Chapter 2

CHARLESTON CASE STUDY

by

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INTRODUCTION

This chapter examines the potential impact of future sea level rise on coastal wetlands in the area of Charleston, South Carolina, for the year 2075. We investigate the hypothesis from Chapter I that a generally concove marsh profile implies that a rise in sea level would cause a net loss of wetlands. The chapter builds upon previous EPA studies that had assessed the potential physical and economic impacts of sea level rise on the Charleston area.

We surveyed twelve wetland transacts to determine elevations of particular parts of the marsh, frequency of flooding, and vegetation at various elevations. From these transacts, me developed a composite transect representing an average profile of the area. Using this informa- tion and estimates of the sediment provided by nearby rivers, me then estimated the shifts in wetland communities and net loss of marsh acreage associated with three possible scenarios of sea level rise for the year 2075: (1) the current trend, which implies a rise of 24 cm (0.8 ft), relative to the subsiding coast of Charleston; (2) a low scenario of 87 cm (3.0 R); and (3) a high scenario of a 159-cm rise (5.2 ft).[1]

We examine background information concerning global warming and future sea level rise, the ecological balance of coastal wetlands, and the potential transformation of these ecosystems as sea level rises. Next, we examine the wetlands in the Charleston study area and describe a field study in which we developed wetland transacts. Finally, we discuss the potential impact of future sea level rise on Charleston's wetlands, and suggest ways to improve our ability to predict the impact of sea level rise on other coastal wetlands.

Ecological Balance of Wetlands

Recent attention concerning rising sea level has been focused on the fate of economic development in coastal areas. However, the area facing the most immediate consequences would be interfidal wetlands. Lying between the sea and the land, this zone will experience the direct effects of changing sea levels, tidal inundation, and storm surges.

The intertidal wetlands contain productive habitats, including marshes, tidal flats, and beaches, which are essential to estuarine food webs. The distribution of the me6ands is sensitively barred for existing tidal conditions, wave energy, daily flooding duration, sedimentation rates (and types), and climate. Their elevation in relation to mean sea level is critical to determining the boundaries of a habitat and the plants within it, because elevation affects the frequency, depth, and duration of flooding and soil salinity. For example, some marsh plants require frequent (daily) flooding, while others adapt to irregular or infrequent flooding (Teal 1958). Along the U.S. East Coast, the terms "low marsh" and "high marsh" are often used to distinguish between zones (Teal 1958; Odum and Fanning 1973) that are flooded at least daily and zones flooded less than daily but at least every 15 days. Areas flooded monthly or less are known as transition wetlands.

Regularly flooded marsh in the southeast United States is dominated by stands of smooth cordgrass *(Spartina alternit7ora),* which may at first appear to lack zonation. However, work by Teal (1958), Valiela, Teal, and Deuser (1978), and others indicates total biomass varies considerably within the low marsh, ranging from zones of tall *S. alternit7ora* along active creek banks to stunted or short *& atternit7ora* stands away from creeks and drainage channels. The tall *S. attemit7ora* may be caused by a combination of factors, including more nutrients, a higher tolerance for the reductions in oxygen that result from subtle increases in elevation along levees (DeLaune, Smith, and Patrick 1983), and differences in drainage created by variations in the porosity of sediment. The zone where *S. alternit7ora* grows is thought by many to be limited in elevation to mean high water. This is probably too broad a simplification according to Redfield (1972), who emphasized that the upper boundary of the low marsh is, at best, indistinct.

High marsh, in contrast, consists of a variety of species. These include *Salicornia spp.* (glassworts), *Distichlis spicata (*spikegrass*), Juncus* spp. (black needlerush), *Spartina patens* (salt- marsh hay), and *Borrichia frutescens* (sea ox-eye). Teal (1958) reports that *Juncus* marsh tends to be found at a slightly higher elevation than the *Salicornniad/Distichlis* marsh..

The high marsh can also be distinguished from low marsh on the basis of sediment type, compaction, and water content. High-rnarsh substrate tends to be firmer and dryer and to have a higher sand content. Low-marsh substrate seldom has more than 10 percent sand (except where barrier-island washover deposits introduce an "artificial" supply) and is often composed of very soft mud. Infrequent flooding, prolonged drying conditions, and irregular rainfall within the high marsh also produce wide variations in salinity. In some cases, salt pannes form, creating barren zones. But at the other extreme, frequent freshwater runoff may allow less salt-tolerant species, such as cattails, to flourish close to the salt-tolerant vegetation. These factors contribute to species diversity in the transition zone that lies between *S. alternit7ora* and terrestrial vegetation.

By most reports, low marsh dominates the intertidal areas along the southeast (Turner 1976), but the exact breakdown can vary considerably from place to place. Wilson (1962) reported *S. alternit7ora* composes up to 28 percent of the wetlands in North Carolina, whereas Gallagher, Reimold, and Thompson (1972) report for one estuary in Georgia that the same species covers 94 percent of the "marsh" area. Low marsh is thought by many to have a substantially higher rate of primary productivity than high marsh (Turner 1976). Data presented in Odum and Fanning (1973) for Georgia marshes support this notion. However, Nixon (1982) presents data for New England marshes that indicate above-ground biomass production in high marshes comparable to that of low marshes. Some data from Gulf Coast marshes also support this view (Pendleton 1984).

Potential Transformation of Wetlands

The late Holocene (Last several thousand years) has been a time of gradual infilling and loss of water areas (Schubel 1972). During the past century, however, sedimentation and peat formation have kept pace with rising sea level over much of the East Coast (e.g., Ward and Domeracki 1978; Duc 1981; Boesch et ad. 1983). Thus, apart from the filling necessary to build the city of Charleston, the zonation of wetland habitats has remained fairly constant there. Changes in the rate of sea level rise or sedimentation, however, would alter the present ecological balance.

If sediment is deposited more rapidly than sea level rises, low marsh will flood less frequently and become high marsh or upper transition wetlands, which seems to be occurring at the mouths of some estuaries where sediment is plentiful. The subtropical climate of the southeastern United States produces high weathering rates, which provide a lot of sediment to the coastal area. Excess supplies of sediment trapped in estuaries have virtually buried wetlands around portions of the Chesapeake, such as the Gunpowder River, where a colonial port is now landlocked.

If sea level rises more rapidly in the future, increased flooding may cause marginal zones close to present low tide to be under water too long each day to allow marshes to flourish. Unless sedimentation rates are high wetlands can maintain the distribution of their habitats only if they shift along the coastal profile-mving landward and upward, to keep pace with rising sea levels. Total marsh acreage can only remain constant if slopes and substrate are uniform above and below the wetlands, and inundation is unimpeded by human activities such as the construction of bulkheads. Titus, Henderson, and Teal (1984), however, point out that there is usually less land immediately above wetland elevation than at wetland elevation (See Figure 1-5). Therefore, significant changes in the habitats and a reduction in the area they cover will generally occur with accelerated sea level rise. Moreover, increasing development along the coast is likely to block much of the natural adjustment in some areas.

Louisiana is an extreme example. Human interference with natural sediment processes and relative sea level rise are resulting in the drowning of 100 sq km of wetlands every year (Gagliano, Meyer Arendt, and Wicker 1981; Nummdal 1982). There is virtually no ground to which the wetlands can migrate. Thus, wetlands are converting to open water; high-marsh zones are being replaced by low marsh, or tidal flats; and saltwater intrusion is converting freshwater swamps and marsh to brackish marsh and open water.

COASTAL HABITATS OF THE CHARLESTON STUDY AREA

As shown in Figure 2-1, the case study area, stretching across 45,500 acres, is separated by the three major tidal rivers that converge at Charleston: the Ashley, Cooper, and Wando Rivers. In addition, the study area covers five land areas:

- **West Ashley,** which is primarily a low-density residential area with expansive boundary marsh;
- **Charleston Peninsula,** which contains the bulkheaded historic district built partly on landfill;
- **Daniel Island,** which is an artificially embanked dredge spoil island;
- **Mount Pleasant,** which derives geologically from ancient barrier island deposits oriented parallel to the coast; and
- **Sullivans Island,** which is an accreting barrier island at the harbor entrance.

Six discrete habitats are found in the Charleston area, distinguished by their elevation in relation to sea level and, thus, by how often they are flooded (Figure 2-2):

- *highland* - flooded rarely (47 percent of study area)
- *transition wetlands* - flooding may range from biweekly to annually (3 percent)
- *high marshes* - flooding may range from daily to biweekly (5 percent)
- *low marshes* - flooded once or twice daily (12 percent)
- *tidal t7ats* - flooded about half of the day (6 percent)
- *open water* - (27 percent)

This flooding, in turn, controls the kinds of plant species that can survive in an area. In Charleston, the present upper limit of salt-tolerant plants is approximately 1.8-2.0 m (6.0-6.5 ft) above man sea level (Scott, Thebeau, and Kana 1981). This elevation also represents the effective lower limit of human development, except in areas where wetlands have been destroyed. The zone below this elevation (delineated on the basis of vegetation types) is referred to as a critical area under South Carolina Coastal Zone Management laws and is strictly regulated (U.S. Department of Commerce 1979).

