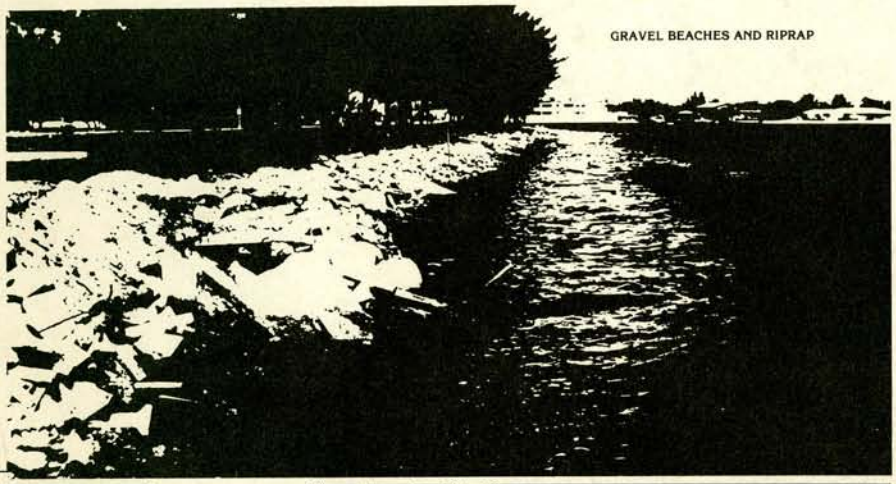
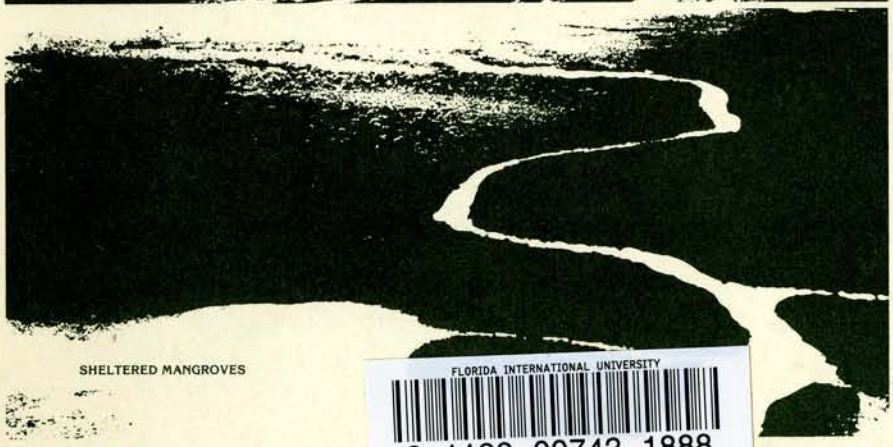
THE SENSITIVITY OF COASTAL ENVIRONMENTS AND WILDLIFE TO SPILLED OIL IN

SOUTH FLORIDA



GRAVEL BEACHES AND RIPRAP

COARSE-GRAINED SAND BEACHES



SHELTERED MANGROVES

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RPI/R/81/1/9-1
January 1981

PREFACE

A significant increase in tanker traffic in the Straits of Florida increases the likelihood of a collision or groundings which would cause a major oil spill to reach South Florida's beaches, Biscayne Bay, Card Sound, and the Florida Keys. These areas rank among the most valuable in Florida, with respect to their recreational attributes and wealth of biological resources. The threat of oil pollution in these critical areas amplifies the need for a detailed description of the distribution and seasonality of critical resources of South Florida, as well as recommendations for measures to prevent oil pollution.

In response to this need, the South Florida Regional Planning Council, with funding provided by the Coastal Energy Impact Program (CEIP), commissioned this project to conduct an analysis of the sensitivity of coastal environments and wildlife of South Florida to spilled oil. This text and a series of maps provide a framework upon which further contingency planning may be based.

This project was funded in part through a Coastal Energy Impact Program Grant through the Florida Department of Veteran and Community Affairs, Division of Local Resource Management, Office of Federal Coastal Programs, with funds from the United States Department of Commerce, under the Coastal Zone Management Act of 1972 (PL-92-583) as amended.

EXECUTIVE SUMMARY

A shoreline assessment was conducted throughout South Florida by means of aerial overflights, ground stations, and literature review. A total of 23 maps, this report, and six data supplements were produced. The 23 maps show RPI's Environmental Sensitivity Index which depicts shoreline and wildlife sensitivity to spilled oil on a scale of 1-10. The following shorelines were shown on color-coded maps:

Exposed, Vertical Rocky Shores and Seawalls (ESI=1)
Exposed Rocky Platforms (ESI=2)
Fine-Grained Sand Beaches (ESI=3)
Coarse-Grained Sand Beaches (ESI=4)
Mixed Sand and Gravel Beaches and Fill (ESI=5)
Gravel Beaches and Riprap (ESI=6)
Exposed Tidal Flats (ESI=7)
Sheltered Rocky Shores and Seawalls (ESI=8)
Sheltered Tidal Flats (ESI=9)
Mangroves (ESI=10a)
Sheltered Mangroves (ESI=10b)

The following oil-sensitive wildlife were also shown on these maps:

Resident Mammals
Marine Birds
Sea Turtles and Crocodiles

The first subject of this report was to describe the environments and wildlife which appear on the maps. Special features related to placing booms, skimmers, and access for cleanup during oil spills are also shown on the maps and discussed in this report in detail. Additional detail is given in this report concerning cleanup techniques. Also described are resources which are more variable in their sensitivity to oil, usually being less sensitive since they are either underwater habitats or animals capable of avoiding oiled areas:

Coral Reefs
Seagrass Beds
Whales and Dolphins
Marine Fisheries

Mangroves, sand beaches, and man-made structures are the dominant shorelines of South Florida. The barrier island system from Boca Raton to Key Biscayne affords protection of inner, more oil-sensitive environments within the intercoastal waterway and northern Biscayne Bay. Oil which physically impacts these outer beaches would be relatively easy to clean, and these efforts would be aided by natural processes (waves and currents). Efforts to protect the in-

ner bays and waterways should be concentrated at the four large inlets which connect inner bays and waterways to the Straits of Florida.

Biscayne Bay and Card Sound are exposed through a ten-mile-wide corridor to the Straits of Florida. Biscayne Bay is a productive and sensitive estuary which contributes a vital support to the local economy as it supports fisheries and nursery stock (including a lobster sanctuary) for fish and shellfish and numerous forms of marine recreation. In addition, southern Biscayne Bay and Card Sound are ringed with oil-sensitive mangroves, bird rookeries, and crocodile forage areas. Biscayne Bay and Card Sound afford the greatest potential of any area in South Florida for severe biological and economic damages due to a large oil spill.

The Florida Keys are characterized by numerous channels and creeks in which booms and skimmers are recommended. There are numerous lagoons filled with sheltered mangroves which are often connected by only narrow tidal creeks which are easily boomed. Numerous bird rookeries are found throughout the many offshore islands in this region.

In general, oil-spill protection in South Florida involves ocean-going skimmers at the spill site (first line of defense), deflection booms at inlets, channels, and creeks (second line of defense), and containment booms across canals in sheltered waters (third line of defense). In addition, sorbent booms in front of mangroves may trap oil before and after they become oiled. Cleanup techniques are recommended which utilize natural processes whenever possible. Techniques which utilize manual labor and natural processes are much less environmentally damaging and are recommended for cleanup in nearly every case over the use of heavy machinery and dispersing chemicals.

ACKNOWLEDGMENTS

M. Barry Peterson, Sharyn Dodrill, Sandra Barrett, Joe Yuska, Judy Froggatt, and Kim Woodbury of South Florida Regional Planning Council have contributed technical support, editing, and field assistance. Robert Weiss, the Federal Programs Coordinator of the Coastal Energy Impact Program in Florida, is thanked for his continuing support. We thank Mr. Jim Tillmont of the Biscayne Bay National Monument for use of a park boat during the survey of the monument. To our pilot, Mr. Michael W. Getter we are indebted for safe, low flying. Larry Thebeau and Tom Ballou of Research Planning Institute, Inc. (RPI) contributed to sections of the report. The maps and the report artwork were done by George Miles, Sidney Pearce, Susan West, Gene Spear, Len Mangum, Joanne Trauger, Mark Morris, Timothy Reaka, and Charlotte Johnson of RPI. Daniel Domeracki reviewed and edited the maps. The report was edited and typed by Diana Gaines, Phyllis Carter-Frick, Linda Parker, and Patrice Cunningham of RPI.

We are indebted to the following persons: (1) Dr. Daniel Odell of the Rosenstiel School of Marine and Atmospheric Science, University of Miami, for the location of manatee winter aggregations; (2) Mr. Ross Whitham of Florida Department of Natural Resources, for the location of the marine turtle nesting beaches; (3) Dr. Herbert Kale of the Florida Audubon Society for the localities of coastal bird rookeries.

INTRODUCTION

Objectives

This report and a set of maps present the results of an investigation to describe and to show the distribution of oil-sensitive, coastal resources and provide guidelines for protecting them from oil-spill damages. The investigation has three objectives:

1) To describe and map coastal ecosystems, focusing on oil-sensitive shorelines and wildlife, and to determine their relative sensitivity to spilled oil.

2) To discuss other ecologically important resources of South Florida which are sensitive to spilled oil only under certain conditions.

3) To provide a basis for oil-spill response priorities and to aid in the selection of protection and cleanup methods for oil-sensitive areas.

This report and the maps will assist oil-spill response efforts by aiding in the establishment of lines of defense during an oil spill. The maps provide a focal point for strike teams charged by the Coast Guard on-scene coordinator with the responsibility of protecting coastal environments threatened by an oil spill. In addition to their operational value during an oil spill, this report and maps provide a basis to develop and plan appropriate coastal protection and cleanup strategies before a spill occurs. This type of study has also proven to be useful in oil-and-gas leasing studies.

Probability of an Oil Spill

A vessel traffic study conducted by the U.S. Coast Guard showed that an average of 100 vessels per day transited the Florida Straits in 1976. Of that number, 38 vessels per day were oil-carrying tankers. Estimating the average, oil-carrying tonnage per tanker at 31,210 tons, the Coast Guard approximated over a million tons of crude oil per day were being carried by tankers passing within five to 25 miles of the South Florida shoreline.

The study identified three major crossing and merging areas of vessel traffic. These are approximately 13 miles south-southeast of Miami, approximately 14 miles south of the Dry Tortugas, and approximately 13 miles south-southeast of West Palm Beach. These crossing and merging areas cre-

ate the potential for collisions. The remainder of the vessel routes and tankers stay in coastal waters in order to avoid Gulf Stream currents which create additional potential for collisions and groundings.

There has been a recent significant increase in tanker traffic in the Florida Straits related to increased offshore oil production in the Gulf of Mexico and the Caribbean Sea, increased Mexican oil production, increased U.S. dependency upon large supplies of foreign oil, and an increase in the size of oil tankers themselves. As tanker traffic increases, the probability of collisions, groundings, and resultant major oil spills increases, as do the potential amounts of oil spilled.

Physical Setting

Physical Processes

Low latitude and proximity to the ocean and the Gulf Stream control the climate of South Florida. The region has a subtropical marine climate of balmy winters and long, warm summers punctuated by afternoon showers. Mean annual temperature in Miami is 75.5°F and in Key West is 78.2°F (Veri et al., 1975). Rain is abundant, with average annual precipitation ranging from 40 inches at Key West to 60 inches at Miami (Butson, 1962).

Prevailing winds in South Florida are easterly and southeasterly as the area lies in a transitional zone between the trades and westerlies. Most winds approach the coast from over the water, and these seabreezes tend to temper the climate. Average wind velocities in the region range from 8-10 knots (Veri et al., 1975). The area has two tides a day, and a mean range of 2.2 ft. Because of the shallowness of the continental shelf and the very low tidal range, these low velocity easterlies tend to pile water against the southeastern edge of the Florida Keys, therefore enhancing flood-oriented circulation into Florida Bay.

Hurricanes and tropical storms are short-term events which can cause major physical and biological changes on the coast (Ball et al., 1967; Craighead, 1971). The Florida peninsula juts into the path of storms from the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea and can be impacted from either direction. South Florida averages 1.7 storms a year (ranging from 0-5) during the hurricane season. The direction of expected hurricane approach changes during the season from easterly and southeasterly (August to early September) to southerly and southwesterly (late September to October) in response to a westward shift of the probable center of hurricane generation (Butson, 1962).

These storms can cause catastrophic erosion and deposition despite their infrequency and short duration. During hurricanes, sustained winds of 65 knots are common with gusts up to 120 knots. Wave heights may increase to 6-15 feet. The coastline has abundant evidence of the influence of hurricanes; keys have been cut in half by rising water. Hurricane rubble mounds, such as Little Molasses Reef south of John Pennekamp Coral Reef State Park, are deposited during a single storm (Turmel and Swanson, 1976). Mangrove forests on windward coasts have been destroyed by hurricanes and storm wrack lines have been deposited hundreds of feet inland (Craighead, 1971). Therefore, South Florida is a hurricane-dominated system with respect to the lasting effects of erosion and deposition.

Geological History

The Florida peninsula is the emergent part of the Floridan Plateau which is an extension of the North American continental land mass separating the Atlantic Ocean from the Gulf of Mexico. It is a low (mostly less than 18 ft), coastal ridge. The platform extends subtidally for 2-3 miles off the Atlantic coast and more than 100 miles beyond the Gulf Coast. The Floridan Plateau is composed of 14,000-20,000 feet of mostly carbonate sediments which have accumulated on granitic basement rocks for the last 225 million years (Goodell and Garman, 1969). This plateau is quite extensive as similar rocks crop out in Guatemala, Mexico, and Gulf Coast states. Although Florida bounds the tectonically active Caribbean, there is no major faulting or deformation in the limestone deposits (Mallory and Hurley, 1968).

The surficial rocks in South Florida are made of two formations: the Key Largo Limestone and the Miami Limestone. Both rock types were deposited during an interglacial period 95,000-130,000 years ago, when sea level stood at about 25 feet higher than today. The shape and orientation of the Florida Keys is a function of which rock type occurs at the surface. The upper Florida Keys, from Soldier to Newfound Harbor Keys, are composed of the Key Largo Formation; and the lower Florida Keys, from Big Pine Key to Key West, are composed of the Miami Formation. A difference is obvious in the elongation of the upper Florida Keys (NE-SW) and the lower Florida Keys (NW-SE).

The Key Largo Formation is an elevated coral reef rock which originated as a line of patch reefs on a broad platform similar to the present Florida reef tract (Hoffmeister and Multer, 1968). The arcuate ridge of the upper Florida Keys, oriented parallel to the continental margin, reflects the growth pattern of the patch reefs which grew in a manner

to receive the greatest amount of nutrients. The Miami Formation of the lower Florida Keys is composed of oolitic carbonate sandstones which originated as underwater sand banks formed parallel to the Key Largo coral reef. These oolite banks became broader and eventually covered the corals to the south. The NW-SE orientation and shape of the lower Florida Keys reflects the underwater topography created by scouring of channels by tidal currents flowing through these oolite banks.

Types and Properties of Oil

The term oil is used to describe a wide range of petroleum hydrocarbons, from crude oil to various types of refined products such as gasoline and asphalt. These petroleum hydrocarbons differ greatly in both their physical and chemical properties which affect the behavior of slicks, weathering processes, persistence, ecological impact, effectiveness of control and recovery, and fate in the marine environment. Table 1 lists oil types grouped into three categories with similar characteristics in terms of their physical, chemical, and toxicological properties.

Under the tropical conditions in South Florida, all types of oil weather rapidly, primarily by evaporation and solution into the water column, but also by emulsification, microbial degradation, and photooxidation. Evaporation from an oil slick is responsible for the loss of about one fourth of most crude oil spills within 24 hours, representing those components that volatilize most readily. The evaporation losses from light crude oils and distillate fuels would be even greater. The most volatile portions of crude and light distillate oils are also the most soluble, although evaporation is the most dominant mechanism of loss in the early stages of spillage. Ecological damage from the water-soluble fractions is greatest for nearshore spills where fresh oil quickly enters shallow coastal habitats.

Oil can form either oil-in-water (o/w) or water-in-oil (w/o) emulsions. The o/w emulsions are readily distributed through the water column and increase the surface area of oil exposed to degradation processes. The w/o emulsions, known as "mousse," float and agglomerate into large masses which are viscous enough to substantially retard evaporation. They are very stable and inhibit natural degradation of the oil. Mousse has over twice the volume of the original oil and interferes with cleanup operations because of its viscosity. Mousse forms under high-energy conditions and can develop from all types of oil, from gasoline to asphalt.

TABLE 1. Classification and properties of oil types with respect to their behavior during spills.

OIL TYPE	EXAMPLES	PHYSICAL/CHEMICAL PROPERTIES	TOXICOLOGICAL PROPERTIES
(1) Light, volatile oils	Distillate fuels such as gasoline, diesel, No. 2 fuel oil	- Spread rapidly - High evaporation and solubility rates - Tend to form unstable emulsions - Very toxic to biota when fresh - May penetrate substrate - Can be removed from surfaces by simple agitation and low pressure flushing	- Acute toxicity is related to the content and concentration of the aromatic fractions - Aromatic fractions are very toxic due to the presence primarily of napthalene compounds and, to a lesser extent, benzene compounds - Heavy molecular weight compounds are acutely less toxic, but may be chronically toxic since many are either known or potential carcinogens - Acute toxicity of individual aromatic fractions will vary among species due to differences in the rate of uptake and rate of release of these compounds - Mangroves and marsh plants may be chronically affected due to penetration and persistence of aromatic compounds in sediments
(2) Moderate to heavy oils	Medium to heavy paraffin-based refined oils and crude oils	- Moderate to high viscosity - Toxicity variable depending on light fraction composition - In tropical climates, rapid evaporation and solution form less toxic weathered residue with toxicity due more to smothering - Light fractions may contaminate interstitial water	- Acute and chronic toxicity in marine organisms is likely to result from: 1) Mechanical or physical coverage - oil completely smothering organisms often causing death 2) Chemical toxicity - results from the exposure of very toxic aromatic fractions of the oil to marine organisms 3) A combination of mechanical or physical coverage and chemical toxicity.

TABLE 1. (Continued)

OIL TYPE	EXAMPLES	PHYSICAL/CHEMICAL PROPERTIES	TOXICOLOGICAL PROPERTIES
		- Tend to form stable emulsions under high physical energy conditions - Variable penetration, a function of substrate grain size - High potential for sinking after weathering and uptake of sediment - Generally removable from water surface when fresh - Weather to tar balls and tarry residue	- Mechanical or physical smothering causes acute toxicity in many marine organisms and chronic toxicity in many marine plants (especially mangroves)
(3) Residual oils	Asphalt, Bunker C, No.6 fuel oil, waste oil	- Form tarry lumps at ambient temperatures - Non-spreading - Relatively non-toxic due to substrate - May soften and flow when stranded in sun - Cannot be recovered from water surface using most cleanup equipment - Easily removed manually from beaches	- Acute and chronic toxicity occurs more from smothering effects than from chemical toxicity, due to the small proportion of toxic aromatic fractions found in heavy, residual oils - Toxicity is more common in marine plants (especially mangroves) and sedentary organisms than in mobile organisms - Acute and chronic toxicity also results from thermal stress, due to the elevation of temperatures in oiled habitats

The toxicity of spilled oil depends upon both the types and concentrations of hydrocarbons and related compounds present. However, certain trends in toxicity have emerged from studies of past spills and detailed laboratory experiments. Two types of toxicity must be considered for spilled oil: acute and chronic. Acute toxicity refers to the short-term lethal effects, less than 96 hours. Chronic toxicity refers to lethal effects which occur over longer periods of time.

In general, light volatile oils are more toxic (acutely and chronically) than moderate to heavy oils and residual oils. These differences in toxicity are related primarily to the different types and concentrations of toxic aromatic fractions within each type of oil. Light volatile oils contain the highest proportion of highly toxic, low molecular weight, aromatic fractions which are readily soluble in sea water and are rapidly accumulated by marine organisms. Moderate to heavy oils and residual oils usually contain considerably lower proportions of these low molecular weight, aromatic compounds and are less toxic than light volatile oils.

The aromatic fractions of all three types of oil contain certain similar aromatic compounds, such as benzene or napthalene. Differences in acute toxicity among the three types of oil are related to differences in the concentration of soluble aromatic derivatives. Acute toxicity varies among different species of marine organisms and is related to differences in both the rate of uptake and rate of release of these aromatic compounds. Aromatic compounds such as phenanthrene, which are rapidly accumulated and slowly released, are generally the most toxic. In general, estuarine and benthic species are more oil tolerant than oceanic species. Additionally, adult members of a species are generally more oil tolerant than juvenile or larval forms.

Chronic toxicity can result not only from the low concentration of aromatic compounds but also from mechanical or physical coverage which may smother many marine organisms and plants. In general, smothering cuts off the oxygen supply to most species affected and usually results in death, unless species have alternate metabolic pathways for dealing with conditions without oxygen. Moderate to heavy and residual oils have a higher potential to cause smothering effects than lighter volatile oils. In general, sedentary organisms and plants have a higher potential for smothering effects than mobile organisms.

In addition to effects from aromatic fractions, chronic toxicity can also result from (1) the accumulation and biological transformation of heavier molecular weight, less toxic compounds (many of which are known or suspected carcinogens), and (2) thermal stress associated with the eleva-

tion of temperatures in oiled habitats. Examples of chronic toxicity have been observed in both red and black mangroves, in mangrove tree crabs, and in mangrove epiphytic prop root communities (Getter et al., 1980b).

Sensitivity of Plants and Animals to Oil

In addition to the differences in toxic effects of different oil types, plants and animals themselves possess behavorial, physiological, and life-history characteristics which give each a relative sensitivity to spilled oil. One of the most significant factors is the ability of mobile animals to avoid spilled oil. Animals capable of avoiding spilled oil include whales and dolphins, terrestrial mammals which utilize coastal areas, certain coastal birds, adult marine fishes, and certain invertebrates.

On exposed sand beaches during the IXTOC I oil spill in Texas during 1979, dolphins and mullet avoided oiled nearshore waters. Coastal birds either avoided these oiled beaches entirely, or used back beach areas which were less oiled (Getter et al., 1980c). Ghost crabs migrated further up the beach face to avoid the oiled foreshore. During the PECK SLIP oil spill in Puerto Rico during 1978, mangrove periwinkles moved out of oiled mangroves (Getter et al., 1980a). By avoiding oiled areas, these animals avoided toxic exposure to oil.

Other animals which are less mobile are prone to be impacted. These include small burrowing worms, clams, beach hoppers, and mole crabs (infauna). At oiled sand beaches during the IXTOC I spill, a significant decrease in the numbers of infaunal organisms was noted. Oil from the PECK SLIP caused significant damage to communities of small animals inhabiting algae growths on mangrove roots. These animals are small and have a limited habitat; thus, they were forced to remain in oiled habitats.

Sessile animals and rooted plants have no means of avoiding oiling. This is true of corals, mangroves, sea grasses, and red algae, which form a biogenic substrate over large areas in South Florida. Should oil lead to the death of these organisms, substrate formation could be interrupted and habitats could disappear entirely, especially if substrates sustained heavy oiling. This could lead to a direct loss of habitat to residents of oiled habitats, a loss of food and forage value to animals which visit these environments, and/or failure of corals, sea grasses, or mangroves to recolonize.

