DELINEATION OF THE SOUTH CAROLINA COASTAL ZONE BY USE OF VEGETATIVE GUIDES

by

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ABSTRACT

A new coastal zone boundary and salt zone boundary were mapped from high altitude color infrared photography by the identification of plant communities along estuaries. The South Carolina Coastal Zone defined by the new coastal zone boundary is at least 300,000 acres small in area than the zone defined by the existing boundary. Precision estimates are ±0.06 miles for most of the boundary and are ±0.25 miles in a few specified difficult areas. Recommendations to South Carolina and other member states of the Coastal Plains Regional Commission concerning the mapping and maintenance of coastal zone boundaries are included.

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ERRATA

1. Abstract: "small" should be "smaller"
2. Page 1, sentence 2: Prior to that, in July 1967, three Atlantic states--North Carolina, South Carolina and Georgia --joined forces to form the Coastal Plains Regional Commission. They were joined by Virginia and Florida in March 1975 to form the present five-state Commission.
3. Page 2, second to last paragraph, second sentence: "examples" should be "example".
4. Page 3, third sentence: According to Soils Memorandum SC-4 (1) of the U. S. Department of Agriculture Soil Conservation Service, marshes....
5. Page 5, line 4: Juncus roemerianus should be in italics.

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I. Introduction

In 1972, the federal Coastal Zone Management Act was signed into law, which required states bordering on oceans, Gulf, and Great Lakes to define their own coastal zones. Subsequently, five Atlantic States (Virginia, North Carolina, South Carolina, Georgia, and Florida) joined forces to form the Coastal Plains Regional Commission to assist them in complying with the Coastal Zone Management Act. Of these states, South Carolina was chosen as a test case from which the other members of the Commission could learn the methods and costs of mapping a coastal zone. Though a tentative South Carolina coastal zone boundary had been defined along cultural features (highways and the Intra Coastal Waterway), the South Carolina Coastal Zone Planning and Management Council saw the need to redraw this boundary on an objective, scientific basis. In response to this need, the Council, under a grant from the Coastal Plains Regional Commission, retained Geospectra Corporation of Ann Arbor, Michigan in late 1974 to manage a technical program designed to map the boundary of the South Carolina Coastal Zone, employing remote sensing methods. This report describes the results of that program.

II. Technical Approach

Most of the data used in this study were supplied free of charge by NASA in the form of high altitude (60,000 feet) false color infrared photographs, collected along the entire South Carolina coast in August, 1972. In addition, LANDSAT I multispectral scanner images were purchased from the U.S. Department of Interior, and low altitude (6,000 feet) color infrared photography covering selected areas along the coast were taken in October, 1974, as part of this program. The low altitude photography, plus data collected during a June, 1975 field trip by scientists of various South Carolina state agencies and Geospectra Corporation, were used as "ground truth" verification for the high altitude photo interpretation.

A decision was made to define the inland-most points appreciably affected by salt water on each estuary along the South Carolina Atlantic Coast, and to connect these points overland to form the coastal zone boundary. Therefore, the fresh water-brackish water interface along each estuary became the control points through which the coastal zone boundary was defined.* Inland from these points the use of water from rivers and streams involves the same ecological principles as other fresh water areas in the state, with the exception of uses which would produce large changes in the volume of channel or ground water flow near the coastal zone boundary. This exception, which can produce significant changes in the coastal zone boundary, will be addressed later. For land seaward of the coastal zone boundary, an ecology quite different from fresh water areas is encountered. For instance, flood irrigation in the brackish zone requires flood gates that permit the influx of water to agricultural fields only at low tide, when fresh water dominates the estuary, whereas flood gates are unnecessary for irrigation in the fresh zone. This is the primary reason why the coastal zone boundary was interpolated overland between fresh-brackish interface control points along the estuaries. Since irrigation is impossible in the salt zone except from underground sources, the salt zone boundary was also defined, though it was not required for this study.

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*The line interpolated overland through fresh-brackish interface control points along each estuary is the coastal zone boundary. Landward of the coastal zone boundary is the fresh zone. A similar line drawn overland through brackish-salt interface control points along each estuary is the salt zone boundary. The area between the coastal zone and salt zone boundaries is called the brackish zone, and the area between the salt zone boundary and the sea is the salt zone.

