

11-2001

Chesapeake Bay Dune Systems: Evolution and Status

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Recommended Citation

Hardaway, C. S., Varnell, L. M., Milligan, D. A., Thomas, G. R., & Hobbs, C. H. (2001) Chesapeake Bay Dune Systems: Evolution and Status. Virginia Institute of Marine Science, College of William and Mary. <https://doi.org/10.21220/V5043W>

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Evolution and Status*

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Final Report

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This project was funded, in part, by the Department of Environmental Quality's Coastal Resources Management Program through Grant #NA87OZ0253-01 of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.



Executive Summary

Dune systems of the Commonwealth of Virginia are a unique and valuable natural resource. The primary dune and beach of existing shore systems are protected under the Coastal Primary Sand Dune Protection Act (the Act). Until 1998, the exact extent of existing dune systems in the Chesapeake Bay was largely unknown. In addition, the relationship between primary and secondary dunes had not been explored.

The goals of this study were to locate, classify, and enumerate the existing jurisdictional dunes and dune fields within the eight localities listed in the Act. These include the counties of Accomack, Lancaster, Mathews, Northampton, and Northumberland and the cities of Hampton, Norfolk, and Virginia Beach. Only Chesapeake Bay and river sites are considered in this study. To provide a basis for sound resource management and consistency within dune management programs, this project set forth to:

- determine the extent of the existing dune systems around Chesapeake Bay,
- determine morphologic changes of selected dune systems and the factors that influence their evolution,
- develop a geology-based classification of dune system types using influencing factors, and
- determine the relationship between primary and secondary dunes.

A second goal of this study was to characterize horseshoe crab spawning habitat for the beaches adjacent to Bay dunes. Four beach elements were assessed in conjunction with beach/dune assessments; beach thickness, grain size, moisture and beach slope.

All dunes in the Chesapeake Bay estuarine system are mobile features. Unlike ocean dune fields that are relatively continuous features exposed to the open ocean, the dunes of the Chesapeake form across a temporal and spatial geomorphic matrix driven by sand volume, varying wave climate, and inconsistent shoreline geology. These factors, in concert with seasonal and stochastic effects, can amplify the difficulties of determination, delineation, and management of dunes in estuarine settings.

Almost 50 miles of potential dune areas were identified in the eight localities administering the Act. At the completion of the field work, the extent of the sites that are identified as jurisdictional dunes actually is closer to 40 miles. The dunes occur with a wide variety of fetches and site conditions. Dune lengths vary from a few hundred feet to a few thousand feet. Dunes reside in areas of sand accretion and stability such as around the mouth of tidal creeks, embayed shorelines, in front of older dunes, as washovers, as spits, and against man-made structures like channel jetties or groin fields.

There were 365 potential dune sites of which 259 were visited. Of those, 219 sites were determined to have jurisdictional primary sand dunes. The total length of visited (surveyed) dune sites is approximately 39.6 miles. Of the 219 sites surveyed, 165 were primary dune only

sites and amounted to about 20.3 miles of coast. There were 54 sites that had secondary dunes amounting to about 19.3 miles of Bay coast. There are almost three times the number of primary dune sites vs. primary/secondary. The average primary dune site is about 650 feet long whereas the average primary/secondary dune site is 1,884 feet long, usually as dune fields (dune feature greater than 500 feet alongshore)

A dune classification system was developed with 3 main categories that attempt to describe dune system genesis; these are Natural, Man-influenced and Man-made. These categories are appropriate designations but were found to be insufficient as descriptors. Additional site parameters measured include: fetch exposure, shore orientation, nearshore gradient, morphologic setting, relative stability, geologic underpinnings, shore structures influence, and ownership. The dune morphology and wind/wave exposure more adequately display the nature of a given dune site.

Dune morphology in the cross-shore direction is best described by beach and dune profiles. All profiles have a MLW water position and a primary dune crest position. The position of the primary dune crest is pivotal in describing the morphology of the primary and secondary dune elements. Of the 219 sites visited and determined to be jurisdictional dunes, 194 were profiled. There were 140 sites with primary dunes only, and another 54 sites had both primary dunes and secondary dunes.

Primary dunes are more easily defined than secondary dunes. Generally, a primary dune crest can be identified in the field. The back or landward limit of the primary dune is more subjective because of the variability of the break in slope. The back of the primary dune also marks the front of the secondary dune as defined in this study. The crest of the secondary dune can be difficult to define in many cases due to linear variability of the crest ridge. The back of the secondary dune can be even more subjective and might end at the wood line rather than at a well-defined break in slope.

Plant community structure can be used as an indicator of dune stability and history. Primary Bay dunes that are relatively stable generally have robust communities of American beachgrass, saltmeadow hay, and sea rocket. These species thrive in the hot, dry, and salty conditions associated with primary dunes. Conversely, dunes which have shrub communities or herbaceous species generally not characteristic of areas such as dunes that frequently encounter extremes of heat, dessication and salt may provide evidence of erosion or instability. For example, shrub communities are common in dune fields landward of primary dunes. Shrubs growing on primary dunes could indicate erosion through the primary dune into the secondary dune field. For situations such as these, the Dune Act and its associated intent becomes problematic.

Recommendations from this study include: 1) amend the legal definition of a dune to be more consistent with coastal geology, 2) expand the jurisdiction of the Dune Act to include other localities with dune fields adjacent to Chesapeake Bay, 3) establish Resource Protection Areas (RPA) landward of dunes and beaches eliminate overlapping regulatory authority, 4) emphasize dune and beach restoration/creation for shore erosion control and 5) establish a comprehensive

dune and beach monitoring program to provide scientists and managers the information necessary to make informed decisions and guide restoration and mitigation efforts. The latter has been initiated through the Virginia Coastal Program. Finally, This study has shown that Chesapeake Bay beaches adjacent to dunes, within the preferred area of horseshoe crab spawning, are generally consistent in physical character. This may aid management efforts since changes could be applied consistently throughout the Bay. This would require assuming that beaches located immediately bayward of uplands exhibit the same physical characteristics as beaches supported by dunes. If more detailed information that would potentially result in spawning site ranking are needed, further study is required.

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1 Introduction

1.1 Purpose

Dune systems of the Commonwealth of Virginia are a unique and valuable natural resource. The primary dune and beach of existing shore systems are protected under the Coastal Primary Sand Dune Protection Act (the Act). Until 1998, the exact extent of existing dune systems in the Chesapeake Bay was unknown. In addition, the relationship between primary and secondary dunes had not been explored.

The goals of this study were to locate, classify, and enumerate the existing jurisdictional dunes and dune fields within eight localities listed in the Act. These include the counties of Accomack, Lancaster, Mathews, Northampton, and Northumberland and the cities of Hampton, Norfolk, and Virginia Beach (Figure 1, Appendix A). Only Chesapeake Bay and river sites are considered in this study. To provide a basis for sound resource management and consistency within dune management programs, this project set forth to:

- determine the extent of the existing dune systems around Chesapeake Bay,
- determine morphologic changes of selected dune systems and the factors that influence their evolution,
- develop a geology-based classification of dune system types using influencing factors, and
- determine the relationship between primary and secondary dunes.

A second goal of this study was to characterize horseshoe crab spawning habitat for the beaches adjacent to Bay dunes. Since the beginning of this study in 1998, some noteworthy changes have occurred that are important to future horseshoe crab fishery and habitat management. Pierce *et al.* (2000) demonstrated genetic distinction between Chesapeake Bay and Delaware Bay horseshoe crab stocks. Their study hypothesized that the Chesapeake Bay horseshoe crabs collected in Maryland waters near Kent Point were resident so differences in lower Bay horseshoe crabs that have more access to offshore waters, and a greater probability of genetic exchange, may not show the same differences. Botton and Ropes (1987) found that the highest abundances and frequencies of occurrence of offshore horseshoe crab populations occurs between Virginia and New Jersey, which may reflect proximity to the Delaware Bay and Chesapeake Bay spawning areas. However, the findings of Pierce *et al.* (2000) could affect future management in the Chesapeake Bay.

1.2 Background

Dunes form by the accumulation of sand resulting from the interaction of wind and wave action along the shore. Sand deposited on the beach during periods of relatively low wave energy is moved landward by the action of onshore winds. Vegetation takes root along the dune line above the intertidal zone where it acts as a baffle, slowing the wind and causing wind-borne sand to settle in the vegetation resulting in further accretion of the dune. The size and location of primary dunes therefore are determined by the amount of sand available and the ability of wind and waves to move the sand as well as the degree to which vegetation can trap it. Thus, just as

the intensity, direction, and duration of winds and waves constantly change through the seasons, so, too, do coastal dunes remain in a state of flux.

Dunes are a reservoir of sand which can buffer inland areas from the effects of storm waves and, in the process, act as natural levees against the effects of coastal flooding. During high energy conditions, such as the northeast storms which frequent the eastern seaboard, dunes may be subject to attack by wind-driven waves aided by storm surges. In response to seasonal storm effects, dunes generally undergo a dynamic pattern of erosion and accretion. The dune may erode and deposit sand in an offshore bar. Then, under low-energy conditions, the sand may move back to the beach and dune.

All dunes in the Chesapeake Bay estuarine system are mobile features. Unlike ocean dune fields that are relatively continuous features exposed to the open ocean, the dunes of the Chesapeake form across a temporal and spatial geomorphic matrix driven by sand volume, varying wave climate, and inconsistent shoreline geology. These factors, in concert with seasonal and stochastic effects, can amplify the difficulties of determination, delineation, and management of dunes in estuarine settings.

Dunes perform important functions to both littoral marine systems (as habitat for flora and fauna) and the adjacent landward environments (erosion control and protection from storms). These functions form the basis of the Act and the related resource management effort. Management has been inconsistent partly because the legal definition of a coastal primary sand dune is not always supported by coastal plain geology. According to the Act, primary dunes must meet three criteria:

- substance (a mound of unconsolidated sandy soil contiguous to mean high water)
- morphology (landward and lateral limits are marked by a change in grade from >10% to <10%)
- character (dunes must support specific plant species or communities which are named in the Act)
-

This definition generally is more accurate when applied to ocean coastal primary dunes since their morphology is more consistent over a shoreline reach than bay and river dunes which vary within the landscape. In addition, man-influenced and man-made dunes can further complicate the definition criteria. For bay and river dunes, the definition often excludes contiguous areas of importance such as secondary dunes and maritime forests.

