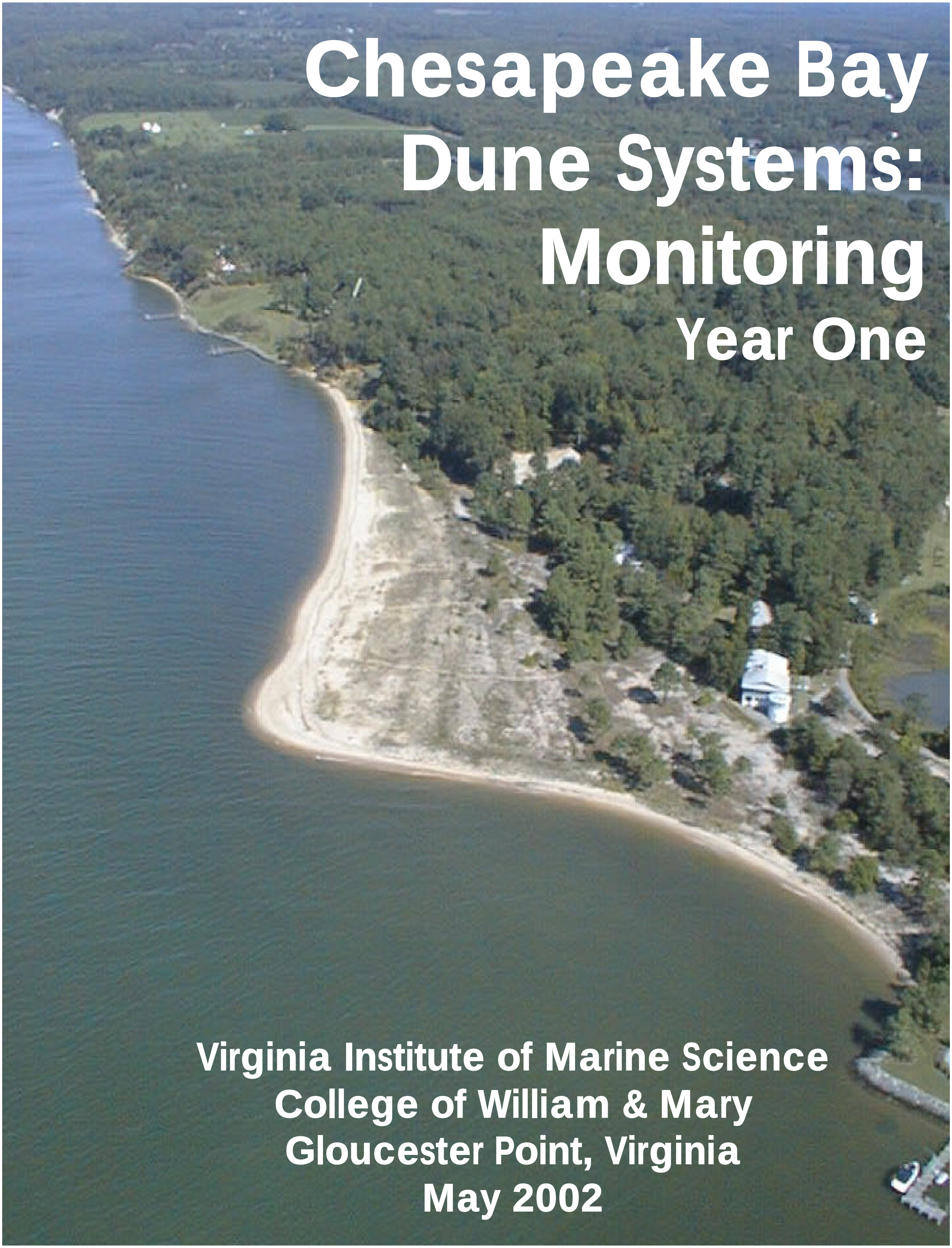

Chesapeake Bay Dune Systems: Monitoring

Year One

Virginia Institute of Marine Science
College of William & Mary
Gloucester Point, Virginia
May 2002

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Executive Summary

The scope and tasks of this study are to:

1) Characterize and enumerate dunes in non-jurisdictional localities. These localities include the counties of Middlesex, Westmoreland, Isle of Wight, Surry, and York and the cities of Newport News, Suffolk and Poquoson.
2) Develop a Bay-wide monitoring program of selected dune sites. This program characterizes the seasonality of dune resources, biological assessments, groundwater dynamics and analyses of historical shoreline change for selected dune fields (with emphasis on secondary dunes).
3) Define, quantify, and delineate adjacent dune ecosystems that complement functions of coastal primary dunes (secondary dunes and dune fields).
4) Continue the assessment of horseshoe crab spawning habitat, and habitat suitability index development and refinement.

Results of this study are that:

1) Approximately 30 additional dune sites were identified in the eight (8) non-jurisdictional localities listed above. Most of the "new" dune sites occur in Middlesex County and Westmoreland County as Open Bay and Bay-influenced while sites in the remaining localities are mostly Riverine.

2 and 3) Nine monitoring sites were established and include sites in Lancaster County (LN39), Mathews County (MA3), Northampton County (NH10, NH17, NH51), Northumberland County (NL42, NL58, NL59), and Virginia Beach (VB4) with 33 total surveyed shore profiles. Preliminary results indicate a considerable variability alongshore and cross-shore within each site. By averaging measured parameters like primary dune and secondary dune crest heights, the analysis showed that secondary dune heights are equal to or slightly higher than the corresponding primary dune heights at the seven monitoring locations with secondary dunes. This generally holds with the original model cross-section for the relationship between primary and secondary dunes. Dune crest heights are lower on sites with low backshore areas. All sites have a distinct evolutionary history through natural and man-induced activities. In almost all cases, the secondary dune was once the primary dune. Some current primary dunes, particularly along parts of site MA3, have developing foredune features that may become the primary dune in the near future, relegating the existing primary dune to secondary dune status. Storm events have been generally lacking in Chesapeake Bay since fall 1999, and we attribute much of this beach/dune growth to that fact. Vegetative distributions among the primary and secondary dunes are typical for bay and coastal communities except for one section at NL58 where the jurisdictional primary dune has typical secondary dune vegetation, simply due to loss of the typical primary dune feature.

4) From the perspective of horseshoe crab spawning habitat suitability, the dune-associated beaches in non-jurisdictional localities do provide the required habitat characteristics similar in magnitude to the beaches of jurisdictional localities.

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1 Introduction

1.1 Background and Purpose

Dune systems of the Commonwealth of Virginia are considered a unique and valuable natural resource. The primary dune and beach components of existing dune systems are protected under the Coastal Primary Sand Dune Protection Act (Act). Until 1998, the exact extent of existing dune systems in the Chesapeake Bay was unknown as was the relationship between primary and secondary dunes. At that time, a study entitled "Chesapeake Bay Dune Systems: Evolution and Status" was initiated (Hardaway *et al.*, 2001a). The goals of that study were to locate, classify, and enumerate the existing jurisdictional dunes and dune fields within eight localities listed in the Act (Figure 1-1). These include the cities of Hampton, Norfolk, Virginia Beach, and the counties of Accomack, Mathews, Lancaster, Northampton and Northumberland.

Results of that study indicated the variable nature of dune systems around Chesapeake Bay in terms of shoreline change and developmental pressures. In order to better understand these issues, this present study resolved to:

1) Characterize and enumerate dunes in non-jurisdictional localities. These localities include the counties of Middlesex, Westmoreland, Isle of Wight, Surry, and York and the cities of Newport News, Suffolk and Poquoson.
2) Develop a Bay-wide monitoring program of selected dune sites. This program characterizes the seasonality of dune resources, biological assessments, groundwater dynamics and analyses of historical shoreline change for selected dune fields (with emphasis on secondary dunes).
3) Define, quantify, and delineate adjacent dune ecosystems that complement functions of coastal primary dunes (secondary dunes and dune fields).
4) Continue the assessment of horseshoe crab spawning habitat, and habitat suitability index development and refinement.

This project is aimed at developing an understanding of detailed beach and dune change, both morphologically and vegetatively. It is the goal of this program to accomplish two things through vegetation monitoring. The first would be to determine the effects of dune dynamics on the vegetation communities growing upon the primary dune. Second, we wish to characterize the vegetation communities of secondary dunes. Vegetation community characterization has been accomplished for Bay primary dunes, therefore our goal for the primary dune is to assess only those changes in vegetation that accompany changes to the dune due to natural physical forces.

1.2 Chesapeake Bay Dune Systems

1.2.1 Geographic Extent

The distribution of dunes varies around Chesapeake Bay. Hardaway *et al.* (2001a) found that the occurrence of Bay dunes is due, in part, to three main factors: 1) morphologic opportunity (*i.e.*, relatively stable setting), 2) abundant sand supply in the littoral transport system, and 3) conducive onshore wind/wave climate. Deposited sand must remain above a stable backshore to allow dune vegetation to become established. Each dune that has been documented by Hardaway *et al.* (2001a) has its own history of change -- both growth and decay. Many miles of natural dunes have been altered by development and many have been created due to man's influence. In fact, dunes around the Chesapeake Bay estuarine system in the localities within the Act encompass only about 40 miles of shoreline (Hardaway *et al.*, 2001a). This is about 0.4% of the total Bay shore making it a rare shore type.

