relatively short-lived without continual disturbance. Washover surfaces can be re-vegetated only one year after initial disturbance (Godfrey 1979).

Piping Plovers used beaches that were over two times wider than those not used. This result is generally consistent with studies that report their use of wide, sparsely vegetated beaches (Patterson et al. 1991). In addition, used beach segments provided more direct access to backside island mudflats and marshes. Direct access to these habitats is most often associated with extensive breaks in the dune line caused by storm overwash. Access to backside wetland habitats has been shown to be an important modifier of space use in other populations of Piping Plovers (Haig and Oring 1985). Piping Plovers likely use these areas to gain greater access to

Table 18. Generalized habitat availability for species that depend on island disturbance from washover.

Island	**Habitat Availability by Year (ha)**						
	1949	**1955**	**1962**	**1977**	**1985**	**1994**	**2002**
Assateague	n/a	n/a	0	0	0	0	29.9
Wallops	0	n/a	n/a	0	0	0	0
Assawoman	10.4	37.9	0	0	n/a	20.4	46.92
Metompkin	36.1	0	17.3	0	86.8	145.2	83.6
Cedar	13.3	10.3	27.35	0	14.3	0	83.4
				0	0	0	0
Parramore	32.8	n/a	55.7	0	0	49.65	0
Hog	n/a	n/a	39.5	0	11.6	0	0
Cobb	50.0	26.1	25.0	0	0	0	0
Wreck	32.9	19.3	n/a	0	0	6.6	8.2
Ship Shoal	0	0	n/a	0	23.8	19.8	17.4
Myrtle	47.1	18.9	22.6	0	0	0	0
Smith	65.3	17.3	71.2	0	7.2	17.4	14.7
Fisherman	6.5		n/a	0	n/a	0	31.3
Total*	294.5	130.4	259.2	0	143.7	258.9	315.5

*note that total summation does not include area estimates for islands listed as not available.

additional foraging areas. In addition, backside mudflats and wetlands are considered important habitat for foraging and survival by recently fledged chicks (Patterson et al. 1991).

American Oystercatchers use recent washover areas to gain many of the same benefits as Piping Plovers. Oystercatchers typically use a combination of habitats for foraging including open beach and surf, marshes and mudflats (Nol and Humprey 1994). Washover areas provide Oystercatchers with extensive nesting habitat in combination with better access to foraging habitats other than the surf zone.

The use of washover areas by colonial beach-nesting birds is consistent with other reports of their use of beaches for nesting (Erwin et al. 1981). Terns and Skimmers typically use open beaches covered with sand, cobble, and little or no vegetation. This entire group of species forages in open water and individuals will often travel kilometers between nesting and foraging sites. Their use of areas with more direct access to backside habitats are likely the result of the covariation between habitat variables than a requirement for the entire suite of conditions associated with washovers per se.

Within the Virginia Barrier Island Chain, disturbance to beaches vary in both magnitude and return interval. Systematic variation in the spatial distribution of disturbance often equates into a mosaic of conditions within and between islands. Because conservation and management goals often prescribe habitat protection, disturbance regimes must be used as a primary determinant of habitat distribution and availability for beach nesting birds. Most importantly, the area and extent of protection must be large enough to reflect the spatial and temporal distribution of the disturbance regime. Beach nesting birds use islands that are most frequently and severely disturbed compared to those that undergo fewer disturbances. Within individual islands, birds use areas that are most recently disturbed and harbor the suite of conditions associated with storm washover. Occupancy rates for most beach nesting species were higher and more consistent on islands such as Metompkin, Cobb, and Cedar. However, beach nesting birds are often able to cue onto specific beach segments on islands such as Hog, Ship Shoal, and Smith that receive lower disturbance frequency and magnitude. In general, habitat availability for beach nesting birds on the Virginia Barrier Island dynamics operates on a mass balance scale where habitats can be open for long periods of time on frequently disturbed islands and for shorter periods of time on islands not as frequently disturbed.

The magnitude and return intervals for storm washovers and the recovery rates for disturbed portions of beach in this study are not entirely known. Disturbed beach segments were observed to recover over the course of this study. However, the total number of disturbance events that takes place between our measurements is unknown. In general, our measurements show that disturbance and full recovery of a dune line occurred at least one time and sometimes two times across the history of an individual beach segment. Dunes also appear to remain stable within individual segments for one to two decades on islands with a low frequency of disturbance.

Reasons for the variance in disturbance within and between islands are not known. Elevation is a primary determinant of storm washover. Open beaches lower than 1.5m in elevation may be consistently open through repeated washover. Beaches higher than 3m elevation may only be washed over during large scale storms. We did not measure beach elevation for this study but it is likely that it was the most contributing factor. The development of new technologies, such as optical remote sensing using LIDAR (Light Detection and Ranging) will provide new means to determine the relationship between elevation and washover probability over the entire island chain.

