

# Coastal Submergence and Marsh Fringe Erosion<sup>1</sup>

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## ABSTRACT

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Coastal wetlands may shrink, expand, or remain constant in area during coastal submergence, depending on sedimentation rates on the wetland surface in comparison with rates of submergence. Losses of coastal wetlands are primarily reflected in shoreline recession due to erosion and drowning. In Delaware Bay sea level rise, subsidence, and dissection are combining to produce rapid shoreline erosion and a net loss of wetlands as the coast is submerged. In Pamlico Sound, erosion rates are less severe, but still sufficient to cause a net loss of wetland area. Along the Atlantic and Gulf coastal plain, marsh shoreline erosion rates of more than about 0.3 m/yr (and perhaps much less) will result in a loss of wetlands at a greater rate than new marshes can be created.

**ADDITIONAL INDEX WORDS:** Coastal submergence, Delaware Bay, marsh fringe, marshes, Pamlico Sound, shoreline erosion.

## INTRODUCTION

A recent review of literature on response of tidal salt marshes to rising sea level identified three possible responses (ORSON, *et al.*, 1985): marsh drowning if sediment supply and accretion is less than the rate of coastal submergence; marsh expansion if sedimentation exceeds coastal submergence; and marsh maintenance if sedimentation balances coastal submergence. The term coastal submergence is used to refer to all factors causing a relative increase in sea level with respect to adjacent land. This encompasses eustatic sea level rise and compaction or subsidence of coastal land. This study will examine the response of marshes to coastal submergence, with an emphasis on marsh fringe erosion. A case study based on fieldwork in marshes surrounding Delaware Bay will be presented, with results then applied to marshes of Pamlico Sound, North Carolina. The purpose is to determine the extent to which sea level rise may be responsible for wetland shore erosion, and whether a net loss of wetlands is to be expected as a result of recent submergence.

## STUDY AREA

It is commonly assumed, and in some cases demonstrated, that tidal marshes are able to maintain themselves during sea level rise, and that sea level rise enhances marsh aggradation (LETZSCH and FREY 1980; PETHICK 1981). Maintenance need not imply maintenance in place. One model of marsh response to sea level rise involves bidirectional expansion, with vertical accretion accompanied by marsh encroachment on adjacent uplands (REDFIELD 1972; ORSON, *et al.* 1985). These processes may be accompanied by truncation of the seaward edge.

Such a model has been developed for Delaware Bay. According to the model, the fringing marshes (which often have sandy veneers or barriers) are eroding, with associated upward and landward migration of the marsh system (WASHBURN, 1982; KRAFT, *et al.*, 1976; KAYAN and KRAFT, 1979). There is clear evidence of both shoreline erosion and upland encroachment in Delaware Bay marshes. But there is also evidence that for at least several decades there has been a net loss of coastal wetlands that fringe the bay. HARDISKY and KLEMAS (1983) report, based on aerial photographic surveys, that 3.9 hectares of marsh per year were eroded

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and 2.8 hectares per year created by natural processes in Delaware from 1973 to 1979.

Delaware Bay and its surrounding wetlands occupy a delta formed by the Delaware River during a lower stand of sea level. As sea level has risen during the Holocene, the estuarine depocenter has migrated upriver. The bay/delta has changed from a constructional to a destructional system during this period (WEIL, 1977). Recent studies of marsh response to coastal submergence in Louisiana in a delta-deterioration situation have concentrated on marsh surface accretion rates (DeLAUNE and SMITH 1984; HATTON, DeLAUNE, and PATRICK 1983). This study will approach the problem by considering processes at the bayward edge of the marshes. A key question is the extent to which sea level rise is responsible for shoreline erosion, and whether a net loss of coastal wetlands can be anticipated.

The study area is a 52 km long shoreline zone along the New Jersey shore of Delaware Bay. Shoreline erosion data were collected for the entire study area as shown in Figure 1, and field data were collected at selected sites within the study area (Figure 1). The geological situation and evolution of the bay are described by WEIL (1977). Generally, from the deepest, middle portion of the bay (the ancestral river channel), there are wide tidal flats near shore, mainly derived from shore erosion. The shoreline zone typically consists of a marsh fringe or a sandy barrier overlying marsh sediments. There are extensive marshes between the shoreline and the adjacent upland — about 20,000 ha within the study area.