The observations and analyses of the project data have raised as many questions as provided answers and show that the aforementioned factors have significant coastal zone management implications. The main products of the present project are: a tabulation of the location and lengths of the primary dunes in the Virginia portion of Chesapeake Bay in the eight Act localities; development of a Chesapeake Bay dune classification system; and elucidation of the relationship of primary dunes to secondary dunes.

1.3 Dune Morphology

Dunes are a ubiquitous feature along shorelines around the world. Every coastal sandy beach setting invariably has some type of dune feature associated with it. Coastal dunes along open ocean coasts have been studied extensively over the past 50 years (Davis, 1957; Goldsmith, 1973; Goldsmith *et al.*, 1977; Gutman, 1978; Hobbs and Hennigar, 1978; Short and Hesp, 1982; Chapman 1983; Goldsmith, 1985; Pye and Tsoar, 1990; Carter and Wilson, 1993; Psuty, 1993; Wal and McManus, 1993; van de Graaff, 1994; Nordstrom, 1994; Rust and Illenberger, 1996; Mathews *et al.*, 1998). Yet, little has been done to document estuarine dune systems.

Coastal dunes vary widely in size, shape, and locations depending upon sand supply and climate. A sandy beach is part of a prism of sediment that include the dune area and the subaerial and subaqueous beaches (Figure 2). This prism is subject to reworking at various time scales, and erosional processes may be magnified for dunes in estuarine systems. Under the impact of extreme events, the incipient foredune, and more rarely the established foredune, are subject to reworking such that a large amount of stored sand is released into the active zone (Chapman, 1983). Short, steep erosional waves can prevent onshore movement of sediment between storms, resulting in a permanent loss of material from the beach face and dune. On ocean dunes, long, low depositional waves occurring between storms replenished most of the material carried away during the storm. This fresh beach material acts as a buffer against the erosion of the dunes during the following storm (Nordstrom, 1977).

Narrow estuarine beaches provide a limited amount of sand supply to the aeolian transport system. Beach sand supply and aeolian transport are greatest at low water levels when more beach width is exposed and surface drying occurs. Increased sand transport occurs when the wind is onshore and oblique to the shoreline. This causes an apparent increased beach width and thus an increase in sand source for aeolian transport (Nordstrom and Jackson, 1993). For Bay dunes, this implies their site setting relative to dominant annual and storm wind directions is important.

The first dune ridge or foredune is by Virginian law, the primary dune. This dune feature possesses a characteristic cross-sectional shape - a steep windward slope and a gentler lee slope. This morphology is the result of the relationship between sand transport rate (local accretion aided by adaptive vegetation) and the pattern of wind as it passes over the dune feature obstruction.

Coastal sand dunes are different from other coastal landforms in that they are formed by air-rather than water-movement (Pethick, 1984). Often dunes will evolve on an overwash, which is a water-born feature created during storm events. After that, pioneer vegetation will become established, and wind becomes the dominant force. Dune vegetation is specially adapted for wind blown regions and sand accumulation. In the absence of stabilizing vegetation, blowing sand often drifts into large "live" dunes that move back and forth such as Jockey's Ridge in North Carolina (Woodhouse, 1982).

Pethick (1984) explains that coastal dune morphology consists of several dune ridges with an actively accreting foredune, an embryonic or incipient dune evolving on the seaside, and one

or more dune features landward. Woodhouse (1982) divides the vegetated ocean coastal dune complex roughly into three zones. This procession also is sometimes evident in the older and larger dune fields around Chesapeake Bay. In order both of increasing distance from the sea and increasing age, these are (1) the pioneer zone, (2) the intermediate or scrub zone and (3) the back dune or forest zone. The location and extent of these zones vary widely depending on such factors as coastal topography, climate, nature and rate of erosion and deposition, and sea level changes. The pioneer zone sometimes is absent due to recent severe storms or to persistent, long-term beach recession. In extreme cases, both the pioneer and intermediate zones may be lost leaving the forest zone next to the beach.

The Pioneer zone (Woodhouse, 1982) is the area of recent or continuing sand movement that usually occurs on the upper beach and foredunes. It is wide on prograding beaches, less so on stable sites, and narrow to nonexistent on receding coasts. Vegetation in a typical pioneer zone is limited to a few species of grasses, sedges, and forbs that can withstand salt spray, sandblast, sand burial, flooding, and drought, as well as wide temperature fluctuations and low nutrient supply. Although pioneer species for any given region tend to be few in number, individual species often play distinctly different roles. Some might be termed “dune initiators” and others “dune builders” while the majority act largely as stabilizers. Along the Atlantic and Gulf Coasts, sea purslane (*Sesuvium portulacastrum*) and sea rocket (*Cakile maritima*) are good examples of “dune initiators” which are capable of invading the upper beach where they get trapped by debris and form low, embryonic dunelets.

The primary dune builders in the pioneer zone are few in number but are generally adapted over very wide geographic ranges. *Ammophila* species (*breviligulata*), American beachgrass, dominates the dune building process along the North and Mid-Atlantic coasts of North America. Sea Oats (*Uniola paniculata*) is the principal dune builder along most of the South Atlantic and Gulf coasts of North America from the Carolinas to Mexico. There are numerous secondary species that invade the foredunes along the ocean coasts and assist in the stabilizing process. Opportunistic dune vegetation can trap wind blown sands and cause the foredune to grow vertically to a height dependent on site conditions and shore evolution. Ocean foredunes can reach elevations of 10 m to 30 m.

The Scrub or Intermediate Zone (Woodhouse, 1982) is a highly variable, ill-defined area lying immediately behind the more active pioneer zone. It consists of secondary dune ridges and swales, flats, deflation plains, and, occasionally, the back slopes of large foredunes. Plants in this zone may include (in addition to the pioneer species), forbs, shrubs, and stunted trees. The area receives little fresh sand and nutrient levels are often low resulting in a scrubby, starved appearance of the vegetation. This zone on ocean coasts is normally considered a progression in the ecological succession toward the stable climax forest, away from the highly changeable, unstable state of the pioneer zone. Sand movement decreases or ceases completely. In this area, wind can create bare, low swales between higher vegetated ridges (Pethick, 1985). Three or more areas of dune ridges may occur in an area of long-term shoreline advance.

The Forest Zone (Woodhouse, 1982) occurs only on sites with considerable protection from salt spray and only after a substantial period of soil development. The Forest Zone begins to

develop along the third set of dune ridges. The vegetation varies and includes dense thickets of trees, shrubs and vines of the maritime forests of the South Atlantic and Gulf coasts.

1.4 Chesapeake Bay Shorelines

1.4.1 Physical Setting

Rosen (1976) classified Chesapeake Bay beaches based on thickness and substrate into three morphologically distinct types that include permeable, impermeable, and marsh barrier beaches. About 80% of Chesapeake Bay shoreline is fronted by beaches of varying width. It is noteworthy that the majority of beach shorelines are not associated with dunes.

Permeable beaches are composed totally of sand. According to Rosen (1976), it is the most prevalent coastal environment in the Bay system and comprises 59% of the beach shorelines and 47% of the total shoreline (Figure 3). Seventy-five percent of the permeable beaches are some sort of accretionary landform such as spits and dunes fields (although presently may be eroding). Seventy-three percent of the permeable beaches have some form of dune in the back beach.

Impermeable beaches are composed of a veneer of sand overlying impermeable, pre-Holocene sediments having a high clay content. Impermeable beaches comprise 30% of the Virginia Chesapeake Bay shoreline and 24% of the beaches. These shore types have higher erosion rates than the other two types.

Marsh barrier beaches are composed of a veneer of sand overlying salt marsh peat. The main concentrations of this environment are in the northeast and southwest ends of the Bay (Morrison and Holdahl, 1974). These regions also correspond with higher subsidence rates that in turn result in greater marsh development. Rosen (1976) found that all marsh barriers he sampled had some form of dune vegetation in the backshore.

The beach types of Rosen (1976) are often part of littoral cells where there is an erosion zone, a transition zone, and an accretion zone (Figure 4). Impermeable beaches often lie in the erosion zone. Beaches become more permeable toward the accretion zone. This morphologic evolution is discussed by Hardaway *et al.* (1997) who found that wider beach and backshore areas of the accretion zone (permeable beach) provide the needed width and height of sand to allow dune formation and protect the base of upland banks from storm wave action.

Shoreline erosion rates, which influence dune creation and dynamics, vary around the Bay and are a function of numerous parameters including but not limited to fetch, nearshore morphology, bank composition, bank height, beach/marsh buffer width, shoreline geometry, shoreline orientation, and tide range (Rosen, 1976; Riggs *et al.*, 1978; and Hardaway *et al.*, 1992). Byrne and Anderson's (1978) data show average historic erosion rates (1860 to 1940) for the Western, Eastern and Southern Bay shore provinces to be -0.6, -1.0 and -1.4 ft/yr, respectively.

The volume of sediment supplied annually by shoreline erosion is 2,701,260 cy (Byrne and Anderson, 1978). Another estimate of bank and nearshore erosion is approximately 5.7 million cy/yr based on down-cutting that ceases at the -8 ft MLW contour (U.S. COE, 1990). The

annual volume of potential dune building material provided from bank erosion is a function of bank height and erosion rate. The amount of sands and gravels are a function of bank composition.

Sand and gravel are the building blocks of beaches and dunes around Chesapeake Bay. The volume of sand that resides alongshore and offshore on the Bay terraces is difficult to estimate. Sand deposition on the Bay bottom is confined to the shoreline and nearshore terrace and is derived from erosion of the fastland (upland) (Ryan, 1953; Lukin, 1983). More sand material occurs in the nearshore terraces of the southern (Norfolk and Virginia Beach) and eastern shores (Northampton County) than the western shore of the bay.