The Chesapeake Bay geography allows us to group dune sites into three main regions. The Eastern Shore, Southern Shore, and the Western Shore. These three regions are subject to similar wind and wave climates. However, the previous study also showed that dune morphology varies significantly within each region. In addition, localities not in the Act (Figure 1-1) are important because the extent of their dune resources have not been characterized.

1.2.2 Classification

In Hardaway *et al.* (2001a), a Chesapeake Bay dune classification was developed. This classification is based on parameters that are unique to certain dune systems and have a basis in dune field evolution, vegetative zones, lateral and vertical extent of primary and secondary dunes as well as anthropogenic impacts. The dune classification system was developed for use as a management tool. Dune classes can be used to guide shoreline development decisions, shoreline management strategies, and restoration goals.

The dune classification system is three tiered (Figure 1-2). The primary tier characterizes the level or type of human involvement in the dune system. These three categories (Natural, Man-Influenced, or Man-Made) reflect how the state of the dune is most impacted. The second tier in the classification (A to G) are the parameters most influential in defining the status of a given dune system. Parameter values within each second tier category define a range of limits or characteristics for each category. Categories A, B and C relate to the nature of the impinging wave climate at a given site while categories D, E, and F relate to geologic parameters.

Exposure (A) is a qualitative assessment of the wave exposure and wave climate across open water. Wave impact, particularly during storms, is the dominant natural process driving shoreline erosion and sediment transport along the Bay coasts. Bay Influenced (A.1) is somewhere between the Open Bay exposure (A.2) and Riverine exposure (A.3). Generally, A.1 sites have fetches of 5-10 nautical miles (nm); A.2 have fetches of >10 nm; and A.3 have fetches of <5 nm. Hardaway *et al.* (2001a) suggested that, the large elevations and dune-field widths of the dunes along the open bay coast of Virginia Beach are a function of abundant sand supply and long fetch to the storm dominant northwest, north, and northeast wind-wave fields. In contrast, the areas of more limited fetch in the riverine environs of Lancaster County that face the milder southerly wind-wave climate have only modest dunes. The high percentage of open bay dune shoreline (85%) is a function of sand supply and more aggressive wind and wave climates (enhanced wave runup) combining with geomorphic opportunities for beach/dune development. Riverine sources of sand are relatively low, and reduced wave periods result in less runup potential to form and maintain beach berms, the foundation for dune development.

Shore Orientation (B) is the direction the main dune shore faces according to eight points on the compass. Shoreline exposure to dominant directions of wind-waves is a component of fetch and wave climate as well as aeolian processes that assist in dune growth, development, and decay.

Nearshore Gradient (C) controls wave refraction and shoaling which effect the nature of wave approach and longshore transport as well as onshore/offshore transport. The presence or absence of bars will indicate the relative amount of nearshore sediment available for transport.

The Morphologic Setting (D) indicates the dune form and is significant in the genesis of a particular dune site. Aerial images were used to determine and classify the nature of the Morphologic Setting. Four basic categories were developed including: 1) Isolated dunes, 2) Creek mouth barrier dune/spit, 3) Spit and 4) Dune fields. Morphological Settings 1 and 4 are distinguished only by shore length (*i.e.* Morphologic Setting 1 < 500 ft and Morphologic Setting 4 > 500 ft) as an arbitrary boundary. These categories were subdivided to reflect the nature of the setting into four subcategories. These include: 1) Pocket, 2) Linear, 3) Shallow Bay, and 4) Salient.

The morphology of Chesapeake Bay dune sites shows that 72% or almost 29 miles of dune coast are dune fields (Hardaway *et al.*, 2001a). The long, continuous coast of Norfolk and Virginia Beach have the longest per-site average. The isolated dunes in Lancaster appear to result from human influence. The creek mouth dune sites in Mathews are a reflection of the coastal morphology since they occur along natural coasts.

The Relative Stability (E) or state of a dune site was very subjective. This parameter is a value judgement as to the overall present and future integrity, of a particular site. If the site had wave cut scarps along the primary dune face and/or was actively moving landward (overwash), it was termed Land Transgressive/Erosional (E.3). If the backshore/dune face had only a slight gradient with stabilizing vegetation it was stable (E.1) and possibly even accretionary (E.2). It is common for all three states to occur within one site. Where one end may be eroding, sand is transported across the central area (stable) and is deposited at the downdrift end

The situation may be seasonal within isolated dune sites as the beach/dune shifts back and forth. Accreting shorelines, which offer the potential for dune expansion, account for only 8% of the total dune shore length while 44 % are eroding. This might infer that dune shorelines are on the decline. However, characterization of the overall condition of the dune site is the objective of this parameter. The true measure of a dune sites stability requires more detailed analysis of shore change.

The underlying substrate (F) is a general category for the type of sediment the dune resides on and against. Two broad categories were chosen -- marsh and upland. Marsh substrates, which include creek mouths and bottoms, are usually low regions where storm surges can easily penetrate, inundate, and force sand landward in the form of washovers. Upland substrates usually rise up and create a “backstop” for landward moving sand masses under storm attack. This could help explain the relatively high frequency of upland sites that are man-influenced since development often occupies the “high ground”. In fact, man-influenced upland dune shorelines have a greater frequency of occurrence than dunes against natural uplands.

If the site was not Natural (1) (*i.e.* Man-influenced, 2, or Man-made, 3), then the nature of man’s impact was determined by type of modification. The shore structures include Groins (G.1), Revetments and Bulkheads (G.2), Breakwaters (G.3), Jetties (G.4), for Beach Fill (G.5). The degree of impact any given structure or combination of structures had on the local dune feature was not always clear. It was qualitatively assessed as having an influence on dune development. The Relative Stability (E) relates in part to whether man’s influence was erosive (destructive) or accretionary/stable (constructive).

1.2.3 Dune Site Measurements

Each dune has several slope breaks that are common to one another, yet given site specific conditions, make it unique. By analyzing the slope break relationships (*i.e.* primary dune crest elevation, primary dune width, secondary dune elevation, etc.) the nature of the dune features can be related, at least semi-quantitatively, to the geographic occurrence and, eventually, to the environmental setting (Figure 1-3).

The results of this analysis for Bay dunes by Hardaway *et al.* (2001a) led to the characterization of "growth components". The primary dune will grow when it 1) is in a relatively stable setting, 2) has an abundance of sand in the littoral/shore system, and 3) has an onshore wind field climate capable of transporting sand from a broad beach/backshore to the dune face.

Primary dune elevations are highest in Virginia Beach, Norfolk, and Hampton. These dunes in these "metropolitan" localities possess all three components and may be enhanced by various beach nourishment projects. At the same time, developmental pressures are perhaps the greatest in these same three localities. In fact, all of the dune sites in Norfolk are man-influenced.

Primary dune heights become smaller as the three growth components decrease in magnitude. Lancaster, with the lowest average primary dune elevations, has the most riverine primary dunes, and they are relatively small, sometimes little more than vegetated sand berms. The extreme range of primary dune crest elevations of 16.5 feet MLW for Virginia Beach and 4.6 feet MLW for Lancaster indicate the variation in magnitude of the growth components around Chesapeake Bay.

2 Methods

2.1 Monitoring Sites

2.1.1 Site Selection

Monitoring sites for seasonal surveys were selected using the following criteria**:**

a. Presence of a secondary dune
b. Near or adjacent to developmental pressures (existing or potential)
c. Reasonable land access for surveys
d. General geographical distribution around Bay localities.
5. Research stability (*i.e.* State land)

A total of 9 sites were selected for seasonal surveys to be conducted spring and fall for 3 years and after significant storm events (Figure 2-1).

Site MA3: Chesapeake/Bavon Beach, Mathews County. This site represents a linear dune field that has faced developmental pressures for over 20 years.

Site LN39: Near Mosquito Point, Lancaster County. This site is a relatively natural dune field that has developed near the mouth of the Rappahannock River around a salient feature. It has two shoreline exposure components - riverine and Bay influenced.

Site NH10: Just north of Silver Beach, Northampton County. This Bay site is part of a dune field that is both natural and man-influenced.

Site NH17: Floyd's Farm on Savage Neck, Northampton County. This site transitions along a natural spit feature and includes a primary dune only. The adjacent land use is agricultural, but the block to the north is presently being developed. Potential exists for shoreline hardening and subsequent downdrift impacts in the near future. This site also was chosen for groundwater analysis.

Site NH51: Pond Drain, Northampton County. A Department of Conservation and Recreation natural site with an extensive dune field and no potential for development except for adjacent properties.

Site NL42: Smith Point, Northumberland County. This site has an extensive dune field and is significantly impacted by Little Wicomico River mouth jetties and a few groins. Development is presently occurring across secondary dunes at this site.

Site NL58: South side of Hack Creek, Northumberland County. This dune field site has been impacted by jetties at Hack Creek and a few groins, but the upland is undeveloped.