A sea level rise curve constructed for the Atlantic coast of Delaware based on radiocarbon dates of basal peats indicates a rise in relative sea level of about 1.2 mm/yr for the past 2,000 years, and more rapid rates for earlier periods (KRAFT 1971). A recent increase in worldwide sea level rise has been noted, and the current rate of sea level rise in New Jersey is generally thought to be about 3 mm/yr. This is supported by recent (post 1910) tidal gauge data for the three stations nearest the study area: Atlantic City, New Jersey; Philadelphia, Pennsylvania; and Lewes, Delaware (HICKS, DeBAUGH, and HICKMAN 1983).

## METHODS

Shoreline erosion was measured from aerial photographs. Photography for the years 1940 and 1978 was obtained from the Mosquito Extermination Commission and Engineering Department of

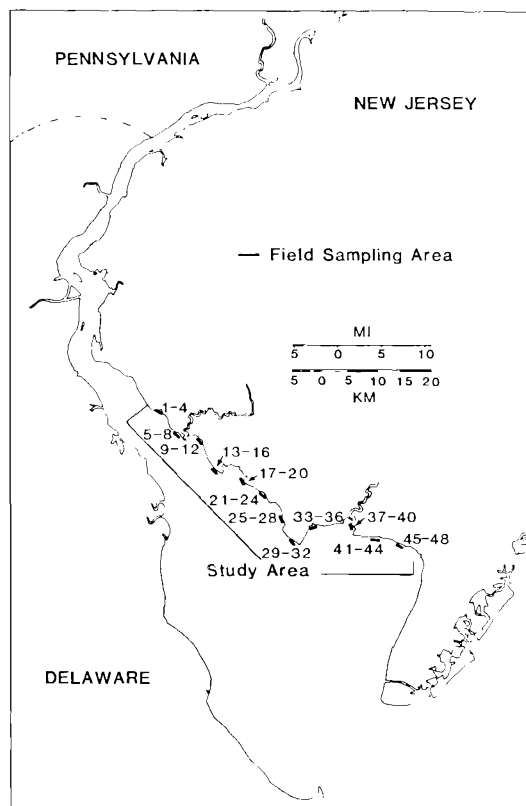


Figure 1. Delaware Bay study area. Numbers refer to field study sites where data were collected.

Cumberland County, N.J. Both sets of photographs are vertical black-and-white images printed at identical scales of 1:4800. Attempts were made to utilize only the center portions of photographs, which have a standard 60 percent forward overlap, to minimize distortions due to tilt and parallax. A lack of fixed points that could be tied to plane coordinate systems prevented the use of metric mapping systems, and the method used is similar to that of HAYDEN, DOLAN, and FELDER (1979).

The 1940 shoreline was traced onto the 1978 photographs, with the shoreline defined as the mean high water mark. The MHW point was defined according to changes in vegetation (the low/high marsh line is very distinct) or according to changes in gray tones corresponding with MHW on sand beaches. The distance between the two shorelines was measured along and normal to the 1978

shoreline at distances corresponding to 100 meters on the ground, using a Numonics digitizer. Shoreline change is expressed in meters per year.

Because the years 1940 and 1978 were arbitrarily selected due to availability of good quality photography, additional measurements were made to determine whether 1940-78 shoreline change rates are representative of recent change. Shoreline change was also digitized from photorevisions of U.S. Geological Survey 1:24,000 topographic maps of the study area. In addition, spot measurements were made comparing the 1940 and 1978 photographs with an additional set of 1963 photographs. All these measurements were consistent with the general trends and magnitudes of erosion shown in the 1940-78 data.

The entire study area was reconnoitered in the field, with detailed morphological and vegetation data collected at 48 sites (see Figure 1). The hierarchical sampling design used is described elsewhere (PHILLIPS, 1986).

It is also necessary to know something of the morphology of the adjacent upland surface over which the marsh complex is thought to be encroaching. Topographic maps do not provide sufficient elevation detail in this area, so mean elevations of soil units adjacent to coastal wetlands were computed from the county soil survey (POWLEY, 1977).