To define the control points, three physical parameters were considered: water salinity, soil composition (particularly pH and sulfur content), and vegetative guides. Since water salinity varies hourly and monthly with the tides and since no inexpensive remote sensing technique is now known for making direct accurate measurements of salinity, this parameter was eliminated because of high costs in time and money. Likewise, soil composition was eliminated from consideration because the dense vegetation cover made soils directly unobservable in most areas, and the cost of taking soil samples along South Carolina estuaries was too high. Thus, vegetative guides were chosen as the physical parameter most likely to be amenable to cheap, accurate analysis, because remote sensing methods could be employed.

The first approach taken involved an attempt to map the fresh-brackish and brackish-salt interfaces solely according to individual plant species. This approach failed because several marsh species can grow in more than one salinity zone. For example, smooth cordgrass (*spartina alterniflora*) can be found in salt, brackish, or fresh water marshes. Consequently, it became necessary to search for more general properties of plant communities rather than just individual species and to consider cultural features, such as the Intra Coastal Waterway and irrigation ditches, as additional information.

In complex problems, general trends can often be helpful, if exceptions to these trends can be tolerated. Two trends in plant growth, stemming from the same causal factor, were observed which produced a helpful effect on false-color infrared photographs. All plants, even those in salt marshes, require fresh water for their growth. As one travels seaward along an estuary, progressively less fresh water is available for plant nurture, both from surface water and from near-surface underground water. Since broad-leafed lower plants generally require more moisture than narrow-leafed lower plants, one of the trends in plant growth is for narrow-leafed plants to become progressively predominant in the seaward direction along the estuaries. Another plant growth trend along estuaries, likewise caused by changes in the availability of fresh water, is for plants nearer the sea to grow slightly farther apart, i.e., for plant density to decrease toward the sea. These two effects tend to reduce the leaf-area-index (a measure of the percentage of ground area covered by plant leaves when viewed from directly above-ground) of the plant communities as the sea is approached. In a false color infrared photograph, plant communities with greater leaf-area-indices appear redder in the photo, owing to the high reflectance of leaves in the reflective infrared wavelength region. Therefore, one general effect that the photointerpreter can employ for mapping coastal zones is that fresh water marshes should be redder on false color photographs (taken near the season of maximum vegetation vigor) than brackish marshes, which in turn should be redder than salt marshes. This trend, verified by field observations and low altitude photography (where spatial resolution is good enough that many individual plant species can be identified by their geometry), is not sufficient in itself, however, to permit mapping of the various zones. Exceptions to the trend can be troublesome.

A second tool which has provided assistance is photographic texture (as seen through a hand lens). The best examples of this is pickerelweed (*Pontederia* sp.), a fresh water plant. The smallest object that can be spatially resolved on the high altitude photography is approximately 20 to 30 feet in diameter, and pickerelweed is a broad-leafed plant that tends to grow in clumps on the order of a hundred feet and smaller near the brackish-fresh interface along estuaries. Brighter "freckles" of red on the photography usually meant the start of pickerelweed, hence, the brackish-fresh interface. The texture was a necessary observation for distinguishing between pickerelweed and dense patches of cordgrass (*spartina* sp.) along the estuary.

A third tool, less important, was the use of cultural features. Abandoned irrigation ditches usually are located in the brackish zone, for example. Causeways sometimes provided good distinction between brackish and fresh zones because the flow of surface and near surface water was artificially altered, yielding quite different vegetative patterns on either side of the causeway. Finally, the Intra Coastal Waterway, parallel to the seashore in many places, has become the best fresh-brackish boundary in the northern coastal counties of South Carolina. In some places along the canal, the fresh and salt zones appear to be adjacent.

(a)

(b)

Figure 1. (a) High altitude color infrared photograph (August, 1972) of the Combahee River between U.S. 17 and the old S.A.L. railroad.

(b) Low altitude color infrared photograph (October, 1974) of boxed area shown in figure 1. (a).

North is to the top in both photographs.

