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SENSITIVITY OF COASTAL ENVIRONMENTS AND WILDLIFE TO SPILLED OIL, STATE OF SOUTH CAROLINA

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EXECUTIVE SUMMARY

This report is an explanatory text for a series of 50 maps which cover the coast of South Carolina (Fig. 1). These maps delineate the sensitivity of coastal environments to oil spill impact. The classification system used, the Environmental Sensitivity Index (ESI), ranks coastal environments on a scale of 1 to 10 in increasing order of sensitivity (i.e., 1 is least sensitive, and 10 is the most sensitive). Biological considerations, such as the location of bird colonies and shellfish areas, are indicated on the maps.

Field work was carried out between January and June 1981. A shoreline assessment technique called the integrated zonal method was used to classify the coastal environments present in the study area. The technique included aerial reconnaissance of the shoreline, site-specific studies at approximately 100 shoreline stations, and an extensive review of available literature. Using this information, 14 different coastal environments were identified and assigned ESI numbers as listed below.

1) Exposed vertical seawalls
2) Not present in South Carolina
3) Fine-grained sand beaches
4) Medium- to coarse-grained sand beaches
5) Exposed tidal flats (low biomass)
5a) Mixed sand and shell beaches
5b) Sheltered erosional scarps
6) Shell beaches
6a) Exposed riprap
7) Exposed tidal flats (moderate biomass)
7a) Erosional scarps in marsh
8) Sheltered coastal structures
9) Sheltered tidal flats (high biomass) and oyster beds
10) Marshes

Basic strategies for spill response and protection are briefly outlined in the text. Of all the habitats present, salt marshes, sheltered tidal flats, and sheltered coastal structures are considered the most sensitive to long-term, oil spill damage and should receive the highest priority for protection in the event of a spill. In contrast, exposed seawalls and fine-grained sand beaches (ESI 1, 3), which are quite common throughout the study area, would be cleaned rapidly by wave action and, therefore, would require less protection.

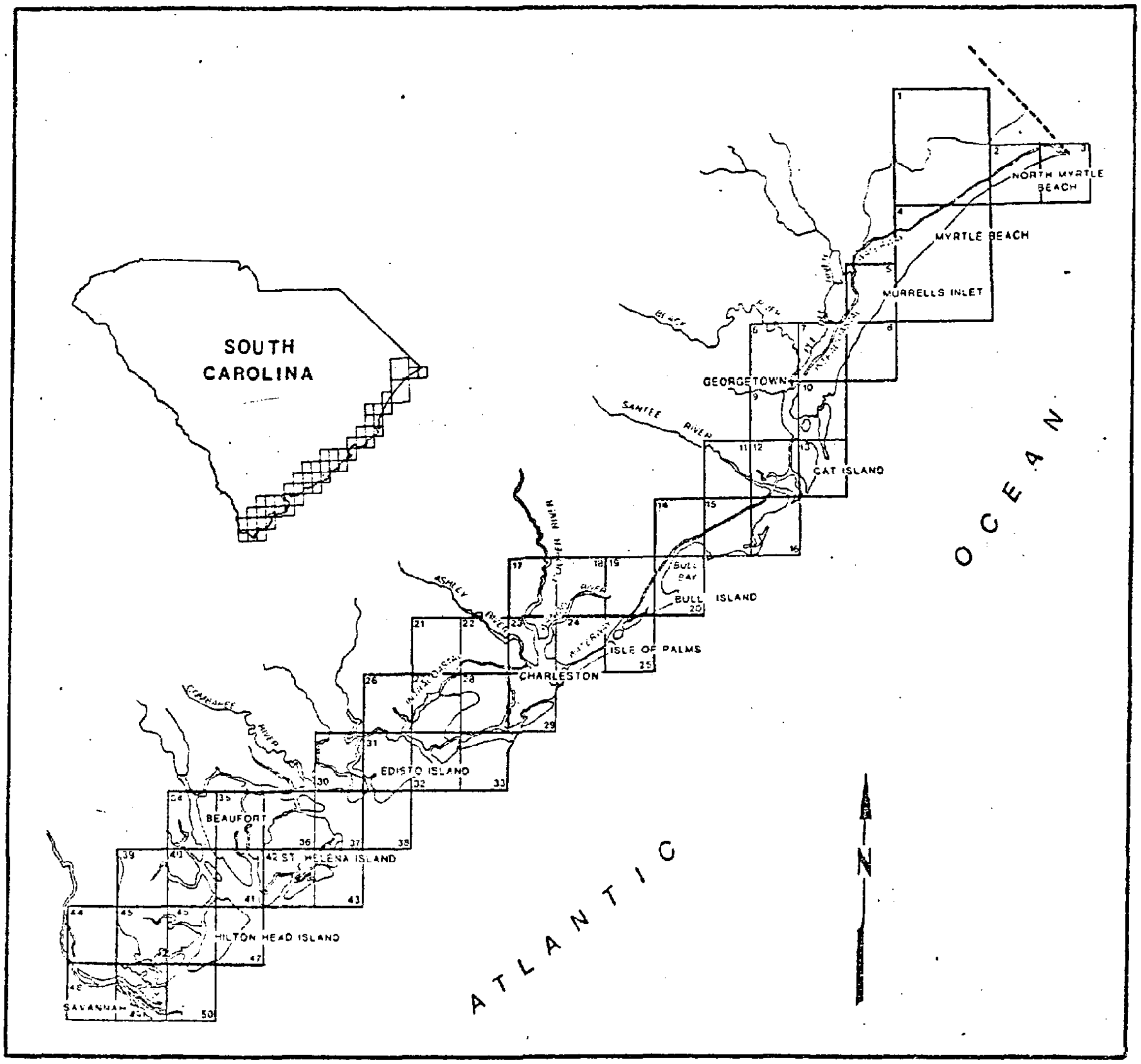

FIGURE 1. Map of South Carolina showing the location of each ESI map.

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TABLE OF CONTENTS

PAGE

INTRODUCTION

The state of South Carolina, like many other coastal states, has become increasingly aware of the problems related to oil spills and their long-term impact. Recent interest in offshore oil exploration further increases the future risk of oil pollution along the South Carolina coast. In response to this need, the South Carolina Department of Health and Environmental Control (DHEC) in coordination with the United States Coastal Energy Impact Program (CEIP) has prepared a contingency plan for dealing with possible oil spills in the state. As part of this program, DHEC asked Research Planning Institute, Inc. (RPI) to prepare a set of Environmental Sensitivity Index (ESI) maps which classify the various coastal environments of South Carolina in terms of their sensitivity to spilled oil.

The ESI has evolved since 1975 from oil spill research conducted by RPI in numerous locations around the world. The index was originally referred to as the Oil Spill Vulnerability Index (Gundlach and Hayes, 1978) which classified coastal environments primarily in terms of their physical response to spilled oil. The ESI (Hayes et al., 1980) was developed to add biological and socioeconomic components to the geomorphic considerations.

Since 1977, the Vulnerability Index and ESI have been applied to extensive coastal regions (Fig. 2), including much of Alaska, Puget Sound (Washington), and the states of California, Florida, Massachusetts, and Texas. Similar projects are planned for other coastal states. The ESI was applied to South Carolina to aid in the preparation of oil spill contingency planning. The index, developed from oil spill case studies, field research, and extensive literature review, classifies coastal environments on a scale of 1 to 10 in order of their increasing sensitivity to spilled oil. This report provides a synthesis of study methods, the environments classified by the ESI, and suggestions for shoreline protection strategies. There is also a summary of geomorphic parameters, major biological resources, and socioeconomic considerations and a description of their probable response to oiling. In total, 50 maps (1:24,000 scale; 7.5-minute quadrangles) were prepared. (Note: The only available maps at the time of this report for Nixonville and Myrtle Beach were 15-minute quadrangles.)

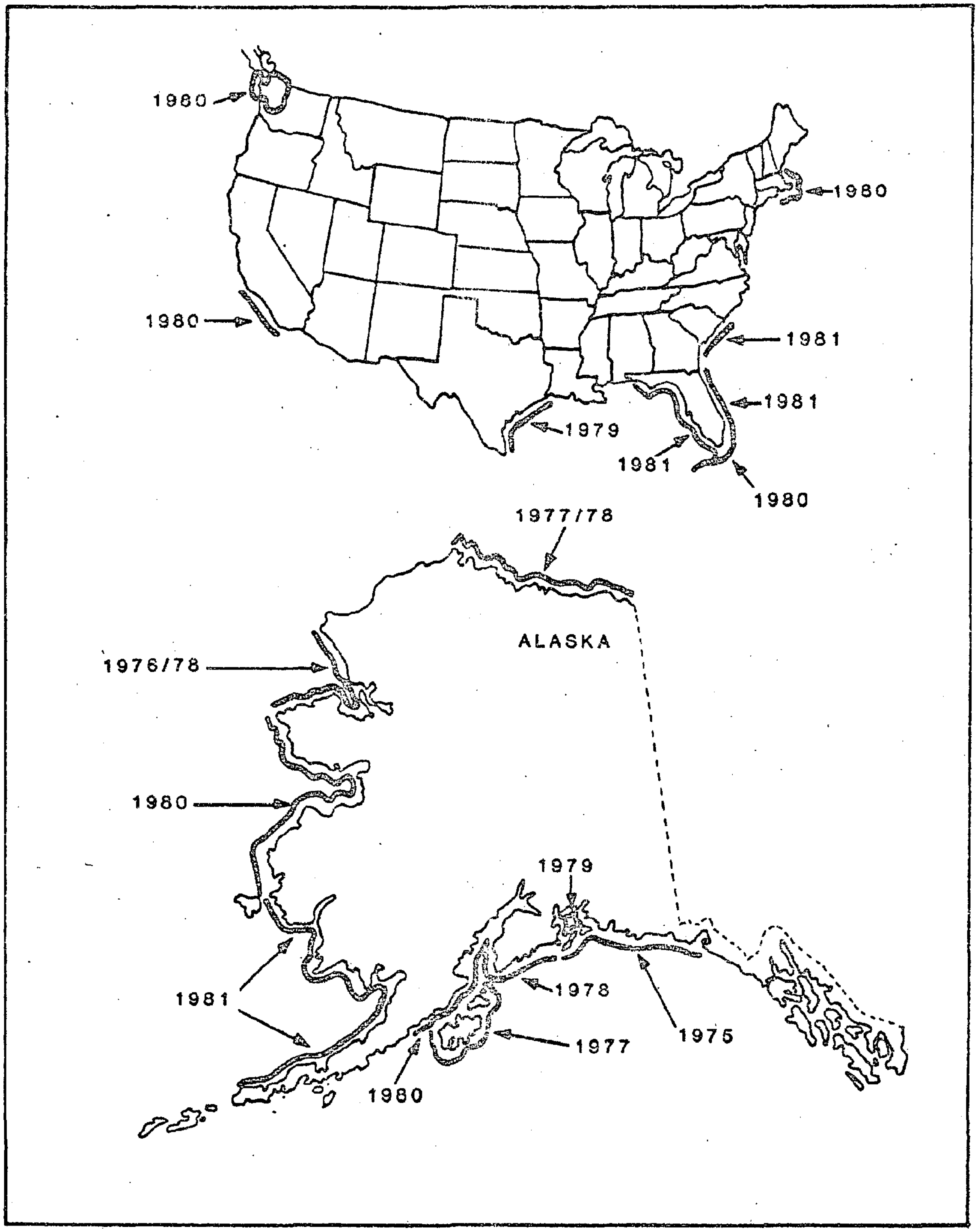


FIGURE 2. Map of the United States indicating environments mapping studies for oil spill response planning conducted by RPI personnel.

PHYSICAL SETTING

Geology

The eastern portion of the South Atlantic seaboard states is composed of a seaward-thickening wedge of sedimentary deposits known as the Atlantic Coastal Plain Province. In South Carolina, these deposits range in age from Late Cretaceous (100 million years old) to Recent and lie on top of much older crystalline rocks of the Piedmont Province. They vary in thickness from a feather edge at the Piedmont/Coastal Plain contact near Columbia, called the Fall Line, to over 800 meters (m) at Charleston.

The Atlantic Coastal Plain has its present dimensions because it formed on the trailing edge of the North American plate and has been relatively stable with respect to global tectonics since the Cretaceous period. Thus, the position of the shoreline at any point in time is primarily controlled by sea level changes with local effects due to sediment supply. The sediments are derived from weathering and erosion of the Piedmont rocks, and they are composed predominantly of unconsolidated sand and clay with lesser amounts of gravel and carbonate. The depositional units which make up the Coastal Plain are very similar to those forming today: gravel to silt deposits carried by rivers and deposited on floodplains, shoreline deposits of sand and mud, sediments of fine-grained sand and mud deposited offshore, and chemical precipitates in deep water.

Although the depositional history of the Coastal Plain is complex, it can be divided into three belts which roughly parallel the present shoreline: (1) the upper Coastal Plain with surficial sediments of Cretaceous to Miocene age, (2) the middle Coastal Plain with deposits of Miocene to Pleistocene age, and (3) the lower Coastal Plain with surficial deposits of Pleistocene to Recent age (Fig. 3; from Colquhoun, 1971).

The surface of the lower Coastal Plain is one of primary topography, whereas fluvial and aeolian erosion has nearly obliterated the original landforms of the middle and upper zones. On the lower Coastal Plain is a series of scarps which get progressively younger seaward and reflect interglacial, high sea level stands. Between the scarps, deltaic deposits, remnant barrier island chains, marshes, and individual beach ridges are readily visible on aerial photographs. Thus, the modern coastal sedimentation and morphology are similar to processes which have been active along the South Carolina coast for tens of thousands of years (Hayes et al., 1981).

Coastal Geomorphology

The South Carolina coast is composed of barrier islands, strandline beaches, estuaries, deltaic headlands, and some of the most extensive marsh/tidal flat systems in the United States. The coastal morphology is a transition between that of North Carolina and Georgia. North Carolina's coast is predominantly made up of long, thin barrier islands separated by a few tidal inlets and backed by extensive open lagoons or bays. The Georgia coast, in contrast, is dominated by tidally generated deposits and

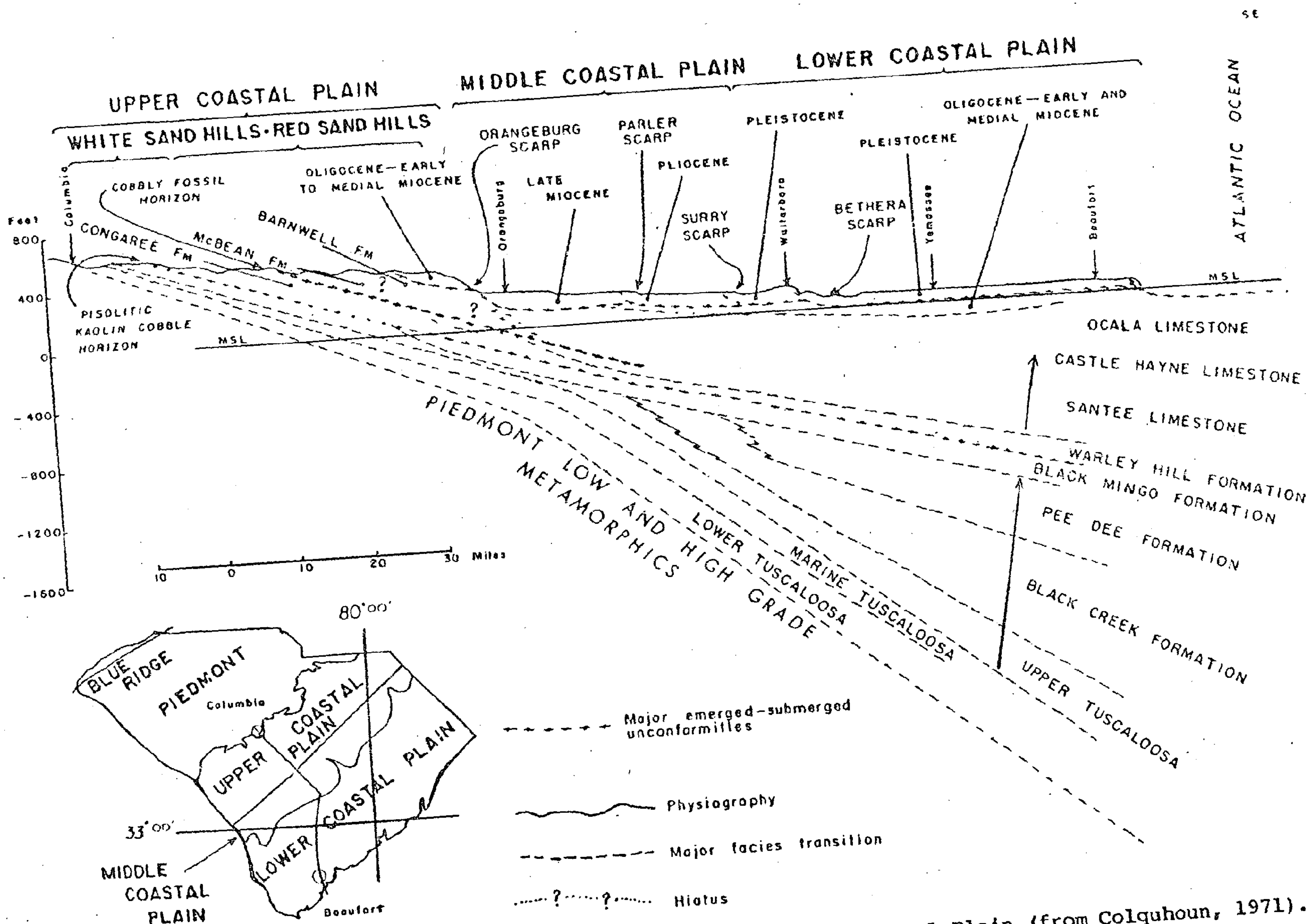


FIGURE 3. Stratigraphic cross-section of the South Carolina Coastal Plain (from Colquhoun, 1971).

contains numerous tidal inlets and broad expanses of marsh between seaward barriers and the mainland. The morphology of the South Carolina coast is dominated by a mixture of wind- and tidal-generated controlling forces, which produces a variation between the North Carolina and Georgia depositional settings.

On the basis of geomorphology, the South Carolina coast can be classified into the arcuate strand, cuspate delta, and barrier island zones (Brown, 1977). The barrier island zone is further divided into islands that have beach ridges (beach-ridge barriers) and those that have no beach ridges (transgressive barriers) (Fig. 4). Each of these four zones has its own characteristic sediment type, bathymetry, and erosional/depositional history.

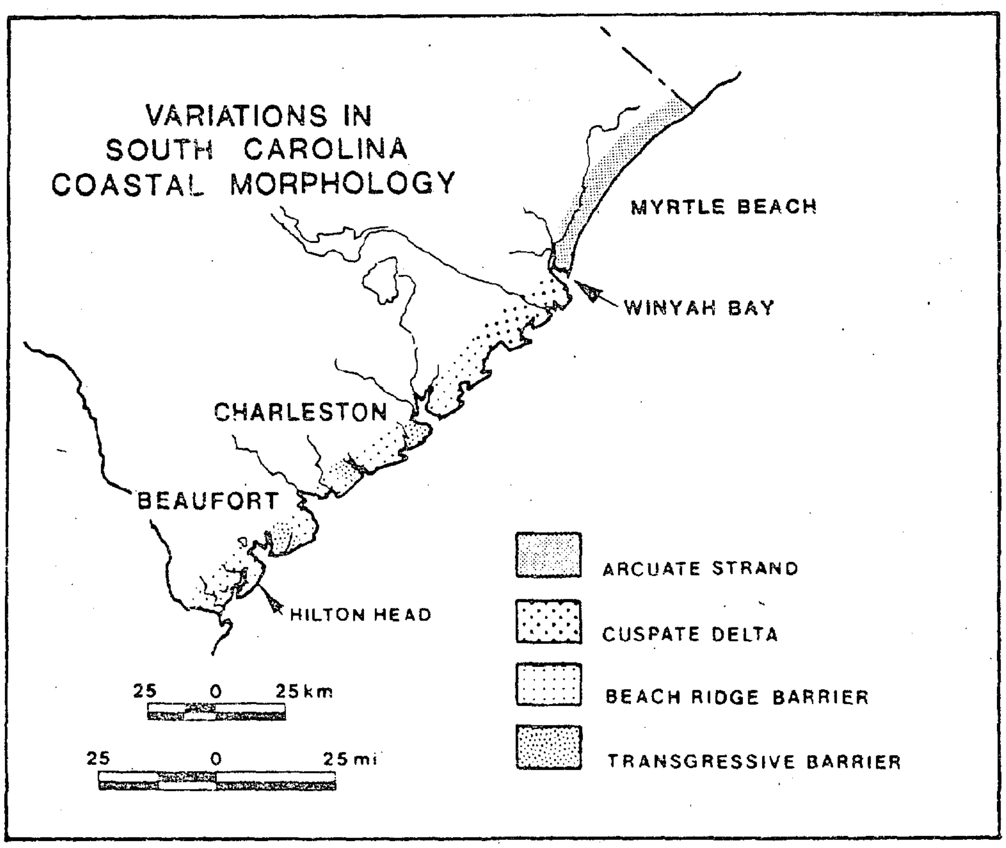


FIGURE 4. Map of the South Carolina coast showing the four major morphological zones (from Brown, 1977).

Arcuate Strand

The arcuate strand (Fig. 4) forms a gentle crescent between the North Carolina border and Winyah Bay, a distance of approximately 100 km. Few tidal inlets breach the coast in the northern section, but the number of inlets increases south toward Winyah Bay. Inlet size also increases southward (Brown, 1977). This portion of the coast is normally backed by a well-developed dune system. Salt marshes are either poorly developed or totally absent in the north and central portions of the strand, but become more prominent in the southern section. The beaches of this area are characteristically wide and flat, showing general, long-term shoreline stability. The shoreline owes its stability to the barrier sands of the Myrtle Beach Formation which formed before the Wisconsin glacial period, approximately 100,000 years ago (Johnson and DuBar, 1964). The present shoreline configuration generally parallels the orientation of these resistant relict beach ridges (Hayes et al., 1981).

There is moderate seasonal variability in the strand beaches although the net changes are small except around inlets. The nature of the back shore varies greatly throughout this area. Well-developed and vegetated dunes up to 3 m high occur locally. These dune systems act as a buffer zone, taking the brunt of the short-term changes in the beach without threatening man-made structures. Dunes provide the versatility for handling the short-term erosional/depositional events which occur each season. Back beach seawalls and riprap have been constructed along portions of the arcuate strand to protect developed property. In some cases, however, they pose additional problems and increase erosion rates.

Winyah Bay Estuary and the Santee Delta

South of the Grand Strand is Winyah Bay, a drowned river estuary of the Pee Dee, Waccamaw, Black, and Sampit Rivers. The drainage basin of these four rivers encompasses 36,000 km^2 including almost one-third of South Carolina and a large portion of central North Carolina. Winyah Bay is bordered by extensive salt marshes and relatively undisturbed maritime forest including several publicly and privately owned wildlife preserves. Mixing of fresh water discharged from rivers with salt water from the ocean produces a seasonally variable stratified flow, typical of partially mixed estuaries (Pritchard, 1967). The resultant estuarine circulation pattern in Winyah Bay partially controls surface transport of contaminants. During high runoff periods, there is a tendency to flush introduced floating contaminants out the estuary in the less dense, surface fresh waters (Zabawa, 1976).