## RESULTS

The mean erosion rate was found to be 3.21 m/yr, with a standard deviation of 1.85. The alongshore pattern is highly variable, but virtually the entire area has undergone recession during the study period. The implications of the spatial pattern are discussed elsewhere (PHILLIPS, 1986). This is a high rate of erosion compared to other estuaries, and is affected by some extremely high values approaching 15 m/yr. This is reflected in the positive skewness of 1.13. An examination of reaches with erosion rates greater than 5 m/yr (approx-

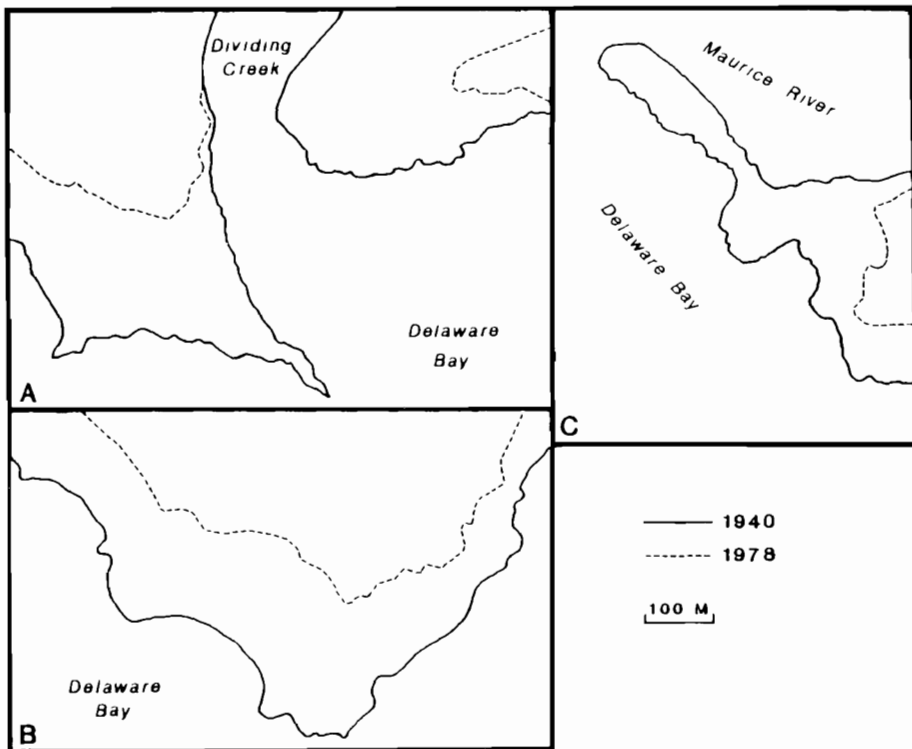


Figure 2. Examples of extreme shoreline change during the period 1940-78. At the mouth of Dividing Creek (A) channel changes and the drowning of the creek mouth have resulted in dramatic bayshore erosion. Exposed peninsular points such as Ben Davis Point (B) are often rapidly truncated. Channel change at the mouth of the Maurice River (C) led to rapid drowning of a marshy peninsula.

imately one standard deviation more than the mean) yielded three types of situations.

First, peninsular points exposed to wave activity on three sides typically experienced rapid truncation. Second, dramatic shoreline change was often associated with processes occurring near the mouths of tidal streams, such as the opening of new stream mouths and subsequent drowning of the islands. Examples are shown in Figure 2. The third situation exists where dikes for salt hay farms have been breached by storms. Many of the *Spartina patens* high marshes around Delaware Bay have historically been farmed for hay. Dikes composed of marsh peat blocks piled on wooden faggots were constructed to allow farming. It was observed that once an abandoned dike was breached by a storm, waters formerly impounded behind the dike as well as subsequent spring tides used the opening, rapidly incorporating the area in front of the breach into the bay.

In addition, widespread subsidence was observed in diked marshes. Many high marsh areas which were once farmed are now inundated by each tidal cycle. These marshes are subsiding more rapidly than non-diked marshes, suggesting that compaction or subsidence is more rapid or sedimentation less rapid on the diked marshes. The latter seems more likely. Annual removal of biomass and the exclusion of sediment-laden storm and spring tides by the dikes could dramatically reduce sediment accretion.