If any plant genus should be singled out as most helpful, it would have to be the pickerelweed (*Pontederia* sp.), which in South Carolina reliably grows only in fresh water marshes. The black rush (*Juncus roemerianus*) was generally helpful in marking the salt-brackish interface, since the salt marshes generally excluded all but the cordgrasses of the *Spartina* genus (smooth cordgrass, *Spartina alterniflora,* big cordgrass, *Spartina cynosuroides,* and some marshhay cordgrass, *Spartina patens*). According to the South Carolina Soil Conservation Service's Soils Memorandum SC-4 [1], marshes dominated by low-growing smooth cordgrass (*Spartina alterniflora*) have a water salinity above 15,000 ppm. Where the salinity level becomes less than 15,000 ppm, the dominant vegetation changes to black rush (*Juncus roemerianus*).

III. Experimental Conditions and Results

The high altitude aerial false color infrared photography achieves complete coverage of the coastal zone in a sequence of individual photographs which overlap one another by approximately two-thirds. These data come from NASA Flight No. 72-144, Accession No. 00627, collected on August 19, 1972 between approximately 9 A.M. and noon EST. The infrared film type was 2443, which is sensitive in the 0.51-0.90 um wavelength region. The Coastal Zone boundary is most accurately portrayed on acetate overlays (not shown in this report) for selected photographic frames of this sequence, which provide a continuous view of the Coastal Zone with only slight photo overlap. In order to follow the Coastal Zone boundary from North to South, the high altitude photography should be viewed in the following numerical order: 2957, 2954, 2952, 2950, 2915, 2917, 2919, (2921, 2943, 2942), (2923, 2940), (2924, 2938, 2978), (2936, 2980), 2935, 2934, 2930.

Throughout much of the Coastal Zone, the boundaries between marsh types are quite clearly defined by flora, topography (highland regions over ten or so feet above sea level have trees), and man-made structures. In these well-defined areas, the precision of the determination is estimated to be within the thickness of the line on the overlay, i.e. within a band approximately one-eighth-mile wide (± 0.06 miles). In some cases, the marsh boundaries were more difficult to place, because the transition from one marsh type to another was more gradual. In such areas, the precision of the determination is considered to be more reasonably placed within a one-half-mile-wide band (± 0.25 miles).

Various data were available for different regions. High altitude aerial photography was available for the entire coastal zone, low altitude aerial photography (also color infrared) was available for portions of four estuaries, and field determinations were available for two of the rivers. In all cases, each type of information confirmed the results of the others. The low altitude photography, collected near noon on October 25, 1974, was able to clearly resolve some difficult areas on the high altitude photography, even though the two series were taken at different times of the year.

As an example, figure 1(a) is a portion of a high-altitude false color IR photo, showing the Combahee River between highway 17 (to the North, or top) and the old S.A.L. railroad (South, or bottom). The box indicates the location of figure 1 (b), which is part of a low-altitude false color IR photo, taken at a different time of year. This site makes an excellent example, because it shows salt, brackish, and freshwater marshes all adjacent, with excellent boundaries between them. It should be noted, however, that this is a highly unusual area with respect to the rest of the Coastal Zone, where, in general, the boundaries are less distinct and further apart.

In the high altitude photograph of figure 1(a), salt marsh (S) appears mostly blue; brackish marsh (B) appears more reddish; and freshwater marsh (F) appears bright red and mottled. Another indicator of the seaward boundary of brackish marsh can be the beginning of a network of canals indicating past or present rice fields. In this example, the old railroad marks a sharp boundary between fresh and brackish marsh to the northeast of the Combahee, and between brackish and salt marsh to the southwest of the river. Highway 17 marks a clear brackish-freshwater boundary at the top of the figure 1(a).

In the low altitude photo of figure 1(b), the vegetative types responsible for the patterns observed at high altitude are more discernible. In the salt marsh area of this frame, the dark color indicates mixtures of species of cordgrasses or *Spartina* (Sp), while the brackish zone of this example is dominated by black rush or Juncus Roemerianus (Ju), a good indicator of the brackish-salt interface. The freshwater zone shows a mixture of freshwater plants, and indicates the over-all brightness and mottled pattern which characterizes freshwater marshes.