During the PECK SLIP spill, oil floated over coral reefs, seagrass beds, and red algae, but physically impacted

intertidal communities. In almost all known cases during oil spills in the Gulf of Mexico and Caribbean Sea, oil has failed to impact subtidal environments, except for those immediately adjacent to oiled shorelines. During these spills, physical or chemical impacts to corals and sea grasses were not observed. For this reason, these environments were defined as less oil-sensitive environments in this report.

Oil spills in the Gulf of Mexico and Caribbean Sea have often resulted in heavy physical impact to intertidal communities which are impacted by floating oil. This effect is concentrated by microtidal ranges into a narrow intertidal band (the "bath tub ring" effect). In all of these spills where mangrove forests were impacted, the toxic effects were greater than at other habitats. Long-term (2-5 years) damages to acres of fringing red mangroves are known to follow major oil spills.

Animals and plants may have protective body coverings which prevent oil from contacting tissues. Examples of this include the impervious shell and plates of barnacles and periwinkles, which allow these animals to avoid contact with oil. The relatively impervious seed coat of the red mangrove may allow the propagule to survive short-term exposures without toxic effects. Other plants and animals such as algae, corals, anemones, beach hoppers, worms, and larval fishes have no effective covering to prevent direct oil-tissue contact. Animals and plants also exhibit physiological differences when exposed to oil. Beach hoppers and larval fishes are extremely sensitive to low concentrations of light volatile oils while polychaete worms are tolerant, often increasing their numbers following an oil spill.

Mobility, protective coverings, and physiological sensitivity are controlled by seasonal changes. These changes may occur during any part of an organism's life history, rendering it more or less sensitive to spilled oil during certain times of the year. Animals which are usually highly mobile and capable of avoiding oil, such as wading birds, shore birds, gulls, terns, and sea turtles, are obligated to return to or remain at certain nesting and rookery sites in order to breed. This may expose the breeding adults, eggs, and young of a mobile species during an oil spill. The young of species may be the most sensitive stage to the toxic effects of spilled oil in some species. Avoidance of oil by young birds, reptiles, and fishes may be less than that of adults; protective coverings may not be as well-developed; and even a temporary, or low-level interruption of physiological balance may lead to death of a younger or larval animal.

Mangroves may be sensitive to toxic effects during a number of reproductive events including flowering, germina-

tion, seed formation, dispersal, and sprouting. The seedlings of mangroves are the most vulnerable target of spilled oil. The seedlings of red and black mangroves are present year round in South Florida, but a seasonal trend is apparent. These mangroves drop seeds in the fall and winter months which then are dispersed and sprout in intertidal and shallow subtidal areas.

Federal and state agencies (Environmental Protection Agency and Florida Department of Environmental Regulation) have published policy which discourages the use of chemical dispersants in the coastal waters of Florida. Despite recent advances made in the production of relatively nontoxic chemical dispersants, these substances are untested in Florida. The critical biological resources of South Florida, the untested nature of these substances, and the policy of the federal and state governments suggest a recommendation against the use of chemical dispersants.

History of the Environmental Sensitivity Index

The Environmental Sensitivity Index is based mainly on the results of research at five oil spills (METULA, URQUIOLA, AMOCO CADIZ, PECK SLIP, IXTOC I), several other incidents (including spills under tropical and ice conditions), and an extensive literature survey. A list of the studies of oil spills that have provided the most information on this subject is presented in Table 2.

The first application of the concept of a sensitivity index by RPI was geomorphic mapping of oil-spill sensitivity of the coastline of lower Cook Inlet, Alaska (Hayes et al., 1976; Michel et al., 1978). During that study, an Oil Spill Susceptibility Index was defined on the physical longevity of oil in each environment in the absence of cleanup efforts. This same principle was used by Nummedal and Ruby (1979) to map the Alaskan coast of the Beaufort Sea. Gundlach and Hayes (1978a) expanded the concept to include 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 Environmental Sensitivity Index (ESI) used in this report integrates geomorphic and biological factors. Getter and others (1981a) 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. These symbols include the seasons in which these species use certain areas. Access points to the shore and facilities such as marinas and boat ramps are also indicated on the maps. These refinements

TABLE 2. The Environmental Sensitivity Index predics the 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 U.S. East Coast	Jan.-June 1942	Various; 533,740 tons	Campbell et al. (1977)
TORREY CANYON Scilly Isles, U.K.	Mar. 1967	Arabian Gulf crude; 117,000 tons total; 18,000 tons onshore	Smith (1968)
Santa Barbara Blowout	Jan. 1969	California crude; 11,290 to 112,900 tons total; 4,509 tons onshore	Foster et al. (1971)
METULA, Strait of Magellan, Chile	Aug. 1974	Saudi Arabian crude; 53,000 tons total; 40,000 tons onshore	Hann (1974); Blount (1978)
GARVIS Florida Keys	Aug. 1975	Crude; ~210 tons	Chan (1977)
URQUIOLA, La Coruna, Spain	May 1978	Arabian Gulf crude; 110,000 tons total; 25,000-30,000 tons onshore	Gundlach and Hayes (1977)
AMOCO CADIZ Brittany, France	Mar. 1978	Arabian Gulf crude; 223,000 tons total	Gundlach and Hayes (1978b); Hayes et al. (1979)
HOWARD STAR Tampa Bay	Oct. 1978	Crude and distillate; ~140 tons	Getter et al. (1980b)
PECK SLIP Eastern Puerto Rico	Dec. 1978	Number 6 oil; 1,500 tons	Getter et al. (1980a); Gundlach et al. (1979)
IXTOC I Gulf of Mexico	June 1979 to April 1980	Crude oil; several hundred thousand tons	Getter et al. (1980c); Gundlach et al. (1981)
BURMAH AGATE Texas	Nov. 1979	Crude and refined product	Thebeau and Kana (1981)

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), Shelikof Strait, Pribilof Islands, and Norton Sound (Alaska).

For this study, the Environmental Sensitivity Index was expanded to accurately reflect the character of South Florida's coastline. The major modification made during this study was to integrate man-made structures into the ESI (such as seawalls, fill, and riprap) on the basis of their geomorphic and biological similarities to naturally occurring shorelines. While other investigators (Stephenson and Stephenson, 1971) have documented these similarities, their inclusion was based upon many observations during the oil spills listed in Table 2. Their response to oiling has been observed to be analogous to natural habitats as have protection and cleanup strategies.

METHODS OF STUDY

Acquisition of Data

A combination of literature review, and ground and aerial surveys were carried out during this study. During all stages of the project, the literature was searched for regional and local information pertaining to the ecological setting, geology, climate, and socioeconomic factors. All available wildlife data were added to the base maps (USFWS, 1978; 1980; CEQ/CZM, 1980; Odell, 1980; Whitham, 1980).

An intensive field survey was undertaken during May 1980. A total of 150 ground stations were established at approximate two-mile intervals along the coast throughout the study area (Figs. 1 and 2). Station locations were chosen on the basis of the following criteria:

1) Areas representing dominant shoreline types and habitats of critical concern were chosen. This allowed geomorphic and biological characterization of all shoreline types in a ten-habitat classification scheme.

2) Ecologically sensitive areas which were projected as likely to be physically impacted were selected. These areas were designated as high priority for protection during oil spills.

At major and minor inlets, observations were recorded on field tape and on film concerning protection strategies. At each remaining station (about 100), a transect was selected to represent the characteristic geomorphology and biological communities within and adjacent to the selected station. At these stations, geomorphic features were measured, including a profile of the topography. Using a method modified from Emery (1961), sampling was carried out along the transect within each major ecological zone. Each area was then photographed and a verbal description was recorded on tape. The following methods were utilized for biological assessment:

1) Plants were censused for percent coverage and and biomass within three randomly selected areas in each ecological zone.

2) Animals were censused for density and diversity within three randomly selected areas within each zone.

3) Small burrowing animals were censused with triplicate cores driven 15-20 cm straight into the substrate at the low-water mark. Infaunal

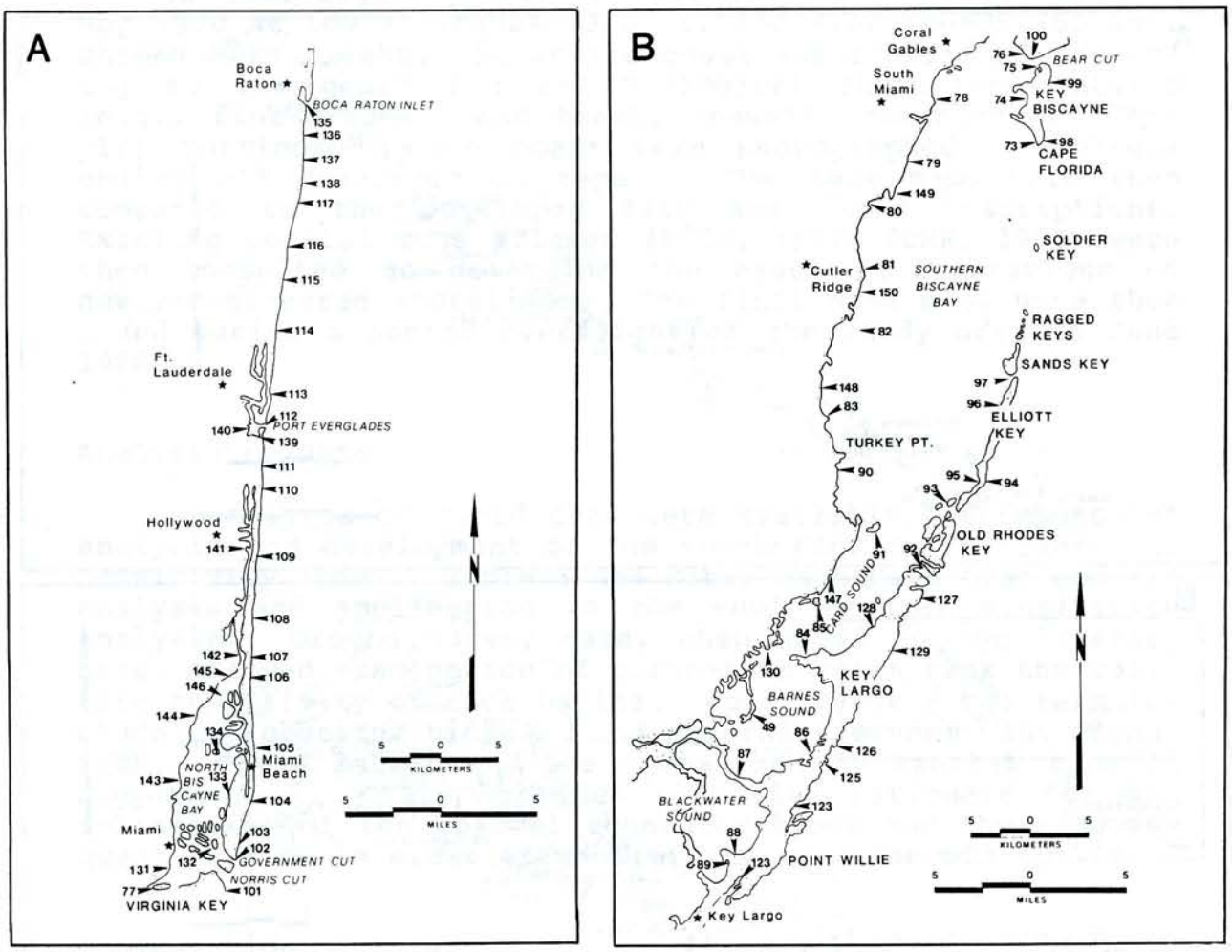


FIGURE 1. Ground stations from (A) Boca Raton Inlet to Virginia Key, and from (B) Key Biscayne to Key Largo.

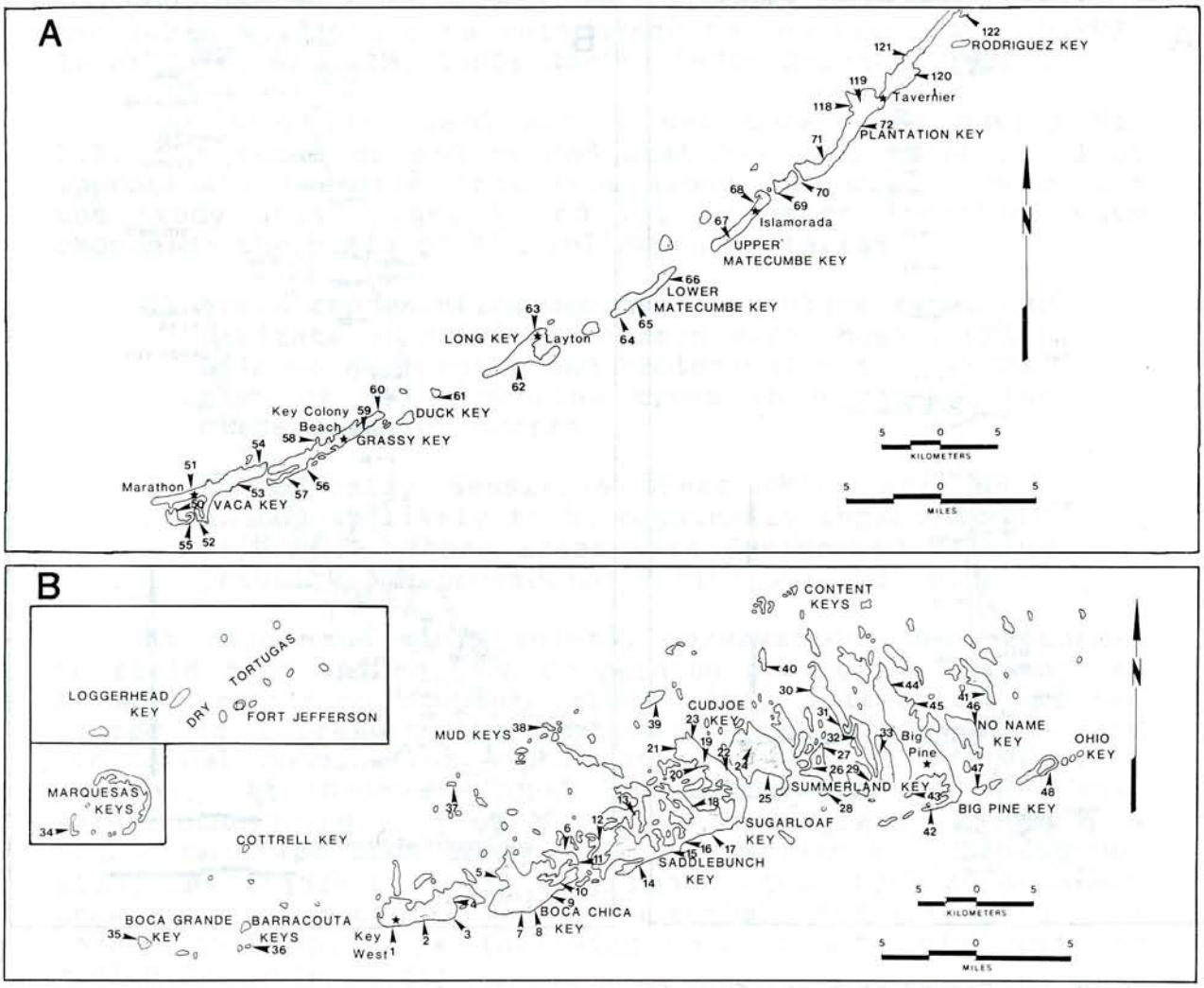


FIGURE 2. Ground stations from (A) Rodriguez Key to Marathon, and from (B) Ohio Key to Dry Tortugas.

samples were then passed through a sieve with 1-mm mesh and sorted to lowest taxonomic group.

Areas and core sizes were selected to best represent observed patchiness in distribution of plants and animals (quadrats = 0.015 m^2; core diameter = 13 cm).

An overflight by airplane was made of the study area in May 1980 at low altitudes (200 ft) and slow speeds (60 kn). During this flight, the entire coast was classified according to its geomorphic and biological shoreline features (e.g., fine-grained sand beach, seawall, mangroves). Complex portions of the coast were photographed at oblique angles and described on tape. The base maps were then compared to the developed film and taped descriptions. Existing coastal zone atlases (FCCC, 1974; FDNR, 1975) were then consulted to determine the exact configurations of newly-engineered shorelines. The final base maps were then trued during a second overflight of the study area in June 1980.

Analysis of Data

Four types of field data were available for subsequent analysis and development of the South Florida Environmental Sensitivity Index. Table 3 describes each data type and its analysis and application to the environmental sensitivity analysis. Ground survey data, when added to the literary base, allowed examination of parameters which rank the relative sensitivity of each habitat type. These parameters include the density, biomass, and diversity of dominant organisms. These parameters are summarized by habitat type in Supplement 1. This provides objective rationale for the delineation of ten coastal community types and their subsequent ranking in order of sensitivity to major oil spills.

Presentation of Data

The ecological types of organisms (based on numerical superiority) are noted on the maps by a wildlife marker system as outlined in Figure 3. The type of distribution exhibited by each type of organism is displayed with a specific symbol in order to differentiate between exact point localities, home ranges, aggregations, and forage areas (Fig. 4). Coastal types were added to these maps to complete the series. Map coverage of the study area is shown in Figures 5 and 6. These environments and wildlife are the primary subject of discussion in this report. The raw data summaries, field notes, taped observations, and photographs are bound under separate cover as Supplements 2 to 6. These supplements are on file with the South Florida Regional Planning Council.

TABLE 3. Data analysis by data type and mode of treatment.

DATA TYPE	DESCRIPTION	ANALYSIS AND APPLICATION
1) Base maps with literary/field applied coastal communities and wildlife.	Colored 7.5 USGS topo sheets and wildlife markers.	Becomes draft 1 of Environmental Sensitivity Index.
2) Description of coastal communities.	Tape recording	Constitutes detailed background information concerning all coastal communities noted on biology base maps. Used for characterization of communities. This constitutes baseline biological information useful for determining "prespill" conditions after a major oil spill within the study area.
3) Detailed photographic log.	Photographs taken during survey	Constitutes a photographic record (color and infrared) of the coastal communities of the study area. Representative photo used in report.
4) Ground survey data	Distribution and abundance of coastal community assemblages and geomorphic data	Analysis of biomass, density (numbers and percent coverage), and diversity allows characterization of community assemblages.

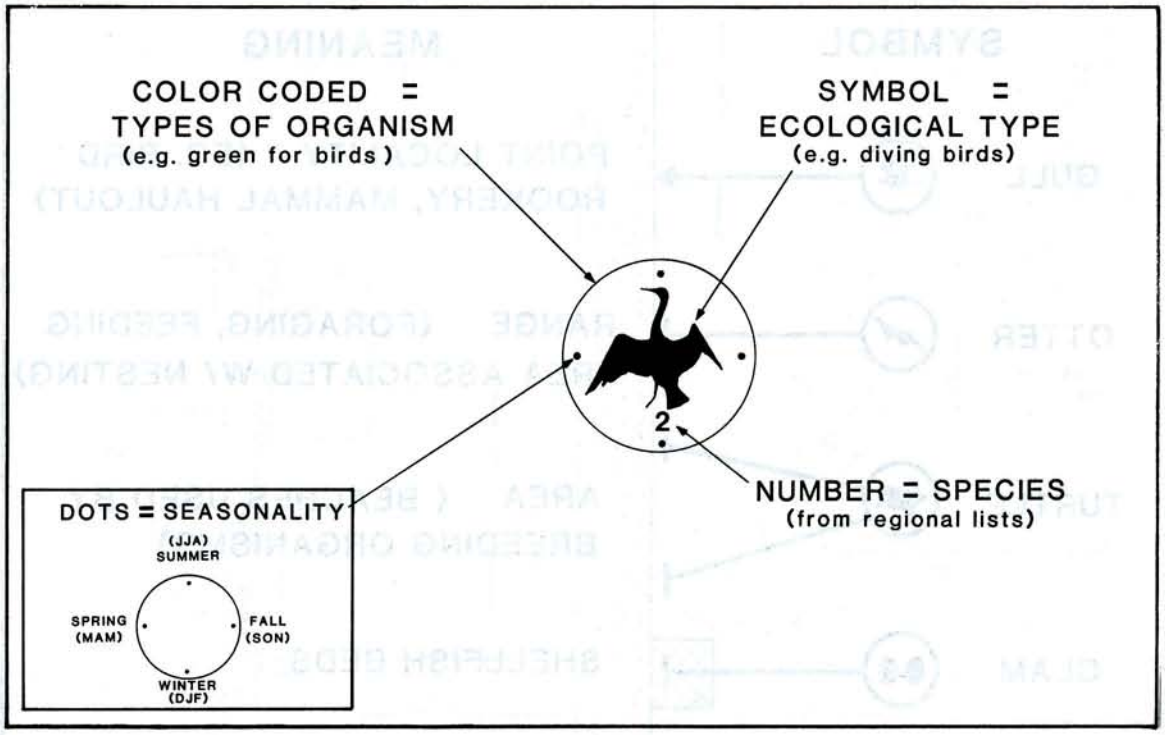


FIGURE 3. A key to the information which appears on wildlife markers, including color codes, ecological type symbols, seasonality, and species (from Getter et al., 1981a).

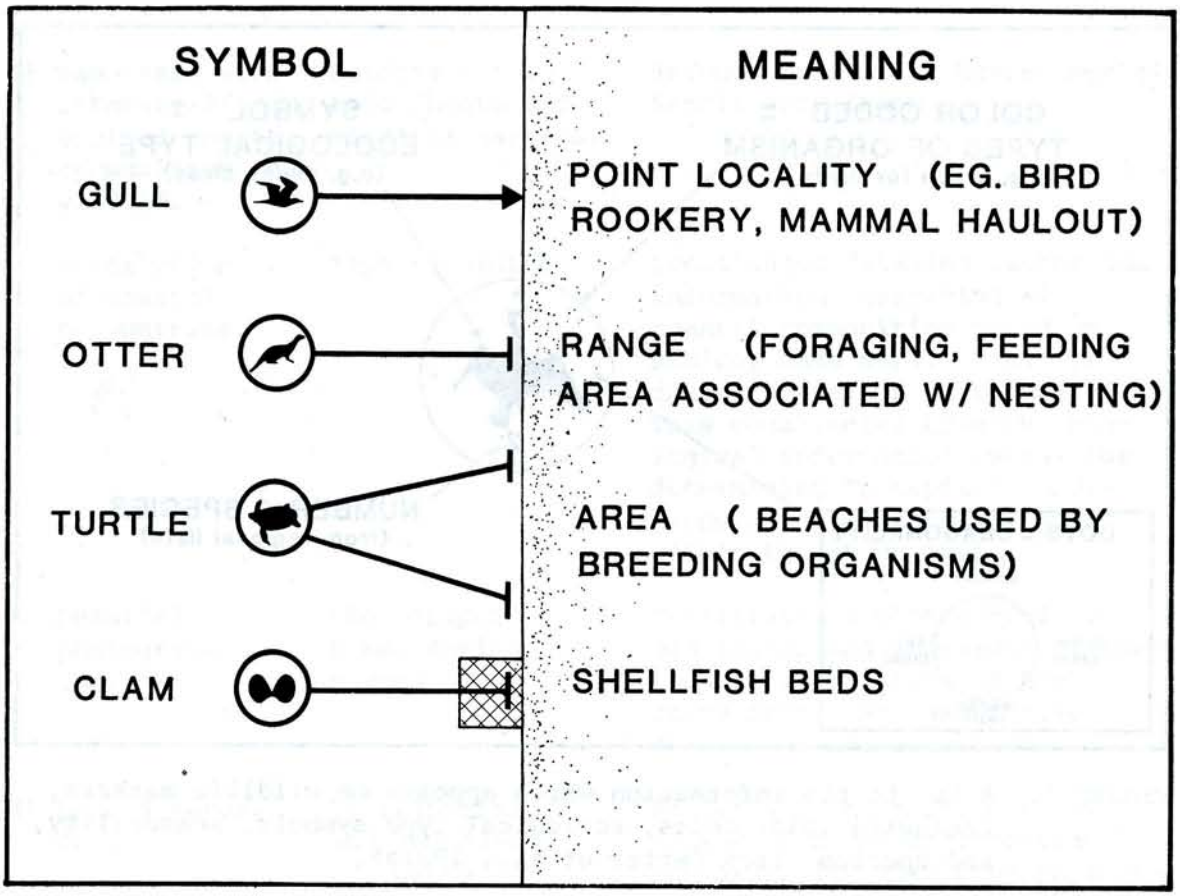


FIGURE 4. A key to the types of symbols used to show the distribution of coastal wildlife, including point localities, ranges, areas, and shellfish beds (from Getter et al., 1981a).