The Santee River delta adjoins Winyah Bay, extending 30 km along the South Carolina coast (Fig. 5). As the largest deltaic complex on the east coast of the United States (Brown, 1977), its shoreline components include (Fig. 5): (1) a cuspate foreland, Cape Romain; (2) an eroding beach/barrier complex, Raccoon Key; and (3) distributary mouth sand bars and mud flats. The lower delta plain is presently covered by salt marsh. Washover terraces and truncated beach ridges along the shoreline of the delta attest to its rapid retreat. Erosion of the Santee delta complex has been

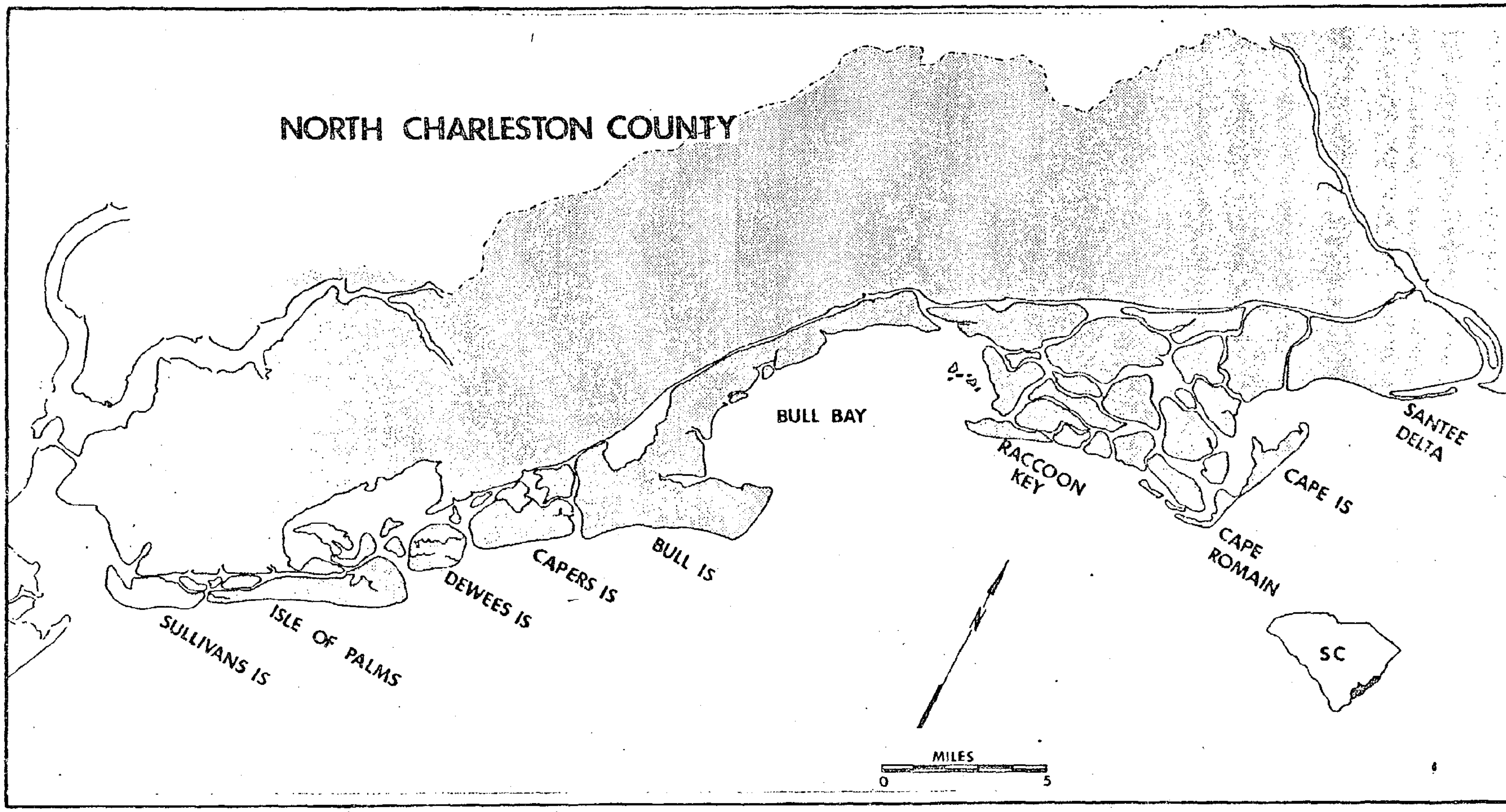


FIGURE 5. Central South Carolina barrier islands between the Santee delta and Charleston. This area contains several, major East Coast wildlife preserves and would be highly sensitive to spilled oil. Cape Romain is a cuspate foreland backed by extensive marsh and tidal flats.

related to the decreased sediment supply after damming of the Santee River in 1942 (Aburawi, 1972). Prior to the 1930s, the delta was in a stable or constructional phase. After that, the delta entered a destructive phase which presently continues. Sequential, vertical aerial photographs reveal that, in some cases, over 215 m of erosion have occurred since 1941 along Cape Romain (Stephen et al., 1975). Along Raccoon Key to the south, erosion of up to 275 m was noted at some localities.

South Carolina's cuspate foreland, Cape Romain, owes its origin in part to the sediments supplied by the Santee River. Subsequent erosion by predominantly northeast storm waves has given the cape its characteristic shape. Sediment eroded from the vicinity of the cape moves away in two directions, forming recurved spits to the north and west. Beach profiles in this area reflect a general shoreline instability. The cape is dominated by beach erosion and washover deposition. A steep beach face (medium- to coarse-grained sand) and extensive washover terraces are typical for much of the central portion of Cape Romain (Stephen et al., 1975). Erosion of the cape headland has caused its northern flank to change orientation dramatically during the past century, shifting from N-S in 1886 to its present NNE-SSW oreintation. Since 1886, the northern arm of the cape has elongated approximately 1.8 km, while the westward arm has grown a length of 3.7 km (Shepard and Wanless, 1971).

Barrier Islands

Between Bull Bay and the Georgia border, a distance of approximately 160 km, multiple barrier islands front the coast. They average about 7 km in length and are separated from the mainland by numerous tidal inlets and creeks and a zone of salt marsh which generally increases in width toward the south. These islands are of two types, beach-ridge barriers and transgressive (erosional) barriers.

Beach-ridge barriers form the majority of the central and southern portions of the South Carolina coast. These islands are characterized by extensive beach ridges, formed as the shoreline prograded. The morphology of beach-ridge barriers is characterized by a bulbous updrift (northern) end, a straight to crescentic central position, and a downdrift end which elongates and progrades through the formation of recurved spits (Hayes, 1979). Shoreline stability of these barriers is greatly affected by the adjacent tidal inlets. Wave refraction and storm protection afforded by the ebb-tidal delta in front of the inlet can cause accretion on the adjacent beach, producing the bulbous updrift end of the island (Hayes, 1979).

In areas where the barriers are shorter (Capers, Dewees, and Seabrook Islands) or where the inlets are much larger (Hilton Head Island), this pattern becomes more complex. The shorter islands are more influenced by the changes due to migration of the inlets and their associated offshore sand shoals.

Transgressive barrier shorelines are of lower relief and exhibit typically higher rates of erosion than beach-ridge barriers. They are characteristically straight with a thin veneer of sand which retreats landward as a succession of washovers. Transgressive barriers are presently changing at an extremely rapid rate with erosion rates of up to 15 m/yr documented at Morris Island (Stephen et al., 1975). Evidence of such rapid rates of erosion can be observed in the outcropping of marsh sediments along some of the transgressive barrier beaches.

Coastal Sediments

When sand grain size and sorting parameters are plotted on a statewide basis, three distinct groupings can be seen which correspond to the arcuate strand, cuspate delta, and barrier island zones (Brown, 1977). The sediment types of these zones reflect three different sources of beach material. There is presently no direct source of fluvial sediments on the arcuate strand, although several rivers in this area emptied into the ocean during the relatively recent geological past (Johnson and DuBar, 1964). While some sand is being transported alongshore into the area, most beach sands on the arcuate strand are apparently derived from ancient deposits lying directly behind the shore as the area continues to erode. Sediment samples from the arcuate strand show a wide range of size and sorting values.

The cuspate delta area sediments are supplied by the Santee River and since the delta lies near its fluvial source, sediment samples from the area are generally coarser than those found elsewhere on the coast. This proximity to the source also results in sediments that are "immature," showing a wide range of size and sorting values.

The barrier islands of the central and southern portions of the coast are further removed from their fluvial sediment sources and are presently receiving very little sand. Sediments from this area have undergone a great deal of reworking and, hence, are much better sorted than sediments to the north. Due to lower wave energy along the southern portion of the state (and the constant reworking), these sediments are significantly finer than those to the north. These fine-grained sands pack very well, providing a hard pavement over which most motor vehicles can easily drive.

Sheltered by the barrier beaches themselves, the back barrier environments of South Carolina consist of a complex suite of fine-grained sediments. Marshes and sheltered tidal flats are predominantly muddy (silt and clay) with admixtures of carbonate shell material, sand from overwash deposits, and coarser channel lag deposits. Distribution of back barrier sediments follows the morphology of the marsh and tidal creeks with finer grain sizes in the most sheltered areas away from major tidal entrances and coarsest sediments in the channels. Tidal creek point bars generally contain fine-grained sand or silt. Biogenic activity generally decreases with increasing exposure to wave action. Extensive colonies of intertidal oysters (*Crassostrea virginica*), which fringe many of the tidal creeks, as well as cluster on the surface of mud flats, add an important carbonate component to sediments along the coast.

Physical Processes

South Carolina's climate is mild with an average temperature for the coastal region of 18.7°C, ranging from 10.1°C in December to 27.2°C in July. The coastal plain, which makes up 40 percent of the state, receives an average of 118.4 cm of precipitation annually (Landers, 1970). Hurricanes and tropical storms affect the coast at a frequency of two storms every three years (Crutcher and Quayle, 1974).

Seasonal wind patterns occur in conjunction with the summer Bermuda High and extratropical cyclones common in fall and winter. As the wind roses of Figure 6 indicate, south and southwesterly winds prevail in spring and summer, whereas northerly winds predominate in fall and winter. Seasonal offshore wave energy similarly varies (Fig. 6) with a net longshore energy flux directed to the south (U.S. Naval Weather Service Command, 1970). Breaking wave heights along exposed beaches generally decrease from Myrtle Beach to Hilton Head with a typical mean of 60 cm for the central South Carolina coast (Kana, 1977). Complex nearshore bathymetry associated with tidal deltas produce considerable local variation in wave energy.

Tides are semidiurnal (twice daily) ranging from 1.5 m to almost 3 m due to geographic and temporal variations. For example, tide range increases from north to south due to effects of a widening continental shelf into the Georgia embayment. The fortnightly cycle produces periodic variations in range between neap tides (lowest) and spring tides (highest). Occasional astronomic events superelevate tides as much as 30 cm above the spring tide level. Storm surges associated with extratropical or tropical storms further alter the predicted astronomic tides, causing super tides which have ranged as much as 3.5 m above normal in historic times (Myers, 1975). The most recent hurricane which affected the coast was DAVID in September 1979 with a storm surge estimated at 1.0-1.5 m at Edisto Beach (pers. comm., Geoffrey Scott).

The increasing tidal prism from north to south along the coast has several effects, including modification of the shoreline and back barrier morphology. Tidal inlets become more frequent and are larger to accommodate greater tidal flow. Salt marshes become more extensive, and ebb-tidal deltas (seaward shoals of inlets) become much larger off inlets in the southern portion of the state.

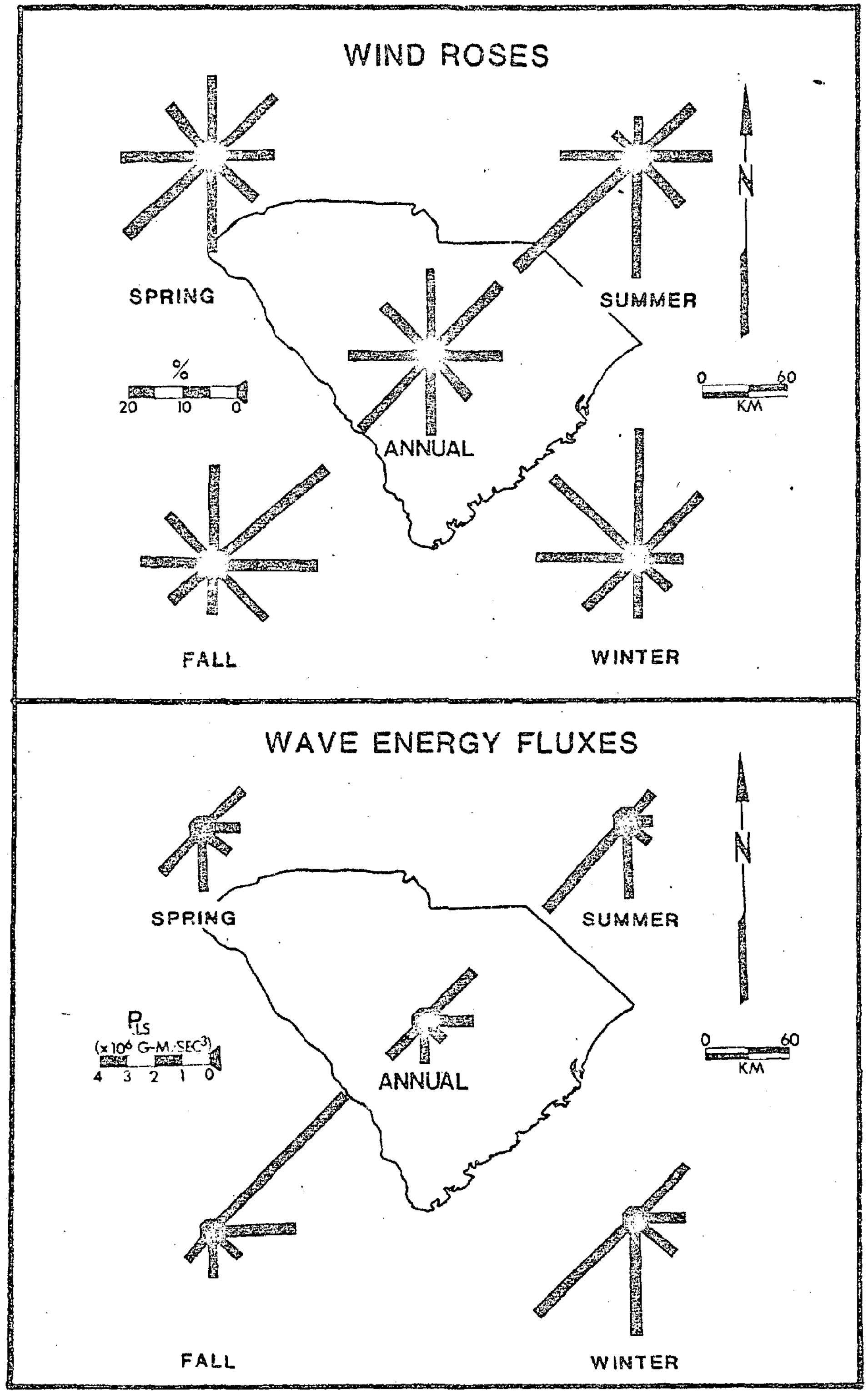


FIGURE 6. Seasonal and annual wind and wave energy roses for the South Carolina coast derived from shipboard observations (U.S. Naval Weather Service Command, 1970). The length of any bar is a relative measure of the wind or wave energy coming from that direction (from Brown, 1977).

METHODS OF STUDY

To undertake a project covering a shoreline as extensive and complex as South Carolina, a technique is required that can be used to assess large sections of shoreline rapidly, and synthesize the findings onto maps of a suitable scale (1: 24,000 in this study). The method employed in this study is called the integrated zonal method, developed by Hayes and others (1973) to classify large sections of the Alaskan coast for the Office of Naval Research. This method has been used to classify shorelines in other areas including Massachusetts, South Florida, and Texas. The addition of biological components to these geologically oriented field studies provides an integrated approach to determine priorities for environmental protection.

Shoreline Mapping

For the present study, field survey data were combined with existing socioeconomic, biological, and geological baseline data to prepare a set of 50 maps indicating the distribution of environmentally sensitive shorelines in South Carolina. Base maps are standard 7.5-minute, U.S. Geological Survey topographic maps at 1:24,000 scale. (Note: Two quadrangles, Nixonville and Myrtle Beach, are older 15-minute series.) The classification of various coastal environments is given as a color-coded border along each shoreline. Table 1 contains a list of quadrangles used to prepare ESI maps for the present study. The methods used to collect the information presented on these maps are described below.

A combination of literature review and ground and aerial surveys was used to prepare the final product. During all stages of the project, the literature was reviewed for regional and local information pertaining to ecological setting, geology, climate, and socioeconomics. This baseline data, as well as RPI's extensive experience in South Carolina coastal studies, was used to establish the ESI criteria for the state. During low tide on various days between January and June 1981, aerial reconnaissance of the entire coastal zone was conducted. Observations and shoreline classifications were recorded onto USGS topographic maps using a standard color code. Aerial photographs were taken with a 35-mm camera, and descriptions were recorded on tape.

Ground Surveys

Ground study sites were selected on the basis of all information available, including accessibility, socioeconomic, and environmental importance. A total of 100 stations were surveyed to provide a fair geographical and environmental distribution along the coast (Fig. 7). Two types of ground stations were established: (a) rapid-survey sites, and (b) detailed profile sites.

At the rapid-survey sites, assessment of the biological and geomorphic characteristics of the ground station was conducted. A series of

TABLE 1. List of U.S. Geological Survey topographic maps used in preparation of ESI maps. Note: Nixonville and Myrtle Beach are outdated 15-minute series. (*orthophotomap)

ESI MAP	QUADRANGLE NAME	SURVEY DATE (update)	ESI MAP	QUADRANGLE NAME	SURVEY DATE (update)
1	Nixonville,	1937	26	Adams Run	1960 (1972)
2	Wampee	1943	27	Wadmalaw Island	1960 (1971)
3	Little River	1943	28	Legareville	1959 (1971)
4	Myrtle Beach	1937	29	James Island	1959 (1971)
5	Brookgreen	1943 (1973)	30	Bennetts Point	1960 (1971)
6	Georgetown, N	1943 (1973)	31	Edisto Island	1960 (1972)
7	Waverly Mills	1942 (1973)	32	Rockville	1960 (1971)
8	Magnolia Beach	1942 (1973)	33	Kiawah Island	1959 (1971)
9	Georgetown, S	1943 (1973)	34	Laurel Bay	1962 (1972)
10	North Island	1942 (1973)	35	Beaufort	1958
11	Santee	1943 (1973)	36	Frogmore	1956 (1972)
12	Minim Island	1943 (1973)	37	St. Helena Sound	1956
13	Santee Point	1942 (1973)	38	Edisto Beach	1956 (1972)
14	Awendaw	1943 (1973)	39	Jasper	1958
15	McClellanville	1943 (1973)	40	Spring Island	1958 (1972)
16	Cape Romain	1942 (1973)	41	Parris Island	1956
17	North Charleston	1958 (1971)	42	St. Phillips Island	1956 (1972)
18	Cainhoy	1958 (1971)	43	Fripp Island	1958
19	Sewee Bay	1959 (1973)	44	Limehouse	1955 (1971)
20	Bull Island	1959 (1973)	45	Pritchardville	1955 (1971)
21	Ravenel	1960 (1971)	46	Bluffton	1956 (1971)
22	Johns Island	1958 (1971)	47	Hilton Head	1956 (1971)
23	Charleston	1958 (1971)	48	Savannah	1978*
24	Fort Moultrie	1959 (1971)	49	Fort Pulaski	1975
25	Caper's Inlet	1959 (1973)	50	Tybee Island, N	1978*

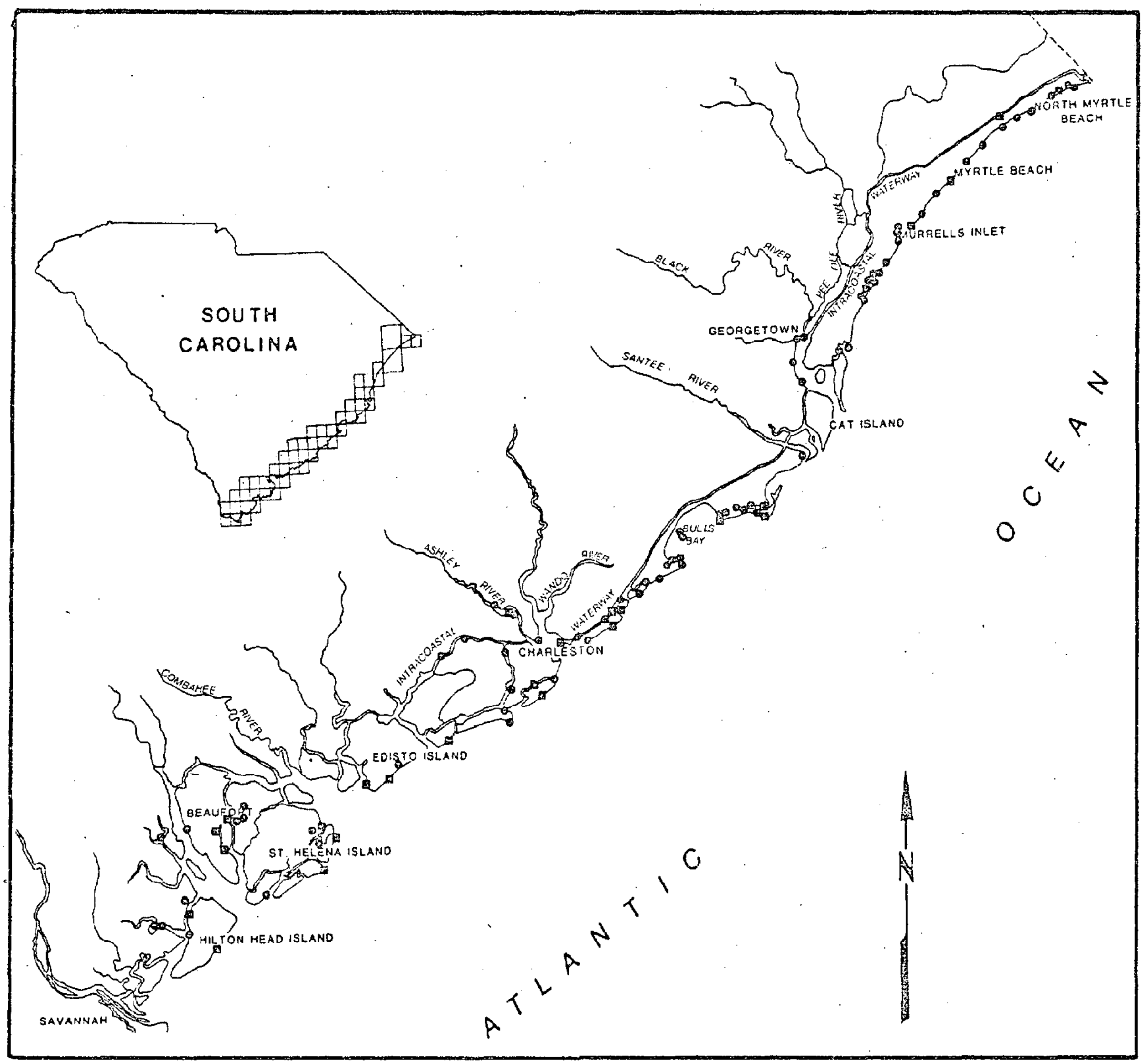


FIGURE 7. Approximate distribution of detailed profile (squares) and rapid-survey (circles) sites monitored for baseline environmental information.

photographs were taken at various positions to document the biota and shoreline morphology present at the station. In addition, a detailed description of the ground site was recorded on tape.

At the detailed profile stations, the following methods were used to collect pertinent data:

a) A topographic profile of the shoreline was surveyed using the Emery (1961) method. Descriptions of geomorphic features, sediment types, and biological information (e.g., species, densities, and abundance) were recorded along the profile.

b) Sediment samples were collected at selected locations along the profile. These samples were later checked for grain-size characteristics. The location of each sample was recorded on the profile data sheet. Because of an extensive sediment data base provided by other studies (e.g., Brown, 1977), sediment samples were not collected at all ground stations during this study.

c) Macroflora and macroepifauna were censused within three randomly selected 1/25 m^2 quadrats within each interval. The abundance of macroflora was recorded as percent coverage of the surface area, whereas macroepifauna were recorded as numbers of individuals of each taxa per 1/25 m^2. These data are presented in discussions of oil-sensitive environments.

d) Macroinfauna were censused with triplicate cores (core diameter = 10 cm) driven 15-20 cm into the substrate within randomly selected 1/25 m^2 quadrats. Samples were placed in 500-micron (0.5-mm) mesh Nytex bags and sieved in the field. The bags were placed in ten percent formalin containing rose bengal to preserve and stain the infauna. The bagged samples were then sorted in the laboratory and the organisms were placed in 45 percent isopropyl alcohol to preserve them for later identification. Identification was to the lowest taxonomic group. These findings were used to describe biological utilization at coastal environments sensitive to oil.

e) A sketch was made to illustrate all aspects of the profile site. Sample locations as well as biological and geomorphic features were located on the sketch.

f) Photographs were taken at several angles to document the morphological and biological aspects of each station.

g) Detailed verbal descriptions of the biological and geomorphic characteristics of the site were recorded on tape.

These data were compiled and used to characterize and describe each environment with respect to its sensitivity to damage by spilled oil. Each environment type is represented on the maps by a color corresponding to its number rank in the ESI; the higher the number, the greater the sensitivity of that environment to spilled oil.

In addition to characterizing the shoreline classifications, areas of special biological importance were identified. The localities of oil-sensitive, protected, or commercial species and communities are noted by colored circles. The information provided on each circle is illustrated in Figure 8. The color of the circle allows rapid identification of the type of organism present: yellow = marine mammals; green = birds; red = reptiles; blue = finfishes; and orange = shellfish. The silhouette in the center of the marker refers to the ecological groups listed in Table 2. The number refers to a species or species group as listed in Appendix I. Seasonality data, indicated on the outer perimeter of the color-coded marker (see Fig. 8), are shown to indicate the seasons of the year that a particular species or group of species (i.e., mixed bird colonies) are present and susceptible to oil impact. Consideration is given to such factors as reproduction, migration, and feeding behavior (Getter et al., 1981).