A review of the coverage and regional pecularities of the South Carolina Coastal Zone, from North to South, follows:

1. From the North Carolina-South Carolina border to the juncture of the Waccamaw River with Winyah Bay (near Hare Island), the Intra Coastal Waterway is taken as the beginning of the fresh-water area. Most of the salt marshes in this stretch adjoin wooded and inhabited headlands, leaving little or no land under the influence of brackish waters.
2. The boundaries in the Winyah Bay, Pee Dee and Waccamaw River areas have been set by high and low altitude photography, with some field confirmation.
3. From Winyah Bay to a point just East of McClellanville, the boundaries have been set by high-altitude photography.
4. From the previous point to Charleston Harbor, wooded and inhabited headlands mark a fresh-salt boundary, again leaving little or no land under brackish water influence. For roughly half this distance the headlands lie adjacent to, or nearly adjacent to the Intra Coastal Waterway.
5. From Charleston Harbor to the N. Edisto River, the boundaries have been set by high altitude photography. Classification of the U.S. Naval Reserve due East of North Charleston was difficult to determine. It has been tentatively relegated to the fresh zone.
6. Both coastal zone and salt boundaries along the S. Edisto and Ashepoo Rivers and around Ashe Island were difficult to determine initially, but were clarified with the aid of field information, low altitude photography and several high altitude frames.
7. The Combahee River coastal zone and salt boundaries were very clearly indicated by both high and low altitude photography.
8. Both boundaries along the Broad River were determined with difficulty by high altitude photography.
9. The Savannah River boundaries were determined solely by high altitude photography, and no pecularities were observed.

Boundaries in the difficult regions described in points 5, 6, and 8 above have a precision no better than ± 0.25 miles.

To simplify consideration of the South Carolina Coastal Zone as a whole, a map has been prepared at a scale of 1:250,000 (herein presented as Figure 2, at a scale of approximately 1:500,000). This map does not have the accuracy of the photo overlays; hence, the acetate overlays should be considered the best technical presentation of the coastal zone boundary.

The broad areas indicated on the map as "Salt" and "Brackish" apply to the salt zone and brackish zone, as defined earlier. The lines on the map have the following meanings:

Dashed Black Line— current coastal zone boundary.

Solid Thin Line— recommended new coastal zone boundary, resulting from this study. This line is the same as the solid blue and dashed blue lines on the acetate overlays; thus, where it crosses estuarine marshes, it is the border between freshwater marsh and brackish marsh. Where it crosses solid ground, it merely connects control points on two estuaries. In the northernmost region, this line follows the old boundary, which is the Intra Coastal Waterway.

Solid Thick Line— salt zone boundary. Where it crosses an estuarine marsh, it is the salt-brackish marsh boundary. Where it crosses solid land, it connects control points on two estuaries. In the northernmost region, this line generally follows the coastline, where saltwater meets highland (approximately 10 foot elevations and higher).

