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The IXTOC I Oil Spill:
The Federal Scientific Response

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COVER PHOTO

IXTOC I well on fire, taken September
1979 from the R/V G.W. PIERCE.
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Acknowledgments

    I would like to acknowledge the assistance of the over 200 scientists who performed the work described in this report. The major organizations these people represented are listed in Chapter I. I would also like to acknowledge the efforts of the authors of each of the chapters as they essentially wrote most of the report.

    There are four people who I am especially appreciative for their efforts in publishing this report: Dr. Robert Hannah of NOAA's Office of Marine Pollution Assessment in Bay St. Louis, Miss., who offered extremely useful ideas on the general organization of the report; Joan Myers, who spent countless hours doing the detailed editing; Rosalie Redmond, who typed, retyped and typed again the entire report as it went through many revisions.

EXECUTIVE SUMMARY

On 3 June 1979, a Petroleos Mexicanos (PEMEX) exploratory well, IXTOC I, blew out in the Bay of Campeche, about 80 km northwest of Ciudad del Carmen, Mexico. The spill, not brought under control until 27 March 1980, became the largest oil spill in history.

During the IXTOC I spill more than 200 scientists from a number of Federal and State agencies, academic institutions, and private companies were marshalled to forecast the trajectory of the spilled oil and to give advice on beach processes, danger to living resources, and changing composition and toxic qualities of the petroleum over the several months that much of the oil remained at sea.

The following summary describes the numerous operational support activities and scientific studies performed under the purview of the Federal Scientific Support Coordinator. The primary purpose of the physical, chemical, and biological activities described herein was to provide the Federal On-Scene Coordinator (OSC) with timely information concerning the location, toxicity, and potential ecological impact of the oil on the Texas coastline so that mitigation measures could be initiated. These studies did not constitute a comprehensive damage assessment program.

Offshore Oil Trajectory Modeling Studies

Computer modeling studies in support of the response to the IXTOC I blowout began early in the spill and continued throughout the summer and fall of 1979. Three distinct types of trajectory models were applied. The first concentrated on the regional problem along the Texas coast, providing daily forecasts of the expected movement and spreading of the oil. This information was presented in a format that was available on an immediate basis to on-scene personnel. A second effort was used to describe the long-term prospects for IXTOC I oil movement and define the strategic threat under which the response should be planned. These models provided information useful in scheduling the buildup and shutdown of the larger scale components of the response, those associated with cleanup activities and scheduling of scientific and aircraft personnel. The third type of modeling was a receptor-oriented study that identified threat areas associated with particular high-value regions. This information was available for the planning of observational programs and the delineation of minimum search areas to be covered. Using these three techniques, the scientific team was able to forecast accurately the pathways the oil would follow from the wellhead through impact on the Texas coast.

Nearshore Movement and Distribution

As the oil began to reach the Texas shoreline on 6 August 1979 contin-
uous beach surveys were undertaken to map its movement and distribution.
Throughout the late summer and early fall of 1979, the barrier islands
along the south Texas coastline were periodically impacted by oil. Between
these periods of impact, storms would often rework the oil and redistribute
it along the shore, depositing clean sand over the beached oil or eroding
the preshore causing the oil to move into the surf zone. The oil tended to
persist longer on shell beaches than fine-sand beaches. There was initially
considerable speculation concerning the fate of oil within the nearshore
environment. Large mats of sunken oil were often conjectured; however,
several diving surveys extending up to 300 m offshore turned up no substan-
tial evidence of large quantities of sunken oil in the nearshore zone.

The strategy for oil spill defense along the south Texas shoreline was
to rely on the barrier islands to absorb most of the oil impact, concentrat-
ing containment resources on the protection of biologically productive
Laguna Madre. The breaks in this line of defense are inlets and overwashes.
The four major inlets (Brazos-Santiago, Mansfield Channel, Fish Pass, and
Aransas Pass) were protected by booms and skimmers deployed under direction
of the U.S. Coast Guard. Cedar Bayou, a shallow pass between San Jose and
Matagroda Islands to the north, was first boomed and then dammed with sand
across the inlet. Booms were also placed in Pass Cavallo, still farther to
the north, in preparation for the advancing oil.

Although the containment operations were not totally effective, espe-
cially during periods of adverse weather and at night, there is no evidence
of great quantities of oil penetrating the defensive structure.

Chemical Characterization and Fate of the Oil

The IXTOC I oil spill was unique not only because of its magnitude,
but also because of the long interval between the release of oil and its
impact on coastal habitats. During this time, many physical and chemical
processes acted on the spilled oil. These processes, cumulatively referred
to as "weathering," included evaporation, dissolution, emulsification,
adsorption onto suspended sediments and detritus, photochemical oxidation,
and microbial degradation. These processes altered the original physical
and chemical properties of the oil, transforming it into several distinctly
different types of petroleum residues. Physical changes included increased
viscosity and density (and therefore lessened buoyancy) and the formation
of various emulsions and oil residues. Chemical changes included oxidation
and degradation caused by photochemical and microbial action. The original
oil slick was transformed into oil-and-water emulsions of various composi-
tions: sheens, flakes of emulsions, tar balls, pancakes of various sizes,
tar mats, and possibly other physical forms as it weathered during its
transport in the open gulf.

One important aspect of the scientific support effort for the IXTOC I spill included collecting oil samples that could be quickly analyzed to determine both the density and toxicity of the oil for making operational decisions. In addition, a project to take advantage of the research opportunities afforded by the IXTOC I spill was undertaken, culminating in a cruise by the NOAA ship RESEARCHER and a contract vessel, the PIERCE, to the well site and then following oil plumes during their northward transect.

During the Federal response to IXTOC I, over 1400 samples were collected in the northwestern Gulf of Mexico. Over 1000 additional samples were collected near the well head during the RESEARCHER and PIERCE cruises. Sample collections started in mid-July 1979, before the oil impacted Texas beaches and continued on a limited scale to the summer of 1980. Nine major cruises by research ships or cutters were undertaken for this purpose, together with extensive beach sampling and collection of commercial fishery products.

Analysis of the RESEARCHER samples indicated weathering had already changed the composition of the IXTOC I oil by the time it reached the surface. Other physical weathering processes caused the oil to form a "water in oil" emulsion (chocolate mousse) in various forms. Visual observations suggested photochemical weathering of the oil. These transformations were reflected by color changes in the emulsions and by a tendency for a crust to form on the floating mousse. Physical agitation caused larger emulsion pancakes to break into smaller particles known as tarflakes. These flakes, which ranged in size from several millimeters to several centimeters, frequently contained a heavily weathered outer crust and a less weathered inner material. The chemical characteristics of the inner material often resembled those of fresh oil samples that were collected near the well head.

Resources at Risk

A wide variety of environmental resources were at risk in the south Texas area during the IXTOC I incident. Padre Island and the Laguna Madre are known to be one of the most important staging and wintering areas for waterfowl, shorebirds, and colonial waterbirds in the United States. The endangered brown pelican, whooping crane, and peregrine falcon all inhabit this area. Sensitive marsh areas are also found in association with the extensive lagoonal system that provides an important nursery for commercial fish species upon which the Texas fisheries industry depends. Eighteen species of marine mammals and five species of marine turtles are reported to be residents of the offshore area of south Texas; all except one are classified as protected, threatened, or endangered.

Resource Protection Measures

The blowout of the IXTOC I well in the Bay of Campeche was unique from the standpoint of resource protection, since the time between the initial blowout and the subsequent impact of U.S. waters was approximately two months. This allowed a protracted period that is not usually available in spill situations to plan and prepare the response.

Measures taken to mitigate environmental damage by the scientific team included the following general activities:

- Identification and prioritization of sensitive areas using ground surveys and remote sensing.

- Tidal, wind, and bathymetric studies in support of boom placement efforts.

- Fishery resources protection through a voluntary shrimp inspection program to ensure consumer confidence as well as slick location broadcasts to minimize lost fishing time and losses of catch and gear.

- A monitoring program to detect the presence of hydrocarbons in key shellfishing areas.

- Establishment of bird, mammal, and turtle cleanup stations along the Texas coast.

- Testing of dispersants and biological agents to determine the feasibility of their use to break up and degrade the oil as it reached U.S. waters.

- Studies to determine the most environmentally sound cleanup and disposal techniques.

Biological Studies

Numerous biological studies were conducted during the IXTOC I spill to monitor changes in dominant, important, or indicative species. These studies were undertaken to indicate the onset of measurable biological changes, so that to the extent practicable, mitigation measures could be initiated. A secondary objective was to provide some baseline information for any subsequent damage assessment studies.

The results of these studies show, however, that in general the oil had only a minimal impact on local biota. This is no doubt influenced by the presence of the coastal barrier islands which largely prevented the oil from entering the more biologically sensitive lagoonal system.

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The biological program consisted largely of two general types of studies: field studies and laboratory analyses. The results of all over-flight population census, remote sensing flights, beach surveys, site intensive impact studies, as well as offshore cruises, made up a field study data base. A battery of toxicological tests comprised the laboratory data base. The results of these studies are outlined by habitat type.

● Inlets and Lagoons

IXTOC I oil failed to impact large areas of marshlands. Small amounts of oil that entered inlets appeared to have little or no measurable effects on the productivity of marshes and inlets. This was observed both through direct observations as well as through physiological bioassays on representa-tive phytoplankton and seagrasses.

● Sand Beaches

During the period of heaviest oiling of beaches, population densities of wading and shorebirds remained low. Substantial increases in bird populations occurred after the natural removal of oil from beaches by tropical storms and correlated with the influx of newly arriving migratory bird species. Birds avoided oiled portions of beaches and moved to other habitats during periods of heaviest oiling. No more than 10 percent of the bird population using beaches was oiled at any time and few carcasses were found. Physiological bioassays using weathered IXTOC I oil on surrogate species related to the peregrine falcon and the whooping crane concluded that neither species would be affected by the consumption of oil-contaminated prey.

Monitoring of infaunal populations at oiled beaches indicated measurable reductions in the population size. Total population densities were signifi-cantly reduced in the lower intertidal zone and in the second bar and trough of subtidal habitats. Numbers of crustaceans (mole crabs and amphi-pods) were significantly lowered in both zones following the spill. It was difficult to distinguish the effects of the oil spill from natural factors, especially storms and natural population variations. Results of acute (96 hour) toxicity tests, exposing IXTOC I oil to dominant infaunal organisms, indicated no significant mortality. These results support the findings of field studies, thus suggesting that IXTOC I oil was not acutely toxic to beach fauna, although sublethal effects (significantly decreased respiration rates and avoidance behavior) were observed in oil-exposed mole crabs.

Results of acute toxicity tests, conducted on subtidal amphipods and zooplankton, suggested that IXTOC I oil was not toxic to these species.

Offshore and Nearshore Environments

Bioassay and toxicity tests of dominant and commercial species were conducted in addition to observations made during cruises. Toxicity tests conducted on adult redfish, seatrout, and brown shrimp indicated that IXTOC I oil was not acutely toxic to these commercially important fisheries species. However, high mortalities were observed in larval and juvenile fish species tested. Toxicity was greatest in larval redfish and many deformities in eggs and larvae were observed. Toxicity tests on redfish larvae indicated that the oil-accommodated seawater (water soluble fraction plus small oil microdoplets of mousse) fraction was more toxic than the water soluble fraction of the IXTOC I oil. Additional redfish larval tests indicated that the mousse fraction was nearly 100 percent toxic. The results of the studies may suggest that toxicity to redfish larval may be due to smothering rather than chemical toxicity per se, since the mousse and oil-accommodated seawater fractions were more toxic than the water soluble fraction. High mortalities were also observed in juvenile seatrout. In open water situations, adult organisms may have been able to avoid contaminated areas; however, impacts to eggs, larvae, and juveniles would likely have occurred in heavily oiled areas.

All toxicity tests were conducted using the mousse collected by the U.S. Coast Guard vessel POINT BAKER, near Brownsville, Texas. These samples did not contain high concentrations of many aromatic oil fractions such as napthalene, methyl napthalene, dimethyl napthalene, and trimethyl napthalene. These compounds have been shown to be acutely toxic to many adult marine organisms; reduced toxicity observed in tests with adults may have resulted from the very small concentrations of these compounds in the samples collected by the POINT BAKER.

The effects of IXTOC I oil on marine mammals are preliminary at this time. General indications are that no observable effects to marine mammals were found during the different research cruises conducted at various times during the spill.

Initial findings indicated that sea turtle mortalities observed were possibly oil-related. However, preliminary findings suggest that incidences of mortality were rare and isolated.

Conclusions

In summary, field studies suggest that IXTOC I oil may have caused: (1) significant population shifts and avoidance by major wading and shore-bird species at heavily oiled beaches; (2) subtle reductions of infaunal population densities throughout the intertidal beach habitat, with signifi-cant declines occurring only in the lower intertidal zone and the second bar and trough of subtidal habitats; major population declines in two species of crustaceans (mole crabs and amphipods); (3) minor impacts to marsh vegetation; and (4) minor impacts to marine turtles and mammals. However, it was difficult to distinguish the effects of spilled oil from effects from natural factors such as tropical storms, seasonality, and normal population variation.

Laboratory studies further indicated that: (1) acute exposures of dominant beach infauna such as mole crabs, surf clams, and polychaete worms to the oil-accommodated seawater fraction were not acutely toxic, although significant sublethal physiological effects and avoidance behavior were observed in mole crabs; (2) acute exposures of subtidal amphipods and zooplankton to the oil-accommodated seawater fraction were not toxic; (3) acute exposures of redfish larvae to the oil-accommodated seawater, water soluble fractions, and mousse fractions were toxic, with highest toxicity being observed in the mousse and oil-accommodated seawater fractions (rather than the water soluble fraction); (4) acute exposures of seatrout to the oil-accommodated seawater fraction resulted in significant toxicity in juvenile fish, but no toxicity in adult fish; and (5) acute exposures of brown shrimp to the oil-accommodated seawater fraction were not toxic. Laboratory studies indicated that IXTOC-I oil was not acutely toxic to the adult marine organisms tested. These laboratory findings tend to support results from field studies, which indicated that IXTOC I oil caused only limited impacts to beach infauna and other marine organisms. Results of subtidal amphipod and zooplankton toxicity tests were inconclusive, in that both species were resistant to low concentrations of oil tested. However, effects of higher concentrations than those tested are unknown.

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INTRODUCTION

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Early in the morning of 3 June 1979, a Petroleos Mexicanos (PEMEX) exploratory well, IXTOC-I, blew out in the Bay of Campeche. The well was located about 80 km northwest of Ciudad del Carmen, Mexico. The IXTOC-I spill soon surpassed the 7.6 million gallons lost by the ARGO MERCHANT in December 1976, and within a few months became the largest oil spill in history, eclipsing the 68 million gallons of oil spilled by the AMOCO CADIZ near the coast of Brittany, France, 15 months earlier.* The blowout continued for over 10½ months until the well was finally brought under control on 27 March 1980.

This report is limited to the operations and scientific studies performed under the purview of the Federal Scientific Support Coordinator (SSC) and the NOAA Hazardous Materials Response Project. The SSC is charged with gathering and coordinating scientific information and advice for the

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*Estimates vary widely on the total amount of oil spilled. PEMEX estimates vary from 30,000 barrels a day at the height of the spill to about 4,000 barrels per day in November after the injection of steel balls reportedly reduced the flow rate. Jerome Milgram of MIT visited the well in October, and he estimated that as much as 50,000 barrels a day could be flowing from the well.

Federal On-Scene Coordinator (OSC) who has charge of the overall response effort. This report is limited to the federally funded studies conducted on the impact of the IXTOC I oil on the Texas coastline; it does not deal with the ecological impact of the spill in Mexican waters. Neither does it discuss the results of the NOAA/BLM damage assessment program initiated after the blowout was controlled, nor does it cover the specifics of the U.S. Coast Guard cleanup effort. Those readers desiring additional informa-tion in the area are referred to the Oil Spill Intelligence Special Report on IXTOC I 4 January 1980 and the U.S. Coast Guard report describing the overall Federal response effort.

Background on NOAA's Hazardous Materials Response Team

At the time of the ARGO MERCHANT oil spill near Nantucket Island in December 1976, a research team of scientists from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Coast Guard (USCG) undertook a limited research project designed to describe the movement and fate of the oil released by this tanker. This was a first-step in assessing the ecological effects of the spill. Many other Federal agencies, state organi-zations, and academic groups were drawn into the work. During this effort, it became apparent that forecasts of the oil's movement and scientific chemical and biological studies could be of considerable assistance to the OSC, who has the responsibility for preventing and combatting such incidents. Therefore, after the ARGO MERCHANT, NOAA established the Hazardous Materials Response Project to provide operational scientific advice to the Federal OSC during oil and toxic chemical spills in the marine environment. Head-quartered in Boulder, Colorado, this group has the capability of bringing together the talents of a wide range of experts from Federal, state, and local agences, as well as universities and the private sector. These experts have been called upon during numerous spills around the coast of the United States, and have also been requested to lend their assistance at foreign spills, most notably during the AMOCO CADIZ disaster in 1978.

The scientific response teams are made up of members from several Federal and state agencies, and from universities and private companies as well as from the various components of NOAA. During the IXTOC-I spill more than 200 scientists from a number of agencies and academic institutions were marshalled to forecast the trajectory of the spilled oil, and to give advice on beach processes, danger to living resources and changing composi-tion and toxic qualities of the petroleum over the period of several months that much of the oil remained at sea.

The following is a list of the major organizations that participated in the scientific response to the IXTOC-I spill:

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Federal agencies:

- United States Coast Guard
- Environmental Protection Agency
- U.S. Department of Interior, Bureau of Land Management,
     Fish and Wildlife Service
- U.S. Geological Survey
- National Park Service
- Food and Drug Administration
- National Oceanic and Atmospheric Administration
- United States Navy

State of Texas Agencies

- Department of Health
- Parks and Wildlife Department
- Department of Roads
- Department of Transportation

Universities

- Corpus Christi State University
- University of New Orleans
- Texas A&M
- University of Texas, Institute of Marine Sciences
- Woods Hole Oceanographic Institute

Private Contractors

- Coastal Ecosystems Company
- Computer Sciences Corporation
- Ecology and Environment, Inc.
- Energy Resources Company
- Research Planning Institute
- Science Applications, Inc.
- SRI International
- USR Company

The following report summarizes the numerous operational support activities and scientific studies performed by the above organizations under the purview of the Federal Scientific Support Coordinator. It should be emphasized that the primary purpose of the physical, chemical and biological activities discussed herein was to provide the Federal OSC with timely information concerning the location, toxicity and potential ecological impact of the oil on the Texas coastline so that mitigation measures could be initiated.

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TRANSPORT, DISTRIBUTION, AND PHYSICAL, CHARACTERISTICS OF THE OIL

Part I: Offshore Movement and Distribution

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The following sections will describe the approach that the Physical Processes Team, a component of the NOAA/Hazardous Materials Response Team, undertook to monitor, map, and simulate the movement of the IXTOC I oil; the problems encountered; and the results obtained.

A wide variety of physical processes each took its turn working on the spilled oil. The scale on which oceanographic processes affected the spilled oil was truly oceanic, and the sequence of meteorological patterns, including tropical storms, created considerable challenge. Although the physical processes studies used standard techniques of computer modeling, mathematical analysis, and geophysical observations, the actual size of the IXTOC I effort had the catalytic effect of forging these together in a number of new and useful ways. The result was a more continuous and comprehensive trajectory study than has been available for any major spill.

INITIAL TRAJECTORY RESPONSE ACTIVITIES

In any spill trajectory study it is necessary to have estimates of the
transport processes affecting the pollutant. The IXTOC I case required,
among other things, current and wind patterns for the Bay of Campeche.
Upon the initial request for trajectory information on June 12,a search for
relevant oceanographic data began. Within a few hours, a research paper
(Nowlin, 1972) was located describing circulation in the southwest Gulf of
Mexico. A call to the National Weather Service offices in Suitland, Maryland,
produced estimated winds for Campeche Bay for 3 June through 13 June.
Concurrently, National Ocean Survey chart No. 411 was digitized for use in
OSSM (On-Scene-Spill-Model) (Torgrimson and Galt, 1979). With this much
preliminary information, it was possible to begin looking at trajectory
scenarios.

Within 10 hours of the original phone request, two trajectory experi-
ments had been run with these data. The results suggested that the spilled
oil would initially drift west to west-northwest under the combined influence
of the currents and winds. Once it reached the vicinity of the Mexican
coast between Cabo Rojo and Tampico, it would be transported north with the
coastal currents playing a dominant role. There was also an indication
that some fraction of the oil could split off from the main body and move
south along the Mexican coast in a circulation feature identified as the
"Campeche gyre" (Figure 2.1). Using climatological wind data (U.S. Navy
Marine Climatic Atlas of the World, Volume 1, North Atlantic Ocean) to
extend the model runs, we found that these trajectory experiments suggested
that oil might initially appear in U.S. waters offshore in early July and
make its first U.S. landfall near Matagorda Bay in the third week of July
(Figure 2.2). These results, along with a list of caveats, were forwarded
to the Regional Response Team.

These initial trajectory results did identify a threat to U.S. waters,
but also a number of weak links in the data. These results also pointed
out several critical circulation and wind features that appeared to have
fundamental roles to play in the movement of the IXTOC I oil.

EARLY DATA GAPS: DEVELOPING A DATA BASE

The circulation feature identified as the Campeche gyre can be clearly
seen in the data presented by Nowlin (Figure 2.1). It is an elongated
(east-west), closed circulation pattern that is generally situated over the
southwestern section of the Campeche Bank. The center of its circulation
is on the Bank approximately at the location of the IXTOC I well. With
this much information, it became obvious that the details of this flow may
well be significant for the trajectory problem. For example, if the center
of the gyre were to shift slightly to the west, the effluent from the well
would initially follow a northward-flowing current, while a shift of gyre
to the east would result in an initial transport to the south.
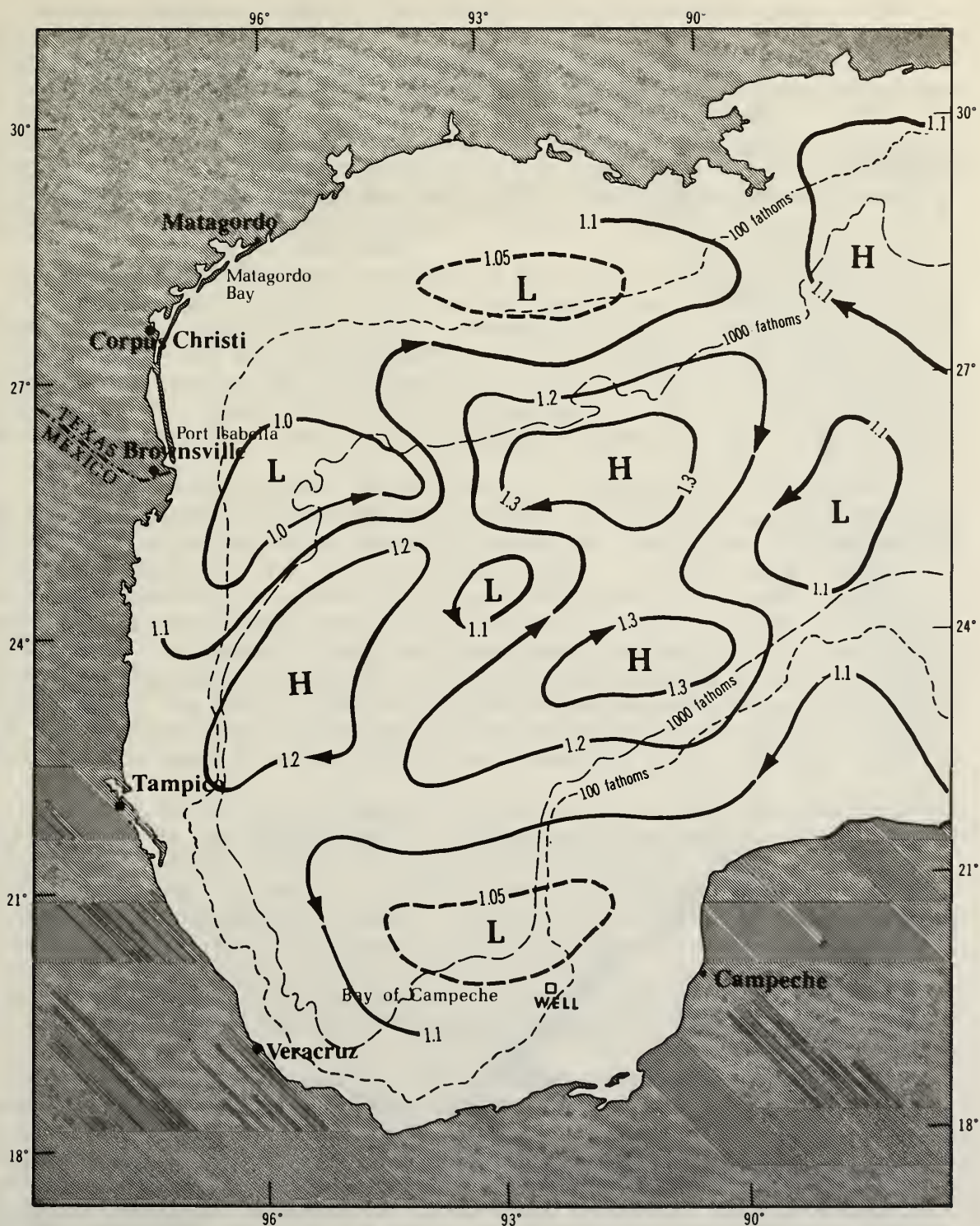
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Figure 2.1 Dynamic topography of surface relative to 1000 - dB
Surface: Alaska Cruise 1-1A, 2-1B, and 3-1C, 22 April - 21
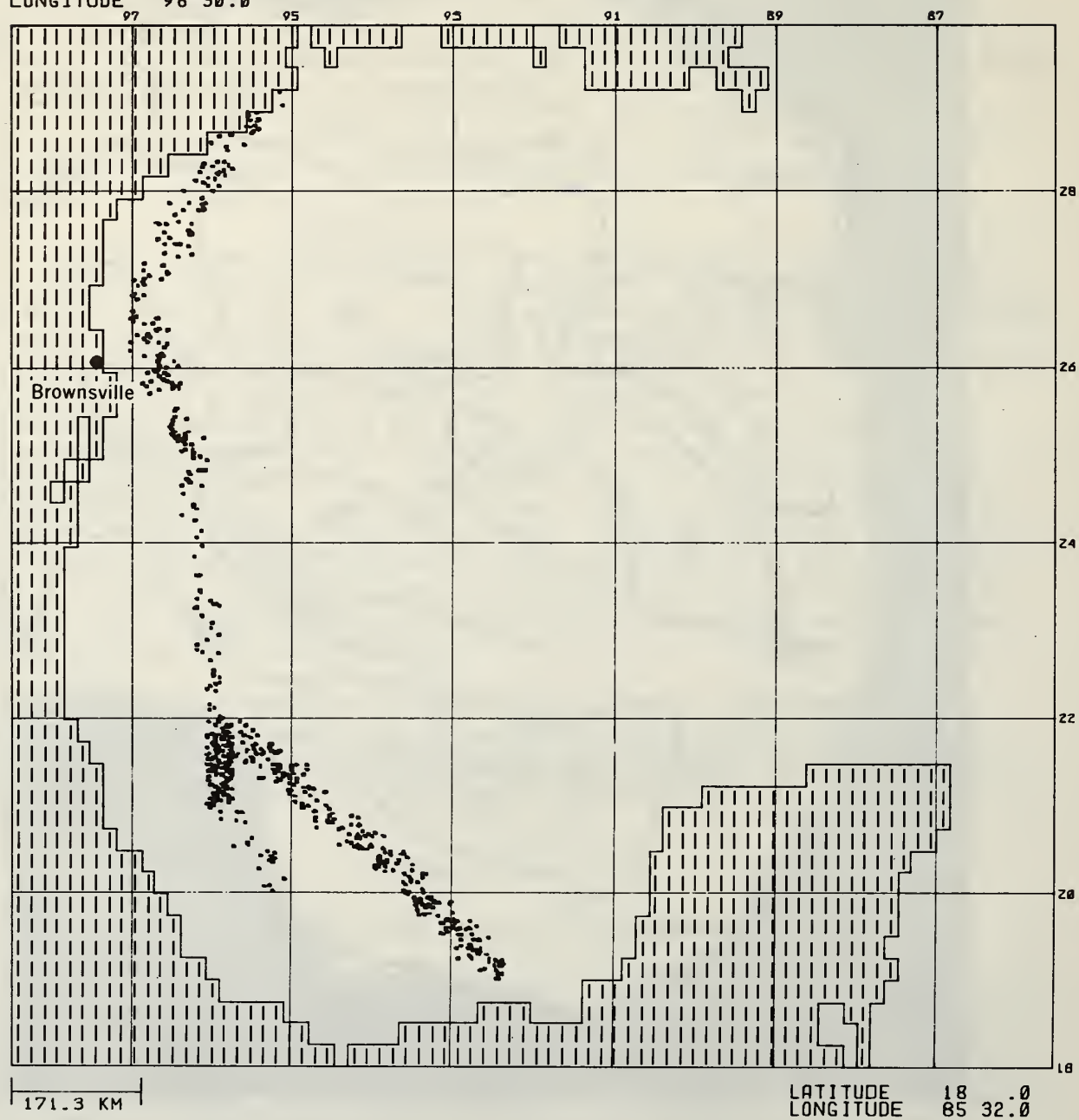August 1951. (After Austin, 1955; and Nowlin and McLellan, 1972).

Figure 2.2 Initial trajectory estimate produced 10 hours after major notification.

Another important detail associated with the Campeche gyre is the extent and shape of its western edge. The position of this southerly flowing segment of the gyre would control onshore transport toward the Mexican coast, thus determining where the IXTOC oil might first be expected to impact the coastline. In addition, the extent and strength of the western edge of the gyre might control the amount of oil recirculated south along or toward the Mexican coast versus the fraction of the oil that would be transported to the west, reaching the Mexican Coastal Current thus moving north with a potential threat to the U.S. (Figure 2.3).

A second data area that appeared to be significant to the trajectory studies related to the details of the northward-flowing Mexican Coastal Current itself (Figure 2.3). This current clearly would play a major role in the transport of oil toward the U.S. It was also obvious that our initial understanding and descriptions of the currents in this area were inadequate. The speed and width of the current, as well as its persistence and possible branches, would all be relevant factors in trajectory studies.

As these data gaps were identified, we increased our data search to try and find further background information. One major source of regional information turned out to be material resulting from Bureau of Land Management (BLM) studies of the offshore Texas region. These studies were initially conducted to develop background information for environmental impact studies associated with Outer Continental Shelf (OCS) gas and oil development. Included in these data sets were the results of a number of current studies that used drift cards and current meters as well as hydrographic data. As useful as this information turned out to be, it covered only the Texas coastal region and did not extend down along the Mexican coast, so a broader coverage of data was essential.

A second source of data came from the current study work and numerical modeling done by the NOAA/Atlantic Oceanographic and Meteorological Laboratory (AOML). These studies used the basic Geophysical Fluid Dynamics Laboratory's (GFDL) general circulation model (Bryan 1967) to look at the currents within the Gulf of Mexico. This detailed study included seasonal variations in the wind and represented a full annual three-dimensional circulation pattern for the entire Gulf of Mexico. This study gave valuable information for the deep waters of the gulf, although its scope was not such that it provided sufficient resolution over the Continental Shelf.

A third very useful data set was located in a Texas A & M University Master's thesis by Alberto Mariano Vazquez de la Cerda (1975). This researcher had access to data obtained during a number of hydrographic cruises along the Mexican coast which specifically covered the Mexican Coastal Current. As such, it greatly extended the earlier work done by Nowlin (1972) and explained a number of significant features. In particular, these data and de la Cerda's analysis made it clear that the Campeche gyre was limited in its western and northwestern extent by the topographic features associated with the Campeche Bank. This meant that oil moving from the well would have a tendency to move to the southwest along the edge of the Campeche Bank and was not likely to move directly west into the deeper waters of the Gulf of Mexico.
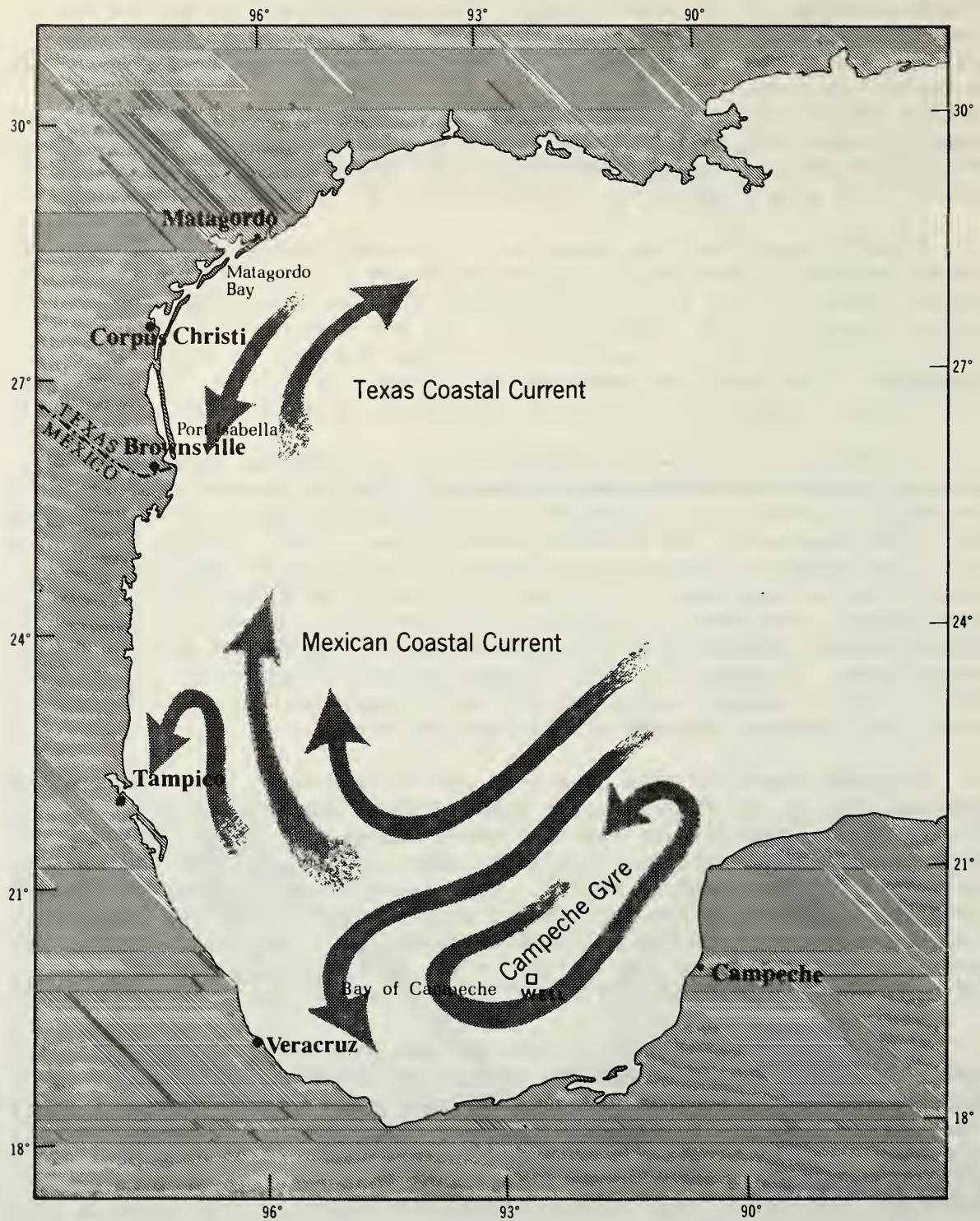
Figure 2.3 Representation of flow patterns significant to the movement of oil into U.S. waters.