Although most of the marsh in this area is flooded twice daily, the upper limit of salt-tolerant species is considerably above mean high water. Because of the lunar cycle and other astronomic or climatic events, higher tides than average occur periodically. Spring tides occur approximately fortnightly in conjunction with the new and full moons. The statistical average of these, referred to as mean high water spring, has an elevation of 1.0 m (3.1 ft) above mean sea level in Charleston (U.S. Department of Commerce 1981).

Less frequent tidal flooding occurs annually at even higher elevations ranging upwards of 1.5 m (5.0 ft) above mean sea level. In a South Carolina marsh near the case study area, the flooding of marginal highland occurred at elevations of 1.5-2 m above man sea level (approximately 80 cm above normal). The peak astronomic tide that was responsible for the flooding included an estimated wind setup of 15-20 cm (0.54.0 ft) under 7-9 m/s (1347 mph) northeast winds.

FIGURE 2-1
CHARLESTON STUDY AREA

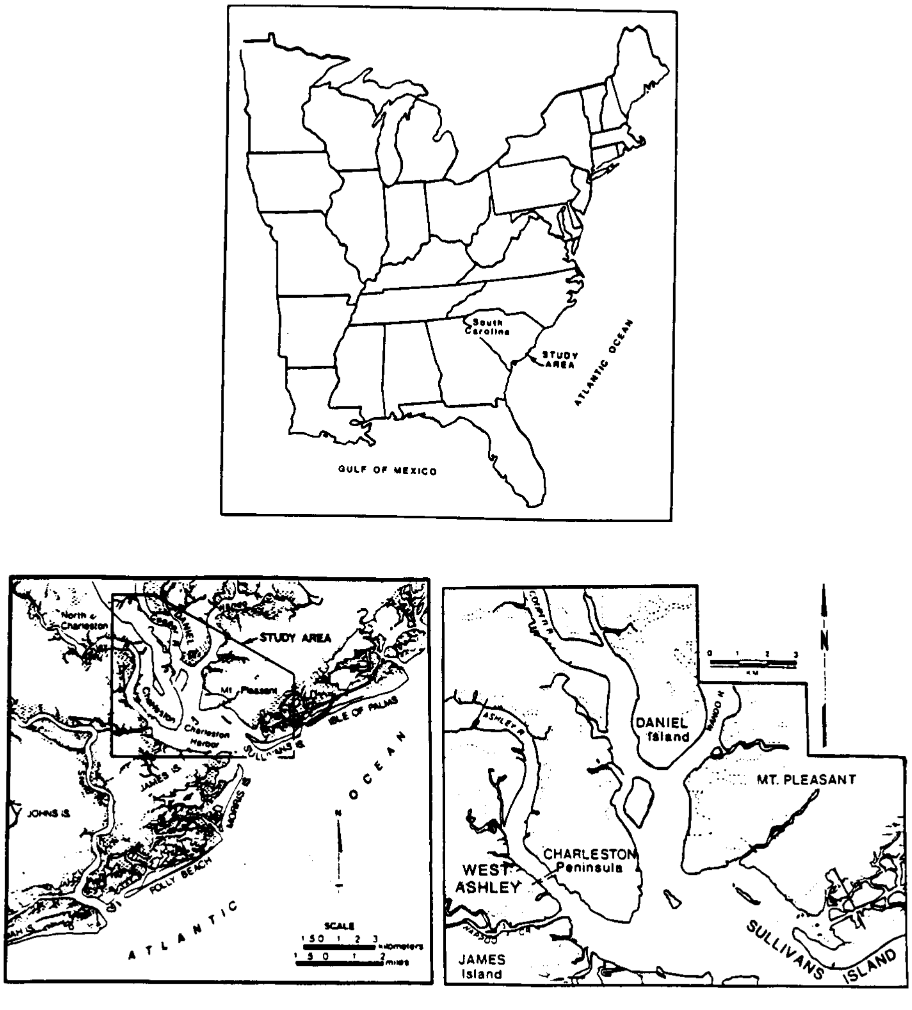
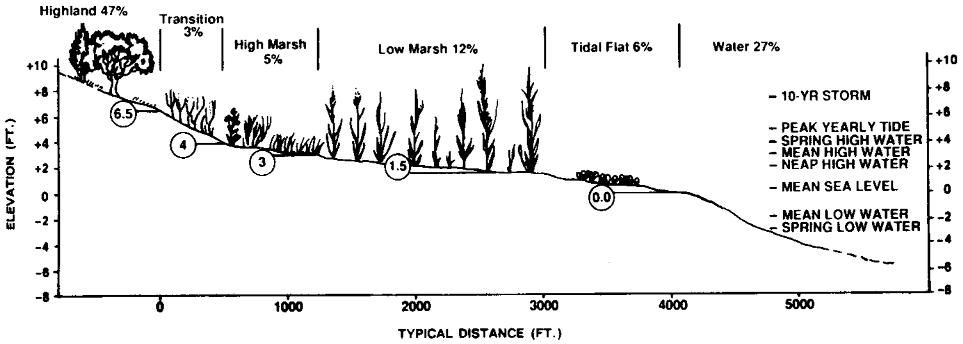


FIGURE 2-2
COASTAL WETLAND HABITATS



The Charleston area has a complex morphology. Besides the three tidal rivers that converge in the area, numerous channels dissect it, exhibiting dendritic drainage patterns typical of drowned coastal plain shorelines.

A back-barrier, tidal creek/marsh/mud-flat system near Kiawah Island, approximately 20 km south of Charleston, has a typical drainage pattern. Throughout the area, highlands are typically less than 5 m (16 ft) above man sea level. With a mean tidal range of 1.6 m (5.2 ft), a broad area along the coastal edge is flooded twice each day. The natural portions of Charleston Harbor are dominated by hinging salt marshes from several meters to over one kilometer wide.

The upper limit of the marsh can usually be distinguished by an abrupt transition from upland vegetation to marsh species tolerant of occasional salt-water flooding. Topographic maps of Charleston generally show this break to have an elevation of about 1.5 m (+5 ft). Along the back side of Kiawah Island, just south of the case study area, one can observe such an abrupt transition between highland terrestrial vegetation and the marsh area. Where the waterfront is developed, the transition from marsh or tidal creeks to highland can be very distinct because of the presence of shore-protection structures, such as vertical bulkheads and riprap. Another marsh/fidal-flat system located behind Isle of Palms and Dewees Island, just outside of the Charleston study area, contains a mud flat and circular oyster mounds near the marsh and tidal channels. Oyster mounds were found at a wide range of elevations along tidal creek banks, but over tidal flats most were common at elevations of 3046 cm G.0-1.5 ft).

Large portions of the back-barrier environments of Charleston consist of tidal flats at lower elevations than the surrounding marsh. The most extensive intertidal mud flats around Charleston generally occur in the sheltered zone directly behind the barrier islands. They are thought to represent areas with lower sedimentation rates (Hayes and Kana 1976) away from major tidal channels or sediment sources.

Much of the Charleston shoreline has accreted (advanced seaward and upward) during the past 40 years (Kana et al. 1984). Marshes accrete through the settling of fine-grained sediment on the marsh surface, as cordgrass *(Spartina altemiflora)* and other species baffle the flow adjacent to tidal creeks. Marsh sedimentation has generally been able to keep up with or exceed recent sea level rises along this area of the eastern U.S. shoreline (Ward and Don-&racki 1978). Much of the sediment into the Charleston area derives from suspended sediment originating primarily from the Cooper River, which carries the diverted flow of the Santee River (until planned rediversion in 1986; U.S. Army Corps of Engineers, unpublished general design memorandum).

WETLANDS TRANSECTS: METHOD AND RESULTS

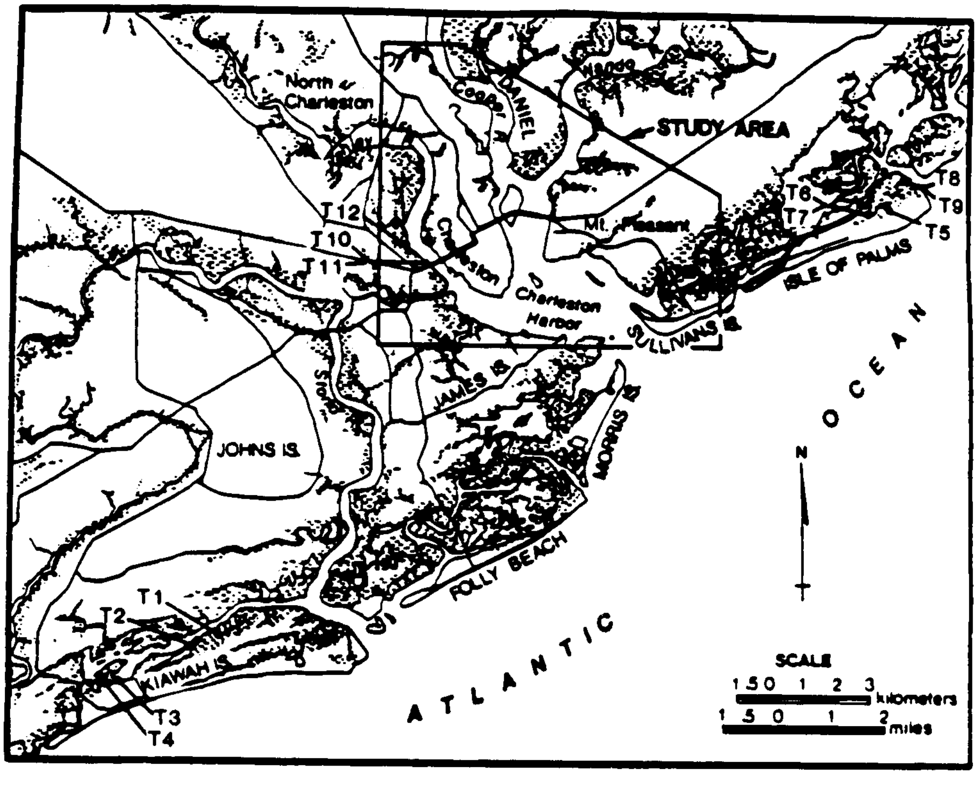
To determine how an accelerated rise in sea level would affect the wetlands of Charleston, one needs to know the portions of land at particular elevations and the plant species found at those elevations. To characterize the study area, we randomly selected and analyzed twelve transects (sample cross sections, each running along a line extending from the upland to the water). This section explains how the data from each transect were collected and analyzed, presents the results from each transect, and shows how we created a composite transect based on those results.