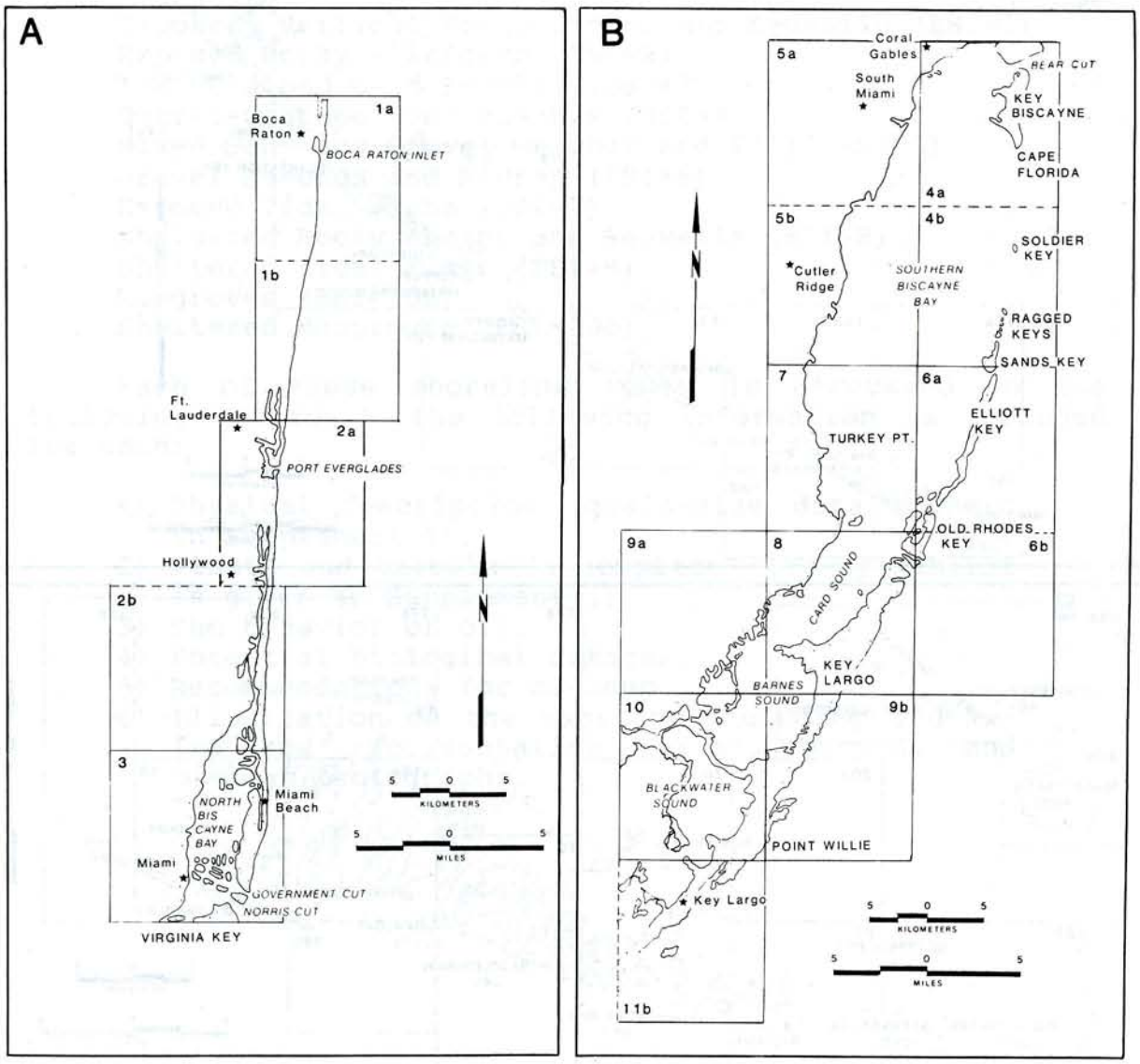


FIGURE 5. Areas of coverage by maps, showing insets from (A) Boca Raton Inlet to Virginia, and from (B) Key Biscayne to Key Largo.

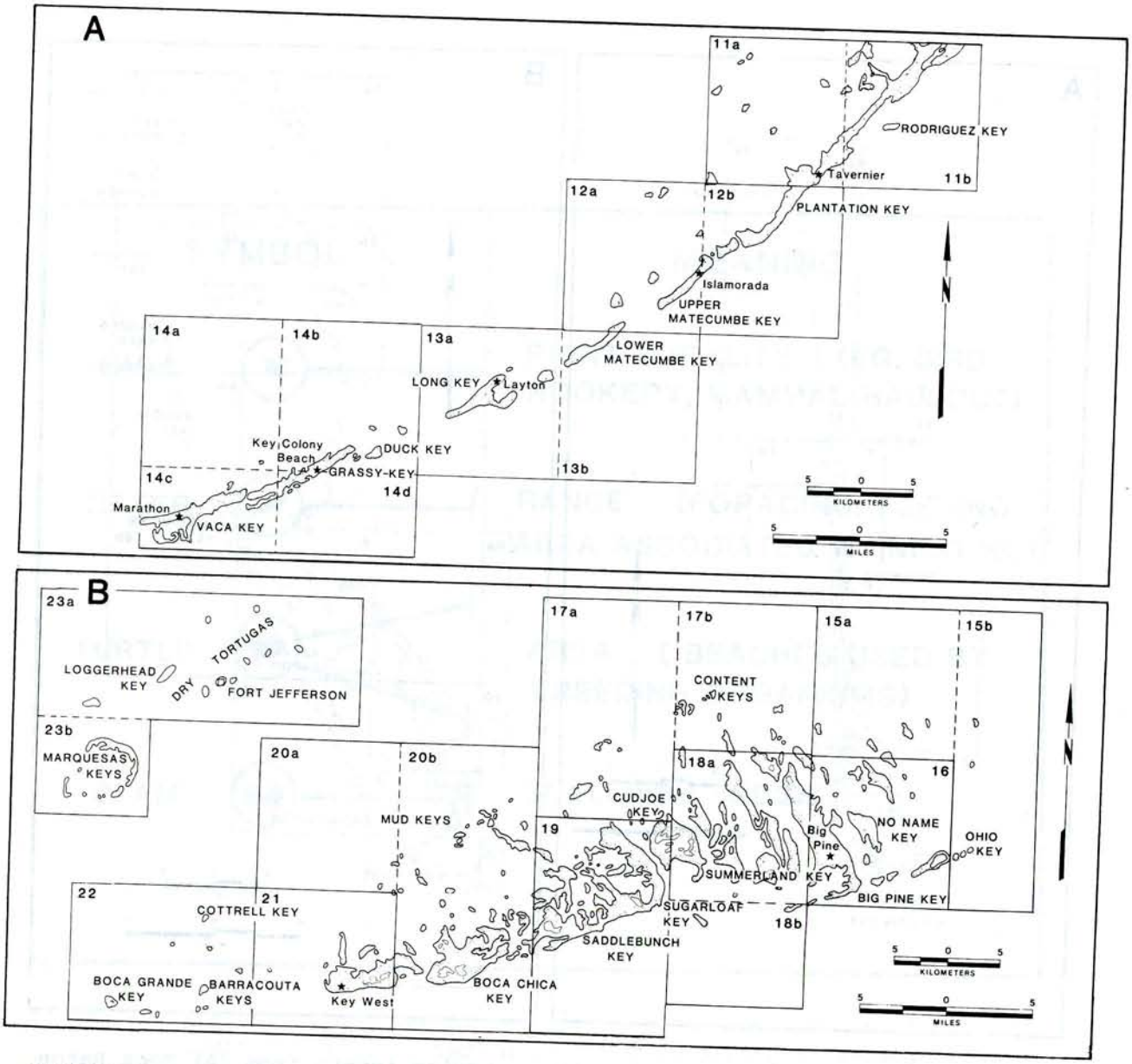


FIGURE 6. Areas of coverage by maps, showing insets from (A) Rodriguez Key to Marathon, and from (B) Ohio Key to Dry Tortugas.

OIL-SENSITIVE SHORELINES AND WILDLIFE

Oil-Sensitive Shorelines

The following shorelines were determined to be oil-sensitive and were ranked relative to sensitivity by the Environmental Sensitivity Index:

Exposed, Vertical Rocky Shores and Seawalls (ESI=1)
Exposed Rocky Platforms (ESI=2)
Fine-Grained Sand Beaches (ESI=3)
Coarse-Grained Sand Beaches (ESI=4)
Mixed Sand and Gravel Beaches and Fill (ESI=5)
Gravel Beaches and Riprap (ESI=6)
Exposed Tidal Flats (ESI=7)
Sheltered Rocky Shores and Seawalls (ESI=8)
Sheltered Tidal Flats (ESI=9)
Mangroves (ESI=10a)
Sheltered Mangroves (ESI=10b)

Each of these shoreline types is discussed in the following section. The following information is included for each:

1) Physical description (grain-size data appears in Supplement 1).
2) Plants and animals (a complete list by habitat is given in Supplement 1).
3) The behavior of oil.
4) Potential biological damages.
5) Recommendations for cleanup.
6) Illustration of the habitats including a drawing and representative aerial, ground, and closeup photographs.

EXPOSED, VERTICAL ROCKY SHORES AND SEAWALLS (ESI=1)

Physical Description

- Steep scarps in limestone bedrock:
  - Little or no sediments in intertidal zone
  - Exposed to high wave energy
- Man-made, concrete or tightly cemented seawalls:
  - Generally extend below low-tide mark
  - Located on shorelines facing open ocean or open fetch areas exposed to high waves or strong currents
  - Usually found with other types of man-made structures designed for shoreline protection (riprap, fill)
  - Subtidal sediments natural or dredged bedrock, sand to boulder-sized fill, or natural sand with seagrass beds
  - Usually backed by low, sandy fill or concrete structures

Plants

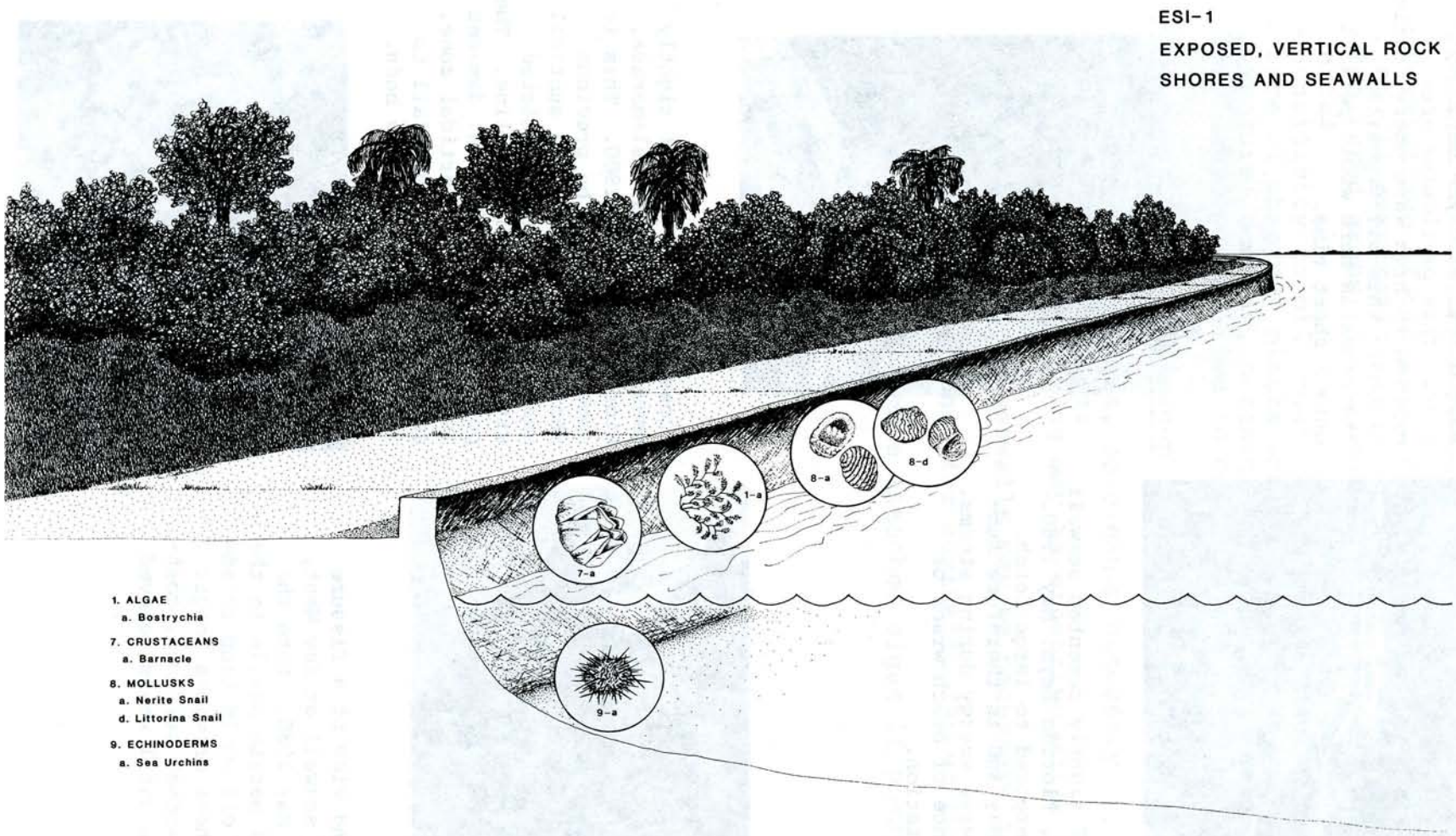
- Attached vegetation:
  - Composed of attached algae
  - High biomass and species diversity
  - Dominant species: Bostrychia (algae)

Animals

- Moderate epifaunal densities with high species richness and diversity:
  - Dominant organism observed: nerite snails
- Infauna and underrock fauna absent due to lack of available sediments and unconsolidated sediments

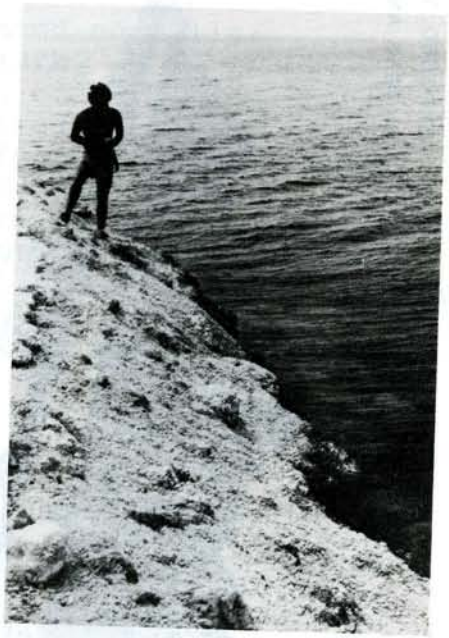
Behavior of Oil

- Heavy and weathered oils would adhere to rough surfaces and in crevices
- Low elevation would allow large waves to break and push oil over structures
- On more exposed shores:
  - Oil would be held offshore by reflected waves
  - Deposited light oils would be removed rapidly by wave action; heavier, sticky oils likely to remain longer
- On less exposed shores:
  - Oil removal would depend upon storm frequency



The geomorphic setting and the dominant, oil-sensitive species at exposed, vertical rock shores and seawalls, ranked as ESI=1.

Aerial view of exposed seawall at Ragged Key, Biscayne Bay, May 1980. This particular area is exposed to high wave energy during storms. This oil deposited on the seawalls here would persist only a short time.



Ground view of tightly cemented seawall at Islamorada, Florida Keys, May 1980. This area is exposed to large fetch over Florida Bay and is therefore subject to high wave energy during storms. Note the absence of beach wrack or attached vegetation.

Close-up ground view of tightly cemented seawall at Islamorada, Florida Keys, May 1980. This is same locality as the previous photograph, showing the subtidal seagrass bed often associated with this type of shoreline. The potential for biological damages is small in the intertidal zone, and floating oil would fail to impact subtidal seagrass beds.

Close-up ground view of a fissure in an exposed seawall at Key West, Florida Keys, May 1980. Note the aggregation of nerite snails in the fissure. The oil would tend to adhere within these crevices longer than on the exposed surfaces, coating the snails until waves removed the oil.

Potential Biological Damages

- Persistence of oil would be short due to substrate preventing oil penetration
- Sheltered areas have longer exposure periods than exposed areas
- Sensitivity to oil impact would be low due to high tolerance of observed plants and animals and short duration of exposure; however, certain species such as nerite snails are acutely sensitive to oil exposure

Recommendations for Cleanup

- On very exposed shores, no cleanup necessary
- On less exposed shores:
  - High-pressure spraying may be effective while oil is still liquid
  - Manual scraping of seawalls may be necessary for removal of tarry deposits
- Cleanup recommended only for aesthetic rather than environmental reasons
- Cleanup should not remove attached algae if possible

EXPOSED ROCKY PLATFORMS (ESI=2)

Physical Description

- Intertidal areas of rocky beach cut into limestone platform with widths from 15 to 500 feet
- Platform surfaces irregular, and abundant tide pools common
- Sharp drop-off at seaward edges of platforms
- Platforms extending often covered by a thin veneer of sediment (mud to cobble sized)
- Large accumulations of seagrass wrack often along high-tide line
- Located on bay- and ocean-facing shores exposed to direct wave attack
- Narrow, sand and gravel beaches common
- Back beach vegetation controlled by slope:
  - Low-relief shores with mangroves
  - Higher-relief shores with terrestrial vegetation
- Access to shore in unpopulated areas very difficult

Plants

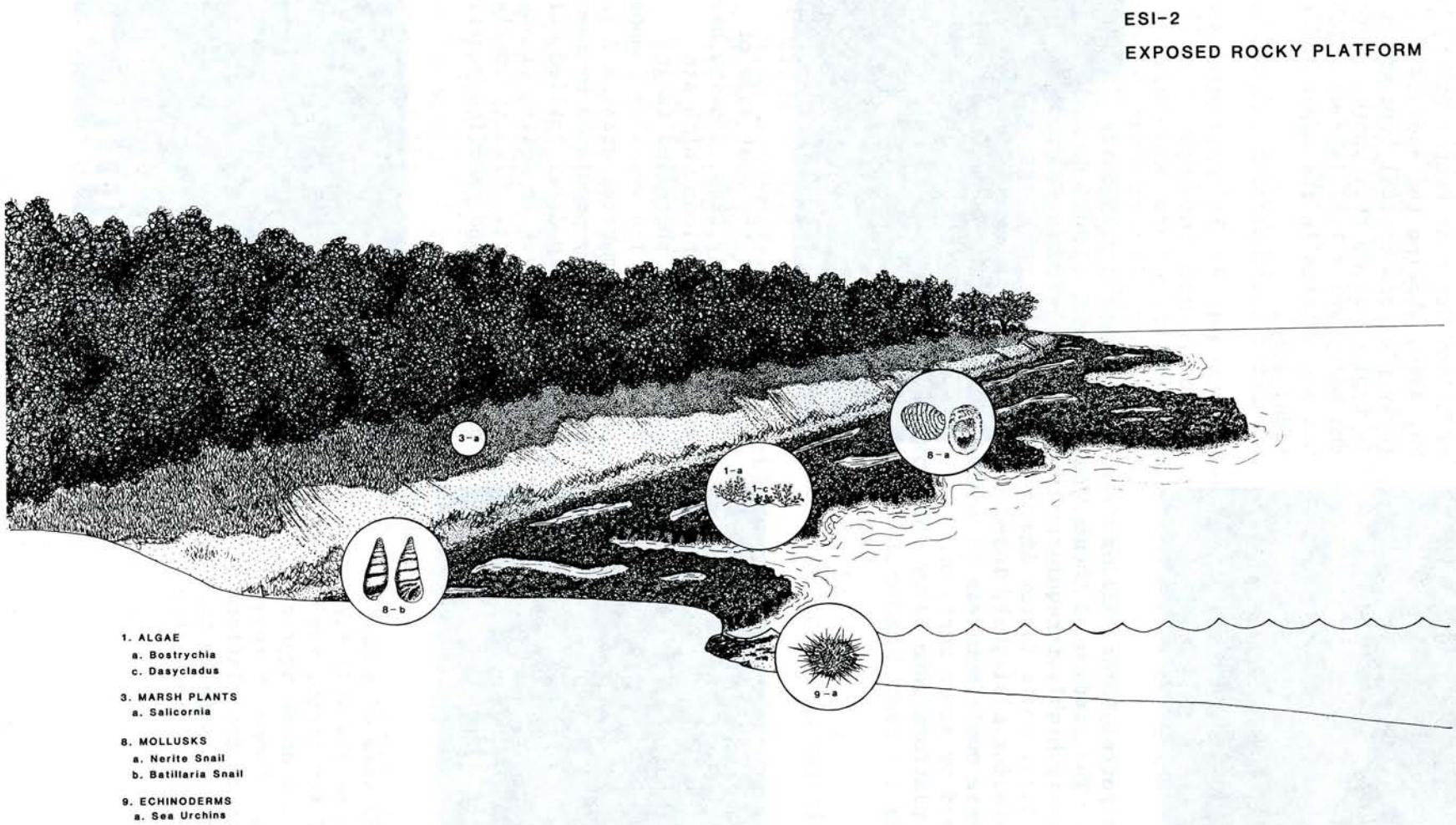
- Rooted vegetation:
  - Associated with rock platforms
  - Dominant species: red and black mangroves
- Attached vegetation:
  - Algae with very high biomass
  - Moderate diversity in high intertidal zones
  - High diversity in low intertidal zones

Animals

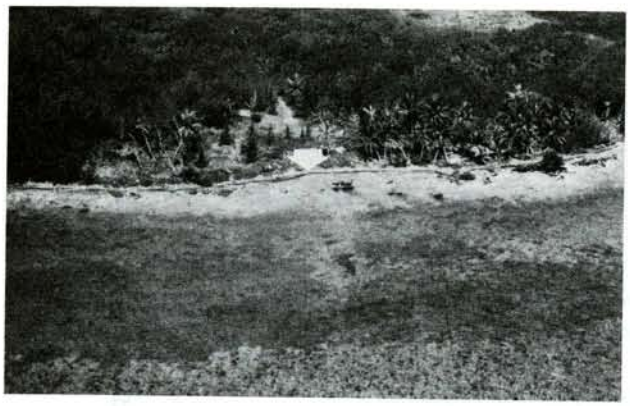
- Epifauna:
  - High densities with moderate species richness and diversity
  - Dominant species: batillaria, nerite, and littorina snails
- Infauna:
  - On rock platforms, infauna absent
  - In subtidal sediments offshore from rock platforms, moderate densities and species richness with low diversity
  - Dominant species (rarely observed): several polychaete species

Behavior of Oil

- Oil would tend to accumulate in wrack deposits, depressions, and sediments along upper intertidal zones
- Oil may persist for several months before cleanup by natural processes would be complete



The geomorphic setting and the dominant, oil-sensitive species at exposed rocky platforms, ranked as ESI=2.