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The analysis by de la Cerda pointed out a number of features of the Mexican Coastal Current between Cabo Rojo and Tampico. At this point, there was considerable evidence that the current behaved in some ways analogous to a western boundary current such as is seen off the east coast of Africa. In addition, this study identified a small coastal recirculation feature, in the vicinity of Tampico, that formed a counterclockwise eddy inside the Mexican Coastal Current. This feature had the potential to move oil inshore and recirculate it back toward Cabo Rojo and thus decrease the threat to U.S. coastal waters.

A fourth additional information set was uncovered in a paper by W. Sturges and J.P. Blaha (1976). They hypothesized that the controlling dynamics for the Mexican Coastal Current were, in fact, similar to those that controlled the Gulf Stream and the summertime development of the Somali Current. The strength of the current is related to the large-scale curl of the wind stress over the Gulf of Mexico. The seasonable variations of the curl of the wind stress for the Gulf of Mexico are known from a statistical point of view, being seen as a biannual pattern with maximas in the summer and winter and minimas in the fall and spring. Given the scale information from de la Cerda's thesis and the temporal correlations with large-scale wind patterns provided by Sturges and Blaha (1976), we began to get a better understanding of the transport processes associated with the Mexican Coastal Current.

As our study accumulated additional information about the IXTOC I transport processes, we also accumulated additional questions that needed to be answered. In particular, there was a significant concern that oil might be moving north or northeast across Campeche Bay to a region where it could become entrained in the Loop Current through Yucatan Strait and, in that way, be carried to the coast of Florida. This supposition needed to be checked and, therefore, the data sources that we had, particularly the time-dependent AOML general circulation models, were examined in considerable detail to study the possibility of oil moving to the northeast.

EARLY OBSERVATIONS

During the early part of the IXTOC I spill event, actual observations of the oil distribution and leak rate available to U.S. scientists were minimal. It was impossible to determine what fraction of the oil was actually evaporating or what fraction of the discharge was actually oil rather than gas. There was also considerable question concerning the quantity of hydrocarbon that was burning. Reports of cleanup and recovery activity were sketchy at best. For these reasons, initial modeling work hypothesized a continuous release rate of oil and no weathering or burning.

The early observations that were available from the IXTOC I site (even though they were quite meager) played an important role in setting up our initial response to the spill event. In about the third week of June, a U.S. observation team went to Ciudad del Carmen and obtained a few first-hand descriptions of the well site and the form of the oil in the vicinity

of the blowout. These observations described the oil distribution in the immediate vicinity of the well, but added no information about the far field, i.e., distances beyond a few tens of kilometers. According to reports at that time, the actual distance that oil extended from the well was quite small.

In addition to observations from the on-scene U.S. observers, the Mexican government was also carrying out overflights. The results of these overflights began to be relayed to the Physical Processes Team on 28 June.

The distribution of the oil released from the blowout was also available from a number of satellite images available from GOES, TIROS, and ERTS. The GOES imagery, available on a regular basis, was particularly useful for determining the direction of the oil plume from the well site. The satellite information was relayed to the Physical Processes Team directly from the Miami Satellite Center. These data were then compared with the computer simulations.

During the third week of the spill, it became obvious that the GOES imagery was unable to show the actual extent of the oil, because only the very thickest oil appeared on the imagery. At the same time, all of the computer simulations indicated that the oil should extend much farther (by a factor of five) than was shown by the GOES imagery.

The computer scenarios were rerun using the most conservative estimates of winds and currents that were available; even accounting for phenomenally high evaporation rates, the oil should have gone farther than was being reported or observed by GOES. Results of the computer experiments suggested that, by three weeks, the oil should be extending to the coastal area in the vicinity of Veracruz (Figure 2.4). Additional studies of TIROS satellite images were particularly informative about this problem. At first, the TIROS satellites identified suspected oil distribution by means of a reduction of the glitter from the ocean in imagery taken at very high sun angles. The idea was that thick oil would suppress the wave action and thus reduce the glitter seen by the satellites. Under these conditions, the oil slick might appear as a dark patch in a brighter image of the ocean.

During the last week of June, prompted by computer predictions that had the oil far in advance of the position shown by the high-sun-angle TIROS images, a more detailed look at low-sun-angle images was suggested. A representation of this is seen in Figure 2.5. In the original low-sun-angle image, the oil was surmised to appear as lighter spots in a darker ocean, caused by the increase in albido from the surface oil film. Thin oil on the ocean was anticipated to take on a grayish appearance that would stand out as lighter than the darker blue background water resulting from the increased reflectivity of the oil film. Contrasted to the high-sun-angle image, there would have to be sufficient oil to actually suppress small gravity waves, in the low-sun-angle images it would only be necessary to have sufficient oil concentrations to reflect more light than the ocean. Thus, the low-sun-angle images were expected to indicate much thinner oil concentrations than the higher sun-angle images.

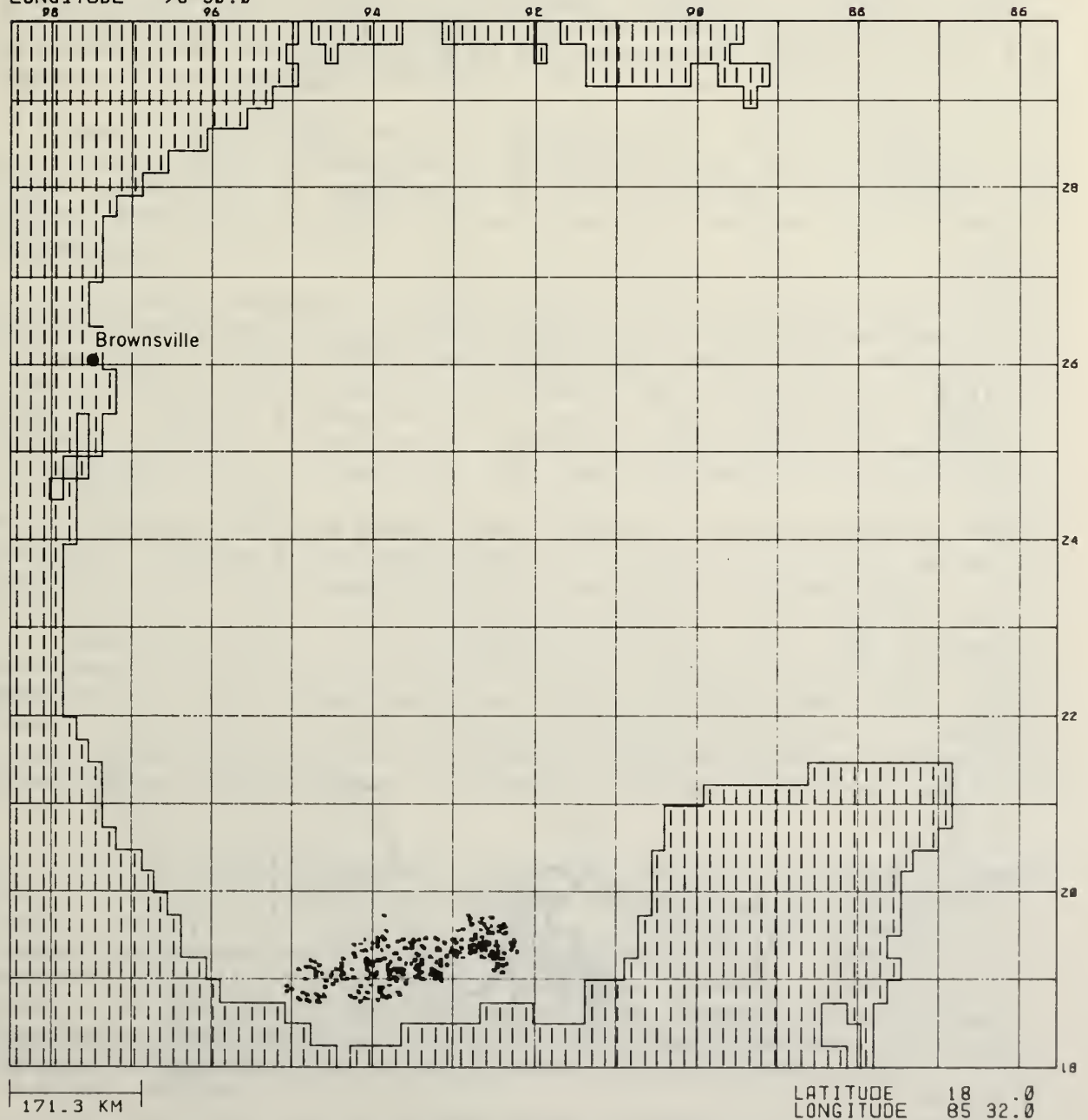Figure 2.4   Computer-generated scenario for the first of July using conservative estimates for wind and current transport.

WEST SIDE OF THE GULF OF MEXICO
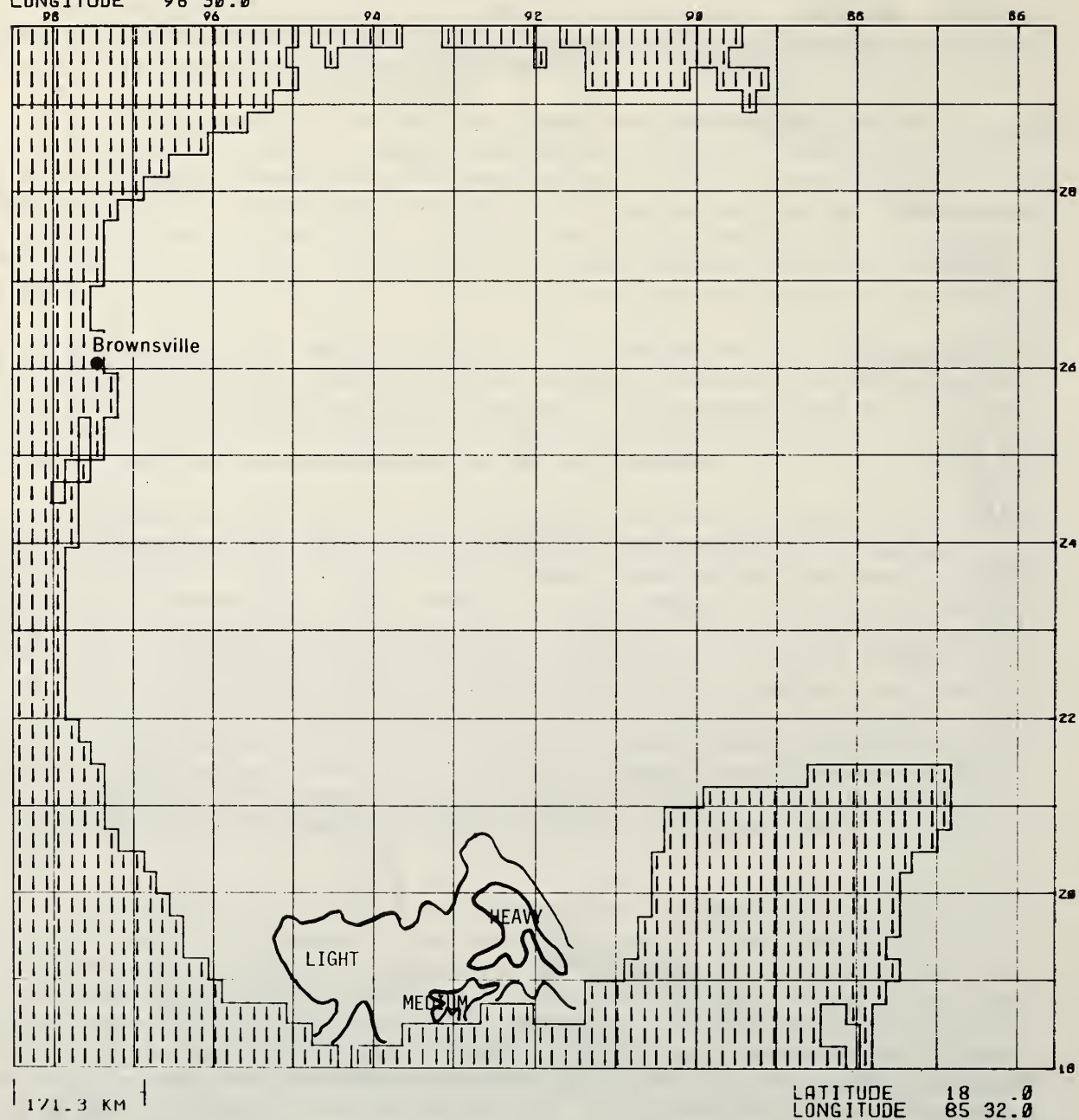18Z 17 JUNE 1979   MIAMI SESS

LATITUDE   29 54.0
LONGITUDE   98 30.0

Brownsville

LIGHT

HEAVY

MEDIUM

171.3 KM

LATITUDE   18   .0
LONGITUDE   85 32.0

Figure 2.5   Representation of oil distribution on 17 June 1979 as seen
from low angel TIROS image.

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The 17 June image suggested that the oil extended west-northwest and then trended to the west-southwest approximately following the edge of the Campeche Bank. At that time, the oil appeared to extend as far west as longitude 95, which put it three-quarters of the way from the well site to Veracruz. The independent agreement of the initial computer experiments and this satellite image was very encouraging. In addition, this information tended to corroborate the findings suggested in de la Cerda's thesis, which suggested that the circulation along the edge of the Campeche gyre, and in particular the western edge of the Campeche Bank, was controlled by bathymetry, and that an excursion of oil directly west across the bank and then into deeper waters of the Gulf of Mexico was unlikely.

Armed with the TIROS satellite imagery and the initial trajectory experiment results, we began the first extensive U.S. mapping effort. The plane (a NOAA P-3) was scheduled to spend 4 or 5 hours over the Bay of Campeche, covering the plume that was expected on the basis of this information.

On 3 July, the NOAA P-3 first encountered oil just north and east of Veracruz and subsequently confirmed that the oil leaving the well site was moving parallel to the northeastern edge of the Campeche Bay, and its initial approach to the coastline would occur in the immediate vicinity of Veracruz. Figure 2.6 shows the full extent of the oil distribution discovered on 3 July. There were no indications that significant amounts of oil were moving north or northeast into the gulf from the well head.

Corroboration of the observations on 3 July, strengthened the original assumption that the key to the transport of oil into U.S. waters rested with the dynamics and characteristics of the Mexican Coastal Current.

Immediately after the first NOAA P-3 flight on 3 July, new requests were made for additional overflight coverage of the Mexican coastal region between Brownsville, Texas, and Veracruz. Such flights were quickly undertaken by the State of Texas Department of Transportation, the U.S. Coast Guard, and NASA. In addition, a research cruise was planned, using a Coast Guard cutter, with the objective of better defining the Mexican Coastal Current.

With this updated data base, continuing numerical experiments suggested that oil would be transported north along the Mexican coast and would possibly impact the U.S. coastal region by late July or early August. A Federal response effort was consequently established with the Hazardous Materials Physical Processes Team joining the Scientific Support Coordinator's staff for direct on-scene support. The Physical Processes Team immediately began supplying the output from various computer scenarios for analysis and consideration by the Scientific Support Coordinator.

The Coast Guard Cutter VALIANT departed Galveston on 16 July enroute to the region on the Mexican Coastal Current. Objectives for the cruise were to (1) find the heavy leading edge of the oil, (2) obtain oil samples, (3) map the large patches of oil that had been seen in previous Coast Guard overflights; (4) document the spatial scale of the Mexican Coastal Current using XBT's (expendable bathythermograph); (5) investigate the size and

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Figure 2.6 Galt/Kennedy overflight 3 July 1979 showing distribution of oil as seen from the NOAA P-3 aircraft.

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extent of the hypothesized counterclockwise recirculation off Tampico (Figure 2.3); and (6) obtain some direct measurements of the speed of the Mexican Coastal Current. All six of these objectives were met. A very heavy concentration of oil was mapped and sampled offshore of Cabo Rojo. A number of cross-shelf XBT transects were carried out which delineated the axis of the Mexican Coastal Current. A counterclockwise circulation off Tampico was seen to extend some 25 km offshore, and direct measurement with Richardson dye probes indicated the strength of the circulation patterns. The maximum speed associated with the Mexican Coastal Current occurred some 50 km offshore and was about 1 knot.

The counterclockwise circulation off Tampico was expected to recirculate oil that was nearshore and thus move it in toward the Mexican coast rather than allow it to continue farther north. This, then, suggested that the maximum threat to U.S. waters would come from oil concentrations that were some 50 km offshore near either Tampico or Cabo Rojo. When the U.S. Coast Guard Cutter VALIANT returned, this information was incorporated into updates of the trajectory scenarios and revised the estimates for the arrival of IXTOC I oil in U.S.waters. These studies showed that oil could be expected in the Brownsville region in the first week of August.

ROUTINE OPERATIONS

As the IXTOC I oil approached the Texas coastal region, more detailed estimates of its movement and spreading assumed particular interest to the on-scene response personnel. To provide these personnel with a more direct flow of information from the modeling efforts, we adapted the on-scene spill model to a tactical mode. These studies focused particularly on the Texas coastal region between Brownsville and Matagorda Bay. Three fundamental elements went into these numerical experiments, which were updated every few days.

The first element was the initial or present positioning of the oil. Daily overflights by the U.S. Coast Guard and NOAA supplied this information, and maps were available a few hours after the return of the observers. Each evening, these maps were presented in the debriefing that took place for all response personnel.

The second element involved in the trajectory study was the definition of the coastal currents for the Continental Shelf region along the Texas coast. The estimates of these currents came from a variety of methods that will be described in more detail below.

The third element to go into the trajectory study was the forecast of local winds over 48-hour or 72-hour periods. These data were provided as part of a special analysis by the National Weather Service on-scene forecaster.

Texas coastal surface currents played a significant role in the movement of oil. The predominant summer flow appeared to move northerly along the Texas coast, but this northern progression of the water did not occur as a regular steady stream. It was controlled by local meteorological events, and throughout the summer, many reversals and stagnations in the current occurred. During periods of strong northerly flow, currents on the order of 1 knot were seen over most of the shelf area. An atmospheric system moving through could stall or stagnate the currents so that northern progress all but stopped. As the season progressed, the intensity of these atmospheric events increased, and reversals in the flow took place. Typically, during the summer, 5 days would show northerly flow and 2 days would show a stagnation. As the season progressed, the average duration of the northerly flow tended to decrease; the stagnations became more frequent and reversals dominated for a day or so. As the season continued, this tendency for increased southerly movement grew and eventually dominated, so that throughout the winter the flow along the Texas coastal region was essentially to the south with atmospheric events leading to stagnations and occasional reversals. The transition from currents that flow dominantly to the north along the Texas coast to those flowing dominantly south typically occurs in late September. The fundamental question for the oceanographers involved in the IXTOC I trajectory study was to define the details of these many current reversals throughout the summer and to attempt to document the transition from the summer regime to the winter regime.

To define these local and smaller scale currents, several observational stratagems were employed. The first was to set up a series of onshore-offshore transects using Richardson current probes deployed by helicopter, with which surface currents off Brownsville, Mansfield Cut, Corpus Christi, and Cedar Bayou could be monitored every few days. Increased coverage was attempted during times of atmospheric disturbance that might retard or reverse the current flow. The second method of monitoring the currents was to place radio frequency drogues along the coast and monitor their positions from radio direction-tracking shore stations. These provided more continuous monitoring of the current, but with significantly less spatial resolution. The third source of regional current information came from satellite drogues. Deployed to study the large-scale circulation for the western gulf, they occasionally drifted through the nearshore region and thus became additional sources of current data. During the maximum extent of the oil penetration into U.S. waters, the Richardson current probe work and satellite-tracked drogues were deployed in a reconnaissance mode farther north along the Texas coast as far as the Louisiana border.

Once the real-time measurements of currents along the Texas coast were available, it became necessary to analyze these data and produce a current field that was both representative of the regional flow and compatible with the requirements of the on-scene spill model. Two specialized routines were used to obtain this current field, which was necessary because the observational data did not give all the information needed, and because errors in the data could lead to vector fields that could not give realistic descriptions of transport processes. The first criterion to be met by the derived flow field was that it conserve water, which means the analysis

routine must take into account the regional bathymetry and configuration of the coastline. A second important feature that derived flow fields should have was related to the constraints imposed by the dominant regional dynamics.

The first of the specialized analysis routines is called Diagnostic Analysis of Currents (DAC). This routine generates the shelf flow pattern (Figure 2.7) consistent with the regional geometry and the first-order geostrophic plus Ekman dynamics, assuming an alongshore wind stress. Furthermore, since shelf circulation can have components that are not in balance with this geostrophic plus Ekman forcing, a second analysis routine, Streamline Analysis of Currents (SAC), was used (Figures 2.8 and 2.9). The composite pattern from these programs (Figure 2.10) generated a mass, or water-conserving, flow field that represented a geostrophic flow with onshore/offshore currents across the outer shelf or through tidal passes.

Independent combinations of the circulation patterns derived from DAC and SAC could be added together to produce a best fit to the observed data that were consistent with the local geometry and some of the major dynamics. These patterns could represent or simulate various combinations of alongshore currents, tidal flow, or large-scale shelf waves. The current fields used in OSSM were thus composites of the analytically derived current patterns, such that they best approximated the set of observed data points. These current patterns were updated as often as new observational data were available, and in this form they made up the second element used in the trajectory study.

The tactical trajectory analyses along the Texas coast continued on a routine basis as long as significant quantities of oil were observed north of the Brownsville region.

LONG-TERM TRAJECTORIES

Throughout September, as the currents along the Texas coast became more southerly and the regional winds tended to shift to the northeast, the threat of coastal impact to the Texas area decreased. It became essential to develop a plan for phasing out coastal cleanup activities, and stand down the cleanup crews. The actual regional response to the spill had become a multi-thousand-dollar-a-day activity. However, before it could be terminated, it was necessary to know if the reversals that were seen in the currents and the winds, and the subsequent lack of oil, were permanent features or just short-term events.

To investigate these questions and to arrive at a longer term under- standing of the oil problem in Texas waters, the Physical Processes Team did a different series of model runs. These focused on the entire western Gulf of Mexico rather than just on the coastal area of Texas. To run these experiments, we took statistical wind data for each month from the U.S. Navy Marine Climatic Atlas of the World (1976), Volume 1, North Atlantic Ocean. These gave the basic probabilities for both speed and direction

BAFFIN BAY TO BROWNSVILLE
DIAGNOSTIC CURRENT MODEL VECTORS

LATITUDE   27 28.3
LONGITUDE   97 40.0
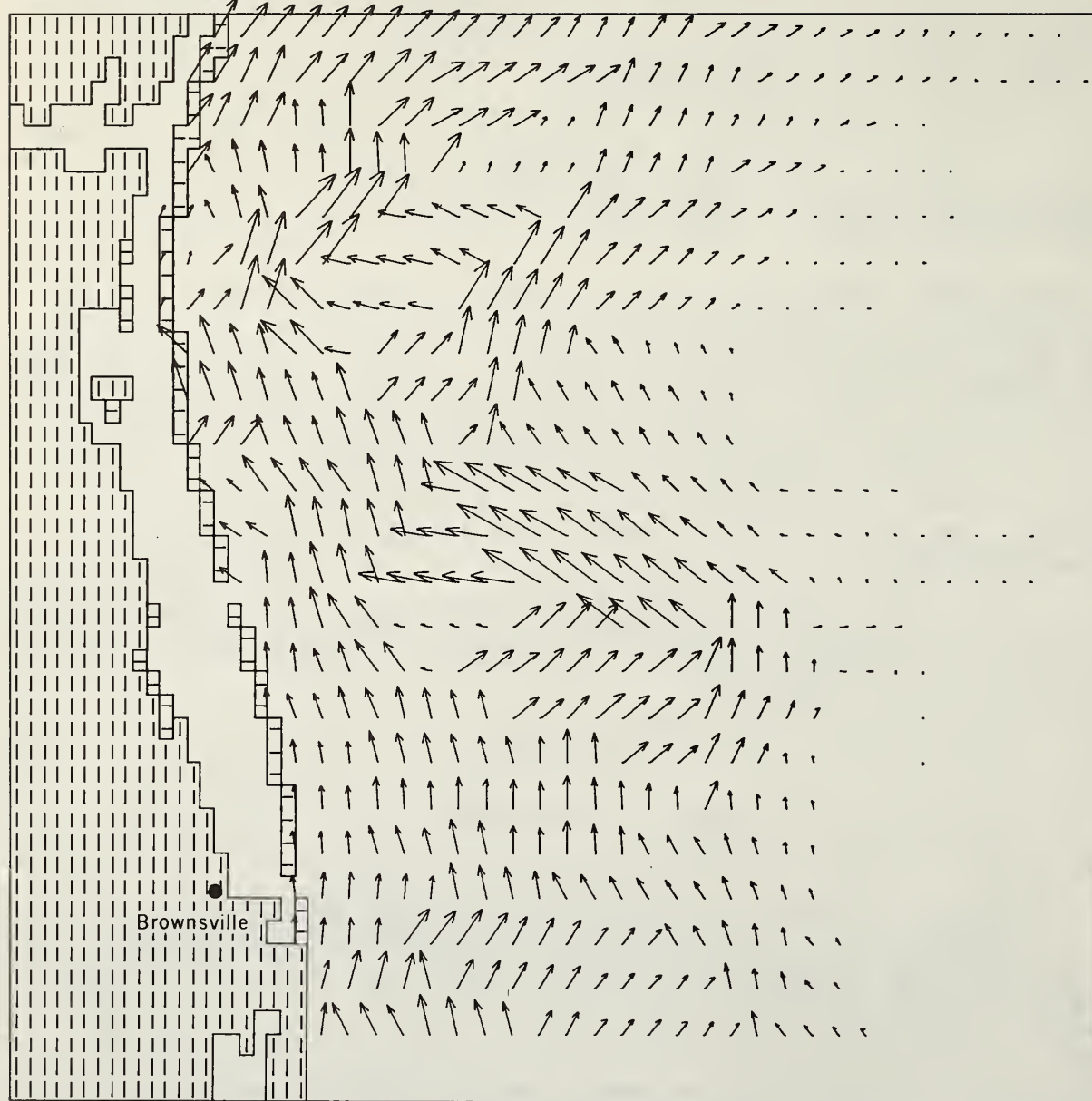
Brownsville

LATITUDE   25 45.0
LONGITUDE   95 45.5

GRID AREA SACB1 ON MAP BROWN2 FILE DMCURB1 FROM CHECKPOINT A31PRED

Figure 2.7 Diagnostic analysis of currents for one of four areas used to
    define Texas coastal currents.

BAFFIN BAY TO BROWNSVILLE
STREAM FUNCTION CURRENT VECTORS

LATITUDE   27 28.3
LONGITUDE   97 40.0

Brownsville

LATITUDE   25 45.0
LONGITUDE   95 45.5
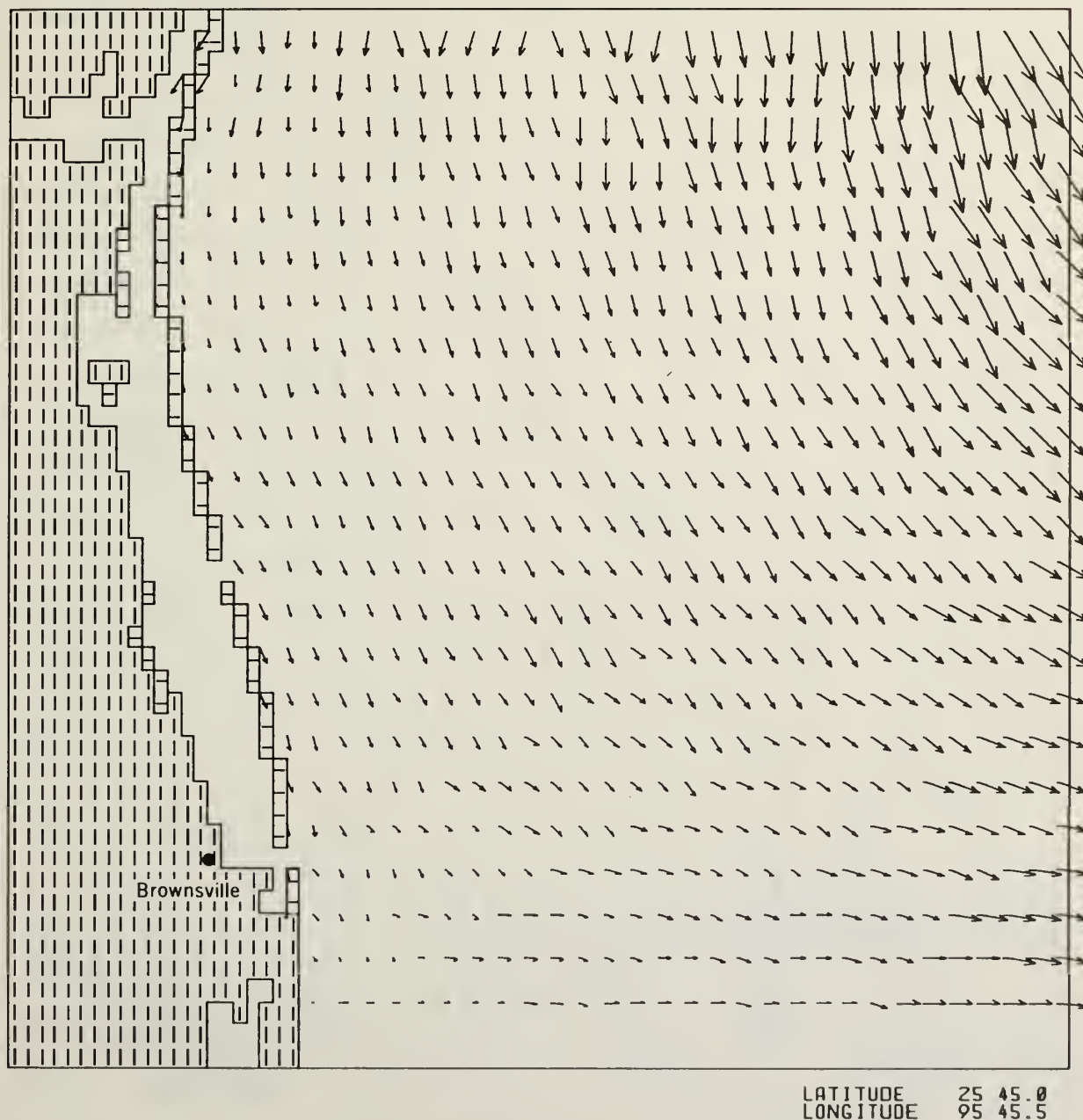
Figure 2.8   Streamline analysis of currents for one of four areas used to
define Texas coastal currents.

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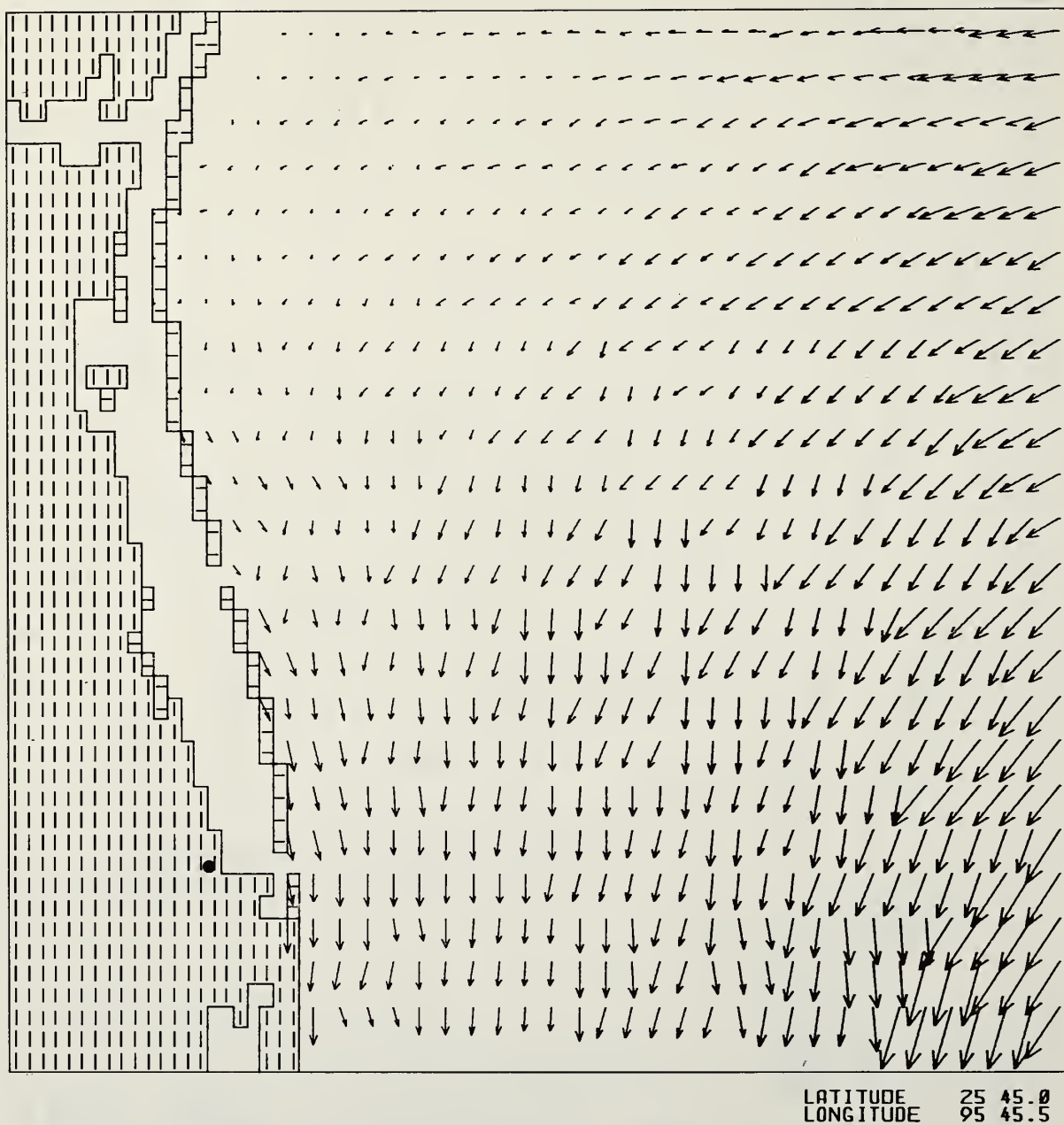
Figure 2.9 Streamline analysis of currents for one of four areas used to
define Texas coastal currents.

Figure 2.10 Composite representation of currents for one of four areas
used to define Texas coastal currents.

classes of the regional winds over the western gulf. The current patterns
used in the long-range projections were composites from three different
sources. The deeper waters of the gulf were covered with the monthly
patterns derived from the AOML general circulation model. These currents
were updated each month and represented the long-term average annual re-
sponse of the Gulf of Mexico to climatological winds.

Over the shallower shelf regions in the western gulf, it became neces-
sary to increase the resolution because the large-scale AOML model did not
cover the coastal region in adequate detail. A simple current was assumed
to run north along the Texas coast in the summertime and south along the
coast in the wintertime. This current exhibited 6 months of northward
flow, with a reversal in September and then 6 months of southward flow.
Along the Mexican coastal region, a flow pattern similar to the one derived
from the U.S. Coast Guard Cutter VALIANT data and the de la Cerda thesis
was used and given a twice-annual variation consistent with the dynamics
suggested by Sturges and Blaha (1976). The Mexican Coastal Current was
entered with a trigonometric variation showing maxima in the summer and
winter and minima in the spring and fall.

Given these wind and current conditions, a continuous flow of oil
released from the location of the IXTOC well was traced over the gulf using
two scenarios. One scenario suggested a continuous leak from 3 June 1979,
when the well blew out, to 15 October 1979. The second scenario specified
a continuous leak through March 1980. Each of these experiments was run in
a test mode that offered the most severe challenge to the model's capability,
since all the oil released at the location of the well blowout was traced
without any mid-course corrections or updates, so that advective and wind-
driven processes within the model were the sole determiners of the distribu-
tion of the oil. This provided a check on the model dynamics and patterns.
For both of the experimental scenarios, monthly patterns could be checked
against actual observations that were available for the first 4 months of
the spill. The projected model distributions compared favorably with
observations, which increased confidence in the usefulness and reliability
of the experimental results from at least a quantitative point of view.