Over the past several decades, the total number of breeding individuals and the number of breeding sites of beach-nesting birds has declined substantially. One objective of this study was to attempt to partial out the relevant contribution of changes in habitat availability to population trends. Our projection of habitat availability, based on a few generalized but appropriate parameters, indicate that habitat trends are exactly opposite of population declines. There are more habitats available to beach nesting birds on some islands than ever before. Moreover, general island patterns have shown that features such as total beach area and average beach width have fluctuated widely over time but has not significantly declined for nearly all islands. There also seems to be a readily supply of open, disturbed patches. The recent declines of beach-nesting birds are probably better explained by factors other than habitat availability. Nest predation by ground predators, such as red foxes (*Vulpes vulpes*) and raccoons (*Procyon lotor*), are among the leading alternative factors. Nest predation can severely impact nest productivity and cause nest site abandonment. The influence that nest predators have the distribution of beach-nesting birds is unknown. Thus, it is impossible to know if habitat use patterns in this study are confounded by such factors. Populations at low densities are typically more selective of habitat because of reduced intraspecific competition for breeding sites. However, in this study, habitat use patterns appeared to be similar when populations were high and after they declined.

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Appendix I. Average value and CV for amount of stable dune (%)for individual beach segments across all years. Islands and segments are ordered north to south.

Island	Beach Segment	N (# of years)	% of Dune Stable	Lowest value over all years	Highest value over all years	CV
Assateague	N End	5	71.8±24.13	39.0	100.0	24.1
	N Middle A	5	69.6±28.10	42.4	100.0	14.0
	N Middle B	5	76.0±42.14	2.7	100.0	14.0
	N Middle C	5	79.3±21.46	48.3	100.0	5.4
	N Middle D	5	47.5±45.41	0.0	100.0	9.1
	N Middle E	5	97.8±4.99	88.8	100.0	0.8
	N Middle F	5	70.9±39.64	3.5	100.0	5.7
	Middle	5	83.0±27.61	36.5	100.0	3.5
	S Middle F	5	85.1±21.32	54.2	100.0	2.4
	S Middle E	5	95.7±9.57	78.6	100.0	1.0
	S Middle D	5	82.1±32.37	25.3	100.0	2.9
	S Middle C	5	62.1±37.91	8.1	100.0	3.2
	S Middle B	5	72.6±31.69	33.3	100.0	2.4
	S Middle A	5	100.0±0.00	100.0	100.0	0.0
	S End	5	83.0±24.62	46.1	100.0	1.6
Wallops						
	N End	5	98.5±3.35	92.5	100.0	3.4
	N Middle	5	100.0±0.00	100.0	100.0	0.0
	Middle	5	98.2±4.10	90.8	100.0	1.4
	S Middle	5	95.7±9.68	78.3	100.0	2.4
	S End	5	87.5±27.86	37.7	100.0	5.6
Assawoman						
	N End	5	50.1±40.07	15.5	100.0	40.1
	N Middle	5	62.6±44.59	5.4	100.0	22.3
	Middle	5	75.3±39.05	10.6	100.0	13.0
	S Middle	5	70.3±40.39	7.3	100.0	10.1
	S End	5	53.7±37.77	14.0	100.0	7.6
Metompkin						
	N End	7	35.7±32.40	0.0	100.0	32.4
	N Middle A	7	33.9±39.56	0.0	93.0	19.8
	N Middle B	7	32.2±37.08	0.0	100.0	12.4
	Middle A	7	39.0±40.90	0.0	100.0	10.2
	Middle B	7	14.6±15.16	0.0	34.1	3.0
	S Middle B	7	36.0±23.97	0.0	60.3	4.0
	S Middle A	7	50.2±36.99	0.0	88.2	5.3
	S End	7	64.3±35.84	0.0	100.0	4.5

Appendix I continued

Island	Beach Segment	N (# of years)	% of Dune Stable	Lowest value over all years	Highest value over all years	CV
Cedar						
	N End	6	64.3±31.23	21.3	100.0	31.2
	N Middle A	7	57.4±34.95	13.7	100.0	17.5
	N Middle B	7	71.5±39.42	0.0	100.0	13.1
	Middle A	7	50.4±47.33	0.0	100.0	11.8
	Middle B	7	54.2±38.88	0.0	100.0	7.8
	S Middle B	7	48.9±32.02	0.0	100.0	5.3
	S Middle A	7	72.4±40.50	14.0	100.0	5.8
Parramore						
	S End	7	85.4±25.34	41.3	100.0	3.2
	N End	6	100.0±0.00	100.0	100.0	0.0
	N Middle A	6	96.8±7.81	80.9	100.0	3.9
	N Middle B	6	100.0±0.00	100.0	100.0	0.0
	Middle A	6	97.6±4.01	90.4	100.0	1.0
	Middle B	6	66.9±45.77	3.9	100.0	9.2
	S Middle B	6	42.3±47.54	0.0	100.0	7.9
	S Middle A	6	41.3±47.25	0.0	100.0	6.7
	S End	6	36.8±38.98	0.0	100.0	4.9
Hog						
	N End	5	100.0±0.00	100.0	100.0	0.0
	N Middle A	5	100.0±0.00	100.0	100.0	0.0
	N Middle B	5	93.0±15.66	65.0	100.0	5.2
	N Middle C	5	100.0±0.00	100.0	100.0	0.0
	Middle A	5	100.0±0.00	100.0	100.0	0.0
	Middle B	5	100.0±0.00	100.0	100.0	0.0
	S Middle C	5	83.1±16.40	62.7	100.0	2.3
	S Middle B	5	80.0±44.72	0.0	100.0	5.6
	S Middle A	5	88.1±26.50	40.7	100.0	2.9
	S End	5	100.0±0.00	100.0	100.0	0.0
Cobb						
	N End	4	47.1±36.68	18.7	100.0	36.7
	N Middle	7	83.3±37.27	0.0	100.0	18.6
	Middle A	7	94.1±15.51	59.0	100.0	5.2
	Middle B	7	65.4±39.23	4.9	100.0	9.8
	S Middle	7	71.6±24.11	42.7	100.0	4.8
	S End	7	64.8±21.62	31.5	83.3	3.6
Wreck						
	N End	6	82.2±32.05	20.8	100.0	32.0
	N Middle	6	73.3±42.33	5.8	100.0	21.2
	Middle	6	79.0±30.20	39.3	100.0	10.1
	S Middle	6	71.4±45.23	0.0	100.0	11.3
	S End	6	67.1±45.43	0.0	100.0	9.1