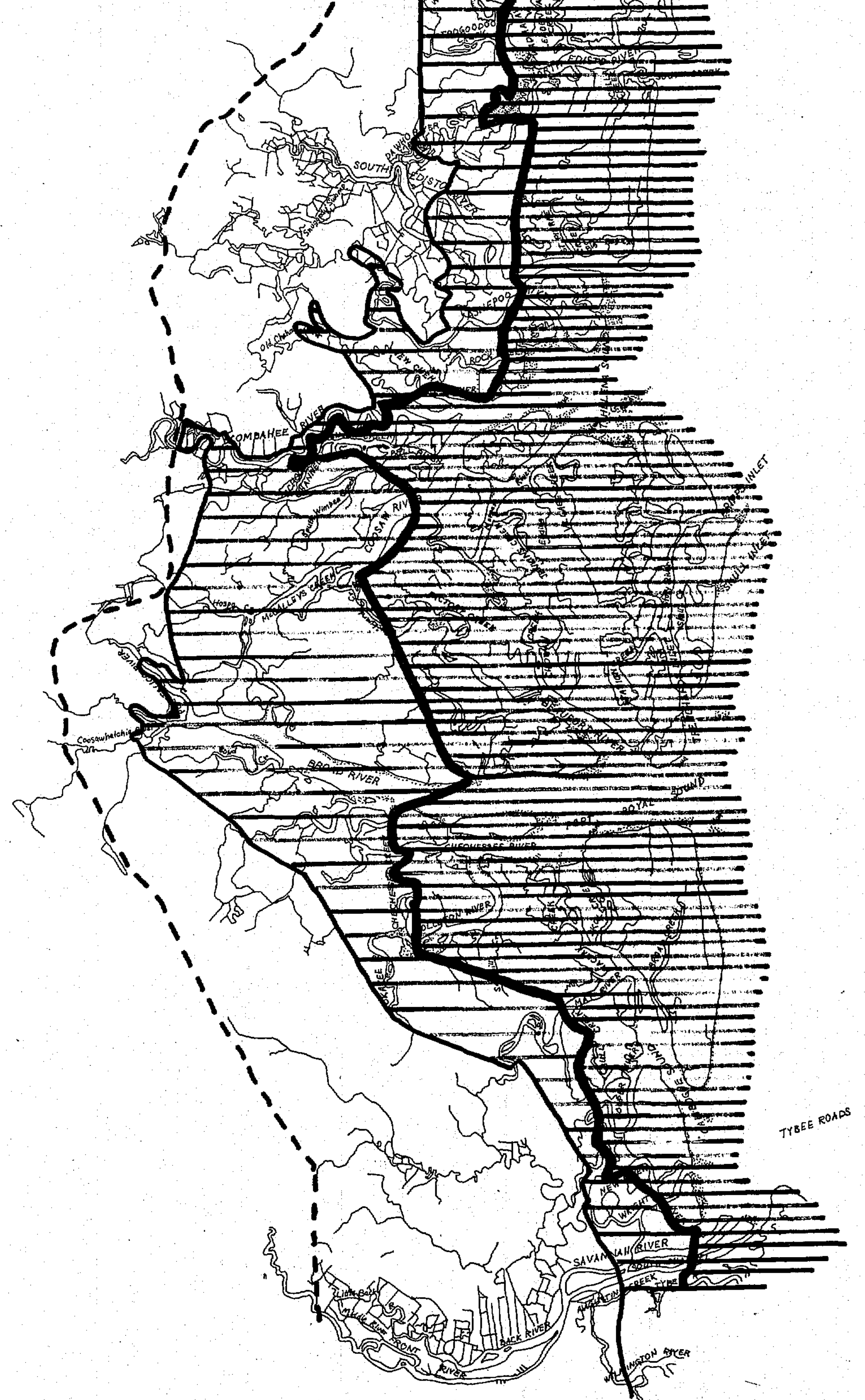
IV. Conclusions and Recommendations

The estimated precision quoted earlier for the coastal zone boundary in Figure 2, ± 0.25 miles in a few difficult areas and ± 0.06 miles for most of the coastal zone, is much better than expected at the onset of this study. It should be stressed, however, that these error estimates relate to how consistently the mapping was done, given the ground truth data and the boundary definitions described in earlier sections. It is possible that interpretation problems not encountered in the ground truth areas have caused mislocation of the coastal zone boundary of greater proportions than the above precision estimates in particular areas, but no such areas are now known.

The only satellite data employed for this study were 1:500,000 false color composite images of two LANDSAT I frames (E-1261-15274 of April 10, 1974 and E-1314-15213 of June 2, 1973) covering the South Carolina coast. These images helped in gaining a synoptic view of the area covered by the high altitude photography, but it was impossible to use the images for detailed work in this project because the spectral and spatial resolution *as displayed in the false color composites* were inadequate. The LANDSAT multispectral scanner has better spectral resolution than aerial infrared film and has a one-acre spatial resolution, which probably would be sufficient for mapping the salt-brackish interface and may be adequate for mapping the fresh-brackish interface, but the computer compatible tapes must be specially processed to produce image or graymap products capable of displaying data with that fine a spectral and spatial resolution. Standard false color composites of three spectral channels just cannot show details to the limits of LANDSAT's capabilities, because the fourth channel is unused and the spatial resolution cell on a color composite is several acres, owing to difficulties in color photographic processing. *Given the fact that NASA bore the costs of data collection,* photointerpretation of high altitude color infrared photography is cheaper than automatic mapping of computer compatible tapes, and is scientifically better for the problem at hand because of superior spatial resolution. Hence, satellite data were not chosen as the primary tools for this project. As long as the primary targets of an investigation are vegetative, satellite data are generally preferable to high altitude color infrared photography only if data collection costs must be considered (the satellite is much cheaper), or if comparisons of data from multiple passes at different times are needed. Color infrared film, when processed corretly, appears to have adequate spectral coverage and superior spatial resolution for vegetative targets.