The results of the long-term experiments indicated once again that the
essential element in transporting oil to the Texas coastal region was the
Mexican Coastal Current. U.S. waters were threatened when the Mexican
Coastal Current was strong enough to move oil north along the Mexican coast
before the winds could blow it onshore. Decreases of oil in the Texas
coastal waters were related to decreases in the flow of the Mexican Coastal
Current and not fundamentally tied to the reversal of the Texas Coastal
Current. The model suggested that over the wintertime, from September
until at least February, the IXTOC I oil would tend to move to the south-
southwest along the edge of the Campeche Bank and approach the coast near
Veracruz. From that point, the oil would tend to remain south of Cabo Rojo
and Ciudad del Carmen with major concentrations around Veracruz (Figure 2.11).

Under the conditions of the second scenario, when the oil continued to
leak throughout the winter, it moved north once again as the Mexican Coastal
Current increased in strength, which would occur throughout January and·

Figure 2.11 Long-term trajectory experiment based on statistical data
representatin oil distribution on 1 October 1979.

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February, raising the potential of once again bringing oil north of Cabo Rojo, up past Tampico, and into U.S. waters. During the spring, however, it was hypothesized that the Texas Coastal Currents would remain flowing south. This suggested that the oil moving north in the Mexican Coastal Current would encounter southerly flowing water somewhere near the U.S.-Mexican border. The convergence in the current patterns would then tend to create an area of oil accumulation, which would put a northern limit on the quantities of oil that could move north of the Mexican Coastal Current. From a statistical point of view, most of the oil moving north in the Mexican Coastal Current would slow down and accumulate just south of the U.S. border, where it could present a threat if atmospheric events occurred that would tend to stop, stagnate, or reverse the southerly flowing currents along the Texas coast. Such conditions were likely to occur at some time in the spring, as the Texas Coastal Current reversed. This, then, suggested that a continuing leak from the IXTOC I well could pose a threat to U.S. waters in the spring, beginning in late February or March (Figure 2.12). The dynamics associated with that threat were related to the increase in strength of the Mexican Coastal Current and the breakdown and intermittent reversal of the southerly flowing currents along the Texas coast.

Computer simulation experiments carried out in December, as well as observational data through mid-January, indicated a northerly movement of IXTOC I oil. This information supported the theory that increased speeds in the Mexican Coastal Current during the winter would carry some oil to a coastal convergence zone between 25° and 26° N latitude. From this position, the oil presented a threat to the United States if either (1) the Texas Coastal Current weakened and reversed its direction of flow in the Brownsville area so that the position of the coastal convergence migrated north, or if (2) the offshore advection associated with the coastal convergence carried oil into a counterclockwise eddy along the edge of the Continental Shelf such that it moved north and then back onshore at some position along the Texas coast.

During the week of 18 through 25 January 1980, a number of activities were undertaken to investigate these possibilities. These included (1) computer analysis of the flow patterns through the three southernmost passes along the Texas coast (Brazos Santiago, Mansfield Cut, and Port Aransas), (2) measurement of alongshore drift at a number of locations along Mustang and Padre Islands, (3) measurement of shelf currents along three transects out to 45 n mi (Corpus Christi, Mansfield Cut, and Brownsville), and (4) analysis of shelf circulations to estimate regional current patterns and persistence of the Texas Coastal Current.

Observations of coastal currents and computer analysis of the regional flow provided some insights into the question of whether oil accumulating south of the U.S. border represented an immediate threat to U.S. coastal waters.

Flow patterns through the various south Texas passes indicated offshore threat areas of about a few kilometers. Receptor mode model studies examining the larger scale circulation indicated that, even under the worst possible conditions, oil was still a few weeks from Texas coastal impacts.
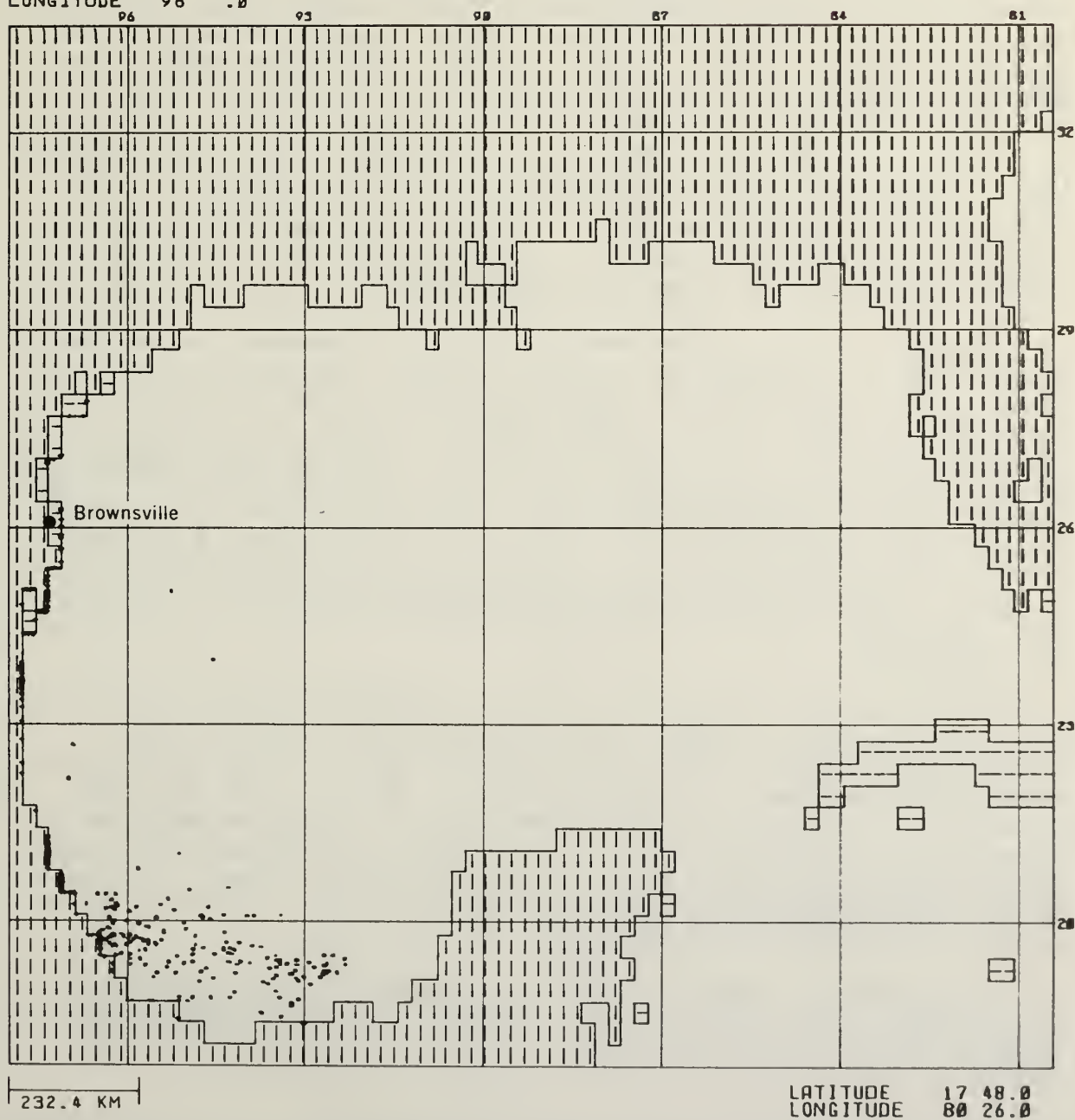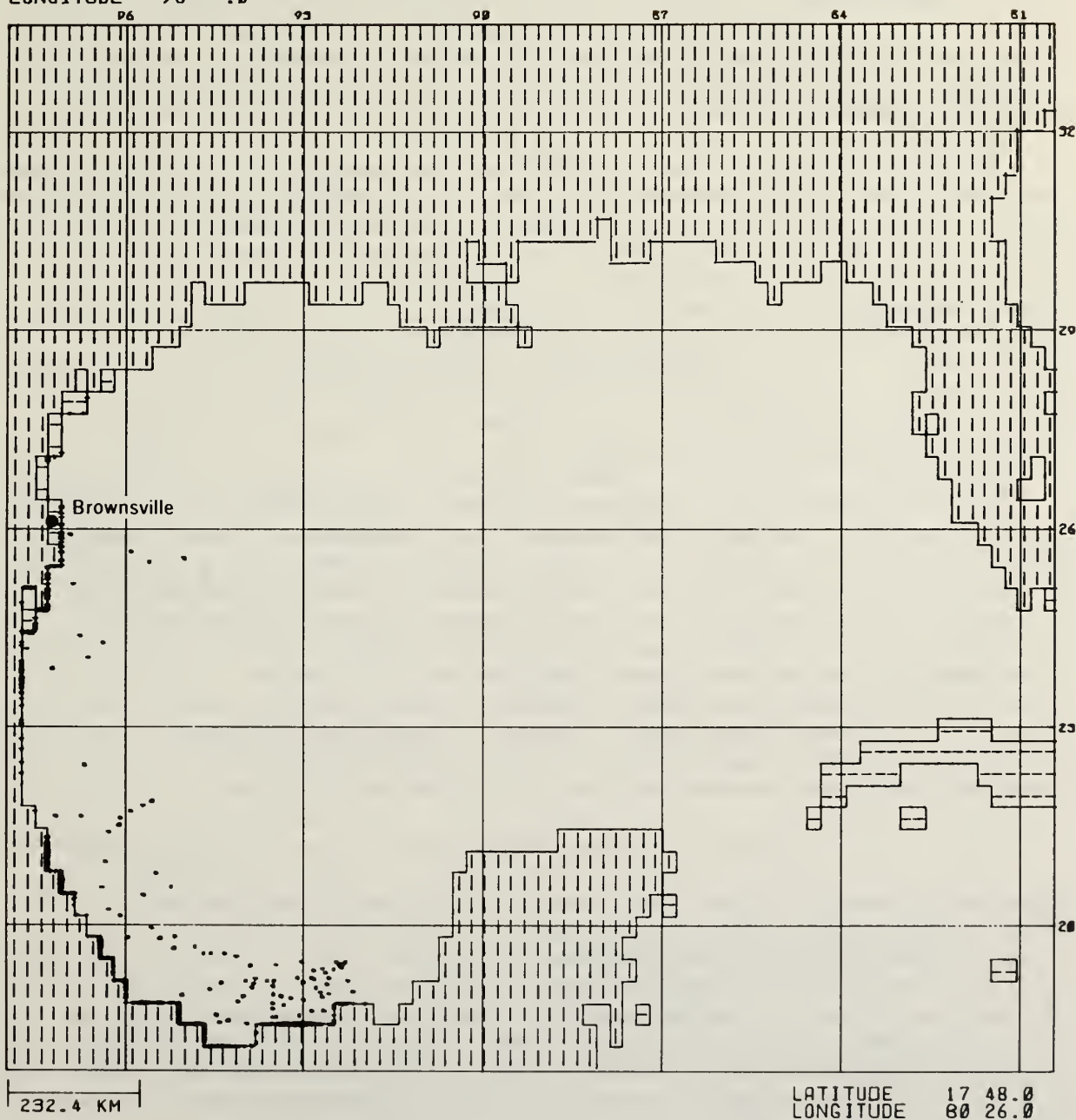
Figure 2.12 Long-term trajectory experiment based on statistical data
representating oil distribution on 1 March 1979.

The Texas Coastal Current showed consistent southerly flow along its major axis (approximately 15 n mi offshore). Along the shelf break and in the Brownsville area, there was evidence of the convergence associated with the Mexican Coastal Current, and it appeared that this boundary was moving north. Along the outer edge of the Continental Shelf, an extension of the Mexican Coastal Current was flowing north. This offered the possibility that oil moving north of 26° N latitude would remain well offshore. The Texas Coastal Current was as expected; however, its weakening and transition from southerly to northerly would need to be monitored to ensure maximum warning on excursions of oil into U.S. waters.

A follow-up study in February 1980 included additional current measurements and a series of computer simulations to investigate the possibility that the pollution threat to U.S. coastal areas would decrease if the IXTOC I well was controlled by mid-February, as was rumored from a number of sources. In these experiments, oil released from the IXTOC I well between December and mid-February was traced, assuming composite currents representing best estimates along with statistical representations of monthly winds. These indicated a small statistical possibility of isolated patches of oil reaching U.S. coastal waters throughout February and March 1980. Provided the blowout was controlled by mid-February, the major threat would be greatly diminished.

Current measurements taken 6 through 8 February 1980 off Port Isabel indicated quite a variable flow, suggesting the presence of shelf waves. These waves could propagate south along the coast and could be expected to be significant during periods of rapid change in the dynamic forcing for the region. With regard to pollutant transport processes, the currents associated with shelf waves implied several things. First, a series of convergence and divergence zones propagate along the coast. The significance of these in accumulating oil was well known. Second, shelf wave dynamics led to significant cross-isobath currents and subsequently enhanced cross-shelf mixing. The exchange of outer and inner shelf waters could bring pollutants to threaten the coast from farther offshore.

On 16 and 17 February, current measurements off Port Isabel coincided with strong winds out of the north ("northers"), in which offshore winds gusted to 40 knots. These conditions were optimum for setting up the winter aspect of the Texas Coastal Current, and the observations confirmed a very strong southerly flow over the entire shelf area. Currents of up to 2.75 knots were flowing south, directed along isobaths. This extremely strong flow would not lead to much cross-shelf mixing (contrasted to the shelf-wave case), and it was expected that the momentum of the current would carry it south along the Mexican coast. This should result in a southerly displacement of the convergence zone between the Mexican Coastal Current and Texas Coastal Current, and its displacement to the south clearly reduced the threat to U.S. coastal waters.

A final series of current observations and model trajectory experiments were carried out the third week in March. The seasonal reversal of the Texas Coastal Current was observed in the fall as a series of stagnations, reversals, and oscillations that appeared to correlate with regional wind events associated with synoptic weather patterns. A pumping action of the synoptic weather patterns on the coastal currents was also observed

during the studies carried out in support of the BURMAH AGATE tanker spill off Galveston. The spring reversal of the Texas Coastal Current was expected to go through a similar evolution of oscillations and reversals dominated by regional weather, but which would trend increasingly toward reduced southerly flow and eventually to northerly flow and the establishment of summer flow patterns. This breakdown and reversal process was indeed underway by early spring. However, computer studies of the shutdown of IXTOC I suggested that the major reduction in the output from the well, limited the amount of oil that could move north through the Mexican Coastal Current system, and that this source should be minimal by mid-April. The result of the March studies indicated that just about the time the Texas Coastal Current reversed, the oil accumulating south of the U.S. border would be reduced, and thus the risk of large accumulations of heavy oil reaching Texas beaches seemed minimal.

RECEPTOR MODEL CALCULATIONS

Throughout the IXTOC I spill, a much larger effort went into defining the distribution of the oil on a regular basis. To support this effort, long-range aircraft overflights were made daily, largely using U.S. Coast Guard aircraft, with additional support from NOAA and the U.S. Navy. To map the oil, two basic approaches were used, each corresponding to a somewhat different view of what information was required. Conceptually, the most straightforward strategem was to go out and map the oil that was anywhere in the western gulf. To do this, the aircraft flew a series of patterns that fit together in a mosaic over the entire region, and they could spot oil wherever it was. Presumably, the track spacing of the flights was such that no major oil concentrations could be missed. This had the obvious advantage that all the oil could be accounted for in a quantitative or mass balance sense, and that no regions were left uncovered. It had the disadvantage that it was extremely expensive and that it required a phenomenally large amount of aircraft support.

An alternate procedure for mapping the oil could be formulated on the premise that all the oil was not of interest, and instead we would concentrate only on the oil that could pose a threat to high-value regions. In this case, it would not be necessary to map the entire western Gulf of Mexico, but only those regions where oil could conceivably get from the observed point to the designated high-value target. To investigate this possibility and define the threat regions for various points along the Texas coast, a receptor mode model study was undertaken.

A standard trajectory model formulation tries to answer the question of where oil will go given its present position and hypothesized winds and currents. A receptor mode model study poses a somewhat different question: Given the winds and currents for a region, where could oil start from to arrive at a particular point? The On-Scene Spill Model was able to address both these questions. Five high-value target areas were identifed along the Texas coast, specifically, the major passes through the barrier island system. These passes represented areas where oil could move into the inner

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lagoons. The first set of these threatened areas was Brazos Santiago, Mansfield Cut, Port Aransas, Cedar Bayou, and, finally, Pass Cavallo. For each of these points, a 1-week threat area was investigated. Alternate scenarios covered all reasonable wind combinations expected throughout the fall and expected variations within the currents. A composite of the threatened areas from each of these scenarios then represented the cumulative threatened region associated with each of the critical passes. If all five composite threatened areas were added together, then a region of the western gulf could be identified as the total threatened area to the five high-value points along the Texas coast. With this in hand, a rational strategem could be developed for determining which sections of the gulf needed to be mapped on a weekly basis (Figure 2.13). This study indicated a greatly reduced area that would require coverage in aerial surveys and defined an appropriate time scale for repeat observations.
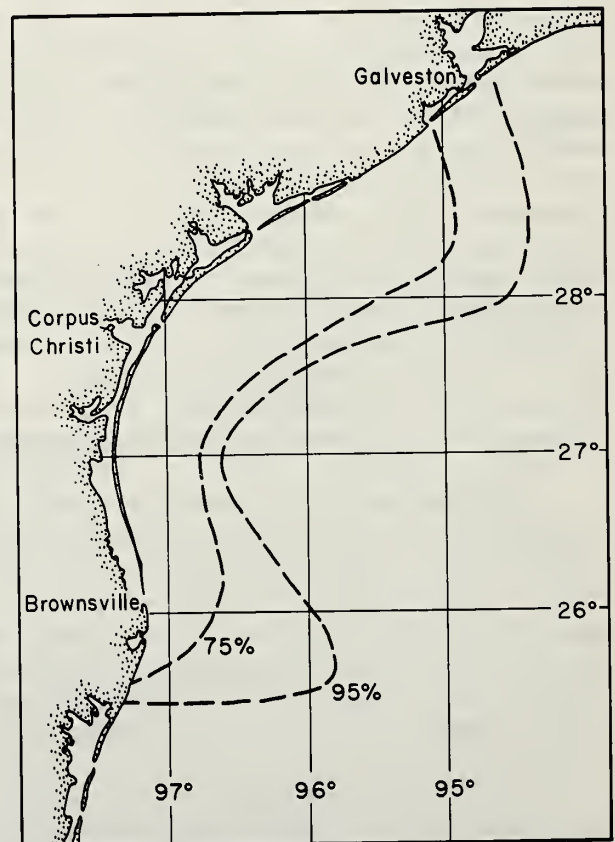
Figure 2.13 Outer line represents area of monitoring needed on a once-a-week basis to ensure no shoreline impact near sensitive areas, assuming steady winds for 1 week. Inner line represents required survey area for < 3 days of steady winds.

SUMMARY OF COMPUTER MODELING STUDIES

The computer modeling studies in support of the response to the IXTOC I blowout began early in the spill and continued throughout the summer and fall. These studies were coordinated with a number of observational programs and other study areas, particularly those observational programs to define and map currents and delineate the distribution of the oil. Input from the National Weather Service was another continuous source of data for the modeling. Throughout the spill, combinations of direct observations, dynamic models, and statistical climatologies were used in various experiments.

The On-Scene Spill Model was run in three distinct modes. The first mode concentrating on the regional problem along the Texas coast, detailed information that was used on a day-to-day basis to determine the expected movement and spreading of the oil for periods of several days. This information was presented in a format that was available on an immediate basis to the on-scene personnel.

A second mode of operation for the trajectory models attempted to describe the long-term prospects for IXTOC I oil movement and define the strategic threat under which the response could be planned. This mode provided information for the buildup and shutdown of the larger scale components of the response, associated with cleanup activities and scheduling of scientific and aircraft personnel.

The third mode in which the trajectory models operated was a receptor mode study that identified threat areas associated with particular high-value regions. This information was available for the planning of observational programs and the delineation of minimum search areas to be covered, as well as the repeat time intervals for the observational sampling.

2

TRANSPORT, DISTRIBUTION, AND
PHYSICAL CHARACTERISTICS OF THE OIL

Part II: Nearshore Movement and Distribution

Erich R. Gundlach and Kenneth J. Finkelstein
    Research Planning Institute, Columbia, S.C.

The previous section described the program and methods used to predict
the movement of the oil from the blowout site in the Bay of Campeche to the
Texas coast. This section describes the transport and distribution of the
oil as it impacted the south Texas coastal zone.

HISTORICAL SEQUENCE

There were three periods of major oil impacts occurring between early
August and mid-September, until current patterns switched. During this
time, oil impacs on the coast were categorized as light, moderate, and
heavy (Figues 2.14 to 2.18) as determined by aerial and ground surveys.
After each survey, a map of the coast was made delineating onshore and
nearshore oil concentrations. The extent of oil coverage on each barrier
island is illustrated in Figure 2.19 and summarized for the entire impacted
shoreline (from the Rio Grande to Cedar Bayou) in Figure 2.20. The estimated
total amount (in metric tons) of oil along the shoreline during the spill
is presented in Figure 2.21. Appendix A describes in detail the methods
used to survey the beaches, to calculate the amount of oil on them, and to
observe the biological impacts. Figure A.1 shows station locations.
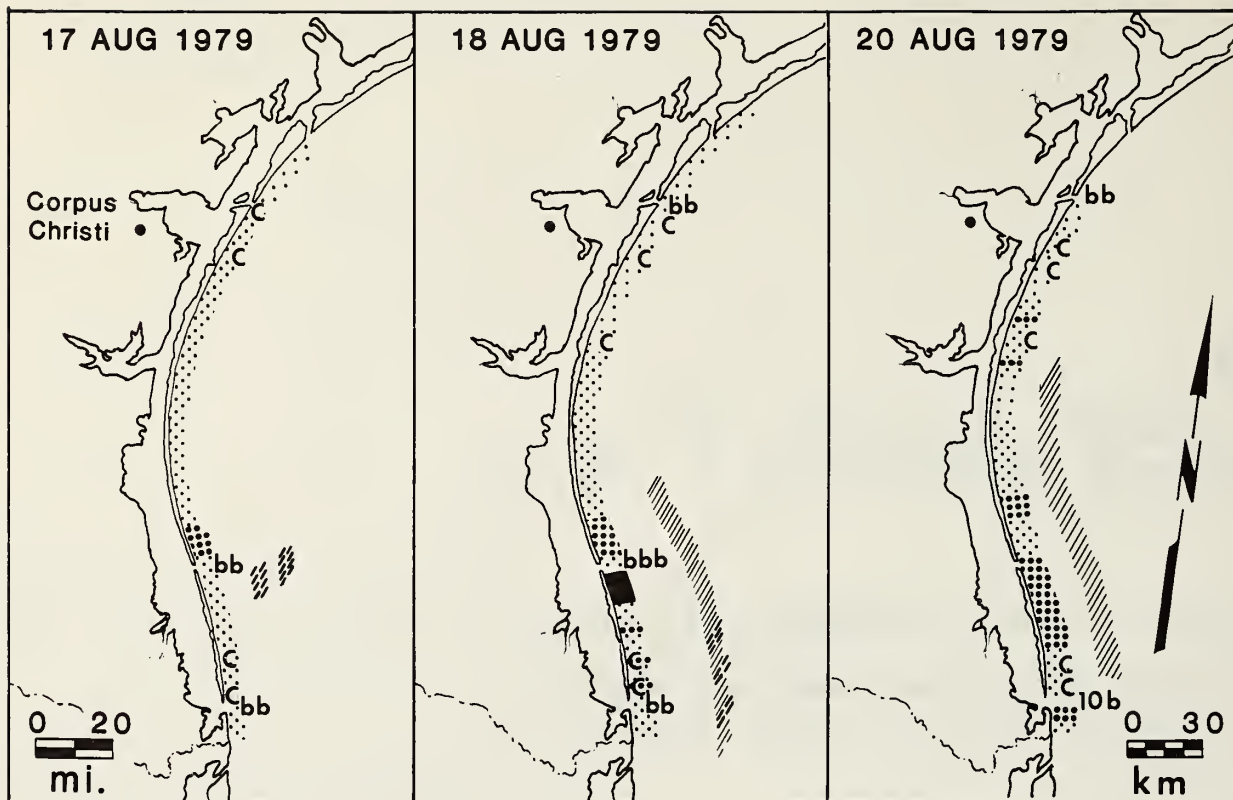
Figure 2.14   Shoreline and offshore oil along the south Texas coast on 17, 18, and 20 August 1979.

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SHORELINE OIL   OFFSHORE OIL

[dotted] VERY LIGHT   [grid] MODERATE   [diagonal] SHEEN

[dotted] LIGHT   [black] HEAVY   [diagonal] MOUSSE
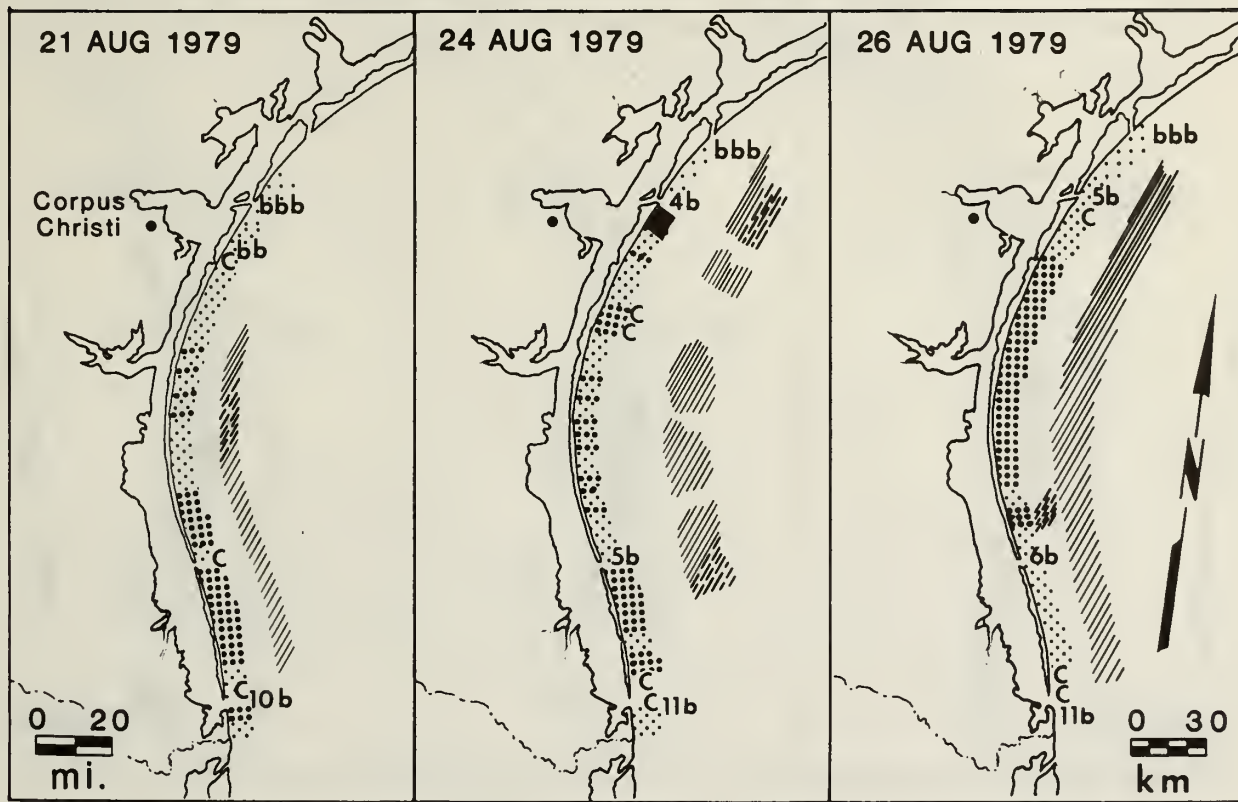
b-BOOM   C-CLEANUP OPERATIONS

Figure 2.15 Shoreline and offshore oil along the south Texas coast on
   21, 14, and 26 August 1979.

Figure 2.16 Shoreline and offshore oil along the south Texas coast on 29 and 30 August and 1 September 1979. Oil coverage reached its maximum (3,900 metric tons) during this period (see Figure 2.21).

Figure 2.17 Shoreline and offshore oil along the south Texas coast on 4, 6, and 12 September 1979.

45
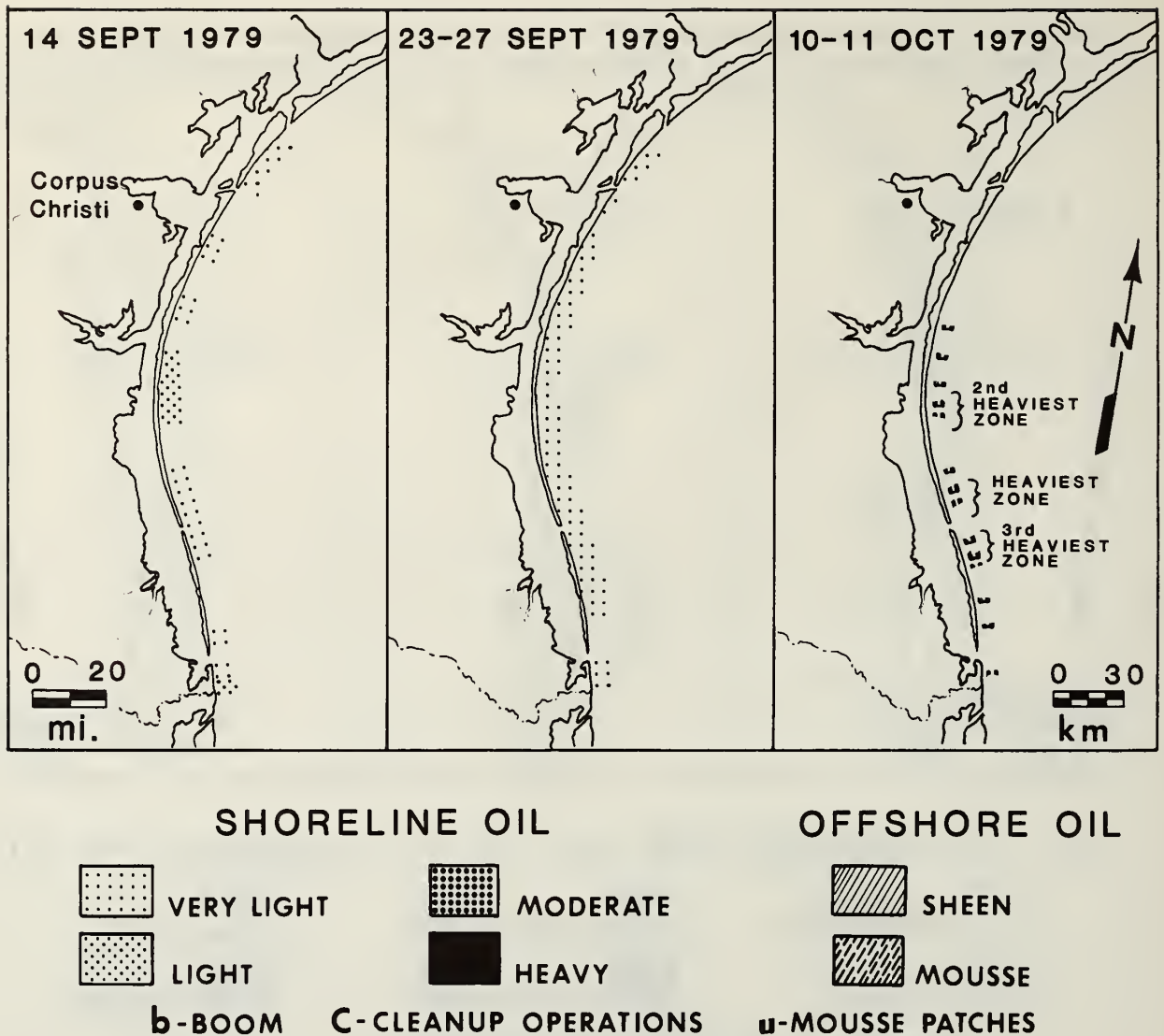
Figure 2.18 Shoreline and offshore oil along the south Texas coast on
14 and 23-27 September and 10-11 October 1979. The survey of 10-11
October indicated areas where outcropping mousse and sediment were
observed. Outcrops ranged from 5 to 65 m long and 2 to 15 m wide.

AUGUST   1979   SEPTEMBER

SHORELINE COVERAGE BY OIL

▦ VERY LIGHT   ▥ MODERATE

▤ LIGHT   ■ HEAVY

☐ NO OIL
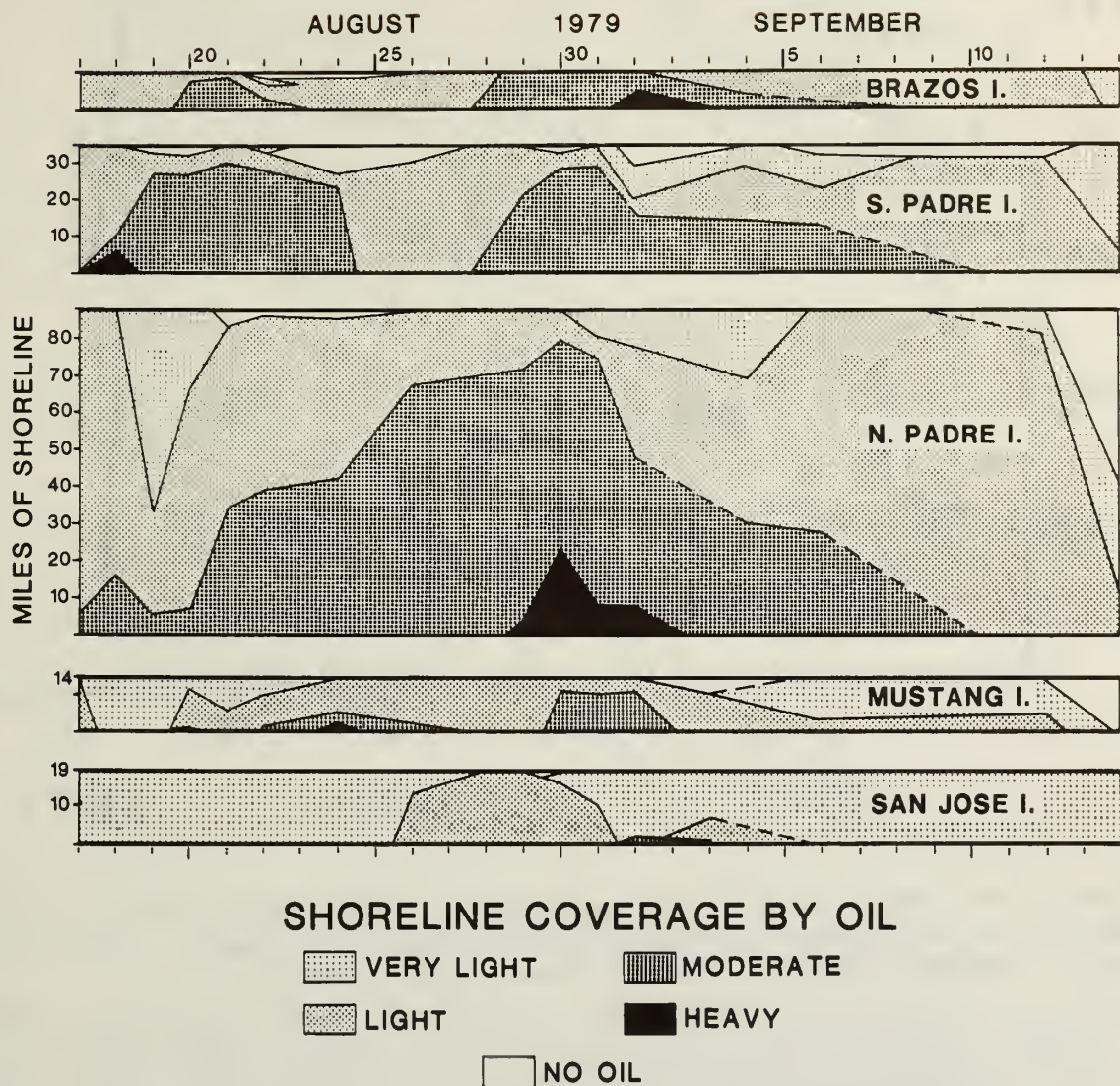
Figure 2.19 Extent of oil coverage along the individual islands of the south Texas shoreline.