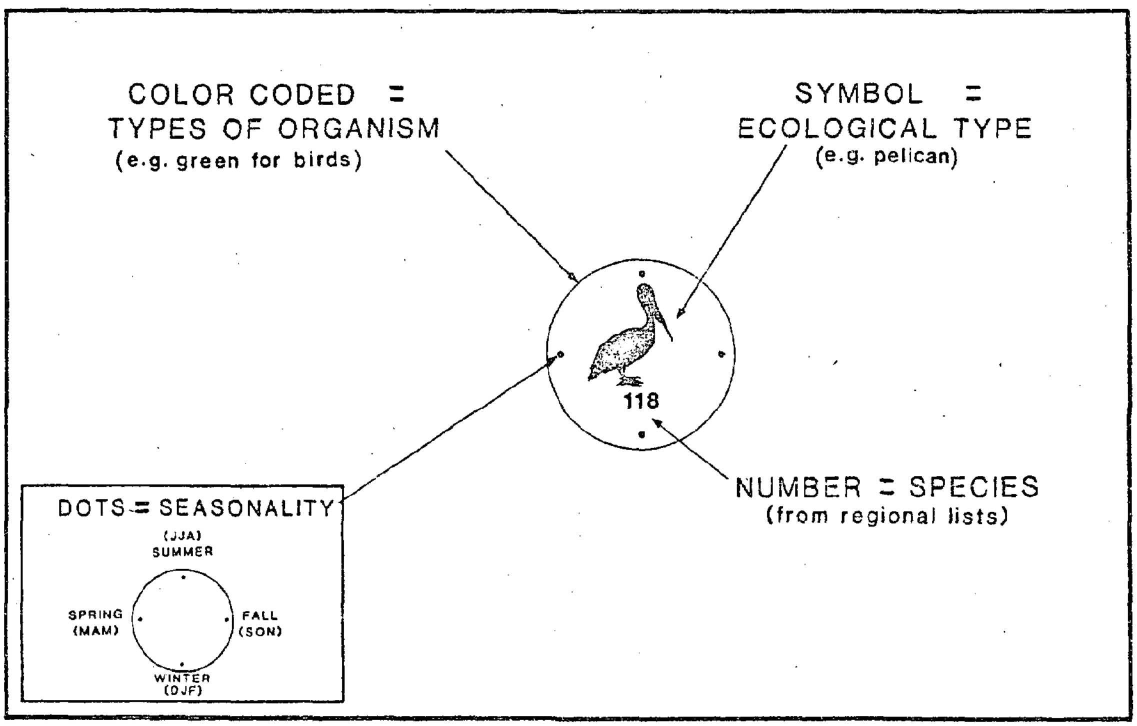


FIGURE 8. A key to the information appearing on wildlife markers, which includes type of organism, ecological type, species, and seasonal utilization.

As described earlier, an extensive literature search was conducted to provide this baseline information. Primary data resources utilized included Fish and Wildlife Service resource atlases (U.S. Department of the Interior, 1978; 1980a; 1980b) and South Carolina Wildlife and Marine Resources fisheries guides (Moore et al., 1980).

TABLE 2. Symbols of critical ecological groups used on the South Carolina ESI maps.

RESIDENT MARINE MAMMALS		
	Bottlenose dolphin	- Feeding grounds
	Manatees	- Summer grounds
BIRDS		
	Gulls and terns	- Rookeries and critical feeding areas
	Wading birds	- Rookeries and critical feeding areas
	Shorebirds	- Nesting, wintering, and feeding areas
	Waterfowl	- Wintering grounds and critical feeding areas
	Diving birds	- Rookeries and critical feeding areas
	Raptors	- Critical nesting and feeding areas
	Passerine birds	- Critical habitats
REPTILES		
	Sea turtles	- Critical nesting beaches
	Alligators	- Critical habitats
FINFISH		
	Anadromous fish	- Spawning areas or runs
	Commercial and sport fishes	- General habitats
SHELLFISH		
	Oysters	- Abundant oyster areas
	Clams	- Abundant clam areas
	Crabs	- Abundant crab areas
	Shrimp	- Abundant shrimp areas

Socioeconomic resource information was presented to provide specialized data and to augment the decision-making processes in the case of an oil spill. The socioeconomic information appearing on the base maps does not affect the ESI numerical rating, but is designed to be used in the same manner as the biological resource information--to highlight especially sensitive areas. Socioeconomic information which is not of direct importance for consideration during an oil spill is excluded from these maps. The physical boundaries appearing on the maps are as exact as possible with a scale of 1:24,000. Since some of the base maps are considerably outdated, an attempt was made to sketch in important unmarked shorelines, tidal flats, or man-made structures. For example, a recently constructed jetty system at Murrell's Inlet (ESI map No. 5) has been indicated. Numerous tidal flats, creeks, and inlet shorelines have naturally shifted since the U.S. Geological Survey mapping was completed. It was considerably beyond the scope of the project to correct and update all shorelines.

ENVIRONMENTAL SENSITIVITY INDEX (ESI)

The ESI for oil spills is based on field investigations of four massive oil spills (METULA, URQUIOLA, AMOCO CADIZ, and IXTOC I) and several smaller incidents (including spills under both tropical and ice conditions), plus an extensive literature survey. A list of the studies of major oil spills that have provided the most information on this subject is presented in Table 3.

The first application of the concept of a sensitivity index by our research group was made during mapping of the geological sensitivity of the coastline of lower Cook Inlet, Alaska, in 1976 (Hayes et al., 1976; Michel et al., 1978). That study defined an Oil Spill Susceptibility Index, which was based primarily on "the physical longevity of oil in each environment in the absence of cleanup efforts" (Michel et al., 1978, p. 109). This same principle was used by Nummedal and Ruby (1979) to map the Alaska coast of the Beaufort Sea. Gundlach and Hayes (1978b) expanded the concept to include some biological considerations. This expanded index, called the Oil Spill Vulnerability Index, was used to map several additional areas in Alaska (e.g., Ruby and Hayes, 1978).

The ESI used in this report integrates geomorphic and biological factors. Getter and others (1981) added living resource information to the index while retaining its relative simplicity. This was accomplished by indicating areas critical to fish, reptiles, birds, and marine mammals for feeding and reproduction with color-coded wildlife symbols. Access points to the shore and facilities such as marinas and boat ramps are also indicated on the maps. These refinements were applied to ESI maps used in energy port planning projects (Hayes et al., 1980).

ESI maps were first tested during a major oil spill following the IXTOC I blowout in the Gulf of Mexico. The ESI maps became an integral part of the overall federal response plan to protect the Texas coast, providing the scientific basis for setting protection priorities and cleanup strategies. Since then, ESI mapping has been carried out in Massachusetts, South Carolina, the remainder of Texas, southern California, Puget Sound (Washington), and Shelikof Strait, Pribilof Islands, and Norton Sound (Alaska).

In addition to combining geomorphic and biological aspects into the index, socioeconomic information was superimposed graphically on the ESI maps. Detailed descriptions of biologic and socioeconomic information are presented later in the text.

The following section outlines the ESI for the state of South Carolina in order of increased potential for damage by oil spills.

TABLE 3. The ESI predicts sensitivity of coastal environments and wildlife to spilled oil. These predictions are based upon observations made during studies at the following key oil spills.

OIL SPILLS	DATE	TYPE AND AMOUNT	STUDIES
WW II Tankers, United States East Coast	Jan.-June '42	Various; 533,740 tons	Campbell et al.(1977)
TORREY CANYON, Scilly Isles, U.K.	Mar.'67	Arabian Gulf crude: 117,000 tons total; 18,000 tons onshore	Smith(1968)
Santa Barbara blowout	Jan.'69	California crude; 11,290 to 112,900 tons total; 4,509 tons onshore	Foster et al.(1971)
ARROW, Chedabucto Bay, Nova Scotia	Feb.'70	Bunker C; 18,220 tons total	Owens(1971);
METULA, Strait of Magellan, Chile	Aug.'74	Saudi Arabian crude; 53,000 tons total; 40,000 tons onshore	Hann(1974); Blount(1978); Gundlach et al.(1981b)
URQUIOLA, La Coruna, Spain	May '76	Arabian Gulf crude; 110,000 tons total; 25,000-30,000 tons onshore	Gundlach and Hayes (1977); Gundlach et al.(1978)
AMOCO CADIZ, Brittany, France	Mar.'78	Arabian Gulf crude; 223,000 tons total	Gundlach and Hayes (1978b); Hayes et al.(1979); Gundlach et al.(1981a)
HOWARD STAR, Tampa Bay,	Oct.'78	Crude and distillate approx. 140 tons	Getter et al.(1980b)
PECK SLIP, Eastern Puerto Rico	Dec.'78	No. 6 oil; 1,500 tons	Getter et al.(1980a); Gundlach et al.(1979)
IXTOC I, Gulf of Mexico	June'79 to Apr. '80	Crude oil; several hundred thousand tons	Getter et al.(1980c); Gundlach et al.(1981c)
BURMAH AGATE, Texas	Nov.'79	Crude and refined product	Thebeau and Kana(1981); Thompson et al.(1981)

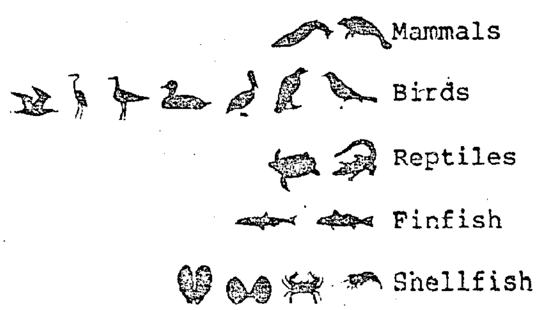
ENVIRONMENTAL SENSITIVITY INDEX
STATE OF SOUTH CAROLINA

SHORELINE TYPES (ESI #)

1) Exposed vertical seawalls
*2) Not present
3) Fine-grained sand beaches
4) Medium- to coarse-grained sand beaches
5) Exposed tidal flats (low biomass)
5a) Mixed sand and shell beaches
5b) Sheltered erosional scarps
6) Shell beaches
6a) Exposed riprap
7) Exposed tidal flats (moderate biomass)
7a) Erosional scarps in marsh
8) Sheltered coastal structures
9) Sheltered tidal flats (high biomass) and oyster beds
10) Marshes

*ESI=2 is wavecut platforms which are common in tectonically active areas such as Alaska.

BIOLOGICAL RESOURCE INFORMATION



SOCIOECONOMIC INFORMATION

Parks and wildlife refuges

Commercial fisheries (in conjunction with finfish and shellfish symbols)

Boat ramps

Marinas

Each environmental classification is discussed in the following section.

1) EXPOSED VERTICAL SEAWALLS

Description

- Physical
  - Man-made structures with little to no beach face at all tidal levels
  - Exposed to strong waves and currents along open ocean shorelines
- Plants
  - Dominant plants are attached green algae such as Ulva and Enteromorpha
  - Zonation is controlled by exposure to waves
  - Surface plant coverage is moderate to high (mean coverage = 85%)
- Animals
  - Barnacles are dominant animals
  - Barnacles have maximum densities in the upper intertidal zone
  - Infauna are minimal due to solid substrate
  - Low diversity, moderate to high density, and low species richness

Predicted Oil Behavior

- Along vertical seawalls:
  - most oil would be held offshore by reflected waves
  - deposited oil would be removed rapidly by waves
  - some oil splash or overtopping may occur

Potential Biological Damages

- Greatest exposure would be to upper intertidal organisms
- Impact to fauna and flora would be low due to short-term oil persistence
- Mortalities may be caused by smothering in cases of heavy oiling

Recommended Cleanup Activity

- In general, little or no cleanup would be necessary; however, high-pressure spraying would be effective and convenient in most areas where exposed vertical seawalls are present
- Cleanup recommended for aesthetic reasons only, since most seawalls are located in high recreational-use areas

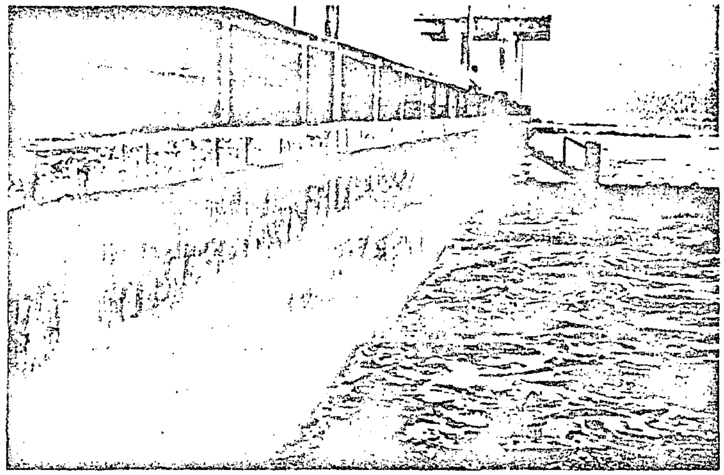


FIGURE 9. Exposed vertical seawall at Folly Beach with view looking north.

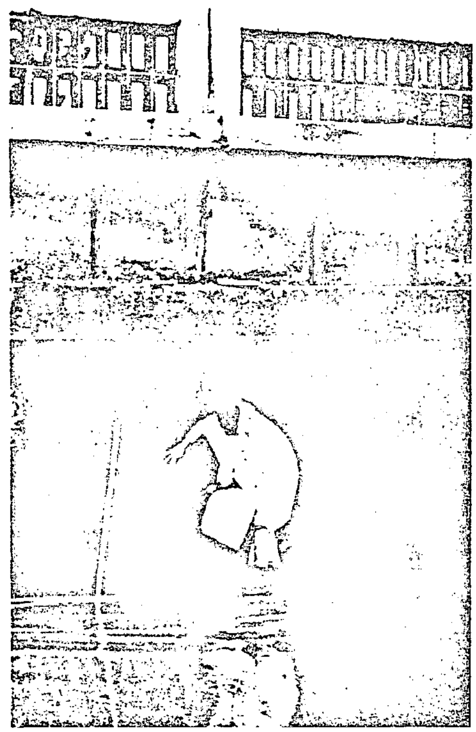


FIGURE 10. Section of vertical seawall over 3.0 m high above narrow low-tide beach. Note the intertidal band of algae and attached barnacles.

2) NOT PRESENT IN SOUTH CAROLINA

Note: ESI #2 is exposed wavecut or rocky platforms which are common in tectonically active shorelines such as Alaska; or along tropical coasts where cemented carbonate beach sands form rocky intertidal terraces.

3) FINE-GRAINED SAND BEACHES

Description

- Physical
  - Usually gentle slope with broad, flat profile
  - Often exposed to moderate and high wave energy
  - Shell accumulations may be present in the lower intertidal zone or back beach area
- Plants
  - Scattered beach grasses and plants growing at the base of natural dunes
  - Beach wrack composed of decaying Spartina grasses
- Animals
  - Insects and amphipods associated with beach wrack are present
  - Burrowing amphipods and polychaete worms are present in the upper and mid intertidal zones
  - Some burrowing clams are present in the lower intertidal to subtidal zones
  - Diversity, density, and species richness low to moderate
  - Ghost crabs are common at base of dunes along back beach areas

Predicted Oil Behavior

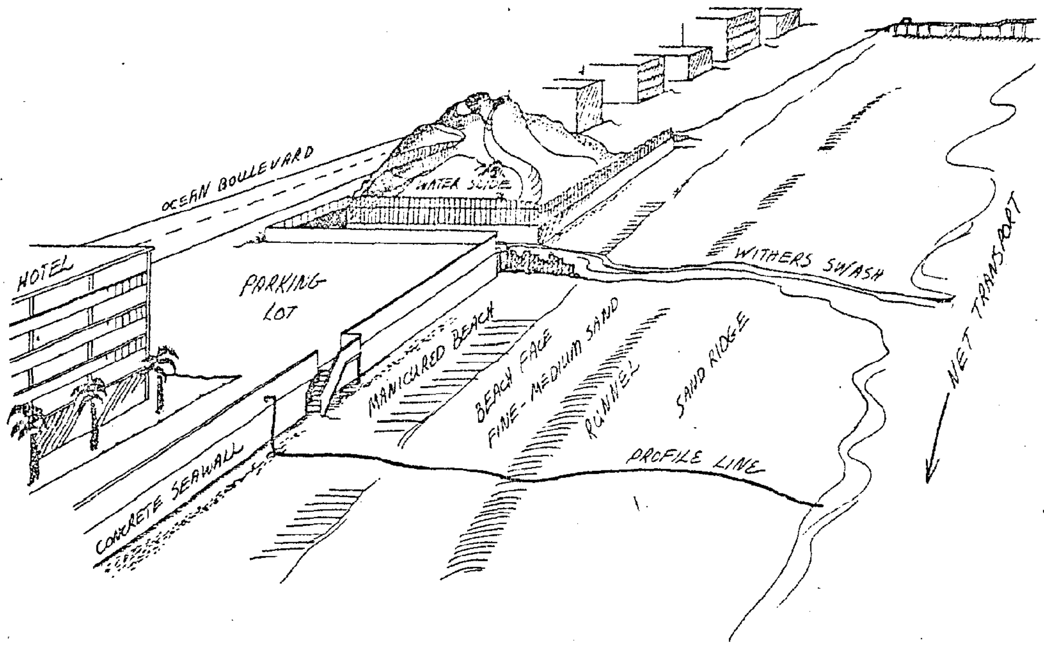
- Large accumulations would cover entire beach face
- Small accumulations would be deposited primarily along high-tide swash lines
- The compact sediments of this beach type prevent deep penetration of oil
- Oil may be buried to a maximum of 10-20 cm along the upper beach face

Potential Biological Damages

- Biological damage would be limited
- Intertidal organisms would have short-term exposure because oil would be deposited over berm crest; impact may occur to supratidal organisms such as beach hoppers (Talorchestian amphipods)

Recommended Cleanup Activity

- Cleanup should begin only after majority of oil is deposited onshore
- Cleanup should concentrate on removal of oil from upper swash zone
- Mechanical methods should be used cautiously, but fine-grained sand beaches are generally among the easiest to clean mechanically because of their hard, compact substrate
- Removal of sand should be minimized



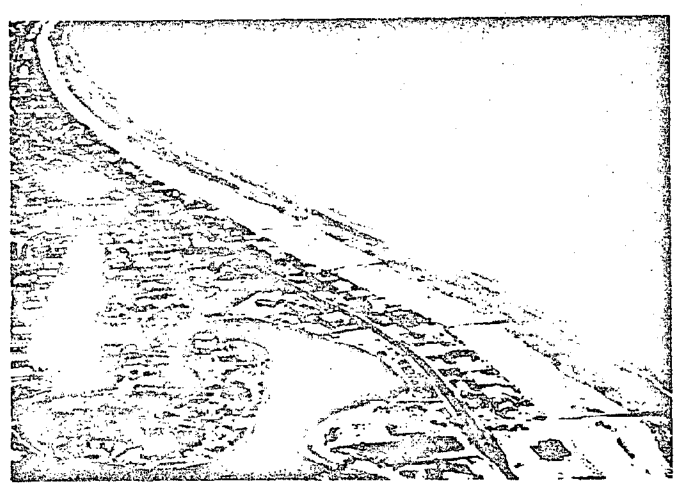


FIGURE 11. An oblique aerial view looking northeast of Garden City showing a wide, fine-grained sand beach at low tide on 3 February 1981. Note the partially buried intertidal groins at lower right of photo.

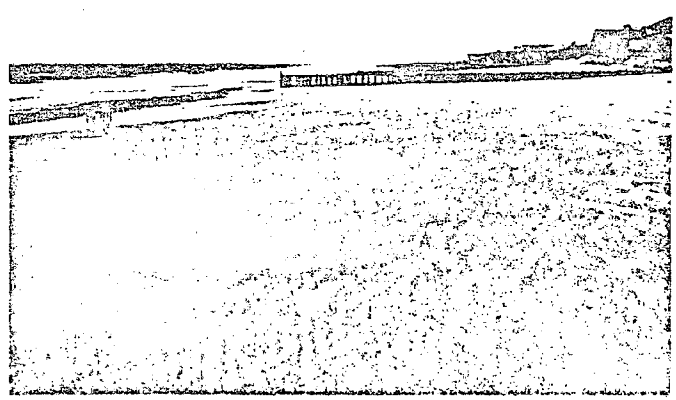


FIGURE 12. Fine-grained sand beach at Pawleys Island, looking south. Photo taken at low tide on 5 April 1981.

4) MEDIUM- TO COARSE-GRAINED SAND BEACHES

Description

- Physical
  - Usually displays a short, steep beach face with a wide back shore or washover terrace
  - Sediments are loosely compacted
  - Beach morphology responds rapidly to changing wave and tidal conditions
- Plants
  - Beach wrack is predominantly decomposing Spartina
- Animals
  - Low species diversity, density, and richness
  - A few polychaetes, amphipods, and clams are found at or between low and mid intertidal zones
  - Beach wrack provides habitat for amphipods and insects

Predicted Oil Behavior

- Large accumulations would cover entire beach face
- Small accumulations would be deposited primarily along high-tide swash lines
- Oil may be buried deeply along berm and berm runnel

Potential Biological Damages

- Biological damages would be minimal
- Supratidal organisms would suffer only short-term exposure unless oil penetrates substrate
- Where oil penetrates substrate, some die-offs of infauna would be expected

Recommended Cleanup Activity

- Cleanup should commence only after majority of oil is deposited onshore
- Cleanup should concentrate on removal of oil from swash zones
- Mechanical methods should be used cautiously
- Sediment removal should be minimized

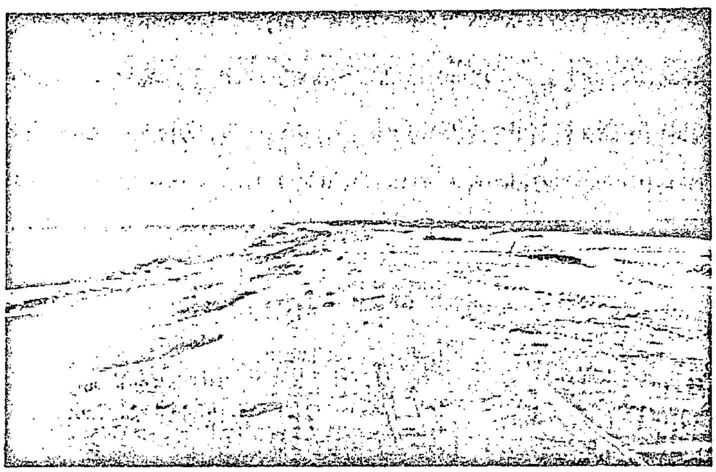


FIGURE 13. Beach face at Cape Romain looking south. Note well-defined berm crest (near right tire track) and broad back beach/washover area.

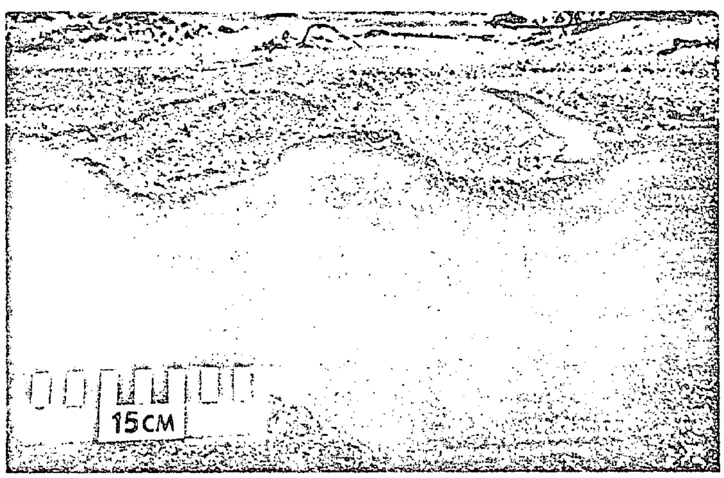


FIGURE 14. Close-up view of beach trench through coarse sand on Cape Romain. Photos by C. H. Ruby.

5) EXPOSED TIDAL FLATS (LOW BIOMASS)

Description

- Physical
  - Sediments are generally fine-grained sand
  - Sediments are very mobile due to waves and tidal currents
  - Associated with tidal deltas and, in some areas, front sand or mixed sand and shell beaches
- Plants
  - Very little flora present
  - Mobile substrate prevents attachment of algae
- Animals
  - When present, benthic infauna are dominant organisms
  - Species diversity, density, and richness vary with substrate
  - Clams, polychaetes, and burrowing crustaceans are the most common macroorganisms
  - Faunal density is lowest at high intertidal zone, increasing at mid and low intertidal zones
  - In sand-bottom flats exposed to high wave energy, deep-burrowing clams dominate simple benthic communities
  - Birds utilize exposed flats as roosting and foraging areas

Predicted Oil Behavior

- Most oil would be pushed across tidal flat surface onto adjacent shores by wave and tidal activity
- Mobile sediments in coarser-grained flats would prohibit long-term accumulation
- Light fractions of oil may contaminate the interstitial waters

Potential Biological Damages

- Oil would impact organisms at high-tide swash zones and in pools left during receding tide
- Oil left on substrate during receding tide would:
  - penetrate burrows of clams and other burrowers
  - come in contact with or be ingested by these organisms
  - be incorporated into the sediments
- Birds foraging on the flats would be exposed to oil by:
  - feather oiling
  - ingestion of immobilized or weakened organisms resulting from oil contamination

Recommended Cleanup Activity

- No cleanup usually necessary in areas where oil accumulation is low
- Removal of sediment should be avoided

FIGURE 15. Oblique aerial view of large, exposed tidal flat at Skull Inlet near Fripp Island. Photo taken by J. Michel on 2 April 1981.

FIGURE 16. Exposed tidal flat (low biomass) at the north end of Hunting Island at the mouth of Johnson Creek. Note the small-scale ripples superimposed on large-scale sand waves which are indicative of highly mobile sediments.