The shoreline in the study area may be classified into seven types. The entire area is predominantly composed of marsh sediments. In many areas there is little or no sand. The marsh fringe shorelines are of three types: Those dominated by *Spartina alterniflora* (cordgrass), those dominated by *Phragmites australis* (common reed), and those dominated by a mixture of species. The differences in vegetation dominance are geomorphically important, due to the more rapid peat production and the dense, erosion-resistant root mat associated with *Phragmites*-dominated systems. In some areas marsh sediments are overlain by sand barriers. These barriers are typically rather narrow (100 m or less) and thin (sandy deposits range from a veneer to about 2 m thick). Two variations on this theme were deemed worthy of separate classifications. In the vicinity of Egg Island Point the barriers are 25 to 75 m landward of the bayside scarp, separated by intertidal peat flats which are pockmarked by pools and potholes. To the northwest of Ben Davis Point, the shoreline consists of small, discontinuous bar-

riers separated by *Phragmites*-dominated marsh. The individual units are too small to map, but form a relatively large area of alternate marsh fringe and barriers. The other two major types of shorelines are modified by man. Shorelines developed for housing or recreation were all classified together, despite some disparities in morphology. The land use history of the tiny bayside settlements is difficult to piece together, but all are located on sand barriers. At most sites this sand has been supplemented by material trucked from inland sites. Shore erosion control structures are also common, ranging from tire breakwaters to rubble rip-rap to continuous bulkheading. Other altered shorelines occur where faggot dikes are aligned along or just above the mean high water shoreline.

The field data indicate that the focus of erosion is typically a scarp or steep slope of marsh sediments. This scarp or slope is typically about a meter in height, ranging from 0.6 to 1.2 m above the tidal flats below. These scarps or steep faces occur on marsh fringe shorelines and in marsh sediments in front of sand barriers.

Barriers themselves appear to be migrating landward, the expected response to coastal submergence. Sand bodies nearly always showed evidence of encroachment on backbarrier marshes, apparently due to overwash processes.

## SHORE EROSION AND COASTAL SUBMERGENCE

It seems unlikely that a sea level rise of 3 mm/yr could produce shoreline recession rates of 3.21 m/yr. BRUUN (1962) suggested the now widely-accepted notion of sea level rise as a cause of shore erosion, confirmed in the laboratory by SCHWARTZ (1965) and along Chesapeake Bay by ROSEN (1978). "The Bruun Rule" holds that, for a shoreline in longshore equilibrium, a given rate of sea level rise will result in shoreline erosion sufficient to deposit sediment in the nearshore zone to a depth equal to the sea level rise. The mean width of the nearshore zone affected by waves within the study area is about 235 meters. Covering a 1 m strip 235 meters long to a depth of 0.3 cm would require 705,000 cubic centimeters of material. Shoreline recession of 3.21 m, along one linear meter of marsh, occurring at a 1 m scarp (typical for the study area) would produce 3.21 million cm<sup>3</sup>. Thus shoreline erosion is providing about 4.5 times the amount of sediment needed to maintain equilibrium for a 3 mm/yr eustatic sea level rise.

Another approach is to examine the amount of accretion necessary to maintain the marsh area. The mean slope of uplands adjacent to Delaware Bay coastal wetlands is 2 percent. From this it can be calculated that to maintain a constant marsh area when shoreline erosion is 3.21 m/yr would require a mean vertical sedimentation rate of 10 cm/yr. This accretion rate is an order of magnitude higher than any reported elsewhere (ORSON, *et al.* 1985; LETZSCH and FREY 1980; DeLAUNE, BAUMANN, and GOSSELINK 1983; DeLAUNE and SMITH 1984; HARRISON and BLOOM 1977; HATTON, DeLAUNE, and PATRICK 1983; PETHICK 1981; REDFIELD 1972; RICHARD 1978). A study in Delaware Bay marshes in Delaware reported a rate of 0.5 cm/yr (STUMPF 1983). This tends to confirm the suspicion that the New Jersey shore of Delaware Bay is experiencing a net loss of marshland.

Data indicate that the study area is experiencing a net loss of marshes, and seem to suggest rapid rates of coastal submergence. This is consistent with data from Louisiana (DeLAUNE, BAUMANN, and GOSSELINK, 1983; DeLAUNE and SMITH, 1984; HATTON, DeLAUNE, and PATRICK, 1983) and with wetland measurements in Delaware (HARDISKY and KLEMAS, 1983). Despite this consistency, field observations along the New Jersey shore of Delaware Bay make it apparent that it may not be representative of other Atlantic Coastal Plain estuaries. Delaware Bay may be experiencing accelerated submergence. Before making general statements regarding sea level rise, coastal marshes, and shoreline erosion, it is necessary to briefly examine factors which may be related to accelerated submergence in the Delaware Bay region. While there are not enough field data on submergence or sedimentation rates to make definitive statements, it is appropriate to speculate on factors contributing to the observed rapid erosion and drowning and to the apparent rapid submergence.