Since 1976, increased developmental pressures have changed the very nature of Chesapeake Bay shorelines. Many shore protection devices that reduce the sand and gravel supplied to the littoral system by shoreline erosion and alter longshore transport patterns have been installed. These structures impact historic shoreline change rates be it erosion or accretion. Hardaway *et al.* (1992) found that shoreline hardening by bulkheads and revetments along 383 miles of Bay coast increased from 58 miles to 71 miles between 1985 and 1990. This, in turn, reduced that amount of sediment input by 400,000 cy over the same time span. Since 1988, 250 miles of Virginia's total shoreline have been hardened (VIMS, 2001). Shoreline structures of all types have had a significant impact on shoreline processes around the Bay.

1.4.2 Hydrodynamic and Aerodynamic Setting

Chesapeake Bay is a fetch-limited and depth-limited, enclosed, coastal sea. Wind- driven waves, which dominate shoreline change, are limited by the restricted widths and depths of the Bay. However, wind-generated waves during storms with associated elevated water levels (storm surges) can cause significant shoreline change. For example, Tankard's Beach on the Eastern Shore has eroded at a rate of almost 20 ft/yr (Hardaway, 1984).

Wind data collected at Norfolk International Airport ([Table 1, Appendix B](#)) show that winds from the north dominate in the low wind category (<5 mph/hr) and in the higher wind categories (>11 mph/hr). The mid-range category (5-11 mph/hr) is dominated by winds blowing from the south. The orientation of the shoreline to the wind will impact the nature of physical processes acting on the site. In general, all open Bay shorelines receive significant wind/wave action over time with some areas getting the worst of a particular storm. But it is the storms that are the main factor in shore retreat.

Wave climate in the lower Chesapeake Bay was studied by Boon *et al.* (1990), Boon *et al.* (1991), Boon *et al.* (1993), and Boon and Hepworth (1993) utilizing data recorded by wave gages. One of the unique features reported in the wave data set is the bimodal distribution of wave directions reflecting a dual energy source which impacts the lower Chesapeake Bay. Boon *et al.* (1990) found that 40-60% of all waves measured each month were between 0.7 ft and 2 ft in height. During late spring and summer months, about 80% of these waves were directed west-northwest, thus generated outside the bay and entering through the bay mouth. During fall and

winter months, only about 50% of the 0.7-2 ft waves were generated outside the bay. Bay-external waves result from ocean swell and shelf-originated wind waves.

Of the fall and winter waves that were greater than 2 ft in height, almost all were directed south, thus generated within the bay. These fall and winter waves result from northeastern, extratropical storms which produce strong north winds along the maximum fetch of the bay. In summer months, locally-generated waves reached only minimal heights. Although the largest wave heights recorded were associated with waves generated inside the bay, these waves were relatively infrequent.

The October 1990 to August 1991 wave sampling (Boon *et al.*, 1993) revealed a similar bimodal distribution of wave energy in the lower Chesapeake Bay. However, an eventful winter and spring season in terms of extratropical disturbances resulted in a more energetic ocean component as compared to the Bay-generated component described in the 1988-1989 data. At least five extratropical weather systems produced wave heights in excess of 3 ft. These were a mixture of bay and ocean-generated waves as indicated in [Table 2](#).

Storm surge is the difference between the observed and predicted water levels during a coastal storm (Ward *et al.*, 1989). Storm surges can exceed 16 ft during hurricanes, but northeast, extratropical storms have a weaker wind fields and generally have surges less than 7 ft. However, extratropical events have longer durations and can span several tidal cycles creating significantly elevated water levels. [Table 3](#) lists the surges of storms that have been recorded in the lower Chesapeake Bay.

Utilizing a two-year design storm, Basco (1993) calculated maximum wave conditions with heights of 8 ft and periods of about 5.8 seconds near the middle of both upper and lower reaches of the Virginia Bay. Wave heights and periods decrease along the tributary rivers.

1.5 Horseshoe Crab Habitat Assessment

The horseshoe crab assessment was initiated in response to fishery management issues, but it also has implications to habitat management issues that affect the stock and fishery. The horseshoe crab (*Limulus polyphemus*) is a common beach and shallow water dwelling arthropod found along the Western Atlantic Coast from approximately the Yucatan Peninsula to Northern Maine (Shuster, 1979). It has existed since at least the Ordovician Period (approximately 450 million years ago) and is considered an ecological generalist able to withstand a wide range of conditions (Eldredge, 1991). In the Mid-Atlantic region, the largest spawning populations occur in Delaware Bay, but a smaller, yet significant, spawning population occurs in Chesapeake Bay (Shuster, 1985). Horseshoe crabs have important ecological, economic, and human health roles. Horseshoe crab eggs and larvae are important seasonal food sources for shorebirds, commercially important finfish and shellfish, and various other species of estuarine fauna with significant ecological roles but of no direct commercial importance (Shuster, 1982; Spraker and Austin, 1997). For example, adult and juvenile horseshoe crabs are an important component in the diet of juvenile loggerhead turtles which summer in and around the Chesapeake Bay. Horseshoe crabs

are commercially exploited as bait in the conch and eel fisheries. At this time, the Asian-Pacific and European markets for conch and eel are a healthy component of Virginia's fishing industry. Additionally, the blood of *L. polyphemus* contains a clotting agent which is the worldwide standard for bacterial contamination screening. Wild stocks are required for blood collection since it is not possible to culture horseshoe crabs since they may not reach maturity until their tenth year and may live up to 18 years (Shuster, 1979).

Horseshoe crabs desire beaches of a particular structure for spawning (Penn and Brockman, 1994; Brockman, 1990; Botton *et al.*, 1988; Botton and Loveland, 1987). Generally, beginning in May and ending in June, horseshoe crabs come ashore during the high spring tides of the new and full moons (Shuster and Botton, 1985). Spawning occurs at or near the high tide line (Barlow *et al.*, 1986). Females dig shallow nests in the sand and each deposits thousands of eggs in the upper portions of the intertidal zone (Shuster, 1982). Eggs are placed from two to eight inches below the beach surface (Shuster, 1979; Botton and Loveland 1989). After about two weeks, the eggs hatch, and the larvae dig to the surface. The larvae exploit shallow water areas, such as intertidal flats and shoals, as nursery habitat. Overwintering of larvae also has been observed (Botton *et al.*, 1992). Horseshoe crab spawning has been anecdotally observed in the lower Chesapeake Bay; however, no science-based spawning studies have examined the overall importance of the lower Chesapeake Bay as a spawning and nursery habitat.

Horseshoe crabs along the Atlantic Coast of North America recently have experienced a heightened management focus due to evolving fishery pressures on a stock of unknown character or size. Fishing rates may negatively impact horseshoe crab populations, leading to subsequent adverse effects on shorebirds, fish, the loggerhead turtle, the commercial conch and eel fisheries, and sectors of the biomedical industry. Adoption of the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (IFMP) for Horseshoe Crabs in October, 1998 placed requirements on states with active fisheries. Among the many requirements was the identification of potential horseshoe crab spawning and nursery habitat. This project provided a unique opportunity to characterize horseshoe crab spawning habitat for the beaches adjacent to Bay dunes. This information, in part, fulfills Virginia's requirement in the ASMFC IFMP.

2 Methods

2.1 Geographic Extent of Chesapeake Bay Dune Systems

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 (Table 4A-4H). 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.

2.2 Dune System Evolution

The evolution of selected dune systems was documented using historical vertical aerial imagery. Digital orthophoto quarter-quadrangles (DOQQ) from 1994 were rectified along with 1937 aerial photos to create a base for comparing selected shorelines and dunes for those dates. Most of Northampton County shoreline and part of Northumberland County from Smith Point to Fletton were analyzed by this procedure. The shorelines for each date were digitized and plotted on each photo base along with the shore position in 1994 of identified dunes from Section 2.1.

2.3 Dune System Classification

A Chesapeake Bay dune classification was developed from the results of tasks performed in sections 2.1 and 2.2 of this report. 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 is three tiered (Figure 5). The primary tier (1, 2, and 3) characterizes the level or type of human involvement in the dune system. Initially, these three categories (Natural, Man-Influenced, or Man-Made) seemed to 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 related to geologic parameters. These dune site parameters were placed in Tables 5A through 5H for each locality.

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.

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 (A) 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 effects 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 from VIMS SAV archives 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. Some of these Morphological Settings are illustrated in [Figure 6 A](#). [Figure 6B](#) shows two large dune fields obliquely from the air to demonstrate the alongshore extent of some of these morphologic settings.

The Relative Stability (E) or state of a dune site was very subjective. It was a value judgement as to the overall present and future integrity. 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).

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. The marsh category includes creek bottoms which should perhaps be a separate category because beach/dune development can occur across the mouth of a creek bottom without a true marsh. The distinction between upland and marsh is that the marsh substrate usually is low and subject to washover processes whereas the high-banked upland area offers a “backstop” to land beach/dune migration.

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).

2.4 Field Investigation

2.4.1 Dune Site Measurements

Once the dune systems were delineated from the analysis of aerial imagery, field checks were performed to verify vegetation types and coastal zone profile. Select beach profile transects were surveyed to characterize the primary and secondary dune (where present) within 100 feet of the shoreline. Standard surveying and biological procedures were utilized.