Appendix I continued

Island	Beach Segment	N (# of years)	% of Dune Stable	Lowest value over all years	Highest value over all years	CV
Ship Shoal						
	N End	6	50.2±30.42	15.6	100.0	30.4
	S End	6	53.1±28.93	12.7	100.0	14.5
Myrtle						
	N End	7	85.1±29.92	20.6	100.0	29.9
	Middle	7	45.6±42.03	5.8	100.0	21.0
	S End	7	68.8±39.58	0.0	100.0	13.2
Smith						
	N End	7	78.9±22.79	46.5	100.0	22.8
	N Middle A	7	44.0±49.29	0.0	100.0	24.6
	N Middle B	7	56.2±44.41	0.0	100.0	14.8
	N Middle C	7	62.0±34.47	0.0	100.0	8.6
	Middle A	7	67.8±36.80	0.0	100.0	7.4
	Middle B	7	79.3±36.55	11.4	100.0	6.1
	S Middle C	7	85.7±37.80	0.0	100.0	5.4
	S Middle B	7	97.7±6.13	83.8	100.0	0.8
	S Middle A	7	92.0±21.07	44.2	100.0	2.3
	S End	7	85.8±25.00	39.5	100.0	2.5
Fisherman						
	W End	5	100.0±0.00	100.0	100.0	0.0
	W Middle	5	100.0±0.00	100.0	100.0	0.0
	Middle	5	92.5±16.86	62.3	100.0	5.6
	E Middle	5	100.0±0.00	100.0	100.0	0.0
	E End	4	85.7±28.60	42.8	100.0	5.7

Appendix II. Average beach width and CV for individual beach segments across all years surveyed. Islands and segments are ordered from north to south.

Island	Segment	N (years)	Beach Width (m) $\bar{x} \pm SD$	CV for all years	Lowest $\bar{x}$ Beach Width (m)	Highest $\bar{x}$ Beach Width (m)
Assateague						
	N End	5	96.1±69.07	71.9	32.3	207.9
	N Middle A	5	75.8±30.74	40.5	32.4	111.1
	N Middle B	5	51.6±22.55	43.7	34.3	90.2
	N Middle C	5	76.9±46.49	60.5	35.0	156.5
	N Middle D	5	160.0±188.40	117.8	46.4	492.9
	N Middle E	5	67.2±32.50	48.4	45.0	124.0
	N Middle F	5	104.7±51.64	49.3	48.9	164.7
	Middle	5	62.0±35.38	57.1	22.3	103.1
	S Middle F	5	55.7±38.95	69.9	21.7	121.8
	S Middle E	5	53.5±36.57	68.3	15.7	108.6
	S Middle D	5	75.6±63.37	83.8	23.0	176.0
	S Middle C	5	92.4±49.11	53.1	24.6	147.8
	S Middle B	5	169.3±111.04	65.6	60.5	347.9
	S Middle A	5	130.4±69.70	53.4	21.9	216.0
	S End	5	104.1±45.41	43.6	35.4	156.3
Wallops						
	N End	5	30.1±11.50	38.2	11.3	39.6
	N Middle	5	16.1±6.99	43.4	5.9	24.2
	Middle	5	10.0±8.27	83.1	0.0	20.5
	S Middle	5	12.4±16.60	133.5	3.2	42.0
	S End	5	49.4±65.12	131.9	15.4	165.7
Assawoman						
	N End	5	105.2±84.71	80.5	20.4	219.2
	N Middle	5	104.9±107.87	102.8	13.8	226.8
	Middle	5	35.5±25.01	70.5	13.3	69.6
	S Middle	5	41.3±28.90	69.9	15.1	88.2
	S End	5	90.2±43.34	48.0	38.3	157.9
Metompkin						
	N End	7	103.2±25.49	24.7	60.4	144.0
	N Middle A	7	97.7±68.67	70.3	8.4	217.1
	N Middle B	7	103.6±67.71	65.4	6.5	204.0
	Middle A	7	96.3±49.68	51.6	18.6	157.3
	Middle B	7	110.4±64.27	58.2	43.4	209.1
	S Middle B	7	72.6±35.87	49.4	33.5	136.5
	S Middle A	7	59.5±28.77	48.3	20.5	97.9
	S End	7	76.8±49.68	64.7	4.0	143.5