At least some of the loss may be attributable to subsidence. Marshes naturally subside under normal conditions due to compaction of marsh sediment under its own weight. This process can be hastened by activities such as mosquito ditching; *i.e.*, ditching designed to reduce surface ponding and eliminate mosquito breeding areas (ORSON, *et al.* 1985). Such ditching has been widespread around Delaware Bay. Subsidence may be more important than sea level rise in determining the rate of coastal submergence (DeLAUNE, BAUMANN, and GOSSELINK, 1983). This appears to be the case in the study area. Field evidence suggests rapid submergence due to

the combination of sea level rise, natural subsidence, accelerated subsidence due to mosquito ditching, and accelerated subsidence due to biomass removal and interruption of sedimentation associated with salt hay farming. Unfortunately, the rate and extent of such subsidence has not been quantified.

As noted above, the rate of conversion of marsh to open water along the bay shore is far in excess of marsh accretion, and is in fact greater than what would be expected in response to eustatic sea level rise alone. There is evidence that the study area wetlands are undergoing accelerated subsidence due to mosquito ditching and salt hay farming, resulting in a rate of coastal submergence greater than the rate of eustatic sea level rise.

Coastal submergence may contribute to estuarine shoreline erosion in ways more subtle than gradual drowning. NORDSTROM (1980) observed that while many ocean beaches undergo cyclic patterns of erosion and deposition, bay shores may not experience much deposition. Bay waves are typically short and choppy. The gentle, long period waves associated with deposition and beach-building are generally absent in estuarine environments, including Delaware Bay. Most sediment lost during an erosion episode is permanently lost to the shoreline. As long as erodible sediments are exposed to wave action, shoreline recession would be expected.

It was observed in the study area that erosional scarps were under wave attack during every tidal cycle. If bay levels relative to the marshes were static, it would be expected that scarps would eventually retreat to a point where only storm conditions would cause wave attack of the scarp face. As no stable scarps were noted during fieldwork, the regular wave attack on scarps throughout the study area suggests that submergence is occurring. In addition to Bruun Rule erosion and marsh drowning, the role of coastal submergence in keeping shorelines, especially marsh scarps, exposed to wave activity should be considered.

Dissection of the marsh surface also appears to play a role in shore erosion and drowning. Marshes in the study area have mature, reticulated drainage systems (see WADSWORTH and BERGER, 1979). The marsh is highly dissected by natural channels and salt pannes as well as mosquito and drainage ditches. As extreme erosion rates were often associated with channel changes at the mouths of tidal streams and with capture of pannes and channels by shoreline recession, the process of marsh dissection seems to contribute to shoreline erosion.

## SUMMARY: SUBMERGENCE OF DELAWARE BAY MARSHES

Coastal submergence of the New Jersey shore of Delaware Bay is resulting in the gradual drowning of bayside marshes. While wetlands are encroaching on adjacent uplands, there is a net loss of wetlands, as marsh creation is insufficient to offset rapid erosion rates averaging 3.21 meters per year. Conversely, the eustatic sea level rise of 3 mm/yr is apparently insufficient to cause the observed erosion rates.

Several factors have been identified which, in combination, appear to be related to the rapid erosion and drowning. All the phenomena listed below need more research attention, especially items 2-5: (1) Bruun Rule shore erosion due to rising sea level, (2) constant exposure to wave attack of erodible marsh sediments, (3) marsh dissection due to development of drainage patterns and salt pannes, (4) natural subsidence, and (5) accelerated subsidence due to effects of mosquito ditching and salt hay farming.

Although shoreline recession rates of more than three meters per year seem extreme at first consideration, the marshland loss in Delaware Bay is qualitatively consistent with observations in other areas. A rapid rate of sea level rise is not conducive to marsh development (RAMPINO and SANDERS 1981), whereas a slower rate tends to encourage marsh development. The apparent recent increase in sea level rise, coupled with obvious accelerated subsidence due to man's activities have helped create a rapid rate of coastal submergence in the New Jersey marshes. A second consideration is that destruction of a delta is typically associated with rapid conversion of wetlands to open water.

This paper addresses the question of whether a general loss of coastal wetlands in Atlantic Coastal Plain estuaries can be expected as a result of shoreline erosion and drowning. In light of the complicating factors in the Delaware Bay area, another estuary was examined.