47
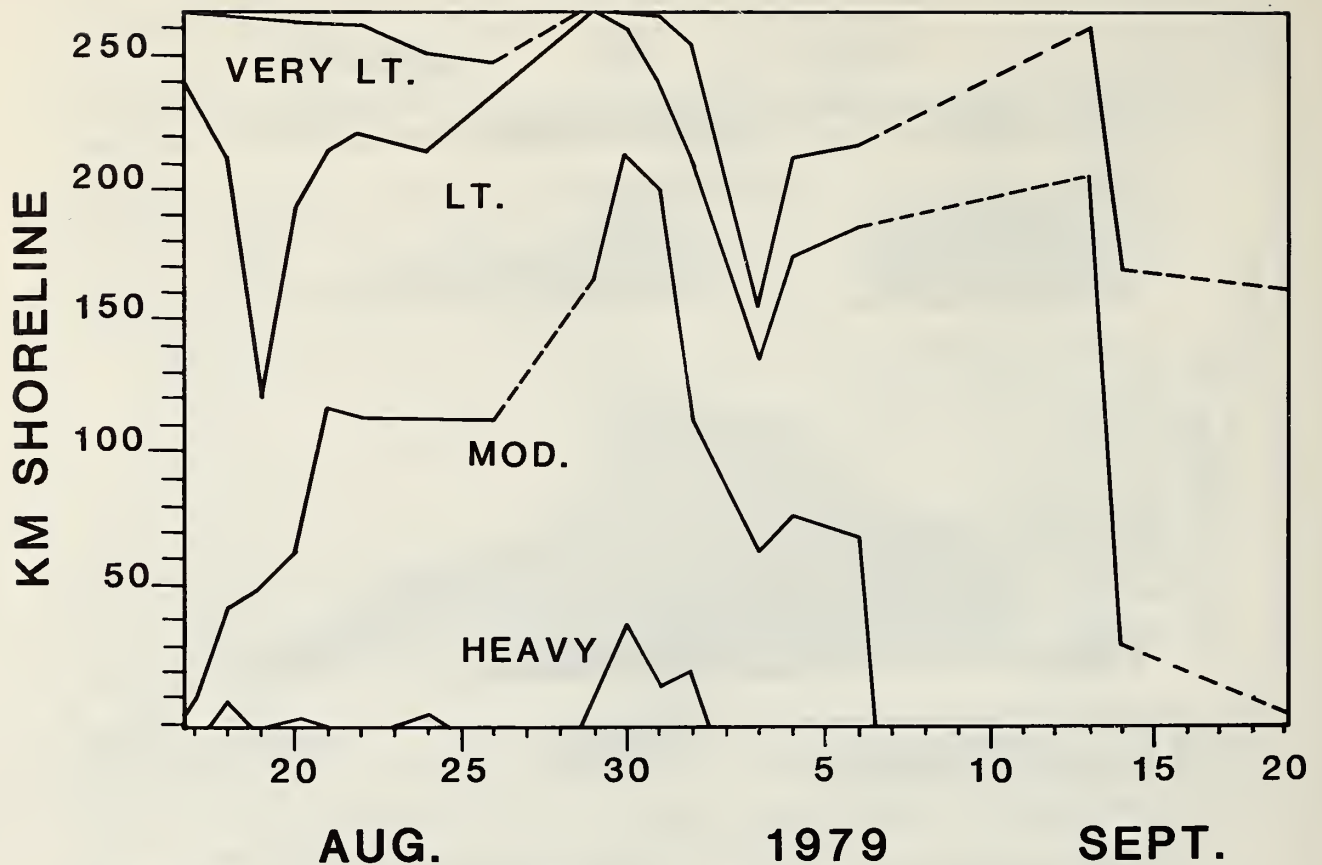
Figure 2.20 Summary of oil coverage along the south Texas shoreline. The extent of oil coverage reached a maximum during late August. Storm activity on 13 September caused a rapid decrease in oil coverage.

The earliest observed impact of IXTOC I oil in south Texas occurred on 6 August, when a total of 16 to 18 miles (26 to 28 km) of shoreline was impacted with light to very light tar ball swashlines. There were no further impacts over the following week, and the beached tar balls desiccated and weathered.

Oil began washing up again on 13 August, this time in heavier concentrations. By 15 August, coverage of North Padre Island was mostly light, with scattered patches of moderate coverage (refer to methods and Figures 2.22 through 2.25 for definitions of oil coverage). As indicated in Figure 2.21, the situation remained static through 17 August. The area just north of Mansfield Pass had been most heavily impacted, and by this time, two
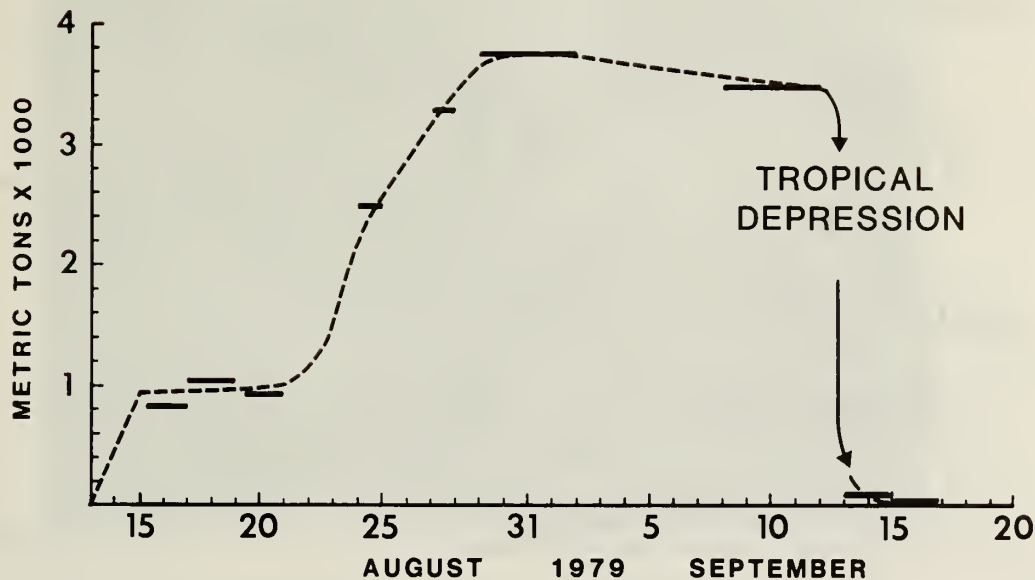
Figure 2.21   Estimated metric tons of oil deposited onshore
during the spill.

booms were in position at Mansfield and Brazos-Santiago Passes, and cleanup
began at the hotel portion of South Padre Island and on Mustang Island.
Heavy mousse patches that were located offshore of Mansfield Pass on 17
August, came ashore and impacted the areas adjacent to the inlet on 18
August.   From 17 August to 22 August, the situation was fairly stable, with
much of the onshore oil being reworked and redistributed along the shore.
Offshore sheens with scattered mousse were common.   Approximately 1,000
metric tons had washed ashore during this period.

The second phase of major oil impact occurred on 24 August, when
several new slicks were sighted off Mansfield Pass and as far north as
Aransas Pass (Figure 2.15).   The same day, some very thick mousse washed
ashore on Mustang Island just south of Aransas Pass (Figure 2.26).   By
26 August, most of North Padre Island had moderate coverage and 30 to
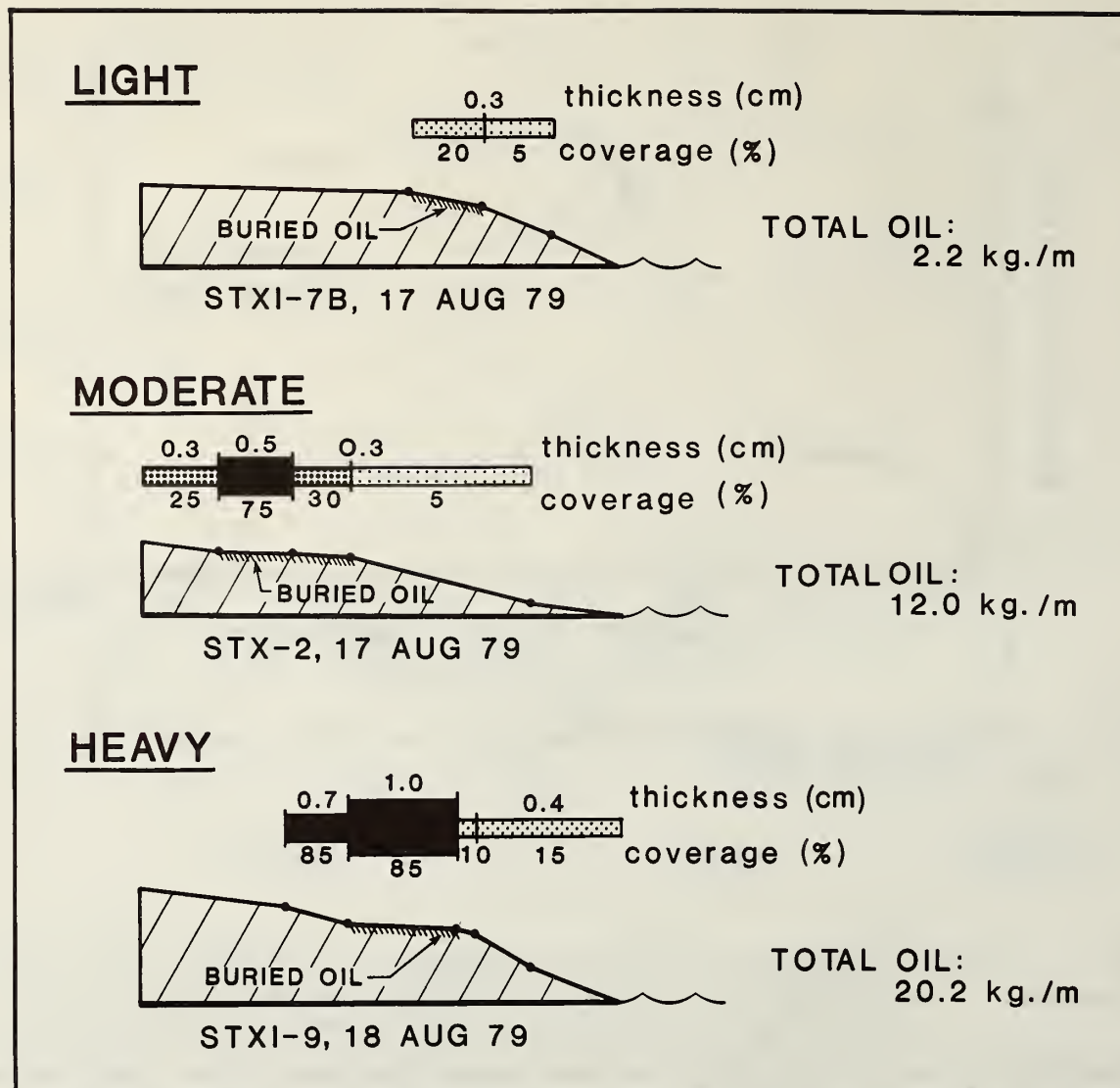
Figure 2.22 Topographic profiles (5:1 ration of elevation to distance) of stations having light (10 to 24 percent coverage of the intertidal zone), moderate (25 to 64 percent), and heavy (> 65 percent coverage) oil accumulation.

Figure 2.23 Station STXI-7B on South Padre Island on
17 August 1979, indicating light oil coverage.

Figure 2.24 Station STX-2 on North Padre Island on
17 August 1979, indicating moderate oil coverage.

Figure 2.25 Station STXI-9 on South Padre Island on 18 August 1979, indicating heavy oil coverage.

Figure 2.26 View of heavy oil coverage that washed ashore on Mustang Island just south of Aransas Pass on 24 August 1979.

40 percent of the offshore waters were covered by sheen (Figure 2.15). Additional slicks were observed north of Mansfield Pass. The Coast Guard continued to place new booms (primarily oil-absorbent type), so that by 26 August, there were three booms across Cedar Bayou, five booms along Aransas Pass, six booms at Mansfield Pass, and eleven booms along Brazos-Santiago Pass.

The heaviest period of oil impact occurred from 29 August through 1 September 1979 (Figure 2.16). Oil coverage was light to moderate along the entire south Texas area. In addition, 20 miles (32 km) of North Padre Island and 4 miles (6.4 km) of Brazos Island had a heavy oil coverage. During this period, oil along the shoreline reached its maximum of 3,900 metric tons (Figure 2.21).

From 2 September until 13 September, only scattered sheen was observed offshore, and no new impacts occurred. The shoreline became noticeably cleaner, primarily due to deposition of clean sand over the surface oil and desiccation of the mousse to form tar at less than half its original volume. The calculation of oil content at 18 stations from 3 to 6 September revealed that approximately 31 percent of the beached oil was on the surface, 53 percent was buried, and 16 percent remained within the swash zone and first trough (Figure 2.27). So even though the beach surface appeared cleaner, the actual oil content ashore stayed approximately the same (Figure 2.21).
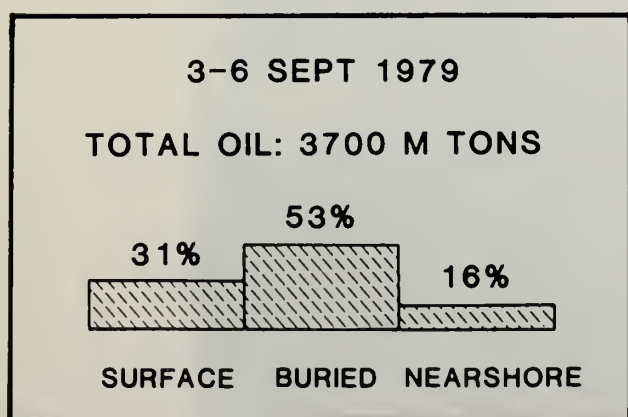
Figure 2.27 Relative proportions of surface, buried, and nearshore (swash zone and first trough) oil as observed at 16 stations from 3-6 September 1979.

On 13 September, a tropical depression hit the south Texas area; tides were raised over 2 ft (60 cm), and strong onshore winds produced 3- to 5-ft (1- to 1.5-m) waves (Figure 2.28). Within 2 days, over 90 percent of the oil on the shoreline was removed by wave action (Figure 2.21). Sheen was common on the surface of the swash zone as waves reworked the oil and sediment. The small amount of oil that still remained was found high up on the beach along the base of the foredune ridge. The survey of 14 September (Figures 2.18 and 2.21) illustrated the drastic reduction in onshore oil. The only area where oil remained was in the shell beaches. As determined during Environmental Sensitivity Index Mapping (ESI), oil was expected to persist longer within this area than in adjacent fine-sand beaches. The low content of shoreline oil persisted until mid-October. Desiccation and burial by wind-blown sand decreased the amount of surface oil.

During the third week in September, approximately 1 week after the tropical depression passed through, erosion of the foreshore was evident. Several deposits of mousse mixed with sediment were discovered along the shoreline (Figure 2.18). The largest of these oil masses or tar mats was located at STX-3 on the southern tip of North Padre Island (Figure 2.29). In total, it measured 15 to 20 m wide, 65 m long, and 15 cm thick. A similar mass, also located at the toe of the beach, was observed after the URQUIOLA spill in Spain (Ruby, 1977).

Figure 2.28 Aerial photograph of Corpus Christ State Park,
showing extent of wave activity high along the shore
during the tropical depression of 13 September 1979.

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Figure 2.29 Overview (A) and close-up (B) of the tarmats
located at the south end of North Padre Island (STX-3).
As measured on 22 September, this oil mass was 15 to
20 m wide, 65 m long, and 15 cm thick.

OIL REACTION ON FINE-SAND AND COARSE-SAND/SHELL HASH BEACHES

As indicated by the prespill ESI mapping, the grain size of exposed gulf beaches is either fine sand or a mixed coarse sand and shell hash. By far the majority of the shoreline is composed of fine sand, 150 miles (240 km) as compared with 12 miles (19 km) of coarse material. The coarse sand/shell-hash area, called Big Shell and Little Shell beaches, is geologically unique for the Texas coast and has been the subject of several studies.

As noted primarily during investigation of the URQUIOLA study (Gundlach et al., 1978), oncoming oil reacts quite differently on beaches of different grain size. Fine-sand beaches, very hard and compact because of good sorting and fine grain size, resist oil penetration into the sediment. In contrast, oil readily percolates into the loosely packed and poorly sorted sediments of the shell beaches. Photographs of typical oil penetration show the depth and extent of oil burial also increase as grain size increases, primarily because coarse-grained beaches respond more rapidly to a change in incoming wave conditions. The repetitive measurement of profiles across each beach type immediately illustrates this variance. Figure 2.30 presents a comparison of the two beach types. Along the much steeper and more variable shell beach, oil was buried 40 cm as opposed to only 7 cm on the fine-sand beach.
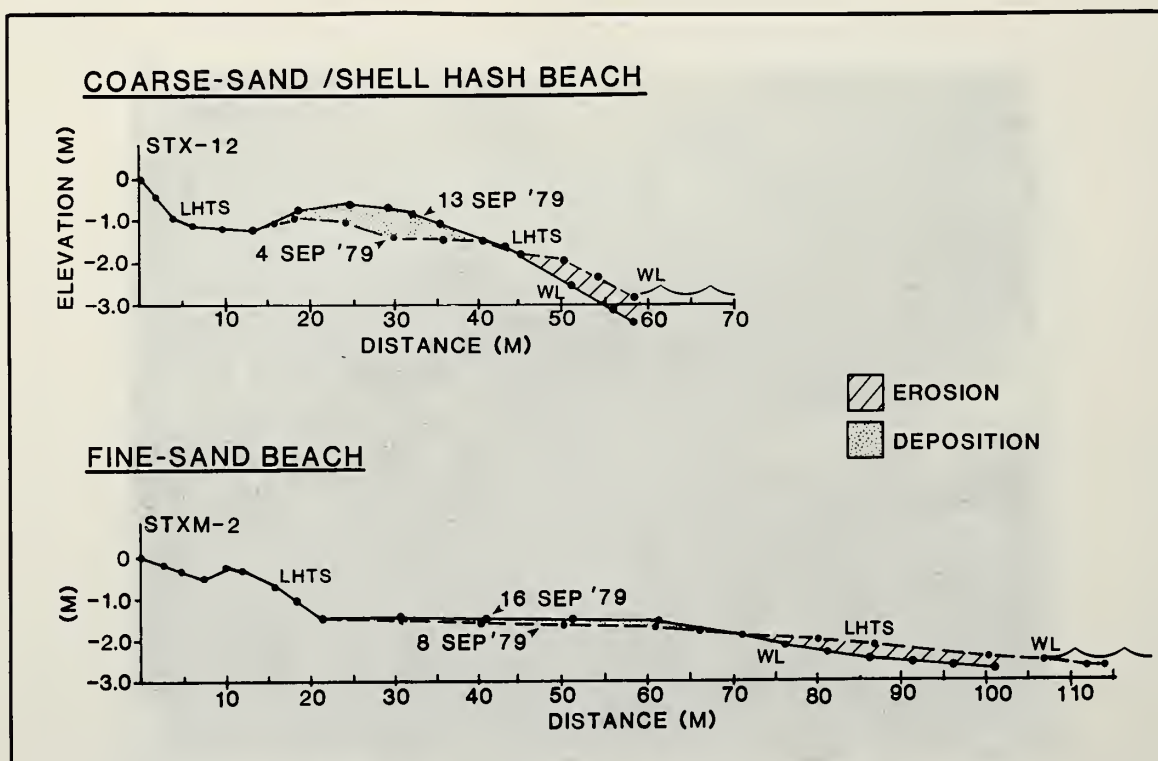
Figure 2.30 Comparison of repetitive beach profiles from a typical coarse-grained, mixed sand, and shell beach (North Padre Island, STX-12) and a typical, fine-sand beach (Mustang Island, STXM-2) from south Texas. During similar periods, the coarse-grained shell beach gained only 10 cm along the backshore (WL = waterline, LHTS = last high tide swashline).

After the heaviest phase of shoreline oiling, during late August, the shoreline rapidly appeared cleaner on the surface as clean sand was deposited over the oil. However, close analyses revealed that the shell beach area had a much greater amount of oil incorporation (90 percent vs. 37 percent) because of the rapid burial and more extensive sediment flux, than did the fine-sand beaches (Figure 2.31).

The inhibition of oil percolation into the sediment and the lesser extent of burial caused almost all of the fine-sand beaches to be cleaned during the 13 September storm. Analysis of the repetitive beach profiles from Mustang Island (Figure 2.30) reveals that the entire previously oiled foreshore was removed by wave activity. Only very light swashlines of small tar balls remained, but were now placed against the foredune ridge (Figure 2.32). In contrast and as predicted during the ESI mapping, oil was still present in significant (although light) quantities on shell beaches even after the storm activity. Figure 2.33 presents photographs of the area a short time after storm passage. Oil persisted for another 2 weeks before being removed by continued wave activity.
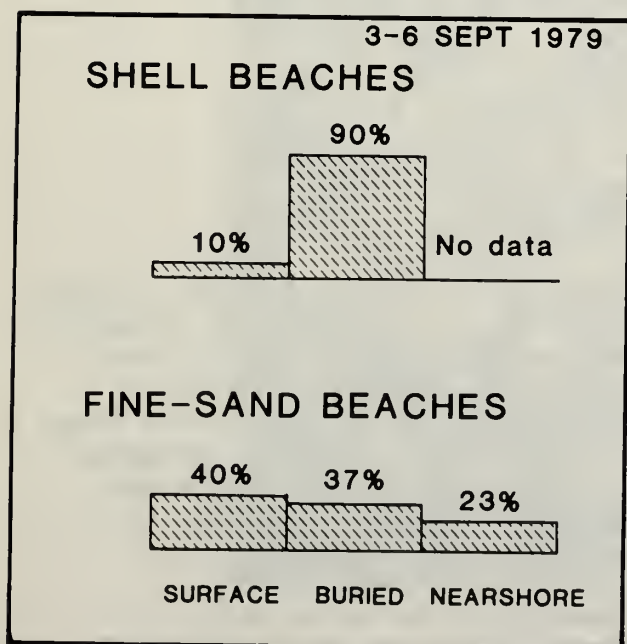
Figure 2.31 Proportional comparison of oil position on fine-sand versus coarse sand and shell hash beaches. This analysis was based on 16 stations examined from 3 through 6 September 1979.

Figure 2.32 Photograph taken on 16 September 1979 at
station STX-7 of oil remaining on a typical fine-sand
on North Padre Island after passage of the tropical
depression on 13 September 1979.

OIL REACTION WITHIN THE NEARSHORE ZONE

The nearshore zone fronting the barrier islands of south Texas consists
of three bars extending out approximately 200 m. The deepest bar is approxi-
mately 10 m below the surface. During all conditions except major storm
activity, the primary breaker zone is at the bar closest to the shore
(first bar). Based on investigations at the AMOCO CADIZ spill, which found
significant quantities of oil were found incorporated in bottom sediments
(D'Ozouville et al., 1979; Michel et al., 1978), the nearshore zone was
intensely surveyed to analyze the mechanism causing oil to sink and to
denote areas of potential biological damage.

Results indicated that during and immediately following major oil
deposition on the shoreline, particularly that which occurred during late
August, oil was commonly found on the bottom within the shoreline breaker
and swash zone and on the first bar. Figure 2.34 illustrates the typical
shoreline conditions along the fine-sand beaches. Sediment-laden or
"armored" tar balls were most common at the shore break and on the first
bar. Tar balls rapidly decreased in size (from 1 to 5 cm and < 1 cm) and
number outside the bar. Seaward of the first bar, the number of tar balls

Figure 2.33 Overview (A) and closeup (B) of station
STX-10 within the shell beach area on 15 September
1979, two days after the storm passed. Sediment-
laden or "armored" tar balls were present through-
out most of the berm-top sediments.

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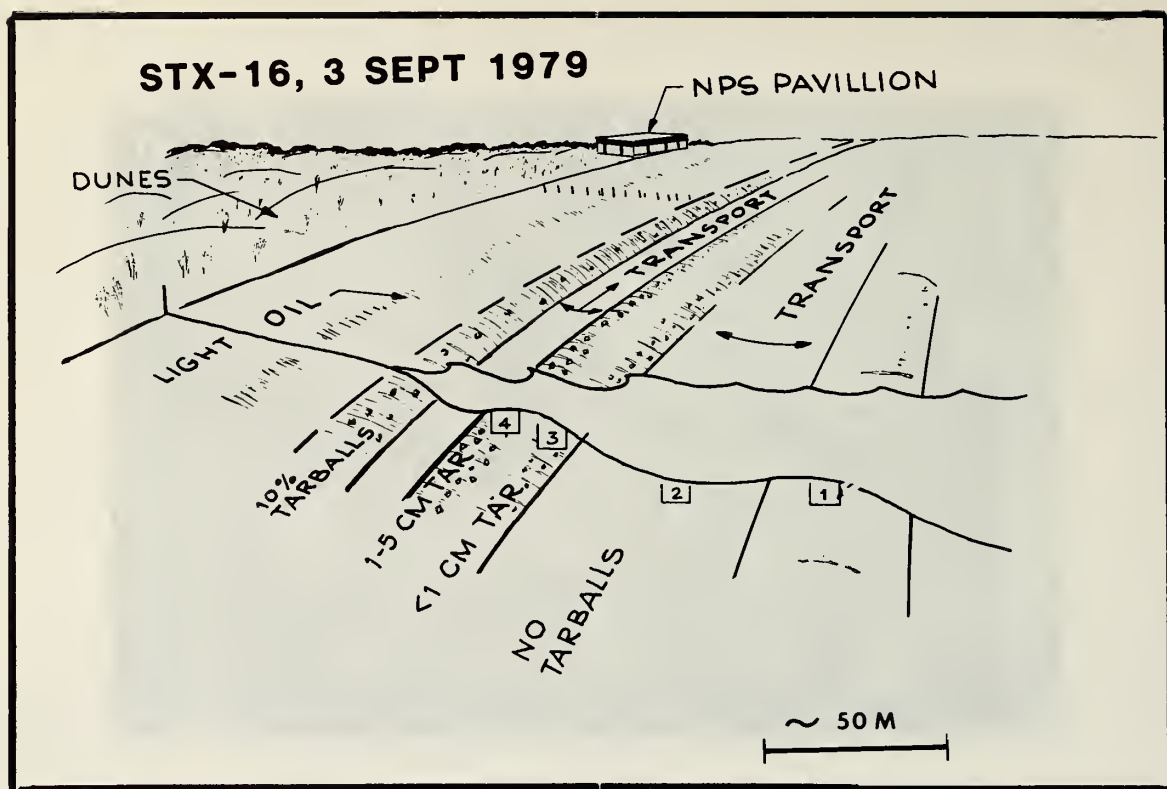
Figure 2.34   Diagram of oil presence on the bottom within the near-
shore zone at station STX-16 (2 miles south of the National Park
Service on North Padre Island) on 3 September 1979.

became very low, and they were very scattered. The continuous reworking of
the armored tar balls by wave activity rapidly decreased the quantity of
oil found within the nearshore zone. Figure 2.35 illustrates the condition
of onshore and nearshore oil on 5 September. At this time, particulate to
5-cm size tar balls covered 25 percent of the surface area of the swash
zone, and, as revealed during examination of box cores taken in the area,
oil was also incorporated into the sediment. Within the first trough,
surface tar balls were very sparse and few were found in the box cores. As
at station STX-16 examined a few days before, the second greatest concentra-
tion (now only 2 percent) occurred on the landward side of the first bar.
Due to constant wave action, particle size and abundance had significantly
decreased over the intervening 2 days.

During the spill, there was much speculation concerning the fate of
oil within the nearshore environment. Great mats of sunken oil often were
conjectured. Based on these speculations, we carried out several diving
surveys extending up to 300 m offshore; these showed no evidence of near-
shore sunken oil. However, before the mid-September storm and at a few

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STX-3N, 5 SEPT. 1979

THICKNESS (mm)
COVERAGE (%)

[2] NUMBER TARBALLS/CORE

4 (mm) thickness
25% coverage

4 (mm)
2%

flecks to 5cm tarballs   flecks to 3cm tarballs
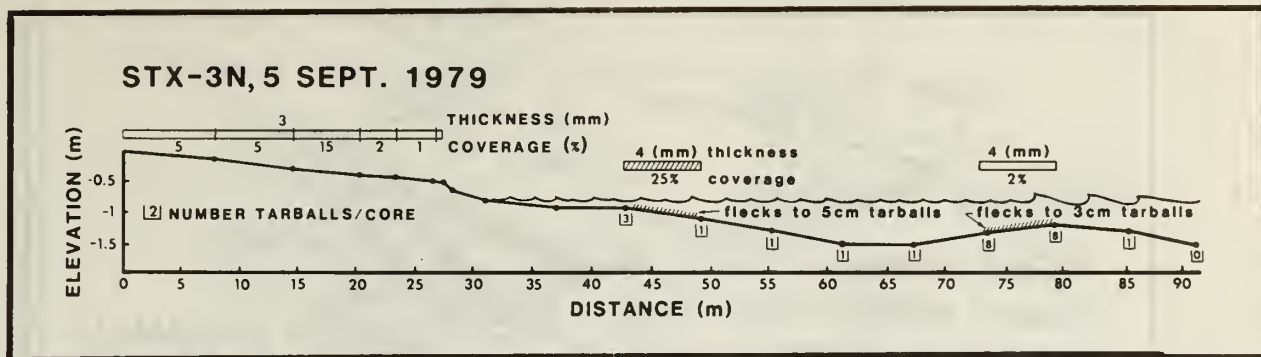
Figure 2.35   Topographic profile of nearshore and onshore oil on
Mustang Island. Oil on the bottom, in the form of sediment-
laden or "armored" tar balls, was most common in the shorebreak
and swash zone (25 percent) coverage, 43 to 49 m distance).
Very few tar balls were found farther offshore. Areas where
box cores were taken and the approximate number of observed
tar balls within each sample are also indicated.

survey stations (e.g., STXI-4 on South Padre Island), sediment-laden mousse
was found in very scattered patches (up to 3 x 4 m and 10 cm thick) on the
bottom, of the first trough.

Figure 2.36 shows most commonly observed sequence of oil reaction
within the nearshore zone. Oncoming oil was primarily swept across the
berm top during spring tides; however, a small percentage became sediment-
laden and rolled around in the swash zone or became incorporated in the
sediments at the toe of the beach. (Essentially, the oil behaved as a
coarse-grained sediment.) Wave action rapidly broke the oil down into
small particles and sheen, which was transported parallel to the shore by
longshore currents until being carried offshore.

TAR MAT SURVEY

During October, a beach survey contracted by NOAA and performed by
Coastal Ecosystem Company of Corpus Christi, Texas, located 36 tar mats
(accumulations of sand, shell, and organic matter bound by oil). The study
method consisted of inspections by digging from the upper beach to the
outer bars at 2-mile (4 km) intervals from the Rio Grande River to Aransas
Pass. Readily visible mats were also mapped according to odometer readings,
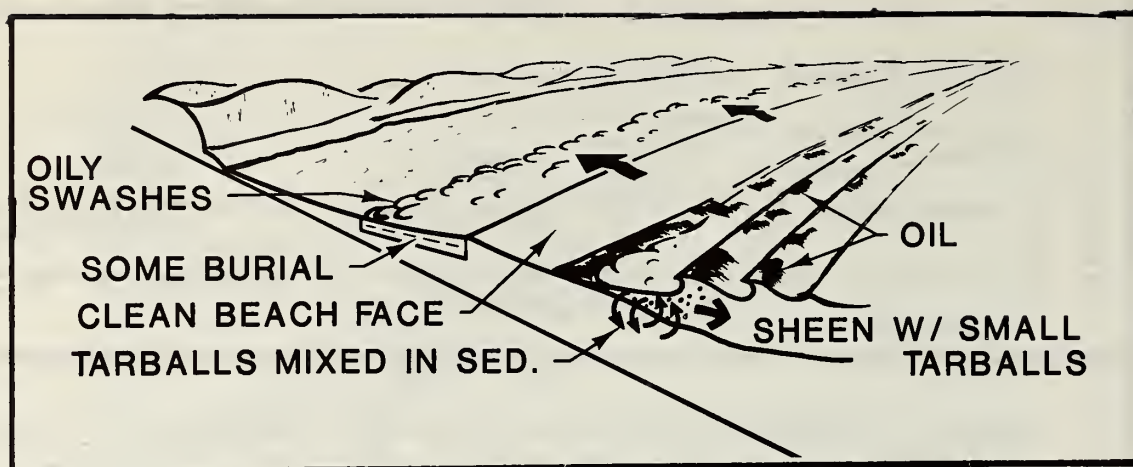
Figure 2.36 Reaction of IXTOC I oil on south Texas
beaches. During spring tides, substantial quanti-
ties of oil were forced over the berm to form oily
swashes, some were buried by clean sand.

and an aerial coverage estimate was made. The majority of oil remaining on
the Texas coast appeared to be contained in the tar mat masses, typically
found in the first trough at the base of the intertidal zone.

Many of the tar mats were rapidly buried by sand, especially during
the winter storm season. In March 1980, the U.S. Coast Guard requested a
second tar mat study to determine the volume and the degree of burial of
each mat and estimate the feasibility of a removing a mat. The study, con-
ducted by Research Planning Institute, Inc., measured and mapped 19 areas
of visible tar mats in various stages of burial (Figure 2.37). Other
digging in random locations revealed only traces of minute tar balls.
Correlation of these 19 mats with the 36 mats found in December is incon-
clusive because of odometer inaccuracies. An area north of Mansfield Ship
Channel, however, is known to contain the majority of the total mat volume,
which averages 7.7 percent oil. In several areas, what was first thought
to be several mats actually proved to be one long discontinuous or par-
tially buried mat. This may, in part, account for the discrepancy between
the December and March studies. Breakdown of smaller mats or complete
burial during the March survey may further explain the difference in the
number of observed mats.

In early 1980, the United States Geological Survey (USGS), the National
Park Service (NPS), and the University of Texas Marine Sciences Institute
(UTMSI) at Port Aransas initiated a joint study of the 19 Padre Island tar
mats. The objective of these studies is to determine the fate and effect
of three of the mats through several seasons.

TAR MAT LOCATION MAP

CORPUS CHRISTI BAY

CORPUS CHRISTI

MUSTANG ISLAND

ARANSAS PASS

CORPUS CHRISTI FISH PASS

GULF OF MEXICO

BAFFIN BAY

P A D R E

M A D R E

L A G U N A

PORT MANSFIELD

PORT MANSFIELD CHANNEL

LAGUNA ATASCOSA NATIONAL WILDLIFE REFUGE

BROWNSVILLE

RIO GRANDE

BRAZOS SANTIAGO PASS

KILOMETERS

MILES

LEGEND

1) Fish Pass A
2) Fish Pass B
3) TM -1
4) TM 0
5) TM 0.5

6) TM 1
7) TM 1B
8) TM 1A
9) TM 2
10) TM 3/3A

11) TM 4
12) TM 5
13) TM 6
14) TM 7
15) TM 8

16) TM 9
17) TM 10
18) TM 16
19) TM 17

◢ STATIONS FOR BURIED OIL SEARCH

Figure 2.37 Tar mat locations in March 1980.

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The USGS and the NPS are studying the physical breakdown of the tar mats and the transport of the resulting particles. Specifically, the USGS at Corpus Christi, Texas, is studying the sediment dynamics, oil transport, and erosion rate of the mats. Sediments around the mats are being sampled to determine the extent of trace metal migration, if any, from the selected study mats. The NPS, also in Corpus Christi, is conducting a statistical grid study of tar balls associated with natural tar mat disintegration. Field work conducted monthly at 11 permanent transects will document the percent coverage of tar balls and the approximate volume of oil present on the National Park beaches.

