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FETCH LIMITED BARRIER ISLANDS OF CHESAPEAKE BAY AND DELAWARE BAY

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ABSTRACT

Barrier islands within bays, lagoons, estuaries and other protected waters have never been the subject of systematic research on a large scale. Within both the Chesapeake and Delaware Bays, barrier islands are numerous and widely distributed. Totaling more than 300 in number, these fetch limited barrier islands exhibit a range of morphologies uncommon along open ocean shorelines. We group the barrier islands in the two bays into three primary categories based on their morphology and location. In general, they are much shorter (~1km), narrower (<25m), and lower (1-2m) than their open ocean analogs, yet they behave in much the same way in their response to oceanographic processes. The greatest difference between ocean and bay barriers is the strong control of evolutionary processes by vegetation, usually salt marsh, in the bays.

INTRODUCTION

For decades barrier islands have been the focus of intense scrutiny (for example Hoyt 1967, Schwartz 1973, Glaeser 1978, Hayes 1979, Oertel 1985, McBride *et al* 1995, Martinez *et al* 2000, Stutz 2002). They are numerous and particularly well-studied along North America's Mid-Atlantic coastline (Swift 1975, Davis 1994, Riggs *et al* 1995, Moslow and Heron 1994, Hayes 1994). However, barrier islands *within* bays such as the Chesapeake and Dela-

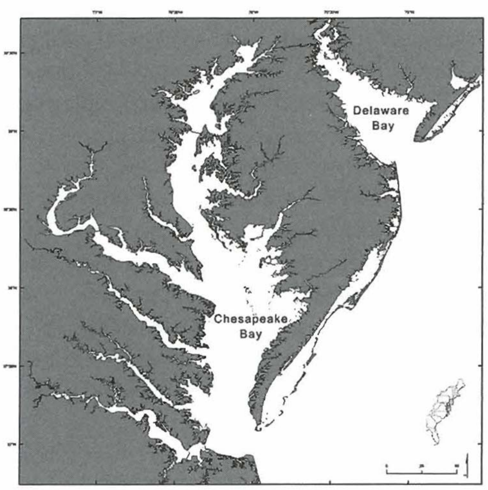

Figure 1: A regional map of the Chesapeake and Delaware Bays.

Figure 2: A typical active fetch limited barrier island, backed by a salt marsh lagoon on the western shore of the Chesapeake Bay.

Figure 3: A patch of junctus grass that completely surrounds an inactive barrier island.

ware (Figure 1) have received little attention and have never explicitly been the subject of any systematic research.

The barriers along the shorelines of both bays are abundant, well-developed, and consistent with the common definition of a barrier island. Oertel (1985) states that a barrier island must be (1) an elongated body of unconsolidated sediment (typically sand) (2) bound by inlets (3) backed by a lagoon (4) fronted by a marine shoreface (5) perched upon a barrier platform and (6) protecting a mainland coastline.

In this paper we distinguish *active* barrier islands (Figure 2), those that form within a fetch limited environment and are subjected to wave and current activity, resulting in modification of the islands, either or both constructive or destructive from *inactive* islands (Figure 3), which are those being currently modified more by subaerial rather than by oceanographic processes (usually because the features are enclosed by salt marsh and mangroves). In this report we focus exclusively on the active barrier islands of the Chesapeake and Delaware Bays.

There are nearly 7500 such *active* barrier island features within lagoons, bays, and other protected marine bodies around the world– a figure nearly three times the number of open ocean barrier islands (Stutz *et al*, 2002). Though abundant and widely distributed, fetch limited barrier islands comprise just one quarter the total shoreline distance covered by open ocean barrier islands, globally. Size is the most glaring difference between barrier islands along open ocean and fetch limited coastlines – fetch limited barrier islands are rarely much more than 1km long, while those on ocean shorelines are usually longer than 10km.

Our global survey and the results of field and remote analysis of barrier islands in the Chesapeake and Delaware Bays focus on low-energy sheltered shorelines which total over 10,000km of estuarine shoreline. Barrier island research more frequently focuses upon the socially and economically more important open ocean coastlines. However, the Chesapeake and Delaware Bays are large wetland ecosystems, and also important for navigation, trade, defense, and recreation. This paper provides an analysis and discussion of the distribution, morphology, and evolution of the bays' barrier island shorelines that have hitherto been overlooked in the literature. Our research relied heavily upon aerial photos, satellite imagery, USGS 1:24,000 topographic maps, NOAA navigational charts, and historical maps and charts. In addition, we conducted field and aerial reconnaissance, plotting the distribution of barrier islands throughout the Chesapeake Bay and the Delaware Bay, and noting trends in island morphology and behavior.

As this research is among the first of its kind to focus on low energy barrier island systems, it is subject to unique limitations. In addition to distinguishing between active and inactive barrier islands, we found it important to note the difference between islands forming under natural processes and those originating from human design, manipulation, or activity. Given the high degree of development and modification throughout both bays, *anthropic* islands are abundant. Differentiating anthropic islands, which are usually formed from dredge spoil, from active islands is the foremost challenge among the factors imposing limits upon this research. The overwhelming dominance of small sand features among the population of barrier islands in the bays, mostly sand bars atop salt marsh rims 10 to 25m in length, posed another concern. Thus, the minimum island length was arbitrarily established as 50m, primarily owing to limitations in remotely collected data and the accuracy of published maps and charts.