Site NL 59: North side of Hack Creek, Northumberland County. This dune field has elements of primary and primary/secondary dunes that are in transition and are being impacted by development and significantly impacted by groins and Hack Creek jetties. This site was chosen for groundwater analysis.

Site VB4: First Landing State Park, Virginia Beach. This site is a relatively natural dune field site that also has an oceanic influence. Development has occurred on secondary dunes on adjacent properties.

2.1.2 Field Surveys

2.1.2.1 Profiles and Site Measurements

A baseline with several cross-shore profiles was established at each site. Each surveyed transect used the crest of the primary dune as the horizontal control and mean low water (MLW) as the vertical control. The MLW line is indirectly obtained from water level measurements. The water level position and elevation are checked in the lab against measured tidal elevations (at the nearest NOAA tide station) and time of day to establish MLW on the profile.

The primary dune profile has several components (Figure 1-3). There is generally a continuous sand feature from the offshore landward consisting of a 1) nearshore region, bayward of MLW 2) an intertidal beach, berm and backshore region, sometimes vegetated, between MLW and base of primary dune, 3) a primary dune from bayside to landside including the crest and where present 4) a secondary dune region. All profiles extended beyond MLW bayward and to the back of the primary dune landward. The back or landward extent of the secondary dune was not always reached but the crest was. The dimensions, including lateral position and elevation of various profile components were measured. These include:

A = Distance from Secondary Dune Crest to Back of Secondary Dune
B = Distance from Secondary Dune Crest to Back of Primary Dune
C = Distance from Primary Dune Crest to Back of Dune
D = Distance from Primary Dune Crest to MLW (E + F + G)
E = Distance from Primary Dune Crest to Front of Primary Dune
F = Distance from Front of Primary Dune to Beach Berm
G = Distance from Beach Berm to MLW
L = Distance from Back of Primary Dune to Back of Secondary Dune (A + B + C)
    A + B = Width of Secondary Dune
    C + D = Width of Primary Dune
    A + B + C + D = Width of Primary and Secondary Dune
T = Elevation of Toe of the beach
U = Elevation of Back of Secondary Dune
V = Elevation of Secondary Dune Crest
W = Elevation of Back of Primary Dune
X = Elevation of Primary Dune Crest
Y = Elevation of Front of Primary Dune
Z = Elevation of Beach Berm

2.1.2.2 Biology

Primary dunes were delineated, where possible, into foredune, crest, and trough. These features must be defined on a site-specific basis as they are dictated by local morphology at the time of sample station establishment. The trough is generally defined as the area landward of the back toe of the crest to the seaward toe of the secondary dune (if present) or upland scarp.

Three randomly selected but permanently established plots for the foredune, crest, and trough along the transect line are established for each sampling transect. The herbaceous layer is sampled using tenth of a square meter plots to determine stem density and percent cover by species. Distances follow the contour of the dunes.

Secondary dunes are sampled randomly within a 66 foot swath with the transect line as the mid point. The number of samples is dependent upon the depth (seaward to landward) of the dune field. The transect that begins at the channelward toe of the secondary dune is divided into ten meter intervals. The first random number denotes the length down the transect within the specific ten meter interval. The second random number denotes the perpendicular distance from the transect line. Even numbers for the second random number require movement to the right (facing landward); odd numbers require movement to the left.

Three strata are sampled– herbaceous, shrub, and tree. The herbaceous strata are assessed using tenth of a meter (0.3 ft) plots to determine stem density and percent cover by species. The shrub strata assessment quantifies stem density by species within the 66 foot diameter. Tree stem density is determined using a bitterlich.

2.1.2.3 Sediments

The sedimentology of the study area is based on both active processes as well as the underlying geology of the region. Sorting and winnowing of the sediments by the littoral currents and waves occurs continuously in the nearshore region and erosion can expose outcrops of material deposited long ago.

Sediment samples were taken along select profile lines, at the sites. Certain morphologic regions were sampled. Base of Dune (BOD) samples represent the area of the beach that is influenced by aeolian transport and run-up from occasional storm events. Sediments were also taken at the Back Base of Primary Dune (BBPD), Primary Dune Crest (PDC), BERM (sometimes an upper and lower berm), midbeach (MB), TOE, and offshore (OS). The toe of the beach is located at the break in slope between the beach face and the nearshore region. It is sometimes evidenced by a distinct change in sediment type.

A grain size determination on each of the sites samples is performed by taking a homogeneous aliquot from the sample. This is wet sieved to separate sands from the fine silts and clays. The water and fines collected in the settling tube are stirred and allowed to settle for a specific amount of time, Stoke’s Law, then a determined amount is pipetted out. The water is dried off, and the residue is weighed. The sands and gravels, left in the sieve, are dried and separated, then weighed. From this, the sand, silt and clay ratio is determined for that particular sample. For finer fractionization of the sands, a settling tube is used. The RSA (Rapid Sand Analyzer) is a large tube filled with water over which a balance is set. The sand is placed onto the surface of the water and allowed to settle onto a weighing pan. The balance is controlled by a computer, which records the weights as the individual grains of sand land on the weigh pan. This data is converted to the statistical and graphical output, all based on Stoke’s Law.

2.1.3 Reach Assessment

A shore reach is defined as a segment of shoreline where littoral processes mutually interact. Subreaches are sets within larger reach segments. Reach boundaries can be defined by natural features such as tidal creeks, large embayments or headlands. Man made structures such as bulkheads, revetments, groins and particularly jetties can create hard boundaries.

High-level, aerial photos taken along the shoreline were retrieved from VIMS’s Shoreline Studies Program and Submerged Aquatic Vegetation archives. The DOQQ (Digital Orthophoto

Quarter Quadrangle) photos were obtained for each monitoring site. DOQQ photos are registered in UTM-1927, and that projection was maintained. The photos were individually rectified to the DOQQ's utilizing procedures in Hardaway *et al*. (2001b). Once all the photos were registered, a photo mosaic image for the entire study area was created and re-rectified. This is a necessary step to ensure that the shoreline is consistent through the study area.

Shorelines were digitized using ESRI's ArcInfo GIS software and ERDAS's Imagine software. The defined dark/light shoreline perimeter of the coast was digitized on screen from the aerial photo mosaics. For VIMS SAV archives this is basically the "toe" of the beach face which normally resides at or a few feet bayward of MLW. For the 1994 imagery, the shoreline perimeter appears closer to MHW. In areas where shoreline perimeters were obscured or washed out, the shoreline was determined using the digitizer's best guess to estimate land-water interface (Hardaway *et al*., 2001b).

Utilizing an extension to calculate distance from a shore parallel landward baseline, rates of change were then determined along the shore reach. However, many areas of the Bay have unique shoreline morphology where the data created from this extension will not provide an accurate representation of shoreline change. A physical inspection of baselines in conjunction with the photo mosaics provides the quality control to determine these areas.

2.2 Non-Jurisdictional Dunes

2.2.1 Site distribution

The alongshore extent of dune systems in Chesapeake Bay was determined with low-level, oblique aerial video using procedures outlined in Hardaway *et al*. (1992). The position of potential dune systems and their alongshore limit were determined within +/- 100 ft over one mile using these procedures. The locations of potential dune sites identified from the video were transferred to topographic maps for location of the centers of the sites. Once the locations of potential dune sites were determined, vertical aerial imagery from the late 1990s, obtained from VIMS's photo archives, was used to determine and plot the lateral limits (alongshore extent) of the dune feature. These maps were used in the field to confirm the nature and extent of the potential dune sites. Most sites were found in Middlesex and Westmoreland counties (Table 2-1 and Table 2-2).

2.2.2 Site surveys

Utilizing procedures established in the original dune project (Hardaway *et al.*, 2001a), each site was surveyed along a representative cross-shore transect. Each surveyed transect used the crest of the primary dune as the horizontal control and mean low water (MLW) as the vertical control. The primary dune crest is determined on site. The MLW line is indirectly obtained from water level measurements. The water level position and elevation are checked in the lab against measured tidal elevations (at the nearest NOAA tide station) and time of day to establish MLW on the profile. See Section 2.1.2.1 for more profile information and site measurements.

2.2.3 Biology

Vegetation community assessment methods were identical to the methods used for jurisdictional localities (Hardaway *et al.* 2001a) to assure the consistency of comparisons between jurisdictional and non-jurisdictional dune resources. Briefly, during each visit, dominant plant communities occupying the primary and secondary (if present) dunes were noted. Plant species distribution is based on observed percent cover in a broad general area of profiling and sampling within the identified dune reach. Table 2-3 provides an example of the vegetation data and database structure. This database includes vegetation community information for all sampled dune sites in Tidewater Virginia.

Variables included in the habitat assessment were chosen based on the horseshoe crab's spawning requirements and were guided by the habitat suitability index (HSI) developed for the Delaware Bay specific to spawning habitat (Brady and Schrading, 1998). The Brady and Schrading model requires four variables (depth of sand over peat, sediment moisture, beach slope, and grain size) expressed as a geometric mean and termed a component index (CI).