In a NOAA-funded study, the University of Texas is investigating biological effects in the intertidal and subtidal zones along transects trending perpendicular to the mats. Chemical analysis will (1) "finger-print" each mat to determine that IXTOC was its source, (2) study weathered material to detect changes in toxic properties through time, and (3) determine the degree of hydrocarbon flux from the study mats into the water column.

OIL INTERACTION WITH THE INLETS AND LAGOONS

The strategy for oil spill defense along the south Texas shoreline relied heavily on the barrier islands to absorb the majority of the oil impact and protect the biologically productive Laguna Madre. The breaks in this natural line of defense occur at a number of inlets and overwashes. The four major inlets (Brazos-Santiago, Mansfield Channel, Fish Pass, and Aransas Pass) were boomed under direction of the U.S. Coast Guard. Cedar Bayou, a shallow pass between San Jose and Matagorda Islands to the north, was first boomed and then dammed with sand across the inlet (Figure 2.38). Booms were also placed in Pass Cavallo, still farther to the north, in preparation for the advancing oil.

The placement of booms along the edge or across each inlet was not totally effective in preventing oil from entering adjacent channels or lagoonal areas. Divers from NOAA's National Marine Fisheries Service and RPI observed small concentrations of flattened tar balls (tar flakes) often passed under booms or through the channel opening. The three primary inlets to the impacted area were surveyed on 11 and 12 September, after the major oil impact and before most of the oil was removed during the tropical depression. Figures 2.39 through 2.41 indicate the distribution of oil within each pass. In Aransas Pass, the marsh/mangrove system on the western shoreline of Lydia Ann Channel showed the most conspicuous signs of oiling, although in all cases oil coverage was very light. Spartina marsh grass was oil-tinged (Figure 2.42), and several large globs of mousse were present. In all other areas, oil was present as lightly scattered tar balls. The high tides and increased wave activity during the tropical depression removed most of the oil beached within the inlet.

Figure 2.38 Aerial photograph (10 September 1979) of
sand barrier formed across the inlet of Cedar Bayou
to prevent oil from passing through the inlet.

In Port Mansfield Channel, oil passed under the booms placed near the
seaward end of the channel and impacted adjacent shorelines (primarily sand
beaches (Figure 2.40). Oil content decreased heading west down the channel.
Almost no oil was observed within Laguna Madre. Mansfield Channel had the
most oil of all the passes, but still this was minor (1.3 metric tons).

To the south, Brazos-Santiago Pass was of particular importance be-
cause of a productive nursery area (South Bay) at the south end of Laguna
Madre and the presence of mangroves directly west of the pass (Figure
2.41). Fortunately, oil impact within this area was the smallest (0.2
metric tons) of the three passes. Oil coverage along the shoreline rapdly
decreased after passing the narrow constrictions of the channel. In all
cases, the jetty structures at the entrance to each pass helped protect the
inlets from the drifting oil.
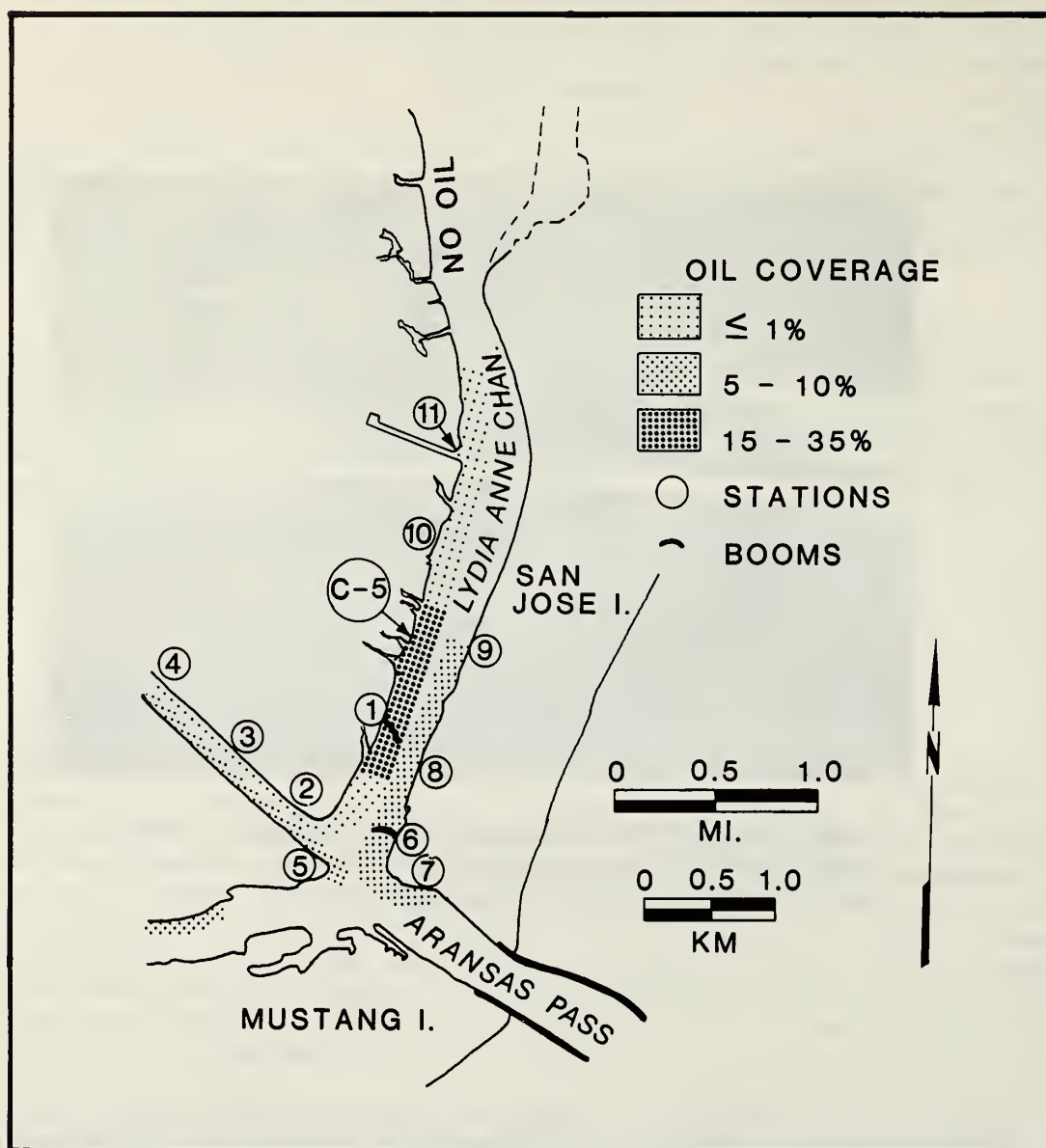
Figure 2.39 Distribution of oil within the Aransas Pass
area on 11 and 12 September 1979. Oil coverage is
described as, surface area coverage within each linear
meter of shoreline.

Figure 2.40 Distribution of oil within Port Mansfield Channel on 12 September 1979. Oil coverage is expressed as the amount of surface area covered by oil along each linear meter of shore-line.
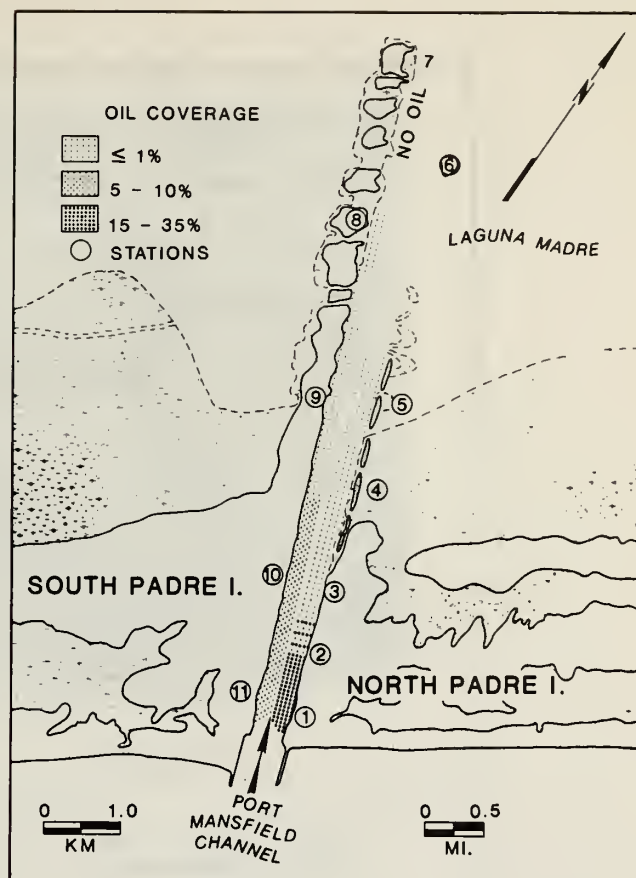
OIL DEPOSITION IN WASHOVERS

During most of the spill, including the time of major impacts during mid- and late August, tide levels were low and there was no threat of oil passing over the barrier islands and into the Laguna Madre through washovers. However, the tropical depression of mid-September substantially raised the tide level and inundated several washovers. In all, there were four problem areas on Mustang and North Padre Islands (one of which was boomed), and two problem sites on Brazos Island. Only one washover (on Brazos Island) had a significant deposition of oil. Oil coverage was light to moderate (10 to 40 percent) on the south side of the washover (due to northerly winds) and extended up to 400 m back from the Gulf of Mexico shoreline. The largest patch of oil-affected area was 150 ft by 30 ft (50 m by 10 m) and 0.2 inch (5 mm) thick (Figure 2.43). The beach in front was entirely free of oil. Some oil was also observed in the water of the lagoon, but this, too, was isolated and occurred only on the southeastern edge.

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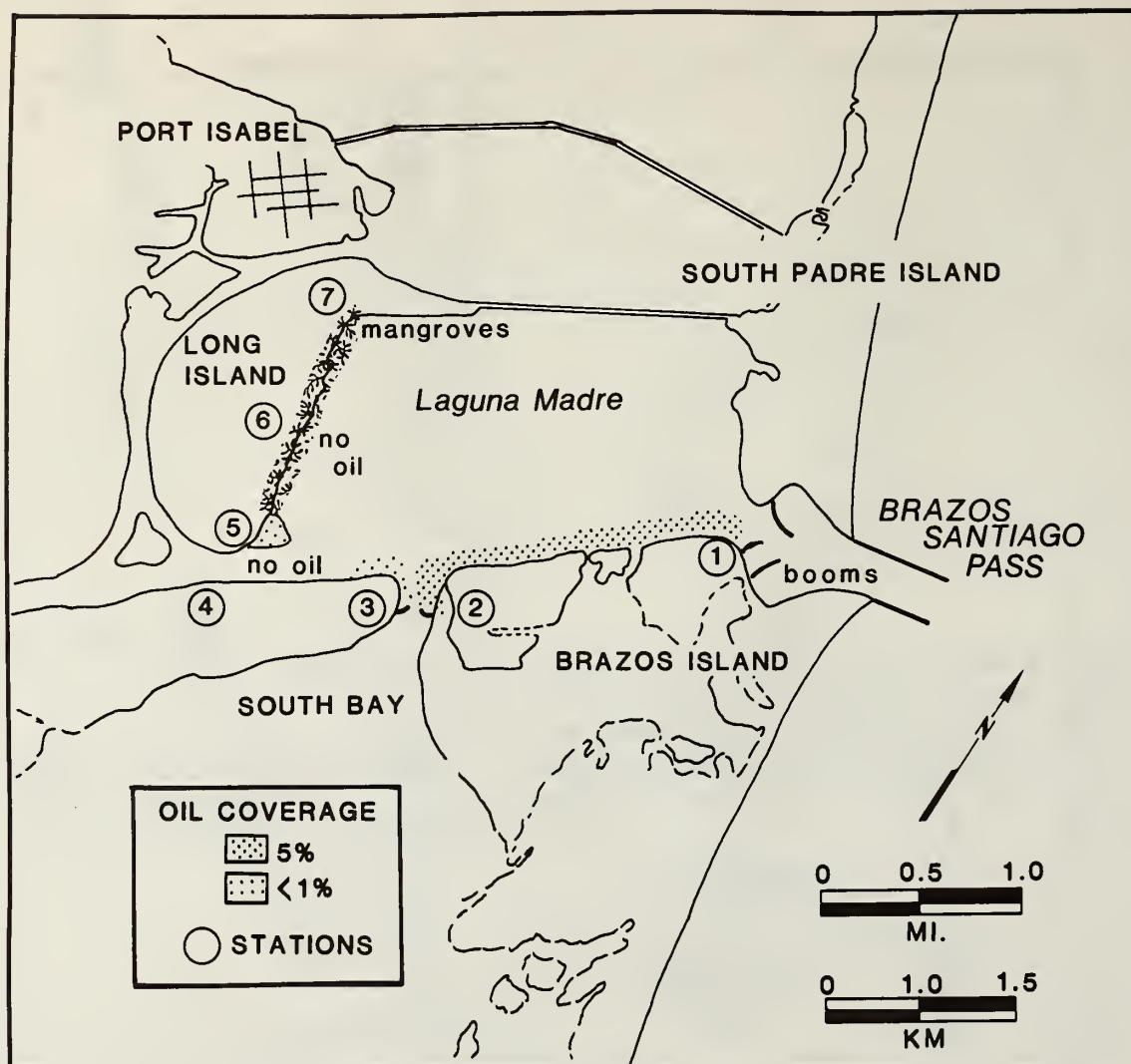
Figure 2.41 Oil distribution within Brazos-Santiago Pass and
waters on 12 September 1979.

SAND/OIL REMOVAL AND ANALYSIS

Commercial cleanup operations were organized and administered by the
U.S. Coast Guard, beginning in mid-August and reaching their peak during
the first few days of September. By mid-September, most of the beach and
inlet cleanup had ceased, although booms remained in all of the active
inlets. Beaches were cleaned by road graders and manual labor. Marcos and
Lockheed skimmers were used in the inlets.

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Figure 2.42 Oil-tinged Spartina marsh grass along the west
shore of Lydia Ann Channel (station C-5 in Figure 2.39).

Figure 2.43 View of the moderately impacted area along the
side of the overwash in the center of BrazosIsland. Oil
is visible at the base of the plants, many of which later
died because of the oiling.

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As of September 1979, when cleanup operations had appreciably declined, a total of 667 metric tons of sand and oil was removed from Mustang and South Padre Island beaches (Table 2.1). At South Padre Island, some 415.5 metric tons of spoil were removed from the beach, while 252 metric tons were removed from the Mustang Island beaches.

Table 2.1 Total amount of oiled sand removed from South Padre Island and Mustang Island Beaches as of 7 September 1979. Removal of sediment declined considerably after this date.

| | REMOVAL OF OILED SAND | | |
	m^3	yd^3	m tons
South Padre Island	4155	5431	415.5
Mustang Island	2520	3295	252.0
TOTAL	6675	8726	667.5

Three sand/oil spoil sites were sampled on 9 September 1979. The spoil sites included two large sediment piles (approximately 50 m by 10 m in area and 3 m high) fronting dunes on North Padre and Mustang Islands. The third major site was located near the main highway on Mustang Island. Some of the material in front of the dunes was reworked by waves during the passage of the tropical depression (Figure 2.44A). The spoil near the main road was later removed to a landfill site.

Two replicate samples were taken at each spoil site to determine the efficiency of the cleanup operation. Table 2.2 indicates that a relatively small amount of oil (< 7 percent) was found in the beach spoil sites and only 9 percent oil was in the road spoil site. Figure 2.44B is a photograph of a typical oil concentration within the spoil pile. Oiled sand samples analyzed during the PECK SLIP and METULA oil spills (Robinson, in press; Blount, 1978) generally exhibited oil values of 10 percent.

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Figure 2.44   (A) Spoil site on Mustang Island being
reworked by waves during the mid-September tropical
depression; however, no additional oil was notice-
ably present around the sites.

(B) Closeup of the spoil site on the beach at
Mustang Island.   Oil concentrations at this site
average only 2.5 percent.

Table 2.2 Analyses of oiled sediment dumpsites on Mustang (Road Dump
1 and 2 and Mustang 1 and 2) and North Padre Islands. A photograph of
the Mustang site (1 and 2) is presented in Figure 2.44. Generally,
oil content was very low.

SAMPLE SITE	BEFORE OIL (grams)	AFTER EXTRACTION (grams)	OIL (grams)	PERCENT
Road Dump 1	111.47	105.40	13.07	11.00
Road Dump 2	111.90	104.65	7.25	6.50
Mean				8.75
N. Padre 1	133.10	124.92	8.18	6.10
N. Padre 2	126.66	117.83	8.83	6.90
Mean				6.50
Mustang 1	125.73	122.24	3.49	2.80
Mustang 2	109.70	107.25	2.45	2.20
Mean				2.50

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CHEMICAL CHARACTERIZATION AND FATE OF THE OIL

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BACKGROUND

The IXTOC I oil spill was unique not only for its magnitude, but also for the long interval between release of oil and its impact on coastal habitats. During this time, many physical and chemical processes acted on the spilled oil. These processes, cumulatively referred to as weathering, included evaporation, dissolution, emulsification, adsorption onto suspended sediments and detritus, photochemical oxidation, and microbial degradation. These weathering processes altered the original physical and chemical properties of the oil, transforming it into several distinctly different types of petroleum residues. Physical changes included viscosity and density (and therefore buoyancy) with the formation of various types and sizes of emulsions, and oil residues with several distinct textures. Chemical changes included oxidative degradation caused by photochemical and microbial actions and were characterized by color changes of the emulsified oil with actual loss of oxidized oil by-products by dissolution of these more polar compounds in the gulf waters. The original oil slick was transformed into oil-and-water emulsions of various compositions: sheens, flakes of emulsions, tar balls, pancakes of various sizes, tar mats, and possibly other physical forms as it underwent weathering during its transport in the open gulf.

One important aspect of the scientific support effort for the IXTOC I spill included collecting oil samples that could be quickly analyzed to determine both the density of the oil, and thus predict whether it would sink before reaching U.S. waters, and its toxicity, for operational decision making. In addition, a project to take advantage of the research opportunities afforded by the IXTOC I spill was initiated. This effort culminated in a cruise to the well site and along the oil plumes during their northward transect, by the NOAA ship RESEARCHER and a contract vessel, the PIERCE.

This chapter gives the rationale and an overview of the chemistry program associated with the IXTOC I oil spill, and describes and interprets the analytical studies performed through the summer of 1980. It does not include a complete synopsis of the chemical results obtained from analysis of the samples collected during the RESEARCHER/PIERCE cruises. A complete synthesis of these results will be reported elsewhere.

OBJECTIVES OF THE ANALYSES

Chemical analyses of samples from oil spills in general, and this spill in particular, can provide a great deal of important information about the spill. First, and probably most important, is information concerning the identification, properties, and source of the spilled substance. Sophisticated chemical analyses can generally identify individual compounds or classes of compounds associated with a spill. Data from these qualitative and quantitative analyses can be used by scientists to identify the spilled substance and to assess its toxic properties. Certain compounds and/or combinations of compounds can often serve as "passive tags" to link the spill to a specific source or discharge. This latter point is particularly important when the source of the spilled material is not definitely known.

Second, the extent of geographical impact and the various types of habitats, communities, and organisms affected by the spill can be uniquely and clearly identified using chemical analytical techniques. In spills such as the IXTOC I blowout, contamination from the oil is not always visible or otherwise apparent to the senses. Chemical analysis can be used to detect elevated levels of petroleum-based hydrocarbons and differentiate those substances from normal background concentrations of hydrocarbons in the environment. This ability to differentiate impacted from nonimpacted samples, however, is generally contingent on the collection and analysis of suitable nonimpacted control samples. Also, certain samples may be impacted by the so called "invisible oil" (environmental degradation products of compounds found in the spilled oil). Such impact can only be detected by sophisticated chemical analyses.

Third, the environment's degree of uptake of the spilled substance can be estimated from statistically significant numbers of quantitative chemical assays. Replicate analysis from a given site must be obtained before levels of environmental contamination can be ascertained. The number of replicate samples required will depend, to a large extent, on the variability in distribution of the spilled substance at a given sampling site. An

even distribution of the spilled oil means that analysis of as few as three replicates at a given site will allow a quantitative estimate of the extent of environmental contamination. An uneven distribution of the spilled oil, such as has occurred from the IXTOC I blowout, means that a much larger number of samples must be analyzed to achieve an accurate quantitative estimate of the impact. Alternatively, a less accurate estimate of the quantitative impact may be obtained by analyzing fewer sample replicates. In certain instances where the distribution of oil is very uneven, only its presence or absence in a given area can be determined.

Fourth, chemical analysis can indicate both the duration of a spill and ultimate fates of petroleum hydrocarbons in the environment. This information is particularly important for damage assessment studies. In general, for spills in high-energy environments, the environment's adjustment to prespill condition can be measured in months. For low-energy environments or protected habitats, such as the Laguna Madre, the recovery period from massive oil spills may take years. Chemical analysis can be used to indicate when the environment returns to the prespill conditions.

The Federal response to the IXTOC I oil spill collected over 1400 samples in and along the northwestern Gulf of Mexico. Over 1000 additional samples were collected near the well head by the NOAA ship RESEARCHER, and PIERCE cruises. Sample collections started in mid-July 1979, before the oil impacted Texas beaches and continued on a limited scale to the summer of 1980. Sample collection activities under Federal sponsorship from 16 July through 13 December 1979, included nine major cruises by research ships or cutters, extensive beach sampling, and collection of commercial fishery products. Table 3.1 lists the numerous sampling activities undertaken during the spill. Appendix B contains a description of each activity. A complete treatment of the sampling program, including numbers, types, and locations of all samples, collector storage methods, and present location of samples is contained in McCarthy et al. (1980). Additionally, a joint BLM/NOAA-sponsored research effort has been undertaken to ascertain the environmental damage from the IXTOC I oil spill in a limited area along the Texas coast. Results from this study will be reported when these studies are complete.

RESULTS AND INTERPRETATION

This section identifies the physical and chemical characteristics of the oil that impacted south Padre Island in the summer of 1979. Very little analytical work was done on samples collected during this impact; therefore, most of the chemical information was inferred from analyses of samples collected during the NOAA ship RESEARCHER cruise to the Bay of Campeche. For example, analysis of these samples indicated evaporative weathering had already changed the composition of the IXTOC I oil by the time it reached the surface. Other physical weathering processes caused the oil to form "water in oil" emulsions (chocolate mousse) of various sizes. Visual observations suggested photochemical weathering of the oil. These transformations were reflected by color changes in the emulsions and

Table 3.1. Sampling Activities

MARINE CRUISES	1979
1. VALIANT	July 16-21
2. POINT BAKER	July 27-28
3. Cruise FSU-I	July 26-31
4. LONGHORN I	August 4-8
5. LONGHORN II	August 15-16
6. OSV ANTELOPE	August 25 - September 8
7. NOAA Ship RESEARCHER/PIERCE	September 11-27
8. Cruise FSU-II	October 31 - November 6
9. LONGHORN IV	November 16 - December 13

BEACH SURVEYS

1. Initial Impact Samples - HAZMAT Team
2. RPI
3. URS

FISHERIES WILDLIFE SURVEY STUDIES

1. R/V WESTERN GULF
2. NMFS Monitoring, Fisheries Products
3. PDS Monitoring, Fisheries Products
4. Patuxent Toxicity Studies
5. UTMSI/PAML Mussel Watch Program

DISJUNCT COLLECTIONS

by a tendency for a crust to form on the floating mousse. Physical agitation in gulf waters caused larger emulsion pancakes to be broken into smaller particles known as tar balls or tarflakes. These tar balls, which ranged in size from several millimeters to several centimeters, frequently

contained a heavily weathered outer crust and a less weathered inner material. The chemical characteristics of the inner material often resembled those of fresh oil samples that were collected near the well head.

By the summer of 1980 the following major questions have been identified and will be discussed in this chapter:

1. What were the characteristics of IXTOC I well head oil?

2. Were toxic compounds present in oil that reached the south Texas beaches?

3. Can oil that impacted the south Texas beaches be unequivocally identified as oil that originated from the IXTOC I blowout?

4. Which components of the ecosystem were impacted by IXTOC I oil?

5. What were the ultimate fates of IXTOC I oil in the Gulf environment?

Characteristics of Well-Head Oil

Several floating oil samples, collected on the NOAA ship RESEARCHER cruise, came from the immediate vicinity of the IXTOC I well and were chemically characterized by high resolution gas chromatography-mass spectrometry (GC-MS). The chemical composition of these samples has been reported in detail at the Key Biscayne Symposium on results from the cruises of the NOAA ship RESEARCHER and M/V PIERCE. A brief summary of the more ecologically significant families of hydrocarbons and nonhydrocarbons (NSO compounds) found in IXTOC I oil is presented herein. The sample contained normal hydrocarbons with as many as 35 carbon atoms in the hydrocarbon on compounds as well as numerous branched, cyclic, and isoprenoid hydrocarbons. The following families of aromatic hydrocarbons were also identified in relatively fresh IXTOC I oil.

Alkyl benzenes (to at least C_{10} alkyl homologs)

Naphthalenes (to C_4 alkyl homologs)

Napthenoaromatics (to C_3 aklyl homologs)

Biphenyls (to C_3 alkyl homologs)

Fluorenes (to C_3 alkyl homologs)

Phenanthrenes (to C_3 alkyl homologs)

The pyrene family (to C_3 alkyl homologs)

The chrysene family (to C_3 alkyl homologs)

The benzopyrene family (to C_3 alkyl homologs)

The following sulfur containing nonhydrocarbon families were identi-
fied by gas chromatography-mass spectrometry:

Benzothiophenes (to at least the C_6 alkyl homologs)

Bibenzothiophenes (to the C_3 alkyl homologs)

Benzonaphthylthipohenes (to the C_3 alkyl homologs)

Nitrogen containing nonhydrocarbon families were also identified in
IXTOC I oil:

quinolines (C_2 to C_5 alkyl homologs)

phenanthridines (X_2 to C_5 alkyl homologs)

carbazoles (C_2 to C_5 alkyl homologs)

Of course, crude oil is composed of many thousands of individual compounds,
and therefore other hydrocarbons and nonhydrocarbons were present in IXTOC I
oil but have not yet been identified.

Toxic Compounds Present in Beached IXTOC I Oil

Aromatic hydrocarbons and nonhydrocarbons are generally considered to
be toxic to marine organisms. The prevalent conception is that the more
volatile aromatic hydrocarbons, such as the benzenes and napthalenes, are
responsible for the acute toxicity of petroleum. Toxicity resulting from
chronic exposure to petroleum is associated with the presence of higher
molecular weight aromatic hydrocarbons and nonhydrocarbons. In many cases,
oxidation of these substances changes a relatively innocuous hydrocarbon or
nonhydrocarbon into toxic or carcinogenic compounds. Additionally, poly-
cyclic aromatic hydrocarbons present in petroleum are considered potential
carcinogens, and, in fact, humans living close to petroleum industries
suffer above average cancer mortalities. These facts lead to the definite
conclusion that chronic exposure to petroleum aromatic hydrocarbons and
nonhydrocarbons should be considered a health hazard to both marine organ-
isms and humans.

Very few samples of oil from the south Texas area have been analyzed,*
and therefore the toxicity of beached oil can only be inferred from the
analysis of samples collected during the NOAA ship RESEARCHER cruise. The
U.S. Coast Guard Cutter POINT BAKER also collected samples of mousse in the
gulf waters south of the U.S.-Mexican border, and these samples were specif-
ically analyzed to determine the identity of toxic aromatic compounds. The

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*Many of the samples will be analyzed under the BLM/NOAA Damage Assessment
Program now underway.

aromatic compounds found in the U.S. Coast Guard Cutter POINT BAKER samples are included in the list of aromatic hydrocarbons and nonhydrocarbons given previously.

Limited analytical data indicate that tar balls and mousse samples, even those considered heavily weathered, retained quantities of both the acutely and chronically toxic aromatic hydrocarbons and nonhydrocarbons. These data suggest that most mousse and tar balls had a physical structure similar to that of a jelly bean. That is, these oil substances were composed of a heavily weathered outer crust that was depleted of aromatic hydrocarbons and nonhydrocarbons. The inner material, which was visually different from the crust, contained essentially all types of the aromatic hydrocarbons and nonhydrocarbons found in fresh well head oil. There was, as expected, tremendous diversity in the quantities of these aromatic substances in the weathered samples. Examination of data from the limited number of beached tar balls analyzed to date suggest there was significant quantities of aromatic compounds present in tar balls that washed ashore on south Padre Island.

As of the summer of 1980, no samples of biota have been analyzed by standard GCMS techniques to determine the uptake of petroleum hydrocarbons and nonhydrocarbons. Samples of shrimp were organoleptically tested (tasted and smelled) and found to be free of petroleum residues using this relatively insensitive technique.

Petroleum aromatic compounds can be oxidized by various natural (photooxidation), biological, and enzymatic processes. These water soluble oxidized compounds cannot be detected by visual inspection of the environment and are therefore, frequently referred to as the "invisible oil." Oxidation generally increases the toxic and carcinogenic properties of aromatic compounds, and consequently this "invisible oil" may present a health hazard to marine organisms and man. No samples from the northern Gulf of Mexico have been analyzed for these oxidized aromatic hydrocarbons and nonhydrocarbons, and therefore nothing can be implied about their impact along the south Texas gulf coast.

Identification of IXTOC I Oil in the South Texas Environment

There is strong observational evidence to link tar balls that impacted the south Texas environment with the IXTOC I blowout. Unfortunately, other sources, both natural (seeps) and anthropogenic (tankers) could have caused a portion of the impact. There is, a need to chemically link the oil that impacted south Padre Island with the oil that resulted from the IXTOC I blowout. As of the summer of 1980, this link has not been unequivocally established with hard chemical evidence.

The question must be proposed, "Do scientists have the analytical tools and established techniques necessary to identify IXTOC I oil if it impacted south Padre Island?" And further, if the answer to this question is yes, how can this identification be accomplished?

The answer to the first question is a qualified yes. The following paragraphs outline what information is needed to link IXTOC I oil with tar balls collected from south Padre Island. It also estimates the degree of accuracy in the identification.

The chemical composition of various crude oils is qualitatively the same (most petroleums contain the same types of compounds). Quantitatively, there is great diversity in the amount of individual compounds in different crude oils. Furthermore, the quantitative distribution of compounds can be affected by the various weathering processes. Consequently, no single qualitative or quantitative parameter can be used as strong evidence to identify a given oil sample as having come from a specific source. A combination of chemical parameters must therefore be used to elucidate the source of petroleum in environmental samples. These identifications must be verified by analysis of a statistically significant number of field samples that were collected from areas known to be impacted by oil from a specific source (exposed sample). Control samples from a nonimpacted area must also be analyzed. It is also extremely useful for oil source identification if samples from the suspected source oil can be analyzed.

The following are typical, but not inclusive, of the chemical parameters that are commonly used to link an environmentally weathered crude oil with its sources. The ratio of carbon 13 to carbon 12 and sulfur 34 to sulfur 32 are characteristic of the diaganetic history of a given crude oil's formation zone. These parameters are relatively insensitive to weathering, and can be used to indicate possible crude oil sources. They should not be used as unequivocal chemical evidence linking petroleum containing samples to specific sources but rather as eliminators of those samples that could not have originated from a given source.

Generally, we do not consider physical data, such as viscosity, boiling points, ultra violet, infra-red, and UV-fluoresence spectra as applicable to the identification of petroleum sources in weathered crude oil samples.

The quantitative distribution of certain hydrocarbons and nonhydrocarbons within a crude oil is very characteristic of the source of that crude oil. Distributions of the following compounds or families of compounds are typically used to qualitatively identify the source of environmentally exposed crude oils:

isoprenoid hydrocarbons

cyclic and branched hydrocarbons

hopanes and stearanes

alkyl benzenes

alkyl naphthalenes

alkyl benzothiophenes

alkyl biphenyls (or acenaphthalenes)

alkyl fluorenes

alkyl phenanthrenes

alkyl dibenzothiophenes

alkyl quinolines

alkyl carbazoles

alkyl phenanthridines

The quantitative comparison of these substances, both within a specific family of compounds and between families of compounds, can present strong evidence to link a given environmental crude oil sample with a specific source. These quantitative distributions are generally obtained from data produced by the analytical techniques of glass capillary gas chromatography and glass capillary gas chromatography-mass spectrometry.

Certain samples, if heavily weathered, are beyond recognition as coming from a specific source. Also, the incorporation of crude oil at very low levels in certain types of samples, such as sediments or biota, substantially increases the difficulty at linking the petroleum to specific sources.

Components of the South Texas Ecosystem Impacted by IXTOC I

Evaporative weathering causes losses of the more volatile components of IXTOC I oil. However, oil that impacted Texas beaches still retained the smell of petroleum. Even though no scientific measurements were taken to evaluate atmospheric impact, it was apparent that atmospheric impact in the south Texas environment is minimal.

Visual inspection of the beaches along South Padre Island indicated most oil that impacted the beaches was in the physical form known as tar balls. Several large tar mats were also observed in the trough line. Strong circumstantial evidence indicates the types of petroleum residue came from the IXTOC I blowout.

Visual observatons before beach impact revealed large quantities of oil floating in the Gulf of Mexico. The quantities of oil that impacted South Padre Island were substantially less than those observed offshore. The discrepancy between visual observations of the amount of oil offshore and of that which reached the beaches led to the speculation that large quantities of oil lost its buoyancy and sunk before it impacted the Texas beaches. These speculations were never verified by chemical analysis.

The extent of impact to other components of the ecosystems, such as the water column, bottom sediments, or various types of biota have not been determined as of the summer of 1980. The BLM/NOAA-sponsored damage assessment program is designed to answer some of these questions.

Ultimate Fates of IXTOC I Oil

The ultimate fates of petroleum in the marine environment has been the subject of much work and speculation. One of the major goals of the NOAA ship RESEARCHER cruise and subsequent analytical efforts was to determine the effects of weathering on IXTOC I oil. Much information is being accumulated from this research venture. Unfortunately, very little information is available on the fates of the IXTOC I oil in the south Texas area, because essentially no chemical analyses have been performed from samples collected in this region.

Synthesis of data from the NOAA ship RESEARCHER cruise is still in progress, but the following general observations can be made.

1. IXTOC I oil formed emulsions (chocolate mousse) within a few kilometers of the well head.

2. Emulsions were subjected to color changes and formed a crust after exposure to sunlight.

3. There is strong evidence to suggest that microbial degradation of the IXTOC I oil occurred at a relatively slow rate (microbes were nutrient starved).

4. Laboratory photolysis experiment using IXTOC I oil indicated that sunlight promoted the formation of numerous fatty acids and oxidized aromatic acids and alcohols.

5. Analysis of weathered emulsion samples did not reveal large quantities of polar oxidized hydrocarbons in the sample. This implies that as the aromatic hydrocarbons and non-hydrocarbons were environmentally degraded to more polar products, and that these products were leached into the water column and diluted in the Gulf of Mexico.

6. The important results will be included in a synthesis document currently being developed.

Of the large quantities of oil that were introduced into the gulf environment by the IXTOC I blowout, very little was recovered by cleanup operations. The fates of the remaining IXTOC I oil, as of this writing, is subject to speculation.

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RESOURCES AT RISK

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Many resources were at risk in the south Texas area during and after the IXTOC I impact period. Padre Island and the Laguna Madre are known to be one of the most important staging and wintering areas for waterfowl, shorebirds, and colonial waterbirds in the United States. The endangered brown pelican, whooping crane, and peregrine falcon all use this area. Sensitive marsh areas are also found in association with the extensive lagoonal system there that provides an important nursery for commercial species upon which the Texas Gulf fisheries industry depends. The dockside value of shell and finfish landed at all Texas ports was $125.5 million in 1978. Eighteen species of marine mammals and five species of marine turtles are reported to be residents of the offshore area of south Texas with all except one classified as protected, threatened, or endangered. Because of their value, these resources and more will be viewed in this chapter from both a biological and socioeconomic standpoint.

BIOLOGICAL SETTING

Lagoons

Laguna Madre, Corpus Christi, Aransas, San Antonio, Matagorda, and Galveston Bays and their drainages make up the Texas lagoonal system. They are divided into the deeper basin and the shallower inshore region on the basis of depth (as by Hedgpeth, 1967).