As a result of this study, the following recommendations are made to the State of South Carolina:

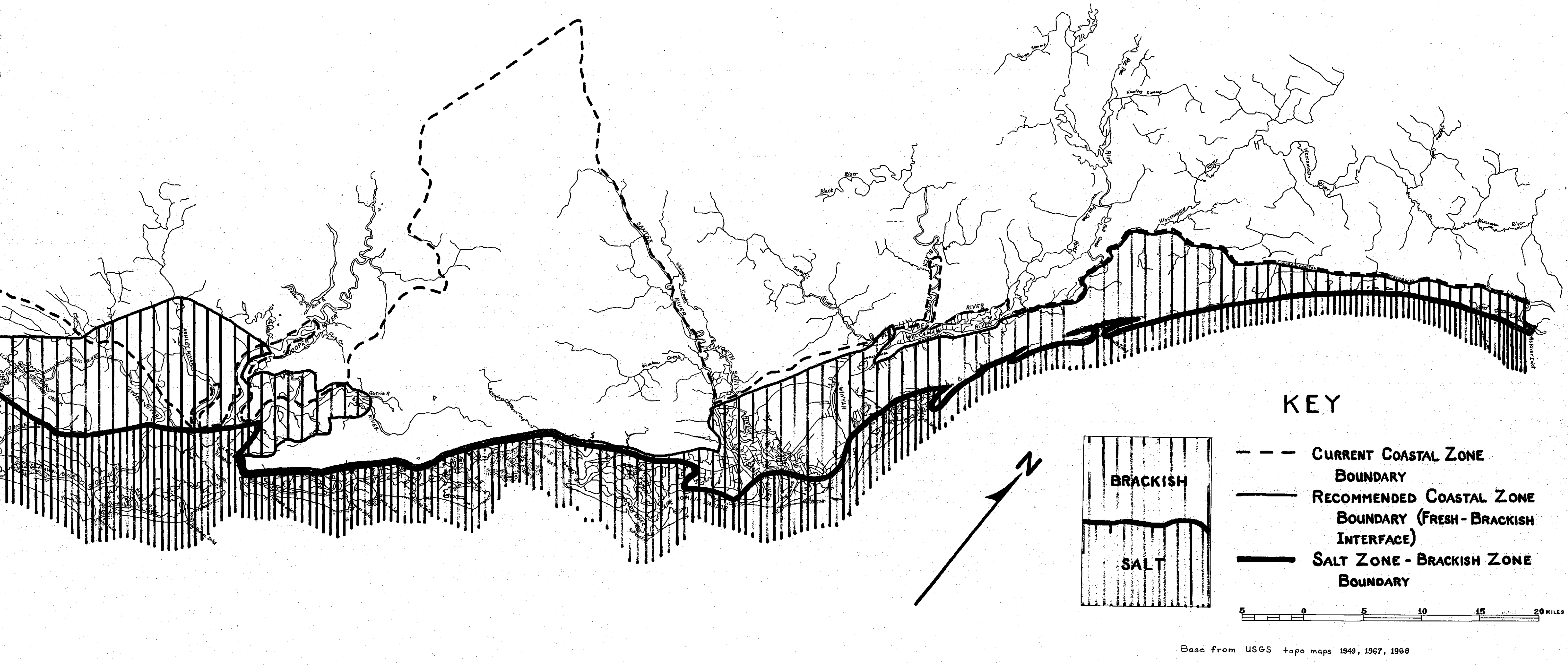
1. If field spot-checks of these findings in difficult areas identified in the previous section confirm the above precision estimates, South Carolina should legally adopt the coastal zone boundary shown on the acetate overlays and in Figure 2. The Francis Marion National Forest is predominately fresh water marsh and is largely outside of the coastal zone boundary in Figure 2. Other practical considerations outside of this study may make it desirable to include the Francis Marion National Forest in the coastal zone, however.
2. The coastal zone and salt zone boundaries should be inspected with high altitude aerial infrared photography or satellite data no less often than every five years. As an example of how changes can occur, field notes from a 1962 memo [1] indicate that a region along the Combahee River a few miles North of Highway 17 has gone from brackish to fresh water marsh sometime within the last 13 years, probably because of long-term effects of the man-made causeway forming Highway 17.
3. There are finer distinctions among marsh types than were made in this study that should be attempted by remote sensing methods. For instance, the following