Each surveyed transect used the crest of the primary dune as the horizontal control and mean low water (MLW) as the vertical control. The location of the primary dune crest is determined on site. The MLW line is indirectly obtained from time-of-tide 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 typical primary dune profile has several components (Figure 7). A continuous sand sheet exists from the offshore landward and consists of a 1) nearshore region, bayward of MLW, 2) an intertidal beach, berm and backshore region 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 bayward beyond MLW and landward to at least the back of the primary dune. The secondary dune crest was always measured, but the back or landward extent of the secondary dune could not always be reached. The dimensions, including lateral position and elevation of various profile components were measured. These dune site measurements are shown on Tables 5A through 5H for each locality and include:

- 1). Primary Dune Crest Elevation (X)
- 2). Distance from Primary Dune Crest to Back of Dune (C)
- 3). Distance from Primary Dune Crest to MLW (D)
- 4). Width of Primary Dune and Beach (C+D)
- 5). Secondary Dune Crest Elevation (V)
- 6). Distance from Back of Primary Dune to Secondary Dune Crest (B)
- 7). Distance from Secondary Dune Crest to Back of Secondary Dune (A)
- 8). Distance from Crest of Primary Dune to Back of Secondary Dune (L or A+B+C)
- 9). Width of Secondary Dune Field (A+B)
- 10). Width of Beach, Primary and Secondary Dune (A+B+C+D)

Dune site measurements were tabulated for each county/city (Table 5A to 5H). Data were measured from the representative beach, dune and shallow water cross-sectional profiles taken at each jurisdictional dune site. Further data analysis presented in Results (Section 3) determined shore lengths, percentages, means (arithmetic averages), and standard deviations of site parameters and site measurements. Sample standard deviation is the square root of the sample variance. It is a measure of how the individual data points vary about the mean or the validity of a mean value. A small standard deviation indicates that observations are clustered tightly around

a central value. Conversely, a large standard deviation indicates that values are scattered widely about the mean and the tendency for central clustering is weak. These analyses were performed on data in each shore type based on the primary tier of the classification scheme (*i.e.* Natural, Man-Influenced, and Man-Made) and then for all data in each locality.

2.4.2 Dune Vegetation

During each site visit, dominant plant communities occupying the primary and secondary (if present) dunes were noted (Figure 7). Plant species distribution is based on observed percent cover in a broad general area of profiling and sampling within the identified dune reach.

2.5 Horseshoe Crab Habitat Assessment

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 Geographic Extent of Dune Systems

Almost 50 miles of potential dune areas were identified in the eight localities administering the Act (Table 6). Figure 8 shows the geographic extent of potential jurisdictional dune sites around the Chesapeake Bay. Figures 9A through 9H depict where each potential site is within each locality. At the completion of the field work, the extent of the sites that are identified as jurisdictional dunes actually is closer to 40 miles. However, over 2.5 miles of potential dune sites in Accomack County and almost 2 miles in Lancaster County were not visited because of inaccessibility of the sites. These sites are mostly isolated pocket dunes along remote marsh coasts. The Bay dunes occur with a wide variety of fetches and site conditions. Dune lengths vary from a few hundred feet to a few thousand feet. Dunes reside in areas of sand accretion and stability such as around the mouth of tidal creeks, embayed shorelines, in front of older dunes, as washovers, as spits, and against man-made structures like channel jetties or groin fields.

3.2 Dune System Evolution

3.2.1 Overview

If one sits back and looks at the shorelines around Chesapeake Bay, one can see the geomorphic expression of each neck of land's shoreline resembles a "hammer headland". Erosion of the upland neck supplies sand to the littoral system, and the result is spits and bars that are reworked by the impinging waves. Along the Western Shore of the Bay, the headlands are somewhat symmetrical. Erosion of the main head supplies sand to both ends of the neck in the form of spits, beaches and bars. This is particularly true of Mathews County, Hampton, and Northumberland's northernmost neck from Fleeton to Smith Point. Windmill Point in Lancaster County also is this type of feature whereas much of the remaining Northern Neck Bay shoreline is more fragmented and low due to numerous tidal creeks and marshes.

The Bay side of the Eastern Shore is characterized by more asymmetrical hammer headlands where erosion of the north end of the upland interfluves generally provides sediment to the middle and southern ends of each neck as well as to the offshore bars. This is most true for Northampton County where high bank uplands abut the Bay shore. Accomack County is dominated by marsh shorelines and many pocket dunes formed on marsh substrates.

The Southern Shore of the Bay is a sand rich system that is characterized by net transport from east to west. Only two breaks, Lynnhaven Inlet and Little Creek, interrupt the littoral flow. The shoreline from Lynnhaven east to Cape Henry is impacted by ocean waves and receives sand transported into the bay mouth. A continuous dune field once existed along much of the Southern Shore, but the shore has been significantly developed and modified with coastal structures including groins, bulkheads, and breakwaters as well as numerous beach nourishment projects. Today, dunes exist in fragmented parcels with occasional long dune fields such as First Landing State Park, Little Creek Naval Amphibious Base, and Ocean Park -- all in Virginia Beach.

3.2.2 Northampton County

Shoreline evolution was examined in detail for Northampton County which has been divided into shore reaches I to V as shown on (Figure 10) based on location of upland necks. The combination of shore change and shore development (*i.e.* change in land use) has significantly altered Northampton's Bay shore since 1937. The detailed analysis of shore change is shown in 16 plates (Figure 10). Beginning at the north end of the county at Occahannock Creek, Plate 11 (Figure 11A), shows dune sites NH1, NH2, NH3, NH4 and NH5. After a field check, sites NH1, NH2 and NH3 were determined not to be dunes as described in the Act. Site NH4 is a dune field that lies within a shallow coastal embayment which has accumulated a great deal of sand since 1937. The area is controlled in part by the tidal creek that issues out at the center of the sight. Site NH5 is an isolated primary dune that occupies an upland between two old tidal inlets (in 1937). The southern inlet is now closed (filled) in and developed.

Significant shoreline recession has occurred on either side of NH5. Shoreline recession continues southward through Plate 12 (Figure 11B). The shoreline in 1937 was almost continuous beach with numerous apparent dune areas. By 1994, most of the shoreline along Plate 12 had been hardened or developed. Sites NH6 and NH7 were determined not to be dunes (Figure 11C). Site NH8 is an isolated primary dune that lies in the influence of a small drainage. Site NH9 was not a dune.

NH10 (Figure 11C) not only is controlled, in part, by an intermittent upland drainage but also is influenced by groins to the south that help perch the beach/backshore. Since 1937, this area has been relatively stable allowing the growth of both a primary dune and a secondary dune. Significant shoreline recession has occurred between this site and Nassawadox Creek. Since 1937, development at and adjacent to Silver Beach has resulted in shoreline hardening and the installation of groins. In 1937, there were dunes north of site NH10 at Silver Beach and on a spit on the north side of Nassawadox Creek. Today, only the isolated dunes of NH11 and NH12 remain.

South from Nassawadox Creek to Hungars Creek (Figure 11D) is Church Neck. The northern section of Reach II from Nassawadox Creek to Westerhouse Creek has eroded adjacent to the creek mouths and accreted at the location of site NH13, a dune field. The eroded shorelines had several dune areas in 1937, but now, only isolated dunes exist along the spit into Westerhouse Creek including sites NH14, NH15 and NH16. Site NH14 and NH15 have secondary dunes associated with them. South of Westerhouse Creek (Figure 11E), a large spit has formed upon which sites NH17, NH18, and NH19 are located. Isolated dunes are scattered along the remainder of the shore including NH20, NH21, and NH23. Site NH 22 was determined not to be a dune. Sites NH24 and NH25 (Figure 11F) are isolated dunes on an old spit on the north side of the entrance to Hungars Creek. This spit is now developed but was an area of dunes in 1937. Site NH26 is an isolated dune feature inside the entrance to Hungers Creek on Wilsonia Neck.

Reach III extends from Mattawoman Creek to Cherrystone Inlet and is the Bay shore of Savage Neck. The subreach from Mattawoman Creek to The Gulf (Figure 11G), has sites NH27, NH28 and NH29. All are isolated dunes that reside on accretionary headlands. Site NH30 is an

isolated dune on a developed point on the south side of The Gulf. In 1937, this point was all dune. Site NH31 was determined not to be a dune. South of site NH31 is Tankards Beach which has been undergoing severe erosion (Figure 11H). Moving south (Figure 11I), site NH32 is an isolated dune at an overwash to a small pond. Site NH33 (Figure 11I) is an extensive dune field that has experienced significant erosion through time. This area has extensive “ancient” dunes and maritime forests that extend landward over 1,500 ft. Numerous areas of secondary, even tertiary, dune grade into maritime forest. Sites NH34 on Plate 3 (Figure 11J) is a dune field along the south end of Savage Neck. Sites NH35 and NH36 occupy the distal spit at the mouth of Cherrystone Inlet.

Reach IV begins on the south side of King’s Creek and extends to Old Plantation Creek. Site NH37 (Figure 11K) is on a spit that has accreted since 1937. Recently, much of the dune was actually covered by an earthen berm as part of an adjacent development. Sites NH38 and NH39 are not dunes. Sites NH40 and NH41 are part of Cape Charles Public Beach at the Town of Cape Charles. Site NH40 is man-influenced by an outfall pipe with a gabion basket spur on the southern side. Site NH41 was man-made with beach fill, sand fencing and grass plantings between 1988 and 1990. The southern part of NH41 has evolved into secondary dunes. The north channel jetty at the entrance to Cape Charles Harbor has helped hold and stabilize the beach fill placed in 1988.

South of Cape Charles Harbor, material dredged from the entrance channel has been deposited on the shoreline several times. Since 1967, approximately 900,000 cy of sand have been placed there (U.S. Army Corps of Engineers, Undated). Over time, this activity has advanced the shoreline as much as 800 ft beyond the 1937 position (Figure 11K). This large disposal headland extends southward over 5,000 ft. From where it intersects the 1937 shore position, the 1994 shoreline has steadily receded southward to the mouth of Old Plantation Creek and is 500 ft landward of its 1937 position. The 1937 spit/dune has rotated and migrated landward over 1,000 ft. into Old Plantation Creek (Figure 11L). The disposal headland may have caused this tremendous shore change by blocking sediment transport and/or altering the local wave climate and littoral sediment transport processes.

Dune sites NH42 and NH43 (Figure 11L) lie on the dredge disposal headland and both have secondary dunes. Sites NH44 and NH45 are isolated dunes that developed on the washover into Allegood Pond that runs parallel to shore. The 1937 imagery shows a similar dune in the same pond bayward and south of the present day site NH45. Site NH46 is on the spit into Old Plantation Creek. Site NH47 was not visited due to limiting water depth.