Appendix II continued

Island	Segment	N (years)	Beach Width (m) x̄ ± SD	CV for all years	Lowest x̄ Beach Width (m)	Highest x̄ Beach Width (m)
Cedar						
	N End	7	75.1±48.00	63.9	1.0	158.3
	N Middle A	7	57.8±33.92	58.7	2.0	102.5
	N Middle B	7	52.6±47.19	89.8	3.0	145.3
	Middle A	7	53.0±50.45	95.2	4.0	130.6
	Middle B	7	54.1±40.14	74.2	5.0	106.7
	S Middle B	7	67.8±35.18	51.9	6.0	108.9
	S Middle A	7	59.3±35.26	59.5	7.0	107.0
	S End	7	96.1±67.91	70.7	8.0	220.1
Parramore						
	N End	6	84.1±50.06	59.5	36.2	164.7
	N Middle A	6	50.2±44.88	89.4	19.0	139.5
	N Middle B	6	34.2±23.75	69.5	12.0	73.5
	Middle A	6	21.9±7.70	35.2	14.6	34.6
	Middle B	6	45.1±30.10	66.7	14.6	86.0
	S Middle B	6	70.7±51.65	73.0	14.5	142.4
	S Middle A	6	109.7±83.97	76.6	13.0	221.0
	S End	6	111.6±52.30	46.8	43.7	193.1
Hog						
	N End	5	252.8±69.25	27.4	151.5	333.5
	N Middle A	5	252.5±53.08	21.0	177.1	303.7
	N Middle B	5	112.4±43.39	38.6	62.2	160.5
	N Middle C	5	62.7±30.17	48.1	30.2	103.1
	Middle A	5	73.9±58.04	78.6	20.5	155.1
	Middle B	5	63.2±33.34	52.7	15.5	104.6
	S Middle C	5	78.1±45.77	58.6	16.0	138.5
	S Middle B	5	101.3±56.22	55.5	38.8	178.5
	S Middle A	5	96.1±62.64	65.2	18.7	148.6
	S End	5	106.1±68.98	65.0	45.0	207.7
Cobb						
	N End	7	87.2±29.70	34.1	24.5	116.4
	N Middle	7	58.2±22.26	38.2	27.3	84.7
	Middle A	7	63.8±43.86	68.7	10.3	138.7
	Middle B	7	79.7±48.16	60.4	20.5	164.4
	S Middle	7	64.8±38.93	60.1	31.2	116.2
	S End	7	65.5±20.88	31.9	29.6	94.4
Wreck						
	N End	6	43.0±24.60	57.2	11.3	78.7
	N Middle	6	50.8±39.33	77.4	18.0	124.1
	Middle	6	40.4±24.69	61.1	18.5	80.5
	S Middle	6	52.6±38.72	73.6	8.8	91.6
	S End	6	62.9±24.15	38.4	24.5	89.0
Ship Shoal						
	N End	6	86.4±31.56	36.5	61.0	143.5
	S End	6	73.0±40.77	55.8	21.1	124.2

Appendix II continued

Island	Segment	N (years)	Beach Width (m) $\bar{x} \pm SD$	CV for all years	Lowest $\bar{x}$ Beach Width	Highest $\bar{x}$ Beach Width
Myrtle						
	N End	7	84.9±35.32	41.6	25.2	138.7
	Middle	7	76.3±48.42	63.5	7.5	142.7
	S End	7	57.2±40.59	71.0	12.5	136.1
Smith						
	N End	7	50.3±18.65	37.1	21.9	77.8
	N Middle A	7	53.6±32.18	60.0	16.4	96.1
	N Middle B	7	65.9±18.12	27.5	45.8	93.7
	N Middle C	7	56.3±21.02	37.3	20.7	78.2
	Middle A	7	46.3±31.55	68.1	16.7	106.5
	Middle B	7	63.6±52.43	82.5	14.0	153.0
	S Middle C	7	103.8±92.61	89.2	16.8	272.3
	S Middle B	7	44.2±13.79	31.2	25.3	66.0
	S Middle A	7	61.9±20.59	33.3	42.2	96.4
	S End	7	72.1±35.95	49.9	38.5	142.2
Fisherman						
	W End	5	34.2±20.53	60.1	3.6	61.4
	W Middle	5	97.2±64.36	66.2	4.9	171.6
	Middle	5	80.5±50.67	63.0	20.5	158.5
	E Middle	5	79.8±36.79	46.1	38.3	114.4
	E End	5	121.1±96.43	79.6	35.4	263.7

Appendix III. Average % of beach-mud interface and CV for individual beach segments across all years surveyed. Islands and segments are ordered from north to south.