Data Collection and Analysis

For budgetary and logistical reasons, m had to use representative transects near, but not necessarily within, the study area. For example, a limiting criterion was nearness to convenient places where reliable elevations, or benchmarks, had already been established. The marshes be- hind Kiawah Island and Isle of Palms are similar to the marshes behind Sullivans Island, but are more accessible. As Figure 2-3 shows, all the transacts %ere within 20 km (12 mi) of the study area.

Each transect began at a benchmark located on high ground near a marsh's boundary, and ended at a tidal creek or mud flat, or after covering 300 m (1,000 ft)-whichever came first. The length of the transacts was limited because of the difficulty of wading through very soft muds. Although this procedure may have biased the sample somewhat, logistics prevented a more rigorous survey.

FIGURE 2-3
LOCATIONS OF STUDY AREA'S TWELVE TRANSECTS



For each transect, m measured elevation and distance from a benchmark using a rod and level. Elevations were surveyed wherever there was a noticeable break in slope or change in species. The average distance between points was about 7.5 m (25 ft). Along each transect me collected and tagged samples of species for laboratory typing and verification, noting such information as the elevation of the boundaries between different species. By measuring the length of the transect that a species covered and dividing it by the transect's total length, m computed percentages for the distribution of each species along a transect.

Results of Individual Transects

Table 2-1 (see page 44) summarizes the results of the twelve transects.[2] It presents the principal species observed along each transect, their "modal"-or most common-elevations, the percentage of each transect they covered, and the length of each transect. For example, in transect number 6, *Borrichia frutescens* was found at a modal elevation of 118 cm (3-86 ft) and covered 40 percent of the transect, or about 37 m (120 ft).

Because species often overlapped, the sums of the percentages exceed 100. In addition, to omit any marginal plants that exist at transition zones, a modal elevation differs slightly from the arithmetic or weighted mean.

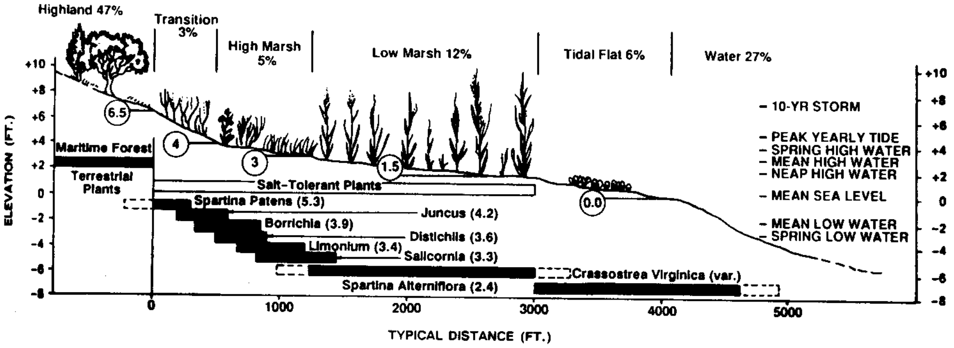
Composite Transect

To model the scenarios of future sea level rise, me had to develop a composite transect from the data in Table 2-1. Thus, for each species, one modal elevation was estimated from the various elevations in Table 2-1. Similarly, the percent of each transect covered by an individual species was used to estimate an average percent coverage for all transacts (Table 2-2, **p.** 45).

This information allowed us to choose for our composite the five species that dominated the high and low marshes in all the transects: *Spartina alternit7ora, Salicornia virginica, Limonium carolinianum, Distichlis spicata, and Borrichia frutescens.* We call these the indicator species. Figure 2-4 shows the modal elevations for these five species, for two other salt-tolerant plants found in the transects (*Juncus roemerianus and Spartina patens),* and for a species found in tidal flats and under water *(Crassostrea virginica).* The primary zone where each species occurs is indicated by the shaded area; occasional species occurrence outside the primary zone is indicated by the unshaded, dashed-line boxes. Figure 2-4 also outlines the boundaries for the six habitats and indicates the estimated percentage of the study area that each covers.

FIGURE 2-4

COMPOSITE TRANSECT—CHARLESTON, S.C.



Composite wetlands transect for Charleston illustrating the approximate percent occurrence and modal elevation for key indicator species or habitats based on results of 12 surveyed transects. Minor species have been omitted. Elevations are with respect to NGVD, which is about 15 cm lower than current sea level. Current tidal ranges are shown at right.

TABLE 2-1

MODAL ELEVATIONS AND PERCENTAGE OF TRANSECT COVERED BY PRINCIPAL SPECIES

SPECIES	Modal Elevations (percent of transect covered) 1	2	3	4	5	6	7	8	9	10	11	12
Batis maritima	-	-	3.13(4)	-	3.20(61)	3.04(14)	-	-	-	-	-	-
Borrichia frutescens	3.90(1)	4.34(33)	4.98(3)	3.48(7)	3.60(14)	3.86(40)	3.17(6)	3.82(27)	3.54(29)	4.94(1)	4.10(9)	-
Distichlis spicata	-	-	-	-	3.52(10)	-	3.20(4)	3.70(23)	3.29(15)	3.80(9)	3.95(35)	3.54(7)
Juncus roemerianus	3.40(1)	-	-	5.34(5)	3.63(2)	3.48(7)	-	-	-	-	5.45(1)	-
Limonium carolinianum	3.27(80)	-	3.07(1)	3.76(1)	3.14(68)	3.04(14)	3.01(4)	3.89(28)	4.35(1)	-	-	-
Polygonum setaceum	-	-	-	-	-	-	-	-	-	5.72(1)	5.45(1)	3.32(7)
Salicornia virginica	3.42(1)	3.38(31)	3.06(9)	3.49(37)	3.12(77)	3.30(34)	3.10(9)	3.30(18)	3.14(31)	-	-	-
Spartina alterniflora	3.27(1)	2.12(75)	2.45(99)	2.05(85)	2.55(78)	-(11)	1.95(62)	2.79(57)	2.71(70)	3.50(99)	3.40(97)	2.65(97)
Spartina patens	-	-	5.35(1)	-	-	-	-	-	-	-	-	-
Spartina cynosuroides	-	-	-	2.51(72)	-	-	-	-	-	-	-	-
Suaeda linearis	-	-	-	-	-	3.61(34)	3.11(4)	4.00(7)	3.22(5)	-	-	-
Transect Length (in feet)	189	51	440	353	933	300	421	387	232	700	588	402

Elevations are relative to NGVD 1929 sea level.