SETTING

The Chesapeake and Delaware Bays are located in the Mid-Atlantic Region of the United States. Both bays are large drowned river estuaries, subject to a highly variable temperate climate regime on the tectonically passive Atlantic margin of North America. The Delmarva Peninsula and Cape Charles protect the Chesapeake Bay from ocean swells, while southern New Jersey and Cape May shelter the Delaware Bay. The bays experience freezing during the winter months and regular, modest flooding during the spring. Nordstrom and Sherman (1982) describe the effects of freezing on estuarine beaches at mid-latitudes, including extreme recession of shorelines, ice scour, wave dampening, and melt runoff. Both bays experience their most severe weather in the late autumn and winter, with storms primarily coming from the north and northeast (Hardaway *et al* 2001).

In terms of size, the bays differ by an order of magnitude: Chesapeake Bay is 11600km^2 in area and has nearly ten thousand kilometers of tidally influenced shoreline, whereas the Delaware Bay, which is 2100km^2 in area has just one thousand kilometers of shoreline. The extreme difference in shoreline length is attributable to the more than one dozen tributary estuaries within the Chesapeake Bay. The Delaware Bay has just one main estuary and its shorelines are comparatively straight and smooth. The length of the primary channel of the Chesapeake Bay is 288km, greater than that of the Delaware Bay (84km) by a factor of 3.5. In addition, the Chesapeake Bay shows a high degree of variability in its shoreline orientation and morphology (Rosen 1980). The non-barrier island shoreline of the Chesapeake Bay is either marsh, barrier beach (not island), heavily modified by humans (seawalled, etc.), rocky, muddy, or riparian. The shorelines of Delaware Bay are characteristically straight (homogeneously oriented) and sandy.

Chesapeake Bay is as much as 53m deep, but on average is 8-10m; Delaware Bay is at most 25m deep and on average 10m.

Hobbs (2003) describes the history of Chesapeake Bay. Pre-existing topography – mainly fluvial deposits – strongly influences the shorelines of both bays (Kayan and Kraft 1971). Modern controls on large scale bay evolution include a rising sea level (~2-4mma^{-1}) and drastic human modification of shorelines (seawalling, dredging, dredge spoil disposal, wetland destruction, pollution, and beach nourishment) (Colman and Mixon 1988; Nikitina *et al* 2000; Smith *et al* 2002). Wave heights are typically very low (<0.25m) throughout both bays except during storms; storm surge wave heights can reach anywhere from 2-3m (Hardaway *et al* 2001). Both bays are subject to a diurnal tidal regime with a range of approximately 1m near their openings and less than 0.3m near the head of the bay.

CLASSIFICATION OF FETCH LIMITED BARRIER ISLANDS

In addition to distinguishing between active, inactive, and anthropic islands, we divide active fetch limited barrier islands in Chesapeake and Delaware Bays into three primary categories and two notable sub-categories as shown in Table 1.

Classic fetch limited barrier islands are the most abundant in terms of total length (134km) and are most similar to the Atlantic open ocean coastal plain barrier islands (Figure 4). They are the longest of the three types of islands, averag-

Table 1:

Types of fetch limited barrier islands
I. Active
I.1 Classic
Relict topography
I.2 Marsh fringe
Wraparound
I.3 Two-sided
II. Inactive
III. Anthropic

Figure 4: A classic barrier island on the western margin of the lower Chesapeake Bay. Such islands are very similar in evolutionary processes to open ocean barrier islands. Note that this island is heavily developed.

ing 2.4km, and the widest by a factor of five (Table 2). Most are greater than 100m wide, and some are as much as a kilometer wide. In their morphology and evolution, we determine that classic barrier island behavior is very similar to that of open ocean barriers. Classic islands are prone to extensive overwash and cross-shore migration as well as alongshore elongation forming recurved spits with dynamic inlets. These islands are occasionally lightly developed with homes and fishing shacks.

Marsh fringe barrier islands are the most abundant in number, with 254 islands accounting for nearly 80% of all barrier islands in the two bays. These islands are thin (1-2m) veneers of sediment perched over salt marsh vegetation, peat, or mud (Figure 5). They are often just tens of meters wide and rarely more than a kilometer long (0.5km on average). Many exhibit a crescent shape, concave to the water and trapped between marsh grass outcroppings (Figure 6), vaguely reminiscent of a pocket beach on a lithified coast. The marsh outcrops act as anchor points or headlands that control the development of the barrier island plan form.

Two-sided barrier islands are similar to classic islands in many ways except that they are often subject to significant fetch in multiple directions. They thus develop active barrier beaches on both the lagoon and seaward sides of the island (Figure 7). Indeed, distinguishing the lagoon side from the 'open water' side is quite impossible. Just thirteen of these islands exist in the Chesapeake Bay (none in the Delaware Bay) averaging in length 1km apiece. Historic Tangier Island is perhaps the most noteworthy example.

The two interesting sub-classes of islands that we identify in this study are ***wrap around*** and ***relict topography*** islands. Wraparound barrier islands are horseshoe-shaped marsh fringe islands which partially or fully enclose a shal-

Table 2: Summary of island types in the Chesapeake Bay and Delaware Bay

Island Type	Description	Number	Total Length (km)	Avg. Length (km)	Avg. Width (m)
Classic	Long, wider, and straight; most similar to coastal plain barrier islands along ocean coasts	55	134.1	2.4	200
Two-sided	Subject to >10km fetch in two directions; develop barrier beaches on two sides	13	12.1	0.9	65
Marsh Fringe	Short and narrow, with irregular shoreline shape; heavily influenced by marsh grasses	254	118.9	0.5	15
Total		322	265.1	0.8	65

Figure 5: A marsh fringe barrier island on the eastern shore of the Delaware Bay.