All measurements and samples were taken during or near low tide, at the estimated mean high water line on the beach adjacent to each coastal primary sand dune. Sediment samples were collected at approximately 3-4 inches depth. Sediment moisture was measured also at 3-4 inches depth using an *in situ* soil moisture meter calibrated prior to each measurement. Beach slopes were measured using a Brunton compass. Beach depth was determined by digging a hole to a maximum of 2.5 ft.

3 Results

3.1 Monitoring Sites

3.1.1 MA3

3.1.1.1 Reach Assessment

Site MA3 is located near the southern end of Mathews County on the Chesapeake Bay (Figure 3-1). It is an open bay coast classified as Man-Influenced Linear Dune Field (secondary dunes). The current land use is residential, and the area is known as Bavon and Chesapeake Shores. Approximately 45 homes occur along the Bavon coast which is on the Bay side of a low neck of land that becomes an island during northeasters. The shoreline along the study site is a Bay barrier system with dunes, beach and nearshore bar system.

The study site is about 4,300 ft long and is set within a larger reach that extends from Dyer Creek on the north to New Point Comfort on the south about 7,500 ft. The MA3 shoreline has an historic erosion rate of about 1.6 ft/yr (Byrne and Anderson, 1978). In 1852, old charts show a series of islands along the coast that extended across the north and south ends of the study site. These islands were probably marshy in nature. By 1942, the islands had disappeared, and the shore position had actually advanced along the southern half of MA3.

The shoreline in 1937 imagery shows a sandy coast with numerous offshore bars and a few remnant marsh headlands (Figure 3-2). The land use was agricultural with two houses located near the shore about mid-way along the study site. A fairly large pond was entrapped by a sandy barrier at the south boundary of the site. By 1960, shoreline retreat has reduced the size of the pond by 90%. Land use was still basically agricultural, but more roads had been built and a few more coastal cottages can be seen. A road now extended to the north end of the point. The physical boundaries of the site were defined by a marsh headland on the north and south. Obliquely attached sand bars still controlled the beach planform, and SAV can be seen in the bar troughs offshore. It is difficult to ascertain the extent of dunes at that time although there was sufficient beach width to support them.

Aerial imagery in 1971 and low oblique aerials in 1973 show the development of fairly continuous dune ridge along the entire site. Behind it was a low landward sloping sandy terrace - the old overwash. About 10 cottages had been built along this sandy chenier which had areas of vegetation and bare zones. The vegetation was most likely dune plants which may have been the initiation of areas of secondary dune development. Most of the agricultural areas had reverted to woods.

In 1987 (Figure 3-2), approximately 35 cottages existed along the shore. Linear dune ridges had developed along the north end of the site as well as on a large beach salient located about 1,000 ft from the south bounding marsh headland. The area between the salient and the north end dune ridges was a relatively thin beach with little of no fore dune vegetation. The shoreline directly across from the main entrance to Chesapeake Shores had the narrowest beach and that trend continues today. It is a Bay shore “hotspot”. The areas in front of and between the cottages had evolved as secondary dune features.

Today (2001) the Chesapeake Shores and Bavon coast are geomorphically diverse alongshore. Linear foredunes have become established and are advancing in response to a lack of storm activity behind shoreline salients that are controlled in part by attached oblique sand bars. The central area between two salients remains a "hotspot". The large beach salient identified in 1987 has been reduced in size and extent. Dune fencing has been used along much of the shore, particularly along the northern portion, in order to advance the foredune feature.

3.1.1.2 Field Surveys

Eight profiles were established along the entire Chesapeake Shores/Bavon coast to represent the alongshore variability in beach/dune planform and secondary dune morphology (Figure 3-1). Alongshore and cross dune variability is shown in Figure 3-3. Profile MA3-1, located on the north end, is set within a slight embayment created by beach salients, and Profile MA3-2 is on a beach salient. The general line of cottages is about 90 feet landward of the primary dune leaving the secondary dune feature relatively unaffected. Dune fencing occurs at both these transects and each shows significant beach accretion between the two profile dates, 19 January 2001 and 04September 2001 (Figure 3-4-1). Profile MA3-3 is located in a transitional area where the cottages are about 50 feet from the Primary Dune which is restricting the secondary dune area but allows a slight accretion of the BOD.

Profiles MA3-4, MA3-5 and MA3-6 (Figure 3-4-1 and Figure3-4-2) are within the chronic "hotspot" that occurs between two beach salients about 500 feet apart. Once again, these beach features are controlled, in part, by the position of attachment of the offshore bar system. Profile MA3-4 had beach face recession while MA3-5 and MA3-6 had beach accretion between the survey dates (Table 3-1). This may reflect a shift in beach material within the "hotspot". The position of the cottage line varies within this region more as a function of order of construction and varies between 50 and 5 feet from the primary dune crest.

The south half of the study area is represented by Profiles MA3-7 and MA3-8 (Figure 3-4-2). Here the cottage line is farther from the primary dune and the secondary dune features tend to be higher and wider than the coast to the north. Some slight changes were noted across the beach face including a general accretion and growth of the nearshore bars. Some accretion is also seen on the secondary dune at MA3-8.

One of the interesting features of the site as a whole is the elevated position of the beach toe. The intertidal beach area is generally elevated due to an abundant sand volume in the littoral system. This causes the beach toe to sit at or above MLW across all transects. Significant SAV beds also exist along the site. They sit between the bars and act to slow sediment transport in that region.

3.1.2 LN39

3.1.2.1 Reach Assessment

Site LN39 is located near Mosquito Point on the Rappahannock River in Lancaster County (Figure 3-5). The site consists of shorelines on either side of the sandy salient. One shore faces westward up the Rappahannock River while the other side faces eastward toward the open Bay. The current land use is residential but the site occurs as a broad sandy salient with low secondary dune field. The site is somewhat Man-Influenced by shoreline hardening both up and downriver of the site.

In 1937, Mosquito Point was a broad natural sandy spit feature trending northwest/southeast with truncated distal end (Figure 3-6). A small entrapped pond occurred at the upland/spit boundary. At the end of the larger spit, a large salient occurred on the southwest side, and a shore spit appendage trended northeast from the northeast side. The sand supply for the spit appears to have come from long-term erosion of the high sandy upland banks upriver where the historic erosion rate was 1.5 to 2.0 ft/yr (Byrne and Anderson, 1978). Land use was mainly agricultural at that time. The spit morphology is controlled by sand supply, tidal currents, and the impinging wave climate. The latter parameter has two components, a river component from the southwest and northwest and a Bay component from the East.

By 1960, a road had been built to the end of the spit, and what appears to be a bulkhead was built across the distal end of the spit. The impact of this shore structure was to separate the end of the spit into a river salient and a creek spit. The downriver end of the salient had retreated upriver adjacent to the bulkhead and the creek spit had turned more northward into Mosquito Creek and had become longer. In the area of the study site, the salient had well- developed dune vegetation.

In 1969, the creek spit had gotten longer and was almost detached from the end of the main spit feature. Groins were added just inside the creek shore and possibly more bulkheading occurred on the end of the main spit. The salient had gotten larger on the upriver side but remained blunted on the downriver side partially due to the impact of the adjacent shore hardening and the impinging Bay waves. By 1987, it appears that the downriver side of the salient had moved further upriver as groins were built on the river side at the end of the main spit. The creek spit had disappeared with the material going ashore or left as a shoal in the creek. A channel had been cut across the creek shoal to shore for boat access.

Today, the downriver side of the spit has formed an embayment from the salient point or cusp and the downriver shore structures. The upriver end feathers into the upland banks. The salient is an odd sand form both in appearance and history. The upriver side has a low primary dune feature, and the downriver side has a higher primary dune feature, due in part, possibly to longer period Bay waves and associated higher runup potential. The area behind these primary dunes is a secondary dune field that appears as a series of low linear ridges trending northwest/southeast that were primary dunes in the past.

3.1.2.2 Field Surveys

Two profiles were established to represent each side of the salient spit feature, bay and river exposure, respectively (Figure 3-7). LN39-1 is on the bay shore, and LN39-2 is the river profile. A secondary dune field exists at LN39-2, but at LN39-1 the linear ridges are truncated by the primary dune so there is no secondary dune feature identified (Table 3-2).

Profile LN39-1 showed a cut and fill change between Feb 15, 2001 and Aug 28, 2001 where the lower beach face had moved onto the upper beach widening the upper beach berm (Figure 3-8). Slight changes at profile LN39-2 show an increase in sand volume across the entire beach zone.

3.1.3 NH10

3.1.3.1 Reach Assessment

Site NH10 lies just north of Silver Beach on the Bay in Northampton County (Figure 3-9). The study site is about 1,400 feet long and extends across a large, lawned, residential lot and an adjacent wooded lot to the north. A small intermittent drainage issues through the upland bank and beach of the wooded section. The site is set within a larger shore reach defined by the limits of Occohannock Neck which extends from Occohannock Creek and Nassawadox Creek. A subreach of this extends from Battle Point to Silver Beach. Battle Point and Silver Beach have evolved into headland features due to shoreline hardening over the years.