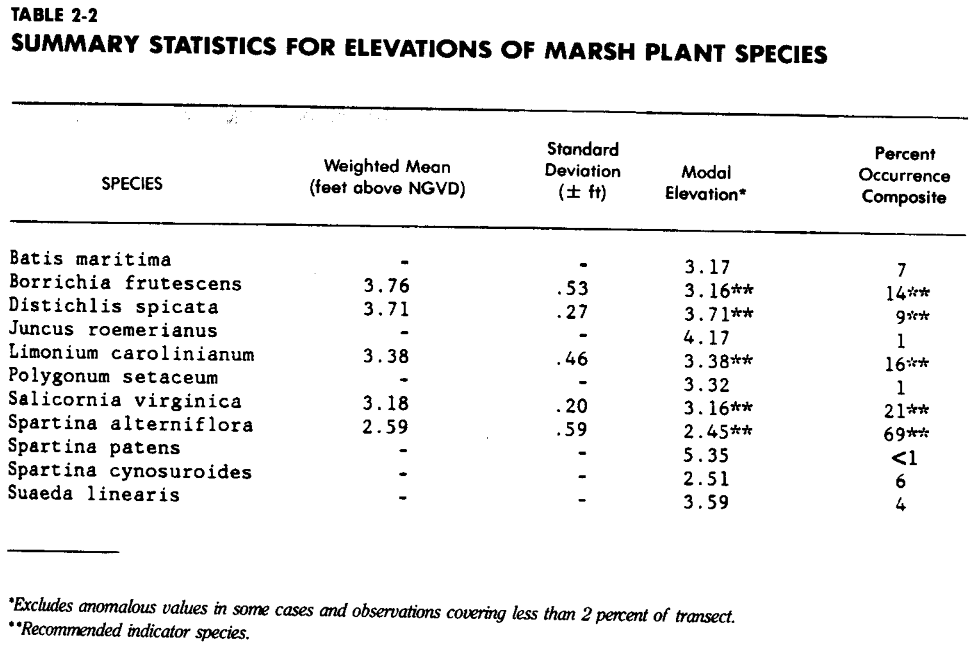


TABLE 2-2

SUMMARY STATISTICS FOR ELEVATIONS OF MARSH PLANT SPECIES

SPECIES	Weighted Mean (feet above NGVD)	Standard Deviation (± ft)	Modal Elevation*	Percent Occurrence Composite
Batis maritima	-	-	3.17	7
Borrichia frutescens	3.76	.53	3.16**	14**
Distichlis spicata	3.71	.27	3.71**	9**
Juncus roemerianus	-	-	4.17	1
Limonium carolinianum	3.38	.46	3.38**	16**
Polygonum setaceum	-	-	3.32	1
Salicornia virginica	3.18	.20	3.16**	21**
Spartina alterniflora	2.59	.59	2.45**	69**
Spartina patens	-	-	5.35	<1
Spartina cynosuroides	-	-	2.51	6
Suaeda linearis	-	-	3.59	4

**Excludes anomalous values in some cases and observations covering less than 2 percent of transect.*
***Recommended indicator species.*

While this profile is by no means precise, it gives some insight into the expected habitat for a Oven elevation and the tolerances various species have for flooding. For example, it establishes the general lower limit of marsh for Charleston, where it is presumed that too frequent flooding kills low-marsh species and transforms the marsh to unvegetated mud flats.

The low-marsh plant *Spartina altemit7ora* was the most dominant species, making up 69 percent of the composite transect. Its modal elevation was 75 cm (2.45 ft), close to today's neap high fide. For Charleston, this is about 15 cm (0.5 ft) below mean high water. Figure 2-4 shows that *S. altemit7ora* extends beyond the limits of low marsh into both high marsh and tidal flat however, this species occurs primarily at low-marsh elevations.

The other indicator species are generally considered to be high-marsh species. These inc*lude Distichlis spicata, Borrichia frutescens, Limoniun carolinianun and Salicomia virginica, Spartina patens,* while having been found to coexist with *Distichlis spicata* in Maryland and North Carolina marshes (E.C. Pendleton, personal communication, December 1984), is uncommon in Charleston at elevations less than 122 cm (Scott, Thebeau, and Kana 1981). The apparent inconsistency in these observations may be related to the significant difference in tidal range between central South Carolina and North Carolina.

Area Estimates

Two sources of information mere available for land area estimates: United States Geological Survey (USGS) 7.5-minute quadrangles and digitized computer maps prepared in an earlier EPA-sponsored case study (Kana et al. 1984). Using topographic and contour maps, me estimated the number of acres of each habitat in the Charleston area (see Figure 2-1)[4]

Our results were graphically determined and spot-checked by a second investigator to ensure they mere consistent to within ± 15 percent for each measurement. Thus, the error limits for the overall study area are estimated to be a maximum of ± 15 percent by subenvironnient.[5]

Tidal-flat areas mere estimated using aerial photos and shaded patterns shown on USGS topographic sheets. The marsh was initially lumped together (high and low marsh) to determine representative areas for each Charleston community. The total number of acres for this zone was divided into high- and low-marsh areas by applying the typical percentage of each along the composite transect (70 percent low marsh and 30 percent high marsh). The transition zone areas mere estimated from the digitized computer maps.

WETLAND SCENARIOS FOR THE CHARLESTON AREA: MODELING AND RESULTS

After establishing the basic relationships among elevation, wetland habitats, and occurrence of species for Charleston, the next steps in our analysis mere to develop a conceptual model for changes in saltwater wetlands under an accelerated rise in sea level and to apply the model to the case study area.

Scenario Modeling

Based on an earlier EPA study (Barth and Titus 1984), me chose three scenarios of future sea level rise (described in Chapter 1, page 9): baseline (current trends), low, and high.[6] To be consistent with the study, me projected the scenarios to the year 2075-95 years after the baseline date of 1980 used to determine "present" conditions; we also assumed that the current rate of relative sea level rise in Charleston is 2.5 mm/yr, although more recent studies suggest 3.4 mm/yr.

The model for future wetland zonation also accounted for sedimentation and peat formation, which partially offset the impact of sea level rise by raising the land surface. Sedimentation rates are highly variable within East Coast marsh/tidal-flat systems, with published values ranging from 2 to 18 mm (.08 to .71 in) per year (Redfield 1972; Hatton, DeLaune, and Patrick 1983). Ward and Domeracki (1978) established markers in an intertidal marsh 20 km (12 mi) south of the Charleston case study area and measured sedimentation rates of 4-6 mm (.16-.24 in) per year. Hatton, DeLaune, and Patrick (1983) reported comparable values (3-5 mm, or .12-.20 in, per year) for Georgia marshes. Although the rate of marsh accretion will depend on proximity to tidal channels (sediment sources) and density of plants (baffling effect and detritus), me believe the published rate of 4-6 mm per year is reasonably representative for the case study area (Ward and Domeracki 1978). Thus, for purposes of modeling, me assumed a sedimentation rate of 5 mm per year. Obviously, the actual rate will vary across any wetland transect, so this assumed value represents an average. Lacking sufficient quantitative data and considering the broad application of our model, me found it was more feasible to apply a constant rate for the entire study area.

As shown in Table 2-3, the combined sea level rise scenarios and sedimentation rates yield a *positive* change in substrate elevation for the baseline and a *negative* change for the low and high scenarios. The positive change for baseline conditions follows the recent trend of marsh accretion in Charleston.

For each of these three scenarios, me considered four alternatives for protecting developed uplands from the rising sea: no protection, complete protection, and two intermediate protection options. Protective options consist of bulkheads, dikes, or seawalls constructed at the lower limit of existing development, which is generally the upper limit of wetlands (S.C. Coastal Council cr*itical area line).* Figure 2-5 illustrates the various options. If all property above today's wetlands is protected with a wall, for example, the wetlands will be squeezed between the wall and the sea. Table 2-4 illustrates the intermediate protection options, whose economic implications were estimated by Gibbs (1984).

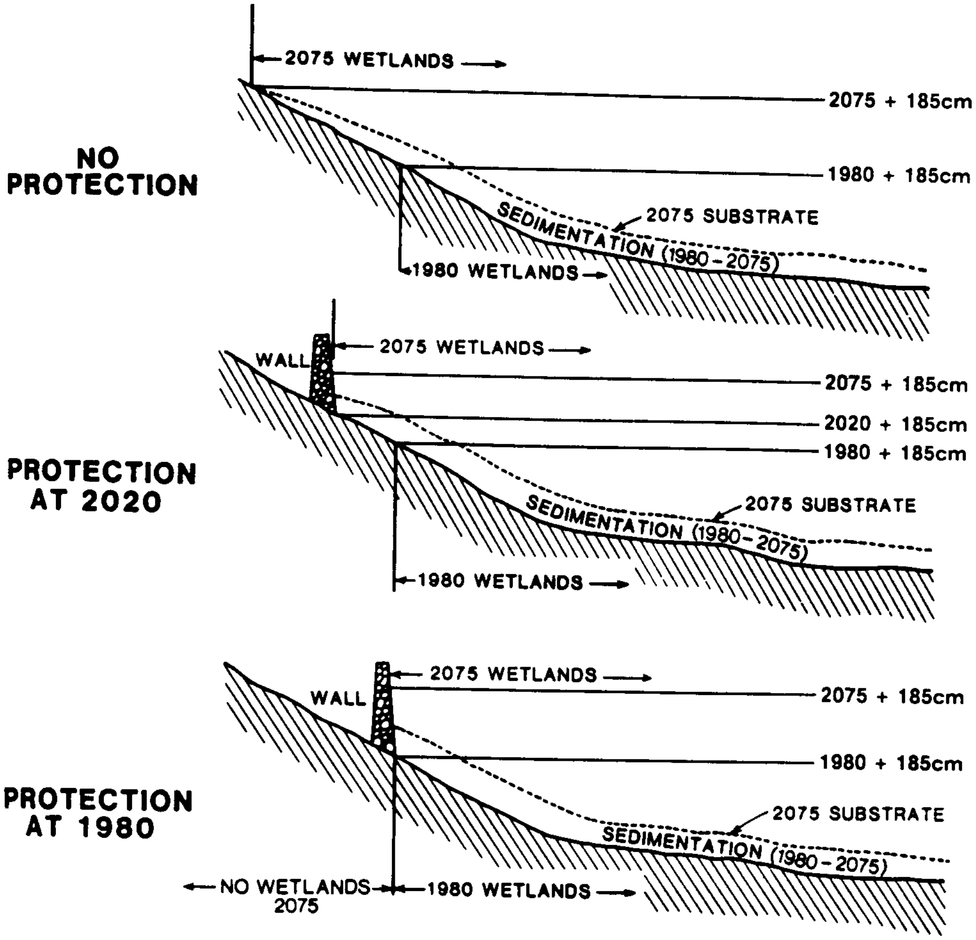
TABLE 2-3

SEA LEVEL RISE SCENARIOS TO THE YEAR 2075

Scenario	Sea Level Rise by 2075	Average Annual Rise	Annual Sedimentation Rate	Annual Net Substrate Change
Baseline	+23.8 cm (0.78 ft)	2.5 mm	5 mm	+2.5 mm
Low	+87.0 cm (2.85 ft)	9.2 mm	5 mm	-4.2 mm
High	+159.2 cm (5.22 ft)	17.0 mm	5 mm	-12.0 mm

FIGURE 2-5

ILLUSTRATION OF HOW SHORE PROTECTION AFFECTS WETLANDS



If people build walls to protect property form rising sea level, the march will be squeezed between the wall and the sea. Sketches show only the upper part of the wetlands which would be affected by shore-protection structures. Mean sea level is off the diagram to the right.