5a) MIXED SAND AND SHELL BEACHES

Description

- Physical
  - Sediments may be either dominantly mobile or stable, dependent on location of beach with respect to wind and wave conditions
  - Generally composed of medium sand and broken shell
  - Natural sorting processes may form sand "stringers" at lower intertidal zones
- Plants
  - Because of scouring action from active movement of beach sediments due to waves, plants are unable to survive
- Animals
  - Few macrofaunal organisms are able to survive in mobile sand/shell beaches
  - Low species diversity, density, and richness

Predicted Oil Behavior

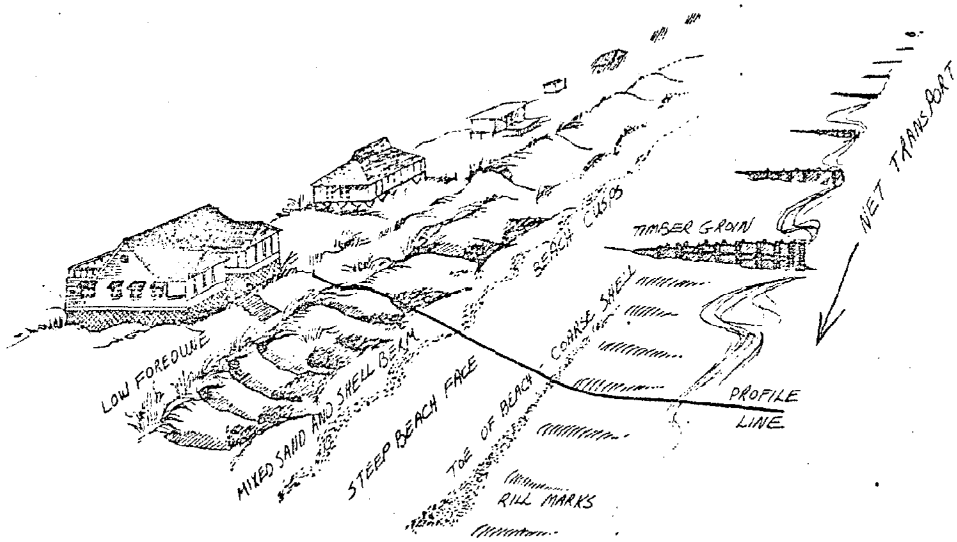
- Oil would be deposited primarily high on the beach face
- Only under heavy accumulations would oil be deposited over the lower beach face
- Burial may be deep along berm
- Long-term persistence of oil is dependent on incoming wave energy; in sheltered areas, oil would remain for several years

Potential Biological Damages

- Roosting birds would be affected by oiled feathers and possible ingestion of contaminated prey

Recommended Cleanup Activity

- Oil should be removed primarily from upper swash lines
- High-pressure spraying may be necessary
- Mechanical reworking of sediment into the surf zones effective if oil accumulations are heavy enough to require it
- Removal of sediment should be restricted



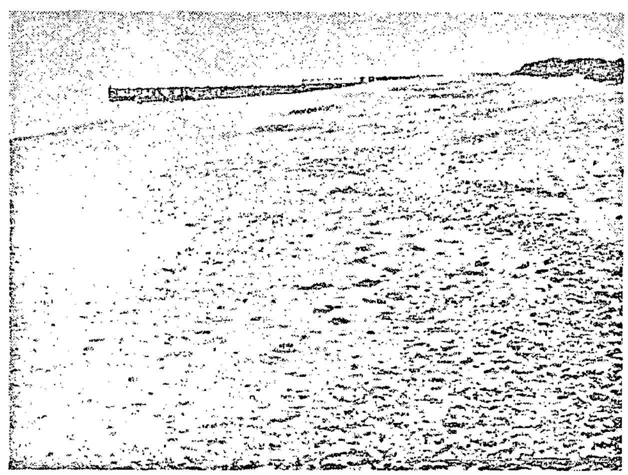


FIGURE 17. A mixed sand and shell beach at Edisto. Note cuspate shell concentrations near the high watermark. View looking south.

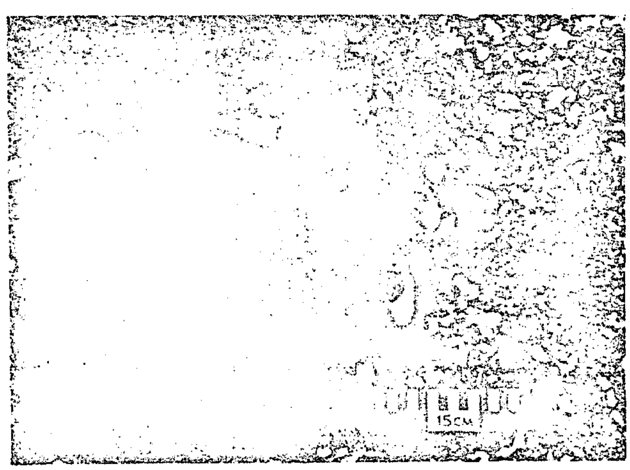


FIGURE 18. Close-up view of mixed sand and shell sediments along Edisto Beach.

5b) SHELTERED EROSIONAL SCARPS

Description

- Physical
  - Occur along tidal creek environments where erosion is occurring to relict (mostly Pleistocene) sediments
  - Includes dredged channel escarpments along the Intracoastal Waterway
- Plants
  - Terrigenous nonmarine detritus, trees, roots, and grasses exposed along shoreline due to slumping of land along erosional scarp
- Animals
  - Infaunal diversity, density, and richness are very low - Only a few insect larvae were found

Predicted Oil Behavior

- Oil would be deposited on detritus and at base of scarp
- Long-term persistence is dependent on incoming wave energy and erosion rates

Potential Biological Damages

- Biological damages would be minimal

Recommended Cleanup Activity

- High-pressure spraying may be effective
- Good place to corral oil if adjacent areas are higher in sensitivity

FIGURE 19. Erosional scarp in Pleistocene sediments along the Intracoastal Waterway near Myrtle Beach. Narrow low-tide beach is littered with fossil molluscs and detritus from terrestrial plants.

6) SHELL BEACHES

Description

- Physical
  - Sediments may be either dominantly mobile or stable, dependent on location of shoreline with respect to wind and wave activity
  - Composed mostly of oyster and/or quahog shells; generally less than ten percent sand
  - Common along banks of dredged channels including the Intracoastal Waterway; reworked spoil banks
- Plants
  - Shell beaches are generally devoid of vegetation
- Animals
  - Shell beaches are generally devoid of fauna

Predicted Oil Behavior

- Oil would be deposited primarily on the upper beach face
- Oil would percolate easily into the sediments
- Burial may be exceptionally deep along the berm

Potential Biological Damages

- Damages would be minimal
- Chronic leaching of oil after percolation into the beach would continue to affect adjacent, more sensitive environments

Recommended Cleanup Activity

- Most shell beaches are formed from dredged spoil material and are generally of limited extent and quite narrow, aligning with channels
- Since they are generally associated with more sensitive marsh and tidal flat areas, they would provide a preferred zone to beach incoming oil
- Cleanup may require removal of oiled shell to minimize oil leaching into adjacent salt marshes

FIGURE 20. An oblique aerial view of the shell beaches (arrow) along the tidal creeks near Little River. Wave action leaches fine sediments from the accumulations which are often associated with reworked dredged spoil.

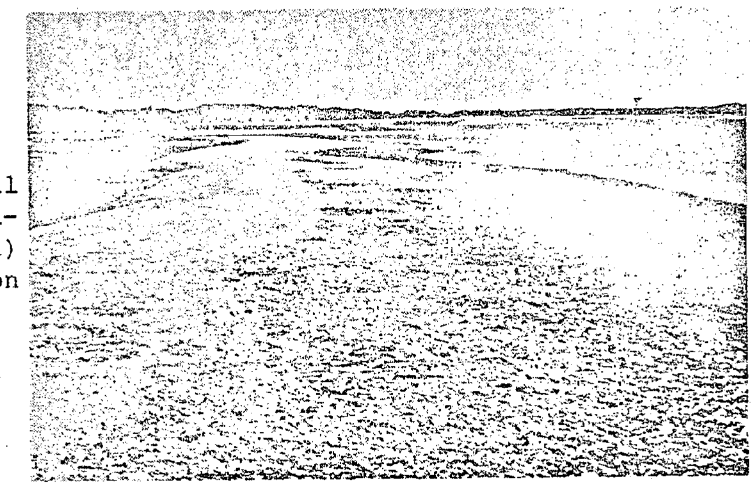


FIGURE 21. A washed shell beach/berm along the Intracoastal Waterway (to right) between Beaufort and Hilton Head Island.

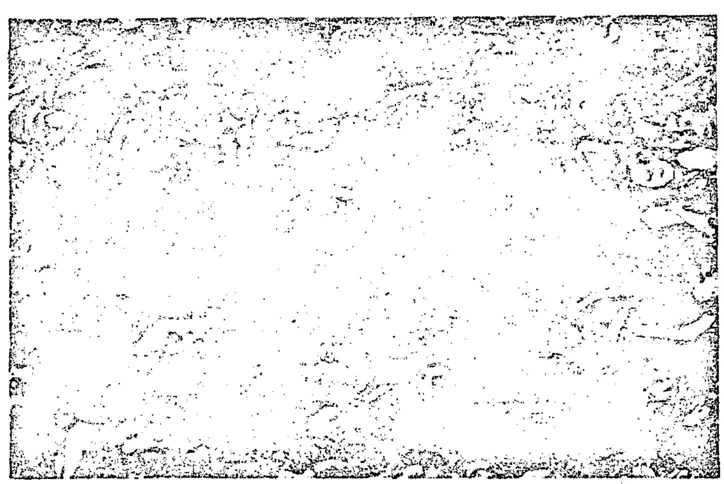


FIGURE 22. Close-up of the shell beach sediments, showing predominance of oyster shell.

6a) EXPOSED RIPRAP

Description

- Physical
  - Predominantly gravel to boulder-sized riprap revetments
  - Riprap is composed generally of quarried Piedmont granite or high-grade metamorphic rocks (e.g., gneiss)
  - Most common along back beach areas as shore protection for developed property
- Plants
  - Green filamentous algae and Ulva observed on some riprap in the intertidal zone
- Animals
  - Infaunal densities are moderate to high
  - Barnacles are patchy with densities ranging as high as 19,500 individuals/m^2 (based on 1/25 m^2 sample)

Predicted Oil Behavior

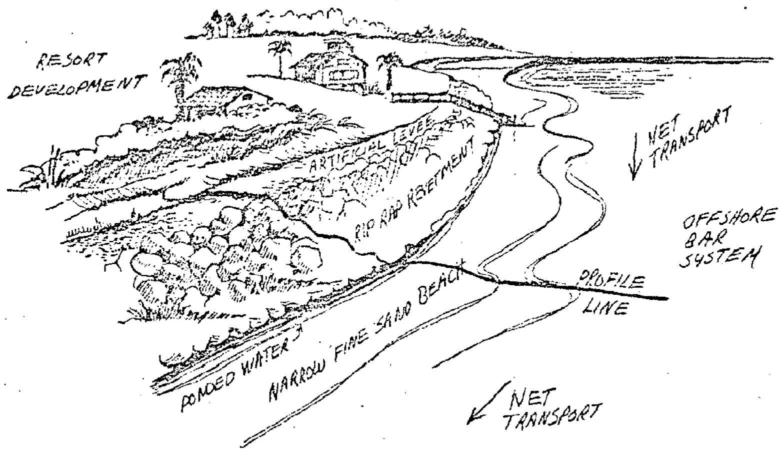
- Oil would percolate easily between gravel and boulder elements of riprap
- Heavy oils would adhere to irregular surfaces of boulders, whereas light oils would be removed by wave action

Potential Biological Damages

- Barnacle community would have short-term impact, primarily from smothering
- Recolonization would occur relatively quickly after boulders are naturally cleaned of oil

Recommended Cleanup Activity

- May require high-pressure spraying:
  - to remove oil
  - to prepare substrate for recolonization of barnacle and oyster communities
  - for aesthetic reasons
- Since riprap is often associated with developed, recreational beaches, cleanup would be advisable to minimize chronic leaching of oil trapped in the rocks



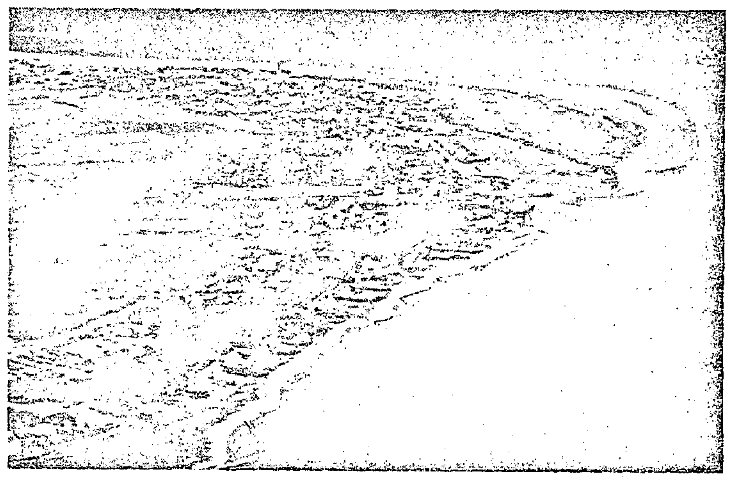


FIGURE 23. An oblique aerial view of Sullivans Island inside the Charleston Harbor entrance. Note zigzag riprap and groins along shoreline in foreground. Photo taken at low tide 4 February 1981.

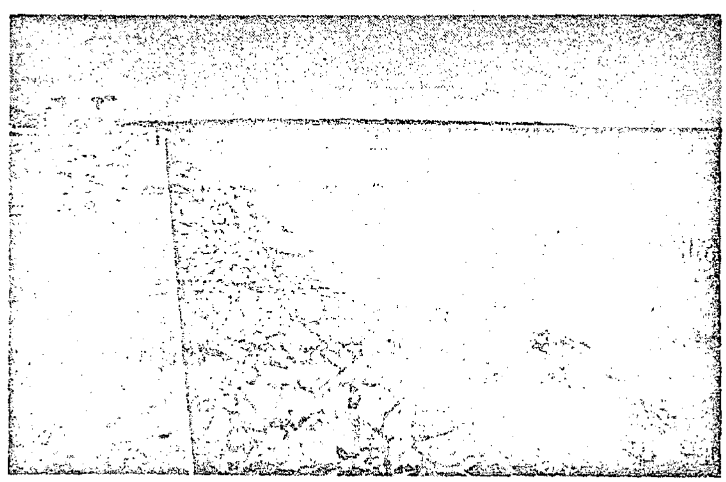


FIGURE 24. An exposed riprap revetment fronting the concrete seawall at the northern end of Fripp Island. Extensive intertidal community of barnacles and oysters covers the lower portion of the structure.

7) EXPOSED TIDAL FLATS (MODERATE BIOMASS)

Description

- Physical
  - Sediments range from mud to coarse shell
  - Generally, sediments are less mobile than those of ESI=5
  - Associated with tidal deltas and prograding spits
- Plants
  - Very few flora are present
- Animals
  - Benthic infauna are dominant organisms
  - Species diversity and density vary with substrate, which ranges from mud to mixed sand and shell
  - As in ESI=5, clams, polychaetes, and burrowing crustaceans are most common macroorganisms, but are found in greater abundance
  - Faunal density is lowest at high intertidal zones, increasing at mid and lower intertidal zones
  - Species diversity is low and richness is moderate to high
  - Deep-burrowing clams dominate simple benthic communities
  - Birds utilize exposed flats as roosting and foraging areas

Predicted Oil Behavior

- Most oil would be pushed across tidal flat surfaces onto adjacent shores by wave and tidal activity
- Mobile sediments in coarser-grained flats would prohibit accumulation

Potential Biological Damages

- Oil would impact organisms at high-tide swash zones and in pools left during receding tide
- Oil laid down on substrate by receding tide would:
  - penetrate burrows of clams and other burrowers
  - come in contact with or be ingested by these organisms
  - be incorporated into the sediments
- Birds foraging on flats during low tide would be exposed to oil by:
  - feather oiling
  - ingestion of oil from preening of contaminated feathers
  - ingestion of organisms which have been immobilized or weakened by oil contamination

Recommended Cleanup Activity

- No cleanup usually necessary where oil accumulation is low
- Removal of sediment should be avoided
- Use of heavy machinery would tend to mix oil into sediments; however, in areas where fine-grained, compacted sand occurs, heavy machinery can be used
- In cases of heavy oiling, the beach side of the flats should be cleaned of oil

FIGURE 25. An oblique aerial view of North Inlet showing exposed tidal flat with moderate biomass in foreground at the confluence of two tributary channels (arrow). View looking seaward at low tide on 3 February 1981.

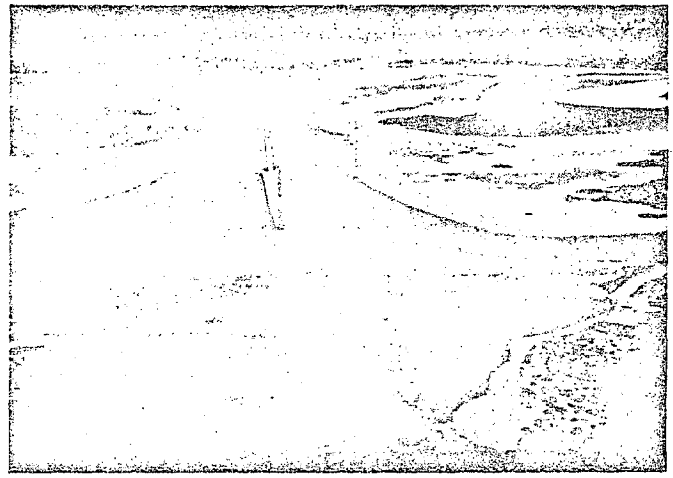


FIGURE 26. Exposed tidal flat (moderate biomass) at the west end of Raccoon Key at low tide on 4 April 1981. Tide pools would trap oil during portions of the tidal cycle.

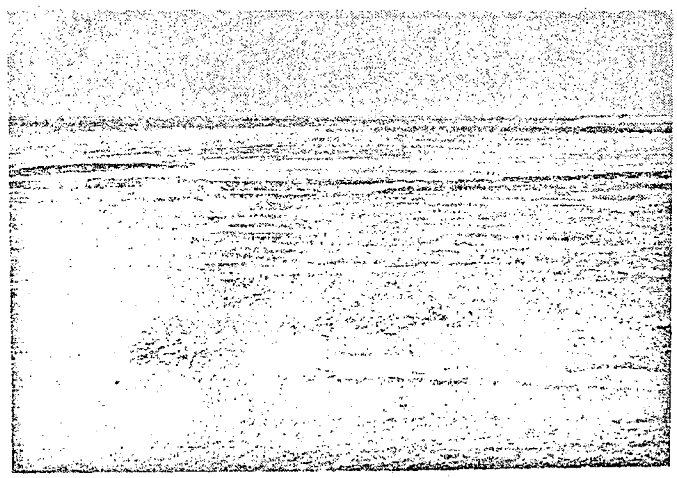


FIGURE 27. Close-up of exposed tidal flat sediments showing mud and organic detritus in troughs of ripples.

7a) EROSIONAL SCARPS IN MARSH

Description

- Physical
  - Eroding scarps along tidal creeks and rivers in cohesive marsh sediments; sometimes a combination of a narrow tidal flat, a narrow beach, and an erosional scarp
  - Commonly associated with less saturated (with water), high marsh sediments and dredge-spoil deposits
  - Most common on the southern half of the coast
- Plants
  - Roots and rhizomes of *Spartina alterniflora* would be exposed and eventually slump into the water
- Animals
  - Would be similar to organisms in ESI=7 tidal flats
  - Few organisms would be found in erosional scarps, but *Uca* burrows would be exposed by the erosion

Predicted Oil Behavior

- Little oil would penetrate cohesive, fine-grained sediments, but would affect intertidal communities or animals
- Erosion processes would naturally remove oil

Potential Biological Damages

- Damage to erosional scarps would be minimal
- Oil coating exposed roots and rhizomes of *S. alterniflora* might kill off fringe plants
- Some impact may occur to organisms in sheltered tidal flats fronting scarps

Recommended Cleanup Activity

- Erosional scarps in high marsh sediments would provide a better location to corral oil due to lower sensitivity than adjacent marshes and tidal flats
- Cleaning and removal may be necessary to protect adjacent, more sensitive areas

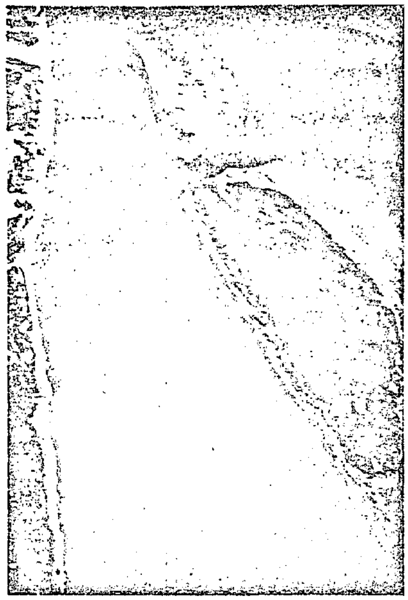


FIGURE 28. Oblique aerial view of erosional scarps in marsh near Calibogue Sound.

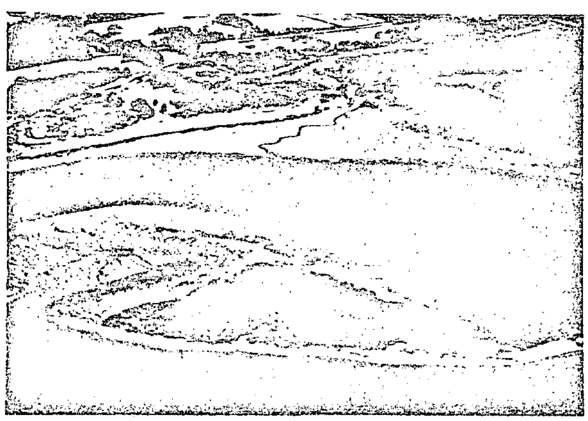


FIGURE 29. Oblique aerial view of an erosional scarp in marsh (foreground) near Beaufort. These features are more common along the southern portion of the state.

8) SHELTERED COASTAL STRUCTURES

Description

- Physical
  - Includes bulkheads, riprap, piers, and docks
  - Typically a low-energy environment, dependent on seasonal storm activity
  - Generally associated with more sensitive, back-barrier environments
- Plants
  - Low to moderate growths of *Enteromorpha* and *Ulva*
- Animals
  - Intertidal zones contain moderate to heavy populations of oysters and their associated biota

Predicted Oil Behavior

- Long-term (1-2 years) persistence of oil, especially between rocks and boulders
- Oil would penetrate more deeply into porous structures

Potential Biological Damages

- Oysters would be impacted by oiling; mortalities would be high in heavy oiling
- Oil persistence would be long-term because of low wave energy
- In cases of heavy oiling, mortalities would be great throughout the intertidal zones

Recommended Cleanup Activity

- High-pressure spraying may be effective in removing oil and clearing substrate for recolonization

FIGURE 30. An oblique aerial view at low tide of dredged canal system and shoreline structures at Garden City. Note the numerous piers and bulkheads. Photo taken on 3 February 1981.

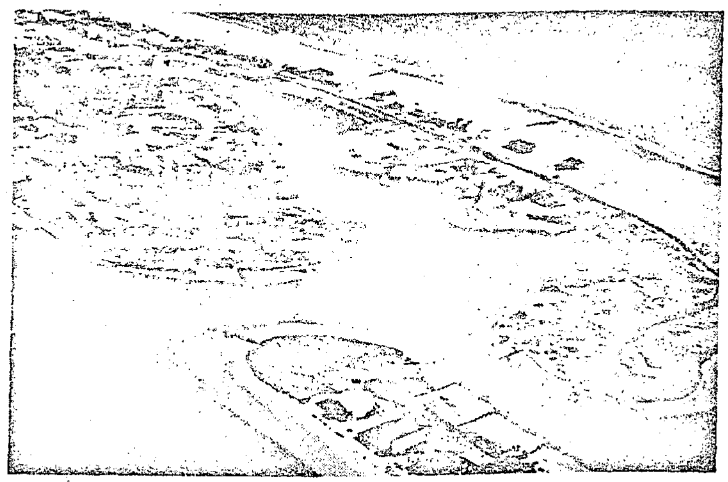


FIGURE 31. Ground view of the Garden City canal system and shoreline structures. Wood sheet pile bulkhead is typical of structures in this area.