### PAMLICO SOUND, NORTH CAROLINA

Delaware Bay may well represent an extreme example in terms of shoreline erosion and accelerated wetland subsidence. Conditions in a nearby coastal plain estuary with a different geomorphic setting and hydrodynamic regime were evaluated to estimate whether it, too, could expect a net loss of wetlands in response to sea level rise. Pamlico Sound,

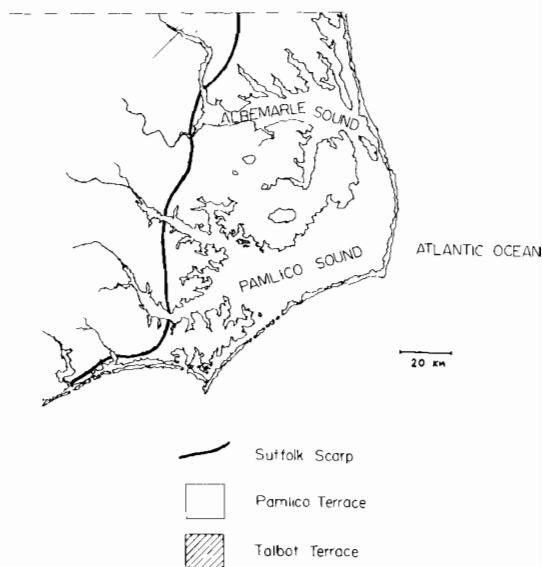


Figure 3. The Pamlico-Albemarle Sound system of North Carolina. The Suffolk Scarp is a relict Pleistocene shoreline.

North Carolina (Figure 3), is a much different estuarine system than the Delaware Bay. In terms of modern physical processes, the most important and obvious difference is that Delaware Bay has a wide connection with the ocean and a mean tidal range of about 1.8 meters, whereas the Pamlico system has connections with the Atlantic only through small inlets and a mean tidal range of about 0.15 m. Pamlico Sound includes numerous critical nursery areas for fish and shellfish, with the fringe marshes playing a major role (see COPELAND, *et al.*, 1984). Management of this system must consider the response of the marshes to existing sea level rise, possible dramatic increases in sea level rise (HOFFMAN, KEYES, and TITUS, 1983) and observed erosion.

The geologic history of the Pamlico is not as clear as that of the Delaware estuary, but Holocene sea level rise has likewise gradually displaced the locus of fluvial sediment deposition upstream. Geological and ecological evidence indicate that the Pamlico is a transgressive system (O'CONNOR, RIGGS and WINSTON, 1972; BELLIS and GAITHER, 1984; HARDAWAY, 1980). A Pamlico-Tar River Foundation survey of Pamlico River tributaries found evidence of wetland encroachment over uplands and

drowning of floodplain forests in all ten sites surveyed (PHILLIPS, 1985).

It is likely that the rate of sediment supply to Pamlico Sound marshes has been declining as sediment accumulation is displaced upstream, decreasing their ability to maintain themselves in response to sea level rise. As shoreline erosion is omnipresent in the marshes, we intuitively expect a net loss of Pamlico Sound marshes.

Few estimates of accretion in Pamlico marshes are available. Radiocarbon dates in brackish marshes of second-order drowned tributaries to the system indicate an average sedimentation rate of only 0.86 mm/yr since the marshes were formed about 4000 BP (BELLIS and GAITHER, 1984). ERLICH (1980) estimated recent sedimentation in swamp forests at the mouth of the nearby Roanoke River at 2.7 mm/yr.

Shoreline erosion for the area was measured from aerial photographs in 1975 (SOIL CONSERVATION SERVICE, 1975) with records ranging from 25 to 32 years in length. Marsh shores of Pamlico Sound showed a mean erosion rate of 0.91 m/yr, with the more protected marshes inside the Pamlico River eroding at about 0.79 m/yr. Based on this information, a qualitative estimate can be made of whether there is a net loss of marshes.