TABLE 2-4

SHORE-PROTECTION SCENARIOS

Area	Without Anticipating Sea Level Rise	With Anticipating Sea Level Rise
Low Scenario		
Peninsula	Protection after 2050	Protection after 2030
West Ashley/James Island	Protection after 2050	Protect half of area after 2050
Mt. Pleasant	None	Protection after 1990
Sullivans Island	None	None
High Scenario		
Peninsula	Protection after 2020	Protection after 2010
West Ashley/James Island	Protection after 2020	Protect half of area after 2030
Mt. Pleasant	Protection after 2050	Protection after 1990
Sullivans Island	None	None

Note: *In West Ashley/James Island, less protection is necessary if sea level rise is anticipated, because more of the low-lying areas are subject to an orderly abandonment.*
Source: *Gibbs 1984. (Note that Gibbs called our high scenario "medium.")*

For our modeling, we used the composite habitat elevations m derived from the twelve transacts (see Figure 24). The cutoff elevation for highland around Charleston was assumed to be an elevation of 200 cm (6.5 ft). In general, land above this elevation around Charleston is free of yearly flooding and is dominated by terrestrial (freshwater) vegetation. Although terrestrial vegetation occurs at lower elevations that are impounded between dikes or ridges, this information is less relevant for sea level rise modeling. The zone of concern is the area bordering tidal waterways, where slopes are assumed to rise continuously without intermediate depressions.

The transition zone is defined as a salt-tolerant area between predominant, high-marsh species and terrestrial vegetation. This area is above the limit of fortnightly (spring) tides but is generally subject to flooding several times each year. If storm frequency remains constant, it is reasonable to assume that storm tides will shift upward by the amount of sea level rise (Titus et al. 1984). However, most climatologists expect the greenhouse warming to alter storm patterns significantly. Nevertheless, because no predictions are available, we assumed that storm patterns will remain the same.

High marsh is defined here by a narrow elevation range of 90 to 120 cm (3 to 4 ft), and low marsh ranges from 45 to 90 cm (1.5 to 3.0 ft). This delineation follows the results of surveyed transacts and species zonation described earlier. The lower limit of the marsh was estimated from the typical transition to mud flats. Sheltered tidal flats actually occur between mean low water and mean high water but were found to be more common in Charleston in the elevation range of 0-46 cm (0-1.5 ft). This somewhat arbitrary division was also based on the contours available on USGS maps, which enabled estimates of zone areas within the case study region.

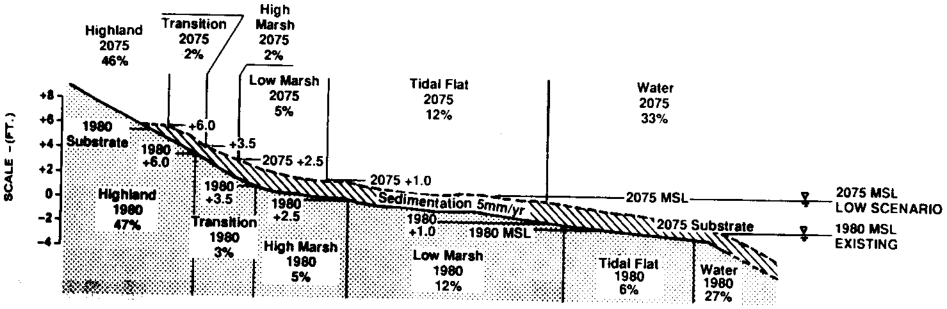
Scenario Results

Based on the shore-protection alternatives for the five suburbs around Charleston, me computed area distributions under the baseline, low, and high scenarios. Figure 2-5 illustrates shore-protection scenarios and their effects on the wetland transect. Our basic assumption was that the wetland habitats' advance toward land ends at 200 cm NGVD (185 cm above mean sea level). Dikes or bulkheads would be constructed under certain protection scenarios at that elevation on the date in question to prevent further inundation.

Because the results are fairly detailed for the five separate subareas and four protection scenarios within the Charleston case study area, m have only listed the overall changes in Tables 2-5 and 2-6 (complete protection and no protection, see p. 50). Results by subarea for all four protection scenarios, given in Appendix 2-B, illustrate the variability of land, water, and wetland acreage from one subarea to another. For example, the peninsula currently has a much loner percentage of low marsh than all other areas. Tidal flat distribution was also variable, ranging from 3.2 percent of the Mt. Pleasant zone to 8.6 percent of the Sullivans Island zone. The summary percentages given in Table 2-6 are appropriately weighted for the five subareas within the study area.

Table 2-5 lists the number of acres for each elevation zone in 1980 (existing) and for the baseline, low, and high scenarios with and without structural protection by the year 2075. The percentage of the total study area that a habitat covers is given in parentheses in Table 2-5 and graphically presented in Figure 2-6, below. Table 2-5 indicates losses under all scenarios with no protection for the four upper habitats and gains in area for tidal flats and water areas. For example, without protection, highland would decrease from 46.6 percent of the total area in 1980 to 41.7 percent in 2075 under the high scenario. This represents a loss of over 2,200 acres or 10 percent of the present highland area. Land that is now terrestrial would be transformed into transition-zone or high-marsh habitats a century from now. Under the 2075 high scenario with no protection, high and low marsh, combined, would decrease from 7,700 acres to 1,535 acres-a reduction of almost 80 percent. While highland and marsh areas would decrease under the no-protection scenarios, water areas would increase dramatically-from 27.4 percent to as much as 48.7 percent-under the high scenario of 2075.

FIGURE 2-6
SHIFT IN WETLANDS ZONATION ALONG A SHORELINE PROFILE



Conceptual model of the shift in wetlands zonation along a shoreline profile if sea level rise exceeds sedimentation by 40cm. In general, the response will be a landward shift and altered real distribution of each habitat because of variable slopes at each elevation interval.

With structural protection implemented at different times for each community (see Table 2-4), highland areas would be maintained at a constant acreage, but transition and high-marsh habitats would be completely eliminated by 2075 under the high scenario (because of the lack of area to accommodate a landward shift). Total marsh acreage would decrease from 7,700 acres to 3,925 acres (2075 low scenario), or 750 acres (2075 high scenario), under the assumed mitigation in Table 2-4.

TABLE 2-5

ACREAGE OF PRINCIPAL HABITAT IN 1980 and 2075

Habitat	Existing 1980 Acres (%)	Baseline 2075 Acres (%)	Low Scenario - 2075		High Scenario - 2075	
			No Protection Acres (%)	Protection Acres (%)	No Protection Acres (%)	Protection Acres (%)
Highland	21,200 (46.6)	21,700 (47.7)	20,445 (44.9)	21,195 (46.6)	18,990 (41.7)	21,195 (46.6)
Transition	1,500 (3.3)	2,820 (6.2)	1,355 (3.0)	605 (1.3)	1,420 (3.1)	0 (0)
High Marsh	2,300 (5.1)	3,320 (7.3)	690 (1.5)	690 (1.5)	675 (1.5)	0 (0)
Low Marsh	5,400 (11.9)	3,910 (8.6)	3,235 (7.1)	3,235 (7.1)	860 (1.9)	750 (1.7)
Tidal Flat	2,600 (5.7)	2,600 (5.7)	5,020 (11.0)	5,020 (11.0)	1,425 (3.1)	1,425 (3.1)
Water	12,500 (27.4)	11,150 (24.5)	14,755 (32.5)	14,755 (32.4)	22,130 (48.7)	22,130 (48.6)
TOTALS	45,500 (100.0)	45,500 (100.0)	45,500 (100.0)	45,500 (100.0)	45,500 (100.0)	45,500 (100.0)

TABLE 2-6

NET CHANGE IN ACRES FOR PRINCIPAL WETLAND HABITATS: 1980 - 2075

Habitat	Baseline Acres (%)	Low Scenario - 2075		High Scenario - 2075	
		Without Protection Acres (%)	With Protection Acres (%)	Without Protection Acres (%)	With Protection Acres (%)
Highland	500 (+2.4)	-744 (4)	0 (0)	-2,210 (10)	0 (0)
Transition	1,320 (+88)	-144 (10)	-895 (60)	-80 (5)	-1,500 (100)
High Marsh	1,020 (+44)	-1,610 (70)	-1,610 (70)	-1,625 (71)	-2,300 (100)
Low Marsh	-1,490 (-28)	-2,165 (40)	-2,165 (40)	-4,540 (84)	-4,650 (86)
Tidal Flats	0 (0)	+2,420 (+93)	+2,420 (+93)	-1,175 (45)	-1,175 (45)
Water	-1,350 (-10.8)	+2,255 (+18)	+2,255 (+18)	+9,630 (+77)	+9,630 (+77)

The net change in areas under the various scenarios listed in Table 2-6 indicates that all habitats mould undergo significant alteration. Even under the baseline scenario, which assumes historical rates of sea level rise, 20-35 percent losses of representative marsh areas are expected by 2075. Protection under the low scenario (as outlined by Gibbs 1984) mould have virtually no effect on high or low marsh coverage; but it would cause a substantially increased loss of transition wetlands. Under the high scenario with protection, highland would be saved at the expense of all transition and high marsh areas and *almost 90 percent* of the low marsh. Even under the low scenario, sea level rise would become the dominant cause of wetland loss in the Charleston area.