The adjacent upland along NH10 is 10 to12 feet above MLW and is composed mainly of sandy strata. The dune field narrows toward the south and terminates just north of Silver Beach. One groin exist on the south boundary of the study site. The dune field at the site is composed of a primary dune at each end with primary and secondary dunes in the middle. NH10 is part of a larger littoral cell with a relatively abundant sand volume occupying the beach and nearshore region. Like much of the bayside coast of Northampton County, there is an abundance of sand in the nearshore bar system.

The historic erosion rate between 1851 and 1942 was 5.7 ft/yr (Byrne and Anderson, 1978). However, more recent net shoreline changes between 1937 to 1994 show little change at the study site (Hardaway *et al.*, 2001b) (Figure 3-10). As one moves both north and south away from the study site, shoreline retreat rates increase to historic rates until Silver Beach and Battle Point where shoreline hardening renders shoreline change rates to zero.

Utilizing aerial imagery from VIMS' archives, a more detailed progression of change can be described. Aerial imagery in 1955 shows a wide beach along the project area and adjacent shoreline. A small patch of "dune" backshore vegetation existed about mid-site just south of an upland drainage ditch. Oblique aerial imagery from 1972 shows the site with a narrow backshore and narrow patchy dunes against a vertically exposed upper fastland bank. By 1987, the beach had widened, and the dune field had begun to mature. Sand accreted up and over the upland bank adjacent to the lawned lot. Several groins were installed by the mid-1990s and may have contributed to a widening of the beach/backshore region.

3.1.3.2 Field Surveys

Three profiles were selected to depict the varying alongshore varying topography at the site as it ranges from a primary dune (NH10-1) and transitions (NH10-2) toward a primary and secondary (NH10-3) morphology (Figure 3-11). Little or no change has occurred across the profiles except for a slight advance of the beach berm between March and September 2001 (Figure 3-12).

The primary dune feature decreases northward from a dune crest elevation of 15 ft above MLW at the southern end of the site to less than 10 ft above MLW at the northern end of the site. The higher primary dune occurs in the area recognized in 1955 imagery. Over time, this system has evolved into a nodal point where historic erosion is slight. This could be attributed to its fortunate position along the larger reach as well as local effects of upland drainages. Another cause could be a decrease in offshore gradient which suggests more sand storage and wave attenuation due to a significant offshore bar series. Site measurements are shown in Table 3-3.

3.1.4. NH17

3.1.4.1 Reach Assessment

Site NH17 is located on the Floyd Farm in Northampton County (Figure 3-13). It is an Open Bay shoreline approximately 960 feet long, between profiles NH17-1 and NH17-4. It is the mainland attached portion of a much larger spit that includes sites NH18 and NH19, identified in the previous report (Hardaway *et al.*, 2001a). These sites are separated by short stretches of non-vegetated spit (sand only). The entire spit is almost a mile long and is unnamed. For the purposes of discussion, it will be referred to as Floyd's Spit.

Floyd's Spit lies within a larger reach defined by Westerhouse Creek on the north and Hungars Creek on the south. Here the curvilinear shoreline is oriented almost north - south. This reach represents the southern two-thirds of the Church Neck bayshore. Historic erosion is about - 0.7 ft/yr but varies north and south at +1.6ft/yr and +1.4ft/yr (Byrne and Anderson, 1978). Recent trends

(1937 to 2000) are shown in Figure 3-14. This data indicates no recession on the north end and a positive trend on the south end of the study site. However, a period of spit recession is described between1992 and 2000 along most of the site. The north boundary remains fixed in time, but shore change is significant elsewhere along the larger reach.

NH17 represents the shore attached section of Floyd's spit where a strong southerly littoral transport system has "fed" the growth of the spit. However, in 1938, the distal end of another shore parallel spit was about 3,000 ft south of the project site. This area of spit development occurs as the shoreline turns from a north-northeast/south-southwest strike to a more north/south strike. A large offshore shoal feature with a north-northeast/south-southwest bearing ran off and down the bay and extended into the Hungars Creek ebb shoal complex. Another similar but smaller offshore shoal occurred to the north just south of Westerhouse Creek. Significant SAV beds had developed in the lee of these shoal features. By 1955, what was once a shore-attached spit in 1938 had migrated alongshore another 3,000 ft (a rate of approximately +175 ft/yr) and was attached south of the study site.

A 1955 aerial photo shows a new spit feature had developed in front of the project site. This was the beginning of the present day Floyd's Spit. This spit was shore attached about 1,500 ft north of the study site and extended along shore about 2,000 ft and several hundred feet offshore. It appears to be the downdrift result of the small spit and shoal complex seen to the north in 1937. This subreach has been a zone of shear and significant sediment transport and deposition over the years. A small salient had formed alongshore at the study site in the lee of the 1955 spit feature. This salient is now the present day north end of the study site and of Floyd's Spit

In 1972, oblique aerial imagery shows the distal end of Floyd's Spit had migrated about 1,000 ft to the south. A narrow tidal creek bordered by wetlands had developed along the lee side between the spit and the mainland. A primary dune feature ran the length of the spit from just north of the study site southward. The older 1937/55 spit feature to the south had migrated ashore and existed as a series of vegetated (dune) arched salients with tidal creeks and marshes. By 1987, Floyd's Spit was about 4,000 ft long with intermittent patches of dune and washover. The north boundary was located at the study site.

Today Floyd's Spit is about 5,500 ft long and firmly attached at the project site. The coast to the north is developing significant offshore bars, shoals and some shore attached salient features all pointing to the south. SAV beds, lee side marshes and dunes have come and gone over the years in this highly active littoral system

3.1.4.2 Field Surveys

Four profiles were established to represent different alongshore sub-morphologic units and all begin along the top slope of the upland bank (Figure 3-15). NH17-1 crosses a very narrow creek and the primary dune and beach, then into the Bay. NH17-2 goes down the bank, across a wet swale, over the primary dune and beach, and into the Bay. NH17-3 crosses a dry swale, over the primary dune and beach and into the Bay. NH17-4 runs from the bank to the back of the primary dune, over the primary dune and beach, and into the Bay. The tidal creek, wet swale, and dry swale are a small watershed with a southward dipping "thalwag" gradient. The spit is encroaching landward from north to south along the study site. The top and face of the upland bank are covered in sand and are stable and protected by the spit. Figure 3-15 shows a wide disparity of the alongshore dune field morphology from the crest both landward and bayward. Once again, a significant series of sand bars occurs across the nearshore region.

Profile data show some changes between the two survey dates (Figure 3-16). The beach berm width (G, Table 3-4) increased slightly at profiles NH17-2, NH17-3, and NH17-4 between survey dates. This corresponded in a slight increase in width (E) and elevation (Y) of the front base of primary dune (Table 3-4). A small sand feature in front of the primary dune at NH17-3 appears largely wind-induced.

3.1.5 NH51

3.1.5.1 Reach Assessment

This study site is set within a shore reach that extends from Old Plantation to the Kiptopeke Ferry and associated pier and offshore breakwaters. A large subreach within this extends from Elliotts Creek to Picketts Harbor Road (Figure 3-17). At one time, a large dune field appears to have extended between Elliotts Creek and Picketts Harbor (called Picketts Hole in Madison's 1807 map of Bay, Stephenson and McKee, 2000). Now the north end has fragmented, and the main dune field extends northward from Picketts Harbor, past Pond Drain (mid-way), to where the shore intersects a high northwest/southeast trending upland ridge, a distance of about 10,000 feet. The study site for this project extends from just south of Pond Drain southeastward for about 2,000 feet. The site lies entirely within DCR's Natural Area.

Historic erosion along the study site from 1888 to 1942 is about -2.3ft/yr (Byrne and Anderson, 1978). Pond Drain and its intermittent inlet was a feature on 1863 boat sheets. Its shore morphology has not changed significantly. The upland ridge that Pond Drain bisects is a linear feature averaging about 25 feet MLW high and is 10 ft higher than the landward bounding plain. This upland ridge appears to be the northern extension of Butlers Bluffs. Its southeastern boundary is the shoreline at Picketts Harbor and the much larger bayside scarp that is also about 25 ft MLW. This scarp runs up the bayside Eastern Shore for some distance and is oriented about north-northeast/south-southwest. This 3-way intersection is also the boundary of the Occohannock Formation. The Butlers Bluff Formation is a very sandy strata whose west boundary is the bayside scarp. The dune field of site NH51 goes back to the upland ridge.

The whole coast is a large headland controlled, in part, by underlying geology and extensive offshore bars. These bars are both shore parallel and oblique and appear to control beach processes and transport. The hydrodynamics and littoral processes are complex and are a blend of bay and ocean generated wave climate. Northwest and southwest winds and abundant sand supply favor foredune formation along much of the reach.

In 1937, aerial imagery shows a protruding shore with a headland south of Pond Drain (Figure 3-18). The shoreline turns to the east toward the upland ridge north of Picketts Harbor. A series of "foredunes" can be seen within the boundaries of the protuberance. The hump is a shore planform salient that appears coincident with attached nearshore bars. By 1955, the hump has smoothed out and elongated along into a more vegetated foredune sequence. The foredunes are distinguished by what appear to be grasses; whereas, the older ridge has intermittent trees and shrubs. The foredune extended south from Pond Drain about 4,500 ft and north about 1,000 ft. Shore salients can be seen where offshore bars attach obliquely to the coast.