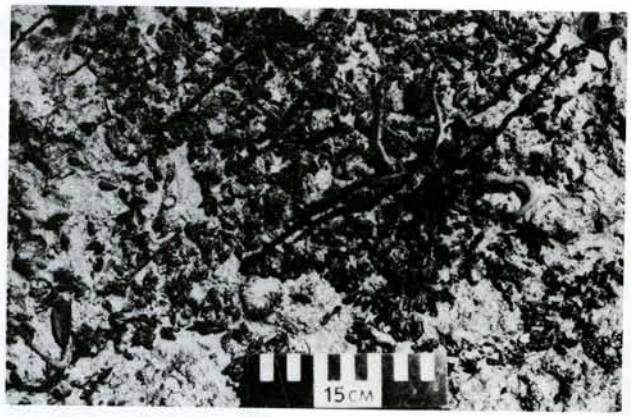


Aerial view of the Atlantic shore of Elliot Key near Petrel Point, May 1980, showing the exposed rocky platform coastal type which is typical along this shore. Note the heavy wrack line (arrow) which has accumulated in the upper intertidal area.

Ground view at Petrel Point, Elliot Key, May 1980. The surface of these rocky platforms is highly irregular with abundant tidal pools (arrow 1). Oil would remain for a slightly longer time in these pools but this would be removed by storm surf, or pushed up the platform into heavy wrack (arrow 2).

Ground view of the west side of Grassy Key, May 1980, showing heavy wrack accumulations which are common on the shoreline facing Florida Bay. The wrack is composed primarily of manatee grass and is usually densely populated by beach hoppers (amphipods). Spilled oil adhered to wrack impacting organisms living within it. Cleanup consists of collecting and removing heavily-oiled wrack.

Close-up ground view of exposed rocky platform on the Atlantic Ocean shore of Key Largo, May 1980. Shown is a dense aggregation of snails. Common throughout the surface of the platforms, these organisms are usually tolerant of oil, unless smothering occurs.



- Light oils would tend to be rapidly removed by waves and evaporation
- Tar balls and heavy oils would tend to melt into crevices and depressions, and may persist for long periods
- On shorelines facing Straits of Florida, chronic tar ball pollution may be heavy

Potential Biological Damage

- Probability of oiling would be great due to high degree of direct physical exposure
- Persistence of toxic oil would be low; rocky substrate would prevent oil penetration
- Light, aromatic fraction of beached oil would degrade rapidly and weather; however, heavier (less toxic) fractions would form a sticky asphalt which would melt and attach to platform serface; oil in this form:
  - would be persistent for an indefinite period of time because it is not easy to remove by natural, physical weathering processes
  - may potentially affect, exclude, or eliminate attached algae and epifauna because of increased thermal absorbance capacities of asphaltic oil
- Sensitivity to oil impact would be low due to:
  - Short duration of exposure to more toxic (aromatic) fractions of oil
  - High weathering rates of oil degradation for these areas
  - High tolerance of observed species to oil exposure; although certain species (such as nerite snails) are acutely sensitive to oil exposure, majority of species are tolerant of acute exposure

Recommendations for Cleanup Activity

- Oiled wrack should be removed where present
- Within high-use recreational areas:
  - High-pressure spraying of rocks may be effective with recovery of released oil
  - Scraping of rocks impossible due to irregular surface
  - No further cleanup is recommended
- Cleanup efforts should not remove attached plants and animals unnecessarily

FINE-GRAINED SAND BEACHES (ESI=3)

Physical Description

- Short stretches of beach with very low volumes of sand in the Florida Keys
- Located on ocean side of the Florida Keys, Virginia Key, and Key Biscayne
- Moderate to high wave activity
- Heavy wrack accumulations along high-tide line
- In the Florida Keys:
  - Offshore areas generally shallow
  - Subtidal grass flats overlying bedrock
- Usually high-use recreational areas with good access
- Uncommon in South Florida

Plants

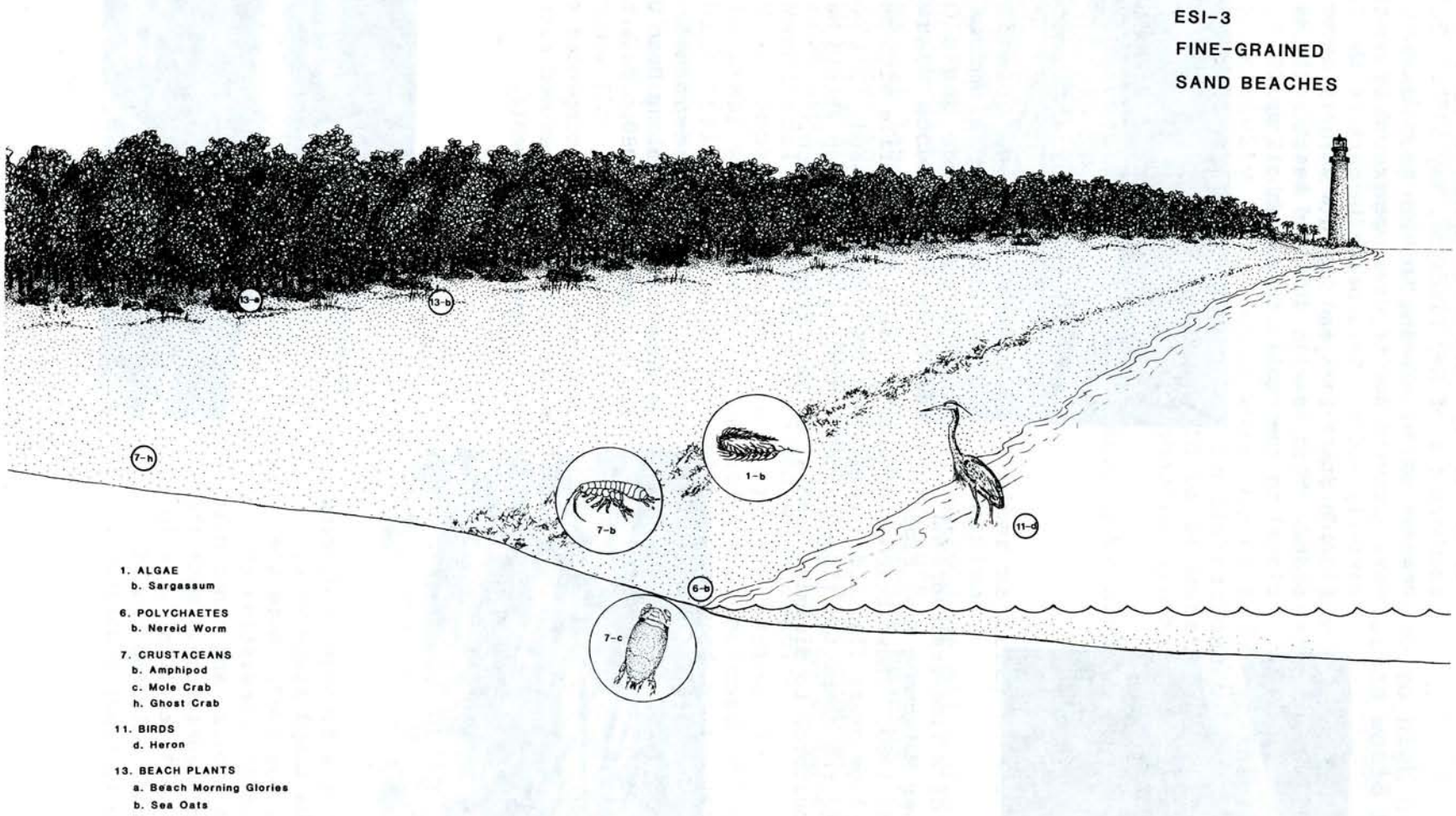
- Rooted vegetation:
  - Usually associated with sand dunes
  - 11 species observed
  - Dominant species: sea oats and beach morning glories

Animals

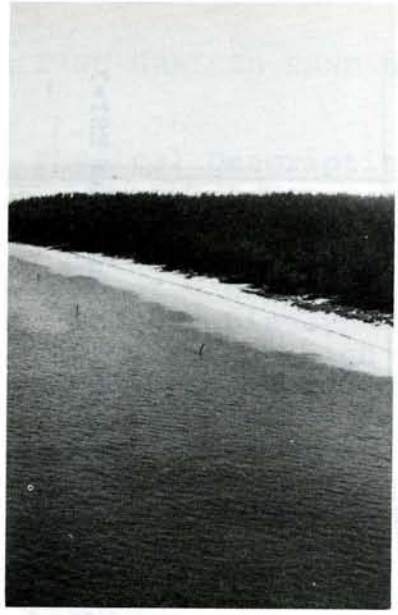
- Epifauna:
  - Low densities, species richness, and diversity
  - Dominant organisms observed: amphipods
- Infauna:
  - Low densities, species richness, and diversity
  - Dominant species: ghost crabs and mole crabs

Behavior of Oil

- Large accumulations would cover entire beach face
- Small accumulations would be deposited primarily along high-tide swash lines
- Compacted sediment would prevent penetration of oil deeper than a few centimeters; light oils penetrate deeper than heavier oils
- Oil may be buried up to 10-20 cm deep along upper beach face within several days due to depositional beach cycles
- Water-soluble fractions may contaminate interstitial water in the beach face
- Oil would accumulate in any wrack present
- Chronic tar balls are a problem in the Florida Keys



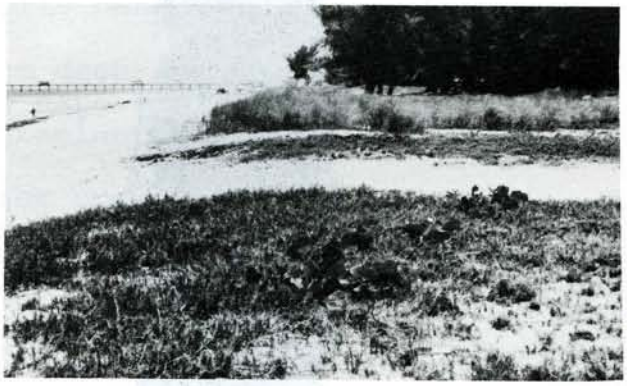
The geomorphic setting and the dominant, oil-sensitive species at fine-grained sand beaches, ranked as ESI=3.



Aerial view of fine-grained, sand beaches on the southern tip of Key Biscayne, May 1980. These beaches can be exposed to high to moderate wave activity due to waves generated by southeasterly winds. This beach is part of the Cape Florida State Park and is in a largely natural state. This heavily utilized beach would be closed to the public during an oil spill.

Ground view of a fine-grained, sand beach on lower Matecumbe Key, Florida Keys, May 1980. These beaches generally have a flat profile with an offshore shallow grass flat and a relatively low volume of sand. Oil would not penetrate the compacted fine-grained sediments and cleanup should be carefully monitored to minimize removal of sand from the beach.

Ground view of a fine-grained, quartz sand beach located along Bear Cut, Key Biscayne, May 1980. This beach is highly erosional. Oil would not penetrate deep into compacted sediments and would be removed naturally by waves and currents.



Ground view of a fine-grained, sand beach at John Lloyd State Park, Miami Beach, May 1980. Note the heavy vegetation, consisting of sea grape, sea oats, and other salt tolerant dune vegetation. Note the dense stand of Australian Pines in the background. Cleanup should avoid damage to beach vegetation.

Potential Biological Damages

- Probability of oiling would be great due to high degree of physical exposure, although sheltered areas would be oiled less frequently
- Persistence of oil impacts would be low to moderate due to small degree of oil penetration into sediments; shallow (5-10 cm) oil burial may occur
- Sensitivity of epifauna would be high due to inability of amphipods to tolerate high concentrations of oil
- Sensitivity of infauna would be somewhat lower (than epifauna) as most nereid polychaetes are highly tolerant of acute oil exposure
- Dune vegetation could be damaged by cleanup activities

Recommendations for Cleanup

- Cleanup should commence only after majority of oil has accumulated so sand removal is minimal
- Cleanup should concentrate on removal of oil and oiled wrack accumulated on upper swash zone
- Manual labor most desirable since these beaches are small in area and highly accessible
- Oiled sediment and beach wrack should be removed carefully from upper intertidal zones, preferably by shovels although mechanical methods may be used with caution
- No attempts should be made to remove buried oil
- In areas where heavy accumulations of beached oil occur, bird hazing techniques should be employed to prevent oiling of shorebirds
- Cleanup activities should avoid physical contact with natural dune vegetation

COARSE-GRAINED SAND BEACHES (ESI=4)

Physical Description

- Beaches north of Virginia Key:
  - Mostly renourished; composed of quartz and shell fragments
  - Characterized by narrow, steep beach faces with wide, high back beaches
- Beaches south of Virginia Key:
  - Mostly natural; composed of locally-produced carbonate sediment
  - Very narrow; usually less than 10 m wide between dune and low water
  - Heavy accumulations of wrack common
- Low to moderate wave activity under fair weather conditions; high wave activity during storms
- Very high-use recreational areas
- Most common beach type in South Florida

Plants

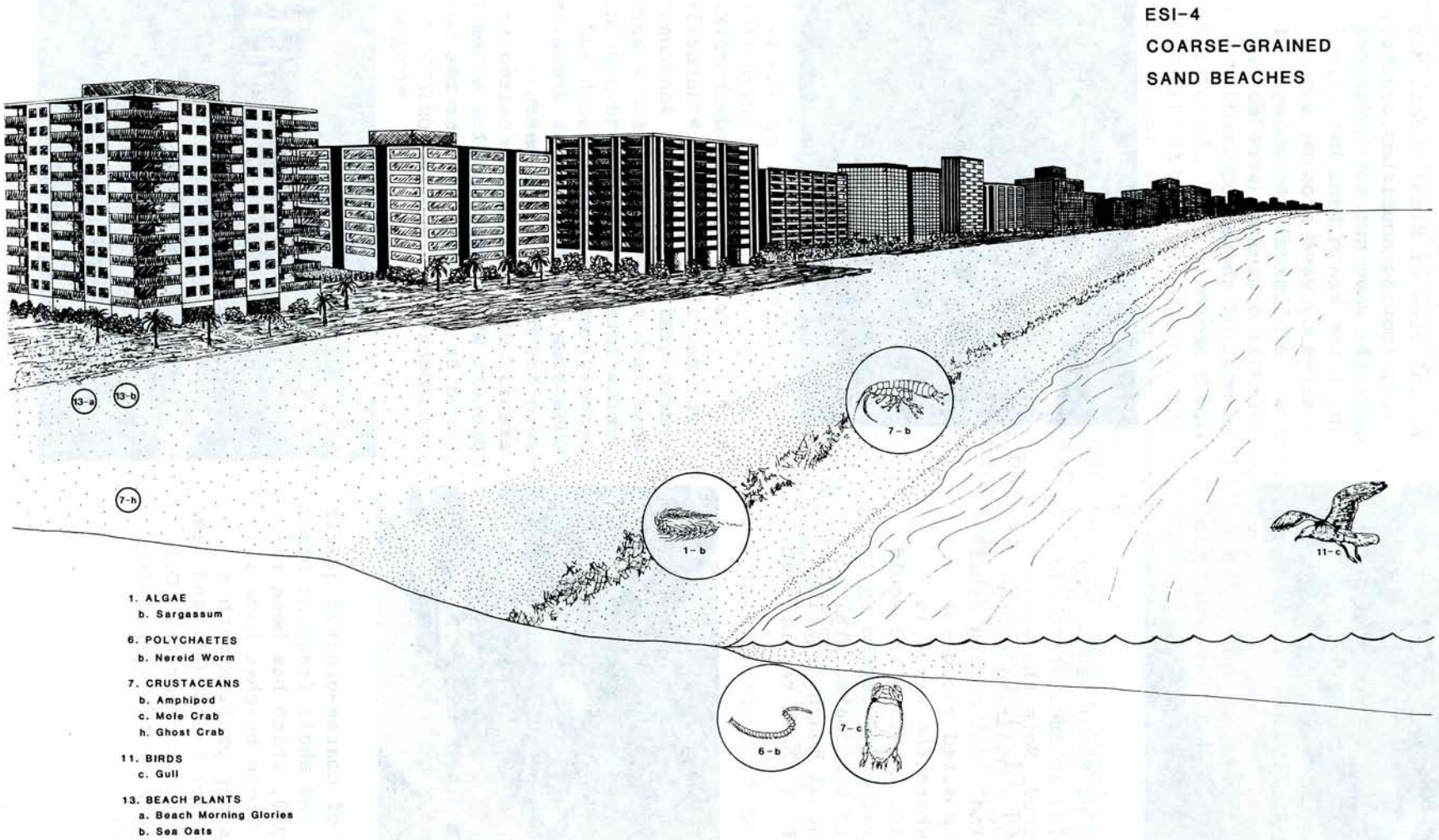
- Rooted vegetation:
  - 13 species observed
  - Dominant species: sea oats, seashore salt grass, and beach morning glories

Animals

- Epifauna:
  - Moderate densities with low species richness and diversity
  - Dominant species: amphipods
- Infauna:
  - Low densities, species richness, and biomass with moderate species diversity on high-use and renourished beaches
  - Dominant species: ghost and mole crabs, and several species of polychaete worms

Behavior of Oil

- Large accumulations would cover entire beach face
- Small accumulations would be deposited primarily along high-tide swash lines and in wrack deposits
- Oil penetration would be up to 10 cm; light oils penetrate deeper than heavy oils
- Oil may be buried up to 50-100 cm deep within several days
- Water-soluble fractions may contaminate interstitial water in beach face
- Chronic tar balls are presently a problem in the Florida Keys



The geomorphic setting and the dominant, oil-sensitive species at coarse-grained sand beaches, ranked as ESI=4.

Aerial view of Miami Beach, May 1980, showing nourished beaches. Note the wave-cut notch (arrow) where the beach face has been lowered by wave erosion about 1 m. Biological assemblages of infaunal organisms were absent in most of these nourished beach areas.

Ground view of Miami Beach, May 1980, showing an area which has been nourished. Note the waves generated by a moderate south-easterly wind. Oil coming ashore would be deposited along the swashline where the wrack is presently accumulating and would have penetration to depths up to 10 cm due to the coarse-grained size. Infaunal beach organisms were absent in these renourished beaches.

Ground view of Man Key, west of Key West, May 1980, showing a natural coarse-grained carbonate sand beach. This is a cuspate spit with a very narrow intertidal zone and a wide, densely vegetated back beach and dune area. Many infaunal organisms were found in natural beach areas. Oil would be deposited at the present wrack-line until a storm removed it or pushed it over the berm into back beach vegetation.

Ground view of coarse-grained quartz sand, coral and shell fragment beach area, May 1980, which has been renourished. These beaches have a relatively steep profile with a wide, flat, back beach area and are heavily used for recreation. Oil would percolate deeply into these coarse sands.