RECOMMENDATIONS FOR FURTHER STUDY

This study is a first attempt at determining the potential impact of accelerated sea level rise on wetlands; there remains a need for case studies of other estuaries. Louisiana provides a present-day analog for the effect of rapid sea level rise on wetlands because of high subsidence rates along the Mississippi Delta (see Gagliano 1984). Additional studies in that part of the coast should attempt to document the temporal rate of transformation from marsh to submerged wetlands.

Accurate wetland transacts with controlled elevations are required to determine the preferred substrate elevations for predominant wetland species. With better criteria for elevation and vegetation, we can use remote-sensing techniques and aerial photography to delineate wetland contours on the basis of vegetation. Scenario modeling can then proceed using computer-enhanced images of wetlands and surrounding areas, for more accurate delineation of marsh habitats. Using historical aerial photos, it may also be possible to infer sedimentation rates by changes in plant coverage or species type, which could be related to elevation using some of the criteria provided in this report.

Another problem that remains with this type of study is the frame of reference for mean sea level. For practical reasons, mean sea level for a standard period (18.6 years generally) cannot be computed until after the period ends. Therefore, fixed references, such as the NGVD of 1929, are used. But sea level in Charleston has an elevation of about 15 cm (NGVD). If everyone uses the same reference plane for present and future conditions, the problem may be minor. But it does not allow us to determine modal elevations with respect to today's sea level. The transacts surveyed for the present study suggest that *S. alterniflora (l*ow marsh) grows optimally at an elevation of 75 cm (2.45 ft) above mean sea level, close to mean high water (U.S. Department of Commerce 1981). Compared with today's mean sea level in Charleston, *S. alterniflora* probably tends to grow as much as 15 cm *below* actual mean high water, which may confuse the reader who forgets that the NGVD is 15 cm below today's sea level.

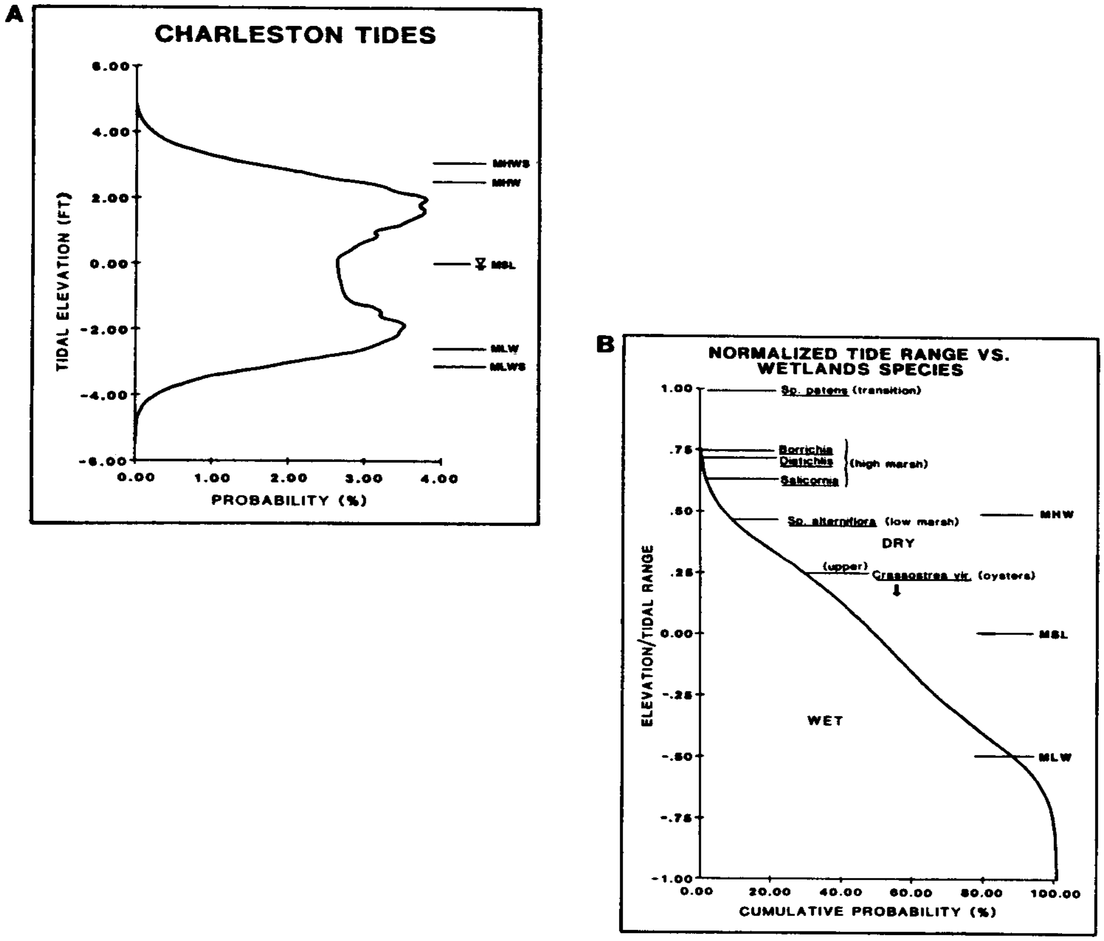
The basic criteria for delineating elevations of various wetland habitats in this study can be easily tested in other areas. By applying normalized flood probabilities (similar to those depicted in Figure 2-7), it will be possible to measure marsh transacts in other tide-range areas and relate them to the results for Charleston.

Normalized Elevations

The absolute modal elevation for each species is site-specific for Charleston. Presuming that the zonation is controlled primarily by tidal inundation, it is possible to normalize the data for other tide ranges based on frequency curves for each water level. Figure 2-7 contains two such "tide probability" curves, based on detailed statistics of Atlantic Coast water levels given in Ebersole (1982) and summarized in Appendix 2-A. The graph of Figure 2-7A gives the probability of various water levels for Charleston. In Figure 2-7B, the data have been normalized for the mean tide range of 156 cm (5.2 ft) in Charleston and given as a cumulative probability distribution. These graphs are applicable to much of the southeastern U.S. coast by substituting different tide ranges. Each graph provides a measure of the duration of time over the year that various wetland elevations are underwater.

In the case of *Salicomia virginica* (+3.16 ft for Charleston), the cumulative frequency of flooding is approximately 4 percent (Figure 2-7B and Appendix 2,A). If one wanted to apply

FIGURE 2-7
TIDE PROBABILITY CURVES



Tide-probability curves based on statistics for Charleston given in Ebersole (1982).

(A) Probability distribution for the range of astronomic tides.

(B) "Normalized" cumulative probability distribution, indicating the preferential elevation for various wetland species.

Abbreviations: *MHWS (mean high water spring); MHW (mean high water); MSL (mean sea level); MLW (mean low water); MLWS (mean low water spring).*

these results for an area with a different tide range but similar species occurrence, such as Sapelo Island (Georgia), the flooding frequency for *S. virginica* could be used to estimate its modal elevation at the locality. With a mean tide range of 8.5 ft at Sapelo, S. virginica is likely to occur around + 5.3 ft MSL (based on substitution of the tide range in Figure 2-7B). This procedure can be applied for other southeastern U.S. marshes as a preliminary estimate of local modal elevations.

We do not consider elevation results for the transects to be definitive because of the relatively small sample size. However, the results are sufficiently indicative of actual trends to allow scenario modeling. With the tide-probability curves presented, it should be possible to check these results against other areas with similar climatic patterns, but different tide ranges.

CONCLUSIONS

Our results appear to confirm the hypothesis that there would be less land for wetlands to migrate onto if sea level rises**,** than the current acreage of wetlands in the Charleston area.

Wetlands in the Charleston area have been able to keep pace with the recent historical nse in sea level of one foot per century. However, a three- to five-foot rise in the next century resulting from the greenhouse effect would almost certainly exceed their ability to keep pace, and thus result in a net loss of wetland acreage.