Figure 6: Two marsh fringe barrier islands between marsh mud capes; these islands are similar in origin to pocket beaches on rocky coasts.

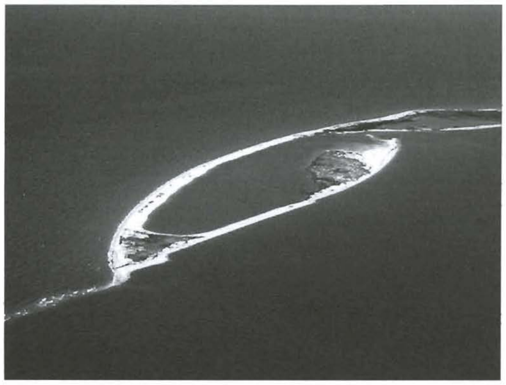

Figure 7: The southern tip of Tangier Island in Chesapeake Bay, shown here, is a two-sided island. Fetch is essentially the same on both sides of the island, so the distinction between open water and lagoon is meaningless.

Figure 8: A wraparound barrier island on the eastern shore of Chesapeake Bay. The island consists of a series of small strips of sand that enclose a salt marsh.

low marsh lagoon. These islands are influenced by wave attack from a dominant direction, but, through wave refraction around a fixed point (often a marsh remnant), tend to envelop the marsh or open water behind that obstacle (Figure 8). Islands that form from drowned Pleistocene or early Holocene river valley topography or Pleistocene barrier islands are termed relict topography barrier islands. These are a special case of classic type islands, and are often much wider than other classic islands (Figure 9). There are several inactive barrier islands in Chesapeake Bay that appear to have developed on the rims of Carolina bays.

ISLAND MORPHOLOGY AND CHARACTERISTICS

The shape of the fetch limited barrier islands – especially among the marsh fringe islands – varies greatly throughout the Chesapeake Bay, whereas barrier islands in the Delaware Bay are characteristically straight and narrow. In both bays the classic islands are consistently long and narrow (though those influenced heavily by relict topography may be up to 1km wide). Most exhibit minimal or no dune development, although the southernmost islands along the western shore of the Delaware Bay have artifi-

Figure 9: An unusual classic type barrier island formed from relict topography (Photo courtesy of the National Oceanic and Atmospheric Association).

Figure 10: A marsh fringe barrier island on the eastern shore of Delaware Bay, with an extensive dissected marsh mud flat facing the open bay.

Figure 11: A close-up of a marsh flat on the open bay beach with numerous stumps that have been overrun by the migrating barrier island, eastern shore of the Chesapeake Bay.

Figure 12: A classic type fetch limited barrier island on the western shore of Chesapeake Bay with an open water. More commonly, fetch limited barriers in these bays are backed by salt marsh lagoons.

cial dunes protecting houses in some areas. Marsh fringe islands in the Chesapeake Bay adopt a surprising array of irregular, undulating plan forms. At one endpoint, wraparound barriers are highly angular, subject to 20km or more fetch in multiple directions, and enclose a shallow marsh lagoon. At the other extreme, short (~100m) barriers adopt a crescent morphology trapped between marsh grass outcroppings. Two-sided islands are linear with a wave-worked subaerial beach on two sides of the inner upland separated by a narrow cat's eye pond or marsh lagoon.

Although there is considerable variation between classic and marsh fringe islands, the low-tide subaerial portion of most islands extends less than 50m in the cross shore direction. Islands are occasionally as little as 5m across in areas of frequent breaching. These barrier islands are generally thin veneers of sand; trenches revealed that the sand is rarely more than 1-2m thick, though classic islands are occasionally much thicker. The sediment is composed largely of brown, coarse, quartz sand with some gravel. Thin layers of dark 'heavy mineral' deposits are observed on southern barriers, where the marine contribution to the sediment is highest. In the northern parts of both bays, much of the barrier island sediment is terrigenous weathered coastal plain and piedmont sand (Langland

Figure 13: A small gap or 'inlet' between two marsh fringe barrier islands on the western shore of Delaware Bay.

Figure 14: A small ebb tidal delta at the mouth of a man-made channel, separating two marsh fringe islands on the western shore of Delaware Bay. Flood tidal deltas are almost nonexistent in the lagoons of the barrier islands of these bays.

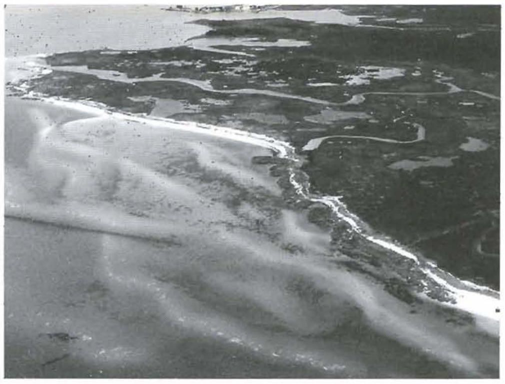

Figure 15: Large rhythmic bars in front of two marsh fringe barrier islands in western Chesapeake Bay. These bars are an important sediment sink for this system.

Figure 16: A marsh fringe barrier island in Delaware Bay with an extensive eroded marsh platform.

and Cronin 2003). Discharge from the many rivers entering these two bays has been limited to fine silts and clays in suspended sediment in recent times (Knebel 1989).