Potential Biological Damages

- Potential for oiling would be great due to high degree of physical exposure, although sheltered areas would be oiled less frequently
- Persistence of oil impact would be moderate to high due to high degree of oil penetration in coarse sediments; deep (50-100 cm) burial of oil may occur
- Sensitivity of epifauna would be high due to inability of amphipods to tolerate high concentrations of oil
- Sensitivity of infauna may be somewhat lower (than epifauna) as ghost and mole crabs, and many polychaete species have high tolerance to acute oil exposure:
  - Some toxicity may occur due to mechanical smothering (rather than chemical toxicity) if large quantities of oil are washed ashore
  - Additionally, subsurface burial of beached oil may result in chronic, sublethal effects in certain infaunal species such as polychaete worms

Recommendations for Cleanup

- Cleanup should commence only after majority of oil has accumulated so sand removal is minimized
- Cleanup should concentrate on removal of oil and oiled wrack on upper swash zone
- Mechanical methods should be used cautiously and only on nourished beaches
- Beaches of natural sand accumulation (south of Virginia Key) should be cleaned manually to minimize sand removal
- Sand removal should be closely monitored on all beaches
- Rapid removal of beached oil would prevent subsurface burial and would reduce duration of oil exposure
- Oiled sediments and beach wrack should be removed carefully from the upper intertidal zones, preferably by shovels although mechanical methods may be used cautiously
- No attempt should be made to remove buried oil
- In areas of heavy beached oil accumulations, bird hazing techniques should be employed to prevent oiling of shore-birds

MIXED SAND AND GRAVEL BEACHES AND FILL (ESI=5)

Physical Description

- Natural sand and gravel beaches:
  - Coarse material composed of shell and coral fragments
  - Located in areas of high wave activity
- Sand and gravel fill:
  - Composed of very poorly-sorted mixture of mud to cobble sediments
  - Can be very hard packed with mobile surface sediment
  - Beach sediment grain size and sorting not always related to wave conditions, thus high or low wave activity present
  - Profile generally artificially steepened
  - Usually easily accessible
  - Back beach characteristically steeply sloping
- Toe of beach face generally composed of coarser, better sorted sediment
- Wrack accumulations can be heavy in the Florida Keys

Plants

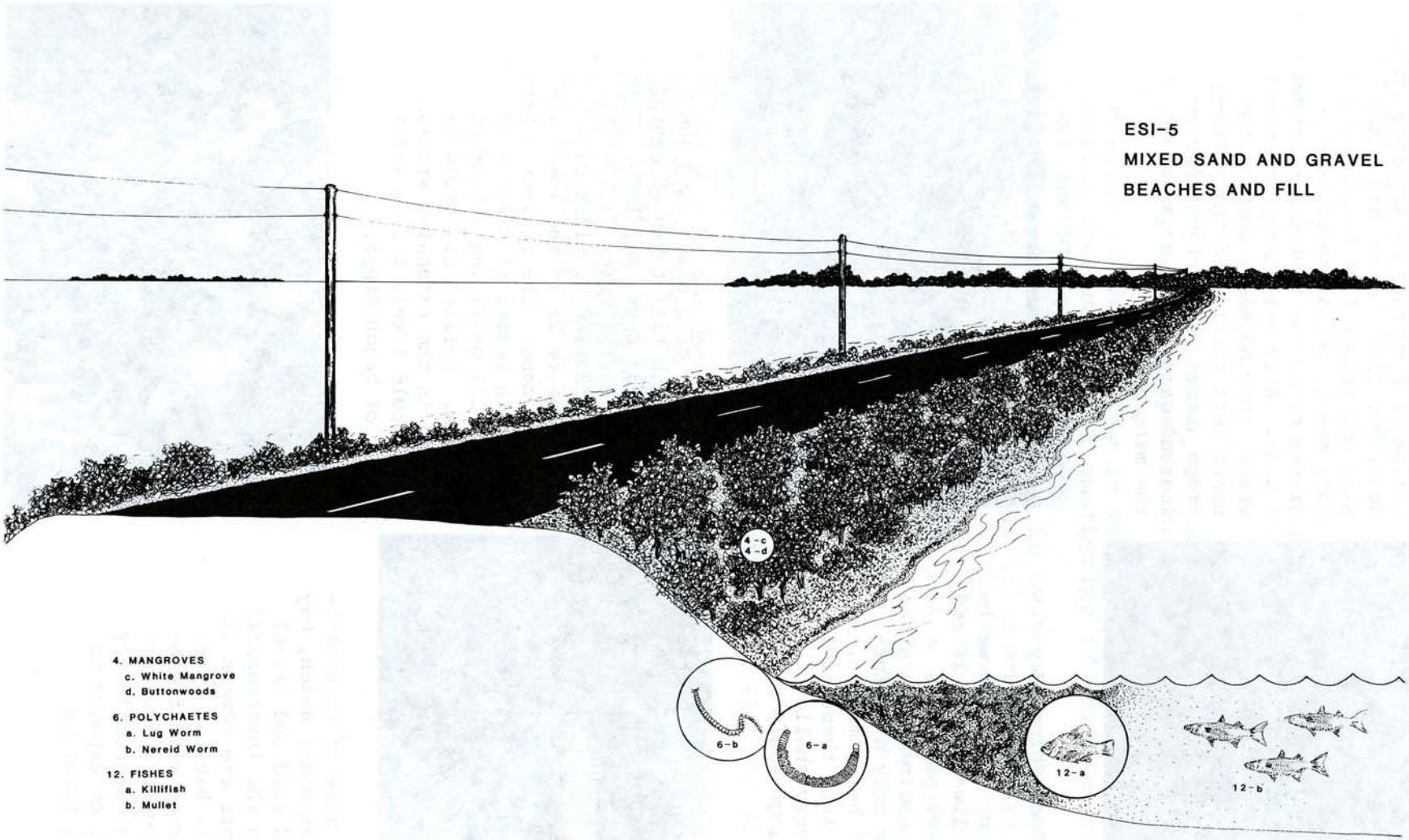
- Rooted vegetation:
  - Nine species observed
  - Dominant species: buttonwoods; white and black mangroves
- Attached vegetation:
  - Six species observed
  - Dominant species: Bostrychia (algae)

Animals

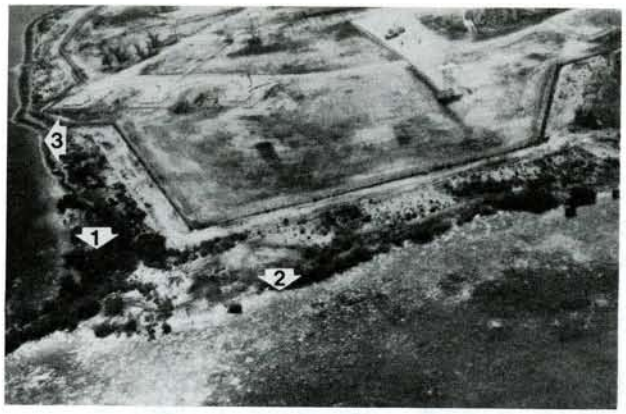
- Epifauna:
  - Moderate densities, biomass, species richness, and diversity
  - Dominant species: nerite snails, barnacles, and oysters
- Infauna:
  - Moderate densities and species richness with high species diversity
  - Dominant species: several species of polychaete worms

Behavior of Oil

- Oil penetration on natural beaches may be high with greatest penetration in coarser, well-sorted sediments
- Little to no penetration in fill due to poor sorting and compactness
- No burial of oil expected in fill



The geomorphic setting and the dominant, oil-sensitive species at mixed sand and gravel beaches and fill, ranked as ESI=5.

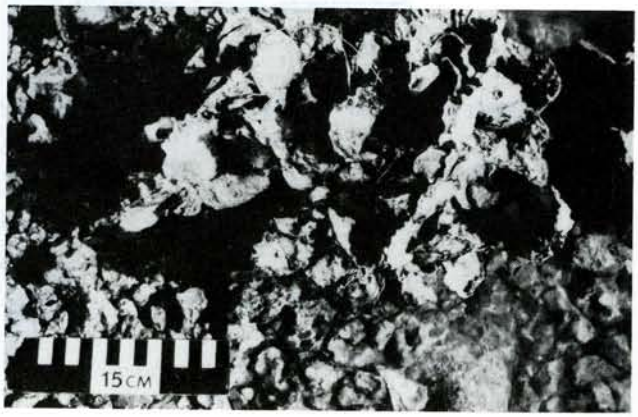


Aerial view of Fleming Key, Key West, May 1980. Shown are mixed sand and gravel fill beaches. Note the colonization of mangroves along the shoreline (arrows 1 & 2). Also note the pronounced wrack line and black zone in the upper left portion of the photograph (arrow 3). Potential biological damages are greatest in the mangroves.

Ground view on Boca Chica, May 1980, showing a mixed sand and gravel fill beach. Note the well-developed wrack line (arrow 1) and the colonizing red mangroves (arrow 2). The sediments here are hard-packed with only a surface veneer of gravel being mobile. Oil penetration into these sediments would be very shallow. These mangroves seedlings would be killed by spilled oil.

Ground view of a mixed sand and gravel beach fill taken at Ramrod Key, Florida Keys, May 1980. This shows extensive wrack (arrow 1), and colonization by black mangroves (arrow 2) in the lower intertidal zone. The sediments here are a thin veneer of mixed sand and gravel fill overlying a bedrock platform. Spilled oil would be trapped in the extensive wrack, which would likely kill a large number of beach hoppers.

Close-up ground view of an oyster-colonized rock at Miami Beach, May 1980, at a mixed sand and gravel fill beach along the intercoastal waterway. Oysters are common inhabitants of this habitat type, especially in areas with freshwater runoff. Oysters are very oil tolerant, unless completely covered with oil or exposed to highly toxic oil fraction.



Potential Biological Damages

- Probability of oiling would be moderate, except in areas with a high degree of physical exposure
- Persistence of oil impact would be somewhat higher at natural sand and gravel beaches due to high degree of oil penetration into coarser, well-sorted sediments and subsequent deep burial
- Sensitivity of epifauna to toxic oil fractions would be low since many observed species are tolerant of acute oil exposures:
  - However, some toxicity in attached sedentary epifauna may result from mechanical smothering if large quantities of oil are washed ashore
  - Chronic, sublethal effects in oysters and mussels may occur due to their known abilities to bioconcentrate aromatic, toxic oil fractions within soft body tissues
- Sensitivity of infauna to toxic oil fractions would be low as most species of polychaetes have a high degree of tolerance to acute oil exposure; some toxicity may occur due to mechanical smothering if large quantities of oil are washed ashore

Recommendations for Cleanup

- Cleanup should commence only after majority of oil has impacted beach
- Oiled wrack and debris deposits should be removed
- Low- and high-pressure spraying may be used effectively
- Mechanical scraping and/or reworking of sediment not recommended or effective
- Cleanup by mechanical means should be used with extreme discretion to avoid excessive sediment removal

GRAVEL BEACHES AND RIPRAP (ESI=6)

Physical Description

- Predominantly gravel- to boulder-sized, riprap revetments
- Riprap generally composed of local limestone; boulders very irregular in size and shape
- Moderate to high wave activity, but sporadic in frequency
- Large accumulations of wrack south of Miami
- On riprap shores, little or no beach exposed at low tide
- Subtidal sediments adjacent to riprap structures tend to be finer grained, better sorted, and naturally occurring

Plants

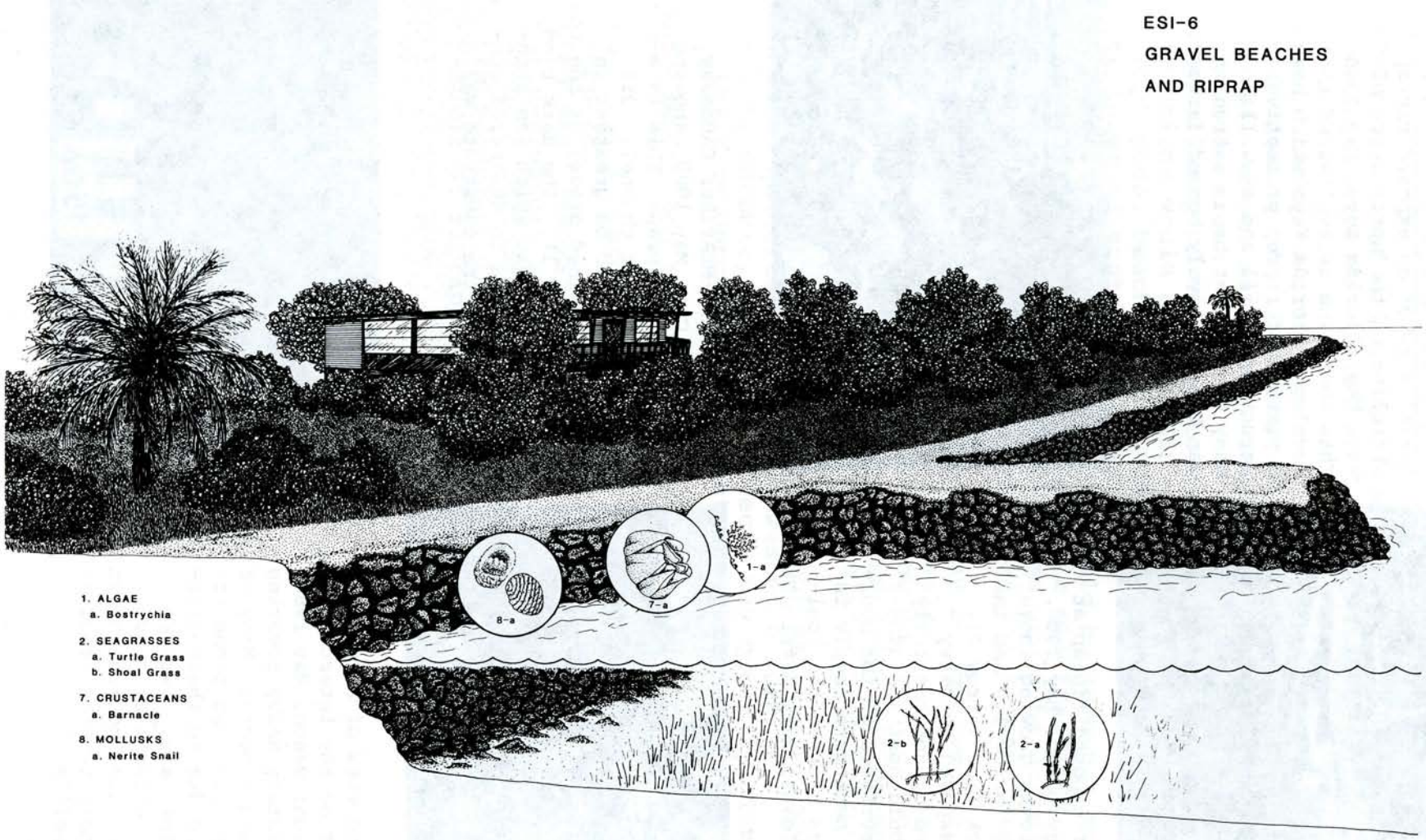
- Rooted vegetation:
  - 15 species observed
  - Dominant species: red mangroves and sea purslane
- In adjacent subtidal grass flats, turtle and shoal grasses dominant plant species

Animals

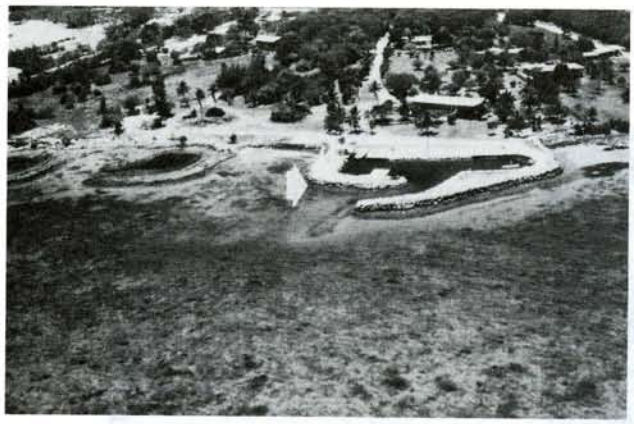
- Epifauna:
  - High densities, species richness, and diversity
  - 23 species observed
  - Dominant species: amphipods, batillaria snails, barnacles, and nerite snails
- Infauna:
  - High densities, species richness, and diversity
  - 12 species observed
  - Dominant species: three species of polychaete worms

Behavior of Oil

- On gravel beaches, oil would coat individual pieces and penetrate to several tens of centimeters
- Cavities in riprap structures may be completely filled
- Penetration would be greatest in areas of largest grain size and least sorting
- Heavy and weathered oils would adhere to irregular surfaces on riprap boulders
- Light oils would be rapidly removed by wave action around riprap



The geomorphic setting and the dominant, oil-sensitive species at gravel beaches and riprap, ranked as ESI=6.



Aerial view of an exposed riprap shoreline on the north shore of Vaca Key, Florida Keys, May 1980. This shoreline is typical of the developed Florida Keys which have a mixture of riprap protective structures, fill and seawalls. Many of the boat basin entrances can be effectively boomed (arrow).

Ground view of exposed riprap at Port Largo, Key Largo, May 1980. Note the mangroves growing above the beach face (arrow 1), and the extensive wrack line (arrow 2). This area is exposed to heavy waves generated by southeasterly winds. Oil would coat and adhere to the rough surfaces of the boulders and also penetrate deeply into the crevices between the boulders making cleanup very difficult.

Ground view at McArthur Causeway, Government Cut, May 1980, showing a seawall and riprap. This is a heavily used boat channel. Oil penetration would be greatest in the coarse-grained gravel at the toe of beach (arrow 1). The dark band (arrow 2) is algae which was abundant and diverse in sheltered conditions where the substrate was stable.

Close-up ground view of an exposed riprap habitat on the intercoastal waterway at Miami Beach, May 1980. Note the moderately heavy covering of barnacles and limpets. Many of these organisms are less prone to chemical oiling due to their closing plates. They are, however, subject to the effects of heavy mechanical coverage and subsequent elevation in temperatures resulting from oil spills.

Potential Biological Damages

- Probability of oiling would be greatest in areas of direct physical exposure; sheltered areas would be oiled less frequently
- Persistence of oil impacts would be moderate to high due to high degree of oil penetration into coarse sediments; deep burial of oil may occur, thus increasing persistence of oil in these areas
- Sensitivity of epifauna to light aromatic (more toxic) oil fractions would be moderate since some of observed species (amphipods, beach roaches, anemones, and mites) are unable to tolerate acute oil exposure:
  - Majority of epifauna present would be somewhat more tolerant of acute exposure to aromatic oil fractions
  - Many attached sedentary organisms would be acutely susceptible to mechanical smothering if large quantities of oil make landfall
  - Additionally, chronic impacts may be observed in filter feeders such as oysters and mussels
- Sensitivity of infauna would be low due to high degree of acute oil tolerance exhibited by most species present:
  - Polychaete worms have a particiularly high degree of tolerance to acute oil exposure
  - Some toxicity from mechanical smothering may occur if large quantities of oil are washed ashore
  - Some chronic, sublethal effects may occur in clams due to their tendency to bioconcentrate petroleum hydrocarbons

Recommendations for Cleanup

- On gravel beaches, heavily oiled wrack and debris should be removed
- Sediment removal should be minimized
- High-pressure spraying of oiled riprap may help in cleaning exposed surfaces, but would have little effect on oil penetrated deeply into structures
- Removal of riprap is not recommended

EXPOSED TIDAL FLATS (ESI=7)

Physical Description

- Vary in width up to tens of meters
- Sediment composition dominated by sand with minor amounts of mud
- Moderate to high wave activity and tidal currents
- Migrating sand bars often present on seaward limit of flats
- Located in open bays, in the lee of offshore islands, or near tidal inlets
- Generally fringed by mangrove forests
- Can be sparsely to heavily vegetated by sea grasses
- Uncommon in South Florida due to small tidal range

Plants

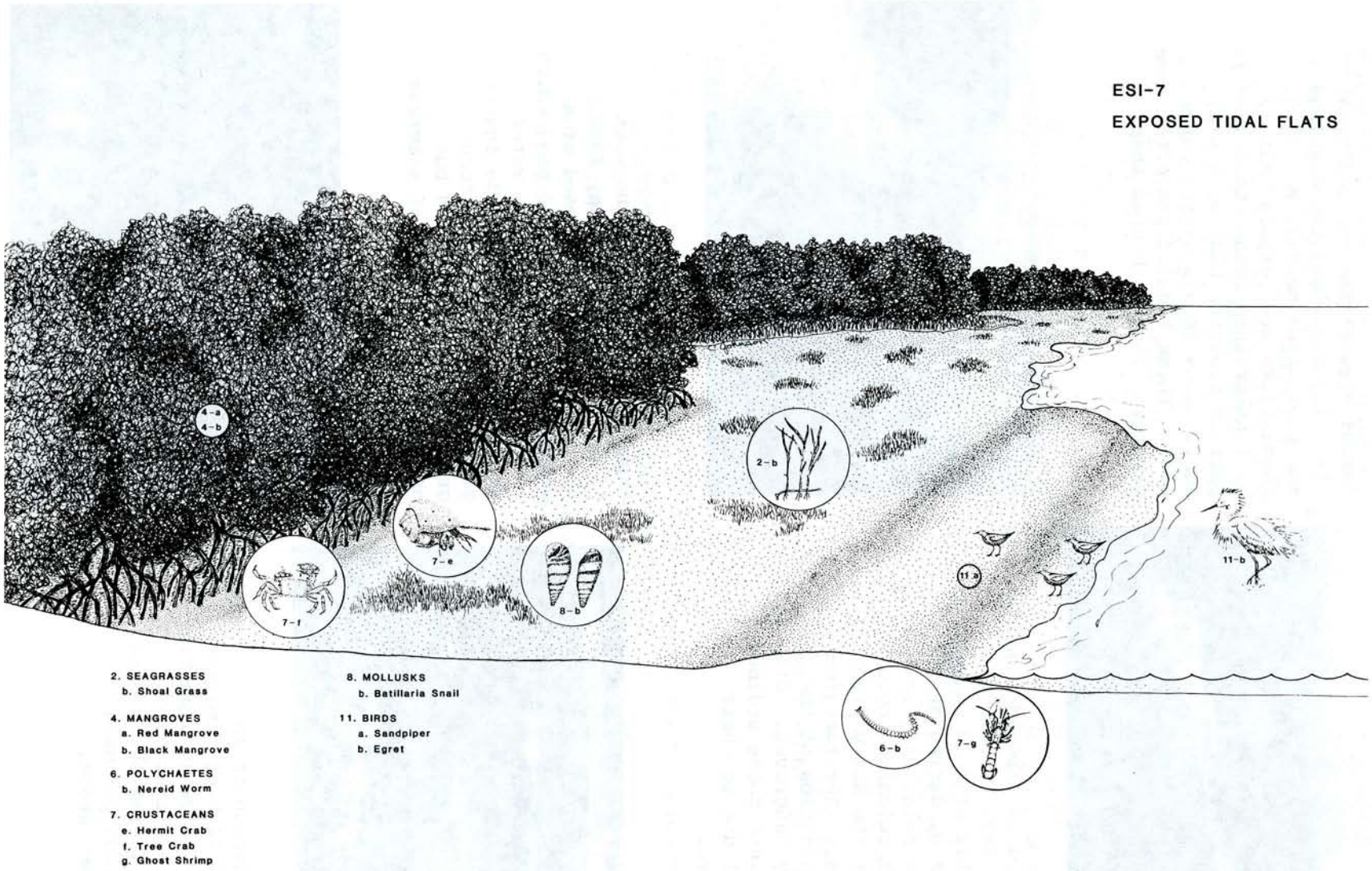
- Rooted vegetation:
  - Eight species observed
  - Dominant species: red and black mangroves
- Shoal grass the only grass observed throughout surface of tidal flats

Animals

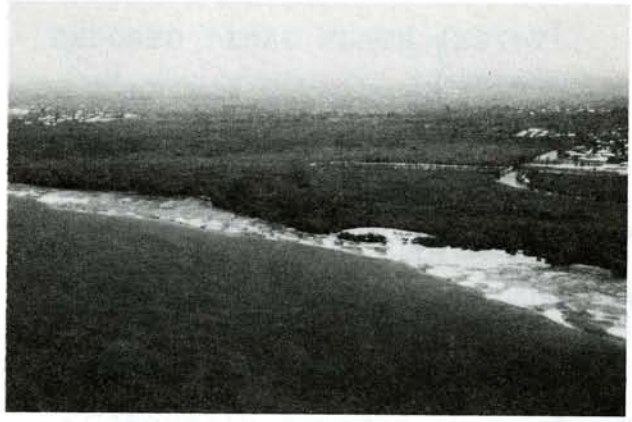
- Epifauna:
  - High densities, moderate species richness, and low species diversity
  - Five species observed
  - Dominant species: land crabs, batillaria snails, and fiddler crabs
- Infauna:
  - High densities and species richness with moderate species diversity and biomass
  - 14 species observed
  - Dominant species: several species of polychaete worms

Behavior of Oil

- Most oil would be transported across tidal flat surfaces by waves and tidal currents
- Oil would be deposited primarily along high tide lines
- Oiled sea grass beds would be cleaned naturally within weeks or after next storm

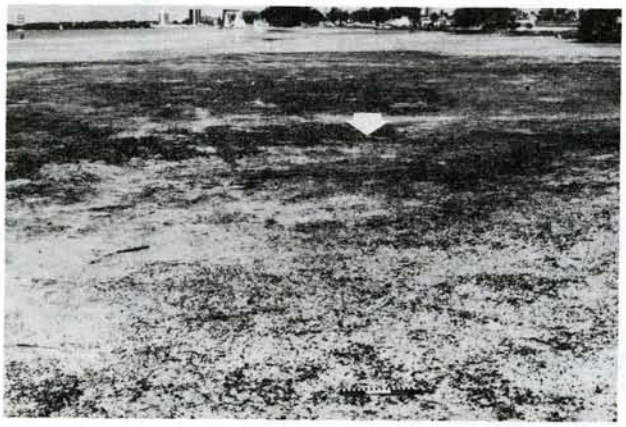


The geomorphic setting and the dominant, oil-sensitive species at exposed tidal flats, ranked as ESI=7.