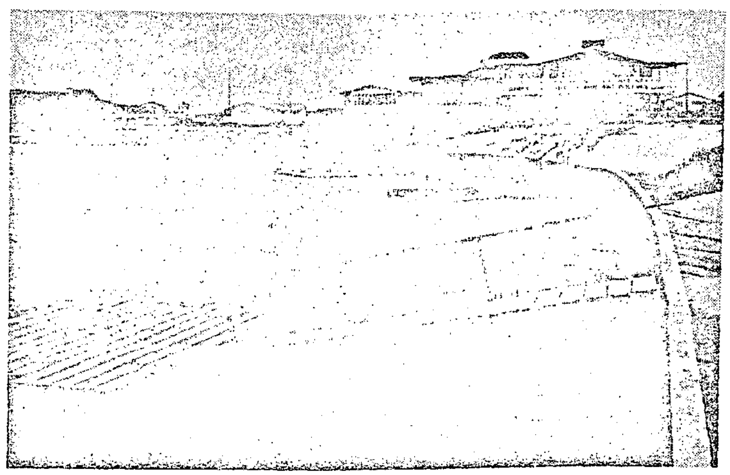
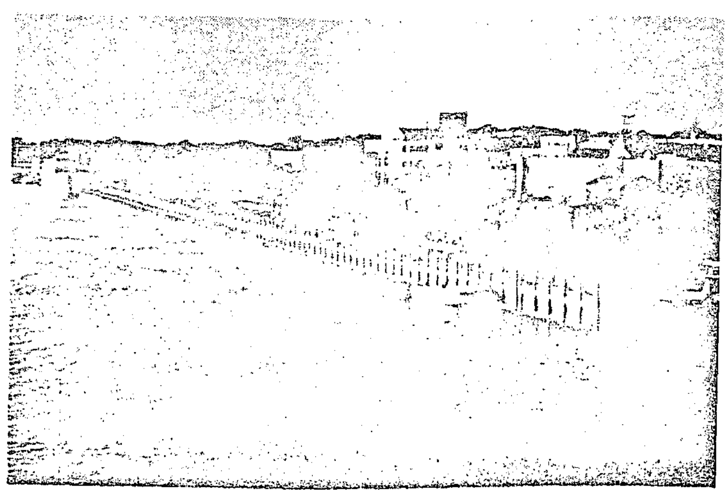


FIGURE 32. Beaufort waterfront showing vertical concrete and timber wharf. An extensive, attached oyster community grows along mid to upper intertidal zone.



9) SHELTERED TIDAL FLATS (HIGH BIOMASS) AND OYSTER BEDS

Description

- Physical
  - Composed of mud or silty sand
  - Sheltered from major wave and tidal activity
  - Usually located in back barrier areas
  - Occur with extensive oyster colonies in many areas
- Plants
  - Mud flats are generally devoid of vegetation
- Animals
  - Macroinfauna species diversity, density, and richness high
  - Extensive clam and oyster populations are present
  - At high tide, these flats support a large epibenthic community of blue crabs, flounder, channel bass, spotted sea trout, and other vertebrate and invertebrate species
  - At low tide, may species of birds feed on tidal flats

Predicted Oil Behavior

- Long-term (several years) persistence of oil due to lack of wave and tidal activity
- Long-term oil incorporation into sediments is common
- Oil would be deposited primarily along high-tide swash zones

Potential Biological Damages

- Extensive die-offs of infauna would be expected
- Mortalities would be caused by smothering and ingestion
- Oil would penetrate burrows, mixing in with sediment several centimeters below the surface
- Recovery would be slow; oil persistence would be long-term
- Stressed clams move to the surface, attracting birds and other scavengers who can become affected
- Impact to birds through ingestion of contaminated food or through preening of oiled feathers

Recommended Cleanup Activity

- Where sediment is compact, manual and mechanical cleanup may be effective for massive accumulations
- Traffic over the flat should be limited

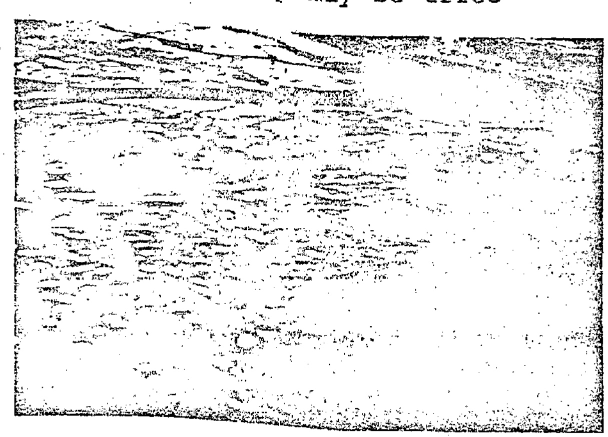


FIGURE 33. An oblique aerial view of a sheltered tidal flat and numerous oyster mounds behind Isle of Palms (Hamlin Sound).

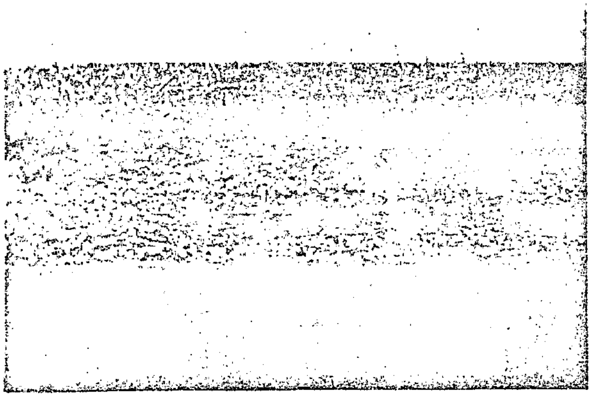


FIGURE 34. Intertidal oysters fringing a Spartina marsh which is a common association in South Carolina.

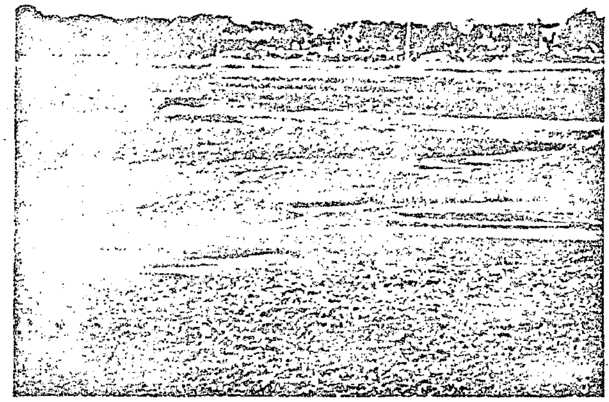
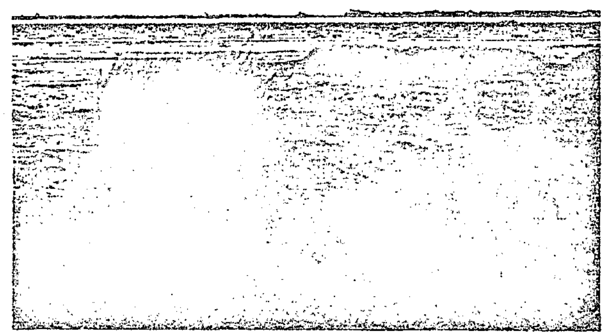


FIGURE 35. Extensive sheltered tidal flat at Beaufort showing dense population of oysters.

FIGURE 36. Sheltered tidal flat with scattered oyster mounds at the mouth of Harbor River near Hunting Island. This tidal flat, composed of soft mud, has a large population of Littorina snails.



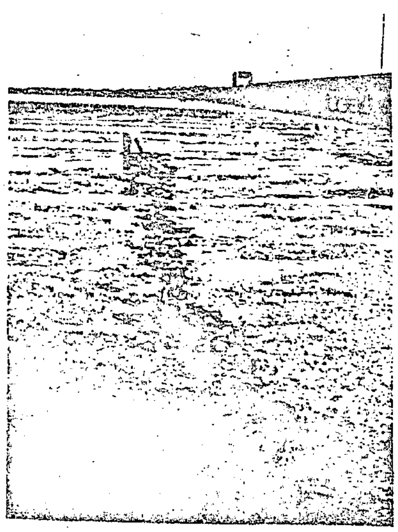


FIGURE 37. A broad tidal flat at the mouth of Harbor River showing extremely soft sediments.

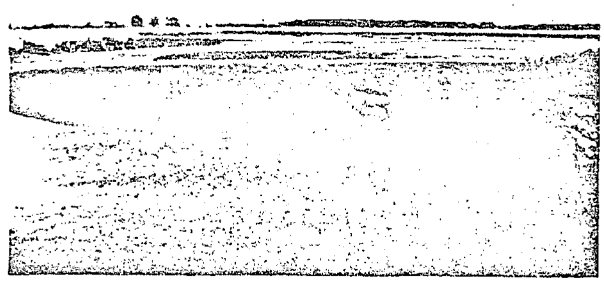


FIGURE 38. Small sheltered tidal flat devoid of oysters near Harbor River.

10) MARSHES

Description

- Physical
  - Over 500,000 acres of coastal marsh of which 334,000 are considered salt marsh
  - Occur as broad areas between barrier islands and the mainland
  - Generally fronted by a sheltered tidal flat
  - Well sheltered from extreme wave and current action
  - By far, the most common shoreline type in South Carolina
- Plants
  - Three types of coastal marshes present:
    1) Low marsh - predominantly _Spartina alterniflora_ occurs in the mid to upper intertidal zones
    2) High marsh - occurs in the upper intertidal to supralittoral zones; some common high marsh plants are _Spartina patens_, _Salicornia virginica_, _S. bigelovii_, _Batis maritima_, _Limonium carolineanum_, _Sporobolus virginica_, and _Distichlis spicata_
    3) Brackish freshwater marsh - dominated by _Juncus roemerianus_ and _Spartina cynasuriodes_
- Animals
  - Associated invertebrates include marsh periwinkles, fiddler crabs, pulmonate snails, polychaetes, amphipods, clams, and mussels
  - Densities of both epifauna and infauna range from moderate to high
  - Marshes utilized by numerous birds, alligators, raccoons, and rodents for feeding and reproductive habitat

Predicted Oil Behavior

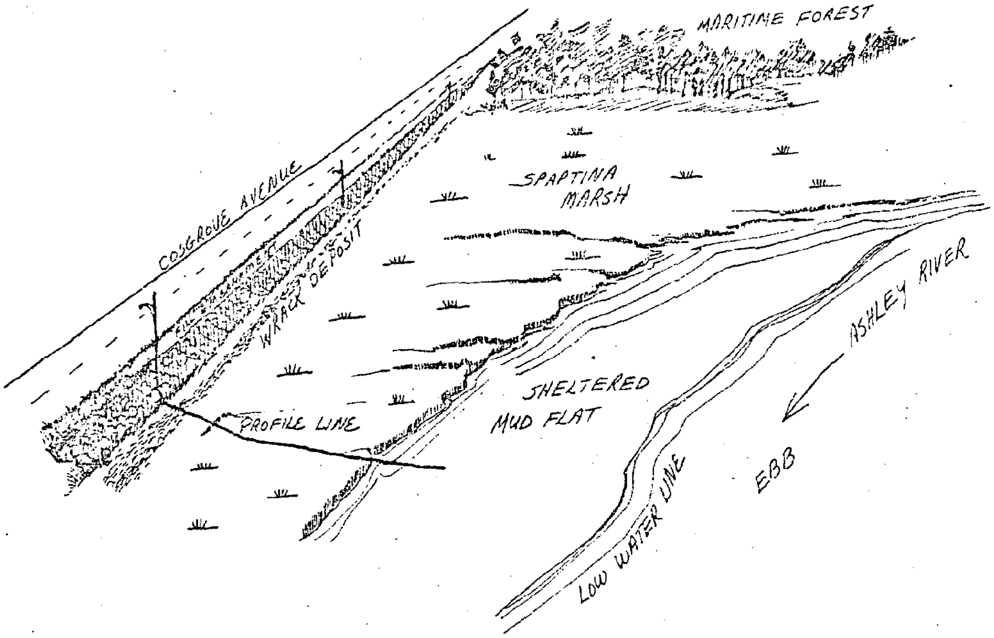
- Long-term (5-10+ years) persistence of oil is common with heavy accumulations
- Oil in small quantities would be deposited along outer fringe
- Oil in large quantities may cover entire marsh

Potential Biological Damages

- Oil would be persistent in sheltered marsh areas
- Long-term exposure to oil would damage marsh plants
- Epifauna and infauna would be affected by long-term exposure

Recommended Cleanup Activity

- Under light oiling, the best practice is to let the marsh recover naturally
- Cutting of oiled fringing grasses or low-pressure flushing may be effective
- Vehicles and cleanup crews should avoid activity on marsh surface, where possible
- Under heavy oiling, complete scraping of the impacted marsh followed by soil renourishment, replanting, and fertilization may be necessary



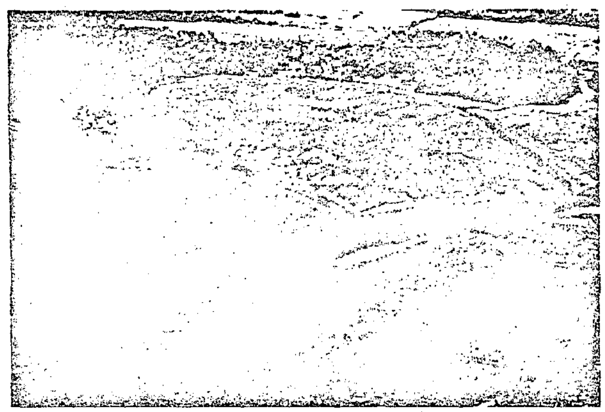


FIGURE 39. An oblique aerial view of *Spartina* marsh and dendritic drainage channels near Edisto Beach.

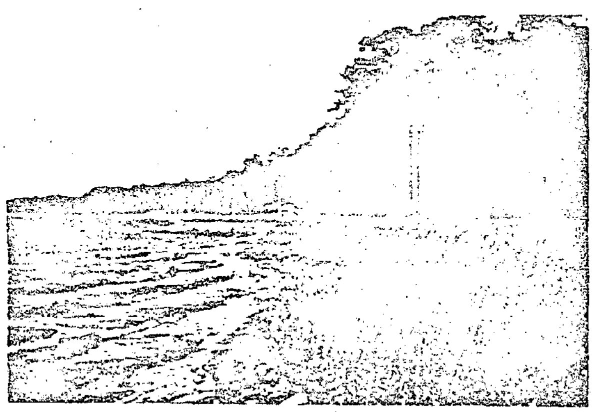


FIGURE 40. Fringing marsh along Calibogue Sound at Hilton Head Island. View is looking north at low tide on 17 January 1981.

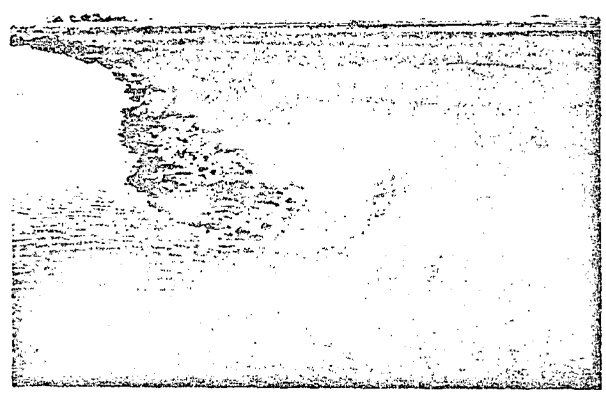
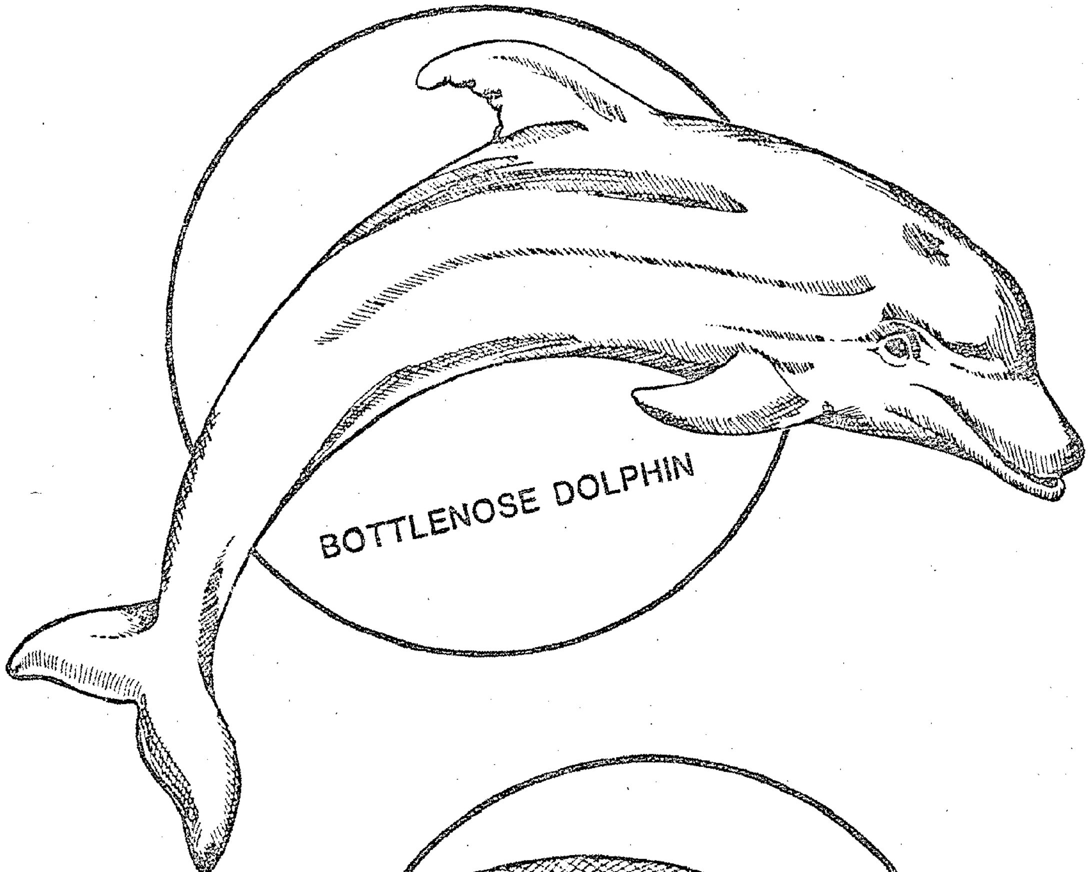
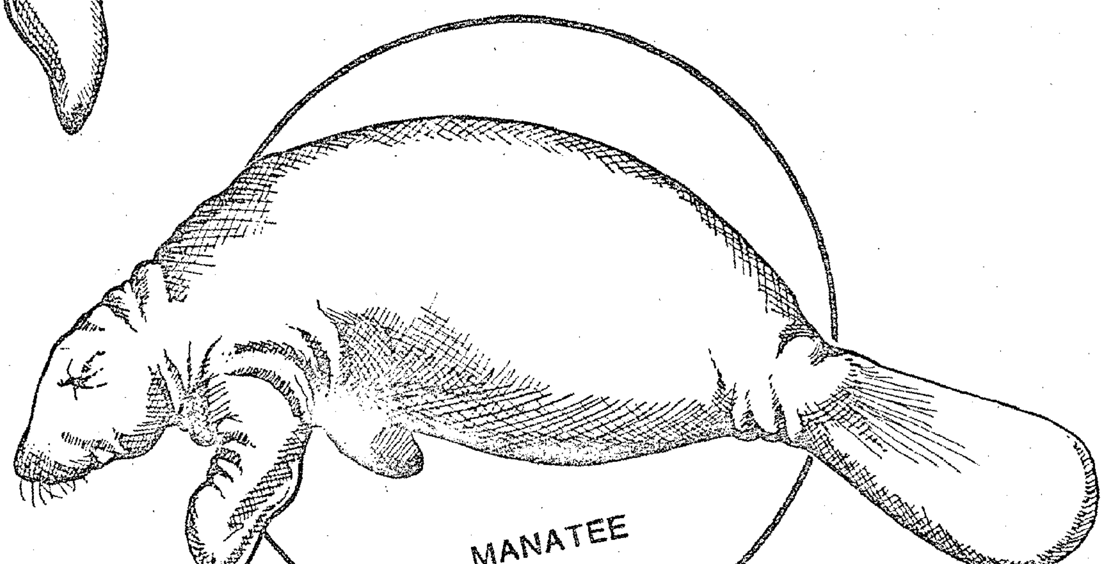


FIGURE 41. Extensive *Spartina* marsh along Johnson Creek near Hunting Island. View is looking south on 19 January 1981.


BOTTLENOSE DOLPHIN


MANATEE

CRITICAL SPECIES AND HABITATS

The ESI maps outline the location of critical areas in the study area with respect to oil spill impact. Location of feeding and breeding grounds of certain important species are also indicated.

This section presents five major groups of wildlife: (1) marine mammals, (2) marine birds, (3) reptiles, (4) finfish, and (5) shellfish. Summaries are given for major species present along with information concerning species distribution and the effects of oiling. In addition, a species list of infaunal organisms collected from the ESI habitats is found in Appendix II.

MARINE MAMMALS

Resident Populations

• Bottlenose dolphin	-Year-round; nearshore; major bays and inlets
• West Indian manatee	-Intermittently summers as far north as North Carolina

Protection Status

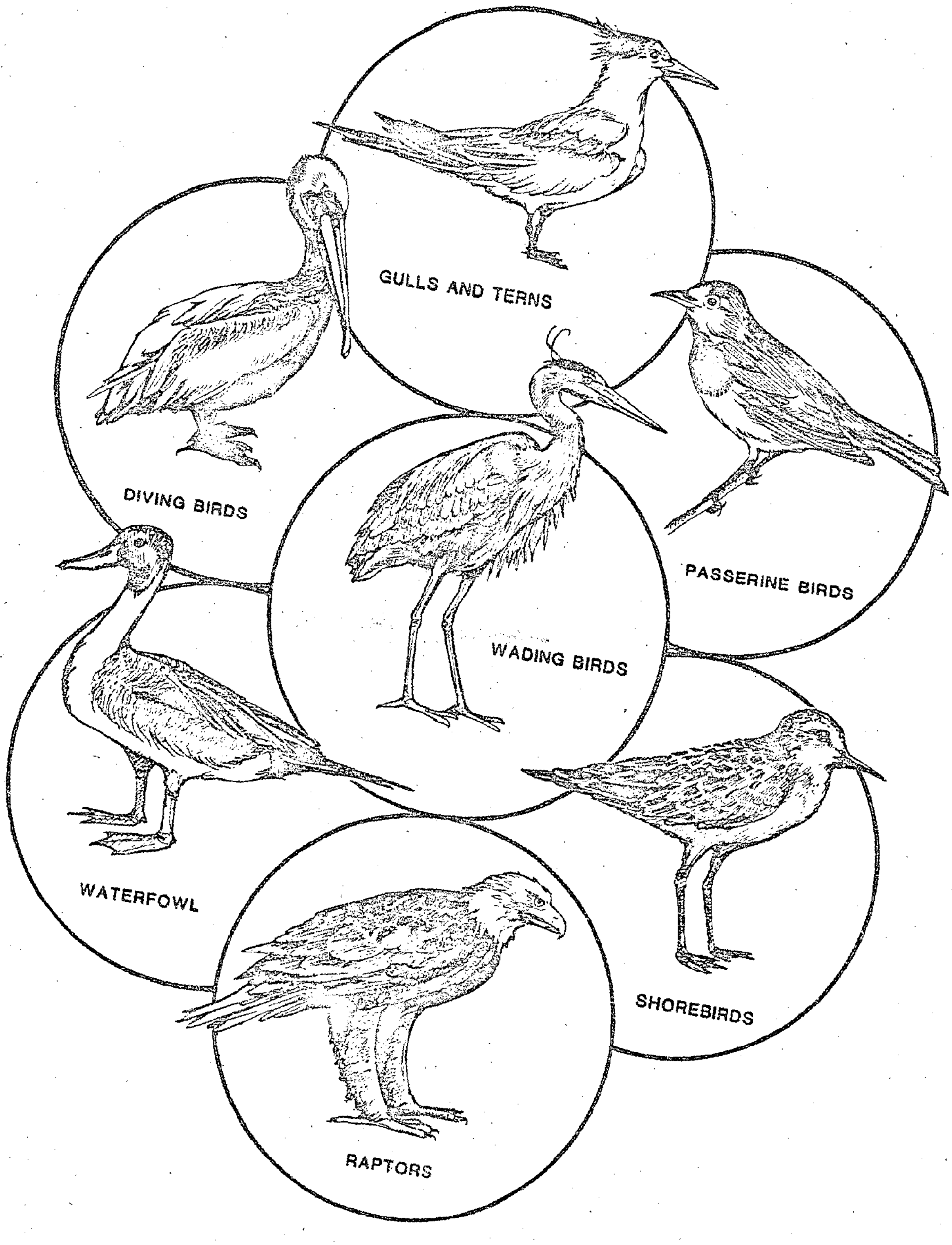
- Protected by Marine Mammal Act of 1972
- Endangered Species Act of 1973 (manatee)
- Endangered Species, South Carolina (manatee)

Predicted Impact

- Bottlenose dolphin
  - Stress may occur through ingestion of oil-contaminated food, oil intake through blowholes, eye irritation, and skin absorption
- West Indian manatee
  - Digestion of oil-contaminated vegetation
  - Eye irritation
  - Possible ingestion into nasal passages when they surface to breathe

Recommended Response Measures

- Bottlenose dolphin
  - Hazing to change swimming pattern
- West Indian manatee
  - Hazing to change swimming pattern
  - Possible capture and removal to uncontaminated waters


GULLS AND TERNS
DIVING BIRDS
PASSERINE BIRDS
WADING BIRDS
WATERFOWL
SHOREBIRDS
RAPTORS

COASTAL MARINE BIRDS

<u>Resident Populations</u> (species of special concern)