In general, barrier islands throughout the bay are located along or near extensive communities of standing salt marsh. Living salt marsh grass (*Spartina alterniflora*) and marsh mud are common features on many beaches (Figure 10). The nearly universal presence of marsh vegetation in such circumstances is interpreted as indication that the island has migrated landward over or onto the marsh and that vegetation is recolonizing in the mud. Frequently stumps are found within salt marsh flats on the beach (Figure 11). In one case a log road from colonial times was observed on a beach marsh flat. That an open water lagoon backs just 21% (71) of the islands (Figure 12) – the balance have standing salt marsh in their backbarrier lagoon – is the best evidence of landward island migration.

Morphologic evolution and transport of sediment in the alongshore direction is clearly evident on classic type islands influenced by high angle storm waves. Many of these exhibit signs of spit elongation and recurving. Comparison of

Table 3: Summary of island chains in the Chesapeake Bay and Delaware Bay

	Chain	Number	Total Length (km)	Avg. Length (km)	Avg. Width (m)	Avg. Lagoon Width (km)	Avg. Fetch (km)
A	Eastern Shore	63	31.7	0.5	20	2.3	23.6
B	Pocomoke Sound	6	0.4	0.1	10	2.8	20.0
C	Tangier Sound (S)	22	17.7	0.8	10	1.7	13.5
D	Tangier Sound (N)	21	7.7	0.4	10	2.4	8.6
E	Deal Islands	5	13.5	2.7	1000	N/A	9.0
F	Nanticoke River	3	2.2	0.7	15	1.2	6.7
G	Hoopers Island	5	1.8	0.4	10	0.4	15.0
H	Bloodsworth Island	5	2.1	0.4	10	N/A	20.0
I	Tangier Islands	29	17.3	0.6	15	N/A	21.7
J	Balls Neck	8	3.2	0.4	10	0.2	33.8
K	Fleet Island	5	8.5	1.7	150	0.3	10.0
L	Gwynn Island	10	18.1	1.8	40	1.2	26.0
M	Plum Tree Island	18	13.2	0.7	45	1.5	24.7
N	Currioman Bay	3	3.5	1.2	25	0.9	10.0
-	No Chain	15	12.3	0.8	290	1.1	11.7
	Chesapeake Bay	218	153.1	0.7	65	1.4	19.2
	Delaware (Eastern)	43	71.4	1.7	45	0.4	15.4
	South Jersey (Western)	28	20.0	0.7	20	1.4	17.4
	Jersey (Western)	34	19.9	0.6	10	1.1	9.5
	Delaware Bay	105	112.0	1.0	30	0.9	16.4
	Total	323	264.3	0.8	50	1.2	17.5

historic maps and charts reveals that marsh fringe islands also migrate and disappear – likely in conjunction with large, singular storms.

True inlets separate less than half of all the islands; most of those with inlets are classic islands. Marsh fringe islands are commonly interrupted only by gaps in the sand deposits. These gaps are usually occupied by mud and marsh grass (Figure 13). Deltas are commonly associated with inlets between classic islands (Figure 14), although most are ebb deltas and flood deltas are extremely rare. Among the classic islands of both bays, tidal deltas appear to be important components of the barrier complex, actively involved in the alongshore movement of sediment from island to island.

Large rhythmic offshore bars are present in both bays, indicating an important nearshore sediment storage system or sink (Figure 15). A true shoreface was rarely observed for marsh fringe islands; instead a broad, eroded marsh platform extends seaward (Figure 16) from the beach. For classic and two-sided islands, a gently sloping sand cover (soft bottom) usually gives way to a peat-mud platform, hardbottom, or the aforementioned ripples within just a few tens of meters from shore.

Chesapeake Bay

We identify 220 active fetch limited barrier islands within the Chesapeake Bay (Figure 17, Table 3). These islands total just 153km in length but comprise large sections of shoreline along the main channel south of the Potomac River. Less than one dozen islands exist along the shorelines of the bay's sub-estuaries (e.g. James River, York River, Potomac River, etc.).

Aside from Fisherman's Island (which we do not consider to be fetch limited), there are no islands in the entrance of the Chesapeake Bay in the vicinity of Hampton Roads and Norfolk. Moreover, for the southern 40km of the eastern (Cape Charles) shoreline, there are no barrier is-

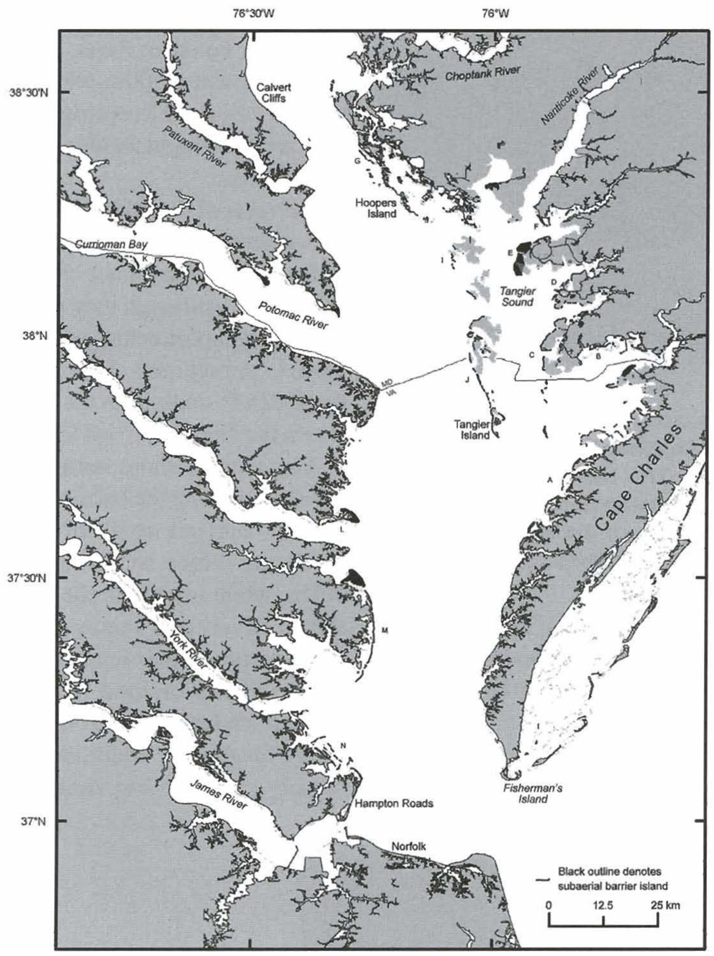

Figure 17: A map showing the location of barrier islands in Chesapeake Bay. The islands are shown by dark lines.