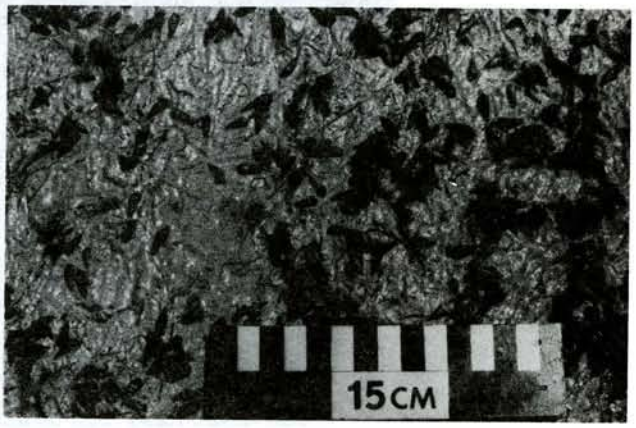
Aerial view of the exposed tidal flats located along the mainland shore of Biscayne Bay, May 1980. These flats are composed mainly of fine-grained sands stabilized in part by seagrass beds with small mobile sand shoals on the outer edge. These tidal flats often have mangroves growing behind them.

Ground view of an exposed tidal flat at Boot Key, Florida Keys, May 1980. This area is subject to high wave energy during storms and consists of a relatively low-sloping beach colonized by mangroves. Note the heavy wrack of manatee grass in the foreground and the colonization of the back beach berm by mangroves. Oil penetration into these sediments would minimal due to their compact nature.



Exposed tidal flat on the west side of Key Biscayne, May 1980. The tidal flat is composed of a well-sorted fine-grained sand which is tightly compacted and water saturated. Note the dense aggregation of snails in the foreground and the scattered but mostly heavy coverage of seagrass (arrow).

This is a close-up of an exposed tidal flat at Virginia Key, May 1980, Showing a portion of the dense aggregation of snails (Batillaria) which numbered over 1,000 per meter squared in some areas.



Potential Biological Damages

- Probability of oiling would be great due to high degree of direct physical exposure of these habitats
- Persistence of oil impact would be low due to minor degree of oil penetration into fine-grained sediments and the high degree of physical exposure
- Sensitivity of epifauna to light aromatic oil fractions would be low to moderate since only a few species (amphipods and brittle stars) present are unable to tolerate acute oil exposure:
  - Majority of epifaunal species present would be more tolerant of acute exposure to aromatic oil fractions
  - Toxicity from mechanical smothering would be low since all epifaunal species observed are mobile and could avoid direct exposure
- Sensitivity of infauna to toxic oil fractions would be low as most observed species have a known tolerance of acute oil exposure:
  - Some mortality may occur due to mechanical smothering if large quantities of oil are washed ashore
  - Chronic, sublethal effects may occur in filter feeders (cockles and clams), which have known potentials for bioconcentrating petroleum hydrocarbons

Recommendations for Cleanup

- Cleanup impossible in most areas due to soft, water-saturated sediments and inaccessibility
- Cleanup should concentrate on oil and oiled debris removal from high-tide line
- Heavy machinery should be restricted because of potential of mixing oil into sediments

SHELTERED ROCKY SHORES AND SEAWALLS (ESI=8)

Physical Description

- Rocky shores composed of limestone bedrock:
  - Very narrow beaches with vertical scarps and no sediment
  - Pitted and irregular surfaces
  - Low-energy wave and current environments
- Man-made concrete seawalls:
  - Dominate shorelines along interior and sheltered areas in populated regions
  - Structures extend beneath low-water level
  - Generally vertical or nearly so with smooth, regular surfaces
- Very common in South Florida

Plants

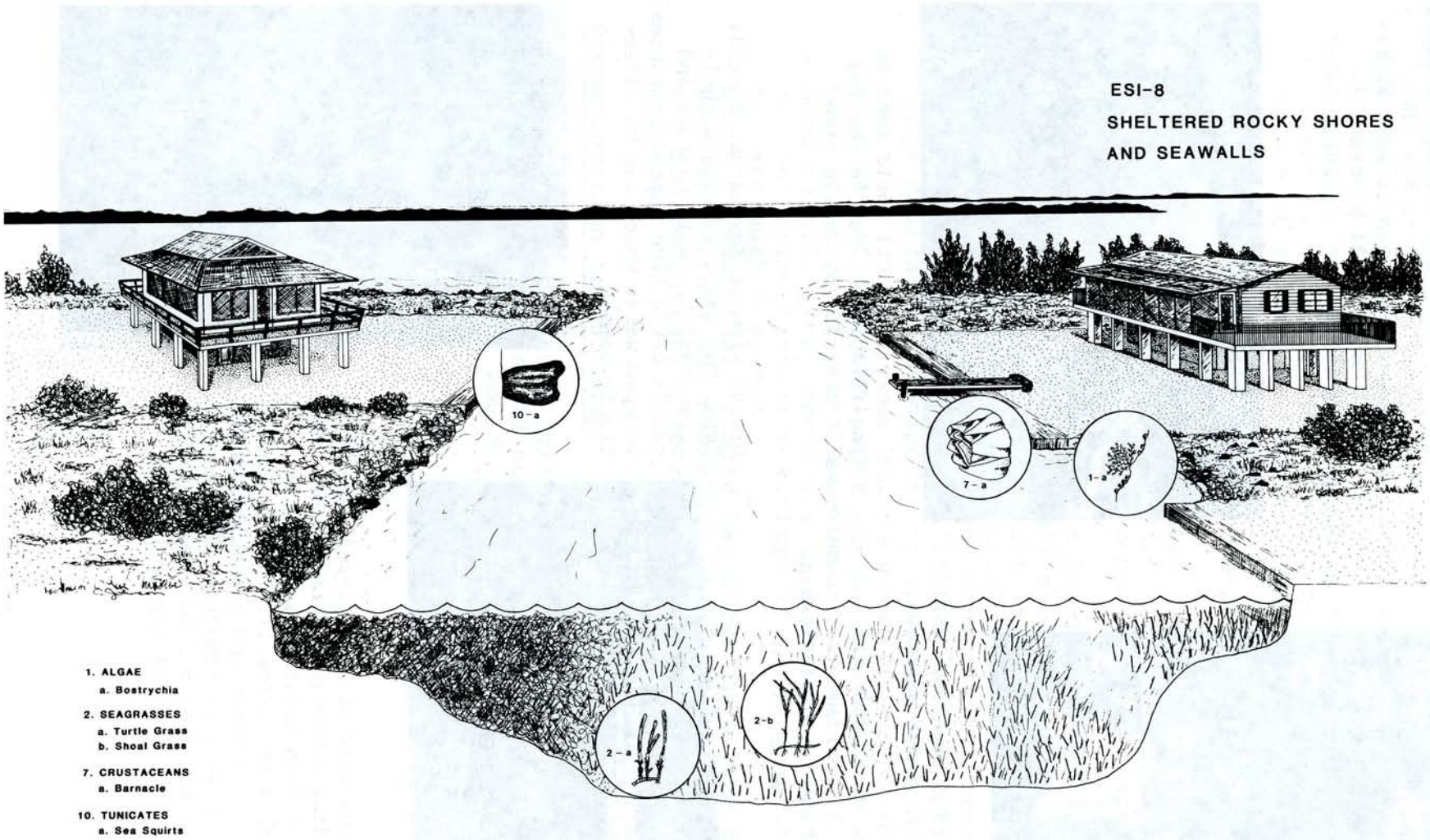
- Rooted vegetation:
  - Five species observed
  - Dominant species: red and black mangroves
- Attached vegetation:
  - Seven species of algae and one species of lichen observed
  - Dominant species:
    - 1) Black lichens in the supratidal zone
    - 2) *Bostrychia* and other types of red algae in the mid to lower intertidal zones

Animals

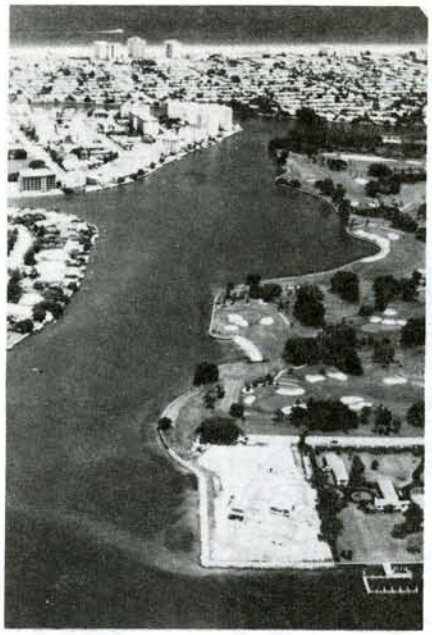
- Epifauna:
  - High densities and species richness with low species diversity
  - 14 species observed
  - Dominant species: barnacles, limpets, ribbed mussels, and oysters
- Infauna:
  - None observed

Behavior of Oil

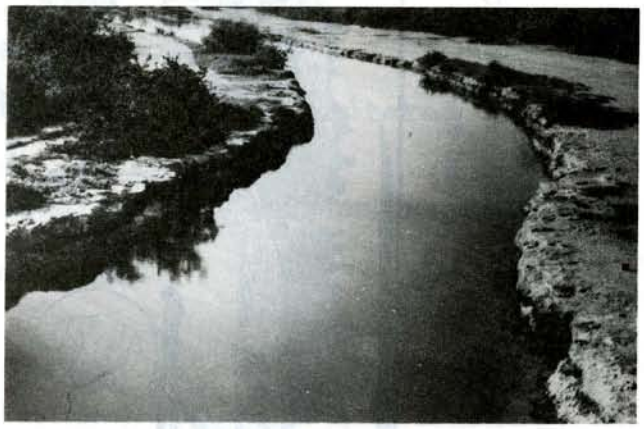
- Heavy and weathered oils would readily adhere to rough surfaces
- Light oils would be less sticky and more easily removed
- Persistence would be long-term (1-5 years), especially on irregular surfaces



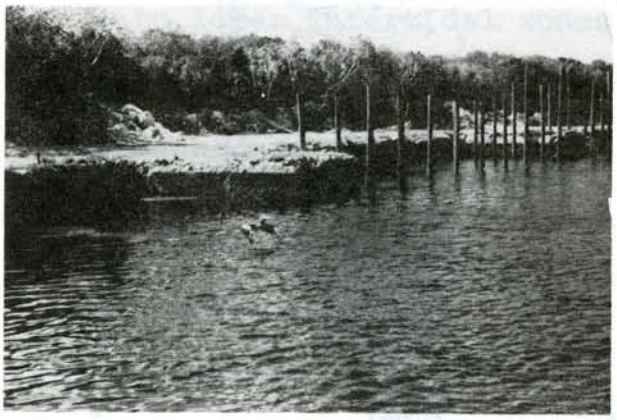
The geomorphic setting and the dominant, oil-sensitive species at sheltered rocky shores and seawalls, ranked as ESI=8.



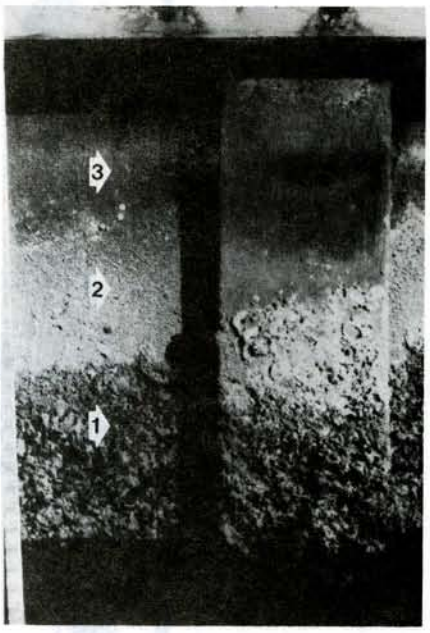
Aerial view of sheltered seawalls located inside canals on Miami Beach, May 1980. These structures are exposed to wave activity only during storms. All precautions should be taken to prevent the entrance of oil into these areas.



Aerial view of a man-made canal on Sugarloaf Key, Florida Keys, May 1980. Canals generally have a vertical rocky face. Oil would tend to adhere to the rough surfaces and have a long-term impact due to the low kinetic energy environment of these types of shorelines. Canals also have a very high recreational use.



Ground view of Key Largo, Florida Keys, May 1980, showing a sheltered marina. Small marinas and canals often have narrow entrances to open water which can be effectively boomed.



Close-up ground view of a sheltered seawall on the intercoastal waterway at Miami Beach, May 1980. Note the lush growth near the water line in a dark zone (arrow 1). This is comprised of algae, oysters and barnacles. Note a white zone above this comprised of barnacles (arrow 2) and then a black zone above this consisting of lichens (arrow 3).

Potential Biological Damages

- Probability of oiling would be low due to the sheltered nature of these habitats
- Persistence of oil impact would be variable:
  - Degree of oil penetration would be low due to impervious nature of sediments; however, lack of physical exposure in these sheltered areas would reduce rate of mechanical weathering, thus prolonging the persistence of spilled oil
  - Vertical faces would have short duration of exposure while topographically more flat (horizontal), rocky intertidal areas would have a more chronic exposure problem
  - With the high temperatures in South Florida, light aromatic fractions of beached oil should weather rapidly; thus, chronic impact may result from mechanical smothering rather than chemical toxicity
- Sensitivity of epifauna to light aromatic oil fractions would be moderate due to inability of certain species (nerite snails and amphipods) to tolerate acute oil exposure:
  - Majority of epifaunal species present would be somewhat more tolerant of acute exposure to aromatic oil fractions
  - Some mortality may occur due to mechanical smothering (rather than chemical toxicity) if large quantities of oil are washed ashore
  - Chronic, sublethal effects may occur in filter feeders such as oysters and mussels, which have known potential for bioconcentrating petroleum hydrocarbons in soft body tissues

Recommendation for Cleanup

- Low- and high-pressure spraying may be effective with recovery of oil released during cleanup operations
- Large accumulations would warrant use of booms and skimmers

SHELTERED TIDAL FLATS (ESI=9)

Physical Description

- Composed of soft mud
- Sheltered from waves and/or strong tidal currents
- Very shallow, even at high tide
- Very inaccessible
- Fringed by dwarf mangroves
- Uncommon in South Florida

Plants

- Rooted vegetation:
  - Associated with tidal flat fringe
  - Dominated by red and black mangroves
- Attached vegetation:
  - Distributed throughout surface of tidal flat
  - Dominant plant types: blue-green algae, microscopic green algae, shoal grass, and manatee grass

Animals

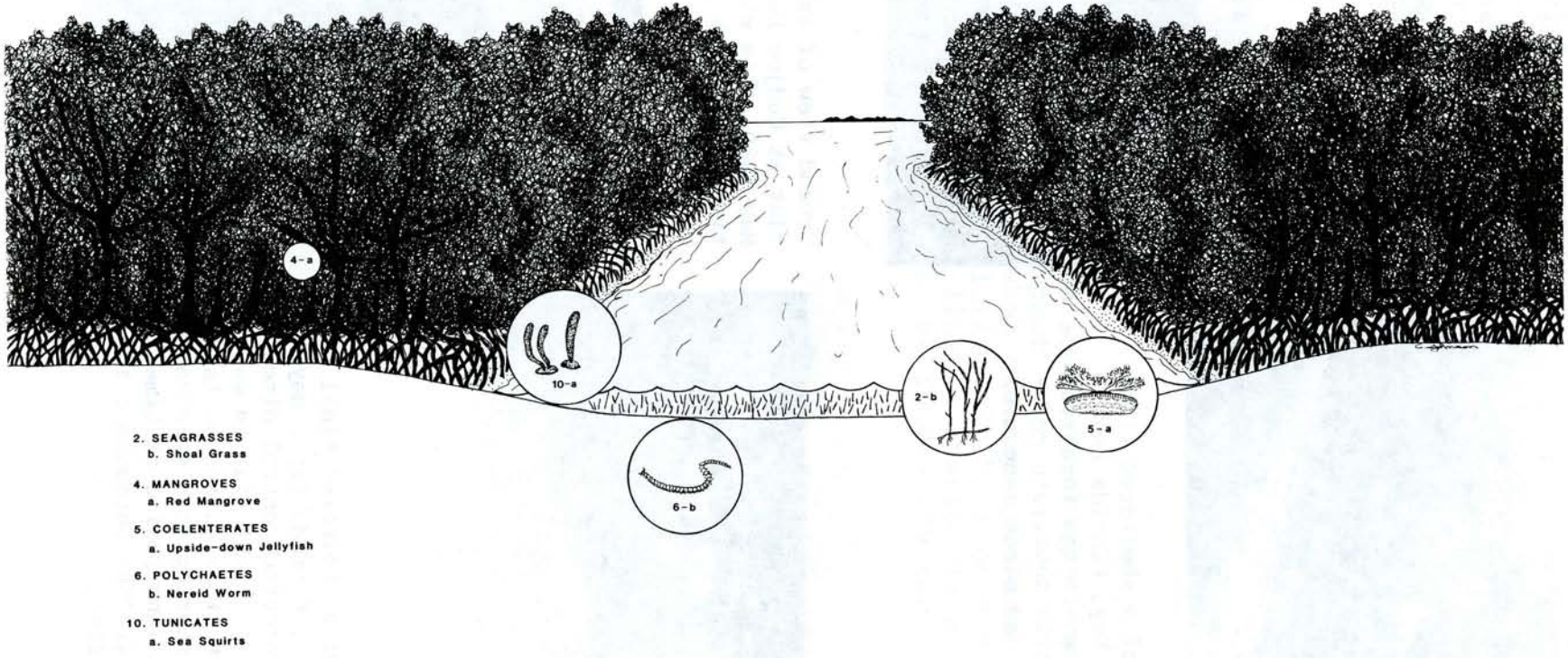
- Epifauna:
  - High densities with low species richness and diversity
  - Two species observed
  - Dominant species: batillaria snails
- Infauna:
  - Low densities, species richness, and diversity
  - Only one species observed: a nereid polychaete worm
  - Upside-down jellyfish and planktonic copepods often associated with this environment

Behavior of Oil

- Persistence of oil would be long-term under heavy accumulations of detritus
- Potential for incorporation of petroleum hydrocarbons into interstitial groundwater in tidal flat sediments

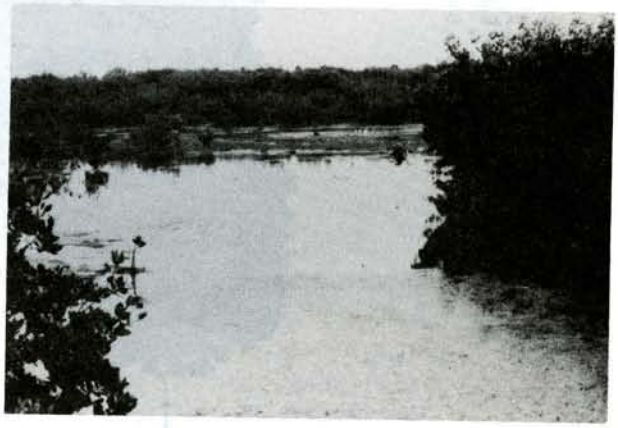
ESI-9

SHELTERED TIDAL FLATS



The geomorphic setting and the dominant, oil-sensitive species at sheltered tidal flats, ranked as ESI=9.

Aerial view of a sheltered tidal flat (arrow) at the head of a lagoon at the Marquesas, Florida Keys, May 1980. These habitats are sheltered from wave, tidal and wind generated kinetic energy.



Ground view of a sheltered tidal flat at Long Key, Florida Keys, May 1980. Shown in the foreground is a muddy/marly substrate colonized by red and black mangroves.

Ground view of sheltered tidal flat at Cudjoe Key, Florida Keys, May 1980. This shows the colonization of the rock and mud substrate by mangroves.

Ground view of a sheltered tidal flat at Boca Chica Key, Florida Keys, May 1980, which has a mosquito control ditch dug through it. This tidal flat is well inland and forms part of an extensive lagoonal system. Oil entering this area would be trapped for a long period of time. Note the growth of seagrasses throughout the surface of the tidal flat.

Potential Biological Damages

- Probability of oiling would be low due to high degree of sheltering
- Persistence of oil would be long-term due to degree of physical exposure to waves and tidal currents
- Sensitivity to epifauna would be high due to low tolerance of acute oil exposure exhibited by amphipods:
  - Batillaria snails would be more tolerant of acute oil exposure; however, chronic sublethal effects may occur
- Sensitivity of infauna would be low due to high tolerance of acute oil exposure:
  - Impacts from smothering may occur if large quantities of oil are washed ashore

Recommendations for Cleanup

- No cleanup recommended since such operations are likely to be more harmful than oil impact
- Under heavy accumulations when cleanup is deemed necessary to prevent chronic oil pollution, sorbent boom may be deployed beyond the low-tide line to absorb oil as it is slowly released, but it must be frequently replaced to be effective

MANGROVES (ESI=10a)

Physical Description

- Possibility of exposure to relatively high wave activity and currents
- Occurrence of heavy wrack deposits in storm swash lines throughout forests
- Sediment ranges from thin layers of sand and mud to muddy peat on bedrock
- Topographic profile generally flat
- Exposed, fringing forests on windward side of Florida Keys often have a low, sand ridge adjacent to shore
- Forests can range in width from 6 to 600 feet
- Rendered inaccessible by density, width, elevation, and sediment type
- Very common shoreline type in South Florida

Plants

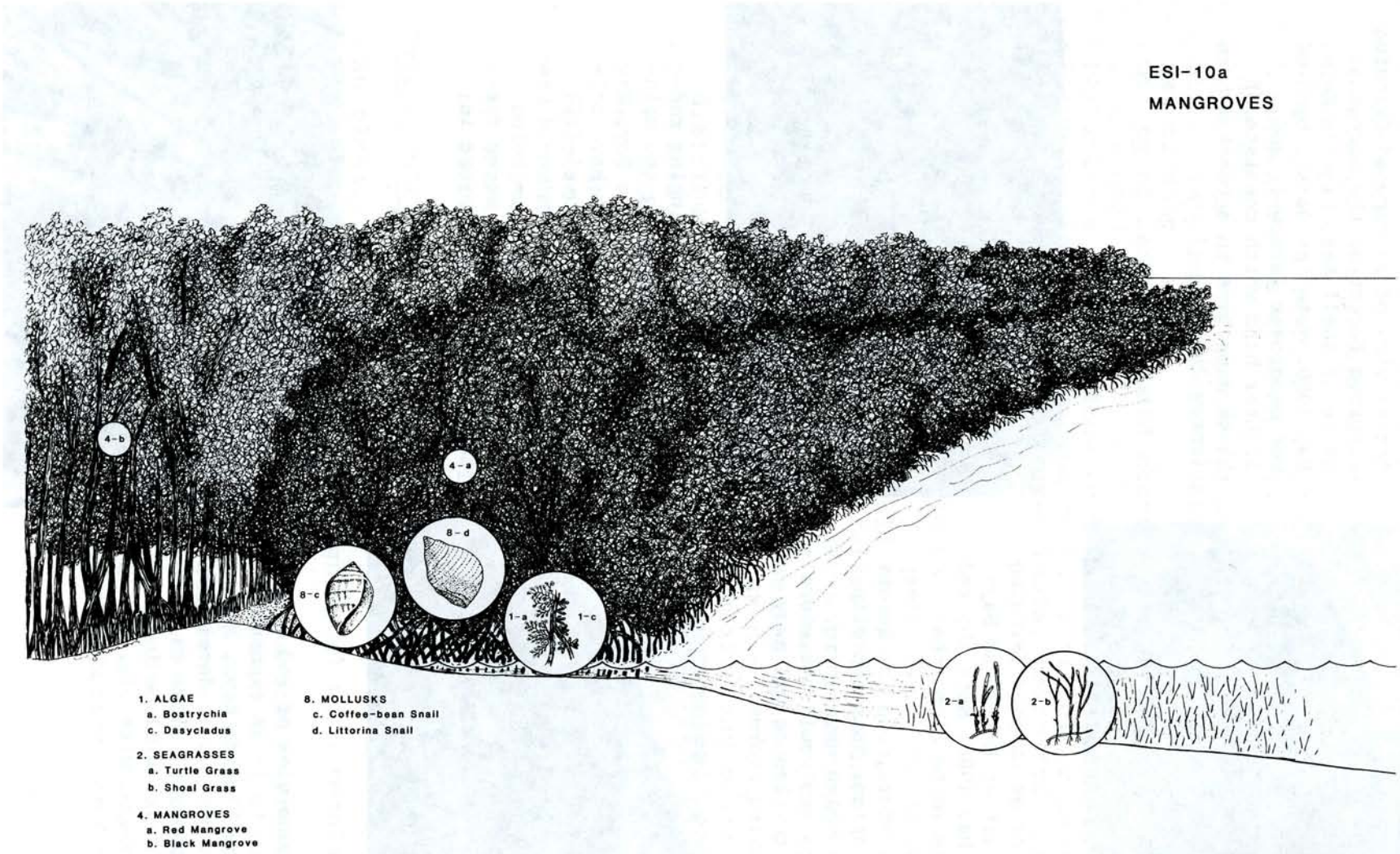
- Rooted vegetation:
  - Dominant species: red, black, and white mangroves
  - Distinct zonation observed with red mangroves occurring on seaward exterior of forests while black and white mangroves occur on forest interiors
- Attached vegetation:
  - Six species of attached algae observed, associated with prop roots
  - Dominant species: Bostrychia and Dasycladus
- Adjacent subtidal grass flats vegetated with turtle and shoal grasses