Island	Segment	N (years)	% Beach-Mud	CV for all years	Lowest	Highest
Assateague						
	N End	5	0.0±0.00	--	0.0	0.0
	N Middle A	5	0.0±0.00	--	0.0	0.0
	N Middle B	5	0.0±0.00	--	0.0	0.0
	N Middle C	5	0.0±0.00	--	0.0	0.0
	N Middle D	5	20.0±44.72	223.6	0.0	100.0
	N Middle E	5	3.8±8.42	223.6	0.0	18.8
	N Middle F	5	0.0±0.00	--	0.0	0.0
	Middle	5	0.0±0.00	--	0.0	0.0
	S Middle F	5	0.0±0.00	--	0.0	0.0
	S Middle E	5	0.0±0.00	--	0.0	0.0
	S Middle D	5	0.0±0.00	--	0.0	0.0
	S Middle C	5	4.4±9.87	223.6	0.0	22.1
	S Middle B	5	6.5±13.16	203.3	0.0	29.9
	S Middle A	5	27.9±36.33	130.0	0.0	83.1
	S End	5	23.4±43.45	185.7	0.0	100.0
Wallops						
	N End	5	0.0±0.00	--	0.0	0.0
	N Middle	5	2.5±5.56	223.6	0.0	12.4
	Middle	5	0.0±0.00	--	0.0	0.0
	S Middle	5	0.0±0.00	--	0.0	0.0
	S End	5	0.0±0.00	--	0.0	0.0
Assawoman						
	N End	5	36.4±36.23	99.4	0.0	80.9
	N Middle	5	33.3±40.97	123.0	0.0	79.3
	Middle	5	5.9±8.79	147.9	0.0	19.6
	S Middle	5	5.3±11.86	223.6	0.0	26.5
	S End	5	23.9±27.91	116.7	0.0	61.5
Metompkin						
	N End	7	27.0±28.34	105.0	0.0	82.4
	N Middle A	7	22.4±36.83	164.2	0.0	100.0
	N Middle B	7	35.6±40.88	114.8	0.0	100.0
	Middle A	7	40.9±36.79	90.0	0.0	100.0
	Middle B	7	26.4±31.29	118.4	0.0	86.7
	S Middle B	7	26.0±33.64	129.5	0.0	75.9
	S Middle A	7	3.9±6.91	177.6	0.0	16.9
	S End	7	15.3±24.51	160.5	0.0	52.9

Appendix III continued

Island	Segment	N (years)	% Beach-Mud	CV for all years	Lowest	Highest
Cedar						
	N End	7	34.1±34.98	102.7	0.0	75.7
	N Middle A	7	21.9±37.67	171.9	0.0	84.1
	N Middle B	7	7.9±20.88	264.6	0.0	55.3
	Middle A	7	19.8±33.99	171.5	0.0	92.3
	Middle B	7	21.3±36.60	171.8	0.0	100.0
	S Middle B	7	22.0±30.92	140.5	0.0	78.7
	S Middle A	7	25.6±29.41	114.7	0.0	67.0
	S End	7	5.5±14.61	264.6	0.0	38.6
Parramore						
	N End	6	0.0±0.00	--	0.0	0.0
	N Middle A	6	0.0±0.00	--	0.0	0.0
	N Middle B	6	0.0±0.00	--	0.0	0.0
	Middle A	6	0.0±0.00	--	0.0	0.0
	Middle B	6	0.0±0.00	--	0.0	0.0
	S Middle B	6	5.2±9.94	190.7	0.0	24.8
	S Middle A	6	28.7±37.22	129.6	0.0	85.5
	S End	6	21.6±32.45	150.5	0.0	67.2
Hog						
	N End	5	30.5±35.92	117.9	0.0	77.7
	N Middle A	5	9.4±21.13	223.6	0.0	47.2
	N Middle B	5	2.4±5.34	223.6	0.0	11.9
	N Middle C	5	16.5±32.85	198.5	0.0	75.0
	Middle A	5	0.0±0.00		0.0	0.0
	Middle B	5	1.6±3.50	223.6	0.0	7.8
	S Middle C	5	13.3±21.53	161.5	0.0	49.5
	S Middle B	5	17.1±38.20	223.6	0.0	85.4
	S Middle A	5	9.9±22.14	223.6	0.0	49.5
	S End	5	9.8±21.90	223.6	0.0	49.0
Cobb						
	N End	7	55.8±34.29	61.5	0.0	100.0
	N Middle	7	34.1±45.57	133.7	0.0	100.0
	Middle A	7	20.4±35.56	174.1	0.0	86.9
	Middle B	7	9.1±16.48	180.4	0.0	41.2
	S Middle	7	3.5±7.36	208.2	0.0	19.7
	S End	7	21.4±25.82	120.6	0.0	67.2
Wreck						
	N End	6	11.8±15.91	135.1	0.0	36.9
	N Middle	6	21.5±31.03	144.6	0.0	78.6
	Middle	6	19.1±25.65	134.5	0.0	61.9
	S Middle	6	21.9±40.26	184.2	0.0	100.0
	S End	6	26.8±43.28	161.8	0.0	100.0
Ship Shoal						
	N End	6	25.9±21.92	84.5	0.0	53.0
	S End	6	12.4±10.27	82.9	0.0	22.5