lands at all. As is also observed on southern Cape May, large (10-15m) dunes covered in trees and shrub back the mainland-attached barrier beaches of southern Cape Charles.

The long, southernmost chains of islands on both the eastern and western shores of Chesapeake Bay contain a discontinuous, irregular mix of classic and marsh fringe type islands. The chains are regularly broken by wide inlets corresponding with the outlet points of rivers, both large and small. The islands on the western shore are typically longer (1km) and wider (75m) than those on the eastern shore (0.5km and 20m, respectively). There is also considerable difference in the width of the backbarrier lagoon between the southern islands of the western and eastern shorelines. Barrier islands on the western shore are backed by a lagoon just half the width on average of that on the eastern shore. This difference is likely attributable to the asymmetric distribution of large storms. Nor'easters, the storms that generate the greatest sediment supply originate from the east and tend to push sediment westward.

Islands in the Tangier Sound and near the mouth of the Nanticoke River on the eastern shore are almost exclusively marsh fringe barrier islands and are associated with marsh wetlands as much as 5km wide. The northernmost islands (Hoopers Islands) are short marsh fring-

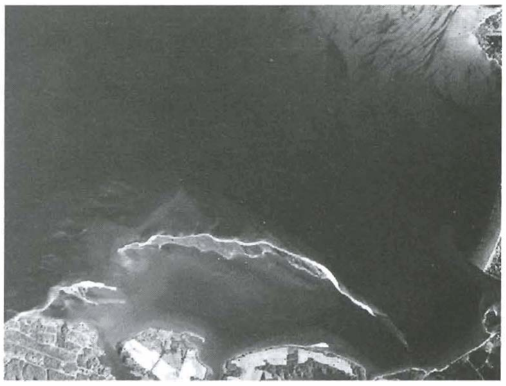

Figure 18: Classic barrier islands in the Currioman Bay of the Potomac River, a branch of the Chesapeake Bay. The backbarrier lagoon is 300m wide and the islands are densely vegetated. (Photo courtesy of the National Oceanic and Atmospheric Administration)

ing barriers associated with the drowned mainland topographic fragments extending from the mainland. The barrier islands within the Potomac River sub-estuary (to the north) and the James River sub-estuary (to the south) are a mix of classic and marsh fringe barrier islands. The three islands of Currioman Bay (Figure 18), within the Potomac River, are densely vegetated and protect a 300m-wide open water backbarrier lagoon. Excepting their short length, they are indistinguishable from open ocean barrier islands.

Two sets of two-sided islands with their long axes oriented north and south divide the Tangier Sound from the main channel of the Chesapeake Bay. Although they appear to be situated in the geographic center of the bay, they sit on a narrow, submerged shallow topographic high that extends south from the mainland 'neck' between the Nanticoke and Choptank Rivers.

The average shore normal fetch varies considerably among the barrier islands in the Chesapeake. Barriers south of the Potomac River mouth are subject to fetches ranging from 20 to 30km, while islands in the Tangier Sound, Potomac River, and James River are subject to shore perpendicular fetch distances of less than 15km. The two-sided islands are subject to 20km fetch both due east and due west. Neither island length, nor width, nor type appear to be closely correlated to shore normal fetch, al-

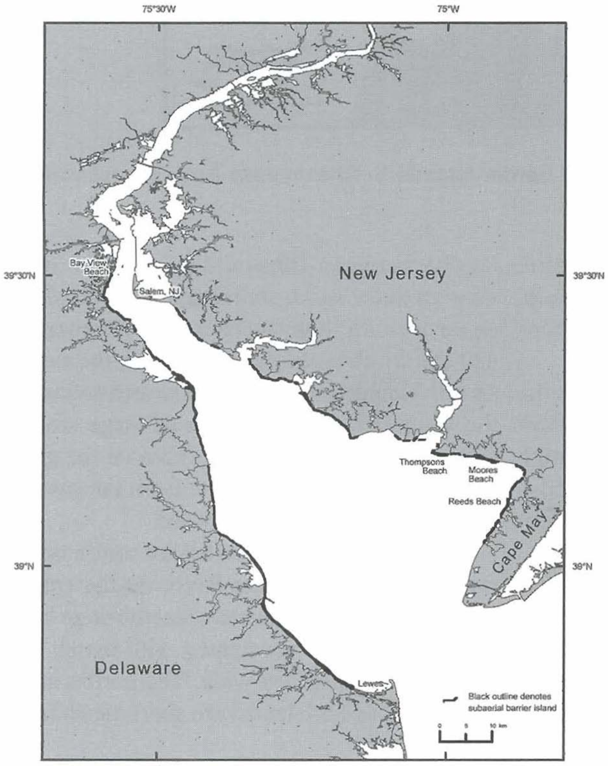

Figure 19: A map showing the location of barrier islands in Delaware Bay. The islands are shown by dark lines.