Reach V begins at the mouth of Old Plantation Creek and extends southward to the end of the Eastern Shore at Cape Charles. Site NH48 (Figure 11L) is a dune field on the south side of Old Plantation Creek. The spit has moved northward over time. It has secondary dunes that appear to have been primary dunes left behind as the spit advanced. Site NH49 (Figure 11M) is a barrier spit across Elliot’s Creek and has the same basic spit form as in 1937 except the whole system has migrated landward over 500 ft. The recessional wedge of the 1937 and 1994 shoreline intersects about 5,000 ft south of Elliot’s Creek where the dune field of 1937 has eroded back to the upland leaving an isolated dune at site NH50. The shoreline south of NH50 has advanced across Pond Drain and ancient dunes with maritime forests occupy the upland region. South of

Pond Drain, the shoreline has advanced as much as 400 ft along with a series of linear ridges marking the progradation of Site NH51. It appears to be a migrating primary to secondary dune sequence.

Site NH51 continues to the south ([Figure 11N](#)) where the dune field feathers out and the shoreline becomes a high eroding sandy bank, part of older upland dune/maritime forest complex that extends from Old Plantation Creek almost to Cape Charles. Site NH52 is a small remnant of the more continuous dune field at Butler's Bluff seen in 1937. The primary dune picks up again toward the Kiptopeke Jetties. The old ferry dock and offshore concrete ships in this area have created a major headland that blocks littoral transport. Many dune ridges have advanced on the north and south sides of Kiptopeke. A secondary dune field has developed at Sites NH53 and NH54.

Site NH54 extends farther south ([Figure 11O](#)) but there are no more primary dunes for over two miles of shore until site NH57 (sites NH55 and NH56 are no longer dunes). Site NH57 ([Figure 11P](#)) is a dune field that extends for about 4,500ft southward toward Cape Charles where it stops short of a stone revetment that protects the Chesapeake Bay Bridge Tunnel (CBBT) access highway. A small isolated primary dune exists at the terminus of Cape Charles, NH58. Sites NH59 and NH60 were not visited since they are located on Fisherman's Island.

3.2.3 Northumberland County

A shoreline evolution assessment also was performed in Northumberland County along Chesapeake Bay from Fleeton north to Smith Point ([Figure 12A](#)). Referring to [Figure 12B](#), Plate 4 begins at Fleeton on Ingram Bay to which the Great Wicomico River empties. This reach includes sites NL28 and NL29 which are isolated remnants of a dune field that extended from Fleeton Point to Taskmakers Creek in 1937. The shoreline has receded an average of 250 ft from 1937 to 1994 with the only area of advance being associated with the boat landing at Site NL28. Significant development also has occurred along this reach, thereby reducing source of sediments to the littoral system.

[Figure 12C](#) shows Plate 3 in Northumberland County. Sites NL30, NL31, and NL32 are isolated dunes, part of a continuous beach that is a curvilinear embayment between two hardened headlands. Note the severe shoreline change between 1937 and 1994. The long spit in the 1937 imagery rotated and moved westward completely blocking a very open tidal creek that existed between sites NL31 and NL32. Farther north along the shoreline are isolated dune sites NL33, NL34, and NL35. These features developed across the landward distal end of tidal coves as the barrier dune/beach system of 1937 migrated westward completely obliterating the nature of the tidal creek at Owens Pond and opening the entire reach to the Chesapeake Bay.

As part of the westward migrating shoreline, sites NL36 and NL37 on [Figure 12D](#) are isolated pocket dunes across old drainage bottoms. Site NL38 is a creek mouth barrier/spit that has not changed position relative to adjacent shore reaches to the south and north. Site NL39 is not a dune but a barrier beach and NL40 occurs as barrier dune. Both cross the westward ends of

antecedent tidal creeks (1937).

Site NL 41 (Figure 12E) is not a dune. Site NL42 is a long dune field that extends for about 4,000 feet to the Little Wicomico River channel jetty. Due to the jetty lengthening, this shoreline has prograded on the northern half and eroded along the southern half of the reach. The erosion is evidenced today as secondary dune elements (*i.e.* pine trees) exposed on the Bay shore. The land side of NL42 recently has come under development pressure. On the Potomac River side of Smith Point, an extensive series of dune ridges have evolved adjacent to the extended jetty and includes Site NL43. Three profiles were taken at site NL43 to give representative cross-sections of the entire reach. Site NL44 is not a dune, and site NL45 is an isolated remnant barrier dune of a larger dune in 1937.

3.3 Dune Classification

3.3.1 Site Parameters: Summary

Three-hundred-sixty-five (365) potential dune sites were identified, of which, 261 were visited. Of those, 219 sites were determined to have jurisdictional primary sand dunes. Accomack County had the highest number of sites not visited due to inaccessibility and remoteness (Table 6). The total length of visited (surveyed) dune sites is approximately 39.6 miles. Of the 219 sites surveyed, 165 were primary dune-only sites and amounted to about 20.3 miles of coast. There were 54 sites that had secondary dunes amounting to about 19.3 miles of Bay coast (Table 7).

In terms of percent, the extremes are 75% of primary dune only in Lancaster County and 72% primary/secondary dune in Virginia Beach. There are almost three times the number of primary dune-only sites vs. primary/secondary dunes. The average primary dune-only site is about 650 feet long whereas the average primary/secondary dune site is 1,884 feet long, usually as dune fields.

The 3 main categories of Natural, Man-Influenced and Man-Made initially were utilized to portray a site's most influential element. Accomack County is the only locality with all Natural dune sites, and Norfolk has none (Table 8). Only two localities, Norfolk and Northampton County have Man-Made sites, and they are a very small percentage of dune shore footage. All localities except Accomack have between 32% and 89% Man-Influenced sites with the majority in Norfolk. The Norfolk shoreline has many old wood groins, newly-installed breakwaters, and a history of intermittent beach nourishment projects. Virginia Beach has mostly Natural dunes along its Bay coast, primarily at Fort Story, First Landing State Park, and Little Creek Naval Amphibious Base.

Regional differences in coastal geology and development occur. For instance, the largest number of dune sites occurs in Northumberland County whereas the largest dune shore length occurs in Northampton County. Northumberland County has the second largest amount of dune shore footage. Lancaster County has the second highest number of dune sites but the second

lowest dune shore footage.

The site parameters shown in [Table 5A thru 5H](#) were reviewed for each locality to reflect the frequency of occurrence and percentage of shore footage. The qualitative assessment of dune site Stability ([Table 9A](#)) shows that they are generally either stable or erosional. Only eight percent of total dune shore footage is accretionary. Mathews County has a significant amount of dune shoreline that is accreting. Localities that have no sites that are accreting (*i.e.* no potential new dune creation) include Hampton, Norfolk, and Virginia Beach -- the lower Bay metropolitan localities. This may be due to developmental boundaries. However, long stretches of stable dunes in Virginia Beach and Norfolk have average dune site lengths over 4,000 feet long. These localities also have a significant number of eroding dunes. Northampton has both the highest total length of stable and eroding dune coast, but site averages are less at 1,172 feet and 1,420 feet, respectively.

The results of the Morphology classification ([Table 9B](#)) of the dune sites show that 152,000 ft of the 209,000 ft of total length of dune sites as dune fields or 73%. Based on morphologic type of dune within localities, the three metropolitan localities (Hampton, Norfolk, and Virginia Beach) have the most dune fields. Accomack also has a high percentage of dune fields, particularly in the southern half of the county. Most of the isolated dune sites occur in Lancaster County. Most of the Creek Mouth sites occur in Mathews County. Northampton and Northumberland are the only localities with Spit dune sites which gives them dune sites that fall into all four morphologic subcategories.

Shorelines are exposed to Open Bay conditions over 85% of total length of dune shoreline. Norfolk and Virginia Beach are 100% Open Bay exposed ([Table 9C](#)). Most of Hampton, Northampton, and Mathews is Open Bay. Most Northumberland sites are considered Open Bay even though many sites lie on the Potomac because of its energetic conditions. The highest percentage of Riverine shoreline occurs in Lancaster County along the Rappahannock River. Riverine shoreline accounts for about 7 % and River/Bay influenced about 8% of total dune shoreline length. River/Bay influenced sites have the highest occurrences in Accomack, Lancaster and Northumberland.

The underlying Substrate includes both marsh and creek bottom in the Marsh category. Marsh sites represent about 35% of the total dune coast, and Upland sites account for the other 65% ([Table 9D](#)). There are no sites with underlying Marsh in Norfolk or Virginia Beach; these dune sites occupy Upland regions. The highest frequency (number of sites) of Marsh dune coast lies in Northumberland, Accomack and Lancaster. However, in terms of percent of total length, Lancaster has only 26% Marsh dune shore. Of those localities that contain Marsh dune coast, Northampton has the lowest frequency.

3.3.2 Site Parameters: Type of Site

Site parameters were sorted into the three site types (*i.e.* Natural, Man-Influenced, and Man-made) for analysis. The results are shown on [Tables 10A, 10B, and 10C](#). Man-made sites are limited to the Town of Cape Charles in Northampton County and much of Willoughby Spit in Norfolk which had Stability classifications of 100% erosional and 100% stable, respectively (Table 10C). Very few sites in the Man-influenced categories showed any accretionary trends. Of the Natural beach/dune systems ([Table 10A](#)), all localities except Hampton and Virginia Beach had accretionary trends with Mathews having not only the highest percentage at 55% but also the lowest percentage of Stable sites in the Man-influenced category ([Table 10B](#)). For the most part, dune sites in the Man-made and Man-Influenced types were either stable or erosional.

The tabulation of dune site Morphology indicates that most of the shore footage of dunes occurs as Dune Fields in all three Shore Type categories. Isolated dune sites are the second-most frequent in the Man-influenced Type. Northumberland County has 50% of the Man-influenced sites occurring as spits. Under the Natural dune sites, Northumberland County is more evenly distributed among the 4 subcategories, whereas Mathews County has 72% of its Natural dune sites occupying creek mouths. All man-made sites occur as dune fields in Norfolk and Northampton County.