Appendix III continued

Island	Segment	N (years)	% Beach-Veg	CV for all years	Lowest	Highest
Myrtle						
	N End	7	7.7±11.09	143.2	0.0	24.0
	Middle	7	24.9±33.93	136.3	0.0	95.5
	S End	7	15.7±20.52	130.5	0.0	48.7
Smith						
	N End	7	42.9±41.30	96.3	0.0	93.0
	N Middle A	7	38.4±42.22	109.9	0.0	90.6
	N Middle B	7	19.6±24.86	126.6	0.0	61.6
	N Middle C	7	12.7±16.77	132.3	0.0	35.2
	Middle A	7	14.7±27.93	190.6	0.0	72.8
	Middle B	7	13.8±28.82	208.2	0.0	77.0
	S Middle C	7	0.0±0.00	--	0.0	0.0
	S Middle B	7	0.0±0.00	--	0.0	0.0
	S Middle A	7	42.9±41.30	96.3	0.0	93.0
	S End	7	38.4±42.22	109.9	0.0	90.6
Fisherman						
	W End	5	3.1±6.83	223.6	0.0	15.3
	W Middle	5	7.8±17.37	223.6	0.0	38.8
	Middle	5	20.1±21.98	109.3	0.0	57.5
	E Middle	5	16.1±27.56	170.8	0.0	63.6
	E End	5	70.1±28.81	41.1	36.6	100.0

Appendix IV. Average distance to nearest wetland and CV for individual beach segments across all years surveyed. Islands and segments are ordered from north to south.

Island	Segment	N (years)	Distance to Wet $\bar{x} \pm SD$	CV for all years	Lowest	Highest
Assateague						
	N End	5	282.8±113.54	40.1	130.9	397.6
	N Middle A	5	318.7±121.34	38.1	138.1	424.6
	N Middle B	5	348.5±92.05	26.4	205.8	433.1
	N Middle C	5	436.4±158.46	36.3	194.0	561.9
	N Middle D	5	595.1±409.98	68.9	98.7	1059.3
	N Middle E	5	802.4±565.11	70.4	176.4	1359.5
	N Middle F	5	414.5±209.58	50.6	194.2	650.3
	Middle	5	403.5±219.05	54.3	101.2	628.5
	S Middle F	5	192.5±55.80	29.0	139.3	263.6
	S Middle E	5	299.7±232.50	77.6	69.8	579.3
	S Middle D	5	145.2±88.40	60.9	41.5	226.0
	S Middle C	5	211.2±155.71	73.7	63.0	437.1
	S Middle B	5	138.1±94.37	68.3	16.3	267.8
	S Middle A	5	369.1±469.38	127.2	16.0	1146.4
	S End	5	697.1±1146.58	164.5	54.1	2736.1
Wallops						
	N End	5	751.4±22.70	3.0	734.8	776.5
	N Middle	5	398.3±125.97	31.6	235.2	589.6
	Middle	5	461.0±30.13	6.5	420.6	505.7
	S Middle	5	336.8±36.68	10.9	273.7	370.0
	S End	5	175.0±34.88	19.9	157.0	236.9
Assawoman						
	N End	5	63.7±71.77	112.7	1.0	176.5
	N Middle	5	51.4±52.11	101.4	7.5	115.0
	Middle	5	74.5±39.35	52.8	15.2	121.3
	S Middle	5	101.6±65.08	64.0	6.1	170.6
	S End	5	46.7±36.96	79.2	3.9	96.9
Metompkin						
	N End	7	80.6±51.21	63.6	0.7	161.3
	N Middle A	7	61.9±46.42	75.0	0.7	135.1
	N Middle B	7	51.6±47.71	92.5	0.2	117.8
	Middle A	7	87.4±115.02	131.6	0.5	327.4
	Middle B	7	206.9±280.27	135.5	0.6	761.5
	S Middle B	7	438.6±652.25	148.7	40.9	1545.0
	S Middle A	7	131.4±153.43	116.8	28.1	468.7
	S End	7	152.5±151.75	99.5	19.1	417.5