Figure 20: A portion of a classic barrier island in western Delaware Bay. The classic barrier islands along the lower shorelines are the best developed within Delaware Bay.

though all of the longest islands (>1.5km) are along the main channel of the lower bay where the maximum fetch along the north-south axis of the bay exceeds 50km.

Delaware Bay

There are 105 active fetch limited barrier islands along the shores of the Delaware Bay (Figure 19). The islands comprise 112km of the nearly 1000km of north-south trending, tidally-influenced, estuarine shoreline that stretches to above the city of Philadelphia, PA. Islands are more numerous on the eastern (New Jersey) shoreline, but account for just one-third of the total barrier island shoreline length within this bay. Barrier island development is far more continuous along the western (Delaware) shoreline than along the eastern. Barrier islands run nearly uninterrupted from just north of Lewes, Delaware to Bay View Beach, Delaware, while the eastern shore has several shorter stretches of islands interrupted by muddy marsh shoreline.

Nearly all of the lower bay shoreline, extending north to the bay narrowing at Salem, NJ, is protected by a barrier island shoreline. Notably, the southernmost 10km of both the Delaware and New Jersey shorelines are mainland-attached barrier beaches, topped on the New Jersey side by large (10-15m) dunes. These dunes are likely relicts of previous sea level high stands (Nordstrom and Jackson, 1994). Along these southernmost reaches, salt marsh vegetation is noticeably absent and development of houses, small harbors, and other structures is quite dense. It is possible marsh fill to accommodate towns such as Lewes, Delaware and Cape May, NJ has resulted in barrier island chains merging with the mainland shore. That a similar distribution is observed in the Chesapeake Bay is not a coincidence. The shorelines nearest the bay mouth are subject to heavy development pressures for sites of urban build-up, defense, transport, farmland accessible by boat, and recreation.

The barrier islands in the lowermost parts of both the Delaware and New Jersey shorelines are consistently classic type islands, the largest, straightest, widest, and best developed of any throughout the bay (Figure 20). Not coincidentally, these islands are subject to the most intense wave climates, occasionally feeling ocean swells on the Delaware shore and receiving marine contributions to the sediment supply. Moving northward on both shorelines, the islands decrease in length, width, elevation, and sediment supply along a gradient in rough proportion to wave energy climate and normal fetch – a pattern much more evident here as compared to the Chesapeake Bay. An exception to this trend is a series of east-west trending islands, comprising Thompson's Beach and Moore's Beach on the New Jersey shoreline, that face south towards the bay entrance. These islands are the longest of any on the New Jersey (eastern) shore, and are subject to wave conditions much more energetic than west-facing neighboring islands to the southeast. The northern islands are almost entirely marsh fringe barrier islands. Two-sided islands do not exist in the Delaware Bay. As with the islands in the Chesapeake Bay, shore normal fetch is not a good predictor of island length or width. In general, though, islands with fetches exceeding 20km in the shore normal direction are classic islands; those with less than 20km fetch are marsh fringe islands.

Figure 21 & 22: A barrier island in Tangier Sound, Chesapeake Bay showing numerous overwash fans. A closeup of overwash aprons on a barrier island on the eastern shore of Chesapeake Bay.

CONTROLS ON FETCH LIMITED BARRIER ISLAND EVOLUTION

The results of this survey raise two related questions: (1) why do barrier islands exist along some bay shoreline segments and not others? (2) What will become of these islands in the future? While no simple answer exists to either question, analysis of ongoing island processes and existing knowledge of barrier island characteristics offer a perspective into island genesis and evolution.

Classic, marsh fringe, and two-sided barrier islands, like open ocean coastal plain barriers, form because they represent a stable shoreline configuration on low-slope coastal plain shorelines. These islands develop in the Chesapeake and Delaware Bays where (1) the land surface slope is low enough (2) the sediment supply great enough and (3) a topographic or vegetative nucleus exists to provide the impetus for island growth and development.

Thus islands are very numerous in the extremely low-gradient southern reaches of both bays, but do not exist along the central-western shore of the Chesapeake Bay in the vicinity of the 10m high Calvert Cliffs. In areas where barrier islands are abundant, tidal and mud flats are universally present, extending a kilometer or more offshore to the 3m contour depth. In the region of the Calvert Cliffs, the 3m contour is just 200m from shore. Likewise, much of the marsh shoreline of Tangier Sound lacks barrier islands because the sediment supply is too low or there is not adequate wave energy to push the sand onshore.

A wave-energy gradient is also responsible for the division between classic and marsh fringe islands. Greater wave energy, in part related to greater fetch, is responsible for creating longer, wider islands, and for smoothing islands into elongated sand bodies. Higher wave energy prevents vegetation from growing on the shoreface and in the inter-tidal zone. The growth of vegetation on and behind marsh fringe barrier beaches, a direct result of lower wave energy, exerts strong controls on the plan form of those islands. Proximity to the bay opening is another distinguishing characteristic between classic and marsh fringe islands, particularly in the Delaware Bay where the division is highly pronounced. Classic islands develop nearest the bay openings; marsh fringe islands develop in the lower wave energy, northern estuarine waters. Both the marine contribution to the sediment supply and wave energy are major reasons for such a division.

Sediment in the intertidal zone, nearshore system and bay bottom is rarely impacted during fair weather conditions. However, heavy seas and high winds will mobilize the sediment. As waves shoal on shore, the existing marsh grass stabilized in a peat or mud substrate reduces wave energy and induces sediment settling. Storm deposits of sediment on the salt marsh fringes of the bays and the consequential

Figure 23: A groinfield on the western shore of Chesapeake Bay near Hampton Roads. The direction of sediment transport is clearly from right to left (North to South) in the photograph.