The success with which coastal wetlands adjust to rising sea level in the future will depend upon whether human activities prevent new marsh from forming as inland areas are flooded. If human activities do not interfere, a three-foot rise in sea level would result in a net loss of about 50 percent of the marsh in the Charleston area. A five-foot rise would result in an 80 percent loss.

To the extent that levees, seawalls, and bulkheads are built to prevent arm from being flooded as the sea rises, the formation of new marsh will be prevented. We estimate that 90 percent of the marsh in Charleston-including all of the high marsh-would be destroyed if sea level rises five feet and walls are built to protect existing development.

This study represents only a preliminary investigation into an area that requires substantial additional research. The methods developed here can be applied to estimate marsh loss in similar areas with different tidal ranges without major additional fieldwork. Nevertheless, more field surveys and analysis will be necessary to estimate probable impacts of future sea level rise on other types of wetlands.

The assumptions used to predict future sea level rise and the resulting impacts on wetland loss must be refined considerably so that one can have more confidence in any policy responses that are based on these predictions. The substantial environmental and economic resources that can be saved if better predictions become available soon will easily justify the cost (though substantial) of developing them (Titus et al. 1984). However, deferring policy planning until all remaining uncertainties are resolved is unwise.

The knowledge that has accumulated in the last twenty-five years has provided a solid foundation for expecting sea level to rise in the future. Nevertheless, most environmental policies assume that wetland ecosystems are static. Incorporating into environmental research the notion that ecosystems are dynamic need not wait until the day when we can accurately predict the magnitude of the future changes.

NOTES

[1] These scenarios mere originally used by Kana et al. (1984). They are based on local subsidence and the Hoffman et al. (1983) mid-low and mid-high scenarios. See Titus et al. (1984) for further explanation.

[2] Plots of the profile of each transect, showing the modal elevations of the substrate and zonation of plant species, can be found in Appendix A of an earlier publication of this study: T. Kana, B. Baca, M. Williams, 1986, *Potential Irnpac4 of Sea Level Rise on Wetlands Around Charleston, North Carolina,* U.S. Environmental Protection Agency, Washington, D.C.

[3] Kurz and Wagner (1957) and Stalter (1968) found lower elevation limits for *S. altemit7ora* growth in the Charleston area. However, we found these marshes to be highly variable and often terminated in oyster reef or steep dropoffs which precluded the growth of vegetation. The lack of vegetation in these areas and the inherent variability of area marshes may explain these discrepancies with earlier works.

[4] For budgetary reasons, me could not rigorously calculate areas using a computerized planimeter. This level of precision would be questionable anyway, in light of the imprecision of USGS topographic maps in delineating marshes and tidal flats near mean water levels.

[5] Because the standard error of a sum is less than the sum of individual standard errors, the errors are likely to be less. Unfortunately, me had no way of rigorously testing these results within the time and budget constraints of the project.

[6] The scenario referred to as "medium" in Barth and Titus is called "high" in this report.

REFERENCES

Barth, M.C., and J.G. Titus (Eds.), 1984. *Greenhouse Effect and Sea Level Rise.* Van Nostrand Reinhold Co., New York, N.Y., 325 pp.

Boesch, D.F., D. Levin, D. Numrnedal, and K. Bowles, 1983. *Subsidence in Coastal Louisiana: Cases, Rates and Effects on Wetlands.* U.S. Fish and Wildlife Serv., Washington, D.C., FWSIOBS-83126, 30 pp.

DeLaune, R.D., C.J. Smith, and W.H. Patrick, Jr., 1983. "Relationship of marsh elevation, redox potential, and sulfide to *Sparfina altemit7ora* productivity." *Soil Science Amer Jow., Vol.* 47, pp. 930-935.

Duc, A.W., 1981. "Back barrier stratigraphy of Kiawah Island, South Carolina." Ph.D. Dissertation, Geol. Dept., University of South Carolina, Columbia, 253 pp.

Ebersole, B.A., 1982. *Atlantic Coast Water-level Clitnate.* WES Rept. 7, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss., 498 pp.

Gagliano, S.M., 1984. Independent reviews (comments of Sherwood Cagliano). In M.C. Barth and J.G. Titus (Eds.), *Greenhouse Effect and Sea Level Rise.* Van Nostrand Reinhold Co., New York, N.Y., Chap. 10, pp. 296-300.

Gagliano, S.M., K.J. Meyer Arendt, and K.M. Wicker, 1981. "Land loss in the Mississippi deltaic plain." In *Trans. 31st Ann. Mtg., Gulf Coast Assoc. Ceol Soc.* (GCAGS), Corpus Christi, Texas, pp. 293,300.

Gallagher, J.L., R.J. Reiniold, and D.E. Thompson, 1972. "Remote sensing and salt marsh productivity." In *Proc. 38th Ann. Mtg. Arner Soc. Photogrammetry* Washington, D.C., pp. 477-488.

Gibbs, M.J., 1984. "Economic analysis of sea level rise: methods and results." In M.C. Barth and J.G. Titus (Eds.), *Greenhouse Effect and Sea Level Rise.* Van Nostrand Reinhold Co., New York, N.Y., Chap. 7, pp. 215-251.

Hatton, R.S., R.D. DeLaune, and W.H. Patrick, 1983. "Sedimentation, accretion and subsidence in marshes of Barataria Basin, Louisiana." *Limnol. and Oceanogr, Vol.* 28, pp. 494-502.

Hayes, M.O., and T.W. Kana (Eds.), 1976. *7&-?igenous Clastic Depositional Environments,* Tech. Rept. NO. 11-CRD. Coastal Research Division, Dept. Geol., Univ. South Carolina, 306 pp.

Hicks, S.D., H.A. DeBaugh, and L.E. Hickman, 1983. *Sea Level Variations for the United States 1&5&1980.* National Ocean Service, U.S. Department of Commerce, Rockville, Maryland.

Kana, T.W., 3. Michel, M.O. Hayes, and J.R. Jensen, 1984. "The physical impact of sea level rise in the area of Charleston, South Carolina. In M.C. Barth and J.G. Titus (Eds.), *Greenhouse Effect and Sea Level Rise.* Van Nostrand Reinhold Co., New York, N.Y., Chap. 4, pp. 105-150.

Kana, T.W., B.J. Baca, M.L. Williams, 1986. *Potential Impacts of Sea Level Rise on Wetlands Around Charleston, South Carolina.* U.S. EPA, Washington, D.C., 62 pp.

Kurz, H., and K. Wagner. 1957. *Tidal Marshes of the Gulf and Atlantic Coasts of Northern Florida and Charleston, South Carolina.* Florida State Univ. Stud. 24, 168 pp.

Nixon, S.W., 1982. *The Ecology of New England High Salt Marshes: A Community Profile.* U.S. Fish and Wildlife Serv., Washington, D.C., FWS/OBS-81155, 70 pp.

Nummedal, D., 1982. "Future sea level changes along the Louisiana coast." In D.F. Boesch *(Ed.), Proc. Conf Coastal Erosion and Wetland Modfification in Louisiana: Causes, Consequences and Options.* U.S. Fish and Wildlife Serv., Washington, D.C., FWSIOBS-82159, pp. 164-176.

Odum, E.P., and M.E. Fanning, 1973. "Comparisons of the productivity of *Spalina alterniflora and Spartina cynosuroides* in Georgia co&" marshes." *Bull. Georgia Acad. Sci.,* Vol. 31, pp. 1-12.

Pendleton, E.C., 1984. Personal communication. U.S. Fish and Wildlife Serv., National Coastal Ecosystems Team, Slidell, LA.

Redfield, A.C., 1972. "Development of a New England salt marsh." *Ecol. Monogr.*, Vol. 42, pp. 201-237.

Schubel, J.R., 1972. "The physical and chemical conditions of the Chesapeake Bay." *Jour. Wash. Acad. Sd.,* Vol. 62(2), pp. 56-87.

Scott, G.I., L.C. Thebeau, and T.W. Kana, 1981. "Ashley River marsh survey - Phase I." Prepared for Olde Charleston Partners; RPI, Columbia, S.C., 43 pp.

South Carolina Coastal Council, 1985. *Performance Report of the South Carolina Coastal Management Program.* South Carolina Coastal Council, Columbia, South Carolina.

Stalter, R. 1968. "An ecological study of a South Carolina salt marsh." Ph.D. Dissertation. Univ. South Carolina, Columbia, 62 pp.

W, J.M., 1958. "Energy flow in the salt marsh ecosystem." In *Proc. Salt Marsh Conf.,* May. W., Univ. Georgia, pp. 101-107.

Titus, J.G., T.R. Henderson, and J.M. TM, 1984. "Sea level rise and wetlands loss in the United States. *National Wetlands Newsletter,* Environmental Law lnst., Washington, D.C., Vol. 6(5).

Titus, J.G., "Sea Level Rise and Wetlands Loss." In O.T. Magoon (ed.) *Coastal Zone '85.* American Society of Civil Engineers, New York, New York, pp. 1979-1990.