SOUTH EDISTO RIVER
DAWHO RIVER
COMBAHEE RIVER
COOSAW RIVER
BROAD RIVER
PORT ROYAL SOUND
CHECHESSEE RIVER
SAVANNAH RIVER
TYBEE ROADS
BACK RIVER
FRONT RIVER

South Carolina Coastal Zone

Figure 2



categories described in the 1962 memo [1] have great significance for land use:

Tidal marsh, firm clays and loams
Tidal marsh, soft
Tidal marsh, firm mucks and peats
Fresh marsh, firm clays and loams
Fresh marsh, firm mucks and peats
Fresh marsh, soft

Both high altitude photography and computer-processed satellite data should be attempted, though the latter will involve some spatial (textural) recognition, as well as spectral recognition. Automatic recognition of more general marsh classes (Level II) has been successfully implemented by NASA [2] with LANDSAT data, but a Level III classification map is necessary for the six marsh classes above.

4. Although both field and remote sensing observations made during this study make it clear that cultural features have artificially changed the coastal zone and salt zone boundaries, there is apparently no source of information that would advise South Carolina as to how far into the freshwater zone the construction of large man-made structures would affect the coastal zone boundary. For instance, causeways produce a damming effect along estuaries, even when bridges cross high over the estuary. However, currently there is no way that the downstream "shadow zone" of the causeway can be predicted. It is recommended that surface and near-surface groundwater flow models be developed which would predict the "shadow zone" of large man-made structures, such as causeways. From such information, reasonable regulations could be made for large constructions near the coastal zone boundary. Similar models might also be considered for irrigation canals which employ flood gates to control salinity in the brackish zone.

With regard to other member states of the Coastal Plains Regional Commission, the following recommendations, in addition to those listed above for South Carolina, are made:

1. If NASA will agree to free high altitude photographic flights, flight lines paralleling the coast (at least three lines side-by-side) should be requested for mid-August, near local solar noon, at an altitude of 50,000 to 60,000 feet. These data should involve the least expensive data interpretation. If free flights cannot be arranged, computer-processed satellite data should be employed on one LANDSAT frame as a test case for mapping the coastal zone. Considering data collection costs, satellite data should be the most cost effective for the complete study, if the technical results on that one frame are good. Photo interpretation of satellite images will not work for mapping the coastal zone.

2. Low altitude photos over a limited area and a short field trip should be made for ground truth purposes before the study. A limited spot-check field trip should be made after the study to confirm results. More field trips will be required for longer coast lines than South Carolina's or for coasts which cross distinct boundaries of vegetative growth patterns.

The South Carolina Coastal Zone recommended by this study is smaller than the area described by the existing tentative coastal zone boundary. Excluding the Francis Marion National Forest from the comparison, the area defined by the recommended new coastal zone boundary is approximately 300,000 acres less than the area described by the existing boundary. If the Marion Forest, which is within the existing boundary, but outside the recommended one, is included in the comparison, the new zone would have approximately 750,000 fewer acres than the old zone.

As a conservative estimate, this study was done in one-third the time and in one-fifth the cost of a traditional study using only men in the field, instead of incuding remote sensing methods. Considering transportation difficulties in marshes, the results of this study are probably more accurate than what would have resulted solely from field trips and photointerpretation of black-and-white aerial photos. This study is a good example of how improved technology can result in better, less expensive ways of solving problems.

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