Lagoonal basins

Most of the deeper portions of Texas lagoons and bays are occupied by an assemblage of crabs, shrimp, croakers, catfish, and other fishes of more or less seasonal occurrence (Hedgpeth, 1967). This assemblage is distinct from the shallow water lagoonal community, differing primarily by size (larger) and seasonality of the species involved. Since many of the organisms are mobile and subtidal, they are able to escape the physical and chemical effects of oiling by actively avoiding oiled areas.

The Laguna Madre supports a considerable commercial and recreational fishery for redfish, drum, and seatrout. Hedgpeth (1953) reported that over half of the total Texas fish landings of these three species came from the Laguna Madre. While commercial and recreational species have a large standing-stock biomass, the diversity of other biota is low (Breuer, 1962), consisting of only eleven resident invertebrates and ten resident fishes. A highly organic detrital substrate and a flourishing plankton population (i.e., copepods) (Breuer, 1962) fuels a productive detrital-plankton based ecosystem.

Seagrass and algae beds

Marine grasses and algae are largely subtidal. In extensive areas of the lower Laguna Madre, macroflora are absent and the dominant producers are blue-green algae. Environmental conditions prevent the successful invasion of shoal grass throughout large areas, although its spores are regularly dispersed throughout the system (Breuer, 1957).

Elsewhere in the Texas lagoonal system, seagrasses contribute significantly to primary productivity (Wood et al., 1967). The three most important seagrasses in Texas lagoons are shoal grass, widgeon grass, and turtle grass. These grasses help stabilize the mud flats and subtidal substrate, and provide critical habitat for numerous animals. Populations of these animals undergo rapid fluctuations because of the seasonal nature of seagrass habitats (Conover, 1964).

Animals in the lagoonal system include the following crustaceans: grass shrimp, caridean shrimps, arrow shrimp, snapping shrimp, and the commercially valuable pink shrimp. Crabs and bivalves characteristic

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of Texas lagoonal seagrass beds include the mud crab, thick lucine, cross-barred venus, and bay scallop. The sea cucumber is also a commonly encountered organism. Among the many gastropods using the seagrass habitat are the virgin nerite, two whelks (Busycon contrarium and B. spiratum), Texas tusk shell, and bubble shell. Wintering waterfowl in the lower Laguna Madre (about one-half million birds) are reported to be attracted to exposed seagrass beds, especially shoal grass (McMahan, 1968).

Oyster Reefs

Oyster reefs, both living and dead, are a prominent feature of Texas lagoons. The American oyster is a sessile bivalve that attaches permanently to almost any firm substrate below mean low tide level. While the commercial value of oysters is in harvesting them for human consumption, oyster reefs are also an important ecological component. They form solid substrate areas that provide attachment sites for subsequent oyster recruitment, as well as for other attached organisms, marine algae, and myriads of small animals. Hedgpeth (1953) characterizes oyster reefs as the most important biotic aggregation in Texas lagoons and documents recent extensive die-offs of oysters due to man-induced changes, including dredging, filling, and manipulation of freshwater runoff characteristics. Large sections of oyster reef habitat are, therefore, no longer living, but consist of the shells of dead animals. Dead oyster reefs, in contracts to live reefs, are judged as relatively low in vulnerability to oiling due to the general absence of living oysters and the subtidal nature of the environment.

Spoil Islands

Dredging operations in the shallow lagoons of Texas have produced numerous islands or chains of islands that have become a substrate for the development of plant and animal communities, many of them are attractive to colonial seabirds and wading birds as nesting sites (Chaney et al., 1978). Among the birds using these spoil islands are endangered and threatened species such as the brown pelican, black skimmer, and least tern. Almost all other birds nesting on spoil islands are protected or considered as having aesthetic value (e.g., great blue heron, little blue heron, roseate spoonbill, and white pelican). Chaney et al. (1978) lists a total of 47 species that nested on these spoil islands in 1977, of which over 30 species are colonial or wading birds.

Lagoonal Beaches

Lagoonal beaches having variable substrate composition, grain size, and organic content comprise a considerable portion of the south Texas coastline (27.3 percent). They are usually steeply sloping habitats, ranging from highly protected to moderately exposed to waves and currents. Three types of lagoonal beaches are addressed below.

Scarps in clay. This habitat is characterized by a very fine-grained, compact sediment, which is relatively stable due to its cohesive nature. The compacted nature of clay/sand sediments and the resulting impermeability and lack of interstitial space are the greatest limiting factors for communities inhabiting clay scarps and beachfaces. In addition, clay affords a poor attachment surface and burrowing medium. Fiddler crabs and wrack-associated amphipods are present in small numbers in the supralittoral zone, a few nereid polychaetes are present in the inter- and subtidal portions of this habitat type.

Sheltered sand beaches. The slope and composition of the beach face sediments are variable and dependent upon physical factors. Sandy substrates are relatively porous, allowing some limited burrowing activity. Interstitial spaces are used largely by bivalves and polychaete worms. Sand, like clay, affords a poor attachment substrate for plants and, therefore, has very low endemic primary productivity.

Mixed sand and shell beaches. Sheltered sand and shell beaches usually have the steepest profiles of all Texas lagoonal beaches. The coarse substrate lacks the stability necessary to sustain a community with a large diversity or biomass, and interstitial pore size is too large for the capillary action necessary to keep beach sediments moist and prevent desiccation of the infauna.

Tidal flats

Tidal flats occur throughout the south Texas lagoonal system and are 20.6 percent of the shoreline. Substrate composition, grain size, and organic content are all variable. Exposure to wave energy is very low to moderate.

Parker (1959) characterizes three tidal flat environments, based on the invertebrates inhabiting them. Breuer (1957), among others, has affirmed the validity of the principles behind this classification in the Laguna Madre lagoonal complex, especially with reference to the fishes. These three tidal flat types are discussed below.

Exposed tidal flats with low biogenic activity. Very few large organisms are capable of adapting to the harsh environment of varying tidal exposure and salinity present in this habitat. Prime among these is the blue-green alga, which in some areas forms dense mats and often constitutes 80 percent of the living community (Sorenson and Conover, 1962). In addition, unicellular green algae, flagellates, diatoms, and bacteria are found (Sorenson and Conover, 1962; Cuzon du Rest et al., 1963). Animals present include ciliates, nematodes, crustaceans, corixid water bugs, and worms (Sollins, 1969). The small clams Mulina lateralis and Anomalacardia cuniemeris are occasionally present beneath the mats (Dalrymple, 1965), and sheepshead minnow is often present above (Odum, 1967).

Exposed tidal flats with moderate biogenic activity. This tidal flat environment is more stable in terms of physical and chemical factors, although physical stresses are still high. An increased standing stock

biomass is present within a low-diversity community. This habitat type is relatively rare (0.25 percent) among south Texas coastal environments, occurring mainly along the more sheltered, better flushed portions of the back shore of the barrier islands.

Sheltered tidal flats with high biogenic activity. The third type of tidal flat habitat is more sheltered from wave activity and has a more stable salinity, encouraging relatively high species diversity and standing stock biomass. Seagrasses in the intertidal portion of this habitat add to the complexity of its trophic relationships. Primary among these seagrasses is shoal grass, although turtle grass is locally abundant. These seagrasses are highly seasonal and die down when temperatures are high in the summer (Hedgepeth, 1953).

Like sand beaches, sheltered tidal flats are inhabited by either burrowing or very motile species. Molluscs, crustaceans, and polychaetes are the dominant burrowing macrofauna. Prime among these are two species of razor clams (Tagelus plebius and Ensis minor). Feeding upon these abundant bivalves are the oyster drill, blue crab, hermit crab, and various shorebirds (especially gulls and terns). The presence of other burrowing bivalves is dependent upon prevailing physical and chemical factors and the individual requirements of each species.

Burrowing bivalves are commonly fed upon by large crabs such as the blue crab, the stone crab, and the whelk. Mud crabs inhabiting sheltered tidal flats include the common mud crab, flat mud crab, and the mud crabs Neopanope texana and Rithropanopeus harrisi Shrimps that burrow in mud include Callianassa jamaicense louisianensis. Gastropods present include the moon snail, common mud snail, and common Atlantic auger. Hermit crabs that occupy the empty shells of these and other tidal flat gastropods include (Clibinarius vittatus, Pagurus longicarpus, and P. pollicaris. Burrowing worms present include the parchment worm, lugworm, and other polychaetes, such as Eteone heteropoda and Laeoereis culveri.

The vulnerability to oiling of any of the three types of tidal flats relates to the mechanical and chemical effects on individuals as well as community diversity and biomass. Physical processes and sediment grain size control oil penetration and persistence. Community structure controls biological response. Organisms in a habitat under stress are already living at or near their physical limits. The effects of oil contamination may thus be devastating to such a community. In addition, low-diversity communities are less capable of withstanding any impact and slower to recover from pulsing, although where there is a large standing stock biomass, the quantitative destruction can be much greater.

Marshes

Marshes occur on the lagoonal side of the sand beaches, the landward side of lagoons, along streams and rivers that drain into the lagoon, and on spoil islands and deltas (Phleger, 1965). Dominant features along the edges of the lagoons are inland or landlocked ponds, commonly ringed with cordgrass and high marsh vegetation. Physical conditions are extreme, with great variability in temperature and salinity. Benthic seagrasses and algae are sparse, but a large standing biomass in fishes and shrimp is characteristic (Gunter, 1950; Hedgpeth, 1950). Also abundant are burrowing polychaetes, hermit crabs, and gastropods. These areas provide rich feeding grounds for migratory waterfowl and shorebirds (Gunter, 1958). Landlocked ponds are considered vulnerable to oiling only when they have surface water connecting with open water. Figure 4.1 illustrates the species characteristic of Texas lagoonal marshes. This habitat closely resembles a marsh type termed "fringing," which dominates long stretches of back-barrier and mainland shorelines.

Vegetation patterns are influenced by a complex of environmental factors and consist of two zonation patterns. The dominant producer, dominating the vegetated tideland zone, is saltwater cordgrass. This shallow subtidal and intertidal vegetation damps impinging waves, tides, and currents, creating a sheltered-water microhabitat. Sediment accretion and stabilization and nutrient remineralization are promoted, and the potential for spawning and nursery habitat is increased.

A second zone characteristic marsh habitat is termed "high marsh." Vegetation is dominated by halophylic marsh plants such as sea ox-eye daisy, glasswort, and saltgrass. The black mangrove is scattered but locally abundant. Black mangroves are largely tropical/subtropical species whose range is limited by low temperatures, especially frosts. Most black mangroves in Texas are less than 1 m tall, and a significant number are dead due to recent frosts. The black mangroves in the study area appear to be at or near their minimum temperature limit.

Animals inhabiting salt marshes are diverse and abundant and, like plants, exhibit physical responses and adaptations to numerous environmental factors that result in a distinct zonation in distribution. Grazing on plant and detrital material takes place in and on sediments and plant surfaces throughout all marsh zones. Intertidal grazers characteristically dominant in Texas lagoonal marshes include small shrimp (Paleomonedes, Tozumia, and Penaeus), killifishes (Adinia, Cyprinodon, Poecilia, Fundulus, and Lucania), and crabs (Callinectes and Clibinarius). The salt marsh periwinkle is an abundant grazer in the aerial parts of saltwater cordgrass. Juvenile and young adult mullet are seasonally abundant invaders of the vegetated intertidal salt marshes of Texas lagoons.

MARSH HABITAT

CHARACTERISTIC SPECIES

1. BIRDS
   a. Rail
   b. Great Blue Heron
   c. Louisiana Heron
   d. Migratory Waterfowl
2. FISH
   a. Sheepshead Minnow
   b. Mullet
3. CRUSTACEANS
   a. Fiddler Crab
   b. Sesarma
   c. Blue Crab
   d. Mud Shrimp
   e. Hermit Crab
   f. Amphipod
   g. Grass Shrimp

4. MOLLUSCS
   a. Coffee Bean Snail
   b. Salt Marsh Periwinkle
   c. Jackknife Clam
   d. Razor Clam
5. WORMS
   a. Polychaete
6. ALGAE
   a. Blue-Green Algal Mat
7. HIGHER PLANTS
   a. Distychlus
   b. Borrychia
   c. Juncus
   d. Batis
   e. Salicornia
   f. Sesuvium
   g. Spartina

Figure 4.1 Characteristic plant and animal community and their zonation which are found at south Texas arsh habitats (Drawing by Charlotte Johnson, Columbia, S.C.).

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Not many infaunal organisms were observed in high marsh zones, nor were abundant infauna noted within intertidal vegetation. In contrast, shallow subtidal waters support a moderate to locally heavy infaunal population consisting of bivalves (_Toredo_ and _Ensis_), mud shrimp, and polychaete worms.

High marsh consumers are dominated by fiddler crabs, which burrow extensively among high salt marsh plants. Amphibious and terrestrial insects, abundant throughout the high marsh and the intertidal zone at low tide, also use aerial portions of intertidal salt marsh vegetation. Mobile consumers, which may invade or inhabit salt marshes, consist of terrestrial mammals, euryhaline fishes, and migratory and shore waterfowl.

Texas lagoonal marshes are highly vulnerable to oiling, due to the sheltered nature of the environment and the sensitivity of resident plants and animals. The impact to dominant components of the Texas marsh ecosystem includes oil-induced mortality of _Spartina alterniflora_ (Baker, 1971), _Sesuvium_, _Batis_, _Salicornia_, and _Avicennia_ (Chan, 1977). Primarily, the impact to salt marshes is related to the toxicity of oil to individual species, the temporal pattern of oiling (chronic spillages), and seasonality.

Inlets

The biological role of Texas coastal inlets has received much study (Hedgpeth, 1953; Günter, 1958; Copeland, 1965; Simmons and Hoese, 1959). The limited numer of inlets bisecting Texas barrier islands increases the relative value of each inlet and also its control of biological processes. Inlets constitute the vital link between the lagoons and the Gulf of Mexico and perform the following biological functions:

1. Influencing the salinity regimes within the lagoonal system and, therefore, the distribution and relative abundance of dominant organisms.

2. Acting as avenues of transport for migrating fishes, shrimp, and crabs that enter the lagoons to feed or spawn.

3. Exchanging nutrients, detrital material, and plankton.

In total, more than 24 species of invertebrates and 55 species of fishes are known to move through Texas passes, including several commercial species (Copeland, 1965). Shrimp and crabs enter passes en route to lagoonal spawning grounds. This is followed by a peak passage out of lagoons by shrimp and crab larvae. Copeland (1965) indicates that there is a net migration into the Gulf of Mexico waters from the Texas lagoonal system, and that peaks in migration occur in May-June and October. Copeland (1965) estimates peak emigrations of up to 318,960 kg of biomass per day through Aransas Pass.

Beaches

Exposed, fine sand beaches

Exposed fine-sand beaches occur on the seaward side of the barrier islands and make up 22.8 percent of the south Texas coast. A considerable body of literature documents research on sand habitats (see Hedgpeth, 1953), including studies on plankton and productivity (McFarland, 1963a), dominant macroinvertebrates (Whitten et al., 1950); Loesch, 1957; Hill and Hunter, 1973), infauna (Keith and Hulings, 1965), and fishes (Gunter, 1958; McFarland, 1963b). An illustration of this habitat and its characteristic species is presented in Figure 4.2.

The lack of stable, solid surfaces and the abrasive action of moving particles does not allow an exposed sandy beach to support the abundant large algae found on rocky shores or the rooted vegetation found in muddy or sheltered, marsh areas. Endemic primary productivity is low and restricted in microorganisms (mainly diatoms) that generally live within the upper few millimeters of sand. The role of microorganisms on sandy beaches is relatively important because of the low standing stock biomass of sessile macroorganisms.

Of the infaunal species (>0.5 mm), burrowing bivalves, polychaete worms, and crustaceans make up significant portions of the macrofaunal community on exposed Texas beaches. Characteristic dominant species of these groups include coquina clams, polycheate worms, mole crabs, and haustorid amphipods. Despite the relatively small number of species, the number of individuals may be tremendous. Loesch (1957) estimated over 10,000 coquina clams per square meter at one station on a Texas beach. Immediately below the intertidal zone to a depth of about 1 m, the number of species increases. Keith and Hulings (1965) report finding 35 species of macroinfauna, including 17 crustaceans, 12 polychaetes, and six molluscs at Texas beaches.

The nearshore community of Texas sand beaches is probably the richest and most diverse of any part of the sand beach. The gentle, sloping substrate, less exposed to the effects of wave action, supports an assemblage of sessile, sedentary, and motile invertebrates and bottom feeding fishes (Hedgpeth, 1953). Conspicuous among these are commercial shrimp (Peneaus). Also occurring within the breaker zone is an assemblage of mud shrimp, portunid crabs (Arenaeus and Callinectes), keyhole urchins, and sand stars. Over 40 species of fishes are reported from Texas beaches (Gunter, 1958), the most abundant being common pompano, sardines, mullet, and croaker. These are all valuable commercial or forage species. Recreational fishes of Texas sand beaches, reported by Springer and Pirson (1958), include redfish, mangrove snapper, drum, croaker, and sheepshead.

The back-beach area of this habitat is dominated by the ghost crab, which feeds at the waterline, mainly at night principally upon the macroinfauna Donax and Emerita (Wolcott, 1978). Its habitat extends from subtidal to landward on the beach foredunes. On Texas beaches, the greatest populations of the ghost crab are found along the foredune ridge (Hill and Hunter, 1973). This portion of the beach is relatively stable and, due to its

EXPOSED SAND BEACH HABITAT

CHARACTERISTIC SPECIES

1. BIRDS
   a. Least Tern
   b. Great Blue Heron
   c. Ring-Bill Gull
   d. Black Skimmer
   e. Black-Headed Gull
2. FISH
   a. Common Pomano
   b. Mullet
   c. Spot
   d. Sea Trout
3. CRUSTACEANS
   a. Ghost Crab
   b. Mola Crab
   c. Haustorid Amphipod
   d. Wrack-Associated Amphipod
   e. Purse Crab
   f. Spotted Crab

4. MOLLUSCS
   a. Coquina Clam
5. WORMS
   a. Polychaeta
6. ECHINODERMS
   e. Sand Dollar
7. ALGAE
   a. Sargassum
8. HIGHER PLANTS
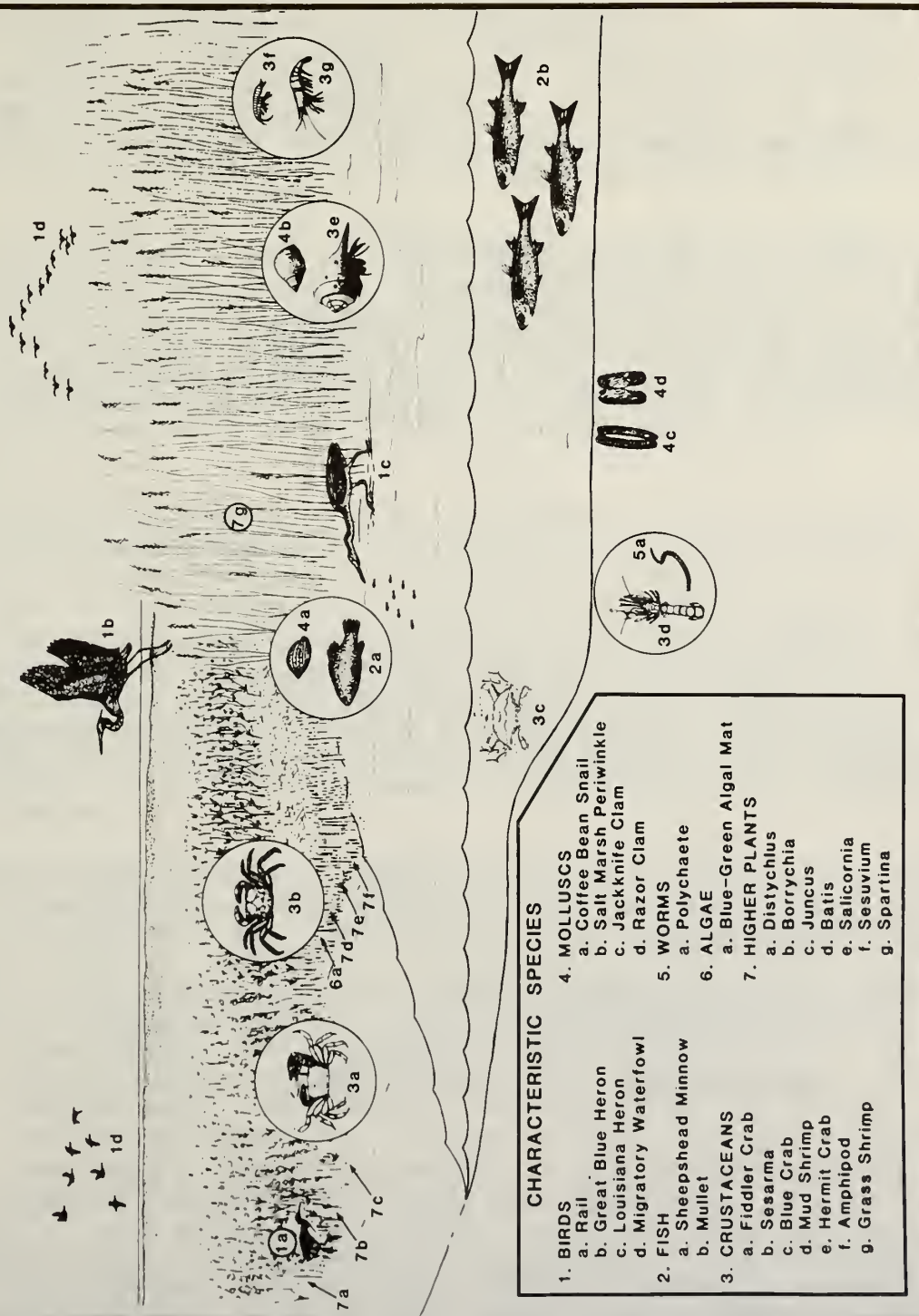   a. Sea Oats
   b. Morning Glory

Figure 4.2 Characteristic plant and animal community and their zonation which are found at south Texas exposed sand beach habitats (Drawing by Charlotte Johnson, Columbia, S.C.).

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elevation, is usually not vulnerable to oiling. Organisms in this area,
however, can be injured by cleanup efforts. Small and juvenile ghost
crabs, partially or completely aquatic and distributed subtidally and
throughout the intertidal region, are more vulnerable to oiling, especially
just following summer recruitments. Impact to ghost crab populations
following oiling is documented by Benny et al. (1975); alterations of
population size and sex ratios were observed.

Beach wrack or swashline debris along Texas beaches consists primarily
of the alga Sargassum. Associated with beach wrack, especially at or below
the last high-tide swash, are populations of amphipods. Orchestia is the
dominant beach hopper, although Talorchestia is also present (Hedgpeth,
1953). The distribution and abundance of these populations are generally
extremely patchy and seasonal.

Mixed sand and shell beaches

Mixed sand and shell is relatively rare along the exposed portions of
the Texas barrier island beaches. The largest concentration of this type
is found on Padre Island, about 9.3 (15 km) south of the park entrance at
two beaches called Little Shell and Big Shell. Mixed sand and shell beaches
were found in this study to have lower species richness, diversity, and
biomass than exposed fine-sand beaches, especially with regard to the
macroinfauna.

Foredunes

Foredunes constitute the highest supratidal portion of exposed sand
beaches. Numerous terrestrial mammals are regular invaders of the foredune
and backbeach areas. These include grey foxes, coyotes, skunks, bats,
kangaroo rats, jack rabbits, and ground squirrels. Judd et al. (1977)
characterized the sand dune vegetation of Padre Island and related its
importance to dune stabilization. Major vegetation types include Uniola
paniculata, Ipomea pes-caprae, Ipomea stolonifera, Spartina patens,
Panicuia amarum, Cassia fascrulata, and Oenothera drummondii.

Birds

The many bird species found along the Texas coasts reflect the wide
variety of available habitat and the suitability of the climate. Migratory
waterfowl, shorebirds, and colonial waterbirds make up much of the bird
population along the coast; the importance of Padre Island and the Laguna
Madre as a staging and wintering area for these birds cannot be overempha-
sized. Information about waterfowl and the colonial waterbirds has been
collected systematically (Texas Parks and Wildlife, 1978-1979 - colonial

waterbird survey, waterfowl survey); but there is still very little information on shorebird migratory patterns, distribution along the Texas coast, and feeding behavior. The beach provides breeding areas for many shorebirds and waterbirds, including the white pelican, olivaceous cormorant, reddish egret, roseate spoonbill, American oystercatcher, snowy plover, Wilson's plover, laughing gull, gull-billed tern, least tern, and others. The endangered brown pelican, whooping crane, and peregrine falcon all use this area.

The Texas gulf coast supports more migratory and seasonal waterfowl than any other single area in the central flyway. It is of primary importance to seven species of waterfowl, including the redhead, mottled duck, fulvous whistling duck, black-bellied whistling duck, lesser snow goose, Canada goose, and white-fronted goose. Important habitats include bays, tidal marshes, estuaries, and Matagorda and San Jose Islands. Except for the redhead, which is limited to the Laguna Madre, most wintering waterfowl are not confined to any specific areas of the coast, but move back and forth among different habitats.

Jetties

These human-made habitats are relatively new along Texas beaches, and comprise only approximately 20 miles (32 km) of shoreline. The general characteristics of Texas jetties and their biota were described and compared with other zoogeographic regions by Whitten et al. (1950) and Hedgpeth (1953). Texas jetties vary in material size from rubble and small stones to large quarry blocks and in length from a few hundred meters to 3.4 miles (5.6 km).

This habitat is subjected to the high wave activity of the open gulf and the variable temperatures and salinities of exiting lagoonal waters. Since the Gulf-Carolinean biota characteristic of Texas beaches have almost exclusively evolved for living on soft substrates (Hedgpeth, 1953), the attached biota at Texas jetties contain few or no endemics. According to Whitten et al. (1950), the intertidal community of Texas jetties consists mainly of three species of barnacles, one limpet, one littorine snail, one mussel, one Thais snail, an anemone, an isopod (Ligyda), and a hermit crab. The jetty fauna represent colonization from nearby habitats, especially oyster reefs, sand and bottom habitats, and salt marshes.

Offshore

Pelagic habitat

The pelagic habitat consists of the major (upper) portion of the water column, and contains variable concentrations of nutrients, suspended solids,

plankton, macro algae, and nekton. Because this community is highly transient and is not physically fixed, the primary contact between the organisms and oil contamination is the surface. Organisms coming in contact with the surface oil could become coated with an oil film, and die from suffocation or other physical impairments. Sinking oil, in the form of tar balls, could have a short residence time in the water column and thereby cause the least damage to the pelagic community. Dissolved toxic hydrocarbons, dissipating from the surface oil downward, would be available for uptake. Ingested substances could be concentrated in tissues or be excreted.

The impact on the planktonic or nektonic community at any given time period or location would be difficult to measure and would probably entail only a temporary disruption (e.g., weeks) of the basic food web (phyto/zooplankton), which could be renewed as new generations of plankton are recruited following the passage of the oil slick. The nekton would either move to avoid the oil or feed upon the contaminated zooplankton. Either the accumulation or excretion of hydrocarbon residues would then occur. A common example of the pelagic organisms that are found in the Texas offshore area is the king mackeral, which is primarily of recreational value.

Benthic habitat

Three recognized habitat types in this area are a soft bottom, a hard bottom such as snapper banks and fouling communities on oil rigs, and the Flower Gardens, the most northern coral reef in the Gulf of Mexico. The benthos, being relatively stationary, serve as a barometer reflecting changes that occur in localized areas (Flint and Rabalais, 1980) and thus would be important in the study of the effects of an oil spill. The south Texas Outer Continental Shelf (STOCS) study conducted by BLM identified the brown shrimp as appearing to be the best indicator organism in their benthic monitoring (Flint and Rabalais, 1980).

Common species found in the south Texas offshore benthic environment are the brown shrimp, white shrimp, pink shrimp, blue crab, red drum, black drum, Atlantic croaker, southern flounder, and red snapper.

Branching tube sponge, Udotea, sea whips, sea fans, and asteroid starfish, are some of the organisms found on the West Flower Garden Bank, one of two coral reefs about 120 miles (192 km) south of the Texas-Louisiana border. This area would be particularly vulnerable to any environmental change since the Flower Gardens are the northernmost living coral reefs on the United States Intercontinental Shelf (C.H., 1979).

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Marine Mammals and Turtles

Information concerning the distribution and natural history of marine mammals in the Gulf of Mexico is limited. Certain species are known in the gulf only from beachings during hurricanes and severe storms. A 1974 publication of the Texas Parks and Wildlife Department (The Mammals of Texas by William B. Davis) describes 18 species of marine mammals that have been sighted in Texas coastal waters, including 16 species of cetaceans (four dolphins: bottle-nosed, spotted, rough-toothed, and bridled; nine toothed whales: sperm, pilot, pygmy sperm, dwarf sperm, gulf-stream beaked, killer, false killer, pygmy killer, and goose-beaked; three baleen whales: blue, common finback, and black right; one species of manatee: West Indian manatee; and one seal: West Indian seal. Of these 18, only the bottle-nosed dolphin is considered a common resident, while the manatee, spotted dolphin, pilot whale, and sperm whale are occasionally seen. Occurrence of the remainder of the listed mammals is rare; they have been sighted only once or a few times. All marine mammals in Texas waters except the bottle-nosed dolphin are classified threatened or endangered.

Marine turtles occur in all tropical and warm temperate seas. Some species are found primarily in shallow waters along the coast and around islands, while others are highly migratory and are found in the open sea. Females of all species must return to land to nest on sandy shores. After an incubation period varying from 40 days to 2-1/2 months, emergent hatchlings enter the sea, where very little is known about their movements until they reach sexual maturity.

Five species of marine turtles are found in the Gulf of Mexico: the loggerhead, the green sea turtle, the hawksbill, Kemp's ridley, and the leatherback. Numbers of sea turtles have diminished so greatly in recent years that the leatherback, hawksbill, and Kemp's ridley have been added to the list of endangered species, and the green and loggerhead are on the protected list.

Socioeconomic Setting

The coastal area impacted by the IXTOC I oil spill begins at the Texas/Mexico border and reaches to the Port Aransas-Corpus Christi area. Eight counties contiguous to gulf or bay waters lie within this area; they are Cameron, Willacy, Kenedy, Kleberg, Nueces, San Patricio, Aransas, and Refugio counties. The affected region has a population of approximately 675,000 with 50 percent of the total in the Corpus Christi and Brownsville-Harlingen-San Benito metropolitan areas. The median family income levels (1970) for these counties ranged from $5,000 to $8,168. Among the industries that contribute an important part of this region's income are commercial shipping and fishing, petrochemical, seafood, shipbuilding, marina, charter fishing, recreation, and tourism. The area offers many opportunities for saltwater recreation; nearly 10 percent of the 5 million acre region is

currently devoted to rural saltwater-associated recreational use. Recreational fishing is a very valuable industry for the State of Texas. The Texas Parks and Wildlife Department estimated the recreational value of its saltwater finfish harvest at $319 million in 1978, and projected that it would increase to $435 million by 1981. Sport fishermen were expected to spend 12.3 to 14 million human-hours of effort harvesting saltwater finfish from 1978 to 1981.

The tourist industry also contributes significantly to the economy of coastal Texas. Expenditures for tourist-related activities in the Texas coastal zone were estimated at $445 million in 1972; in the same year, boats registered in Texas had an estimated value of $95.5 million.

Ports and the Gulf Intracoastal Waterway are extremely valuable to the economy of the State. In 1970, over 193 million tons of goods were shipped and received through southwest Texas ports and waterways -- about 12.6 percent of the total port activity in the U.S. for that year. The major import and export commodity groups handled at Texas ports are as follows: (1) metallic ores constitute the major commodity group in the foreign import category and crude petroleum is second; (2) farm and grain products are the leading commodities exported through Texas ports; (3) crude petroleum is the leading commodity received at Texas ports in domestic trade; (4) petroleum products are the leading commodities leaving Texas for domestic markets.

An input-output model was used to determine the overall economic effect of the Gulf Intracoastal Waterway on Texas in 1970. Total economic benefits were etimated at $1.8 billion. The primary economic value of maintenance of the waterway, water transportation, and port cargo moved in barges is forecast to reach $2.9 billion by 1985.

Two major ports and the 144.4 mile long Corpus Christi Bay-Brownsville Intracoastal Waterway system are located within the oil spill impact area. The Corpus Christi-Harbor Island port system has moved upward of 60 million tons of goods annually since the mid-1970's. Approximately 30 to 40 percent of business operations in the Corpus Christi vicinity depend upon port commerce. The Brownsville port system handles about 3 million tons of freight traffic annually. The volume of goods moved intrastate along the Corpus Christi-Brownsville inland waterway system was 3.5 million tons in 1970.

The petrochemical industry is another sector of the Texas economy that exerts a tremendous economic impact on the state. In 1970, there were 139 petrochemical manufacturing plants operating in Texas; 67 percent of the plants with 88 percent of the capacity were located in the coastal zone. The Texas gulf coast has the greatest concentration of chemical plants in the United States, producing more than 40 percent of all basic petrochemicals, 80 percent of the synthetic rubber, and 60 percent of the sulfur. In 1970, the value of chemicals shipped was over $4.3 billion, or 14 percent of the total for all manufacturing industries. Total plant investment was estimated as the total economic impact of the petrochemical industry on the Texas economy in 1970.

The dominant fish products in the Texas commercial fishing industry are shrimp (brown, white, and pink) and, to a lesser extent, oysters, blue crab, and finfish. Total dockside value and weight of shell and finfish landed at all Texas ports in 1978 was $125.5 million and 105 million pounds. Shellfish alone made up nearly 90 percent of the total weight. According to Texas Park and Wildlife projections, the dockside value and weight of shell- and finfish landings are expected to increase to $133 million and 114 million pounds by 1981. A breakdown of shell- and finfish landings by bay system in 1975 showed a catch of 7.5 million pounds valued at $4.5 million for bays located within the oil spill area. These include Aransas and Copano Bays, Corpus Christi and Nueces Bays, Baffin Bay and Upper Laguna Madre, and Central and Lower Laguna Madre.

Charter fishing boats contribute substantially to the total recreational economy of the Texas gulf coast. In 1970, an estimated 355,000 sport fishermen in the entire gulf region used charter and head boats, spending over $20 million in fees alone. A total 34,268 sport fishermen spent approximately $4,209,000 in coastal communities while charter fishing in 1976. This figure represents expenditures for both charter and noncharter fees. Port Aransas was the major sport fishing community, where nearly $1.8 million or 42.5 percent of the total was spent. Total direct expenditures by charter fishermen at other coastal communities include South Padre ($877,000), Rockport ($718,000), Freeport ($657,000), and Port O'Connor ($164,000). The total economic impact of the charter fishing industry on the State of Texas in 1976 was estimated at over $13.7 million.

Marinas and related marine recreation industries are another important component of the Texas coastal economy. As of 1975, 88 marinas on the Texas Coast had almost 6,000 slips and did a gross volume of business estimated at $10.1 million, assuming slips represented 30 percent of the total turnover, or $28.8 million assuming slips represent 15 percent turnover. These estimates consider direct spending at the marina only. The industry employed approximately 597 people in 1975. Total personal income derived from Texas marinas has been estimated at $5.0 million.

Since 1973, the number of pleasure boats has risen steadily in Texas. In that year, 434,142 boats were registered in Texas; 121,856 of these were in the 16 coastal counties. By June 1975, the figure had increased to 136,676 in the 16 contiguous coastal counties.

The presence of an extensive marina industry has helped other marine-related recreation industries to become firmly entrenched in the economy of Texas, as evidenced by the 52 boat manufacturers; 46 manufacturers of motors, boat trailers, and marine accessories; 13 fishing tackle manufacturers, and 1,965 marine dealers and distributors in business on December 31, 1974.

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5

RESOURCE PROTECTION MEASURES

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INTRODUCTION

The blowout of the IXTOC I well in the Bay of Campeche created a unique spill situation, since the time between the initial blowout and the subsequent impact of U.S. waters was approximately two months. This allowed a protracted period that is not usually available in spill situations to plan and prepare the response.