Open Bay dune sites are the most prevalent, except in Lancaster County. Natural dunes in Lancaster are mostly Riverine with some Riverine/Bay Influenced but no Open Bay exposure. Of Lancaster's Man-Influenced sites, only four percent are Open Bay.

Underlying substrates are all Marsh for the Natural dune sites in Hampton and all Upland for the Natural dune sites in Virginia Beach. In fact, Virginia Beach has Upland substrate for all dune sites as does Norfolk. Man-influenced dune sites are mostly upland for 5 of the 7 localities, except Accomack and Northumberland. Northumberland County's Natural dune sites are mostly Marsh substrate as well because of the abundant creek mouths and spits.

3.4 Field Investigation

3.4.1 Dune Site Measurements

Dune morphology in the cross-shore direction is best described by beach and dune profiles. All profiles have a MLW water position and a primary dune crest position. The position of the primary dune crest is pivotal in describing the morphology of the primary and hence the secondary dune elements. Of the 219 sites visited and determined to be jurisdictional dunes, 194 were profiled. There were 140 sites with primary dunes only, and another 54 sites had both primary dunes and secondary dunes. [Table 11](#) lists the following parameters for all surveyed dune sites ([refer to Figure 7 for delineation](#)): X, C, and D for both the primary only and secondary sites and V, L, A, and B for the secondary sites.

Primary dunes are more easily defined than secondary dunes. Generally, a primary dune

crest can be identified in the field. The back or landward limit of the primary dune is more subjective because of the variability of the break in slope. In this study, the back of the primary dune also marks the front of the secondary dune. The crest of the secondary dune can be difficult to define in many cases due to linear variability of the crest ridge. The back of the secondary dune can be even more subjective and might end at the wood line rather than at a well-defined break in slope.

The front base of the primary dune often coincides with a break in slope and the bayward limit of dune vegetation. In some cases, a small embryonic dune marks an accretionary or stable dune situation and may indicate the beginning of a new primary dune. A scarped primary dune face can mark an erosional event. Recent erosional events show a “fresh” cut with roots of dune vegetation exposed. Older events will have a scarp that becomes less defined as wind-blown material and slumping sands accumulate along the dune face.

A relatively wide beach berm is necessary for a stable dune face and primary dune. Beach berm widths generally are wider along open bay shorelines than riverine or bay-influenced due to increased wave runup. The beach berm and base of dune will be assessed as part of the ongoing research on Chesapeake Bay dunes.

The position of the MLW vertical datum is the bayward limit of the jurisdictional primary dune/beach. The elevation and location of the landward limit of primary and secondary dunes are measured from this datum position.

3.4.1.1 Primary Dune

The elevation of the primary dune crest (X) varies significantly by locality ([Table 11](#)). Norfolk and Virginia Beach have the highest average primary dune elevation at 14.7 and 16.5 feet MLW, respectively. Next comes Hampton and then Northhampton County at 10.9 and 10.3 feet MLW respectively. The remaining order of the average overall primary dune height for Mathews, Accomack, Northumberland and Lancaster is 6.9, 6.3, 5.7, and 4.6 feet MLW, respectively.

The average height of the primary dune varies by locality when comparing primary dune only sites vs. primary dune with secondary dunes sites. If there is a secondary dune present, the primary dune elevation is higher than sites with a primary dune only in Accomack, Hampton, Mathews, and Northumberland. In the other four jurisdictional localities, the sites with primary dunes only have a higher primary dune crest than sites that have a secondary dune as well.

The horizontal distance between the primary crest to the back of the primary dune (C) shows the greatest average distances occur in Accomack County and Virginia Beach. The shortest averages occur in Lancaster and Northumberland. This measure can be subjective in the field as seen by the value of Standard Deviations. When comparing the primary dune only sites versus primary dune with secondary dune sites there continues to be high Standard Deviations (S.D.). Overall, C is wider for primary dunes only except for Mathews and Virginia Beach.

The horizontal distance (D) from the primary dune crest (X) and MLW is less subjective than the measure of C. The greatest average values of D, by far, occur in Virginia Beach, Norfolk and Hampton. The smallest values occur in Lancaster and Northumberland. When comparing D at sites with primary dune only vs. sites that have a secondary dune, Norfolk and Virginia Beach are the only localities that have higher values for the primary dune only sites.

The average width of the primary dune is described by C+D. Virginia Beach, Hampton, and Norfolk have the widest average dune region at 220, 185, and 175 feet from MLW, respectively. Lancaster has the smallest at 69 feet from MLW. The average primary dune only sites are wider than those with primary dunes with associated secondaries in Accomack, Norfolk, and Virginia Beach. The rest are equal to or slightly less.

3.4.1.2 Secondary Dunes

The average elevation of the secondary dunes (V) generally is equal to or slightly higher than the average of all primary dune elevations, except for Norfolk and Lancaster. When comparing the average V to the average adjacent X (secondary), the primary dunes are equal to or slightly higher than the secondary dunes except for Northampton, Northumberland, and Virginia Beach. However, these differences are generally less than a foot and could be considered insignificant.

The horizontal distance from the secondary dune crest (V) to the back of the primary dune and the back of the secondary dune are described by B and A, respectively. Together they define the extent the secondary dune. The width of secondary dune features, A+B, are on the order of 60 feet in Lancaster and 200 feet in Virginia Beach. The average widest secondary dunes are about 80 feet narrower than the average widest primary dune. One problem in measuring secondary dunes is the lack of clear criteria. The backs of secondary dunes are difficult to define because they can have discontinuous slope breaks, ridges, and swales. Some sites have more easily defined secondary dunes.

The landward extent from MLW of sites with secondary features is described by A+B+C+D. Virginia Beach has the widest average primary dune with secondary components. The narrowest average primary/secondary dunes are in Lancaster.

3.4.2 Dune Vegetation

The vegetation associated with coastal, primary sand dunes must be able to withstand intense heat and cold, reflected light, salt spray, low-nutrient availability, strong winds, and shifting substrate. As such, few plants have evolved to exploit the harsh environment associated with dunes. The results of this study support this principle. Plant species identified in this study were American beach grass (*Ammophila breviligulata*), saltmeadow hay (*Spartina patens*), sea rocket (*Cakile edentulata*), switch grass (*Panicum virgatum*), running beach grass (*Panicum ararum*), reed grass (*Phragmites australis*), seaside goldenrod (*Solidago sempervirens*), sea oats (*Uniola paniculata*), yucca (*Yucca filamentosa*), Japanese sedge (*Carex kobomugi*), seabeach

sandwort (*Arenaria lanuginosa*), beach heather (*Hudsonia tomentosa*), Russian thistle (*Salsola kali*), and mixed woody/shrubs including wax myrtle (*Myrica cerifera*), wild black cherry (*Prunus serotina*), loblolly pine (*Pinus taeda*), red cedar (*Juniperus virginiana*), bay berry (*Myrica pensylvanica*), American holly (*Ilex opaca*), black locust (*Robinia pseudoacacia*), and various oaks (*Quercus* sp.). Many of the mixed woody shrubs mentioned are critical food sources for songbirds that migrate through these narrow shoreline dune systems each fall. Infrequent occurrences of opportunistic species such as blackberry and honeysuckle also were encountered as were manipulated and manicured dunes containing lawn grasses and ornamentals.

Virginia's Bay dunes are dominated by American beach grass and saltmeadow hay. Twelve sites contain monotypic communities of these species— six supporting only American beach grass and six supporting only saltmeadow hay. All other primary dunes are characterized by mixed vegetation communities, but the majority are dominated by American beach grass and/or saltmeadow hay. Other occasional dominants are sea rocket, switch grass, Japanese sedge, running beach grass, reed grass, seaside goldenrod, mixed woody/shrubs, and sea oats. Mixed vegetation communities included 69 primary dunes with two species present, 64 sites with three species present, 43 sites with four species present, and 43 sites with five or more species present.

For dune field plant communities, secondary dunes generally are equally or more diverse than the primary dunes. Only 10 of 28 dune fields' vegetation communities are more diverse on the primary dune than on the secondary dunes. The secondary dunes at these sites are either relatively narrow and are approximately the same width as the primary dune or the secondary dune contained large areas with no vegetation.

Over 75% of secondary dunes have three or more co-dominant plant species. Common dominants in decreasing order of occurrence are saltmeadow hay, American beach grass, running beach grass, switch grass, mixed woody/shrub, seaside goldenrod, and reed grass.

Plant community diversity was greatest for the dune systems in Northampton County and Virginia Beach. No sites in Northampton County had less than two species present on primary dune, and only two secondary dune sites had lower than four species. All of the dune sites in Virginia beach had vegetation communities characterized by five or more species except one in which the primary dune supported three species.

Japanese sedge (*Carex kobomugi*) and reed grass (*Phragmites australis*) are the only primary dune dominant plants found in this study not identified in the Dune Act. *C. kobomugi* is dominant on a few coastal primary dunes in Norfolk and Virginia Beach, and *P. australis* has a scattered Bay distribution.

3.5 Horseshoe Crab Habitat Assessment

Chesapeake Bay beaches associated with coastal primary sand dunes are characteristically steep, moist, and consist of a thick layer of sand composed of medium sized grains at the preferred nesting depth. The mean slope of the measured beaches is 11.8% (or 10.6 degrees) with

a standard deviation of 3.7% (Figure 13). Measured beach slopes in the Chesapeake Bay are significantly greater than beach slopes measured in Delaware Bay and Florida spawning sites. Penn and Brockmann (1994) showed beach slopes for both areas consistently between two percent and five percent.

The mean sediment moisture was 75.9% with a standard deviation of 15.5% (Figure 14). The differences in sediment moisture between the Chesapeake Bay sites and spawning areas in Delaware Bay and Florida are significant. Moisture in the upper sediment column at the mean high tide line averaged less than five percent at Delaware and Florida spawning beaches (Penn and Brockman, 1994).