Estimates are based on a simple model alluded to earlier and shown in Figure 4. The marsh is seen as having a level surface overlying older sediments. A constant slope for the adjacent upland is assumed. Encroachment onto adjacent uplands requires that the elevation of the entire marsh surface be raised. Marsh surface sedimentation is not uniform, but an average accretion value for the entire surface necessary to maintain the marsh area for a given rate of shoreline erosion can be estimated. If  $b$  is the rate of shoreline erosion and  $A$  the slope of the upland in degrees, the accretion rate necessary to maintain a constant marsh area under these assumptions is

$$a = b \tan A.$$

Slopes of uplands in the Pamlico Sound area range from near zero to about 2 degrees. Sedimentation necessary to maintain a constant marsh area (for an erosion rate of 0.91 m/yr) must average about 3.2 mm/yr for a 0.2 degree slope, 15.9 mm/yr for a 1 degree slope, and 31.8 mm/yr if the slope of the uplands is 2 degrees. Those accretion rates are far in excess of recorded rates, indicating that the Pamlico system has experienced and will experience a net loss of marshes in response to coastal submergence. This suggests that net losses of coastal

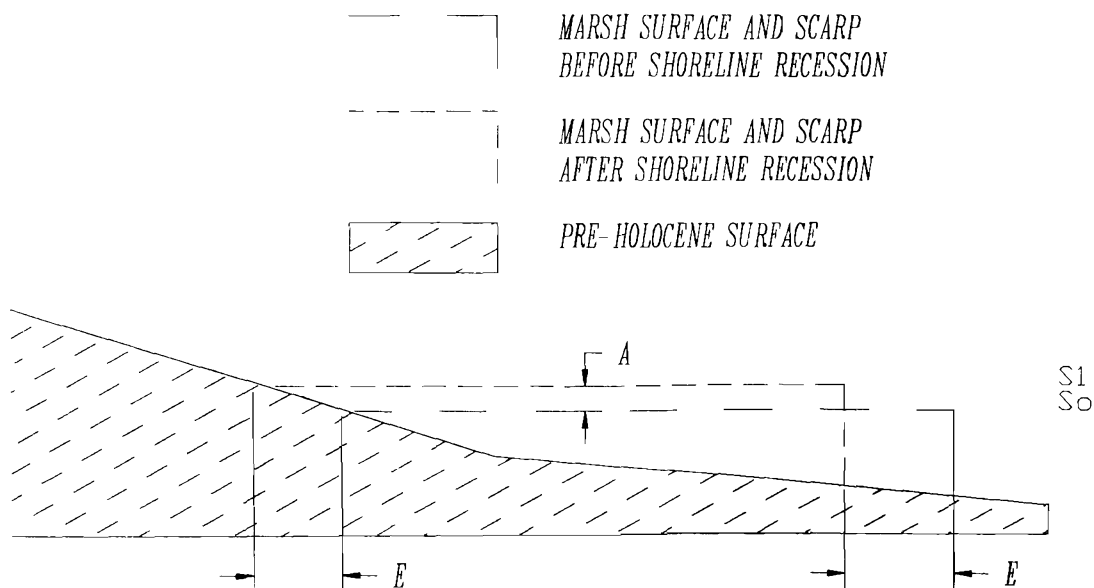


Figure 4. Conceptual model showing surface accretion necessary to maintain marsh area for a given rate of shoreline erosion. If the distance from the upland intercept of the marsh to the land/water interface is to remain constant during a shoreline recession of magnitude  $E$ , then surface accretion of  $A$  is necessary.