However, the situation facing the scientific support organization in July had several disadvantages since an uncontrolled discharge of unknown volume and duration was injecting large quantities of oil into the western Gulf of Mexico. Initially, the destination of the spilled oil was unknown; however, mounting evidence from overflights and trajectory forecasts (see Chapter 2) suggested that some of the oil would very likely impact U.S. shores. Although the total extent of the U.S. coastline that was vulnerable to impact was unknown, it became apparent that the south Texas coast was highly vulnerable to oil and could also be the primary impact area.

Based on this assumption, the Scientific Support Team working with the U.S. Coast Guard began to formulate a spill mitigation plan for the south Texas area, while preparing for possible oil impact of the central and north Texas coasts.

The Federal Response Team also alerted other gulf states and considered the contingency that IXTOC I oil might reach farther east than Texas. In the event that the oil impact area exceeded the original estimate, the scheme for protecting the south Texas coastline could be expanded to include additional impact areas.

Basic to the operational phase of any spill is the defensive action to contain the spilled substance. Although efforts were directed at containment and cleanup of the oil at the well head, these efforts were not under the direct control of the U.S. Government and are, thus, not included as a part of this report. The primary objective of the oil spill response team was to keep the oil from entering the lagoons and bays, to collect oil at sea, and to remove oil from the beaches. The major areas for which mitigation strategies had to be developed included: (1) sensitive areas, both environmental and socioeconomic; (2) commercial fishery; (3) birds, marine mammals, and turtles; (4) beach cleanup; (5) dispersants; and (6) disposal of oiled materials. Each of these subjects will be discussed in this chapter as well as conclusions on the success of these operations.

PROTECTION OF SENSITIVE AREAS

One of the primary purposes of the scientific support function is to identify populations and habitats at risk and to recommend counter measures for their protection. Recommendations for mitigation of the spill effects were provided to the OSC by the SSC through the efforts of a team of personnel from Federal and state agencies with responsibility to protect human health, the physical/chemical environment, fisheries, and special or endangered species. Universities, private companies, and local experts, representing a wide variety of scientific disciplines, provided vital technical support for this team.

Identification of Resources and Determination of Information Base

The first step in devising a protection plan was to determine what resources existed, their geographic distribution, and other pertinent information, which was developed by meeting with local scientific experts knowledgeable of the regional resources and the background information concerning them. To facilitate the identification and organization of the local experts and to document the information they provided, NOAA provided funds for a local scientific advisor. This information base is available from NOAA in two publications, Environmental Directory of Scientists, Facilities, and Projects Along the Central and South Texas Coast (Tunnell and Dokken, 1979), and An Annotated Bibliography of Recent Environmental Studies Pertaining to the Marine and Estuarine Areas of the Central and South Texas Coast (Tunnell and Dokken, 1979).

Environmental Sensitivity Index

Because it was several months before oil from the IXTOC I blowout reached the south Texas shoreline, this spill offered a truly unique opportunity for prespill planning. The major thrust was to determine which shoreline environments were potentially most sensitive to oil spill impact and to collect baseline biological and chemical data. The Oil Spill Environmental Sensitivity Index (ESI; Hayes et al., 1980b), originally developed for lower Cook Inlet, Alaska (Michel et al., 1978), was applied to this task. This index includes shoreline types as well as important biological and socioeconomic features. Low-altitude aerial observations were integrated with ground-station observations to verify the aerial descriptions of the shoreline types. A summary report of the ESI of south Texas was published in 1980 (Hayes et al., 1980a).

Table 5.1 shows the original version of shorelines classified by the Environmental Sensitivity Index, based primarily on a temperate , rocky coastline. However, since few of the world's coastlines contain all ten of these particular environmental types, a classification specific for the Texas coastal environments was developed using a combination of these general shoreline types and a knowledge of the local conditions. The shoreline categories making up the Texas Environmental Sensitivity Index classification are:

Erosional scarps (ESI-1). These features are analogous to the straight, rocky headlands described in the general vulnerability index. Wave reflection and erosional properties associated with these environments tend to prevent the long-term persistance of oil. These areas generally display low biogenic activity and natural cleanup is relatively rapid.

Title (ESI-2). Not applicable to Texas coast.

Exposed fine-sand beaches (ESI-3). Fine-sand beaches found along the Texas coast are characterized by a broad, flat profile. Tight compaction of sediments restricts oil penetration to a few centimeters (2.5 cm = 1 inch). Thus, oil that has accumulated on the beach face can be removed fairly easily by mechanical or hand labor, or be left for removal by natural processes. Biologically, these areas are moderately active. While several studies show that damage from oil impact can be high (Wormald, 1976; Woodin et al., 1972; Rutzler and Sterrer, 1970), many species may repopulate within a short period (Woodin et al., 1972). The length of time required for repopulation depends on the longevity of oil and the properties of the ecosystem (Hyland and Schneider, 1976).

TABLE 5.1   Shoreline types of the Environmental Sensitivity Index developed
   for a high-latitude, rocky coastline (from Gundlach and Hayes, 1978).
   This index was distinctly modified for south Texas coastal environments;
   see text for details

Environmental Index	Shoreline Type	Comments
1	Exposed rocky headlands	Wave reflection keeps most of the oil offshore. No cleanup is necessary.
2	Eroding wave-cut platforms	Wave swept. Most oil removed by natural processes within weeks.
3	Fine-grained sand beaches	Oil doesn't penetrate into the sediment, facilitating mechanical removal if necessary. Otherwise, oil may persist several months.
4	Coarse-grained sand beaches	Oil may sink and/or be buried rapidly making cleanup difficult. Under moderate to high energy conditions, oil will be removed naturally within months from most of the beachface.
5	Exposed, compacted tidal flats	Most oil will not adhere to, nor penetrate into, the compacted tidal flat. Cleanup is usually unnecessary.
6	Mixed sand and gravel beaches	Oil may undergo rapid penetration and burial. Under moderate to low energy conditions, oil may persist for years.
7	Gravel beaches	Same as above. Cleanup should concentrate on the high-tide swash area. A solid asphalt pavement may form under heavy oil accumulations.
8	Sheltered rocky coasts	Areas of reduced wave action. Oil may persist for many years. Clean-up is not recommended unless oil concentration is very heavy.

Environmental Index	Shoreline Type	Comments
9	Sheltered tidal flats	Areas of great biologic activity and low wave energy. Oil may persist for years. Cleanup is not recommended unless oil accumulation is very heavy. These areas should receive priority protection by using booms or oil sorbent materials.
10	Salt marshes and mangroves	Most productive of aquatic environments. Oil may persist for years. Cleaning of salt marshes by burning or cutting should be undertaken only if heavily oiled. Mangroves should not be altered. Protection of these environments by booms or sorbent material should receive first priority.

Sheltered fine-sand beaches (ESI-4). Sheltered fine-sand beaches along the Texas coast are usually found in lagoonal and bay environments. These bay margin beaches tend to be associated with spits and dredge spoil sites and are modified by wind and wave activity. Sheltered fine-sand beaches characteristically have a flat but relatively narrow beach face. Sediments are well compacted and, therefore, restrict deep oil penetration.

Wind-tidal flats (low biogenic activity) (ESI-5). Wind-tidal flats make up long expanses of the south Texas coastal area. These environments are generally located on the bay side of the barrier islands and are rela- tively flat. They have little or no standing vegetation and are subject to frequent flooding (White et al., 1978). Algal mats and salt crusts prevent deep penetration of accumulated oil. Sediments are not as well compacted as those found on the fine-sand beaches. Mechanized cleanup would tend to "churn in" accumulated oil and is, therefore, not recommended for these environments unless the oil is very thick and concentrated.

Mixed sand and shell beaches (ESI-6). Mixed sand and shell beaches have a steep and generally narrow beach face. Coarse-grained beaches tend to respond more quickly to wave action than fine-sand beaches. Mixed sand and shell beaches along the Texas coast historically have shown long-term accretionary trends (Morton and Pieper, 1977). Oil impacting these beaches would not only penetrate deep into the beach, but would be rapidly buried. These areas are considered to have moderate biological activity. Mechanized removal is not recommended because a great deal of sediment would have to be removed with the oil.

Wind-tidal flats (moderate biogenic activity) (ESI-7). These flats are very similar to the wind-tidal flats described above; the difference lies in the greater biological productivity of these environments, because of increased rainfall and tidal coverage. Natural cleaning processes are slow, and mechanical cleanup is not recommended unless extremely heavy accumulations of oil occur.

Human-made structures (ESI-8). Texas coastal environments are heavily used for industrial sites, residential areas, and sports-related activities. At present, 7.5 percent of the south Texas shoreline is modified to some degree by these activities. These areas are given a high priority because of their predicted similarity to sheltered, rocky areas and the direct effects that spilled oil would have on human activity. Loss of tourist trade or industrial and port facilities would be economically undesirable. Furthermore, complicated cleanup procedures would be required in these areas. Environments in this classification should be protected wherever possible.

Sheltered tidal flats (high biogenic activity) (ESI-9). These areas are subject to regular inundation by tidal waters. Wave and tidal activi- ties associated with sheltered tidal flats are limited and do not facilitate rapid removal. Observations of tidal flats impacted by oil show that oil can remain for many years (Gundlach et al., 1981a, b). Mechanical removal is not recommended. These areas should receive priority protection from oiling.

Salt marshes and mangroves (ESI-10). Marshes are one of the most biologically productive environments found along the Texas coast (White et al., 1978). These environments provide food and nursery grounds for many species of commercial and sports fish. Previous spills have shown that marshes are very sensitive to oil impact. The extent of damage sustained by salt marshes depends largely on the inherent chemical properties and persistence of the oil. Observations from the METULA spill showed that the affected salt marshes displayed virtually no indication of natural removal 6.5 years after impact (Gundlach et al., 1981b).

Mangroves, like salt marshes, are an integral part of the oceanic food chain. These biologically rich environments support an extensive and diverse ecosystem. Recovery of mangrove systems has been estimated to require a minimum of 20 years (Odum and Johannes, 1975). Though not as extensive in Texas as salt marshes, mangroves are considered a very sensitive environment. Cleanup of these environments has not been effective when a large quantity of oil was present.

As part of prespill contingency planning, a team of five people mapped over 1,000 miles (1,600 km) of coastline in 28 days. Based on oil impact predictions, maps were presented to the U.S. Coast Guard in three stages: south Texas, central Texas, and north Texas. Duplicate maps of each area with accompanying text are now being printed for distribution to Federal, state, and local agencies involved with planning spill countermeasures.

The use of the Environmetal Sensitivity Index simplifies an often exceedingly complex array of environmental considerations; the maps produced greatly assisted the On-Scene Coordinator and the field-based U.S. Coast Guard Strike Team in placing men and materials for the most efficient protection of oil-sensitive environments. The Laguna Madre, particularly areas adjacent to the inlets (because of more extensive marshes and mangroves), was designated for the greatest degree of protection; whereas the exposed beaches of the south Texas barrier islands ranked lowest. A large number of booms, both standard rubber and oil-absorbent material, were placed along or across all the inlets. The importance of information that these maps made available to the On-Scene Coordinator was amply demonstrated.

Remote Sensing of Texas Bays and Estuaries

The marshes and estuarine areas around Brazos Santiago Pass and Aransas Pass were monitored before and after the spill, using remote sensing techniques coupled with ground verification surveys. The approach was to use a time series of color infrared photographs of these areas that would permit discrimination between stressed and unstressed vegetation, thereby documenting the sequential impact of the oil. Color infrared film is sensitive to stress-induced changes in the cellular structure of plants and it is able to penetrate shallow water. This technique was useful in monitoring submerged vegetation, since early signs of environmental stress could be noted as a shift in red coloration on the imagery. Also, submerged plants exhibiting stress as a loss of biomass would show up as a relative reduction in image

density. Any indication of environmental damage shown by the imagery would be used to initiate a study of the stress area to determine if oil impact had occurred.

Ground surveys verified the mid-August 1979 EPA overflights for compilation of a 1:24,000-scale wetland vegetation basemap of Brazos Santiago Pass. Ground parties were also used to update an existing 1:24,000-scale wetland vegetation map of the Aransas Pass area. A second photographic sequence was made after the spill in October 1979. Analysis of the photographs showed no evidence of appreciable oil damage to estuarine vegetation at either the Brazos Santiago Pass or the Aransas Pass site.

This study, by the Texas A & M University Remote Sensing Center, College Station, Texas, was funded by NOAA. A final report scheduled to be completed in late 1980, will summarize the results and will include photographic and cartographic products.

Boom Placement

During the Campeche spill, a preliminary assessment of the currents in each pass along the south Texas coast was made, based on a review of existing literature, nautical charts, and vertical aerial photos provided by the Galveston District, U.S. Army Corps of Engineers. On 2 August, 4 days before the arrival of the first oil, a presentation was made to the USCG Strike Team, in which a number of generalizations considered useful for planning were offered. Included were comments on (1) the diurnal to mixed tide regime and its effect on the duration of flood currents, (2) the strong effect of local winds that force tides and control the timing of each tidal cycle, (3) the effect of shoals within an inlet which tend to produce flood or ebb-dominated zones, and (4) the local navigation requirements in each pass. In addition, the status of those passes that are closed for parts of the year were reported. With the above general information, preliminary recommendations for boom placement were made.

The second phase of work on inlets involved field measurements of currents, beginning with Brazos Santiago Pass, the assumed first impact area. Three to four days of hydrography measurements were made in each pass to determine peak flood and ebb velocities at several locations, the time lag between predicted and observed tide changes and the duration of flood currents. Although it is impossible to measure the entire range of tidal conditions from neap to spring tides in a few days, these data provided firsthand information on the distribution of tidal currents, making it easier to plan boom placement.

Upon completion of field measurements in each pass, the data were summarized in brief memoranda to the USCG Strike Team. The information included predicted tide curves, observed tidal current curves, bathymetric cross sections, and a detailed map showing recommended boom placements.

During booming and cleanup operations by the U.S. Coast Guard Strike Team, NMFS, in cooperation with USFWS, NPS, and state biologists, coordinated efforts to insure that at least one representative was on the scene to advise the Strike Force Director about which habitats should be protected from oil and cleanup operations within the estuarine areas. These habitats included known nursery areas, as well as areas vital to overall estuarine productivity, e.g., intertidal marshes, submerged grass beds, or oyster beds.

FISHERY RESOURCES

The National Marine Fisheries Service (NMFS) in a cooperative effort with the State of Texas and the Food and Drug Administration (FDA) put into effect a plan to minimize damage to commercial fisheries. The basic framework for fishery resource protection was formulated by NMFS. One objective of the plan, to provide scientific advice to the USCG Strike Team during its effort to control or divert oil from critical habitats to minimize impacts to fisheries, was discussed above. Another objective that will be presented below was to assess the mortalities of marine turtles and marine mammals. Ecological consequences of the IXTOC I spill on living marine resources is the subject of Chapter 6. This section of the report deals with the concerted effort of the state and Federal agencies to protect the shrimp industry.

Consumer Confidence

The first objective was to maintain consumer confidence in seafood products, particularly shrimp. Shrimp were the primary concern because of their great high economic importance and because their offshore benthic habitat was under greater risk than those of the pelagic fisheries. One of the primary concerns was that the broad news coverage of the spill would cause the public to stop purchasing seafood even though the food was safe for consumption. Also, any decrease in demand for fishery products could be furthered by even a few contaminated products reaching the public. The approach was to maintain consumer confidence through a joint industry-government program that intensified surveillance activities at domestic seafood receiving stations and concurrently increased the State of Texas field surveys of commercial shellfish and finfish. Television interviews with fishermen, fishing cooperatives, FDA, NMFS, and state representatives assured the public that inspection programs were stepped up to prevent oil tainted seafoods from reaching consumers.

The gulf seafood industry participated in a voluntary inspection program that allowed NMFS to inspect shrimp for oil contamination at storage, processing, and distribution points. The Texas Department of Health's Division of Shellfish and Sanitation Control collected samples of shrimp,

oysters, crabs, and fish, which were analyzed for oil and hydrocarbons. The department's Division of Food and Drugs inspected food off the boats. They usually conducted organoleptic (smell) tests on the food products as they came off the boats, in conjunction with FDA. FDA inspectors were assisted by that agency's experts in making olfactory evaluations of gulf seafood.

During the spill, products were found to be safe for human consumption, thus contributing to consumer confidence.

Prevention of Lost Time, Gear, and Catch

The second objective of the fishery protection plan was to provide information to the fishery industry to minimize lost fishing time and losses of catch and gear that could be caused by the spilled oil.

One part of this plan was to keep fishermen advised of the locations, sizes, types, and expected movements of major oil slicks on a daily basis. Using this information, the commercial fishermen could avoid large concentrations of oil, reducing the probability of catching contaminated products or of oil ruining their nets. This practice was started on 4 August 1979, when the National Weather Service included information on the position of the first Mexican oil slicks in U.S. waters in their marine weather broadcast. The U.S. Coast Guard also added this information to their broadcasts beginning the next day. A system was set up by which the fishermen at sea could notify the nearest USCG station of unmapped oil locations; this information was then relayed to the headquarters of the On-Scene Coordinator.

The second part of the plan was to conduct at sea fishing experiments in the oil to determine if the marketable quality of each would be adversely affected or if the catch would become contaminated and not safe for consumption. In addition, information would be obtained to determine whether any gear damage or lost fishing time could be attributed to accidental fishing in oil-effected areas. To provide this type of information that was being requested by the seafood industry and state and Federal seafood regulatory bodies, the Texas Parks and Wildlife Department (TPWD), the NMFS, and Texas A & M University conducted a joint cruise on TPWD research vessel, WESTERN GULF.

Seafood inspectors from FDA and NMFS performed standard organoleptic tests (vessel and olfactory) on representative samples of brown shrimp, Atlantic croaker, and kingfish from catches from both oil contaminated and noncontaminated areas. They detected only faint petroleum odors on shrimp samples from oil sheen areas. On the basis of these tests, there was no evidence to conclude that shrimp trawling in oil sheen-covered water produced brown shrimp or finfish that have oil contaminations that would cause them to be rejected from the market.

Several consecutive trawls in oil sheen-covered waters did not result in any gear damage or lost fishing time. However, repeated trawling in oil sheen-covered waters could result in some coating of the net with oil if many tar balls were encountered. Trawling through mousse-covered water should be avoided, since serious vessel and gear fouling could result with possible contamination of catches. A portion of one net accidentally dipped in heavy oil during the cruise. Attempts to wash off the oily residue with high-pressure hosing and household detergent were unsuccessful. Nets contaminated with heavy oil would have to be cleaned before reuse to prevent contamination of subsequent catches.

Most shrimp boats seemed to avoid the oil slick area. During the cruise only one of more than 30 trawlers was observed fishing in oil sheen-covered waters.

Oyster Monitoring Program

In another effort to protect fishery resources, an oyster monitoring program was implemented to detect the presence of hydrocarbons in the pass areas of the Laguna Madre and East Matagorda Bay. This study used the baseline information and the techniques developed in the EPA "Mussel Watch Program."

Since 1976, the EPA-sponsored "Mussel Watch Program" has monitored the bioaccumulation of hydrocarbons and chemical pollutants in shellfish from the coastlines of the United States, including extensive sampling and chemical analysis of oysters from stations in the Gulf of Mexico. A comparison of data from those stations over a period of time has served to identify "hot spots" of pollution and changes in levels of pollution in the coastal areas.

A joint meeting of EPA, NOAA, and the National Mussel Watch Committee was held in Corpus Christi, Texas, 14 September 1979 to discuss the feasibility of using historical data from the Mussel Watch Program as a baseline for determining impact of IXTOC I oil on shellfish populations in the gulf. Identification of the IXTOC I oil in oyster tissues was considered an essential first step preceding expansion of the program for the spill.

An initial collection (29 September to 4 October 1979) and analysis of oysters from oiled and "clean" areas of the gulf was conducted by the University of Texas - Port Aransas Marine Laboratory. Brazos Santiago Pass, Lydia Ann Channel, and East Matagorda Bay were sampled. Fluorescence spectrophotometry of the oyster tissues did not reveal the weathered-oil fluorescence patterns of IXTOC I tar balls. However, contamination by IXTOC I oil was not ruled out, because of the possibility of selective uptake and depuration of the oil by the oysters. Further collections were postponed, pending a reasonable expectation of reoiling of the oysters in spring and summer of 1980.

BIRDS, MAMMALS, AND TURTLES

When the IXTOC I spill began to present an imminent threat to fish and wildlife resources and their habitats along the Texas coast, the U.S. Fish and Wildlife Service (FWS) alerted all field response coordinators to prepare oiled bird cleaning and treatment equipment and supplies. A field response coordinator was assigned the responsibility of coordinating all oiled bird rehabilitation efforts for the lower Texas coast. Efforts were made to set up oiled-bird cleanup stations for the upper Texas coast to Galveston in the event oil impacted this area.

The Regional Contingency Plan for Oil and Hazardous Substance Spills was implemented throughout FWS's entire response efforts. Various Field Response Stations had been previously stockpiled with oiled-bird cleanup equipment, which facilitated prompt response along the Texas coast. In addition, special trailer units equipped with containment booms, sorbent pads, and other necessary supplies were delivered to Aransas and Anahuac National Wildlife Refuges. Containment booms were purchased to be used in sensitive and critical habitat of refuges and adjacent lands.

Seven oiled-bird rehabilitation centers were established along the Texas coast. Oiled-bird cleaning facilities at South Padre and Port Aransas were fully equipped with supplies and manpower to handle large numbers of birds. Other bird cleaning facilities were established on a temporary basis and only used when threat to birds existed. Inquiries from the public on the threat to aquatic bird life along the lower Texas coast were quite intense during the initial landfall impacts of the IXTOC I oil spill. As a result, the Regional Pollution Response Coordinator arranged for the International Bird Rescue and Research Center, Berkeley, California, to train volunteers, State and Federal employees in bird cleaning techniques at South Padre Island, Texas. This emergency training session was held on 9 and 10 August 1979, and approximately 125 individuals participated in the two-day workshop. Additional oiled-bird training sessions ensued at Houston and Galveston Island, Texas, during 5 through 7 October 1979. Response to all our oiled-bird training sessions along the Texas coast were well received by the public.

A total of 26 oiled birds were collected during the oil spill incident. The blue-faced booby was, by far, the most numerous bird collected and rehabilitated. All captured oiled birds brought to the reception center for care and cleaning were generally very lethargic, which required additional rehydrating and feeding care for an extended time before being cleaned. Oiled birds that were moribund were stored in freezers and later shipped to Patuxent Wildlife Research Center for bioassay determinations and additional hydrocarbon toxicity studies.

Species specific plans were made for the protection of the endangered brown pelican, peregrine falcon, whooping crane, redhead duck, and other migratory waterfowl.

A marine mammal and turtle stranding network was established using the FWS bird rehabilitation centers and reporting system. The plan for live animals was to recover and to attempt resuscitation and then to clean the animals of any oil. Necropsies would be conducted on clean animals.

A total of seven oiled sea turtles (6 green and 1 Kemp's ridley) were collected during the oil spill incident. Of this, only one green sea turtle, which was thoroughly oiled, was cleaned and rehabilitated. This sea turtle was later transported to the National Marine Fisheries Service Laboratory in Galveston Island for observation and eventual release. There were occasional reports that dolphins were oiled and stranded along the beach, but no confirmed records were documented. (The above information on birds and other wildlife comes directly from a FWS report, "IXTOC I Oil Spill, A Summary Report of Activities, June 3, 1979 to November 30, 1979," prepared by Charlie Sanchez, Jr.)

The effects of the spill and other observations of birds, marine mammals, and turtles is presented in Chapter 6.

DISPERSANTS AND BIOLOGICAL AGENTS

To determine the feasibility of using chemical dispersants to break up the weathered IXTOC I oil as it reached U.S. waters, EPA conducted some preliminary chemical analysis and dispersant effectiveness tests.

Pre-impact samples from the vicinity of the IXTOC I well (USCG vessel DURABLE, 10 July 1979) and from the leading edge of the slick (VALIANT cruise, 16-21 July 1979) were tested at the Industrial Environmental Research Laboratory, OHMSB, Edison, NJ. Specific gravity of the mousse was found to be 1.055 with water content being variable (percent water = 82,60,60 and 56). Six EPA approved dispersants were combined with the mousse in tests with 1:2 to 10:2 dispersant:oil ratios. Minor effects on the oil were recorded, including some herding of the oil with Correxit 7664 or BP1100WD to oil, the sheen disappeared, but no other major effect was observed. In general, an increase in dispersant concentration did not enhance the dispersant's effect on the mousse.

More comprehensive dispersant effectiveness tests were later conducted by Stanford Research International (SRI), an EPA contractor, using weathered oil samples obtained 10 miles (16 km) off the Port Aransas jetty on 22 August 1979. None of eight EPA accepted dispersants tested were found to be effective in dispersing the oil. Best results, using 50 m Correxit 9527 and 100 g mousse, showed 1.9 percent dispersion after 10 minutes at 23°C. Water content of the Port Aransas samples was 33 percent, with a 12.9 standard deviation.

The RRT considered mitigation of the spill by the addition of microbial degrading agents and/or nutrients to the slick. Possible field-testing of NOSCUM agent was reviewed by the RRT during an 8 August 1979 meeting in Corpus Christi, Texas. The EPA representative recommended against such testing because expert opinions suggested that the product would not be effective in the open sea where supplemental nutrients and the seed culture itself would be quickly diluted in an oligotrophic environment. Additional considerations were also viewed that further supported the suggestion not to test the NOSCUM agent on the IXTOC I oil.

A limited field-test of PETROBAC-R on oiled beach sand was approved by the EPA representative to the RRT on 6 September 1979. Product effectiveness in degrading the oil with or without added nutrients was to be evaluated under strictly controlled conditions at two remote areas of Padre Island. Tropical storms in early September washed the beaches before the test could be implemented.

BEACH CLEANUP

Commercial cleanup operations were organized and administered by the U.S. Coast Guard, beginning in mid-August and reaching their peak during the first few days of September. Beaches were cleaned by road graders and by manual labor. By mid-September after the tropical depression had passed through the area, most of the beach cleaning activity had ceased.

DISPOSAL

Oil removed from the beaches and the tar mats in Fish Pass was disposed of at several sites. There were some spoil sites fronting dunes on North Padre and Mustang Island and one site near the main highway on Mustang Island. The latter was later removed to a landfill site. Cameron County Navigation District has four dumpsites and the Corpus Christi Westside Landfill was used. Also, a private firm disposed of some of the spoil.

The State of Texas strongly endorsed the NOAA recommendation that to the maximum extent practical, oil/sand mixtures accumulated through the cleanup process be used in connection with beach nourishment and stabilization.

6
BIOLOGICAL STUDIES*

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INTRODUCTION

Biological studies were designed to monitor changes in dominant,
important, or indicative species during the IXTOC I oil spill. Monitoring
activities were initiated to indicate the onset of measurable biological

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*This chapter summarizes the results of biological studies conducted
by investigators representing the Federal government, universities, and
the private sector. The marsh studies at Lydia Anne Channel, aerial bird
counts, intertidal infauna analyses, and upper beach faunal studies were
done by the Ecology Division, Research Planning Institute, Inc., Columbia,
South Carolina. All toxicology and bioassay studies (excluding bird studies
were performed by the University of Texas Marine Science Institute, Port
Aransas, Texas. The beach survey and bird mortality summary of wading
and shorebirds and the subtidal infauna analyses were accomplished by
Corpus Christi State University and Coastal Ecosystems Co. of Corpus
Christi, Texas. Toxicity studies of birds and turtle carcass analysis were
carried out by the U.S. Fish and Wildlife Service, at Patuxent, Maryland.
Dolphin observations were done during R/V LONGHORN cruises by Florida
State University and University of Texas personnel and on the R/V WESTERN
GULF cruise by Texas Parks and Wildlife and U.S. National Marine Fisheries
personnel.

changes, and secondarily to provide some baseline information for subsequent damage assessment studies.

These studies were conducted at: (1) inlets and lagoons, (2) sand beaches, and (3) near- and off-shore environments affected by the IXTOC I oil spill. Monitoring consisted primarily of two types of studies: field studies and laboratory analyses. The results of all overflight population censuses, remote sensing flights, beach surveys, site-intensive impact studies, as well as offshore cruises made up a field study data base. A battery of toxicological tests comprised the laboratory data base.

From this report, field and lab approaches were organized by habitat type and taxonomic group to integrate results of differing approaches to common problems. Specific strategies and methodologies are presented within each approach. Results are integrated into the summary and conclusions.

STUDIES OF INLETS AND LAGOONS

Highest priority was placed on keeping oil from entering inlets and lagoons, where biological damages would be most significant. However, large passes were difficult to boom or skim completely, and sheens and slicks occasionally entered larger inlets. The only significant oil impact to marshes was observed at Lydia Anne Channel.

Impact to Marshes at Lydia Anne Channel

On 28-29 August 1979, approximately 12 metric tons (86 barrels) of IXTOC I mousse entered the Aransas Pass Channel and impacted approximately 900 m of fringing marsh shoreline on the western shore (Harbor Island side) of Lydia Anne Channel (Figure 6.1). The vegetation of this area is predominantly a fringing saltwater cordgrass (_Spartina alterniflora_) marsh. Surveys of the oiled marsh were conducted to:

1. Determine the extent and distribution of oil,
2. Assess short-term damages to ecological communities,
3. Make a photographic record of observed impacts, and
4. Collect sediment and biological samples for chemical analyses.

Ground surveys of the oiled area were made on 30 August, 2 September, and 11 September 1979. Data from an earlier (pre-oiling) visit on 23 July 1979 were available for comparison.

Fringing saltwater cordgrass and black mangroves (_Avicennia germinans_) were visibly oiled. Coverage ranged from light (10 percent to moderate
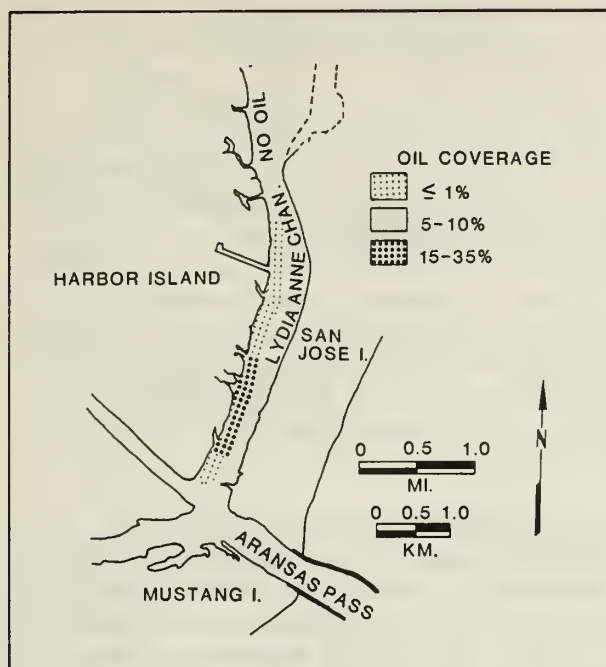
Figure 6.1 Distribution of oil along the shoreline of Aransas Pass by 11-12 September 1979. Oil concentrations are based on oiled surface area coverage of a 1-m wide band. The most heavily oiled area is on the western shore of Lydia Anne Channel.

(30 percent), with locally heavy (>50 percent) oiling concentrated in beach wrack at the high-tide swashline.

Stems and leaves of Spartina and Avicennia were oiled up to 40 cm above the base of the plant. Those areas that had light to moderate oiling were not severely damaged, while heavily oiled plants were dead or dying by the 11 September survey. Moderately oiled plants showed stress symptoms such as browning of stems, but plant growth was still evident. The higher-than-normal tides from Hurricane FREDERICK pushed oil farther back into the marsh, but at the same time dispersed much of it back into the water.

Effects of the oil on animals appeared to be minimal. Littorina, a supralittoral snail, was feeding normally above the oiled areas of the Spartina. Densities were about the same for pre- and post-oiling Littorina populations (averaging 9.6 per m^2 pre-oiling and 7.1 per m^2 post-oiling). Many tar balls on the shore were mixed with detritus. In this oiled detritus, large numbers of hermit crabs (Clibanarius vittatus) were observed. Though oil was observed on the mouthparts and walking legs, crabs appeared to be active and showed no abnormal behavior when handled. Two weeks after impact, the short-term effects of the IXTOC I crude oil on the Lydia Anne Channel marsh appeared to be minimal. Some of the plants in heavily oiled areas were dead, but these were in small localized areas.

A crude oil spill at Harbor Island on 3 October 1976 had similar results (Holt et al., 1978). Delaune et al. (1979) found that Spartina alterniflora was capable of tolerating light oiling. Holt et al. (1978) also observed that mangroves were sensitive to heavy oiling, but were able to tolerate light oiling.

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Toxicity and Analysis of Phytoplankton and Seagrasses

This study assessed the acute toxicity of IXTOC I oil to mixed phyto-
plankton populations and seagrasses by comparing photosynthetic rates in
the presence and absence of a water-soluble fraction (WSF) or oil-accommodated
seawater (OAS) preparation. This type of measurement is by nature an acute
bioassay, which can only indicate whether the material being tested has an
immediate effect on photosynthesis of the cells involved. Earlier studies
have shown that seawater equilibrated with No. 2 fuel oil (Pulich et al.,
1974; Gordon and Prouse, 1973) and some crude oils (Lacaze and Villodon de
Naide, 1976) was inhibitory in varying degrees to photosynthesis of micro-
algae (e.g., blue-greens, greens, and diatoms) and mixed phytoplankton
samples, with the effect from No. 2 fuel oil being immediate, while the
response to crude oil was more delayed or chronic.

Seawater samples were collected at the south jetty in Port Aransas
before spill impact. The natural phytoplankton population (consisting of
diatoms, coccoid greens or blue greens, and green flagellates as determined
by cursory microscopic examination) was concentrated within 2 hours after
collection by centrifugation at low speed (1000 xg) for 20 minutes. The
mixed phytoplankton were resuspended in 10 to 15 mℓ filtered seawater for
photosynthesis measurements. Photosynthesis and respiration were measured
using a sensitive Clark-type oxygen microelectrode system as described by
Pulich et al. (1974). All measurements were made at light saturation or
higher. Water-soluble fractions (WSF) were prepared by mixing 150 g of
crude oil with 1 ℓ of offshore seawater and shaking for 2 hours, followed
by filtering through a 0.4 μm glass-fiber filter. Toxicity of the oil (100
percent WSF) to concentrated, mixed phytoplankton populations was determined
by comparing the effect of different seawater-soluble oil extracts with
unexposed controls. Two runs were made with mix phytoplankton samples to
test the immediate effect of water-soluble fractions on photosynthetic
activity. In this case, the concentrated phytoplankton were not exposed to
the oil until oxygen measurements were started and then for only about
30 minutes total.

Shoal grass (Halodule) and clover grass (Halophila) photosynthesis was
measured by H^{14}CO$_3$ uptake as described by Pulich et al. (1976) with one
modification - HCO$_3$ was added at a saturating level (200 mg/ℓ). Seagrasses
were exposed to oil-accommodated seawater (i.e., the unfiltered seawater
phase described above) in the following manner. Intact leaves of Halodule
and Halophila were in direct contact with oil micro-droplets during the
photosynthetic H^{14}CO$_3$ fixation, including 1 hour in the dark before incuba-
tion in the light for 6 to 7 hours. The total quantity of oil present in
the incubation bottle was 2.9 mg organic C per 68 mℓ seawater.

The results, presented in Table 6.1, indicated no significant change
in photosynthetic rate compared with controls for either set of samples.