A sand thickness of at least 8 inches is preferred to allow egg placement above anaerobic peat-based sediment (Brockman, 1990). Botton *et al.* (1988) hypothesized that horseshoe crabs may be able to detect beach quality from offshore by sensing compounds characteristic of anaerobic sediments such as hydrogen sulfide (H₂S), iron monosulfide (FeS), and Pyrite (FeS₂). However, horseshoe crabs have been known to bury eggs in areas with less sand (Carl Shuster, personal communication). Optimal sites have sand thicknesses of at least 16 inches. Only one site (LN21) had a sand thickness less than 8 inches, and five sites had sand thicknesses of between 8 and 16 inches (LN16, LN21, NL3 E, AC57, and AC59).

The mean of the median grain size is 0.024 inches (0.612 mm) (N=234; Figure 15), which is consistent with the optimum grain size found by Brady and Schrading (1998) at documented Delaware Bay spawning beaches (Figure 16A through 16D). However, median grain sizes were smaller in the Chesapeake Bay than the 0.04 inches (1.0 mm) Penn and Brockman (1994) found in Delaware Bay but marginally larger than the 0.012 inches (0.31 mm) beach sand found at a known spawning site on the Gulf of Mexico in Florida. Although median grain sizes for this study ranged from 0.007 to 0.34 inches (0.17 to 8.66 mm), grain size distribution across all sample sites showed little variation (SE \pm 0.0024 (\pm 0.062)). Variation is further reduced when the data set is analyzed after removal of three samples with median grain sizes greater than 0.3 inches (8 mm). These samples contained a large gravel fraction not normally characteristic of estuarine beaches. A mean median grain size of 0.02 inches (0.508 mm) (SE \pm 0.0066 (\pm 0.167)) describes the data for those 231 sample sites (Figure 17).

4 Discussion

4.1 Geographic Extent of Dune Systems

Dunes around the Chesapeake Bay estuarine system encompass only about 40 miles of shoreline. 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 (Accomack and Northampton), Southern Shore (Norfolk and Virginia Beach) and the Western Shore (Hampton, Mathews, Lancaster, and Northumberland). These three regions are subject to similar wind and wave climates. However, dune morphology can vary significantly within each region.

4.2 Dune System Evolution

Dunes and dune systems are products of sand source, transport, and deposition. The deposited sand must remain above a stable beach backshore to allow dune vegetation to become established. Each dune that has been documented 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. The Bay shores of Northampton County and Northumberland County from Fleeton to Smith Point were assessed in detail with the comparison of shoreline position in 1937 and 1994. Dramatic changes are revealed with this analysis.

Northampton County's Bay shore has eroded and accreted as much as 800 feet since 1937. The very nature of these extremes destroys dunes in one area and creates dunes in another. The sand budget, the loss, transport, and gain of beaches in response to the impinging wind-wave climate across a variable substrate, defines the histories and the present states of the dune sites. Man's impact is significant. Small cottage communities at Smith Beach and Silver Beach with associated groins, bulkheads and rip-rap have eliminated as well as created dune areas.

Can we predict the fate of existing dune sites? In some cases the nature of changing land use might be a key. For example, Site NH17 (Floyds Farm) is a dune field that has evolved and grown over time on a spit fed, in part, by eroded sediments from updrift shorelines. Those shorelines, once unmanaged and/or agricultural, recently have been converted to residential lots. Land use conversion is an important consideration in the evolution of dune sites. This residential coast has now become more valuable. If the new owners seek to halt the loss of this land through defensive measures such as bulkheads or rip-rap, the source of sand that has fed the spit, beach, and dune field to the south may be eliminated. This may cause the decay and landward migration of the spit feature overtime. Different types of erosion control measures will have varying impacts on downdrift shore features.

Creek mouths and man-influenced features like groins and jetties provide an area for sand accumulation that might, with time, allow dunes to form. Sand supply from outside the dune site also is important to the long-term integrity of dune sites. The sand can come from a combination of longshore and onshore/offshore transport mechanisms. Anthropogenic sources, such as beach

nourishment, also can provide the means for sand supply to adjacent shores such as at Ocean Park Beach in Virginia Beach.

4.3 Dune Classification

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 three main categories of natural, man-influenced, and man-made were an initial attempt to describe the genesis of dunes around Chesapeake Bay. These categories are appropriate designations but insufficient as descriptors. The dune morphology and wind/wave exposure more adequately portray the nature of a given dune site. For instance, 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.

Dune site stability is a qualitative assessment of the overall tendency of the site toward erosion, accretion, or generally stable. 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. 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 morphology of Chesapeake Bay dune sites shows a that 72% or almost 29 miles of dune coast are dune fields. The dune field designation of greater than 500 feet width is purely arbitrary because some site might only be 450 feet which would place them in another category. 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 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.

The underlying substrate of marsh or upland generally reflects the nature of the adjacent Bay coast. 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.

4.4 Field Investigation

4.4.1 Dune Morphology Parameters

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 (*i.e.* locality) and, eventually, to the environmental setting.

Primary dunes elevations (X) can be placed in order from highest to lowest: 1) Virginia Beach, 2) Norfolk, 3) Hampton, 4) Northampton, 5) Mathews, 6) Accomack, 7) Northumberland and 8) Lancaster. The primary dune feature 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. These can be termed “**growth components**”. Virginia Beach, Norfolk, Hampton and Northampton all possess these three components, and in the first three, which are “metropolitan” localities, this is enhanced by various beach nourishment projects. At the same time, developmental pressures are perhaps the greatest in these same three localities. All of the dune sites in Norfolk are man-influenced. Northampton County, although more remote, is facing more pressure from increased waterfront development.

Primary dune heights become smaller as the three growth components decrease in magnitude. Lancaster 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.

The relationship of the heights of primary dunes only to primary dunes with secondary dunes is more ambiguous with no clear trend as to geography. In an obvious separation in Norfolk, the primary dune only elevation averages 18.5 feet MLW while primary dune features with secondary dune average 11.6 feet MLW. Numerous beach nourishment projects may have added to the sand source, but limited data also may be a factor.

Even with developmental pressures, the average widest primary dune features (C+D) are also found in the three “metropolitan” localities. The other localities are listed in order as well: 1) Virginia Beach, 2) Hampton, 3) Norfolk, 4) Northampton, 5) Mathews, 6) Accomack, 7) Northumberland, and 8) Lancaster. This list places the localities in the same order as for average primary dune elevations (X). This is reasonable since the width should increase with the height.

Secondary dune elevation (V) averages are, in order of highest to lowest: 1) Virginia

Beach, 2) Hampton, 3) Norfolk, 4) Northampton, 5) Northumberland, 6) Mathews, 7) Accomack, and 8) Lancaster. Once again, the three “metropolitan” localities have the highest secondary dune elevations, and Lancaster has the lowest “V”. The associated average primary dune elevations are within about 1 foot of the average secondary dune elevations and might reflect the morphologic evolution since secondary dune crests were once primary dune features. In many cases, the secondary dune crests are slightly lower than the companion primary dune crests. This lower elevation of most secondary dune crests relative to the companion primary dune crests is probably a product of maturity and deflation in the lee of the primary dune crest.

Secondary dunes have average widths (A+B) of highest to lowest: 1) Virginia Beach, 2) Mathews, 3) Northampton, 4) Accomack, 5) Norfolk, 6) Northumberland, 7) Hampton, and 8) Lancaster. This order of localities is significantly different from the secondary dune elevation list most likely due to site specific coastal evolution/morphology and landside development variables. Mathews supplants Hampton and Norfolk for the number 2 position. However, Virginia Beach still has the widest average secondary dunes, and Lancaster has the narrowest.

The landside boundary of secondary dunes is more subjective which, in turn, makes defining the landward limit of a dune system (primary plus secondary) subjective. Total dune system widths (A+B+C+D) are in order by locality, highest to lowest: 1) Virginia Beach, 2) Mathews, 3) Hampton, 4) Northampton, 5) Norfolk, 6) Accomack, 7) Northumberland, and 8) Lancaster. Mathews is in the second position in the list possibly due to the low nature of its coast and ranking 3rd in primary dune width with secondary dunes. Also, Mathews has the highest percentage of dune coast that has been identified as accretionary ([Table 10A](#)) which provides a mechanism for dune system expansion.

4.4.2 Dune Vegetation

Plant community structure can be used as an indicator of dune stability and history. Primary dunes that are relatively stable generally have robust communities of American beachgrass, saltmeadow hay, and sea rocket. These species thrive in the hot, dry, and salty conditions associated with primary dunes. Conversely, dunes which have shrub communities or herbaceous species generally not characteristic of areas such as dunes that frequently encounter extremes of heat, dessication and salt may provide evidence of erosion or instability. For example, shrub communities are common in dune fields landward of primary dunes. Shrubs growing on primary dunes could indicate erosion through the primary dune into the secondary dune field. For situations such as these, the Dune Act and its associated intent becomes problematic.

Japanese sedge (*Carex kobomugi*) and reed grass (*Phragmites australis*) are not preferred communities but appear to function well in dune stabilization. Under current law, dunes with monotypic Japanese sedge or reed grass communities are not defined as jurisdictional. Both plants are invasive species that could potentially create monotypic communities.

Geological analyses of secondary dune fields showed a broad size range of a few feet to a few hundred feet. Of particular note is the general correlation between size and plant diversity for

secondary dune fields. This relationship will be explored in depth through the subsequent monitoring programs.

4.5 Horseshoe Crabs

Duplication of Brady and Schrading's HSI model for Chesapeake Bay beaches was planned; however, differences between the beaches in Delaware Bay and those in Virginia's portion of the Chesapeake Bay made this impracticable. The Brady and Schrading component index is calculated as follows:

$$CI = (V_1 \times V_2 \times V_3 \times V_4)^{1/4}$$

where $V_1 - V_4$ are separate HSIs for the four habitat variables previously described. Each HSI is calculated using the relationships shown in (Figures 16A-16D). Figure 16B shows moisture content above 18 percent results in a zero value for the HSI. The CI of the Brady and Schrading model is zero if any one variable's HSI is zero. Therefore, use of this model for Virginia's Bay beaches would result in CIs of zero for all sites. This is not an accurate measure of spawning habitat suitability for the lower Chesapeake Bay. High sediment moisture may be a primary factor affecting spawning activity and/or success in the lower Chesapeake Bay.