In 1989, the position of the shoreline at and adjacent to Pond Drain had advanced bayward with an associated recession northward toward Elliotts Creek (Figure 3-18). This appears to a be a cut and fill sequence with erosion of the northern subreach providing material for advancement to south. This advance had provided the beach and backshore width for expansion of the linear foredune feature which is now well established and extends to Picketts Harbor. The recession has destroyed the semi-continuos dune feature that once extended to Old Plantation Creek. The foredunes north of Pond Drain had been reduced to about 500 ft alongshore.

Today, three isolated dunes occur along the northern subreach to Old Plantation Creek, sites NH48, NH49 and NH50 from the previous report (Hardaway *et al*, 2001a). The foredune sequence south of Pond Drain is well established, but erosion of the dune face is prevalent several hundred feet south of Pond Drain. Foredunes have increased to the north behind beach salients that are controlled, in part, by the extensive offshore sand bars.

Shoreline change patterns (Figure 3-18) show a "nodal point" (zero crossing point) at about cell NH10-18 south of Picketts Harbor Road. From Pond Drain north to Elliotts Creek and beyond, the long-term trends (1937 to 1992) are generally accentuated by the short term (1992 to 2000) as seen in the latest long term rate (1937 to 2000). From Pond Drain southward to the "nodal point," the opposite occurs where the short-term rate is opposite the long-term (retreat vs advance) thus reducing the latest long-term rate. The study site covers the more erosive end of this subreach.

3.1.5.2 Field Surveys

Three profiles were established across the DCR property (Figure 3-17). In order to adequately portray this reach, two or three profiles were needed south to Picketts Harbor Road; however, permission could not be obtained from the private land owner. Profile NH51-1 is generally representative of the linear foredune field in front of the established secondary features (Figure 3-19). Profile NH51-3 is in the active erosional zone adjacent to Pond Drain where the foredune zone narrows to the pioneer tree zone, and NH51-2 is a transitional cross-section. The back base of the primary dune (C) is 55ft and 51ft from the primary dune on NH51-1 and NH51-2 (Table 3-5). These profiles represent a more established area of the linear dune feature, and NH51-2 rests comfortably behind a beach salient controlled by an attached, oblique offshore bar. NH51-3 has a narrower but higher primary dune feature.

The interpretation of a secondary dune in the study area is difficult because of the variable ridge and swale topography landward of the primary dune along the shore reach. The variability of the primary dune height (X) and width (D) alongshore conveys to the secondary dune ridges when the shore advances and the primary dune becomes a secondary dune.

Little or no measured change has occurred landward of the primary dune crest (Figure 3-20). There was, however, an increase in beach width (D) along NH51-1 and NH51-2 (Table 3-5). Sea rocket and *Ammophila* has advanced across the widened backshore and has helped establish an upper berm feature on those profiles (Figure 3-21). Profile NH51-3 has shown a loss of the lower berm and beach face. This profile holds a steeper dune face due to intermittent erosional events.

3.1.6 NL42

3.1.6.1 Reach Assessment

Site NL42 is located just south of Smith Point along the Chesapeake Bay shoreline (Figure 3-22). The study site is set within a larger shore reach the begins on the north at the Little Wicomico River entrance and associated stone jetties and extends southward to Taskmakers Creek. A smaller subreach of the northern half extends from Smith Point down to Gaskins Pond, about 10,500 ft. The dune field within the boundaries of site NL42 is about 3,800 ft. This is an Open Bay site with fetch exposure to the northeast (Smith Island), east (Tangier Island) and southeast of about 12nm, 11nm, and 25nm, respectively.

Smith Point area is a large spit that has formed over the centuries as the result of sediment transport down Northumberland's shore on the Potomac River and up it's shore along the Bay. The Little Wicomico River inlet was several thousand feet north and west of its present position until 1930's when jetties were built to hold the new inlet position at the apex of Smith Point. Historic erosion along the NL42 study site is about -2.6 ft/yr (Byrne and Anderson, 1978), but that doesn't tell the tale of this highly dynamic estuarine coast.

Aerial imagery on March 29, 1937 (Figure 3-23) shows the Smith Point Jetties during construction. The channel was dredged and material placed upriver, closing off the old inlet. The south shoreline (NL42) was a long irregularly-shaped salient with two protrusions along the shore, a large one on south and a smaller to north but one feature. A series of sparsely vegetated "foredunes" can be seen across a broad sandy spit with a reciprocal morphologic planform to the shoreline. The spit is over 1,000 ft wide before abutting the Little Wicomico River where that shore is characterized with tidal marsh fringes. The shoreline against the south side of the Smith Point jetties extended over 300 ft bayward relative to shore attachment on the north side of the Smith Point jetties. Beyond the large sandy salient shore of NL42, the coast southward consisted of a continuos beach and backshore system until Taskmakers Creek with only two small tidal creeks at Gaskins Pond and Owen Pond. Two intermittent drains from two unnamed ponds just north of Gaskins also were present. A large partially-vegetated, hooked spit protruded southward across Taskmakers Creek. These beaches were narrow creek mouth barriers especially across Owens Pond.

By 1960/61, the large protruding salient resided further south, and the shoreline toward the jetties had receded and become more linear. The shoreline against the jetties had advanced bayward farther on both sides with the south side maintaining the larger advance. The protruding salient shore planform appears to mimic offshore sand bars. The coast to the south was still mostly continuous to Taskmakers Creek, but Owens Pond had been jettied (wood), and the creek mouth barrier had gotten very narrow with numerous washovers and was migrating westward. The hooked spit across Taskmaker Creek was gone, rotated in part westward and closing off the mouth of the Northeast Branch, converting it into an intermittently open saltwater pond.

In 1969, there were two distinct protruding salients (the south one being larger) along NL42 with the curvilinear embayment formed between the two receding and intersecting the earlier foredune. Vegetated foredunes appear to have formed following the coast along the backshore terrace of each salient feature and along the sand fillet against the south jetty. Groins appear along the coast to the south as evidenced by small shore protuberances with a slight northward transport expression.

By 1978, an access road had been built down the middle of the NL42 spit. Two protuberances, a large one on the south and smaller one to the north, had become well established. In 1987, the salients were still in about the same positions. The shoreline to the south had become bulkheaded and groined, and the creek mouth barrier across Owens Pond was gone. Sand had migrated and filled small bays on the creek's west side to form small pocket beaches. Sand bars sit in what was once the Owens Pond. Today, the largest salient has groins up to it and the smaller salient has developed into two.

3.1.6.2 Field Surveys

Four profiles were established along NL42 (Figure 3-22) and represent different morphologic areas of the spit. Profile NL42-1 is located near the south jetty, an historic area of shore flux. It currently has an erosive primary dune face with little backshore region. There is a relatively long distance to Profile NL42-2 due to unavailable property owners. Profile NL42-2 crosses a shore salient while Profile NL42-3 is in the adjacent shallow embayment. Profile NL42-4 is within the southern groin field, a direct man-influenced shore. These subreaches are morphologically different but constitute the dune field that was generally categorized as a linear dune field. Figure 3-24 depicts the alongshore variability.

Profiles NL42-1 and NL42-4 were profiled twice (Figure 3-25). Shore change was significant on NL42-4 across the backshore, berm, and toe section of the profile demonstrating some seasonal flux within the groin field. Profiles NL42-2 and NL42-3 were surveyed only once during the monitoring period due to difficulty in locating and acquiring landowner's permission. Table 3-6 shows measured site parameters.

3.1.7 NL58

3.1.7.1 Reach Assessment

Sites NL58 and NL59 are located on either side of Hack Creek on the Potomac River in Northumberland County. Site NL58 begins at the entrance channel to Hack Creek and extends downriver approximately 900 feet. NL59 extends from Hack Creek upriver approximately 1,688 feet. Both sites are considered Open Bay due to long fetch exposures to the Northeast and East of over 14nm and 15nm, respectively.

Sites NL58 and NL59 are a subreach of a larger shore reach that is loosely defined by Smith Point downriver and Hull Creek upriver; a shoreline length of about 42,000 ft. This shore is primarily upland or fastland coast that is a fairly straight, slightly convex headland intermittently interrupted by tidal inlets. The subreach can be defined by Condit Pond and Flag Pond. Hack Creek is currently a jettied inlet that can be considered a subreach boundary which then places each site into separate but similar coastal compartments.

The historic erosion rate of this reach is about -4.9 ft/y (Byrne and Anderson, 1978). The upland coast is about 10 to 15 ft above MLW with a historic annual eroded sediment load of 1.9 cy/ft/yr. The current shoreline along NL58 consists of a relatively wide sandy beach and dune system that is controlled by a groin field. These groins are of the 60 ft x 60 ft design and extend from Hack Creek downriver past the site for another 1,000ft**.**

Site NL58 is a creek mouth barrier like many other dune sites along this reach of shoreline (Figure 3-26). Eroding fastland interfluves provide copious sand for littoral transport both along and offshore. The many offshore bars and creek mouth shoals are evidence of this. Alongshore moving sands get trapped within a tidal creek's shoals as well as move landward across low drainages often covering marsh complexes associated with the tidal creek. Hack Creek is such a system. Generally, the net movement of littoral sands is downriver with a dominant onshore/offshore component and frequent reversals.