Figure 24: A jetty at Reeds Beach, NJ in Delaware Bay shown here has trapped a significant amount of sand by the standards of fetch limited barrier islands.

overwash and future storm breaching are the primary mechanisms for island development.

These barrier islands are thus subjected to breaching and overwash with each passing storm event (Figures 21 and 22). Because subsequent fair weather conditions are inadequate to return shoreface profiles to equilibrium, sediment likely moves dominantly in the onshore direction. The Bruun Rule of shoreline response to rising sea level is thus particularly inapplicable along these low energy shorelines (Pizzuto 1985).

Erosion – better termed barrier island migration in the landward direction – is the dominant long term trend for these islands. Rosen (1980) determines that classic type islands are eroding at 0.85m/year, though with a high degree of variability (1.85 m/yr standard deviation), while marsh fringe islands are eroding at just 0.66m/yr. The lower erosion rate may be related to reduced fetch as well as to the complex interactions between fetch limited waves, the marsh platform and the presence of marsh grass on the shoreface. Pizzuto (1986) gives an erosion rate of 3m/yr for a classic transgressive barrier island along the western shore of the Delaware Bay, though this figure cannot be taken as representative for all of the barrier islands of the bay (Phillips 1986).

Stevenson *et al* (1996) describe the processes impacting island erosion and development throughout the Chesapeake Bay and conclude that antecedent topography plays an important role. They also note that shoreline evolution differs dramatically between the east and west shores of the bay. They observe an evolutionary process by which topography is drowned, becomes detached, and begins to behave as a barrier island system.

A slow but constant sea level rise is a collaborating factor, serving to augment storm surges and expedite erosion. Sea level rise alone, though responsible for loss of marsh wetlands, is unable to "drown" the barrier islands because the islands are so easily activated and are highly mobile during large storms.

Tides and aeolian processes appear to be of little importance in the long term evolution of fetch limited barrier islands within these two bays. The narrow tidal range in this region may be important in maintaining inlets and ensuring the health of backbarrier marsh communities, but likely has little impact on the overall morphology of barrier island shorelines. As dunes are rare, except for artificial ones, wind-blown sediment processes do not appear to contribute significantly to island genesis or evolution.

Given the extent of development in zones within ten kilometers of both bays' shorelines, human impact on the fetch limited barrier islands is very significant. Artificial islands are common, usually as piles of dredged sand along small channels, and were ignored in our survey. More localized influences were impossible to

Table 4: Comparison of Open Ocean and Fetch Limited Barrier Islands

	Open Ocean (Virginia & New Jersey)	Fetch Limited (Chesapeake & Delaware Bays)
Number	20+	300+
Avg. Length	>10km	1km
Avg. Width	>400m	50m
Avg. Lagoon Width	>5km	1km
Dunes	3-5m	Negligible
Maritime Forests	Dense	Negligible
Delta size (approx)	>300m^2	<100m^2
Marsh grass on beach	Rare	Common
Overwash	Important response	Dominant response
Storm waves	Significant impacts	Dominant process
Fair weather waves	Significant for alongshore transport and cross-shore stability	Negligible
Aeolian processes	Important	Negligible
Tidal dynamics	Important (many tidally-dominated)	Negligible
Response to SLR	Landward-migration or 'backstepping'	Landward-migration or 'back-stepping'
Vegetative Control	Negligible	Dominant control
Geologic Control	Primary control	Important
Human development	Dense (highrise structures)	Light (fishing shacks)

exclude. Foremost among these is the existence of extensively sea-walled shorelines throughout the bay. Many of the largest classic islands are heavily sea-walled, which has in effect "frozen" the islands in position. Jetties, groins, breakwaters, and nourishment each have associated effects on barrier island processes (Figure 23) – the cumulative impact of which may be quite significant. There is no doubt that the construction of a large jetty has adversely impacted the downdrift shorelines of Reeds Beach, NJ (Figure 24). Nourishment, an ongoing process on the western shore of Delaware Bay, has stabilized the barrier beaches, but has likely resulted in narrower than normal beaches because the islands are not permitted to overwash naturally. Indeed any human activity or development that mandates a stable shoreline imperils the barrier islands that are so heavily dependent upon being fully responsive to storms.

Because these barrier islands and their marsh lagoons are much more interdependent than open ocean barrier islands, ecological damage to the wetlands has profound implications for barrier island evolution. Marsh grass die-offs, wetland loss, ecosystem disturbance, and marsh dredging bode ill for the sustained existence of fetch limited barrier islands.

CONCLUSIONS

The important features and controls on the fetch limited barrier islands of Chesapeake and Delaware Bays can be concisely expressed as a comparison to the oceanic barrier islands of New Jersey and Virginia (Table 4).