Animals

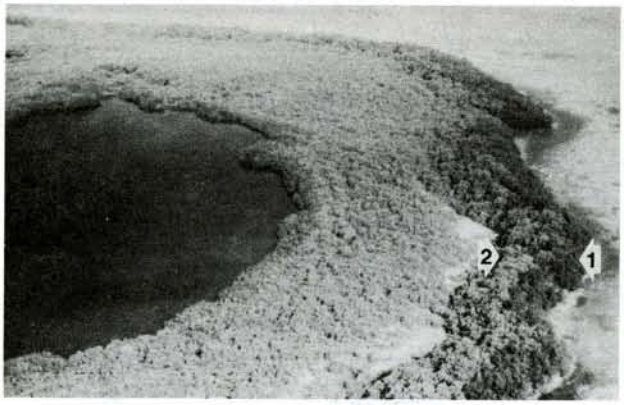
- Epifauna:
  - Moderate densities, biomass, species richness, and diversity
  - 12 species observed
  - Dominant species: coffee bean snails, angulate littorina snails, amphipods, and batillaria snails
- Infauna:
  - Moderate densities and species richness with high species diversity and low biomass
  - 26 species observed
  - Dominant species: West Indies bubble snails and several species of polychaete worms

Behavior of Oil

- As oil moves into forests, roots and associated epiphytic communities would be coated with a band of oil

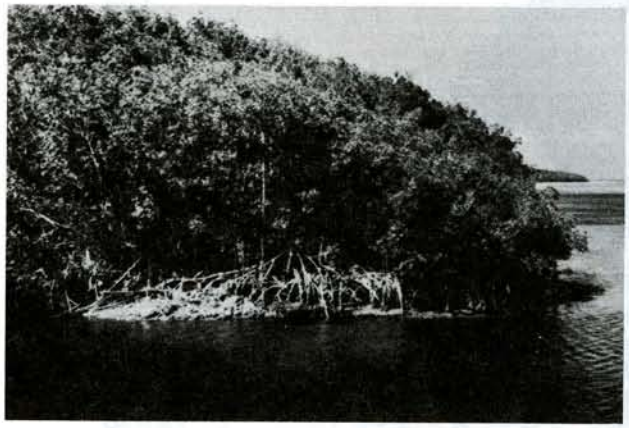


The geomorphic setting and the dominant, oil-sensitive species at mangroves, ranked as ESI=10a.



Aerial view of an exposed fringing mangrove forest on the northeast shore of Shell Key, Florida Keys, May 1980. Note the darker band of red mangroves (arrow 1) and a lighter band which consists of black mangroves on a coastal berm (arrow 2).

Ground view of an exposed fringing mangrove forest at Homestead Bayfront Park, May 1980. Note the red mangrove prop roots along the water's edge, the relatively steep slope of the shore, and the height of the vegetation. This shoreline is exposed to high wave energy during storms and would therefore be expected to cleanse oil away naturally during storms.



Ground view of a fringing red mangrove forest along the mainland shore of Biscayne Bay, May 1980. These mangroves have colonized a sand and gravel-fill beach. The beach berm would prevent floating oil from being pushed by tides and waves further back into the forest in most cases.

Close-up ground view of red mangrove prop roots in an exposed forest at the Florida Keys, May 1980. This shows a well-developed growth of epiphytic algae on the prop roots, which will be impacted if covered with oil.

- Width of band of oil would be dependent upon size of slick and tidal range
- Epiphytic prop root algae would act as a natural oil absorbent

• Presence of a beach berm would limit extent of oil impact to seaward side of berm, thus preventing oiling of forest interiors
• Prop roots of red mangroves would tend to act as baffles, often trapping oil during ebbing tide, thus inhibiting natural cleanup
• Oiling of sediment would occur if large quantities of oil were washed ashore
• Persistence would be long term with heavy accumulations
• Potential for contamination of interstitial groundwater and brackish backwaters by water-soluble, toxic fractions

Potential Biological Damages

• Potential for oil impact would be great due to high degree of physical exposure
• Persistence of oil impact would be high due to:
  - 1) high degree of oil penetration into sediments
  - 2) large availability of mangrove prop root surfaces and associated epiphytic prop root communities for oil impact
  - 3) lowered photooxidative weathering rates of oil due to high degree of mangrove canopy shading
  - 4) secondary movement of oil by snails and crabs which redistribute oil from intertidal to supratidal zones
• Oil sensitivity would be great due to:
  - 1) long persistence of toxic oil fractions within sediments
  - 2) inability of adult and juvenile mangroves to cope with chronic, oil-induced stress
  - 3) inability of mangrove-associated epifauna, particularly mangrove tree crabs, to cope with oil-induced stress
  - 4) inability of certain infauna, particularly amphipods, to tolerate chronic oil-induced stress

Recommendations for Cleanup

• No cleanup recommended
• Recovery would be natural (though slow) with regular and storm-generated flushing
• Placement of sorbent boom along the mangrove forest fringe may reduce quantity of oil significantly
• With heavy accumulations when cleanup is deemed necessary to prevent chronic pollution of surrounding areas, low-pressure flushing (used in conjunction with sorbent boom) may be effective in cleaning oil from prop roots of fringing mangroves (only during periods of ebbing tides)
• No attempts should be made to clean interior mangroves

SHELTERED MANGROVES (ESI=10b)

Physical Description

- Located in bays and basins well-sheltered from waves and tidal currents
- Sediments composed of thin to thick deposits of mud or irregular rock surface
- Very flat topographic profiles

Plants

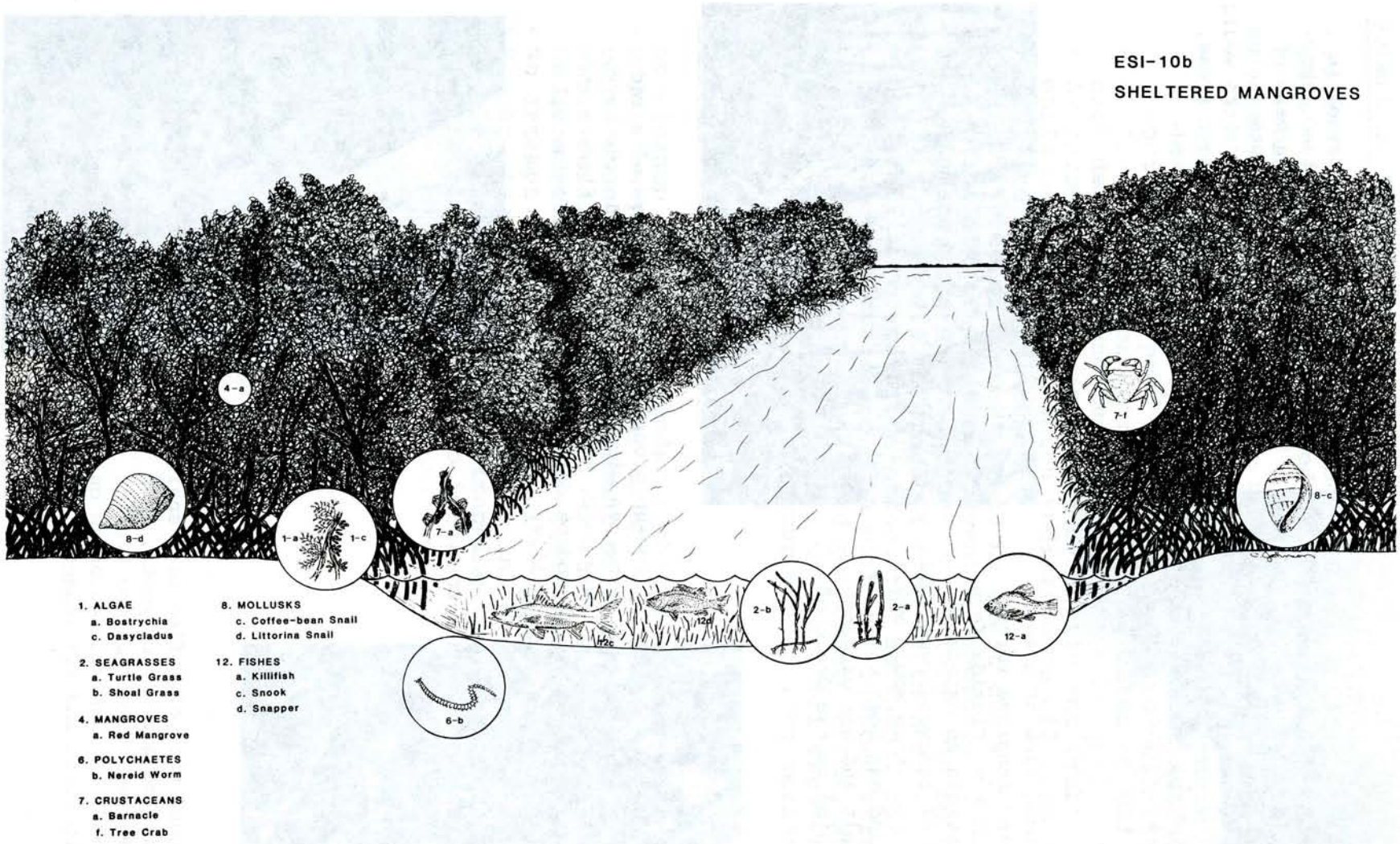
- Rooted vegetation:
  - Dominant species: red and black mangroves
- Several species of algae attached to mangrove prop roots with high biomass and moderate diversity
  - Dominant species: Bostrychia and Dasycladus
- Adjacent subtidal sea grass beds vegetated with manatee, shoal, and turtle grasses

Animals

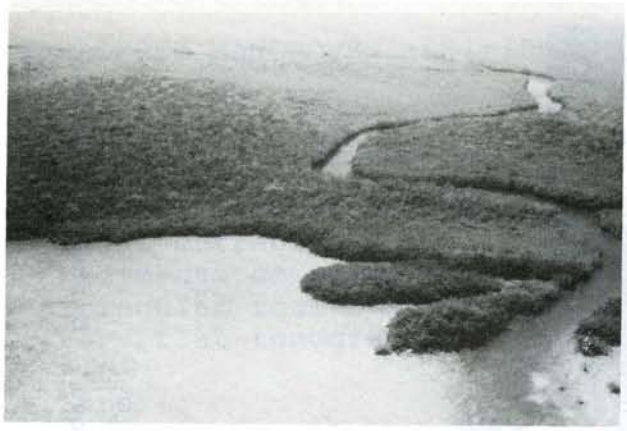
- Epifauna:
  - Moderate densities with low species richness and diversity
  - Dominant species: angulate littorina snails and barnacles
- Infauna:
  - Moderate densities and species richness with high species diversity
  - Dominant species: nereid polychaete worms
- Recreationally/commercially important, mangrove-associated species observed include mangrove snappers

Behavior of Oil

- Movement of spilled oil in mangrove forests controlled mainly by geomorphic features; berms tend to trap oil and promote penetration of oil in front of them
- As oil enters mangrove forests, their roots and associated epiphytic communities would be covered with a band of oil:
  - Width of this band of oil dependent on size of slick and tidal range
  - Epiphytic prop root algae would act as a natural oil absorbent
  - Prop roots of red mangroves would tend to act as baffles, often trapping oil during ebbing tides; thus prolonging natural cleanup
- Oiling of sediments would occur if large quantities of oil were washed ashore



The geomorphic setting and the dominant, oil-sensitive species at sheltered mangroves, ranked as ESI=10b.



Aerial view of a tidal creek in the Florida Keys, May 1980, showing a tidal creek with a band of sheltered fringing forests lining it. Oil entering these creeks would impact the mangrove forest areas, remaining for a long time.

Interior ground view of a sheltered fringing mangrove forest at Summerland Key, Florida Keys, May 1980, reveals an extensive root system of red mangroves. Oil impact in these areas would cover prop roots and has been known to interrupt salt and gas exchange systems leading to the death of trees.

Close-up ground view of clusters of a red mangrove with seeds (arrow), Florida Keys, May 1980. Mangroves drop their flowers and produce deformed seedlings following oil spills.

Close-up ground view of coffee bean snails colonizing red mangrove prop roots, in a sheltered mangrove forest in the Florida Keys, May 1980. Many animals colonize on red mangrove prop roots and are impacted during oil spills.

Potential Biological Damages

- Potential for oiling would be greatest in areas of highest physical exposure; sheltered areas would be less likely to be impacted
- Persistence of oil would be great due to:
  - 1) high degree of sheltering or lack of physical exposure
  - 2) high degree of oil penetration into sediments
  - 3) large availability of mangrove prop root surfaces and associated algal prop root communities for oil attachment
  - 4) lowered photooxidative weathering rates of oil due to high degree of mangrove shading
  - 5) secondary movement of oil by snails and crabs, mobile epifaunal organisms, which redistribute oil from intertidal to supratidal zones
- Sensitivity to oil impact would be great due to:
  - 1) inability of adult and juvenile mangroves to cope with oil-induced stress; high tree mortalities can be expected if 50 percent oil coverage of prop roots occurs
  - 2) inability of mangrove-associated epifauna, particularly mangrove tree crabs, to cope with oil-induced stress
  - 3) infauna, especially nereid polychaete worms, would be more tolerant (than epifauna) of acute oil exposure; however, chronic impacts may occur due to long residence time of oil in these environments

Recommendations for Cleanup

- No cleanup recommended under light to moderate accumulations
- Under heavy accumulations, to prevent chronic oil pollution of surrounding areas, placement of sorbent along fringe mangrove forests (to absorb oil as it is slowly released) may be effective under close scientific supervision
- No attempt should be made to clean interior mangroves
- Proper strategic boom placement in sheltered lagoonal areas may be highly effective in trapping large quantities of oil, thus reducing oil impact to interior mangrove forests

Oil-Sensitive Coastal Wildlife

The following groups of animals were judged to be the most sensitive to a major oil spill in South Florida:

Resident Mammals
Marine Birds
Sea Turtles and Crocodiles

The species of these groups which breed in coastal areas of South Florida are shown on the ESI maps and are listed in Supplement 1. The following section addresses their life history, their sensitivity to oil, and suggests means of reducing stresses and mortalities to them during a major oil spill.

Resident Mammals

Two species of mammals which are residents of the South Florida coastline are addressed in this section. The West Indian manatee is a threatened species of estuarine/aquatic mammal which ranges throughout Florida. They reside in rivers, shallow estuaries, and saltwater bays where they tend to cluster around freshwater runoff. Factors affecting the distribution of manatees include: (1) availability of a food source (usually aquatic vegetation), (2) proximity of waters greater than six feet in depth, (3) access to warm water during cold snaps, and (4) a source of fresh water.

Manatees mature at four to six years of age and have no well-defined breeding season. They are thought to bear a calf every two years. Manatees feed on a plant diet ranging from terrestrial plants to submerged vegetation such as algae, turtle grass, and manatee grass. A slow decline in manatee densities is expected in the future due to: (1) propeller kills from power boats, (2) vandalism, (3) poaching, and (4) habitat destruction.

During the PECK SLIP oil spill, manatees avoided oiled areas by remaining in unoiled tidal creeks. It is conceivable that manatees which become trapped in spilled oil, even for short periods of time, may suffer respiratory stress due to inhaling oil or fumes. Especially vulnerable would be clusters of manatees wintering at power plant effluents. In this case, careful hazing (or scaring) of manatees from oiled areas may be effective. Only federal, state, or local wildlife authorities should conduct activities which influence manatees. These efforts should avoid unnecessary stress or injury to animals. Manatee habitats which have been oiled should be subsequently monitored to ensure that food sources have not been damaged.

The key deer is an endangered species found only on those islands in the vicinity of the National Key Deer Refuge on Big Pine Key in the Florida Keys. Key deer prefer pine and hardwood forest habitats but often move into red mangrove forests during the day to find more moderate temperatures. The mating season occurs in September and October. The present key deer population is small. It is estimated at 300-400 animals and appears to be relatively stable in spite of high mortality and naturally low reproductive potential. Key deer are very mobile, often traveling among different islands. Adult males maintain a homing range of 300 acres compared to only 130 acres for females. The greater homing range may render the male more vulnerable to oil spills since travel among the islands is by swimming.

The effects of oil on key deer populations are unknown, but should be closely monitored during major oil spills. Potential effects are sublethal, but may include the contamination of food sources and preferred habitats such as red mangroves. This may cause key deer to move to less than optimal habitats or it may interrupt seasonal events such as courtship.

Coastal Birds

The South Florida coast with its numerous mangrove-covered islands provides an excellent nesting habitat for coastal birds. It is also a wintering ground for several waterfowl species, especially diving ducks. There are over 15,000 nesting birds in South Florida. This includes colonies of sooty terns and brown noddies on the Dry Tortugas. Louisiana herons, cattle egrets, great egrets, snowy egrets, and white ibises also nest in South Florida. The double-crested cormorant and brown pelican are the two most common nesting birds in the Florida Keys. Peak nesting for most species occurs from March through September.

Several South Florida coastal bird species are considered endangered, threatened, rare, or of special concern, including wood storks, peregrine falcons, and Cuban snowy plovers. Wood storks are the most critically endangered species. Alteration of their feeding habitat is primarily responsible for declining populations. Peregrine falcons winter in South Florida. They feed on coastal bird species and are attracted to wounded or crippled birds. Shore birds contaminated by oil would be possible prey. The Cuban snowy plover feeds and breeds on open, dry, sandy beaches, which makes it vulnerable to oil contamination. Increased use of beaches by man has reduced their population in South Florida.

Large numbers of marine birds have perished during major oil spills, including 10,000 during the TORREY CANYON spill, and 3600 in the Santa Barbara blowout of 1969. Birds may be affected by oil in several manners. When covered with oil, the plumage loses its insulating and waterproofing properties, which render oiled birds susceptible to temperature extremes, resulting in death by pneumonia or drowning. Ingestion of oil through preening of feathers may result in internal organ degeneration and hemorrhaging in the digestive tract. Other effects include nervous disorders, egg losses due to embryo suffocation, and reduced reproductive potential.

Birds along the South Florida coast are most vulnerable to oiling during the nesting season. The eggs and young could become oiled from contaminated breast feathers of adults during this season. Gulls, terns, and pelicans would be especially vulnerable because of their feeding habits. Cormorants and diving ducks would be vulnerable because of their swimming and feeding behavior. Several waterfowl species winter in South Florida coastal waters. These include pintails, lesser scaup, hooded mergansers, and red-breasted mergansers. These species spend much of their time in the water and may be exposed to oiling. Pelagic birds such as shearwaters, petrels, storm petrels, jaegers, boobies, and gannets are vulnerable to offshore spills. Because of their pelagic nature, they are hard to monitor for impact.

Several methods have been applied toward hazing birds away from oiled areas. Some of these include propane cannons, flares, blank guns, and scarecrows. The use of cannons with timing mechanisms has been especially effective in hazing birds from oiled foraging areas (tidal flats and beaches). Only federal, state, and local wildlife managers should be authorized to conduct hazing. Care should be taken to avoid hazing near rookeries.

Sea Turtles and Crocodiles

There are five species of sea turtles and one species of crocodile found in South Florida, including the Atlantic green turtle, the Atlantic hawksbill turtle, the Atlantic ridley turtle, the Atlantic loggerhead turtle, the Atlantic leatherback turtle, and the American crocodile. Of these, the Atlantic loggerhead turtle, the Atlantic leatherback turtle, and the American crocodile reproduce in South Florida.

Sea turtles are discussed first. Since they nest on sand beaches, oil could physically impact adults, nests, and eggs. The Atlantic loggerhead turtle is a threatened species which nests along suitable sand beaches throughout

South Florida, especially north of Miami and in the Marquesas Islands. Nesting begins in May and ends in September. Females deposit an average of five clutches per season. Each clutch typically averages 120 eggs. During the nesting season, the turtles aggregate making the population more vulnerable to spilled oil.

The Atlantic leatherback turtle is the largest of all marine turtles. It is a rare species in South Florida. Nesting season extends from April to July with primary nesting areas on beaches north of Miami. Each clutch averages 80-85 eggs with as many as six clutches per season. Toxic effect from spilled oil during nesting may be severe; however, impacts during other times of the year (August through September) would be confined to offshore habitats.

The technique for transplanting the eggs of sea turtles has been advanced to allow rapid transportation of eggs and young from oiled beaches to unoiled areas. Only federal, state, and local turtle authorities should be authorized to conduct and monitor the transplanting of turtle eggs and young. During the IXTOC I spill, several thousand sea turtles were removed successfully from oiled beaches and released in unoiled waters.

The American crocodile in Florida represents the only population in the United States. The crocodile is an endangered species with scattered populations being found in the National Key Deer Refuge (Big Pine Key, Little Pine Key, and Howe Key), southern Biscayne Bay (south and west along the mainland), and Key Largo (Card Sound, Barnes Sound, Lake Surprise, Buttonwood Sound, and Blackwater Sound extending as far west as McCormick Creek) areas. It has been estimated that only 25 breeding females remain in the United States. Primary nesting sites are in hardwood thickets at the heads of small sand beaches, on high marl banks of narrow coastal creeks, and occasionally on canal banks in mangrove swamps. Females utilize the same primary nest for several years, but may maintain alternate nests close by. Nesting activities begin in April with 20-80 eggs being laid in late April to early May. The eggs hatch in late July or early August with the hatched juveniles maintaining a close relationship to the female for several days or weeks to provide some protection from predators.