Appendix IV continued

Island	Segment	N (years)	Distance to Wet $\bar{x} \pm SD$	CV for all years	Lowest	Highest
Cedar						
	N End	7	482.5±474.54	98.3	0.7	1415.1
	N Middle A	7	239.3±150.31	62.8	44.2	411.0
	N Middle B	7	176.4±80.32	45.5	67.2	291.1
	Middle A	7	100.6±68.41	68.0	1.1	185.7
	Middle B	7	78.6±48.96	62.3	0.8	137.2
	S Middle B	7	97.5±66.90	68.7	15.5	189.4
	S Middle A	7	142.0±106.84	75.2	18.1	277.4
	S End	7	306.7±188.93	61.6	130.7	608.0
Parramore						
	N End	6	1033.6±396.13	38.3	377.6	1445.6
	N Middle A	6	915.2±330.77	36.1	526.9	1393.6
	N Middle B	6	912.1±185.79	20.4	662.6	1162.7
	Middle A	6	636.5±195.88	30.8	330.3	793.5
	Middle B	6	369.8±115.79	31.3	232.7	539.2
	S Middle B	6	88.1±52.91	60.1	36.8	142.0
	S Middle A	6	95.3±88.28	92.6	3.6	201.2
	S End	6	252.8±347.10	137.3	0.3	934.6
Hog						
	N End	5	294.8±243.88	82.7	1.4	501.3
	N Middle A	5	388.0±329.25	84.9	15.1	870.0
	N Middle B	5	442.5±399.04	90.2	34.2	968.2
	N Middle C	5	424.8±320.28	75.4	105.5	772.0
	Middle A	5	424.4±45.45	10.7	356.4	483.8
	Middle B	5	258.7±45.56	17.6	205.1	322.2
	S Middle C	5	183.0±78.30	42.8	107.0	315.4
	S Middle B	5	284.5±164.43	57.8	70.7	451.2
	S Middle A	5	259.4±185.61	71.6	58.6	440.7
	S End	5	623.5±620.49	99.5	48.2	1613.3
Cobb						
	N End	7	408.5±552.30	135.2	9.4	1318.5
	N Middle	7	406.8±368.65	90.6	14.2	1114.1
	Middle A	7	405.0±227.35	56.1	8.1	752.6
	Middle B	7	224.4±145.02	64.6	1.6	366.7
	S Middle	7	133.5±73.73	55.2	40.9	258.1
	S End	7	65.6±20.71	31.6	40.2	105.4
Wreck						
	N End	6	100.2±86.00	85.8	0.4	210.1
	N Middle	6	136.0±142.48	104.8	0.4	388.6
	Middle	6	122.9±83.76	68.1	6.3	212.4
	S Middle	6	102.7±95.59	93.1	2.6	229.4
	S End	6	122.1±83.81	68.6	5.3	215.3
Ship Shoal						
	N End	6	111.9±87.55	78.2	6.1	250.5
	S End	6	186.2±199.20	107.0	6.8	468.7

Appendix IV continued

Island	Segment	N (years)	Distance to Wet (m) $\bar{x} \pm SD$	CV for all years	Lowest	Highest
Myrtle						
	N End	7	156.4±151.73	97.0	0.6	479.4
	Middle	7	36.8±51.05	138.9	2.7	142.6
	S End	7	69.4±47.47	68.4	37.1	146.9
Smith						
	N End	7	62.0±27.79	44.8	24.6	90.6
	N Middle A	7	36.5±32.72	89.6	3.5	92.7
	N Middle B	7	44.4±40.48	91.2	11.2	133.6
	N Middle C	7	86.8±71.95	82.9	21.0	239.7
	Middle A	7	77.4±22.20	28.7	37.5	103.2
	Middle B	7	120.4±30.92	25.7	60.2	147.1
	S Middle C	7	150.0±73.76	49.2	33.5	274.4
	S Middle B	7	488.5±194.91	39.9	213.2	660.2
	S Middle A	7	395.3±166.70	42.2	152.1	584.8
	S End	7	90.6±58.62	64.7	31.9	182.6
Fisherman						
	W End	5	320.7±26.47	8.3	284.5	347.2
	W Middle	5	201.3±57.21	28.4	152.3	297.9
	Middle	5	68.4±44.37	64.9	24.1	131.5
	E Middle	5	199.0±39.11	19.7	155.3	255.6
	E End	5	423.9±302.48	71.4	35.3	805.7

Appendix V. Average % of beach-vegetation interface and CV for individual beach segments across all years surveyed. Islands and segments are ordered from north to south.

Island	Segment	N (years)	% Beaah-Veg	CV for all years	Lowest	Highest
Assateague						
	N End	5	83.4±28.79	34.5	33.5	1.0
	N Middle A	5	80.0±44.72	55.9	0.0	1.0
	N Middle B	5	80.0±44.72	55.9	0.0	1.0
	N Middle C	5	80.8±43.04	53.3	3.8	1.0
	N Middle D	5	80.0±44.72	55.9	0.0	1.0
	N Middle E	5	80.0±44.72	55.9	0.0	1.0
	N Middle F	5	80.0±44.72	55.9	0.0	1.0
	Middle	5	80.0±44.72	55.9	0.0	1.0
	S Middle F	5	80.0±44.72	55.9	0.0	1.0
	S Middle E	5	72.4±43.68	60.3	0.0	1.0
	S Middle D	5	50.2±46.65	92.9	0.0	1.0
	S Middle C	5	48.5±37.84	78.0	0.0	1.0
	S Middle B	5	69.0±40.98	59.4	0.0	1.0
	S Middle A	5	52.1±43.85	84.2	0.0	1.0
	S End	5	42.4±46.73	110.1	0.0	1.0
Wallops						
	N End	5	100.0±0.00	0.0	100.0	1.0
	N Middle	5	94.2±13.02	13.8	70.9	1.0
	Middle	5	59.9±23.21	38.8	39.5	1.0
	S Middle	5	80.0±44.72	55.9	0.0	1.0
	S End	5	79.6±29.38	36.9	34.2	1.0
Assawoman						
	N End	5	63.6±36.23	57.0	19.1	1.0
	N Middle	5	57.5±39.07	67.9	14.0	1.0
	Middle	5	94.1±8.79	9.3	80.4	1.0
	S Middle	5	91.1±19.85	21.8	55.6	1.0
	S End	5	70.5±37.12	52.7	14.7	1.0
Metompkin						
	N End	7	51.0±35.55	69.8	0.0	0.8
	N Middle A	7	63.3±45.14	71.3	0.0	1.0
	N Middle B	7	58.0±46.78	80.7	0.0	1.0
	Middle A	7	54.3±42.44	78.2	0.0	1.0
	Middle B	7	44.2±43.07	97.5	0.0	1.0
	S Middle B	7	69.2±39.93	57.7	0.0	1.0
	S Middle A	7	80.6±36.14	44.8	0.0	1.0
	S End	7	65.0±43.50	66.9	0.0	1.0