A nearly continuous chain of oceanic barrier islands runs from Raritan Bay at the New York-New Jersey border south to Fisherman's Island at the mouth of the Chesapeake Bay. Only a 60km stretch of the Northern New Jersey and a similarly-long stretch of the Delaware and Maryland shorelines are not fronted by barrier islands (Figure 25). The twenty-two open ocean

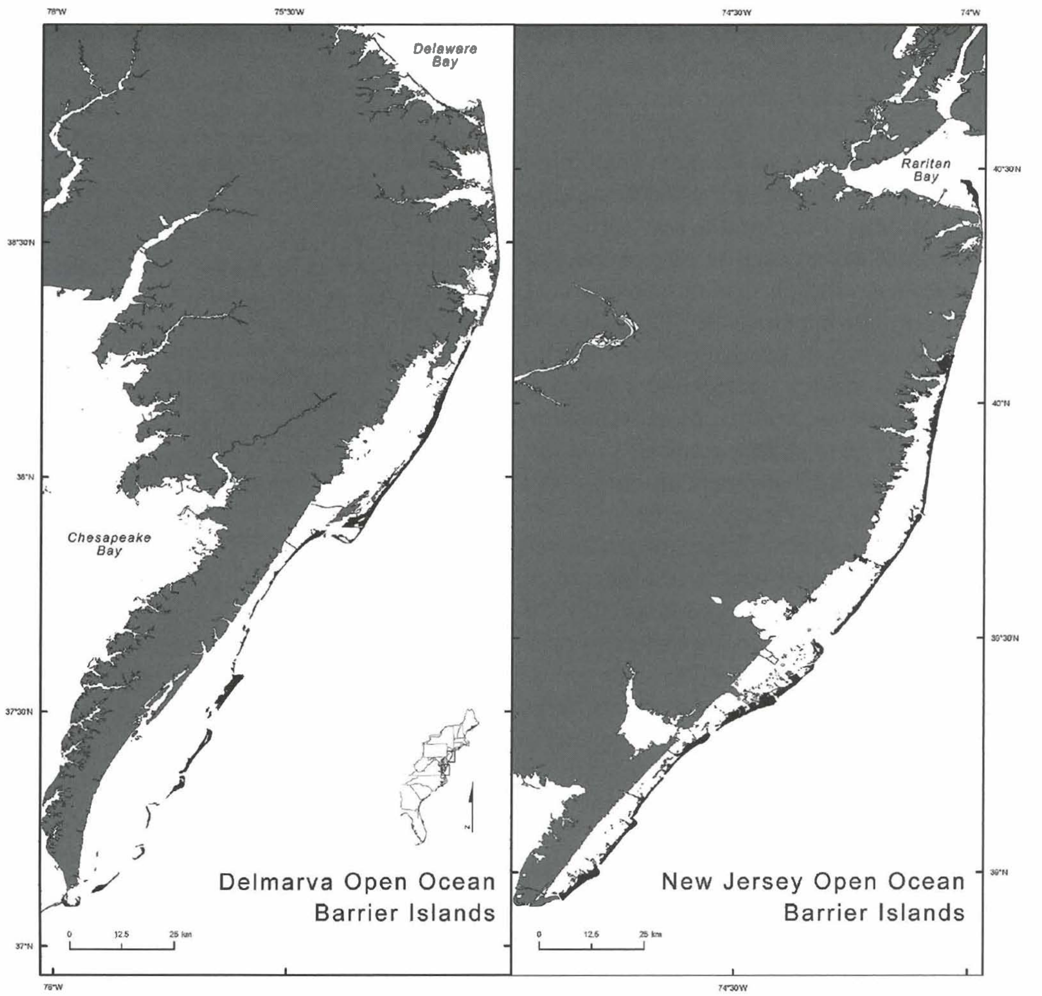

Figure 25: Maps showing the open ocean barrier islands on the New Jersey and Delmarva shorelines. Clearly they are much larger features than fetch limited barrier islands, but evolutionary processes are very similar.

barriers on average exceed 10km in length and 400m in width – making them an order of magnitude greater than fetch limited barriers in each dimension. The open ocean islands also consistently have well-developed dunes, dense maritime forests, large inlet-delta complexes, and extensive open water backbarrier lagoons, features that exist on scales far greater than those found on fetch limited barriers. Unlike fetch limited barrier islands, the open ocean islands are subject to daily, fair-weather wave processes that contribute to the alongshore flux of sediment, tidal processes that significantly impact the shoreface, and aeolian processes that move large volumes of sediment in the cross-shore direction.

Both open ocean and fetch limited barrier islands in the Mid-Atlantic are migrating landward in response to storm surges and sea level rise. The overwash and island rollover model of response to sea-level rise is attributable to islands along both ocean and estuarine shorelines. Fair weather waves operating on Atlantic coastlines after storms have passed, however, are responsible for restoring the nearshore systems to pre-storm conditions, slowing the landward movement of the island systems. However, along low energy shorelines, the absence of appreciable fair weather waves means that profiles of these islands are basically storm profiles.

Open ocean barrier islands never exhibit living marsh grass colonies on the beach and similarly are only incidentally controlled by vegetative influences such as stumps and outcropping compacted marsh mud. Geologic controls are far more important for development of barrier islands in open ocean conditions than for barrier islands in fetch limited waters (Riggs *et al* 1995). However, both types of islands require a low-sloping surface gradient, sufficient wave energy to drive sediment onshore, and a stabilizing point to serve as a nucleus.

The difference in scale between fetch limited and open ocean barrier islands is a function of differences in sediment supply and mobility and wave energy, all of which are greater in open ocean settings. That most of the component geographical features and many of the large scale controls and processes are similar, however, implies fetch limited barrier islands are but scaled down versions of the more commonly studied oceanic barrier islands.

Human-induced pressures that beset the intensely developed New Jersey coastline exist along the embayed shorelines as well. Moreover, fetch limited barrier islands are an important component in preventing wetland loss and storm damage to wetland ecosystems and human communities.

An important task for coastal scientists will be devotion of more time and efforts towards tracking the changes and behaviors of barrier islands within the Chesapeake and Delaware Bays with emphasis on the interaction of the islands and the marshes.

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