Oil spills in the Panama Canal recently have led to long-term damages in crocodile populations there. However, little is known from these spills concerning the details of the effects of spilled oil on crocodiles. A very high priority is recommended for protecting areas where crocodiles are known to breed and forage. Federal, state, and local wildlife managers should be authorized to monitor and reduce damages where possible.

Less Oil-Sensitive Coastal Resources

The following section deals with ecologically valuable environments, protected wildlife, and marine fisheries. These resources are judged as less oil-sensitive due to their subtidal nature, or as with whales and dolphins, their ability to avoid oiled areas. The following resources are discussed:

Coral Reefs
Seagrass Beds
Whales and Dolphins
Marine Fisheries

Coral Reefs

Corals form the basis for one of the most productive ecosystems in the world. They thrive in tropical waters where they form extensive reefs that provide habitats for many other organisms. Coral reefs are generally less susceptible to damage from oil than other marine organisms due to their subtidal nature. Several investigators have reported little or no visible damage to corals from oil spills (Rutzler and Sterrer, 1970; Chan, 1977).

However, laboratory studies have indicated that oil can harm corals in many ways. Exposure to floating oil can disrupt the normal feeding and clearing activity of corals (Reimer, 1975; Bak and Elgershuizen, 1976; Cohen et al., 1977). If oil comes into physical contact with corals for more than a few hours, tissue destruction can occur (Johannes, 1967; Reimer, 1975; Bak and Elgershuizen, 1976). Reproduction and recolonization after natural disruption are also affected by oil. In chronically oiled areas, the ability of corals to recolonize after disruption is greatly reduced (Fishelson, 1973; Loya, 1975; 1976). Premature release of coral larvae following exposure to oil has been reported (Cohen et al., 1977). Some studies have indicated a reduction in growth rates of corals following short-term exposure to oil (Birkeland et al., 1976), but Loya (1976) found similar rates of growth in oiled and controlled corals. Corals should be monitored during spills of soluble oil because mixing may occur and oil may be delivered subtidally. Most coral responses to oil are not readily detectable in the field because long-term changes are involved.

Seagrass Beds

Seagrass beds are predominantly subtidal features in South Florida which are characterized by moderate to dense growths of marine grasses. These grasses grow in sandy and muddy substrates where they are limited in distribution by the depth, clarity, and subsequent penetration of light into coastal waters. Sea grasses contribute significantly to the primary productivity, water quality, and carrying capacity of South Florida's coastal waters. The most important seagrass species in South Florida are turtle grass, shoal grass, and manatee grass. Seagrasses form a dense substrate, providing habitat for numerous algae, invertebrates, and microorganisms. While these grasses constitute the majority of biomass in South Florida seagrass beds, an associated plant community may consist of numerous species of epiphytic algae (Humm, 1964). Other associated organisms include a diverse assemblage of fungi, which contribute to the breakdown of plant tissue, thereby speeding up nutrient recycling as well as an abundant bacterial population (Wood, 1965). Numerous studies in South Florida's seagrass beds (Hopper and Meyers, 1967; O'Gower and Wacasey, 1967; Moore, 1963) reveal a tremendous variety of abundant animal life associated with seagrass beds, includ- ing shrimp, crabs, bivalves, gastropods, sea cucumbers, and sea urchins.

Very few observations are available on the effects of spilled oil on tropical sea grasses. At the PECK SLIP and ZOE COLOCOTRONIS oil spills in Puerto Rico, no significant damages were measured to sea grasses, even those scattered intertidal grass beds which received heavy physical smothering. Literature from temperate areas indicates that oil tends to cause acutely toxic effects to intertidal sea grasses and their inhabitants, but few chronic effects have been reported.

Whales and Dolphins

A total of 26 species of whales and dolphins have been reported from Florida waters, including:

ENDANGERED SPECIES

black right whale
sei whale
fin whale
humpback whale
sperm whale

RARE SPECIES

minke whale
Bryde's whale
rough-toothed dolphin
Risso's dolphin
spinner dolphin
short-snouted spinner dolphin
bridled dolphin
striped dolphin
saddlebacked dolphin
pygmy killer whale
false killer whale
killer whale
dwarf sperm whale
Antillean-beaked whale
dense-beaked whale
True's beaked whale
goose-beaked whale

COMMON SPECIES

Atlantic bottlenosed dolphin
Atlantic spotted dolphin
short-finned pilot whale
pygmy sperm whale

Oil-spill impacts to dolphins and whales may occur if oil is spilled in offshore coastal waters and inshore estuarine and bay waters. Several cruises during the IXTOC I oil spill in Texas in 1979 indicated that dolphins did not avoid oil-contaminated waters. The Atlantic spotted dolphin is among the more common species of dolphin observed along the South Florida coast. This species occurs in herds of up to several hundred individuals, although groups of 50 or less are more common. The spotted dolphin is generally found outside the 100-fathom curve, but may move closer to shore during the spring and summer. Exposure to spilled oil may occur in nearshore waters during spring and summer and offshore waters during the fall and winter. The Atlantic bottlenosed dolphin is a common species in South Florida. It is more commonly found nearshore, often entering bays, lagoons, and estuaries. These dolphins usually occur in aggregates of up to several hundred individuals, comprised of numerous small pods containing an average of 12 individuals per pod. The pygmy sperm whale and the short-finned pilot whale are also commonly observed species of whales in South Florida offshore waters. Toxic effects to whales and dolphins may include eye irritation and respiratory stress. Hazing from small boats may be possible; however, only authorized personnel should attempt this.

Marine Fisheries

South Florida has important commercial and recreational marine fisheries which are divided into offshore and inshore

components. The target species of these fisheries is diverse and includes the following offshore fishes:

OFFSHORE FISHES

dolphin fish	white marlin
sharks	sailfish
kingfish	red snapper
swordfish	yellowtail snapper
baracuda	cubera
blackfin tuna	jewfish
bonito	grouper
blue marlin	ballyhoo

Oil would likely fail to physically impact offshore species.

It is unlikely that oil would cause toxic effects to adults of inshore species unless they inhabited extremely shallow waters.

INSHORE FISHES AND SHELLFISH

lobster	tarpon
stone crab	mullet
shrimp	pilchard
blue crab	mangrove snapper
snook	menhaden

All these species possess a pelagic egg and larval stage which are vulnerable to spilled oil. During the ARGO MERCHANT and AMOCO CADIZ oil spills, the effects of petroleum on larval fishes were monitored. These efforts, when combined with laboratory studies, indicate an acutely toxic effect of oil on larval fishes, resulting in many cases in stress, deformities, and death. The effect of oil on marine fisheries is difficult to monitor due to the extreme variability of yearly catches. Following a massive oil spill, however, long-term effects may appear such as depressed catches. During an oil spill, the market value of seafood may decrease due to actual (or perceived) tainting of flesh by petroleum hydrocarbons.

The location of oiled areas and their effects on local fisheries should be monitored during a major oil spill.

During the IXTOC I spill, the positions of oil slicks were broadcast daily to fishermen and mariners. In addition, the tainting of seafood by oil should be monitored. Long-term effects may become more apparent only upon examining catches after a major oil spill, and comparing them with long-term fisheries data.

APPLICATIONS

This report is meant to be used with the ESI maps through the following applications:

Determining Sensitive Areas
Protecting Sensitive Areas
Selecting Cleanup Techniques

Determining Sensitive Areas

The South Florida study area is divided into four regions for discussion of sensitive areas. These are:

Boca Raton Inlet to Virginia Key
Key Biscayne to Key Largo
Rodriguez Key to Marathon
Ohio Key to the Dry Tortugas

A discussion of each region follows.

Boca Raton Inlet to Virginia Key

The exposed coast in this region consists of three barrier islands with four inlets. The beaches have been nourished with coarse quartz sand and shell fragments creating coarse-grained sand beaches (ESI=4). These beaches support a tourist-based economy and are adjacent to a continuous strand of ocean-front hotels and condominiums. Oil coming ashore at these beaches would damage tourism. Tourism is at its height in the winter months, peaking in late December and early January. A major oil spill just before or during these months would, therefore, maximize the negative effect on the local economy.

The beaches, especially those between Boca Raton and Hollywood, support moderate numbers of nesting sea turtles. Two species are known to lay their eggs on these beaches. The Atlantic loggerhead turtle nests from May through September, and the Atlantic leatherback turtle nests from April to July. Nesting sea turtles are, therefore, likely to be present from late spring to early fall. Oil reaching beaches with egg-laying turtles, egg-filled nests, or newly-hatched turtles is expected to have a toxic effect as are certain types of cleanup activities. Both toxic (chemical) and mechanical effects are anticipated to adults, eggs, and juveniles. Transplanting eggs may be a viable option during a spill, but these efforts should be coordinated with local turtle experts.

These beaches are also utilized by numerous species of shore and wading birds. These birds do not breed at these beaches and would likely avoid oil. During the IXTOC I oil spill, wading and shore bird populations were observed to avoid heavily oiled beaches. Those birds residing at lightly oiled beaches were observed to avoid feeding in the most heavily oiled, foreshore areas. Wading and shore birds were observed to return to newly cleaned beaches following a tropical storm which removed most of the beached oil by natural processes.

The nearshore area is characterized by a shallow coral reef which extends from 50 feet to over one half mile offshore. This reef system would be vulnerable to light, volatile, petroleum products such as gasoline, diesel, and No. 2 fuel oil. These products, when mixed into the water column by surf, create the potential for delivering toxic, petroleum fractions to nearshore coral and coral reef inhabitants. The effects of a spill of lightly toxic substances under moderate to heavy wave conditions should be monitored carefully, despite the relative futility of preventing toxic effects. Cleanup techniques which push oil back into the surf should be avoided in areas with nearshore reefs due to the potential for siltation and oiling of these areas following those activities.

The coarse-grained sand beaches of this area support a relatively low density of small burrowing animals (infauna). The dominant type of animal appears to be polychaete worms which are generally tolerant of low toxicity, petroleum products. Potential impact due to oil or cleanup efforts to small burrowing animals at these beaches appears to be minimal.

The lagoonal system behind these barrier islands includes northern Biscayne Bay and the intercoastal waterway, and extends from Boca Raton to Virginia Key. This lagoonal system has only four direct connections to the Straits of Florida. These are Boca Raton Inlet, Port Everglades, Government Cut, and Norris Cut. In addition, northern Biscayne Bay is open and therefore susceptible to spilled oil from southern Biscayne Bay via numerous connections. Many manmade structures dominate the inside of these lagoonal systems and the intercoastal waterway. This includes sheltered seawalls and riprap structures. Oil reaching these shores would adhere to these structures, and in sheltered areas would endure years of weathering. Most of these structures line canal systems in northern Biscayne Bay. Oiling of these canal banks would require an intensive cleanup effort, mainly hydroblasting and scraping from a work boat.

Large areas of northern Biscayne Bay are shallow and support extensive sea grass and algae beds. Subtidal sea grasses are usually not susceptible to floating oil except

those components which are highly soluble and toxic. These may cause sea grasses to die or be highly stressed. Residual oils, while less toxic, may sink and cause mechanical coverage of sea grasses. Oil-sensitive fish and wildlife in this lagoonal system include a bird rookery in northern Biscayne Bay and wintering areas for manatees at Port Everglades. Use of this manatee wintering area is highly seasonal and is upstream from Port Everglades, a major oil port. Oil entering northern Biscayne Bay would be expected to interrupt a small but important recreational bridge fishery for shrimp and snook. A surface slick would likely fail to impact the shrimp and snook, but recreational fishing during an oil spill would be suspended due to potential fouling of boats by spilled oil.

Mangrove forests (ESI=10) once dominated this lagoonal system, but are now reduced in distribution to a few islands and to scattered mainland areas, especially along the northwest shore of northern Biscayne Bay and at Port Everglades. At these sites mangroves colonize canal banks as well as forming scattered basin forests. Oil reaching these forests would have variable effects dependent upon the toxicity of the oil, the type of forest, and the time of year. However, oil may cause die-offs of acres of mangroves and result in long-term contamination of the substrate.

In conclusion, the most critical economic and biological areas with regard to oil-spill protection are located within the lagoonal system. This system is linked to the Florida Straits by only four direct connections. Efforts to prevent oil from entering the lagoons should, therefore, be the primary objective. These efforts should be concentrated at Port Everglades (an energy port; CEQ/CZM,1980), Government Cut, Boca Raton Inlet, and Norris Cut.

Key Biscayne to Key Largo

The exposed coast of this region consists mainly of four types. Exposed fine-grained, sand beaches (ESI=3) are found at the seaward side of Key Biscayne. Exposed rocky platforms (ESI=2) are found at the northeastern tip of Key Biscayne and dominate the seaward shore of Soldier Key, Ragged Keys, Sands Key, and Elliot Key. Scattered, exposed rocky platforms are found at Old Rhodes Key and along Key Largo. Exposed, fringing mangrove forests (ESI=10a) are present in small embayments and have colonized exposed beaches along Ragged Keys, Sands Key, Elliot Key, Old Rhodes Key, and Key Largo. Sheltered mangrove forests (ESI=10b) line the numerous tidal creeks which cut through this island chain, especially at the tidal creeks of Old Rhodes Key.

The fine-grained sand beaches at Key Biscayne support a tourist-based economy. A major oil spill during tourist season would be damaging. Like other sand beaches between Miami and Boca Raton, the beaches of Key Biscayne support a number of sea turtle nests as well as wading and shore bird populations. Oil coming onshore there would likely have a negative effect on these wildlife.

The coastal areas of Elliot Key, Old Rhodes Key, and Key Largo comprise a portion of two, federally managed, aquatic preserves. These are the Biscayne National Monument, which includes much of southern Biscayne Bay as well as areas seaward of Elliot and Rhodes Keys, and the Pennekamp Marine Sanctuary which extends seaward of northern Key Largo. A major oil spill in these areas would be expected to interrupt the recreational use of these parks, at least temporarily. These activities include boating, diving, and fishing.

Wildlife damages in the coastal areas of these aquatic preserves would include the oiling of areas around rookeries of the double-crested cormorant which are scattered throughout the seaward coast of Elliot Key, Old Rhodes Key, and Key Largo. Due to their swimming and feeding behavior, cormorants are especially vulnerable to floating oil. This is of special concern during nesting when oiled birds may return to nests, thereby contaminating eggs.

Oil-induced damages to the offshore coral reef tract in this region would be minimal from floating petroleum products, especially those with lower toxicity and solubility. Nearshore shallow corals, such as the gorgonian patch reefs off Elliot Key and Key Largo, would be vulnerable to a major oil spill involving light oils and distillates, especially during moderate to heavy seas which promote dispersion into the water column and absorption onto suspended particles with subsequent deposition to subtidal areas.

The potential for spilled oil to enter southern Biscayne Bay is great since there is no seaward barrier from Cape Florida to Sands Key. This provides a ten-mile-long corridor for spilled oil to enter Biscayne Bay. The potential for spilled oil to enter Card Sound is also great due to its proximity to the numerous wide, well-flushed tidal creeks between Elliot Key, Old Rhodes Key, and Key Largo. In addition, vessels moving through the shipping channel to the Turkey Point Power Plant and the intercoastal waterway present opportunities for small spills. The lagoonal system further south consists of Barnes and Blackwater Sounds, and is relatively safe from receiving oil spilled in the Florida Straits due to the barrier effect of northern Key Largo.

Southern Biscayne Bay and Card Sound are probably the most vulnerable target for a major oil spill. This area

forms a highly productive estuarine system which is vital to the economic and biological integrity of South Florida. The estuarine system provides a heavily utilized nursery ground for larval fishes and juvenile lobster, contains thousands of acres of sea grasses and mangroves, supports a major commercial and recreational fishery, is an important marine recreation area, and is the site of a federally managed, aquatic preserve and numerous coastal parks. The estuary provides a breeding ground for a dozen or more species of wading and diving birds, and is an important forage area of the endangered American crocodile. Sea turtles forage throughout the estuary as do numerous commercial and recreational fishes including tarpon, bonefish, mullet, and snook.

The economic and biological damages from spilled oil to southern Biscayne Bay and Card Sound would depend upon the toxicity, solubility, and amount of petroleum product as well as the season during which it was spilled. The worse case situation would include a large spill of light, volatile fuel during moderate to heavy seas which moved into southern Biscayne Bay and Card Sound. Other types of petroleum offer potential for biological damages. Bunker C and other residual oils, have a relatively low toxicity, but are deleterious through a mechanical or smothering effect. One of the greatest potential damages from residual oils in this region would be to mangroves. The mechanical coverage of mangrove prop roots has been implicated in the death of acres of mangrove forests in Florida and Puerto Rico. Southern Biscayne Bay and Card Sound are ringed by an extensive, fringing mangrove forest which could be damaged in this manner.

The primary effort in protecting Biscayne Bay and surrounding waters should be concentrated on employing ocean-going skimmers at the spill site (first line of defense). Skimmers may also be concentrated at major inlets such as Sand Cut and Angelfish Creek (second line of defense). At these sites, containment by deflection to skimmers may be employed. Success will depend mainly on weather conditions. Cleanup of oiled mangroves is not recommended should oil enter Biscayne Bay, but sorbent booms may prevent oil from leaching out of oiled mangrove forests into surrounding waters. These efforts should be concentrated especially where sheltered mangroves are heavily oiled.

Rodriguez Key to Marathon

This region consists of a string of long, narrow islands which are exposed to the Straits of Florida to the southeast, and to Florida Bay and the Gulf of Mexico to the northwest. With the exception of sheltered embayments at Plantation, Grassy, and Vaca Keys, this is an exposed coast

consisting of exposed seawalls (ESI=1), exposed rocky platforms (ESI=2), riprap (ESI=6), and exposed tidal flats (ESI=7). Therefore, the coast is expected to suffer only short-term damages following a major oil spill in this region.

The protected embayments in this region are dominated by sheltered tidal flats (ESI=9) and sheltered mangrove forests (ESI=10b). The largest and most sensitive of these embayments are at Long Key and Vaca Key. Oceangoing skimmers, exclusion booms, and sorbent booms are recommended at the entrances to these embayments to protect them from economic and biological damage. In addition, the Vaca Key embayment (Boot Harbor) provides harbor for a large fleet of commercial and recreational vessels. In addition to these natural embayments, canals are very common throughout this region, especially at Vaca, Grassy, and Upper Matecumbe Keys. The shores of these canals are either sand and gravel fill (ESI=5), riprap (ESI=6), or sheltered seawalls (ESI=8), and afford the potential for long-term duration of spilled oil due to their sheltered nature.

There are several large bird rookeries in this region, especially in the offshore islands just to the north and at two small islands next to Vaca Key. The waters surrounding this region support an important recreational fishery for bonefish, tarpon, and permit. Islamorada and Marathon are important tourist centers, especially during the winter months. Oil spilled in this region would have the potential to decrease the tourist trade and cause failures to reproducing birds.

Except for the protected embayments in this region, the exposed shore here should suffer only minor, short-term damages followed by relatively rapid, natural cleanup. The primary effort in this region beyond protection of canals and embayments should be toward preventing oil from passing through the channels between Plantation Key and the Matecumbe Keys. Oil passing these channels may reach sensitive areas to the northwest, including eastern Florida Bay.

Ohio Key to the Dry Tortugas

This region, called the lower Florida Keys, consists of an extensive mangrove lagoonal system. Large expanses of sheltered mangroves (ESI=10b) within the lagoonal systems are the most oil-sensitive coastal environments in the lower Keys. These are connected and flushed through a limited number of relatively narrow, shallow tidal creeks. Such creeks are recommended for exclusion booming or complete closure during oil spills.

Another of the most sensitive coastal environments of the lower Florida Keys region are the sheltered, fringing mangroves (ESI=10b) lining the long passes between larger Keys. Oil entering these passes, via strong winds or currents, would encounter more sheltered conditions, and then drift into fringing mangrove areas. Seagoing skimmers, as well as reflection booms, are recommended for preventing oil from reaching these mangroves. Sorbent booming would also be effective in front of mangroves.

The lower Florida Keys harbor numerous oil-sensitive coastal fish and wildlife. Among these are the endangered key deer which feeds and rests in red mangroves by day. Also included are the endangered American crocodile which resides in sheltered, mangrove forests. Numerous species of marine birds, including ibis, cormorants, frigate birds, and heron, nest and forage in large numbers on offshore mangrove islands. The Tortugas area is an important commercial fishing ground, as well as a primary nursery ground for the pink shrimp.

Selection of Protection Strategies

Protection of large stretches of shoreline from spilled oil is seldom possible. Limitations of time, manpower, and equipment make preparation for protection strategies in advance an essential part of a rapid and effective response. The ESI maps are an integral part of prespill contingency planning because they identify the areas most sensitive to oil-spill contamination. However, in South Florida, much of the shoreline is dominated by mangroves and classified as highly sensitive. Thus, protection strategies recommended for this shoreline concentrate on preventing oil from entering the sheltered, more sensitive interior environments where oil persistence and damage would be more severe. The shoreline of South Florida has many inlets and channels through which oil can pass to reach the more sensitive areas. Many of these openings are very wide and/or have high current velocities, making containment of oil nearly impossible. However, many canals have narrow openings and low current velocity and can be successfully closed to oil slicks.

Discussed below are recommended lines of defense for protecting priority areas along South Florida's coast.

First Line of Defense

The first line of defense during an oil spill should center on containment at the spill site, whether it is off-

shore or inside an embayment. Depending on the nature and size of the spill, on-site containment and recovery of the oil has proved to be effective. Even if on-site efforts are not 100 percent successful, it provides time for deployment of a second line of defense.

Second Line of Defense

Using available climatological data, spill trajectory models, and overflight observations, potential spill landfall areas can be identified and second line of defense strategies can be implemented. These strategies concentrate on preventing oil from entering major inlets, canals, and creeks directly exposed to the slick. In South Florida, the selection of appropriate shoreline protection techniques depends on the following factors: (1) wave activity, (2) surface current velocities, (3) water depth, (4) type and quantity of oil, and (5) access.

Waves over a foot in height, especially when they are short and choppy, cause oil to pass up and over booms. Surface current velocities dictate the boom type and deployment methods. At currents greater than about one knot (kn), which is the case for many South Florida inlets, oil is dragged beneath the boom, rendering it ineffective. To reduce surface flow, the boom is placed at an angle to the current. For example, at velocities of 1.5 kn, the minimum deployment angle is 30° from the bank (McLean and Hann, 1980). The maximum flow velocity at which stationary booms are effective is about 2 kn. In areas with greater current velocities, oceangoing skimmers in conjunction with booms can be used if the water depths are at least seven feet.

The type and quantity of spilled oil are important factors in the selection of protection techniques. Light oils evaporate and spread rapidly, hampering recovery. Residual oils can be nonfluid at spill temperatures, making recovery from the water surface difficult. Small oil slicks can be contained and recovered using sorbent booms and pads. However, a large number of skimmers and booms are needed to contain and recover massive amounts of oil threatening a shoreline. All of the protection techniques described require access by land and sea for equipment deployment, anchoring, and maintenance. The recommended boom sites on the ESI maps were selected on the basis of optimal shoreline protection as well as access.

Figure 7 is a decision key for the use of several types of booms and skimmers for different purposes and spill conditions. All booms are effective only against floating oil; there is no defense available for oil dispersed in the water column. Recommended sites for booms and skimmers are shown