The nearshore region is relatively broad and contains a series of extensive offshore sand bars. These bars are generally shore parallel and run alongshore well beyond the boundaries of the site. There are 4 distinct bars off Hack Creek which indicate the relative abundance of sandy material. Hack Creek ebb shoal interrupts the nearest bar feature and acts to control littoral processes in the immediate area.

Historical and recent aerial imagery show the general evolution of the subject coast (Figure 3-27). A relatively wide beach existed in 1937 along both sites, and Hack Creek was still a natural feature with extensive shoals, both ebb and flood. The extent of site NL58 can been seen in the imagery, and the dune field extended almost to Vir-Mar Landing. The coast was farm, marsh, woods, and no development. In 1960, 10 to 12 cottages had sprung up just downriver of Vir-Mar Landing. Hack Creek and adjacent shores were still relatively natural with no groins installed to date. The creek mouth barrier appeared relatively stable.

In 1976, there were no groins across NL58, and Hack Creek had not been jettied. However, groins had been installed at the first cottage downriver of Hack Creek in response to development along the uplands toward Vir-Mar Landing. The downriver extent of the dune field had diminished. An erosional dune scarp can be seen at the site along with embryonic dune formation near Hack Creek. The dune field appeared to have secondary dune features as evidenced by numerous pine and live oak trees.

In 1987, approximately 12 groins were added across NL58, and Hack Creek had been jettied on either side with wood structures. An ebb shoal jet was created by the jetties which may have a localized effect on impinging wave climate. By 1997, the seaward edge of the site had stabilized and resembled the general dune morphology existing today. The groins control littoral processes making the site generally stable.

3.1.7.2 Field Surveys

Dune morphology transitions alongshore and across shore. Three zones were identified, and a profile was established as representative (Figure 3-28). Profile NL58-1 represents the low primary dune section nearest Hack Creek. NL58-2 is “mid-site” with a primary and secondary dune feature. NL58-3 is the downriver one-third of the site. This section of shore appeared to have a primary dune with a foredune feature. However, upon analysis, the profile resembles more of secondary dune due to vegetation. Further assessment will determine if this is the case. The growth of the foredune growth feature may warrant primary dune status. This may be an area of perpetual shear causing difficulty in forming a stable primary dune feature.

Profile data taken in the spring and fall of 2001 show slight changes across the beach face from March to August, 2001 (Figure 3-29). A minor increase in intertidal beach width occurred across profiles NL58-1 and NL58-2, and a slight decrease occurred in beach width (F) and beach toe position on profile NL58-3 (Table 3-7). The remaining profile landward of the front of the primary dune appear stable.

Much of this reach’s sand budget is within the nearshore region out 500 feet or more. Figure 3-28 shows one or two bar sets. These bars may feed the beach and nearshore during calm periods as well as act as wave buffers and sand sinks during storm events.

3.1.8. NL59

3.1.8.1 Reach Assessment

Site NL59 is the updrift, upriver component of the dune field adjacent to Hack Creek (Figure 3-30). It shares a similar site setting and history as NL58. Portions of this dune field occur as creek mouth barrier across Black Pond but much of it abuts the adjacent fastland (Figure 3-27). The current status is a dune field controlled in large part by the existing groin field. NL59 tends to widen downriver toward Black Pond and Hack Creek and feathers out upriver toward Condit Pond.

In 1937, the dune area of NL59 was shorter with a wide beach and washover into Black Pond and adjacent to Hack Creek. There was no development along the Mob Neck coast. By 1962, a dirt road was built across the Black Pond washover to a house perched on a high back dune feature. This probably effectively dammed the pond. Development was beginning on the upriver side of Hack Creek closer to Condit Pond, but no groins existed. Given the historic erosion rate, it can be conjectured that the upland coast existed as a vertically exposed and actively eroding fastland bank.

By 1976, the shoreline between Hack Creek and Condit Pond had not become more developed, but numerous groins (approximately 34) had been installed along the entire reach, possibly in preparation for future development. Between 1960 and 1976, these groins had accreted enough sand to create a wide beach and primary dune field. The upper part of the previously eroding fastland can be seen in the imagery. The accreted beach and dune field extended from Hack Creek to within about 1,000 ft of Condit Pond. Hack Creek inlet had a single groin/jetty built on the upstream shore.

In 1987, Black Pond was still blocked off, and development had not occurred, but the groins were still maintaining the beach and dune field. The dune field was still fairly low and narrow with no apparent secondary dune development. By 1997, a wider more robust dune had developed, and more cottages can be seen along the upland. The beach zone was fairly straight along the dune field. Today, the beach is intermittently wide and narrow, and the dune is correspondingly erosional along the dune face. Unlike the nearshore bar fields at NH42, MA3 and NH10, there is a shore parallel trough that separates the first bar from the beach. The beach toe is well below MLW.

3.1.8.2 Field Surveys

Three profiles were established to represent different morphologic subunits of the dune field (Figure 3-31). NL59-1 represents the primary dune only section, NL59-2 represents a short transitional section, and NL59-3 reflects the primary and secondary dune relationship. This is the same general order (*i.e*. upriver to downriver) of primary transitioning to primary and secondary as Site NL58.

Noticeable change has occurred between profile dates but primarily across the beach face as with site NL58. Profile NL59-1 showed an increase in beach width (D) between the spring and fall surveys (Figure 3-32). Profile NL59-2 showed a decrease in beach width while NL58-3 remained fairly stable.

3.1.9 VB4

3.1.9.1 Reach Assessment

Site VB4 is located within the larger shore reach defined by Cape Henry to the east and Lynnhaven Inlet to the west (Figure 3-33). The site typifies the dune-laden coast of First Landing State Park. The site is classified as a natural Open Bay dune field that is partially exposed to oceanic conditions including sea swell and northeast storm waves. Adjacent properties are Fort Story to the east and residential private properties to the west. Site VB4 is the natural reach of shoreline left between two developed coasts.

In 1937, the larger reach from Cape Henry to Lynnhaven Inlet was not developed (Figure 3-34). There were several cross roads that led to the Bay. Only two housing units can be seen, and one is at the present location of the State Park Visitor Center. The housing structures at this time were protected by what appears to be a vertical bulkhead about 200 ft long in the backshore area. The housing complex was built bayward of the primary dune or on it. The adjacent primary dunes had receded landward on the west side and may have advanced or built out on the east side. The bulkhead appears to have acted like a littoral block in this fashion indicating a movement of beach sands to the west.

By 1962, the shoreline had advanced across the study site about 150 ft. Waves of sand can be seen moving alongshore with associated attached nearshore bars. Beach cottage development had increased significantly to the west and foredune development can be seen migrating from east to west in front of the bulkheaded area. By 1970, primary and secondary dune development can be seen across the study site and adjacent shores as the shoreline in this area continued to advance bayward. By 1976, the beach zone had accreted another 100 ft beyond the 1962 position as the dune system continued to advance.

Today, there are an irregular and hummocky series of 2 or 3 “secondary” dune ridges behind the primary dune feature. The cause of this shoreline movement is not clear but may be related to the ongoing beach nourishment at the City’s Resort Strip on ocean coast. The city nourishes that beach annually with between 150,000cy and 300,000cy of beach fill that is trucked in or by-passed from Rudee Inlet. Over time, the littoral system may have moved the material northward around Cape Henry and onto the Bay beaches.

3.1.9.2 Field Surveys

Three beach and dune profiles were established along the First Landing State Park coast (Figure 3-35). These profiles were situated to capture the area in front of the old bulkhead and housing complex (VB4-2), now the park offices, and the adjacent “updrift” and “downdrift” coasts, profiles VB4-3 and VB4-1, respectively. Movement of the beach face and berm are evident between survey dates in March and September of 2001 (Figure 3-36). The beach berm (F) advanced at VB4-1 and VB4-3 while a slight recession was measured at VB4-2 (Table 3-9). The first offshore bar draws close to the beach between VB4-3 and VB4-2. It’s position varies along the coast but generally moves further offshore toward VB4-1.

The primary dune crest elevation (X) tends to decrease in elevation toward the east. This could be happenstance based on the selection of profile locations or indicate that the easterly section, the updrift, is a newer feature as the shoreline advances at a slightly faster rate. However, the position and elevation of the back of the primary dune and secondary dunes show more randomness. This is expected in the more turbulent wind streams on the lee of the primary dunes.

3.1.10 Biology

Twenty-five transects were established on the nine monitoring sites. No data are available to compare with our year one findings; therefore we offer a general description of the observed vegetation communities. Percent cover means were calculated only for those plots that contained a certain species, *i.e.* a “where present” qualifier is applied to all reported means.