• Pelagic Birds	-Year-round; offshore
• Diving Birds	
- Double-crested cormorant	-Resident; winters; coastal
- Brown pelican	-Resident; coastal; endangered species
- Common loon	-Winters; nearshore; major bays and inlets
- Red-throated loon	-Winters; nearshore
- Red-necked grebe	-Winters; nearshore
- Horned grebe	-Winters; nearshore; bays and inlets
• Waterfowl	
- Lesser scaup	-Winters; migratory; nearshore; bays and inlets
- Redhead	-Winters; migratory; bays and inlets
- Canvasback	-Winters; migratory; bays and inlets
- Bufflehead	-Winters; migratory; nearshore; bays and inlets
- Ruddy duck	-Winters; migratory; bays, inlets, and estuaries
- Red-breasted merganser	-Winters; migratory; bays, inlets, and estuaries
• Raptors	
- Southern bald eagle	-Resident; nesting; endangered species
- Peregrine falcon	-Migration; endangered species
- Osprey	-Resident; nesting; state-protected
• Wading Birds	
- Common egret	-Resident; nesting; estuarine
- Snowy egret	-Resident; nesting; estuarine
- Cattle egret	-Resident; nesting; estuarine
- Great blue heron	-Resident; nesting; estuarine
- Louisiana heron	-Resident; nesting; estuarine
- Little blue heron	-Resident; nesting; estuarine
- Green heron	-Resident; nesting; estuarine
- Black-crown night heron	-Resident; nesting; estuarine
- Yellow-crown night heron	-Resident; nesting; estuarine
- Glossy ibis	-Known to nest only on Pumpkinseed Island
- White ibis	-Resident; nesting; estuarine
- Black rail	-Resident; nesting; estuarine
- Clapper rail	-Resident; nesting; estuarine
- American coot	-Resident; nesting; estuarine
• Shore Birds	
- American oystercatcher	-Resident; nesting; winters
- Black-bellied plover	-Winters; migrates
- Piping plover	-Winters; migrates
- Semipalmated plover	-Winters; migrates
- Wilson's plover	-Resident; nesting; migrates
- Killdeer	-Resident; nesting
- Whimbrel	-Winters; migrates
- Willet	-Resident; nesting; winters
- Lesser yellowlegs	-Winters; migrates
- Short-billed dowitcher	-Winters; migrates

- Ruddy turnstone -Winters; migrates
- Knot -Migrates
- Dunlin -Winters; migrates
- Sanderling -Non-nesting resident; winters; migrates
- Least sandpiper -Winters; migrates
- Semipalmated sandpiper -Winters; migrates
- Gulls and Terns
  - Great black-backed gull -Winters
  - Herring gull -Winters; migrates
  - Ring-billed gull -Winters; migrates
  - Laughing gull -Resident; nesting
  - Bonaparte's gull -Winters; migrates
  - Least tern -Resident; nesting; threatened species
  - Common tern -Resident; migrating; nesting
  - Royal tern -Resident; nesting
  - Caspian tern -Winters; migrating
  - Black skimmer -Resident; nesting
- Passerine Birds
  - Bachman's warbler -Summer resident; nesting; endangered species

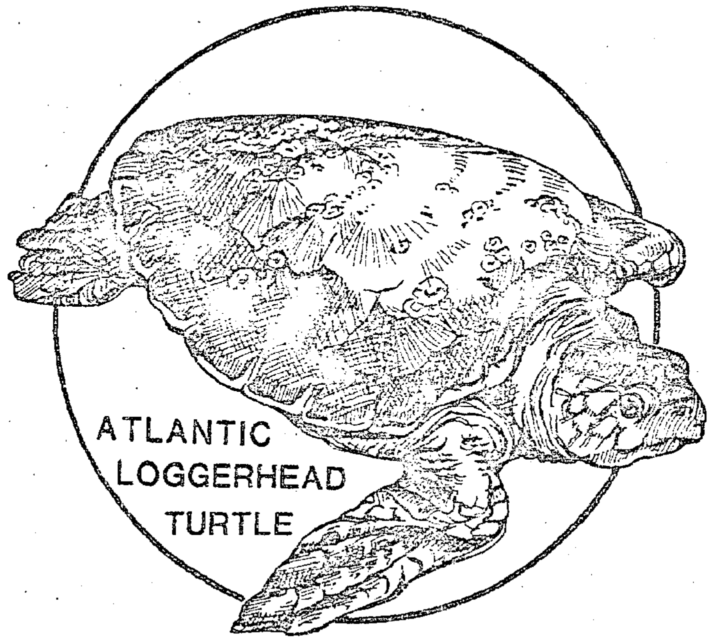
Predicted Impact

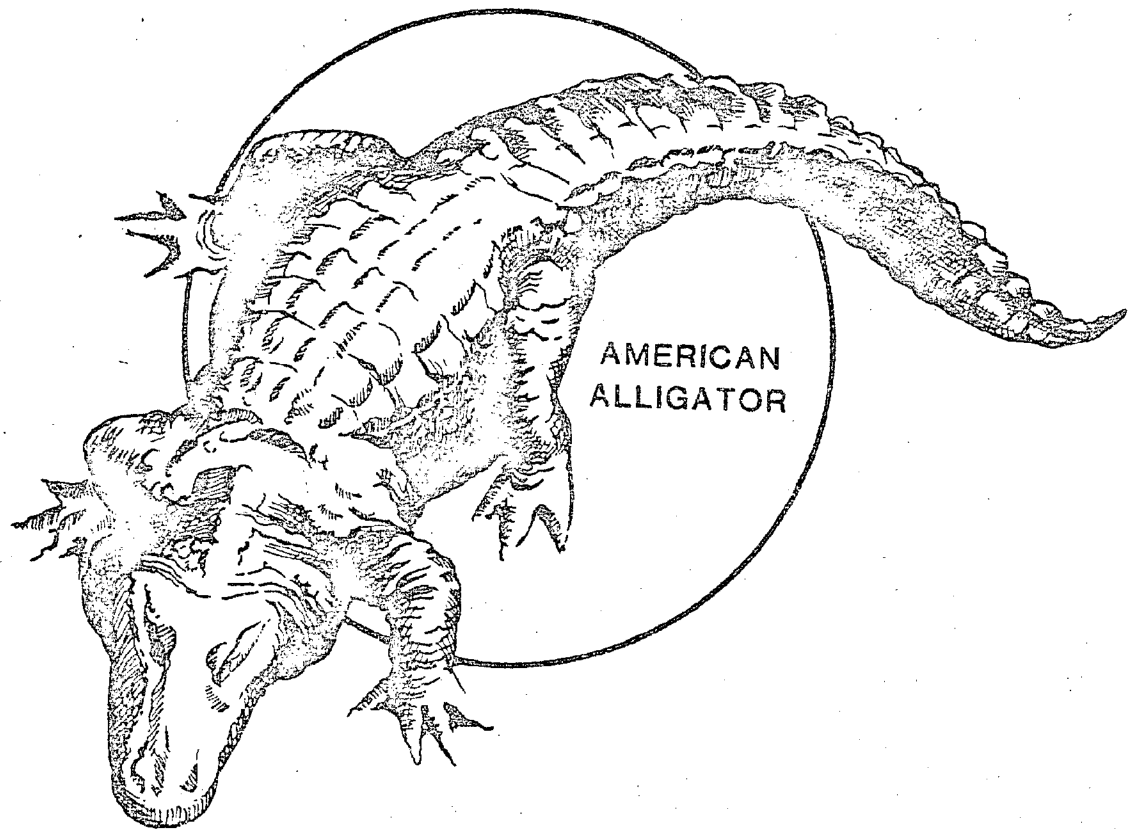
- Pelagic Birds
  - May become contaminated at night when roosting on water
  - May attempt to feed in contaminated waters
  - Because of pelagic nature, birds dying from oil contamination may sink to bottom or may be eaten
  - Impact would be difficult to determine
- Diving Birds
  - May dive or swim into oiled waters
  - Sometimes form large feeding flocks - these would be especially susceptible to mass oiling
- Waterfowl
  - Coastal species would be especially vulnerable
  - Ducks dive for food and are found in coastal or offshore waters:
    1) Contamination could result from swimming in oiled waters
    2) They may land in oil-calmed waters for evening roost
    3) They sometimes form large rafts which may result in massive oiling
    4) They may dive through or surface in oiled waters
- Raptors
  - Bald eagles feed on fish and seabirds; they may capture oil-weakened sea birds or contaminated fish for food
  - Peregrine falcons feed on waterfowl, shore birds, and sea birds:
    1) They are attracted to weakened birds
    2) They may feed on oil-contaminated prey
- Shore Birds
  - May feed or roost on oil-contaminated beaches
  - May ingest contaminated food
  - May ingest oil when preening contaminated feathers
- Gull and Terns
  - Form large colonies on isolated islands when nesting
  - May attempt to feed in oil-contaminated waters
  - Oil on feathers can be transferred to eggs

  - May roost in oiled waters or on contaminated beaches
  - May ingest oil when preening contaminated feathers
- Passerine Birds
  - Bachman's warbler
    1) Major impact would be destruction of habitat

Recommended Response Measures

- Hazing of birds from oiled waters may be effective
- During nesting season:
  - If still early in season, birds should be driven from rookeries and a watch maintained to insure that they do not return
  - If young in nests, attempts should be made to boom around colony; however, minor disturbances may drive adults from nests
- Human disturbances should be kept to a minimum
- Aircraft should not be operated over or near colonies


ATLANTIC
LOGGERHEAD
TURTLE


AMERICAN
ALLIGATOR

REPTILES

Resident Populations

- Atlantic loggerhead turtle -Nesting; mating
- American alligator -Resident; nesting

Protection Status

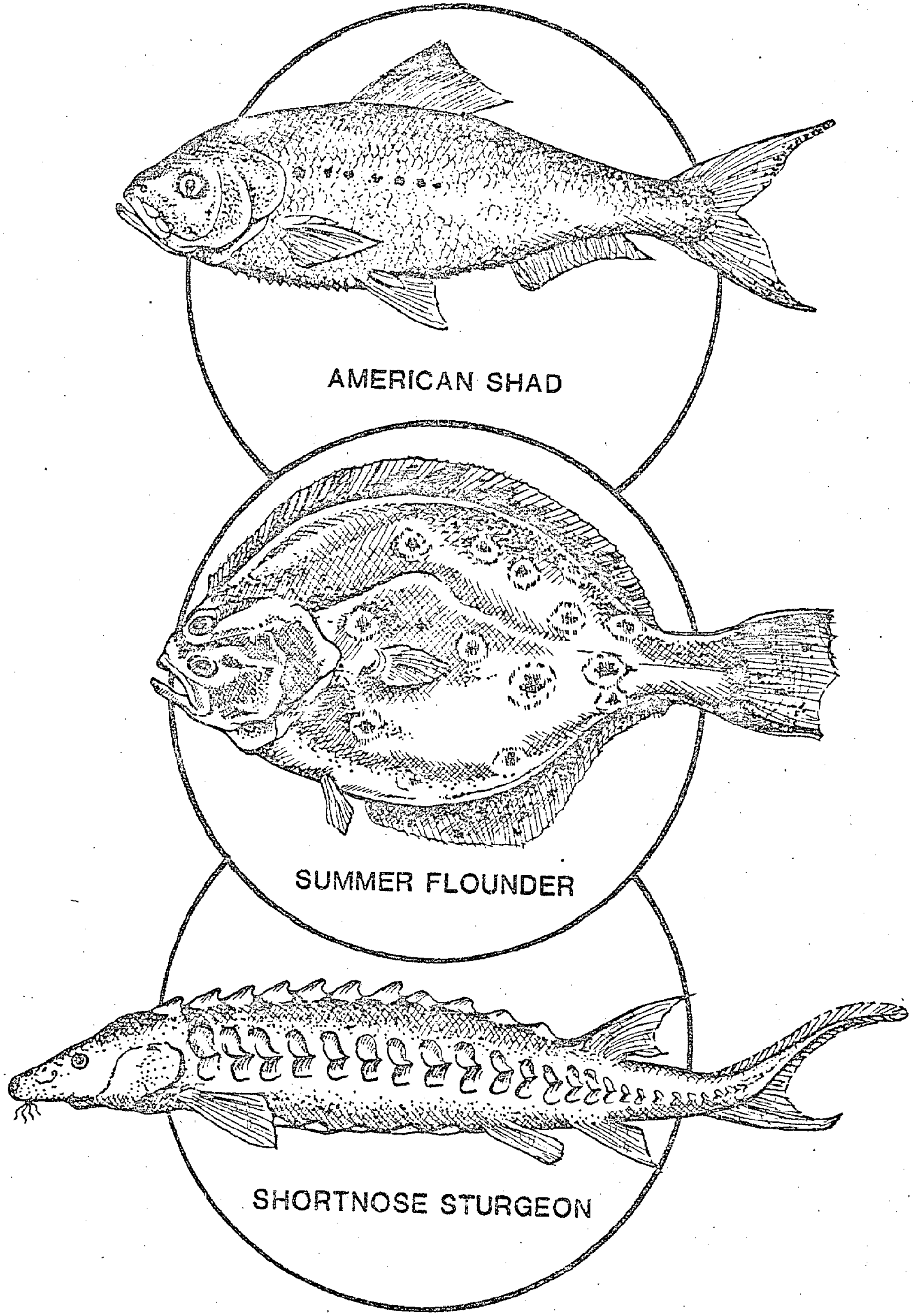
- Atlantic loggerhead
  - Federal threatened species
  - Endangered Species Act of 1973
  - State-protected
- American alligator
  - Federal threatened species south of Georgetown
  - Federal endangered species north of Georgetown
  - State threatened species east of U.S. Highway 17
  - State endangered species west of U.S. Highway 17

Predicted Impact

- Atlantic loggerhead
  - Some juveniles have been found asphyxiated with tar balls in their throats (tar balls appear similar to food juveniles eat)
  - Recent data indicate newly hatched turtles may spend first year in salt marshes; if salt marshes are impacted by oil:
    1) Young turtles may be asphyxiated by oil when coming to surface to breathe; oil may clog nostrils
    2) Intake of oiled food may cause impact
  - Atlantic loggerhead nest on sand beaches; females may become covered with oil when crawling ashore to lay eggs
  - If oil covers beach after egg laying, black oil would raise temperature, overheating and killing eggs
  - If oiled beaches occurred during hatching period, young hatchlings would be covered by oil while crawling out to sea
- American alligator
  - Possible effects may be due to ingestion of contaminated prey (e.g., dead oil-covered birds)
  - Juveniles may be affected when coming to surface to breathe; oil may clog nostrils or irritate eyes
  - Eye irritation to adults may occur

Recommended Response Measures

- Atlantic loggerhead
  - Clean nesting beaches as rapidly as possible of all oil
  - Use hand-intensive methods; the weight of vehicles on beach may destroy eggs
  - If nest locations are known, remove eggs to incubators
  - Remove oiled turtles to cleaning stations; clean and return to water beyond area of oil spill
- American alligator
  - Capture and remove to unimpacted areas


AMERICAN SHAD
SUMMER FLOUNDER
SHORTNOSE STURGEON

FINFISH

Resident Populations

∘ Shortnose sturgeon	-Anadromous; endangered species
∘ Atlantic sturgeon	-Anadromous
∘ Alewife	-Anadromous; spring; summer; fall
∘ American shad	-Anadromous; winter; spring; summer
∘ Blueblack herring	-Anadromous; spring; summer; fall
∘ American eel	-Catadromous
∘ Spotted seatrout	-Estuarine resident; year-round
∘ Red drum (channel bass)	-Estuarine resident; year-round
∘ Flounder	-Estuarine resident; spring; summer; fall
∘ Black sea bass	-Estuarine nursery; spring; summer
∘ Striped bass	-Anadromous; spring; fall; winter

Protection Status

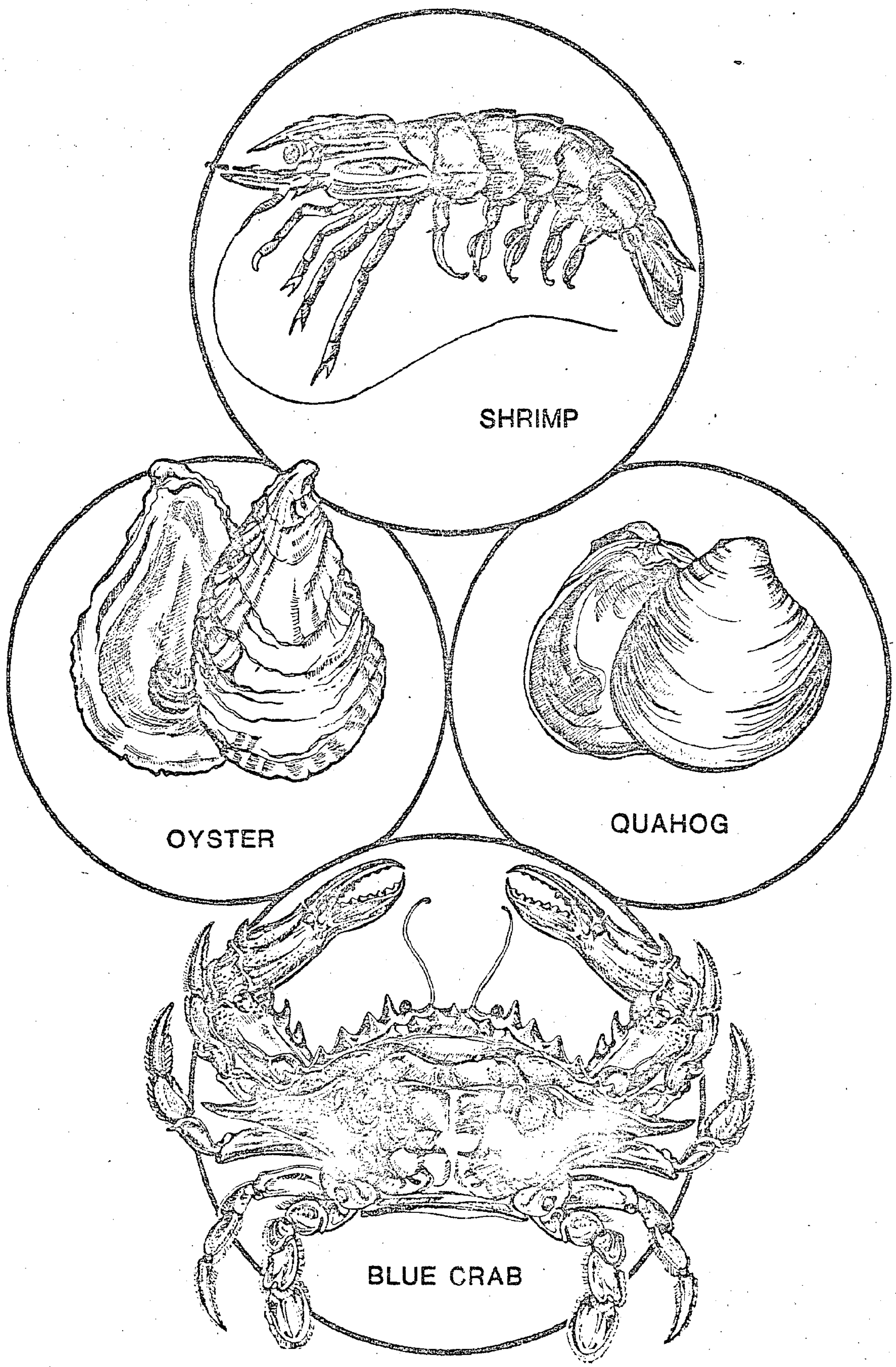
- Shortnose sturgeon
  - Endangered Species Act of 1973
  - South Carolina Law 50-17-2200

Predicted Impact

- Shortnose sturgeon
  - Benthic feeders; oil mixed with detritus that sinks to the bottom can be ingested during feeding
  - Fish fry are extremely sensitive to oil contamination; shortnose sturgeon fry exposed to oiling may be affected
- Other species
  - Oiling of marshes and estuaries could have strong impact to species that use them for nurseries (e.g., spotted sea trout, channel bass, flounder)
  - Anadromous fishes would be most susceptible during migration period to or from salt water
- General
  - Fish are sensitive to contamination from oil
  - Studies on eggs, larvae, and adults have been well documented (Kuhnhold, 1972; Lachotowich et al., 1977; Rice et al., 1977; and others)

Recommended Response Measures

- Oil should be deflected away from major fish runs and tidal creeks
- Open-water skimmers with paravanes should be used to remove oil before it strikes fish run areas


SHRIMP
OYSTER
QUAHOG
BLUE CRAB

SHELLFISH

Species of Special Concern

∘ American oyster	-Estuarine; commercially important
∘ Quahog	-Estuarine mudflats; commercially important
∘ Blue crab	-Estuarine; bays; inlets; commercially important
∘ Brown shrimp	-Estuarine; open ocean; bays; inlets; commercially important
∘ White shrimp	-Estuarine, open ocean; bays; inlets; commercially important
∘ Pink shrimp	-Estuarine; open ocean; bays; inlets; commercially important

Predicted Impact

- Oysters and Quahogs
  - Planktonic larvae would be impacted by oil in the water column
  - Adults can be smothered or ingest oil during filter feeding and respiration
  - Long-term impact can occur due to the persistence of oil in sheltered tidal flats and marshes
  - Sublethal oil contamination of oysters and quahogs would make them unpalatable, impacting local commercial fisheries
- Crabs and Shrimp
  - Marshes and estuaries used as nursery grounds; juveniles may be impacted from contamination of these areas
  - Sublethal oil contamination of shrimp and crabs would make them unpalatable, impacting local commercial fisheries

Recommended Response Measures

- Removal of oil from water surface by open-water skimmers
- Boom protection of sheltered tidal flats and tidal areas
- High- and low-pressure spraying may remove heavy oil accumulations from oyster beds; though this would impact organisms present, it would prepare the substrate for future recolonization

Critical Intertidal Habitats

The shoreline habitats that rank highest on the ESI are salt marshes (10), sheltered tidal flats (9), and sheltered coastal structures (8). Therefore, these areas should receive the highest priority for protection in the event of an oil spill. Exposed tidal flats are ranked lower (ESI=5, 7) on the index, dependent upon the density of the biomass present. The population numbers of biological communities are strongly controlled by exposure to wave and current activities. Diversity, density, and species richness levels are indicated in Table 4 for each of the ESI types discussed.

TABLE 4. Diversity, density, and richness of South Carolina habitats, based on infaunal sample, epifaunal count, and percent vegetation cover estimates.

	DIVERSITY			DENSITY			RICHNESS		
	L	M	H	L	M	H	L	M	H
1	*			*	*	*	*	*	*
2	Not present in South Carolina								
3	*	*		*	*		*	*	
4	*			*			*		
5	*	*		*	*		*	*	
5a	*			*			*		
5b	*			*			*		
6		*		*			*		
6a	*			*	*		*	*	
7	*	*			*	*		*	
7a		*	*		*	*		*	*
8	*			*	*	*	*		
9			*			*			*
10		*	*			*		*	*

Marshes (ESI=10)

Tidal marshes comprise the largest portion of shoreline in South Carolina. Over 504,000 acres of tidal marsh exist (Tiner, 1977). Three types of tidal marshes occur: (1) salt marsh, (2) brackish water marsh, and (3) freshwater tidal marsh. Salt marshes comprise 77 percent of the tidal marshes in the state. They provide habitat for a large fiddler crab population, marsh periwinkles, and ribbed mussels.

Marsh infauna are comprised of polychaetes, bivalves, and crustaceans. The most common polychaetes are *Streblospio bombyx*, *Nereis* sp., and *Glycera* sp. Fiddler crabs (*Uca* sp.) and amphipods are the most common infaunal crustaceans, while crabs from the families Tellinidae and Veneridae are most common, especially along the marsh fringe. Marshes have one of the highest densities of organisms/m^2 (Table 5).

Marshes are considered the most sensitive habitat because long-term biological damage can result after oiling, especially where oil penetrates roots of marsh plants and kills new growth, inhibits gas exchange, and/or alters sediment/ microbial relationships. These effects may have long-term duration (exceeding ten years in some cases), especially following multiple spillages of oil (Baker, 1971; Gundlach and Hayes, 1978b; Gundlach et al., in press).

TABLE 5. Estimated populations of major macrofaunal groups, shown as number of infaunal organisms/m^2. *These estimates are low, based on head count only. **Hard substrates (seawalls, riprap, etc.); no infaunal samples taken.

ESI STATIONS	POLYCHAETES*	BIVALVES	CRUSTACEANS	TOTAL
1	-----**	-----	-----	-----
2	-----	-----	-----	-----
3	382	913	1,040	2,081
4	42	169	1,444	1,656
5	85	1,466	63	1,613
5a	594	255	1,529	2,378
5b	-----	-----	-----	-----
6	85	63	594	700
6a	-----	-----	-----	-----
7	233	361	4,374	4,969
7a	-----	-----	-----	-----
8	-----	-----	-----	-----
9	339	4,056	234	4,629
10	1,486	2,888	64	4,438

Sheltered Tidal Flats (ESI=9)

Sheltered tidal flats found in South Carolina are either associated with salt marshes or found at bay heads. They are well protected from extreme wave activity and can be extensive or a narrow fringe fronting a salt marsh along a tidal creek. They are usually composed of fine-grained materials ranging from mud to fine sand. Sheltered tidal flats provide substrate for an extensive oyster community on the coast. A rich and diverse infaunal community of clams, polychaetes, amphipods, and other invertebrates is also present.