Appendix V continued

Island	Segment	N (years)	% Beach-Veg	CV for all years	Lowest	Highest
Cedar						
	N End	7	43.8±43.04	98.4	0.0	1.0
	N Middle A	7	73.9±36.44	49.3	15.9	1.0
	N Middle B	7	92.1±20.88	22.7	44.7	1.0
	Middle A	7	80.2±33.99	42.4	7.7	1.0
	Middle B	7	78.7±36.60	46.5	0.0	1.0
	S Middle B	7	66.5±36.14	54.4	17.4	1.0
	S Middle A	7	73.5±30.67	41.7	32.5	1.0
	S End	7	87.7±12.74	14.5	61.4	1.0
Parramore						
	N End	6	87.2±31.24	35.8	23.5	1.0
	N Middle A	6	88.0±29.45	33.5	27.9	1.0
	N Middle B	6	100.0±0.00	0.0	100.0	1.0
	Middle A	6	100.0±0.00	0.0	100.0	1.0
	Middle B	6	100.0±0.00	0.0	100.0	1.0
	S Middle B	6	93.0±14.29	15.4	64.3	1.0
	S Middle A	6	66.4±38.28	57.6	14.5	1.0
	S End	6	52.9±46.16	87.2	0.0	1.0
Hog						
	N End	5	69.5±35.92	51.7	22.3	1.0
	N Middle A	5	90.6±21.13	23.3	52.8	1.0
	N Middle B	5	97.6±5.34	5.5	88.1	1.0
	N Middle C	5	74.2±33.52	45.2	25.0	1.0
	Middle A	5	100.0±0.00	0.0	100.0	1.0
	Middle B	5	98.4±3.50	3.6	92.2	1.0
	S Middle C	5	86.7±21.53	24.8	50.5	1.0
	S Middle B	5	80.0±44.72	55.9	0.0	1.0
	S Middle A	5	90.1±22.14	24.6	50.5	1.0
	S End	5	85.8±23.27	27.1	46.4	1.0
Cobb						
	N End	7	27.5±23.30	84.8	0.0	0.6
	N Middle	7	64.4±44.41	69.0	0.0	1.0
	Middle A	7	79.6±35.56	44.7	13.1	1.0
	Middle B	7	90.9±16.48	18.1	58.8	1.0
	S Middle	7	91.8±12.01	13.1	74.0	1.0
	S End	7	72.4±29.50	40.7	32.8	1.0
Wreck						
	N End	6	70.1±39.51	56.4	0.0	1.0
	N Middle	6	74.5±31.86	42.8	21.4	1.0
	Middle	6	80.9±25.65	31.7	38.1	1.0
	S Middle	6	78.1±40.26	51.5	0.0	1.0
	S End	6	63.8±49.87	78.2	0.0	1.0
Ship Shoal						
	N End	6	65.3±30.85	47.3	28.0	1.0
	S End	6	45.7±29.91	65.5	15.4	1.0

Appendix V continued

Island	Segment	N (years)	% Beach-Veg	CV for all years	Lowest	Highest
Myrtle						
	N End	7	79.0±36.56	46.3	0.0	1.0
	Middle	7	68.6±36.89	53.7	4.5	1.0
	S End	7	75.6±29.70	39.3	22.6	1.0
Smith						
	N End	7	56.1±42.78	76.2	0.0	1.0
	N Middle A	7	56.1±43.04	76.7	0.0	1.0
	N Middle B	7	74.4±34.16	45.9	24.6	1.0
	N Middle C	7	78.0±36.17	46.4	8.8	1.0
	Middle A	7	75.7±33.04	43.6	27.2	1.0
	Middle B	7	69.7±37.90	54.3	23.0	1.0
	S Middle C	7	100.0±0.00	0.0	100.0	1.0
	S Middle B	7	100.0±0.00	0.0	100.0	1.0
	S Middle A	7	89.5±18.01	20.1	61.4	1.0
	S End	7	56.1±42.78	76.2	0.0	1.0
Fisherman						
	W End	5	89.1±11.05	12.4	74.1	1.0
	W Middle	5	92.2±17.37	18.8	61.2	1.0
	Middle	5	76.3±29.68	38.9	24.6	1.0
	E Middle	5	83.9±27.56	32.9	36.4	1.0
	E End	5	29.9±28.81	96.5	0.0	0.6