Foredunes were generally non-vegetated, but sparse communities of American beach grass (*Ammophila breviligulata*), sea rocket (*Cakile edentula*), running beach grass (*Panicum amarum*), saltmeadow hay (*Spartina patens*), and seaside spurge (*Euphorbia poligonifolia*) were enumerated. Crests were also usually dominated by the “no cover” category. The tall but clumped growth patterns of plants commonly found on primary dune crests, especially American beach grass, give the appearance of overall dense growth; however, close observation and analysis shows patchy and/or sparse stem distributions. Where present, American beach grass averaged approximately 21 percent cover and generally was the dominant plant species. Switch grass (*Panicum virgatum*), seaside goldenrod (*Solidago sempervirens*), Japanese sedge (*Carex kobomugi*), seabeach sandwort (*Arenaria lanuginosa*), and saltmeadow hay also had areas of local dominance on dune crests.

The trough feature was not present at stations NL-42, NL-58, or NH-10. Where a trough could be defined, plant density was also more sparse than it appeared, and the "no cover" category again dominated. Running dune grass, saltmeadow hay, switch grass (*Panicum virgatum*), aster (*Aster sp.*), American beach grass, Japanese sedge, and bluestem (*Schizachyrium littorale*) showed local dominance.

Sites NL-42, NL-59, and NH-17 do not have secondary dunes. The herbaceous layer for those sites containing secondary dunes was again dominated by "no cover" but contained healthy communities of American beach grass, bluestem, seaside goldenrod, saltmeadow hay, running dune grass, Japanese sedge, trumpet vine (*Campsis radicans*), dandelions (*Taraxacum officinale*), and greenbrier (*Smilax sp.*). The shrub layer was dominated by loblolly pines (*Pinus taeda*), various oaks (*Quercus sp.*), wax myrtle (*Myrica cerifera*), holly (*Ilex opaca*), and black cherry (*Prunus serotina*). LN-39 and NH-51 also had large numbers of persimmon trees (*Diospyros virginiana*) growing upon the secondary dunes. Trees generally were absent, but transects NL-58, LN-39, and NH 51 had large loblolly pines. The secondary dune at site MA-3 contains one large black cherry tree.

These data provide the basis for assessing changes and natural recovery of primary dunes and are a useful tool to characterize the vegetation communities of secondary dunes. It is our opinion that vegetation indicators can be developed to help define the landward limits of secondary dunes.

3.2 Non-Jurisdictional Sites

3.2.1 Site Distribution

Eight non-jurisdictional tidewater localities were investigated to determine the extent of primary dune sites including the counties of Middlesex, Westmoreland, Isle of Wight, Surry, and York and the cities of Newport News, Suffolk and Poquoson. Most of the dune sites reside in the counties of Middlesex (15 sites) (Figure 3-37) and Westmoreland (12 sites) (Figure 3-38). Isle of Wight has five sites; Surry has none; York has 3 very small pocket dunes on Chesapeake Bay; Newport News has one linear dune feature upriver of Skiffes Creek; Suffolk has none; and Poquoson has one small pocket dune on Plum Tree Island.

3.2.2 Site Surveys

Surveys were done for the sites in Middlesex and Westmoreland counties (Table 3-10 and Table 3-11). One survey was done on IW1 in Isle of Wight. Secondary dune sites are rare in the non-jurisdictional localities. In Westmoreland, WM6 has a secondary dune, and in Middlesex, MS7 and MS24 have secondary dunes.

3.2.3 Biology

3.2.3.1 Vegetation

The plant communities of non-jurisdictional dunes generally are consistent in character to those of dunes in jurisdictional localities. Primary dunes are dominated by saltmeadow hay (*Spartina patens*) and American beach grass (*Ammophila brevigulata*) in Middlesex, Westmoreland, and York

Counties. Switch grass (*Panicum virgatum*) is a frequent co-dominant on Westmoreland dunes, and the scrub/shrub community is a common co-dominant on Middlesex dunes. Monotypic communities of saltmeadow hay are characteristic of the limited number of primary dunes in Isle of Wight and James City County.

Middlesex and Westmoreland Counties' dune plant communities are as diverse as those found on primary dunes in Northampton County and Virginia Beach. For example, Westmoreland's dunes had at least four species present on all of the identified primary dunes.

A generally low plant diversity characterizes the lone secondary dunes identified in Middlesex and Westmoreland Counties. No greater than three species co-occur. American beachgrass is the dominant species, with scrub/shrub co-dominant in Middlesex County.

3.2.3.2 Horseshoe Crab Spawning Habitat

Beaches contiguous to primary dunes in non-jurisdictional localities generally are slightly narrower and steeper, and hold a greater mean amount of moisture than similar beaches in jurisdictional localities. Mean intertidal beach width in the non-jurisdictional localities is 12.2 feet compared to 22.7 feet for jurisdictional localities' beaches. Mean beach slopes were slightly greater for non-jurisdictional localities (12.97 percent compared to 11.78 percent for jurisdictional localities); however the standard deviation of each mean renders this apparent difference insignificant.

Beach moisture, measured just above the mean high tide elevation (the zone of nesting) during low tide was 90 percent for non-jurisdictional localities and 76 percent for jurisdictional localities. Based on a limited number of previous studies, these levels of moisture are not preferred, and may not be suitable, for efficient horseshoe crab spawning development and/or survival.

The mean of the median grain size (0.68 mm) was statistically larger in Westmoreland and Middlesex counties as compared to the sediments analyzed from jurisdictional localities (0.508; $P = 0.017$). However, we do not interpret this to constitute a significant difference from the perspective of horseshoe crab ecology. The grain sizes of all sampled Bay beaches are consistent with the range of grain sizes reported from suitable horseshoe crab spawning beaches outside of the study area (Brady and Shrading 1998, Penn and Brockman 1994).

4 Discussion

4.1 Site Monitoring

Dune sites around Chesapeake Bay, like all natural systems, have an evolutionary history of development based on a local and regional parameters. Dune development in the Bay is a function of the 3 “growth” parameters of 1) sand supply, 2) relative stability and 3) hydro/aerodynamic settings. If a site is or becomes stable with abundant sand available and is exposed to a relative strong and/or frequent energy setting, then primary dune growth will occur. With time, the primary dune will grow higher and generally wider. Further along, a foredune may develop, the embryonic stage of the next primary dune, which will grow and relegate the old primary dune to secondary dune status. This process may also go the other way as the local setting and the relative importance of the 3 “growth” parameters change, *i.e.* reduced sand supply and more erosive.

The nine sites selected for monitoring represent a wide range of dune site settings around the Bay with an emphasis on secondary dune fields and proximity to future development. There is a coastal hazard component as well as associated coastal habitat component. Dunes are a rare feature in the Bay today and although not quantified, this is due to development along many reaches of coast. Conversely, some dune field are the result of man’s activities so the balance and tradeoffs of development and dune creation are an issue. From a coastal hazard perspective, most would agree that having a healthy dune system along their property is preferable to not having one.

Some preliminary results of the monitoring data can be assessed by looking at the elevations of the primary and secondary dune crests averaged for each site (Table 4-1). The primary dune crest is the constant reference point for each profile. Generally, sites with low geologic underpinnings and/or facing less dominant wind/wave directions have a relatively lower primary dune crest. These include LN39, NL42, and, to some degree, NH17. The remaining sites have higher primary dune crests as a result of greater exposure to dominant wind/wave climates and higher adjacent uplands that reduce the potential for overwash.

The relationship of the primary to secondary dunes warrants discussion because, in many cases, the secondary dune(s) were once the primary dune feature. This is well documented at VB4, NH51, and NL42. It is less clear at the other sites with secondary dunes. Generally, the averaged secondary dune elevations are higher than the associated primary dune elevations at VB4, NL58, NL59, and NH10. They are similar at NH51 and NL42 and lower at LN39 and MA3. At this point, these trends have no clear cause but will be the subject of continued monitoring.

The ecosystem relationship of primary and secondary dunes are based on morphology and vegetation. The vegetation to date shows differentiation among the four zones monitored - foredune, crest, trough, and secondary dune crest. The occurrence of a shrub zone with associated trees and shrubs may provide biologic parameters for secondary dune delineation.

4.2 Non-Jurisdictional Sites

Due to the relative abundance of dune sites in Middlesex and Westmoreland counties, these two localities may warrant inclusion in the Dune Ordinance. Further analysis of those sites will be performed, and the results will be included as a subset to the Chesapeake Bay Dune Database. Another issue is the many miles of beach that do not have dunes across the backshore. These beaches, in some cases, may provide the foundation for future dune development. In fact, beaches are a unique habitat, horseshoe crabs not withstanding, and although regulated, are not considered important.

4.3 Horseshoe Crabs

Our earlier study of horseshoe crab habitat spawning suitability showed that classic indices could not be applied to Virginia's portion of the Chesapeake Bay (Hardaway *et al*. 2001a). The dune-associated beach habitat assessments for non-jurisdictional localities support this conclusion-- similar spawning habitat characteristics are provided. However, these data still proved valuable in horseshoe crab management efforts and have been presented to the Atlantic States Marine Fisheries Commission as part of Virginia's compliance with the Interstate Fisheries Management Plan for horseshoe crabs. Due to sampled tidal beaches generally having little variability in geological structure, a habitat suitability index may not be a necessary management tool for Virginia's horseshoe crab population. It is noteworthy to recall that our analysis included only those beaches associated with dunes.

5 References

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