Of all the coastal habitats surveyed, sheltered tidal flats have the most diverse and rich infaunal community. From the infaunal samples collected, 35 species were identified. This was twice the number of species found on exposed tidal flats (ESI=7), which had the second highest number of species. When inundated, sheltered tidal flats support a variety of benthic and nektonic organisms such as crabs and demersal fish. During exposed periods, marine birds utilize the sheltered, tidal flat environments for foraging and resting.

Short-term or toxic effects of an oil spill on a tidal flat depend on the quantity of oil on the flat and its toxicity. Long-term or chronic effects are controlled by the binding of petroleum fractions within the sediments. In sheltered tidal flats, sediments may remain oiled for years and thus delay recolonization.

Sheltered Coastal Structures (ESI=8)

Sheltered coastal structures have been given a high sensitivity ranking because of their socioeconomic value. These structures include bulkheads, seawalls, docks, piers, and protected marinas. Impact from oiling to these structures would be primarily aesthetic and economic (cost of cleanup and repair), although some intertidal, attached and epibiotic organisms might be affected.

Habitats with Variable to Slight Sensitivity

In addition to the three highly sensitive habitats previously discussed, an additional ten habitats with variable to slight sensitivity have been delineated. Since some coastlines react the same to impact by oil, they are given the same ESI ranking (e.g., exposed tidal flats (low biomass), mixed sand and shell beaches, and sheltered erosional scarps are rated at ESI=5). Sensitivity is dependent primarily on the degree of exposure of the habitats to wave action and tides.

Exposed Tidal Flats (ESI=5, 7)

Exposed tidal flats in South Carolina are found at the mouths of inlets as ebb-tidal delta shoals, are attached to recurved spits, or are found in open sounds and bays such as St. Helena Sound.

Exposed tidal flats are ranked at two ESI levels (ESI=5 and 7). The lower classification (ESI=5) is applied to tidal flats exposed to high wave and current conditions possessing a variable range of species diversity and density as well as low population levels. The higher classification (ESI=7) is given to exposed flats having similar species diversity and density as ESI=5, but possessing increased population levels. The differences in population levels appear to be directly related to substrate type and mobility as well as variances in wave and current energies. In either case, persistence of oil would be low to moderate. Biological damage would vary with type and number of species present.

Beaches (ESI=3, 4, 5a, 6)

Four beach types are defined in the South Carolina area with fine/medium-grained sand beaches (ESI=3) being the most common and least sensitive. Coarse-grained beaches (ESI=4) are found at Cape Romain, while mixed sand and shell beaches (ESI=5a) are located primarily on Edisto Island. Shell beaches (ESI=6) are composed of washed oyster or quahog shell and are generally found along dredged channels.

Sediment size controls moisture and oxygen content of beaches, thereby influencing the abundance and distribution of plants and animals. Shell and very coarse-grained sand fail to hold enough water to support abundant infauna, biomass, and diversity. Sand and mixed sand and shell beaches afford some substrate suitable for burrowing organisms, but support only limited communities. In general, beaches are ranked in standing-stock biomass and diversity.

The sparse biological community found at most beaches may be subject to only a brief exposure to oil, especially on exposed beaches. Even if extensive mortality occurs, the readily cleansed substrate may recolonize within a year.

Erosional Scarps (ESI=5b, 7a)

Two types of erosional scarps occur in South Carolina: (1) erosional scarps in marshes (ESI=7a) and (2) sheltered erosional scarps (ESI=5b). Erosional scarps in marshes are caused by waves and boat wakes. They are generally a composite of other coastal habitats (e.g., an erosional scarp which is fronted by a narrow sand or shell beach fronted by a narrow, exposed tidal flat). Sheltered erosional scarps are found where channels have been dredged through mainland areas such as where the Intracoastal Waterway was dredged through the mainland behind Myrtle Beach. Erosion is caused primarily by barge and boat traffic.

Exposed Riprap (ESI=6a)

Exposed riprap (ESI=6a) includes man-made structures composed of granite blocks, concrete blocks, etc. that are dumped to form a wall to reduce erosion problems along exposed shores. They are found throughout South Carolina, especially at Folly Beach and Seabrook Island. Riprap also includes breakwaters such as those at Murrells Inlet.

Exposed riprap has variable density, attached biological communities such as barnacles and green algae that grow in the intertidal zone. Because of the composition, oil can seep between the riprap, making cleanup difficult which is why it is given the ESI=6a ranking.

Exposed Vertical Seawalls (ESI=1)

Only one such seawall occurs in South Carolina and that is at Folly Beach. It is a concrete wall that supports a biological community of filamentous green algae and barnacles in the intertidal zone. Because it is located on a shoreline of moderate to high wave energy, oil would tend to be refracted away from the wall. But if it did impact the wall, the wave energy would cleanse it naturally. Impact to the biological community would be minor and short-term.

PROBABLE AREAS OF OIL SPILL OCCURRENCE AND IMPACT

Statistics on tanker traffic in South Carolina waters are not complete due primarily to the lack of reporting of Intracoastal Waterway traffic. However, unpublished reports are available for the ports of Savannah, Charleston, and Georgetown which are the primary oil terminal facilities. There are no refineries at present in the state; however, a 30,000 barrels-per-day refinery is proposed for the port of Georgetown. If built, the Georgetown refinery would increase tanker traffic about 1.6 times over the present level. Table 6 gives a summary estimate of the number of tanker arrivals each year at the three major terminals. As indicated in the table, Savannah receives the largest quantity of petroleum products. The estimated quarterly volume handled by the port is six million barrels (± 1 million bbls) (U.S. Coast Guard, Marine Safety Office, pers. comm.). This gives an average annual volume almost twice that of Charleston.

TABLE 6. Approximate annual volume of tanker traffic in South Carolina waters (based on unpublished U.S. Coast Guard records - most recent quarterly reports). *U.S. Coast Guard, Marine Safety Office, pers. comm. **U.S. Army Corps of Engineers (1981).

PORT (no. vessels/month)	VOLUME TRANSFERRED/MONTH (in barrels)
Savannah* (14-17)	2 million
Charleston* (8-9)	1.2 million
Georgetown	
Present (3-4)	Unavailable
After proposed refinery** (9-12)	0.9 million + existing

These sketchy statistics indicate there are four areas of the state that have a higher possibility of oil spillage:

1) Savannah entrance.
2) Charleston Harbor.
3) Winyah Bay - Georgetown Harbor.
4) Intracoastal Waterway (ICWW).

Spills at the harbor entrances would likely involve ships of larger tonnage (typically 150,000 barrels per cargo in Charleston) compared to spills along the ICWW which would involve small coastal barges limited to 12-ft drafts.

Present tanker and barge traffic in South Carolina waters suggest two basic spill scenarios for the state:

1) Harbor entrance spills involving moderate-sized vessels drawing up to 35 feet and cargos on the order of 100,000 to 200,000 barrels.

2) ICWW spills involving smaller draft (12 ft) barges carrying on the order of 10,000 barrels or less.

Harbor entrance spills would tend to involve more shoreline due to natural tidal circulation and numerous tributaries or open water inside the entrances. ICWW spills would be less influenced by tidal currents, except near tidal inlets, and would tend to impact less extensive areas. Spills at the seaward entrance to harbors could potentially impact wide and scattered shorelines due to the effect of tides transporting oil offshore as well as onshore and rapidly spreading slicks away from the area. Along constricted portions of the ICWW, impacts would tend to occur closer to the source of the spill.

Other important considerations in these two basic scenarios are that harbor entrance spills moving offshore would tend to impact less vulnerable environments such as barrier island sand beaches, whereas ICWW spills would likely occur in the midst of the most sensitive environments, marshes and tidal flats. Water-based containment and cleanup equipment would perhaps be more limited along the ICWW due to the shallow depths adjacent to the channel. The success of harbor containment efforts would depend mainly on the location of the spill within the harbor.

Effect of Tides and Winds

There is never any good time for an oil spill, but in a mesotidal regime such as South Carolina, certain environmental conditions would facilitate containment and recovery efforts. Most important in our opinion is location away from constricted channels where tidal currents are strongest. Spills occurring during neap tides when surface velocities are lower would also be easier to contain. Small spills occurring near slack water and during low wind velocities would probably be easiest to contain. However, our experience has shown that few spills can be recovered before several tidal cycles have passed.

In wider portions of harbors away from strong tidal currents, a stiff wind would move the slick in a discrete predictable direction. This can be an advantage for deploying containment or deflection booms. One of the most difficult aspects of a South Carolina spill would be the large transport distances experienced in tidal channels. A 3-knot current, common in inlets at spring tide could transport oil over 15 miles upstream during several hours of an incoming tide. The tide regime, while important for flushing estuaries, would also cause vast areas of wetlands to be exposed to surface oil slicks.

Outer harbor, ocean spills would be more subject to the vagaries of the wind. As the wind roses of Figure 6 indicate, two predominant wind directions occur: southwest and northeast. Southwest winds are most common between May and September, whereas northerly winds are common in fall and winter. A good portion of coastal winds are offshore (winds with westerly components). Another effect to consider is the diurnal sea-breeze/landbreeze cycle which commonly produces onshore winds in the afternoon due to heating of the land. Seabreezes, of course, would increase the likelihood of onshore impacts.

Heaviest tanker traffic at Savannah and prevailing southerly winds make the barrier islands at the southern end of South Carolina somewhat more vulnerable to oil spills. Ocean spills at Savannah entrance would likely affect nearby Daufuskie and Hilton Head Islands during summer when winds are commonly out of the southwest.

But it should be realized that no part of the open coast is immune to spills. For example, during the BURMAH AGATE spill off Galveston (Texas) in November 1979, Bolivar Island north of Galveston and only five miles from the wreck was never impacted; yet, San Jose Island, over 165 miles south of the wreck received a massive slug of oil (Thebeau and Kana, 1981). Offshore spills would tend to be transported much farther than inner harbor spills, making containment and recovery more difficult. The experience of IXTOC I in Mexico and Texas (Gundlach et al., 1981) points to many of the problems of handling offshore spills. Large transport distances disperse the oil, exposing more shoreline to impacts. However, dispersion of the slick also expands the time required to maintain cleanup personnel. Small, intermittent doses of oil may impact shorelines for several months after a spill.

Charleston entrance would be somewhat more vulnerable to spills than Georgetown despite relatively small differences in the number of tanker entries. This is due to the much heavier volume of nontanker vessel traffic into the port. Since most ship traffic proceeds up the Cooper River, that shoreline is more vulnerable than the Ashley or Wando Rivers. However, a spill at the entrance jetties on an incoming tide would potentially jeopardize all three river systems.

It is not really possible to assign in advance quantitative probabilities of oil spills for portions of the state. Experience has shown that each spill has its own "character" and numerous factors must be considered ranging from the type of spill and cargo to the oceanographic processes. As soon as a spill occurs, however, existing winds, currents, and shoreline geomorphology should be considered to determine most likely impact zones. The key is to be able to immediately implement site-specific trajectory models when a spill occurs. This would provide the best information for deploying containment devices and cleanup personnel.

GENERAL STRATEGIES FOR INLET AND HARBOR PROTECTION

This section presents general strategies for protecting priority areas in the event of open-ocean or harbor spills. Since the actual strategy will vary depending on location of the spill, only general guidelines are provided. A key to spill response is to quickly establish lines of defense and focus equipment and personnel according to existing environmental conditions. Since oil must pass through tidal channels to impact sensitive, back barrier environments, this section will focus on inlet and channel protection strategies.

Lines of Defense

1) First Line of Defense. - The first line of defense for offshore or harbor spills is containment and collection of spilled oil at the spill site. Depending on the nature and size of the spill, some offshore containment is possible due to recent improvements in skimming and collection devices. In some instances, such as during the BURMAH AGATE spill (Thompson et al., 1981), the threat of fire forced equipment to stand off from the spill. This increased the radius for the first line of defense and reduced the effectiveness of the response. Even if containment at the source of the spill is not 100 percent effective, it generally provides time for deployment of a second line of defense.

2) Second Line of Defense. - During open-ocean spills, the second line of defense would entail booming or closing tidal inlets. Important components of the second line of defense are the barrier island beaches which would absorb impacts before oil could reach sensitive marsh environments. During IXTOC I, Padre Island (Texas) acted as a natural boom preventing the majority of oil from entering Laguna Madre. In South Carolina, the barrier islands are shorter and tidal inlets occur almost every five miles along the coast, making protection much more difficult. Mesotidal regimes with numerous tidal inlets, such as South Carolina, require much more equipment to establish an effective second line of defense. The equivalent line of defense for a harbor spill would be protection of the mouths of major tidal channels near the spill source.

3) Third Line of Defense. - Generally, the third line of defense centers on preventing oil from entering open bays or lagoonal waters. Booms should be arranged as close to inlet throats as possible so that oil may be flushed from the system during ebb tides. This line of defense would not apply to much of South Carolina's coast due to the predominance of well-developed marsh and incised tidal creeks which limit the amount of open water. This line of defense would be most important at high water when tidal flats are submerged and oil can be transported more easily through the back barrier system. Booms should be positioned away from exposed oyster beds which would abraid the devices as they settled onto the bottom during falling tides.

4) Fourth Line of Defense. - Small channels which feed sheltered marsh and tidal flat systems are the last areas on which to focus containment devices. In some cases, these areas could be temporarily filled to

block incoming oil. Where tidal currents are exceedingly strong or high water would flood the entire marsh flanking the fill, there is little chance of maintaining the artificial closure. Damming of small creeks will be most successful where adjacent topography is above high water. In other areas, multiple booms or shallow-draft skimmers will be required.

In each line of defense, booms and skimmers are used to stop, deflect, or collect spilled oil. Strong currents, winds, and waves all decrease the effectiveness of this equipment, which is designed to operate under generally low-energy conditions. Accordingly, a strong possibility exists that the primary line of defense will be breached during a spill, allowing some oil to pass through into the inlets. Wherever oil is confined to the constricted portions of channels, transport will be subject primarily to tidal currents. Where channels widen, however, low-velocity zones (relative to the flow in the narrow portions) are created which can be used to advantage to collect oil.

A good containment scheme for South Carolina would be to deflect oil into the lower velocity zones of tidal channels where it can be accumulated. Low-velocity zones in tidal creeks occur on the down-current inside of meanderbends or along the margins of channels that flare out from a constricted zone. Often, these low-flow areas are indicated by eddies shed off from the flow. Foam lines or the transport of debris are useful for spotting them. A successful defense of incoming oil in major tidal channels will require a combination of mobile skimmers to collect oil in the center of channels and deflection booms along the margins. Along highly sensitive areas, deflection booms should be deployed to funnel oil away from the banks toward zones where skimmers can operate. If a less sensitive and accessible shoreline exists adjacent to a low-velocity zone, booms can be deployed to trap oil against the shoreline for pickup by shore-based equipment. During massive spills, it may be necessary to implement both schemes to handle large volumes.

The South Carolina marsh shoreline is so complex that it will almost always be preferable to trap oil from offshore spills at the inlets or harbor entrances. Accordingly, this section presents some basic strategies for protecting tidal entrances.

Types of Tidal Entrances

In simplistic terms, South Carolina's tidal entrances fall into several categories based on width, depth, and structural control. The majority of inlets are natural with no channel stabilization by structures such as jetties. Natural inlets range from small, shallow entrances to wide, open sounds. Many are relatively stable, cutting deeply into more resistant, coastal plain deposits. Artificially controlled inlets exist at several port entrances where there has been a need to control shoaling or channel orientation. Table 7 contains an arbitrary but useful breakdown of inlet types.

Figure 42 gives the approximate location of the principal inlets or tidal entrances. In general, only medium- to large-sized inlets are indi-

TABLE 7. Four categories of tidal inlets in South Carolina for purposes of oil spill planning (ordered north to south).

A) Jettied Harbor Entrances

- Murrells Inlet - project depth 12 ft.
- Winyah Bay (Georgetown) - project depth 27 ft.
- Charleston Harbor - project depth 35 ft.
- Savannah Entrance - project depth 40 ft.

B) Sounds, Open Bays

- Bull Bay
- St. Helena Sound
- Port Royal Sound
- Calibogue Sound

C) Medium to Large Inlets

- Little River
- Murrells
- North
- Santee (north distributary)
- Santee (south distributary)
- Cape Romain (open in 1977)
- Key (Raccoon Key area)
- Price
- Capers
- Dewees
- Lighthouse
- Stono
- North Edisto
- Fripp
- Trenchards
- Savannah River

D) Small Inlets (100 m wide at low water)

- Hog (Little River area)
- *White Point Swash (Crescent Beach)
- *Singleton Swash
- *Canepatch Creek
- *Withers Swash (Myrtle Beach)
- Midway
- Pawleys
- Raccoon Creek (Cape Romain area)
- Breach Inlet (Isle of Palms)
- Captain Sam's Inlet (Kiawah Island)
- South Creek (Botany Island)
- *Frampton Inlet (Edingsville Beach)
- *Jeremy Inlet (Edingsville Beach)
- Fish Creek (St. Helena Sound)
- Johnson Creek (Hunting Island)
- Skull Inlet
- Pritchards
- Morse Creek (Prichards Island)
- *The Folly (Hilton Head Island)

*Closure by filling during an oil spill is feasible but subject to state approval.

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cated in the figure. The occurrence and average size of inlets increase from north to south along the coast due to the increase in tidal range.

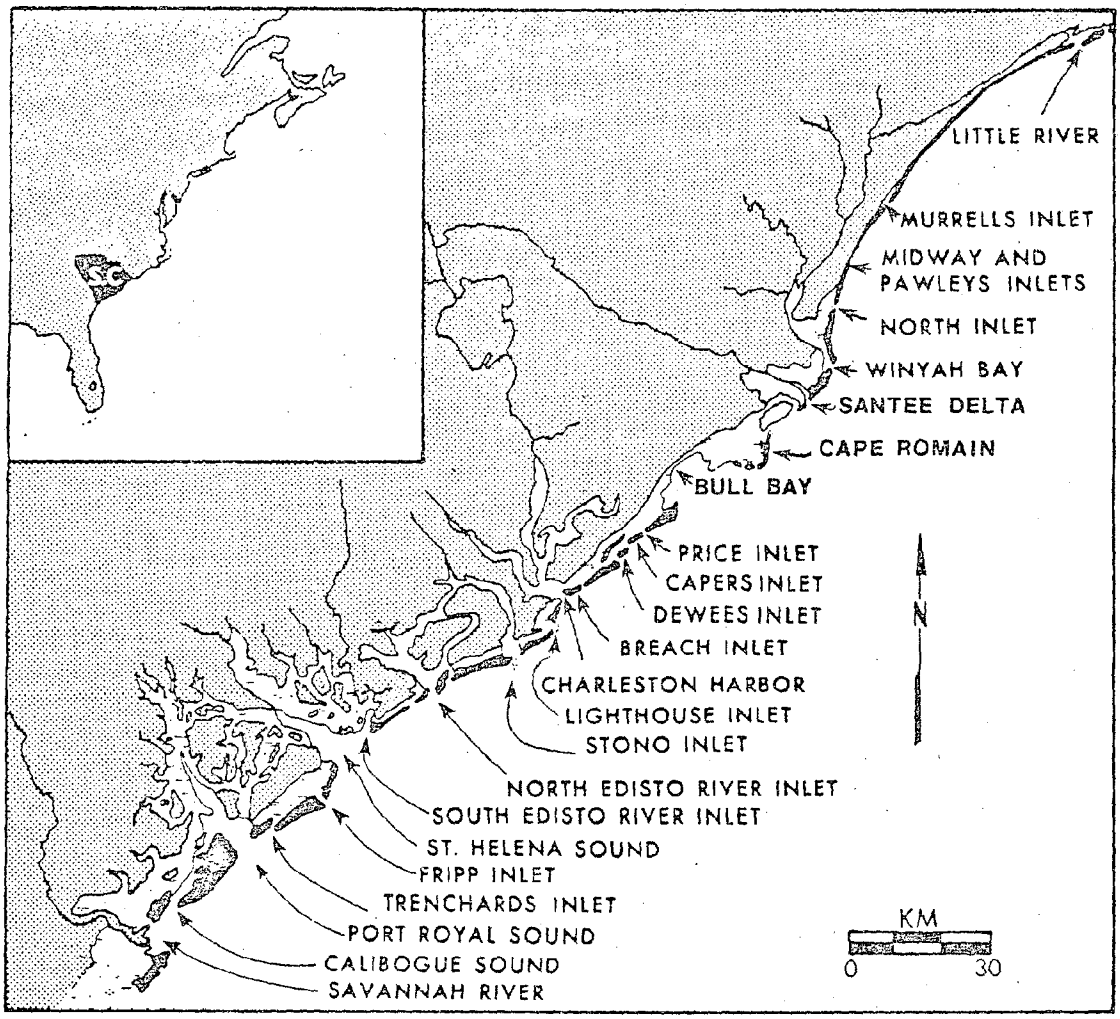

FIGURE 42. Location of the principal inlets, bays, and sounds along the South Carolina coast (modified from Hubbard, 1977).

Almost all South Carolina inlets are dominated by ebb currents which produce a net transport and deposition of sediment along the seaward margin. The seaward shoals form a deltaic lobe of sand referred to as an ebb tidal delta. Figure 43 illustrates typical, tidal delta morphology at Fripp Inlet. Between adjacent barrier islands, flow is confined to a single channel which reaches its deepest depth at the most constricted section, referred to as the inlet throat. Landward of the barrier islands, flow is dispersed into tributary tidal creeks and over the marsh surface at high tide. In a seaward direction, flow diffuses across intertidal shoals with velocities decreasing away from the inlet throat. This produces a decrease in competency, allowing sand to settle out. Consequently, the seaward margin of the inlet channel shoals, and flow often becomes distributed in secondary channels. Since the ebb tidal deltas are exposed to wave energy as well as tidal energy, there is continual shifting of the channels and bars.

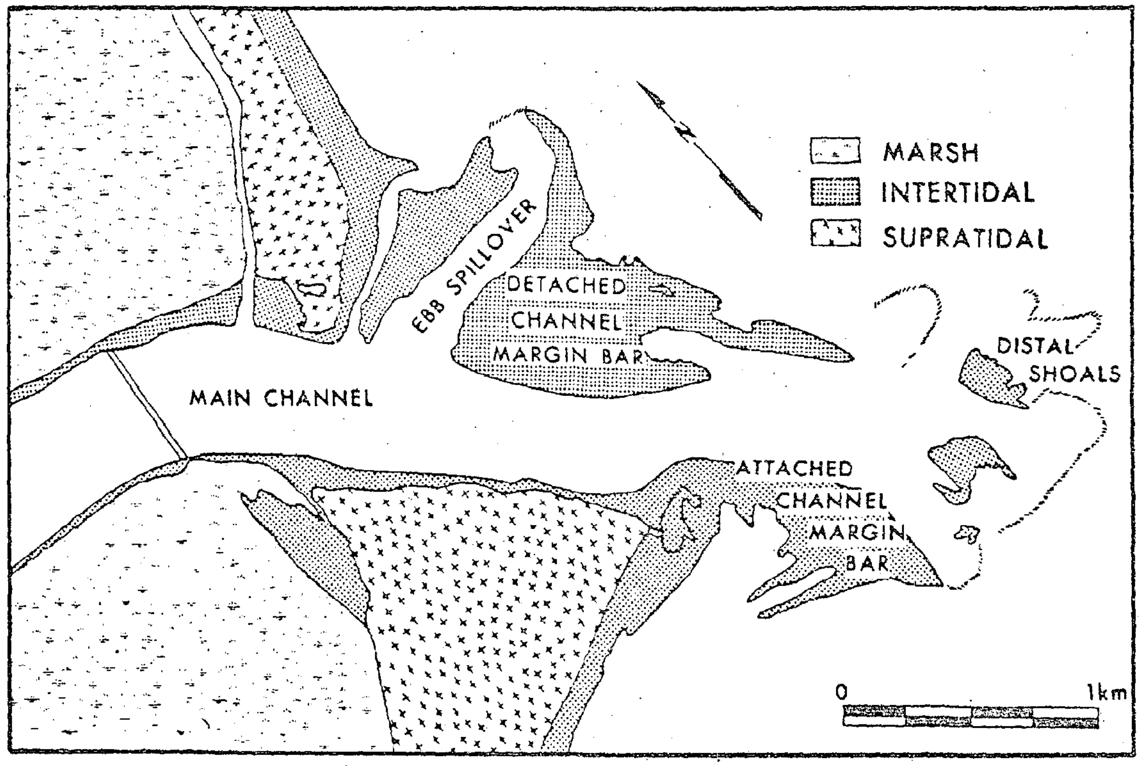

FIGURE 43. Sketch map of Fripp Inlet morphology typical of natural tidal inlets in South Carolina. Note the extensive intertidal shoals forming an ebb-tidal delta seaward of the inlet. Protection strategies should emphasize collection and containment of oil between, or seaward of, the barrier island (supratidal zone on the figure) (from Hubbard, 1977).

In dealing with protection strategies for tidal inlets, two things should be kept in mind:

1) Current velocities will be highest in channels, especially where the flow is constricted by high land.

2) Shoals will be dominated by landward-directed currents produced by wave action.