Titus, J.G., M.C. Barth, MJ. Gibbs, I.S. Hoffman, and M. Kenney, 1984. "An overview of the causes and effects of sea level rise." In M.C. Barth and J.G. Titus (Eds.), *Greenhouse Effect and Sea Level Rise.* Van Nostrand Reinhold Co., New York, N.Y., Chap. 1, pp. 1-56.

Turner, R.E., 1976. "Geographic variations in salt marsh macrophyle production: a review." *Contributions in Marine Science,* Vol. 10, pp. 47-48.

U.S. Department of Commerce, 1979. *State of South Carolina Coastal 7,one Management Program and Final Environmental Impact Statement.* Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, Washington, D.C.

U.S. Department of Commerce, 1981. "Tide tables, east coast of North and South America." NOAA, National Ocean Survey, Rockville, MD., 288 pp.

Valiela, I., J.M. Teal, and W.G. Deuser, 1978. "The nature of growth forms in the salt marsh grass *Spartina altemiflora.* " *American Naturalist,* Vol. 112(985), pp. 461-470.

Ward, L.G., and D.D. Domeracki, 1978. "The stratigraphic significance of back-barrier tidal channel migration." *Geol. Soc. Amer,* Abs. with Programs, Vol. 10(4), p. 201.

Wilson, K.A., 1962. *North Carolina Wetlands. Their Dist7ibution and Management. North* Carolina Wildlife Resources Commission, Raleigh, N.C.

APPENDIX 2-A

TIDE ELEVATION PROBABILITY DISTRIBUTION FOR CHARLESTON, SOUTH CAROLINA

(Based on data given by Ebersole, 1982)

*Common Reference**	*Elevation (ft, MSL)*	*Normalized Elev. (Elevation/ Tidal Range)*	*Probability (%)*	*Cumulative Probability (%)*
	5.2	1.000	0.00	0.00
	5.0	0.962	0.01	0.01
	4.8	0.923	0.02	0.03
	4.6	0.885	0.03	0.06
	4.4	0.846	0.08	0.14
	4.2	0.808	0.13	0.27
	4.0	0.769	0.26	0.53
	3.8	0.731	0.44	0.97
	3.6	0.692	0.72	1.69
	3.4	0.654	1.01	2.70
MHWS	3.2	0.615	1.54	4.24
	3.0	0.577	2.02	6.26
	2.8	0.538	2.55	8.81
MHW	2.6	0.500	2.97	11.78
	2.4	0.462	3.20	14.98
	2.2	0.423	3.40	18.38
	2.0	0.385	3.47	21.85
	1.8	0.346	3.48	25.33
	1.6	0.308	3.22	28.55
	1.4	0.269	3.18	31.73
	1.2	0.231	2.89	34.62
	1.0	0.192	2.76	37.38

TIDE ELEVATION PROBABILITY DISTRIBUTION FOR CHARLESTON, SOUTH CAROLINA (Continued)

*Common Reference**	*Elevation (ft, MSL)*	*Normalized Elev. (Elevation/ Tidal Range)*	*Probability (%)*	*Cumulative Probability (%)*
	0.8	0.154	2.71	40.09
	0.6	0.115	2.69	42.78
	0.4	0.077	2.66	45.44
	0.2	0.038	2.65	48.09
	0.0	0.000	2.66	50.75
	-0.2	-0.038	2.67	53.42
	-0.4	-0.077	2.80	56.22
	-0.6	-0.115	2.94	59.16
	-0.8	-0.154	3.13	62.29
	-1.0	-0.192	3.17	65.46
	-1.2	-0.231	3.47	68.93
	-1.4	-0.269	3.64	72.57
	-1.6	-0.308	3.78	76.35
	-1.8	-0.346	3.72	80.07
	-2.0	-0.385	3.77	83.84
	-2.2	-0.423	3.39	87.23
	-2.4	-0.462	3.14	90.37
MLW	-2.6	-0.500	2.54	92.91
	-2.8	-0.538	2.13	95.04
	-3.0	-0.577	1.67	96.71
MLWS	-3.2	-0.615	1.16	97.87
	-3.4	-0.654	0.86	98.73
	-3.6	-0.692	0.53	99.26
	-3.8	-0.731	0.35	99.61
	-4.0	-0.769	0.21	99.82
	-4.2	-0.808	0.12	99.94
	-4.4	-0.846	0.03	99.97
	-4.6	-0.885	0.02	99.99
	-4.8	-0.923	0.01	100.00
	-5.0	-0.962	0.00	100.00
	-5.2	-1.00	0.00	100.00

*MHW – mean high water
MLW – mean low water
MSL – mean sea level
MHWS – mean high water spring
MLWS – mean low water spring

APPENDIX 2-B

AREA DISTRIBUTION BY ELEVATION ZONE FOR EACH OF THE FIVE PRINCIPAL LAND DIVISIONS IN THE CHARLESTON STUDY AREA

ZONE	NO PROTECTION				LOW SCENARIO			HIGH SCENARIO		
	Existing (1980)	Baseline (2075)	Low Scenario (2075)	Middle Scenario (2075)	Protection @ 1980	With Anticipation Protection @ 2030	Without Anticipation Protection @ 2050	Protection @ 1980	With Anticipation Protection @ 2010	Without Anticipation Protection @ 2020
SULLIVAN ISLAND: TOTAL ACRES = 1,750										
Highland	37.1	36.2	35.6	32.8	37.1	NA	NA	37.1	NA	NA
Transition	2.9	2.9	2.8	3.4	1.3	-	-	0.0	-	-
High Marsh	7.1	2.3	1.2	0.7	1.2	-	-	0.0	-	-
Low Marsh	15.7	13.0	9.6	1.7	9.6	-	-	1.5	-	-
Tidal Flat	8.6	12.4	14.7	3.5	14.7	-	-	3.5	-	-
Water	28.6	33.2	36.1	57.9	36.1	-	-	57.9	-	-
TOTALS	100.0	100.0	100.0	100.0	100.0	-	-	100.0	-	-
DANIEL ISLAND: TOTAL ACRES = 4,500										
Highland	41.6	40.7	40.2	37.5	41.6	NA	NA	41.6	NA	NA
Transition	2.8	2.8	2.6	2.8	1.2	-	-	0.0	-	-
High Marsh	5.0	1.9	1.2	1.1	1.2	-	-	0.0	-	-
Low Marsh	11.7	9.5	7.0	1.7	7.0	-	-	1.5	-	-
Tidal Flat	5.7	8.9	10.9	2.8	10.9	-	-	2.8	-	-
Water	33.2	36.2	38.1	54.1	38.1	-	-	54.1	-	-
TOTALS	100.0	100.0	100.0	100.0	100.0	-	-	100.0	-	-

AREA DISTRIBUTION BY ELEVATION ZONE FOR EACH OF THE FIVE PRINCIPAL LAND DIVISIONS IN THE CHARLESTON STUDY AREA (Continued)

CHARLESTON PENINSULA - 14,000 ACRES - % AREA @ 2075										
Highland	53.4	52.3	51.5	47.9	53.4	52.4	51.9	53.4	51.6	51.0
Transition	3.7	3.6	3.1	3.1	1.2	2.2	2.7	0.0	0.0	0.0
High Marsh	1.1	1.4	2.0	2.1	2.0	2.0	2.0	0.0	1.5	2.1
Low Marsh	2.5	2.1	1.9	2.2	1.9	1.9	1.9	1.9	2.2	2.2
Tidal Flat	7.1	4.6	3.2	2.1	3.2	3.2	3.2	2.1	2.1	2.1
Water	32.2	36.0	38.3	42.6	38.3	38.3	38.3	42.6	42.6	42.6
TOTALS	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
WEST ASHLEY - 9,500 ACRES - % AREA @ 2075										
Highland	29.5	29.0	28.6	26.4	29.5	28.55	28.60	29.5	27.15	28.2
Transition	2.1	1.9	1.8	2.1	0.9	1.85	1.80	0.0	1.35	0.3
High Marsh	7.4	2.2	0.9	0.9	0.9	0.9	0.9	0.0	0.9	0.9
Low Marsh	16.8	14.3	9.9	0.9	9.9	9.9	9.9	0.8	0.9	0.9
Tidal Flat	7.4	12.2	15.6	3.5	15.6	15.6	15.6	3.5	3.5	3.5
Water	36.8	40.4	43.2	66.2	43.2	43.2	43.2	66.2	66.2	66.2
TOTALS	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MT PLEASANT: TOTAL ACRES = 15,750 - % AREA @ 2075										
Highland	53.3	52.1	51.3	47.7	53.3	53.1	51.3	53.3	52.7	49.2
Transition	3.8	3.8	3.7	3.8	1.7	1.9	3.7	0.0	0.0	2.3
High Marsh	7.1	2.6	1.6	1.5	1.6	1.6	1.6	0.0	0.3	1.5
Low Marsh	16.7	13.5	9.8	2.3	9.8	9.8	9.8	2.0	2.3	2.3
Tidal Flat	3.2	10.4	14.9	3.9	14.9	14.9	14.9	3.9	3.9	3.9
Water	15.9	17.6	18.7	40.8	18.7	18.7	18.7	40.8	40.8	40.8
TOTALS	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0