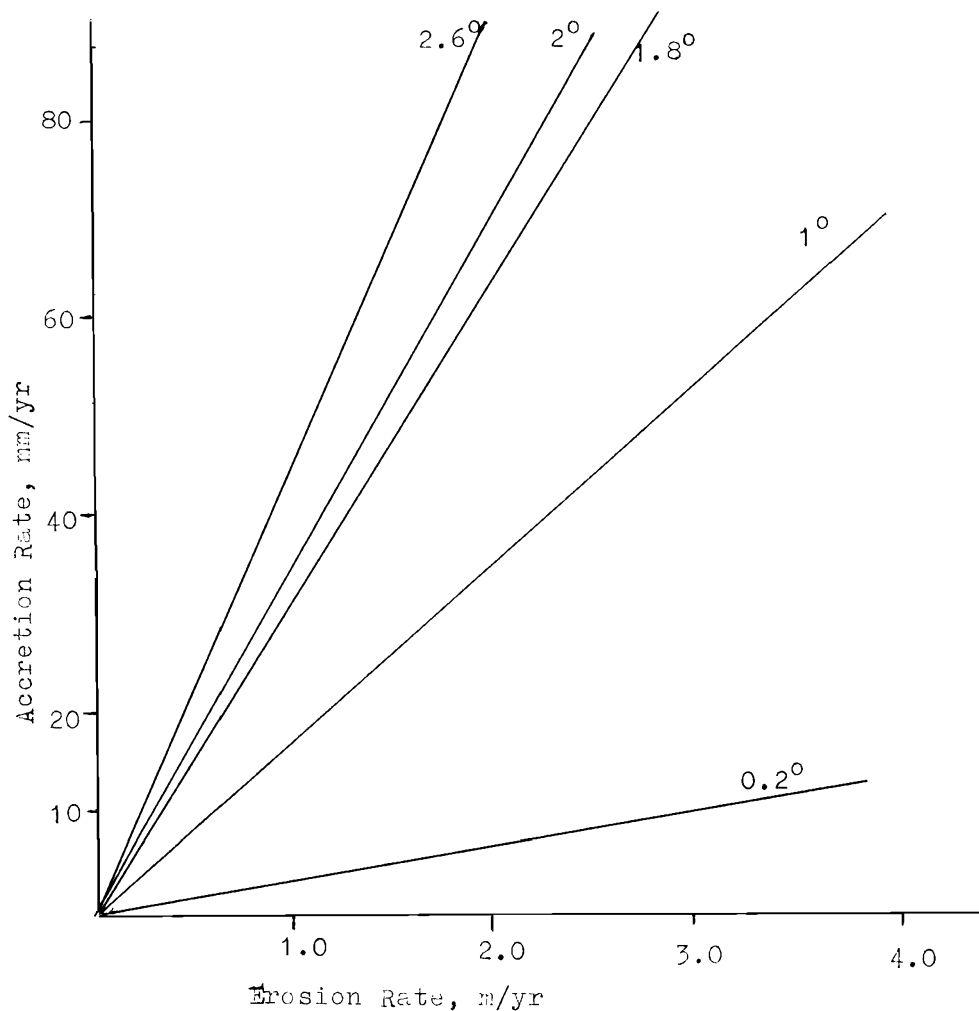


Figure 5. Relationship between marsh fringe erosion rates and accretion necessary to maintain marsh areas for several different upland surface slopes.

wetlands in response to sea level rise is not limited to areas such as Delaware Bay, where human-accelerated subsidence may play a key role and where shoreline erosion is extreme.

### DISCUSSION

Evidence of coastal submergence and widespread estuarine shoreline erosion on the Atlantic and Gulf coasts of the United States has created a legitimate concern for the future extent of coastal wetlands. Using the relationship described above, nomographs can be constructed showing the rela-

tionship between shoreline erosion rates and sedimentation rates necessary to maintain marshlands for a given upland slope. Some examples are shown in Figure 5, using the low slopes characteristic of the North Carolina coastal plain. The highest recorded marsh sedimentation rate for the Atlantic/Gulf coastal plain is also shown.

As a gross generality, it can be seen that any shoreline erosion exceeding about 0.3 m/yr (1 ft/yr), except where upland slopes are very low, will result in a net loss of marshes. The losses now occurring in Pamlico Sound and Delaware Bay are probably also occurring elsewhere.



In Pamlico Sound and other estuaries, loss of marshes by natural processes has potentially serious implications for fisheries management, coastal water quality, and other factors (see TITUS, 1985). Given the probability of continued or accelerated sea level rise in the near future and attendant decreases in marsh area, these implications are worth further exploration.

## CONCLUSIONS

Marsh maintenance in response to rising sea level depends on an adequate supply of sediment to the marsh. Upstream spatial displacement of sediment accumulation may serve to reduce sediment supply, making downstream marshes in drowned river valley estuaries extremely susceptible to erosion and drowning. This is the case in Delaware Bay, where sea level rise, subsidence, and dissection of the marsh are combining to produce rapid rates of shoreline erosion and marsh drowning in a delta-deterioration situation.

Shoreline erosion data for Pamlico Sound, North Carolina, although indicating less rapid erosion, also point to a net loss of coastal marshes. While marshes can maintain themselves in response to coastal submergence, if rapid shoreline erosion is associated with the submergence a net loss of wetlands will result. Shoreline erosion rates of more than about 0.3 m/yr (and perhaps much less) will likely result in a net loss of marshes in the Atlantic/Gulf coastal Plain of the U.S.

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