At low water, exposed shoals will shelter the inlet, making it possible to move seaward with mobile skimmers and collect oil in channels. At high water, wave action across the shoals will force mobile containment efforts to drop back into more sheltered areas. Boom and skimmer deployment schemes should attempt to contain incoming oil in the immediate vicinity of the inlet for it to be picked up or flushed offshore during succeeding tides. The most critical time is during flood tides. Accordingly, strike forces should plan any protection strategies around the predicted periods of incoming tides.

Jettied Harbor Entrances

Murrells Inlet, Winyah Bay entrance, and Charleston Harbor have weir jetty systems which allow operation of mobile containment equipment even during periods of rough seas. The protection afforded by the entrance jetties will benefit the deployment of skimmers and booms during offshore spills. Since navigation would have to be maintained, emphasis should be placed on deploying mobile skimmers, preferably with paravanes, to protect the channel. Entrances such as Charleston could easily accommodate a dozen MARCO Class V skimmers with paravanes and towing craft such as those deployed in Galveston entrance during the BURMAH AGATE spill (Thompson et al., 1981). In our opinion, a spill response in any South Carolina inlet should deploy at least one skimmer for every 100-yd width of channel. (Unfortunately, there are no hard and fast rules; however, this is considered reasonable for prespill contingency planning.)

The weir sections at each harbor entrance provide conduits for incoming oil to cross the jetties. Consequently, a line of defense should be established inside the weir by placing booms to trap oil in the low-velocity zone behind the jetties. If a sand beach is present, as at Murrells Inlet, for example, booms can be deployed to direct oil toward shore for shore-based cleanup. Multiple booms could also be deployed to funnel oil coming over the weir toward mobile skimmers. Experience during IXTOC I in Texas (Thompson et al., 1981) showed that skimmers are generally more efficient than shore-based cleanup for most jetty situations. The U.S. Coast Guard Open-Water Oil Containment and Recovery System (OWOCRS), which consists of a 612-ft skimming boom system, could also be effectively deployed inside the lower velocity weir section of each harbor entrance. The barrier would be most useful during incoming tides.

One general consideration about deployment of booms in harbor entrances is that heavy-duty booms with a height of 30 inches or greater should be used. Experience in San Luis Pass, Texas, during the BURMAH AGATE (Kana et al., 1981) showed that 18- to 24-inch booms are overtopped too easily. Booms such as the Goodyear 36-inch outer harbor type are recommended. This type of boom is a key component of the U.S. Coast Guard's Strike Team inventory.

Sounds and Bays

The biggest problems in protecting South Carolina sounds and bays from oil spills will be their extent, exposure to open-ocean swell, and numerous shoals. The wide entrances to sounds and bays will require more equipment for containment and cleanup. Fixed booms will be ineffectual due to wave action. It will be preferable to combine a mobile force of skimmers with aerial reconnaissance to track large streamers of oil before they enter the sounds. The response should be concentrated offshore if possible, since little containment will be possible among the shoals and diffuse channels. If there is a possibility of deflecting oil onto adjacent, barrier island beaches, this would be preferable to allowing the oil to enter the sounds. Bays and sounds are bordered by the most sensitive shoreline environments and, in some cases, support isolated nesting colonies of endangered birds such as pelicans.

Medium to Large Tidal Inlets

Tidal inlets greater than 100 m wide at low water generally have sufficient depths in the throat section to deploy skimmers and oil-transfer barges. They are not afforded protection by artificial jetties, but they are much easier to protect than open sounds. A good protection scheme would include placement of high-angle trap booms along the shorelines of the inlet throat to divert oil toward less sensitive sand beaches. Multiple booms would be preferable. If the inlet shoreline is inaccessible to onshore recovery equipment, booms should be deployed to deflect oil toward mobile skimmers working the channel.

No matter how many booms are available, mobile skimmers should be deployed to protect the channel. The high current velocities and widths of the channels preclude protecting the entire inlet by booms alone. Experience in Texas during IXTOC I (Kana et al., 1981) indicated that booms longer than 1,000 ft are exceedingly difficult to maintain in a 2-knot current. Since currents commonly exceed three knots during spring tides in South Carolina tidal inlets, booms will have to be deployed at high angles (greater than 70°) to the current to avoid entrainment. Back moorings will also be necessary to maintain proper boom configuration.

Small Inlets

There are approximately 20 small inlets along the South Carolina coast having widths of less than 100 m. The number varies from year to year due to natural closing or opening of these channels. Some of these inlets are formed as barrier islands erode into adjacent marshes, intersecting marsh channels. This is true for inlets at Cape Romain and Edingsville Beach. Because of the changing status of small inlets, aerial overflights must be made at the time of a spill to determine where the openings are.

The list in Table 7 indicates some small inlets that could be artificially filled to prevent any oil from entering the back barrier area. In general, these inlets are very small with almost no flow through them at low water. Filling could be accomplished using land-based equipment such as bulldozers or front-end loaders. It will be preferable to fill these inlets during neap tides when tide range is lowest. Also, the filling operation should be completed around low water and during a rising tide to alleviate the chance of scouring. This method worked for Cedar Bayou, a small pass in Texas, during the IXTOC I spill (Kana et al., 1981). After a spill response is over, any artificially closed inlet should be reopened to restore normal tidal circulation to the adjacent marsh. (NOTE: The decision to fill any tidal channels must be made in consultation with and upon approval of the appropriate governing agency.)

Other small inlets given in Table 7 cannot be closed with facility during a spill response and, therefore, will require combinations of booms and skimmers. The strategies will be similar to medium-sized inlets, but will be limited by the generally shallower depths of these channels. Booms should be deployed to keep oil in the immediate vicinity of the inlet throat or seaward of the marsh areas. Commonly, small shallow inlets are associated with migrating spits. Captain Sam's Inlet, for example, is bounded by a sand spit on its north margin. This provides additional sandy shoreline inside the inlet to corral and contain spilled oil. One consideration is that sand beaches inside inlets are generally less packed and firm than oceanfront beaches. This will limit the mobility of any heavy equipment on the beach to pick up spilled oil.

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APPENDIX I

Master Species List

SHELLFISH

A	Shellfish beds	
B	Crabbing area	
C	Clamming areas	
D	Shrimping areas	
E	Oyster farm	
1		
2		
3		
4	Pink shrimp	*Penaeus dvorarum*
5	Ocean pink shrimp	*Pandalus borealis*
6	Northern pink shrimp	*Pandalus borealis*
7	Sidestripe shrimp	*Pandalopsis dispar*
8	Spot shrimp	
9	Dock shrimp	
10	Humpy shrimp	*Pandalus goniurus*
11	Coonstripe shrimp	*Pandalus danae*
12	Broken-back shrimp	*Heptacarpus* sp.
13	Box crab	*Calappa flammea*
14	Dungeness crab	*Cancer magister*
15	Red rock crab	*Pachygrapsus crassipes*
16	Puget sound king crab	*Paralithodes* sp.
17	Kelp crab	*Pugettia producta*
18	Pismo clam	*Tivela stultorum*
19	Blue mussel	*Mytilus edulis*
20	California mussel	*Mytilus californianus*
21	Butter clam (Washington)	*Saxidomus giganteus*
22	Common cockle	*Laevicardium laevigatum*
23	Horse clam	*Tresus capax*
24	Gaper clam	*Tresus capax*
25	Soft shell clam	*Mya arenaria*
26	Japanese little neck	*Venerupis japonica*
27	Piddock	*Penitella penita*
28	Razor clam	*Siliqua patula*
29	Native little neck	*Protothaca staminea*
30	Octopus	*Octopus dofleini*
31	Northern abalone	*Haliotis kamtschatkana*
32	Geoduck	*Panopea generosa*
33	Pacific pink scallop	*Chlamys hastata*
34	Sea scallop	*Pecten* sp.
35	Rock scallop	*Hinnites multirugosus*
36	Hinds' scallop	*Chlamys hindsi*
37	Pacific Coast squid	*Loligo opalescens*
38	Pacific oyster	*Ostrea lurida*
39	King crab	*Paralithodes* sp.
40	Tanner crab	*Chionoecetes* sp.
41	Bay scallop	*Aequipecten irradians*
42	Quahog (hard clam)	*Mercenaria mercenaria*
43	American oyster (eastern)	*Crassostrea virginica*
44	Horseshoe crab	*Limulus polyphemus*
45	Lobster	*Homarus americanus*

46	Channeled whelk	Busycon canaliculatum
47	Knobbed whelk	Busycon carica
48	Surf clam	Spisula polynyma
49	Blue crab	Callinectes sapidus
50	White shrimp	Penaeus setiferus
51	Brown shrimp	Penaeus aztecus
52	Bean clam	Donax gouldi
53	Rock piddock	Panetella penita
54	Spring lobster	Panulirus interruptus
55	Wavy top snail	Astraea undosa
56	Wart-necked piddock	
57	Sea mussel	
58	Sunset clam	
59	Rough-sided little-necked clam	
60	Abalone	Haliotis sp.
61	Red abalone	Haliotis rufescens
62	Black abalone	Haliotis cracherodii
63	Green abalone	Haliotis fulgens
64	White abalone	Haliotis sorenseni
65	Pink abalone	
66	Jackknife clam	Tagelus californianus
67	Spiny cockle	Papyridea soleniformis
68	Clipped semele clam	
69	Ghost shrimp	Calianassa californiensis
70	Striped shore crab	Hemigrapsus sp.

REPTILES

1	American crocodile	Crocodylus acutus
2	Atlantic green turtle	Chelonia mydas mydas
3	American alligator	Alligator mississippiensis
4	Atlantic ridley	Lepidochelys kempi
5	Atlantic leatherback turtle	Dermochelys coriacea
6	Atlantic loggerhead turtle	Caretta caretta
7	Diamondback terrapin	Malaclemys terrapin
8	Pacific green turtle	Chelonia mydas agassizi

MAMMALS

1	Northern (Steller) sea lion	_Eumetopias jubatus_
2	Harbor seal	_Phoca vitulina_
3	North Pacific fur seal	_Callorhinus ursinus_
4	Killer whale	_Orcinus orca_
5	Pacific blackfish	_Peponocephala electra_
6	Pacific harbor porpoise	_Phocoena phocoena_
7	Sea otter	_Enhydra lutris_
8	River otter	_Lutra canadensis_
9	Beluga whale	_Delphinapterus leucas_
10	Manatee	_Trichechus manatus_
11	Fin whale	_Balaenoptera physalus_
12	Minke whale	_Balaenoptera acutorostrata_
13	Humpback whale	_Megaptera novaeangliae_
14	Gray seal	_Halichoerus grypus_
15	Bearded seal	_Erignathus barbatus_
16	Walrus	_Odobenus rosmarus_
17	(Atlantic) bottlenose dolphin	_Tursiops truncatus_
18	Pygmy sperm whale	_Kogia breviceps_
19	Shortfin pilot whale	_Globicephala macrorhynchus_
20	Right-whale dolphin (northern)	_Lissodelphis borealis_
21	Atlantic spotted dolphin	_Stenella plagiodon_
22	California sea lion	_Zalophus californianus_
23	Guadalupe fur seal	_Arctocephalus townsendi_
24	Elephant seal (northern)	_Mirounga angustirostris_
25	Florida key deer	_Odocoileus virginianus clavium_

FISHES

A Several species of salmon
B Forage fish
C Anadromous fish
D Catadromous fish

1	Sablefish (blackcod)	Anoplopoma fimbria
2	Lingcod	Ophiodon elongatus
3	Pacific sanddab	Citharichthys sordidus
4	Arrowtooth flounder	Atheresthes stomias
5	Petrale sole	Eopsetta jordani
6	Rex sole	Glyptocephalus zachirus
7	Pacific halibut	Hippoglossus stenolepis
8	Butter sole	Isopsetta isolepis
9	Rock sole	Lepidopsetta bilineata
10	Dover sole	Microstomus pacificus
11	English sole	Parophrys vetulus
12	Starry flounder	Platichthys stellatus
13	C-O sole	Pleuronichthys coenosus
14	Curlfin sole	Pleuronichthys decurrens
15	Sand sole	Psettichthys melanostictus
16	Flathead sole	Hippoglossoides elassodon
17	Slender sole	Lyopsetta exilis
18	Plainfin midshipman	Porichthys notatus
19	Pacific cod	Gadus macrocephalus
20	Pacific hake	Merluccius productus
21	Pacific tomcod	Microgadus proximus
22	Walleye pollock	Theragra chalcogramma
23	Wolf-eel	Anarrhichthys ocellatus
24	Pacific ocean perch	Sebastes alutus
25	Silvergray rockfish (short spine)	Sebastes brevispinis
26	Copper rockfish	Sebastes caurinus
27	Puget sound rockfish	Sebastes emphaeus
28	Yellowtail rockfish	Sebastes flavidus
29	Black rockfish	Sebastes melanops
30	Bocaccio	Sebastes paucispinis
31	Yelloweye rockfish	Sebastes ruberrinus
32	Canary rockfish (orange)	Sebastes pinniger
33	Chilipepper	Sebastes goodei
34	Red-banded rockfish (flag)	Sebastes babcocki
35	Rougheye rockfish	Sebastes aleutianus
36	Splitnose rockfish	Sebastes diploproa
37	Green-striped rockfish	Sebastes elongatus
38	Brown rockfish	Sebastes auriculatus
39	Redstripe rockfish	Sebastes proriger
40	Big skate	Raja binoculata
41	Longnose skate	Raja rhina
42	Ratfish	Hydrolagus colliei
43	White sturgeon	Acipenser transmontanus
44	Green sturgeon	Acipenser medirostris
45	Cutthroat trout (coastal)	Salmo clarkii
46	Kelp greenling	Hexagrammos decagrammus

47	Rock greenling	*Hexagrammos lagocephalus*
48	White-spotted greenling	*Hexagrammos stelleri*
49	Buffalo sculpin	*Enophrys bison*
50	Red irish lord	*Hemilepidotus hemilepidotus*
51	Pacific staghorn sculpin	*Leptocottus armatus*
52	Tidepool sculpin	*Oligocottus maculosus*
53	Cabezon	*Scorpaenichthys marmoratus*
54	Redtail surf perch	*Amphistichus rhodoterus*
55	Kelp perch	*Brachyistius frenatus*
56	Shiner perch	*Cymatogaster aggregata*
57	Striped sea perch	*Embiotoca lateralis*
58	Walleye sea perch	*Hyperprosopon argenteum*
59	Pile perch	*Rhacochilus vacca*
60	White sea perch	*Phanerodon furcatus*
61	Penpoint gunnel	*Apodichthys flavidus*
62	Saddleback gunnel	*Pholis ornata*
63	Crescent gunnel	*Pholis laeta*
64	Quillback rockfish	*Sebastes maliger*
65		
66	Pacific herring	*Clupea harengus pallasii*
67	Northern anchovy	*Engraulis mordax*
68	Chinook salmon (king)	*Oncorhynchus tshawytscha*
69	Coho salmon (silver)	*Oncorhynchus kisutch*
70	Pink salmon (humpy)	*Oncorhynchus gorbuscha*
71	Cockeye salmon (red)	*Oncorhynchus nerka*
72	Chum salmon (dog)	*Oncorhynchus keta*
73	Masu salmon (cherry)	*Oncorhynchus* sp.
74	Rainbow trout (steelhead)	*Salmo gairdnerii*
75	Surf smelt	*Hypomesus pretiosus*
76	Longfin trout (steelhead)	*Salmo gairdnerii*
77	Eulachon	*Thaheichthys pacificus*
78	Capelin	*Mallotus villosus*
79	White seabass	*Cynoscion nobilis*
80	Pacific sand lance	*Ammodytes hexapterus*
81	Spiny dogfish	*Squalus acanthias*
82	Cutthroat trout	*Salmo clarki*
83	Salmon fishery (commerical)	
84	Rainbow smelt	*Osmerus mordax*
85	Alewife	*Alosa pseudoharengus*
86	Blueback herring	*Alosa aestivalis*
87	American shad	*Alosa sapidissima*
88	Winter flounder	*Pseudopleuronectes americanus*
89	Cunner	*Tautogolabrus adspersus*
90	White hake	*Urophycis tenuis*
91	Three-spined stickleback	*Gasterosteus aculeatus*
92	Four-spined stickleback	*Apeltes quadracus*
93	Striped killifish	*Fundulus notatus*
94	Atlantic silverside	*Menidia menidia*
95	Mummichog	*Fundulus heteroclitus*
96	Sanddab	*Citharichthys* sp.
97	Tautog	*Tautoga onitis*
98	American eel	*Anguilla rostrata*
99	Atlantic tomcod	*Microgadus tomcod*

100	Sea run brown trout	Salmo trutta
101	Shortnose sturgeon	Acipenser brevirostrum
102	Atlantic sturgeon	Acipenser oxyrhynchus
103	Threadfin shad	Dorosoma petenense
104	Striped bass	Morone saxatilis
105	Hickory shad	Alosa mediocris
106	California grunion	Leuresthes tenuis
107	Spotted sea trout	Cynocion nebulosus
108	Summer flounder	Paralichthys sp.
109	Red drum	Sciaenops ocellata
110	Black sea bass	Centropristis striata

45	Common tern	Sterna hirundo
46	Common murre	Uria aalge
47	Pigeon guillemot	Cepphus columba
48	Marbled murrelet	Brachyramphus marmoratum
49	Cassin's auklet	Ptychoramphus aleutica
50	Rhinoceros auklet	Cerorhinca monocerata
51	Tufted puffin	Lunda cirrhata
52	Wilson's phalarope	Steganopus tricolor
53	Northern phalarope	Lobipes lobatus
54	Great blue heron	Ardea herodias
55	Whimbrel	Numenius phaeopus
56	Spotted sandpiper	Actitis macularia
57	Wandering tattler	Heteroscelus incanum
58	Greater yellowlegs	Totanus melanoleucus
59	Lesser yellowlegs	Totanus flavipes
60	Red knot	Calidris canutus
61	Pectoral sandpiper	Calidris melanotos
62	Least sandpiper	Calidris minutilla
63	Dunlin	Calidris
64	Short-billed dowitcher	Limnodromus griseus
65	Long-billed dowitcher	Limnodromus scolopaceus
66	Western sandpiper	Calidris mauri
67	Sanderling	Calidris alba
68	Black oystercatcher	Haematopus bachmani
69	Semi-palmated plover	Charadrius semipalmatus
70	Killdeer	Charadrius vocirerus
71	Black-bellied plover	Pluvialis squatarola
72	Surfbird	Aphriza virgata
73	Ruddy turnstone	Arenaria interpres
74	Black turnstone	Arenaria melanocephala
75	Belted kingfisher	Megaceryle alcyon
76	Northern bald eagle	Haliaeetus leucocephalus
77	Osprey	Pandion haliaetus
78	Northwestern crow	Corvus caurinus
79	Cormorant	Phalacrocorax sp.
80	Arctic tern	Sterna paradisaea
81	Horned puffin	Fratercula corniculata
82	Glaucous gull	Larus hyperboreus
83	Kittiwake	Rissa sp.
84	Parakeet auklet	Cyclorrhynchus psittacula
85	Pigeon auklet	Cepphus columba
86	Least tern	Sterna albifrons
87	Little blue heron	Florida caerulea
88	Great egret	Casmerodius albus
89	Snowy egret	Leucophoyx thula
90	Black-crowned night heron	Nycticorax nycticorax
91	Glossy ibis	Plegadis falcinellus
92	Great black-backed gull	Larus marinus
93	Cattle egret	Bubulcus ibis
94	Louisiana heron	Hydranassa tricolor
95	Roseate tern	Sterna dougallii
96	Leach's petrel	Oceanodroma leucorhoa
97	Green heron	Butorides virescens

98	Laughing gull	Larus atricilla
99	Red-faced cormorant	Phalacrocorax urile
100	Black-legged kittiwake	Rissa tridactyla
101	Aleutian tern	Sterna aleutica
102	Fork-tailed storm petrel	Oceanodroma furcata
103	Common eider	Somateria mollissima
104	Murre	Uria sp.
105	Thick-billed murre	Uria lomvia
106	Ancient murrelet	Synthliboramphus antiquum
107	Peregrine falcon	Falco peregrinus
108	Kittlitz's murrelet	Brachyramphus brevirostre
109	Crested auklet	Aethia cristatella
110	Dovekie	Plautus alle
111	Least auklet	Aethia pusilla
112	Black guillemot	Cepphus grylle
113	Gyrfalcon	Falco rusticolus
114	Sabine's gull	Xema sabinii
115	White ibis	Eudocimus albus
116	Roseate spoonbill	Ajaia ajaja
117	Great white heron	Ardea occidentalis
118	Brown pelican	Pelecanus occidentalis
119	Frigate bird	Fregata magnificens
120	Yellow-crowned night heron	Nyctanassa violacea
121	Anhinga	Anhinga anhinga
122	Scarlet ibis	Eudocimus ruber
123	Southern bald eagle	Haliaeetus leucocephalus
124	Redhead	Aythya americana
125	Light-footed clapper rail	Rallus longirostris
126	Noddy tern	Anous stolidus
127	Sooty tern	Sterna fuscata
128	Blue-faced booby	Sula dactulatra
129	Northern fulmar	Fulmarus glacialis
130	Red-legged kittiwake	Rissa brevirostris
131	Crested auklet	Aethia cristatella
132	Wood stork	Mycteria americana
133	Black skimmer	Rynchops niger
134	Gull-billed tern	Gelochelidon nilotica
135	Sandwich tern	Sterna sandvicensis
136	Caspian tern	Sterna caspia
137	Royal tern	Sterna maxima
138	Forster's tern	Sterna fosteri
139	Snowy plover	Charadrius alexandrinus
140	Belding savannah sparrow	Passerculus sandwichensis
141	American avocet	Recurviorstra americana
142	Black-necked stilt	Himantopus mexicanus
143	Xantus' murrelet	Endomychura hypoleuca
144	Ashy storm petrel	Oceanodroma homochroa
145	Elegant tern	Sterna elegans
146	Black storm petrel	Oceanodroma melania
147	Bachman's warbler	Vermivora bachmanii
148	Ruddy duck	Oxyura jamaicensis
149	Gloss ibis	Plegadis falcinellus
150	Black rail	Laterallus jamaicensis

151	Clapper rail	*Rallus longirostris*
152	American oystercatcher	*Haematopus palliatus*
153	Piping plover	*Charadrius melodus*
154	Wilson's plover	*Charadrius wilsonia*
155	Willet	*Catoptrophorus semipalmatus*
156	Semipalmated sandpiper	*Calidris pusilla*

APPENDIX II. Species list of macroinfauna (greater than 0.5 mm) collected in 10 x 18-cm can cores.

PHYLUM RHYNCHOCOELA

Species A

PHYLUM NEMATODA

Species A
Species B

PHYLUM ANNELIDA

Eteone heteropoda Hartman, 1951
Exogone sp.
Laeonereis culveri (Webster, 1879)
Nereis sp.
Glycera sp.
Onuphis sp.
Onuphis c.f. *magna* (Andrews, 1891)
Onuphis eremita (Audouin & Milne-Edwards, 1833)
Lumbrineris sp.
Polydora sp.
Scolelepis squamata (Muller, 1806)
Spiophanes bombyx (Claparede, 1879)
Streblospio benedicti Webster, 1879
Magelona sp.
Tharyx sp.
Orbinid sp. A
Orbinia sp.
Orbinia ornata (Verrill, 1873)
Scoloplos sp.
Aricidea sp.
Capitellid sp. A
Dasybranchus sp.
Mediomastus californiensis Hartman, 1944
c.f. *Notomastus* sp.
Maldanid fragments
Sabellaria vulgaris vulgaris Verrill, 1873
Pectinaria gouldii (Verrill, 1873)
Pista sp.
Pista palmata (Verrill, 1873)
Oligochaete sp. A

PHYLUM MOLLUSCA

Littorina irrorata (Say, 1822)
Bivalve sp. A, juvenile
Bivalve sp. B, juvenile
Crassostrea virginica (Gmelin, 1791)
Dinocardium robustum (Lightfoot, 1786)
Mactrid sp. A, juvenile
Mactra fragilis Gmelin, 1791
c.f. *Mulinia lateralis* (Say, 1822)
Tellinid sp. A, juvenile

Donax variabilis (Say, 1822)
Chione cancellata (Linne, 1767)
Mercenaria mercenaria (Linne, 1758)

PHYLUM ARTHROPODA

Copepod sp. A
Mysid sp. A
c.f. *Diastylsis* sp.
Leucon americanus Zimmer, 1943
Chiridotea sp.
Amphipod sp. A
Amphipod sp. B
Ampelisca verrilli Mills, 1967
Microprotopus raneyi Wigley, 1966
Gammaropsis c.f. *maculata* Johnston, 1827
Acanthohaustorius intermedius Bousfield, 1965
Amphiporeia virginiana Shoemaker, 1933
Haustorius sp.
c.f. *Hyale plumulosa* (Stimpson, 1857)
Melita nitida Smith, 1873
Upogebia affinis (Say, 1818)
Pagurus longicarpus Say, 1817
Emerita talpoida (Say, 1817)
Xanthid sp. A
Pinnixa sp.
Grapsid sp. A
Uca pugilator (Bosc, 1801 or 1802)
Insect sp. A, larvae

ECHINODERMATA

Ophiuroid sp. A (brittle star)