The data in the present study demonstrate that horseshoe crab spawning areas on Virginia's Bay beaches adjacent to dunes are generally consistent in physical character. This may indicate that spawning opportunities and success probabilities in the lower Chesapeake Bay are relatively independent of the habitat structure at the nest site. Factors other than those demonstrated for other western North Atlantic spawning areas may be significant. Jegla and Costlow (1982) found embryonic development and early larval growth optimal around 30 parts per thousand salinity. This may favor beaches adjacent to the higher salinity waters near the Bay mouth, and beaches that are not groundwater discharge foci (Holman and Sallenger, 1985). It is noteworthy that the majority of large beach/dune complexes are located near the Bay mouth in Northampton County and the cities of Norfolk and Virginia Beach. Another factor that may be of significance to spawning habitat suitability is the distribution and abundance of submerged aquatic vegetation (SAV) located immediately offshore of many of Virginia's Bay beaches. SAV is generally absent from areas of major spawning activity in Delaware Bay.

5 Conclusions and Recommendations

Based on information from this study and our experience with dune and beach management, we forward the following recommendations:

Dunes and Beaches

- **amend the legal definition of a dune.**

The current definition in the Dune Act is not consistent with Virginia estuarine coastal geology and is not inclusive of all areas that provide the erosion control and habitat functions of “coastal primary” dunes. Unlike ocean coast dunes, estuarine dune fields can contain dunes within the secondary system that are larger than the primary dune (the dune contiguous with mean high water). Delineation is often problematic with estuarine primary dunes because, also unlike ocean coast dunes, a continuous and consistent linear dune feature is not always present or readily apparent.

The plant diversity of estuarine primary dunes, as shown in this study, is more diverse than outlined in the definition in the Dune Act. Due to the highly erosional and accretionary nature of Bay dunes, plants currently growing upon primary dunes may be relic communities that developed on secondary dunes. Many plants that most commonly or exclusively occur on secondary dunes in ocean coast settings are probably able to tolerate the lower salinity salt spray characteristic of estuarine coasts and can therefore survive upon estuarine primary dunes. In addition, evidence from this study shows that estuarine dunes may be able to retain moisture to a greater degree than ocean coast dunes. This would allow survival of plants other than those able to tolerate xeric conditions.

The results of this study suggest secondary dune vegetation community structure may be influenced by location and size. Vegetation is used to define and delineate dune resources as outlined in the Dune Act. Secondary dune vegetation communities commonly include herbaceous and woody dominants not named in the Dune Act. More detailed vegetation studies are needed if it is the Commonwealth’s intent to define, delineate and regulate the use of secondary dunes in a manner consistent with the regulation of primary dunes.

This recommendation would require legislative changes to the Act.

- **expand the jurisdiction of the Act.**

Currently, only eight localities are defined by the Act (Accomack, Lancaster, Mathews, Northampton, and Northumberland counties and the cities of Hampton, Norfolk, and Virginia Beach) to contain jurisdictional dunes. We have identified (and are in the process of documenting through our year 2 effort) dunes and beaches in Bay localities excluded from the Act. These resources likely are performing the same functions of dunes and beaches within the named localities. Of significance in the excluded localities is the potential fate of subaerial beaches (sandy substrate above the mean low water line). Tidal wetlands jurisdiction extends only from

mean low water to mean high water in situations where intertidal plant communities are not present. Subaerial beaches do not generally contain vegetation communities identified in the Wetlands Act. As a consequence, there is currently no regulatory authority covering impacts to subaerial beaches in the localities excluded from the Dune Act. Beaches provide natural erosion control protection and habitat for estuarine aquatic and avian fauna. They are essential fish habitat for horseshoe crabs, which require subaerial beaches for spawning (see further discussion in the section below for horseshoe crabs).

This recommendation would require legislative changes to the Act.

- **establish Resource Protection Areas (RPA) landward of dunes and beaches.**

In most localities, coastal primary sand dunes occur within the boundaries of the resource protection area (RPA). Dune and beach protection could be enhanced if the bay side of the RPA began at the landward extent of either the primary dune (if present) or the subaerial beach rather than at mean high water. Overlapping authority would be eliminated, and the oversight now lacking for many secondary dune areas would be provided.

This recommendation would require implementation changes by localities.

- **emphasize dune and beach restoration/creation for erosion control.**

If constructed properly, dune and beach features can provide effective erosion control on many scales. Additional benefits from this upland protection strategy can include recreational access and estuarine habitat. Natural dune and beach systems can be used to develop design parameters for particular shoreline situations (morphology, stability, volume, etc.). This is further discussed in the section below for horseshoe crabs.

This recommendation would require a broad education effort.

- **consider adopting mitigation guidelines for dune and beach impacts.**

Impacts to dunes and beaches will necessarily occur from shoreline development. As documented in this study, dunes are present along a relatively small percent of the Bay's tidal shoreline. However, erosion control structures updrift can significantly impact beach and dunes downdrift. Consistent with regulatory programs for other important Virginia natural resources, compensatory mitigation should be included in the management of dunes and beaches.

This recommendation would require no legislative or regulatory changes.

- **establish a comprehensive dune and beach monitoring program.**

Our year 2 effort establishes the basis for a Bay-wide monitoring program, and a few localities infrequently assess their shoreline situations. Bay shorelines are highly dynamic, which makes defining, delineating, and managing dunes and beaches problematic. A comprehensive

monitoring program would provide scientists and managers the information necessary to make informed decisions and guide restoration/mitigation efforts.

This recommendation would require long-term funding commitments.

Horseshoe Crabs

Virginia-specific horseshoe crab fishery management measures enacted in response to presumed pressures on horseshoe crab stocks include regulations establishing harvest license requirements, an annual landings quota, prohibitions on the taking of horseshoe crabs by dredge in state waters during spawning season, and prohibitions on harvest during spawning season and in the vicinity of spawning areas (Virginia Marine Resources Commission (VMRC) regulation 4 VAC 20-900-10 et seq.). VMRC regulation 4 VAC 20-890-10 et seq. requires the use of bait bags in the channeled whelk fishery. Bait bags significantly reduces the amount of horseshoe crab bait needed to support the fishery.

These recently-enacted fishery management measures will significantly increase the protection of horseshoe crabs in the Mid-Atlantic region. However, concerns for critical habitat still remain. Since 1993, regulatory losses of intertidal beach habitat in Virginia's Chesapeake Bay has averaged approximately 1.4 acres per year (Virginia Institute of Marine Science Wetlands Program, 1999). Regulatory losses of some backshore (the beach above mean high tide and dunes have been documented, but these data are not readily summarized. The present Virginia tidal shoreline management structure allows for public interest review of projects that propose filling of beaches and dunes in the eight localities where sampling occurred. Resource loss is allowed provided the public and private benefit outweighs the public and private detriment. Tidal localities excluded from the Dune Act allow public interest review of only those projects that propose filling intertidal beaches. Intertidal beaches are defined as wetlands in Virginia and are regulated through the Wetlands Act. Opportunities for public review of filling backshore and dunes in the localities excluded from the Dune Act are not available. Subsequently, these beach and dune losses cannot be quantified. Issues such as these can only be addressed through changes to existing legislation.

Beach nourishment is an effective and preferred method of shoreline stabilization in Virginia. However, nourishment may have a detrimental effect on horseshoe crab spawning and nursery areas if placement occurs upon spawning beaches during the spawning season. Horseshoe crab larvae can potentially be trapped beneath the overburden after nourishment which potentially affects egg and larval oxygen availability (Eagle, 1983), the probability of successful migration from the nest, and the efficiency of shorebird predation on eggs and larvae. Time-of-year restrictions on beach nourishment activities presently exist only in areas adjacent to submerged aquatic vegetation beds. Time-of- year restrictions on all beach nourishment activities should be considered.

Shuster (1985) attributes the apparent lack of spawning activity in the Chesapeake Bay

relative to Delaware Bay to a general lack of beach resources, and the fractured distribution of those resources. Data from this study support Shuster's characterization of Virginia's Bay beaches. Beach restoration should be promoted if more horseshoe crab spawning habitat is desired. Restoration efforts would effectively compensate for losses accrued through regulatory programs and could mitigate natural erosion that affects horseshoe crab spawning success (Botton *et al.*, 1988). The benefits of beach restoration extend well beyond habitat creation and could be incorporated into locality-based comprehensive plans and/or shoreline management plans.

This study has shown that Chesapeake Bay beaches adjacent to dunes, within the preferred area of horseshoe crab spawning, are generally consistent in physical character. This may aid management efforts since changes could be applied consistently throughout the Bay. This would require assuming that beaches located immediately bayward of uplands exhibit the same physical characteristics as beaches supported by dunes. If more detailed information that would potentially result in spawning site ranking are needed, further study is required.

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Acknowledgments

The authors would like to thank the many people who contributed to the field aspect and data

analysis of this study: Thomas Barnard, Walter Priest, Sharon Dewing, Ann Newsome, Rebecca Brindley, Linda Meneghini, Tara Kniskern, and Vicki Pilon. In addition, the authors would like to thank J.J. Orth for allowing us access to the SAV photo archives. Out of a concern for the unprotected and relatively rare secondary dune habitats, coastal managers Jeannie Lewis-Butler and Laura McKay at the Coastal Resources Management Program at Virginia's Department of Environmental Quality were instrumental in initiating and obtaining funding for this multi-year project. Tony Watkinson from the Virginia Marine Resources Commission matched funding for this study. Finally, the authors would like to thank the property owners who allowed access to the shore; they are the true stewards of the Bay.