TABLE 6.1 Effect of seawater-soluble fraction from IXTOC I oil on photo-
    synthesis and respiration by mixed phytoplankton samples. Values are
    averages of two to three measurements ± range, expressed in $\mu\ell$ O_2 per
    µg chlorophyll a per hour.

| | EXPERIMENT I | | EXPERIMENT II | |
Sample	Photosynthesis	Respiration	Photosynthesis	Respiration
Control	5.16 ± 0.58	2.58 ± 0.30	2.70 ± 0.23	2.33 ± 0.22
Treated with 100% WSF	4.92 ± 0.40	7.50 ± 0.64	2.58 ± 0.30	2.25 ± 0.16

    The results obtained from the exposure of seagrasses, Halodule and
Halophila, to the oil-accommodated fractions are listed in Tables 6.2 and
6.3. The data suggest strongly that the oil emulsion at this concentration
has little or no immediate effect on the photosynthetic activities of both
Halodule and Halophila, as measured by carbon fixation. The lower rates
measured in oil-exposed Halodule at low and medium light intensities may be
attributed to shading of leaves by abundant oil droplets present in the
incubation seawater. At the highest light intensity, oil-treated Halodule
achieved the equivalent rate of photosynthesis as the control. For Halophila,
there was no difference between the control and oil-exposed sample at
medium light intensity.

TABLE 6.2 Effect of oil-accommodated seawater on photosynthetic activity*
    of the seagrass, Halodule wrightii, measured at 30°C and three light
    intensities. Rates determined by $H^{14}CO_3$ uptake over 6 to 7 hours.
    Corrected for dark uptake.

| | Photosynthesis Activity* | |
Light Intensity	Control	Oil-Treated
Low	9.6 ± 0.1	7.9 ± 0.2
Medium	13.0 ± 0.6	11.0 ± 0.2
High	12.0 ± 1.0	13.0 ± 0.3

* values in µg C/mg dry wt/hr; approximately
  3.5 µg chlorophyll a per mg dry weight

TABLE 6.3 Effect of oil-accommodated seawater on photosynthetic rate of seagrass, Halophila engelmannii, measured at 30°C and medium light intensity. Rates determined by $H^{14}CO_3$ uptake over 6 hours.

Sample	Photosynthetic Rate (μg C/mg dry weight/hr)
Control	18.0 ± 1.0
Oil-treated	19.0 ± 2.0

Results from these physiological bioassays may be considered evidence that weathered IXTOC I oil (in the form of mousse) would not immediately inhibit photosynthesis or respiration rates of representative, nearshore phytoplankton samples and seagrasses. This information, however, should not be interpreted as evidence that this oil will have no effect (either inhibitory or enhanced) on growth and cell division of the plant species involved. Winters et al. (1977) have pointed out that seawater extracts of fuel oils are quite varied in their immediate effects on photosynthesis. For example, growth of blue-green algae and some green algae was inhibited in water-soluble fractions of New Jersey fuel oil, while only the green algae showed inhibition of photosynthesis. Additionally, pure compounds such as p-toluidine (selectively toxic to blue-greens) and phenalen-1-one (selectively toxic to green algae), which are lethal to the algae mentioned, had no immediate effect on oxygen evolution. Thus, it would not be safe to extrapolate these results to growth of entire Gulf of Mexico phytoplankton populations. At best, we can say IXTOC I oil does not appear to be as toxic as a No. 2 fuel oil. Additional experiments involving growth rate measurements should be carried out for both phytoplankton and seagrasses. Photosynthesis proceeded at approximately 5.16 μl O_2 per μg chl. a per hour for Run I and approximately 2.70 μl O_2 per μg chl. a per hour for Run II. Respiration after photosynthesis was variable, but did not appear decreased.

Additional tests conducted by exposing mixed phytoplankton (mostly diatoms and green flagellates) to 100 percent WSF for up to 8 hours in dim light revealed no significant differences in the rates of phytosynthesis between controls and treated samples. However, there was a significant (p < 0.05) reduction (20 percent of respiration in the WSF-treated samples (4.8 in WSF sample compared with 6.0 μl O_2 per μg chl. a per hour in control). This was particularly noticeable for 2 to 3 minutes after photosynthesis, although later respiration measurements were also depressed.

STUDIES OF SAND BEACHES

Sand beaches occur on the seaward side of the barrier islands, comprising 22.8 percent of the south Texas coast. A considerable body of literature documents research on sand beach organisms (see Hedgpeth, 1953), including

studies on plankton and productivity (McFarland, 1963a), dominant macroin-
vertebrates (Whitten et al., 1950; Loesch, 1957; Hill and Hunter, 1973),
infauna (Keith and Hulings, 1965), and fishes (Gunter, 1958; McFarland,
1963b). Because the sand beaches were the heaviest oiled areas, much of
the ecological monitoring effort was directed there. This included detailed
monitoring of birds and infauna inhabiting oiled beaches.

Wading and Shorebird Studies

Major oil spills may have a devasting effect on marine bird popu-
lations (Lincoln, 1936; Aldrich, 1938; Bourne, 1968; Smail et al., 1972;
and others). Fouled plumage looses its waterproofing and insulative proper-
ties rendering a bird susceptible to temperature extremes (Hartung, 1967).
When ingested during preening or feeding activities, toxic fractions of oil
may cause tissue damage and eventual death. Marine bird populations also
may be indirectly affected by contamination of their food supply (Vermeer
and Anweiler, 1975).

Wading and shorebird studies were designed to assess the effects of
the IXTOC I oil spill on the marine bird populations associated with the
barrier islands and lagoons of the lower Texas coast. Assessment of eco-
logical damage was based upon adequate pre-damage population data (Fidell
and Dubey, 1978). Although McCamant and Whistler (1974) and Blacklock
(1977) have prepared checklists of Padre Island birds, no quantitative
analysis of avian population cycles on the lower Texas coast has ever been
conducted. Thus, in addition to assessing the effects of the IXTOC I oil
spill on marine bird populations, this study may also provide baseline
information for future activities.

Aerial Counts

Ten aerial bird consenses were conducted on Mustang, Padre, and Brazos
Islands between 15 August 1979 and 5 October 1979. These surveys, done by
helicopter, were conducted to provide up-to-date information to the NOAA-SSC
on the use of the gulf beaches by coastal bird species. IXTOC I oil was
present on the beaches when the surveys were started and no prespill data
were available to make comparisons.

Surveys on 15 August and 25 August indicated beaches were being used
by resident species such as sanderlings (Calidris alba), willets (Catoptro-
phorus semipalmatus), ruddy turnstones (Arenaria interpres), laughing gulls
(Larus atricilla), caspian terns (Sterna albifrons), forster's terns (Sterna
forsteri), sandwich terns (Sterna sandvicensis), and great blue herons
(Ardea herodias). A tropical depression passed through on 31 August to
1 September. A 2 September survey showed an influx of migrant species,
especially knots (Calidris canutus). Following a mid-September tropical
storm that resulted from hurricane FREDERICK, much of the oil was removed
from the beaches and the number of birds using the beach areas increased
dramatically (Figure 6.2).

Figure 6.2 Number of birds versus
   beach oiling expressed in thousands
   of tons from 15 August to 3 October
   1979.   Correlated with the tropical
   depression and subsequent removal
   of oil from the beachface, note a
   steady increase in the number of
   birds.

BIRD POPULATION VS. BEACH OILING
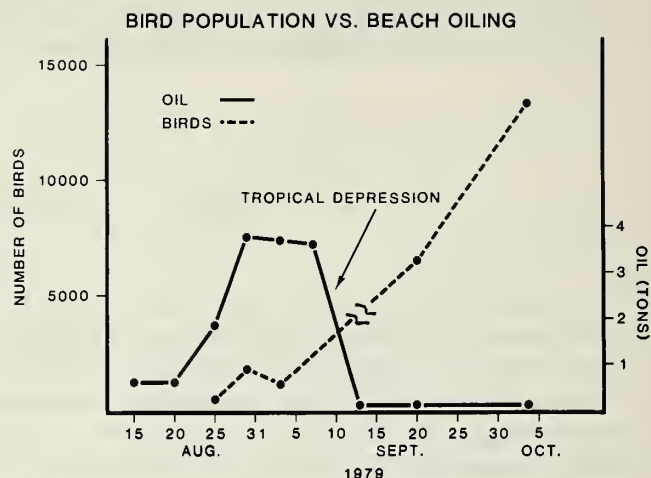
    During heaviest oiling, total bird populations remained low (below
4,000 individuals), indicating probable avoidance of oiled beaches.   Sub-
stantial increases in bird populations (to about 13,000 individuals)
occurred after the tropical depression removed oil from beaches and newly
arriving, migratory species appeared.

Beach Survey

    A total of 15 bird census trips were made on the beach in each of
three study areas: (1) from Brazos Santiago Pass to Mansfield Pass (South
Padre Island); (2) from Mansfield pass to the south end of Malaquite Beach
(Padre Island National Seashore); and (3) from the north end of Malaquite
Beach to Aransas Pass (Northern Padre Island and Mustang Island).   The
three beach censuses were conducted using a four-wheel-drive vehicle.

    During each beach census, all birds using the foreshore and nearshore
waters were identified and recorded according to odometer mileage from a
reference point.   The position of each bird on the beach was registered
with reference to distance from the surf zone.   For example, a bird in the
immediate vicinity of the swash zone or on damp sand up to the high tide
line was noted as being in the "foreshore"; the area above the "foreshore"
that received storm tides and other periodic inundations was designated the
"berm"; and from the "berm" to the base of the foredune ridge, the dry sand
area was called the "backshore."   Whenever flocks of birds were encountered,
the number of individuals of each species in the flock was noted, and
position was recorded for the flock, not the individuals.

On each census trip, the location and extent of oil-contaminated areas were recorded, including the type of contamination (i.e., oil sheen, tar balls, or mousse) and the distribution of the oil in each habitat. All birds were observed for evidences of oil on plumage, bill, and feet. Oiled birds were counted separately by species, and notes made on the extent and position of the oil on the body of each contaminated bird. Severely oiled birds and carcasses were collected and given to the U.S. Fish and Wildlife Service.

The activity patterns of oiled and oil-free birds were compared. Initially, several species of birds were observed, but most data were obtained for sanderlings (Calidris alba) and willets (Catoptrophorus semipalmatus). Methods were similar to the time-budget studies of Dwyer (1965) and Afton (1979). Individuals were observed with binoculars (7x) and activites were tape recorded for 10 to 15 minute intervals. Activities were separated into six categories: (1) feeding, (2) resting (loafing and sleeping), (3) comfort movements, (4) locomotion (walking and flying), (5) alert, and (6) social interactions (threats, chasing and pursuit flights). Calculations of the percent of time spent in various activities were based on the amount of time individuals were actually observed. Observations ended when birds became visually obscured.

Avian populations in beach habitats. Bird population densities responded directly to oil concentrations on the beach. Unlike most other oil spills, the IXTOC I oil initially washed ashore in isolated patches. As these patches washed in, birds abandoned affected habitats and redistributed themselves in areas that remained relatively oil-free.

By the end of August, however, most of the foreshore was coated by heavy concentrations of tar and oil. Avian populations on the beach declined from pre-impact densities (Figure 6.3). Since no oiled shorebirds were ever found dead, the decline in bird density in beach environments probably resulted from habitat shifts. Many birds may have abandoned the beach and sought food in secondary locations. Large numbers of sanderlings were observed feeding on the periphery of rain pools in the center of Padre Island and in similar habitats on the mainland.

Since sanderlings and willets are distributed evenly along the foreshore during the fall and winter (Myers et al., 1979), their populations may serve as an indicator species for oil contamination. Populations of both species declined during the period of heavy oil concentration (Figure 6.4). After the beaches were cleaned, these species reinvaded the foreshore. However, their population densities after impact were barely equal to (sanderlings) or just below (willets) densities before impact. Their population density should have increased as a result of migratory influx (Oberholser, 1974). Thus, the oil may have reduced the populations directly or may have eliminated or contaminated a portion of their food supply.

After a succession of storm tides cleaned oiled beaches, bird populations increased. Most population increases were due to an influx of migratory birds, particularly knots (Calidris canutus) and several species of gulls and terns. Many species of migratory birds use the beach as a staging area for seasonal movements. Their numbers fluctuate as flocks
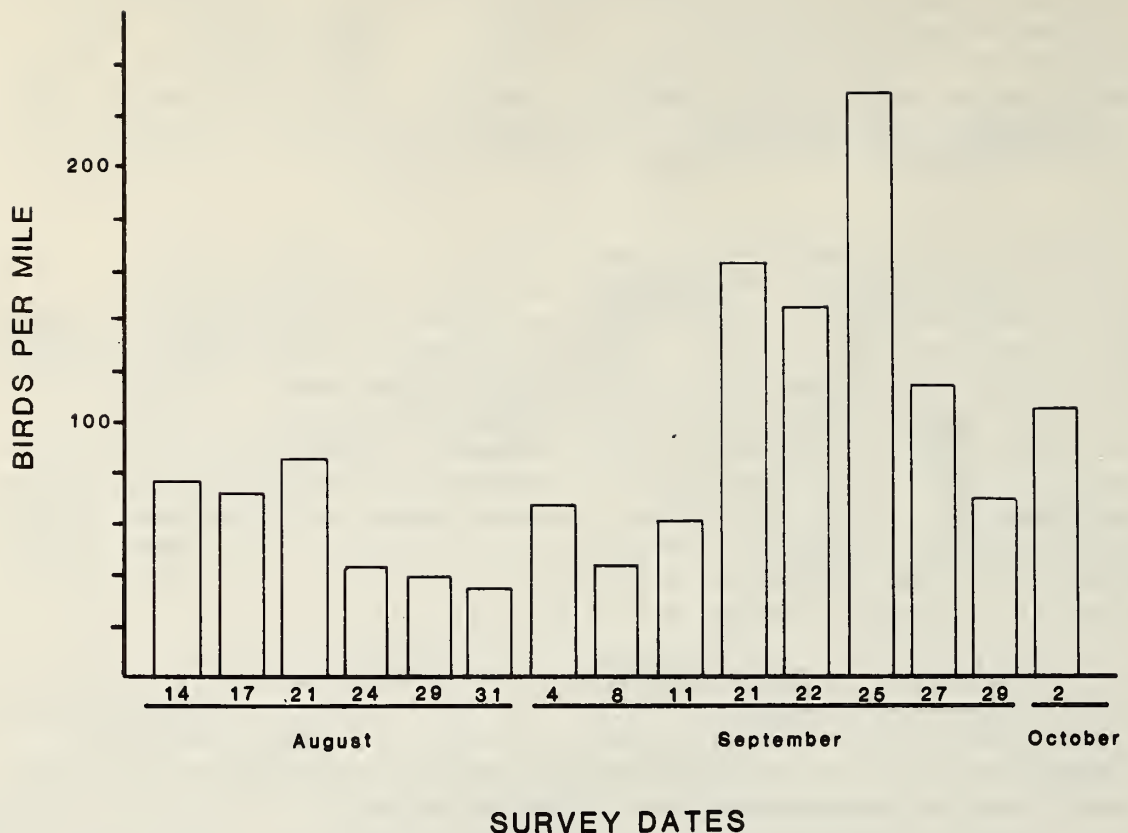
Figure 6.3 Average number of birds per mile on each of 15 surveys
between 14 August and 2 October at oiled beaches in Padre Island
National Seashore. Note the decrease in number of birds per mile
during the period of heaviest oiling at the end of August and the
beginning of September.

move in, feed, rest, and then move on. Unfortunately, there is no baseline
data for comparisons of densities along the Texas coast. Thus, it is
difficult to assess population gains or losses.

The oil on the beach did cause habitat shifts within the beach area.
When oil concentrations increased on the beach, birds moved to the berm and
backshore areas (Figure 6.5). Later, after oil concentrations decreased,
birds returned to the foreshore. It is likely that during the period of
oil impact, many birds were suffering food stress. Species that normally
feed in the swash zone were forced into drier, less productive feeding
habitats. Burnett and Snyder (1954) noted that eiders were forced to feed
upon less favored prey as a result of an oil spill. Gene Blacklock (pers.
comm.) collected several sanderlings on northern Padre Island and found
them to have low fat reserves and little food in their digestive systems.

Oiled birds. The percentage of birds with oil on their plumage never
exceeded 10 percent (Table 6.4). However, some species were more prone to
oiling than others. During the initial stages of oil impact, royal terns

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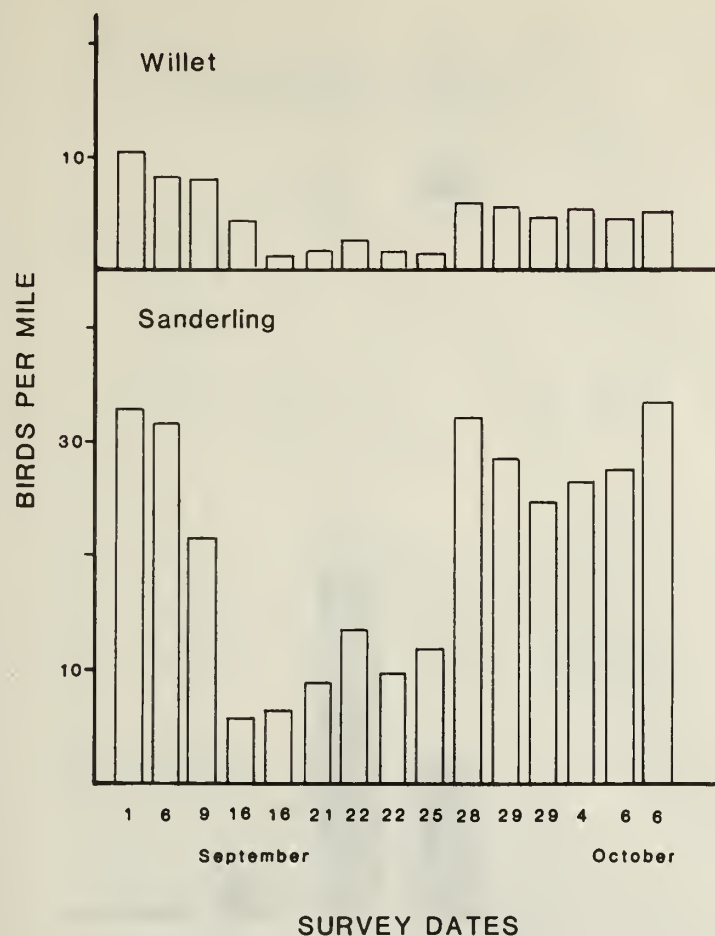
Figure 6.4 Average number of birds, sanderlings, and willets, per mile during each of 15 beach surveys through Padre Island National Seashore between 1 September - 6 October 1979. Note the decreasing and low numbers in mid- to late September during the heaviest oiling of beaches, and the resurgence in numbers in late September and early October.

were the most heavily oiled species of bird. While loafing, royal terns sat along the high-tide line where the greatest concentration of tar balls occurred. By the end of August, approximately 40 percent of the royal terns had oil on their breast feathers. However, by mid-September, royal terns avoided the high-tide line and congregated on the berm above tar concentrations. Most of the royal terns concentrated in relatively oil-free areas such as at the mouth of Mansfield Pass and in the vicinity of water-filled passes.

The percentage of oiled birds increased during the heavy oil accumulations in late August. Most of the birds oiled during this period were sanderlings, willets, snowy plovers (Charadrius alexandrinus), piping plovers (Charadrius melodus), and other shorebirds. The plumage of these birds was oiled in three ways: (1) by sitting in patches of oil, (2) by transferring oil from contaminated plumage to other areas (wings and rump) while preening, and (3) by walking through oil, then scratching (usually the ear region) with their foot. Some birds (25 willets, 40 sanderlings, 10 piping plovers, four black-bellied plovers, three snowy plovers) had up to 75 percent of their body covered by oil. Based on information from an

Figure 6.5 Percent of all birds in each portion of the beach (foreshore, berm, and backshore) on each of four surveys between 9 September and 6 October 1979 at oiled beaches in Padre Island National Seashore. Note the heavy utilization of backshore areas (in black) during the heaviest oiling in mid-September and the subsequent utilization of foreshore areas following the tropical storm in late September and early October.
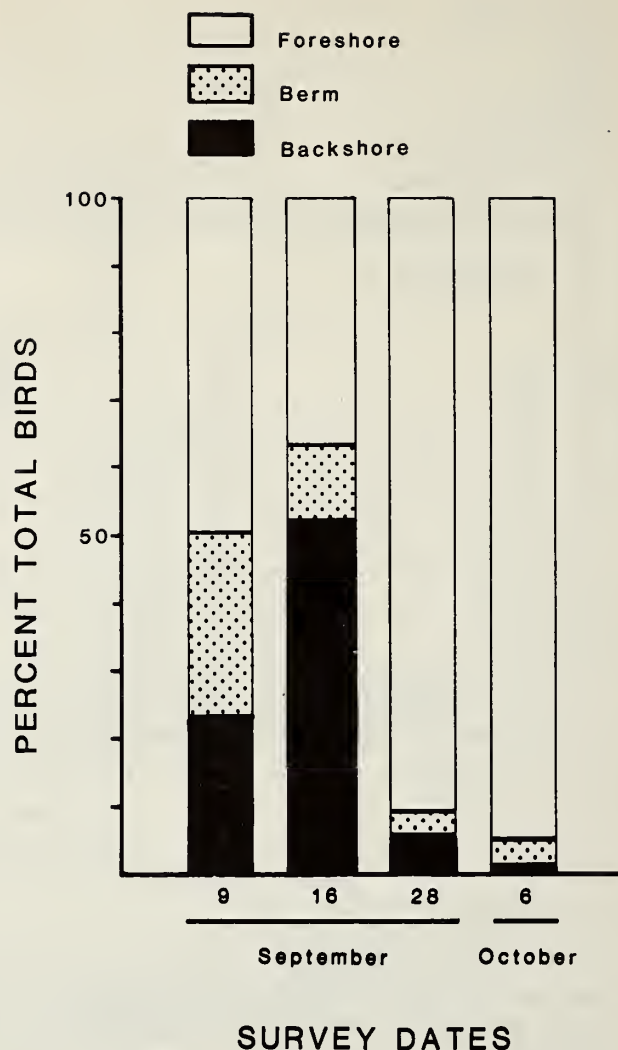
earlier study on the effects of oil accumulation on birds (Eastin and Hoffman, 1978), it is unlikely that the heavily oiled birds survived.

Many wading birds that frequented the beach had large globs of tar and oil on their feet. Two great blue herons (Ardea herodias) had balls of tar up to 20 cm in diameter on their feet and exhibited some difficulty in flying and walking. Many immature black-crowned night herons (Nycticorax nycticorax) and several snowy egrets (Egretta thula) also had large balls of tar and oil on their feet; one snowy egret also had smudges of oil on its breast plumage. Cattle egrets (Bubalcus ibis), which migrate in flocks southward in the fall, frequently rested in beach areas of dense tar accumulations. On many occasions, flocks of up to 15 cattle egrets had heavy tar globs on their feet.

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TABLE 6.4 Percent of birds with obvious oil on feet and plumage on Padre Island National Seashore.

Date		Total Birds	Oiled Birds	Percent Oiled
Aug.	14	4654	372	8.0
	17	4349	139	3.2
	21	5183	91	1.8
	24	2617	187	7.1
	29	2364	159	6.7
	31	2081	171	8.2
Sept.	4	2177	37	1.7
	8	1516	20	1.3
	11	2072	23	1.1
	21	3287	40	1.2
	22	2936	46	1.6
	25	13,429	54	0.4
	27	6973	43	0.6
	29	4289	27	0.6
Oct.	2	6397	12	0.2

It was impossible to speculate on oil-related avian mortality. Few carcasses or oil-immobilized birds were found. Carcasses that were found were mostly pelagic species. Shorebirds that succumbed to either direct or indirect effects of oil pollution were likely eaten by coyotes. Coyotes were often observed patrolling the beaches in the early morning and possibly preyed upon sick or dead birds.

Time-budget studies. A total of 125 sanderlings and 58 willets were observed for a total of 634 and 328 minutes, respectively (Table 6.5). Whenever possible, observations on oiled birds were paired with

TABLE 6.5 Total time of time-budget studies of sanderlings and willets.

Species	Condition		Minutes of Observation
Sanderling	Oil-free		336
	Oiled		298
		Total	634
Willet	Oil-free		170
	Oiled		158
		Total	328

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observations of oil-free birds in the vicinity during the same time of day
to eliminate variations in behavior due to differences in habitat quality,
time of day, and tide cycles.

Oiled sanderlings and willets spent less time feeding and more time
resting and engaging in comfort movements than did oil-free birds (Figure
6.6). Hartung (1967, unpubl. manu.) found similar reductions in feeding
activity among oiled ducks. Presumably, reductions in feeding activity
were related to oil-induced irritations of the digestive tract. Oiled
ducks increased their use of body fats increasing the rate of starvation
after oiling. Reduction in time spent feeding also translates into less
energy metabolized; therefore, it was probable that oiled sanderlings and
willets experienced similar stresses.
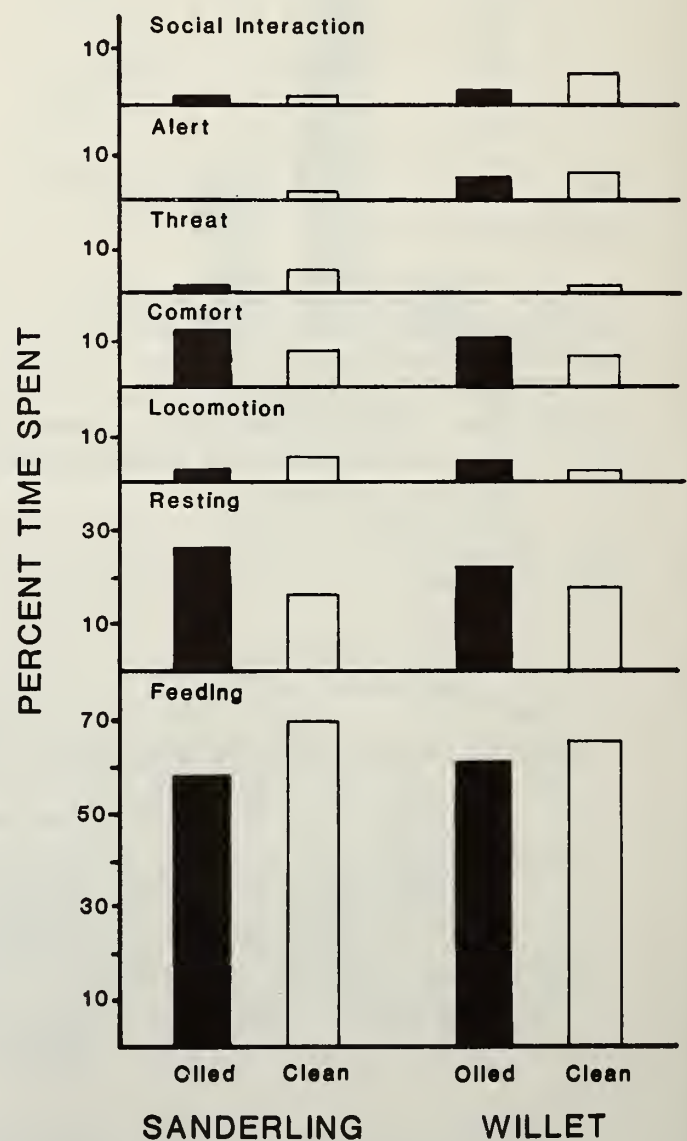
Figure 6.6 Time budget comparisons
of oiled and clean sanderlings and
willets, during beach surveys on
oiled beaches in Padre Island
National Seashore. Among several
trends note decreased feeding
behavior and increased resting
behavior in oiled birds.

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Mortalities

Twenty-six oiled birds were recovered and turned over to U.S. Fish and Wildlife Service rehabilitation centers. Eight of these birds were blue-faced boobies (Sula dactylatia). These birds nest in the Yucatan and are entirely pelagic feeders (Palmer, 1962). Although no boobies were observed during the coastal pelagic census, undoubtedly many were affected by the oil spill. Since these birds rarely were seen in coastal waters (Palmer, 1962), it was probable that those individuals that washed ashore represented only a small fraction of the individuals that became oil-coated; most individuals were probably eaten by predators or sank after dying.

The following is an account of the fate of oiled birds recovered during the bird-beach survey:

1.   A heavily oiled pied-billed grebe was found floating to shore in the surf approximately 15 miles north of Mansfield Pass. The bird was alive, but so heavily covered with oil (thick mousse-like consistency) that it could not fly. The bird was given to U.S. Fish and Wildlife Service for rehabilitation, but it died during the cleaning operation.

2.   A sanderling with a broken wing was collected in the foreshore approximately 25 miles north of Mansfield Pass. The bird was alive and its broken wing was covered with a thick accumulation of oil. The bird was turned over to U.S. Fish and Wildlife Service for rehabilitation, but it was subsequently destroyed.

3.   A heavily oiled pied-billed grebe was found sitting in the fore-shore approximately 20 miles north of Mansfield Pass. The bird was alive when captured, but died within 30 minutes. The carcass was frozen and turned over to U.S. Fish and Wildlife Service for chemical analysis.

4.   A black-necked stilt was captured on 11 September at a rain pool near the base of sand dunes, approximately a half mile south of the south boundary of Malaquite Beach. The bird had a 50-cm-diameter patch of oil on its breast feathers and oil on its bill and feet. It could not walk without falling to one side. The bird rehabilitation center was closed, so the bird was taken home, kept warm, fed water and shrimp slurry, and kept in a quiet dark place. The bird lived until 13 September. The carcass was turned over to U.S. Fish and Wildlife Service for chemical analysis.

Toxicity Studies

Immediate concern arose for two endangered species, the migratory peregrine falcons (Falco peregrinus) and the wintering whooping crane (Grus americana), which were thought to be at risk. The hazards of feather oiling were well known, but the effects of consuming oil had not been tested with either birds of prey or cranes. Toxicity tests were conducted at Patuxent Research Center to examine this question. Tests were made with surrogate species: American kestrels (Falco sparverius) for peregrines and greater sandhill cranes (Grus canadensis) for whooping cranes. In the kestrel studies, birds were fed diets containing 3 percent IXTOC I oil or 3 percent Prudhoe Bay crude oil for 28 days; survivors were fed untreated

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diets for 29 additional days. Birds did not avoid food into which oil was mixed. Kestrels fed diets containing 3 percent oil lost weight and some died (2 of 16 fed IXTOC I oil and 3 of 6 fed Prudhoe Bay oil). Survivors gained weight when untreated food was restored.

In the sandhill crane studies, birds were administered (orally) a single daily dose of 2 to 10 mℓ of Prudhoe Bay crude oil per kg of body weight for 4 to 24 days. Cranes were dosed in this way because they avoided feed into which oil was mixed. Two birds each received more than 1 ℓ of oil during the study. Prudhoe Bay crude oil was used because sufficient IXTOC I oil was not available. No birds lost weight, although oil-dosed birds became progressively more lethargic after 10 days of dosage, and relative liver weights were greater at necropsy.

It was concluded that: (1) the toxicity of crude oil to these two species was not greatly different from toxicity to other species of water-fowl and (2) it was not likely that either peregrines or whooping cranes would be in hazard due to consumption of oil-contaminated prey.

Beach Fauna

Pre-spill, baseline sample collections of infauna focused on the supratidal, intertidal, and subtidal zones of barrier island beaches which had the highest probability of being oiled and for which little baseline information was available. Characteristic, dominant intertidal and benthic infauna of Texas beaches include coquina clams (Donax), polychaete worms, mole crabs (Emerita), and haustoriid amphipods. This was characteristically a low diversity, high-density community. Despite the relatively low number of species, the number of individuals may be tremendous. Loesch (1957) estimated over 10,000 coquina clams per m^2 at one station on a Texas beach.

Infaunal Studies

Infaunal samples were taken with can grabs (12-cm diameter; 0.12 m^3 volume) at the upper (berm crest), mid (mid-beachface), and low (top of the toe of the beachface) portion of the intertidal zone as well as subtidally in the troughs and crests of the innermost three bars. This was done at five transects (1, 2, 3, 4, and 5; Figure 6.7) before (23 July to 10 August 1979) and after (24 to 29 September 1979) impact of oil.

Samples were placed in a solution of propylene phenoxitol for 20 minutes, then transferred into 10 percent formalin containing Rose Bengal. After two weeks, the samples were sieved to 0.5 mm and the remainder put in 45 percent isopropyl alcohol. Organisms were removed from the sediment using a dissecting scope. Taxonomic analysis was to the lowest possible level, usually to species. Mann-Whitney U-tests were used for significance testing to determine changes in species abundance, richness, and diversity of the dominant macro-infaunal groups: crustaceans, annelids, and molluscs. Significance was at the $p < 0.05$ level.
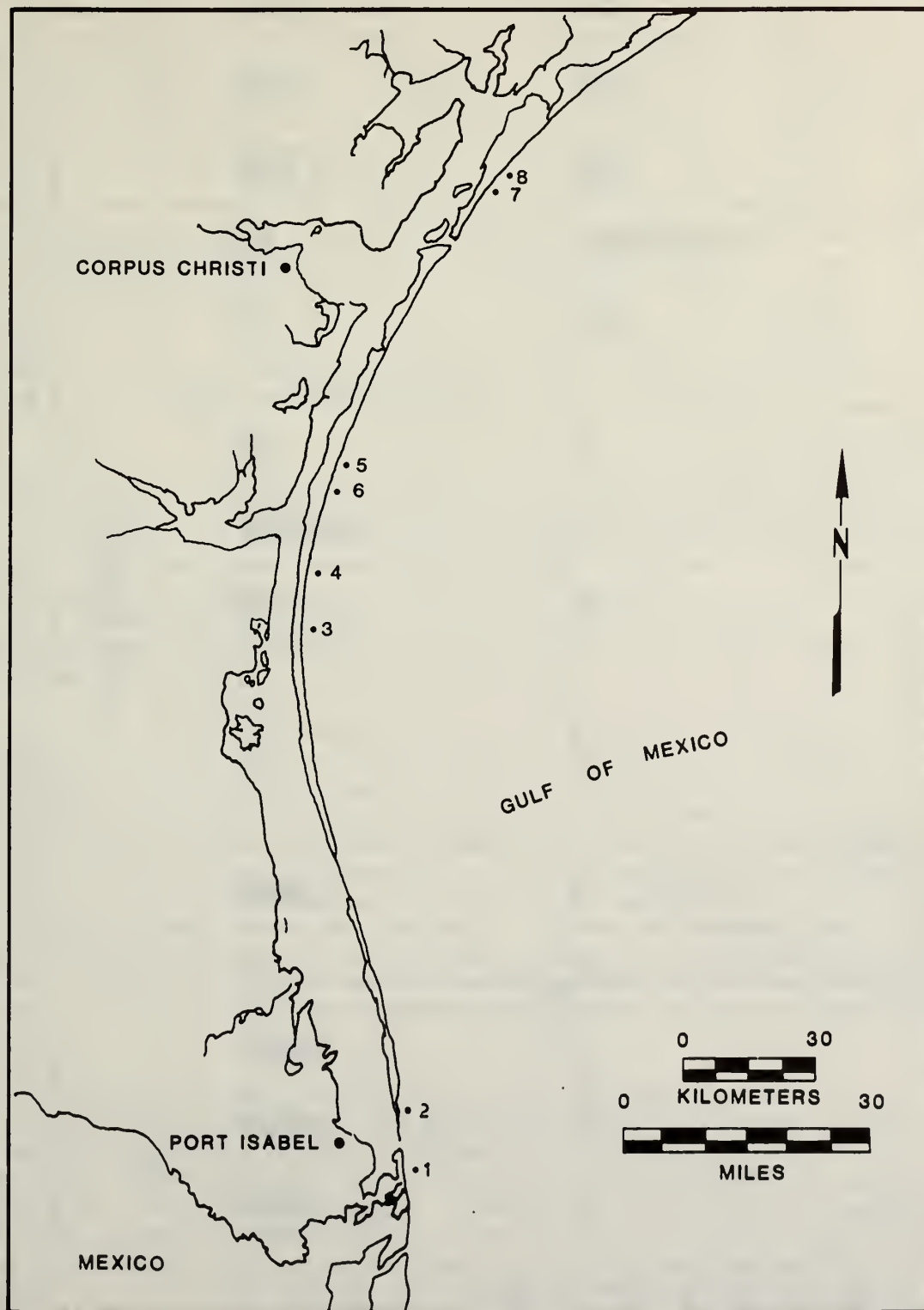
Figure 6.7 Locality of biological monitoring stations throughout the oiled beaches in south Texas.

135
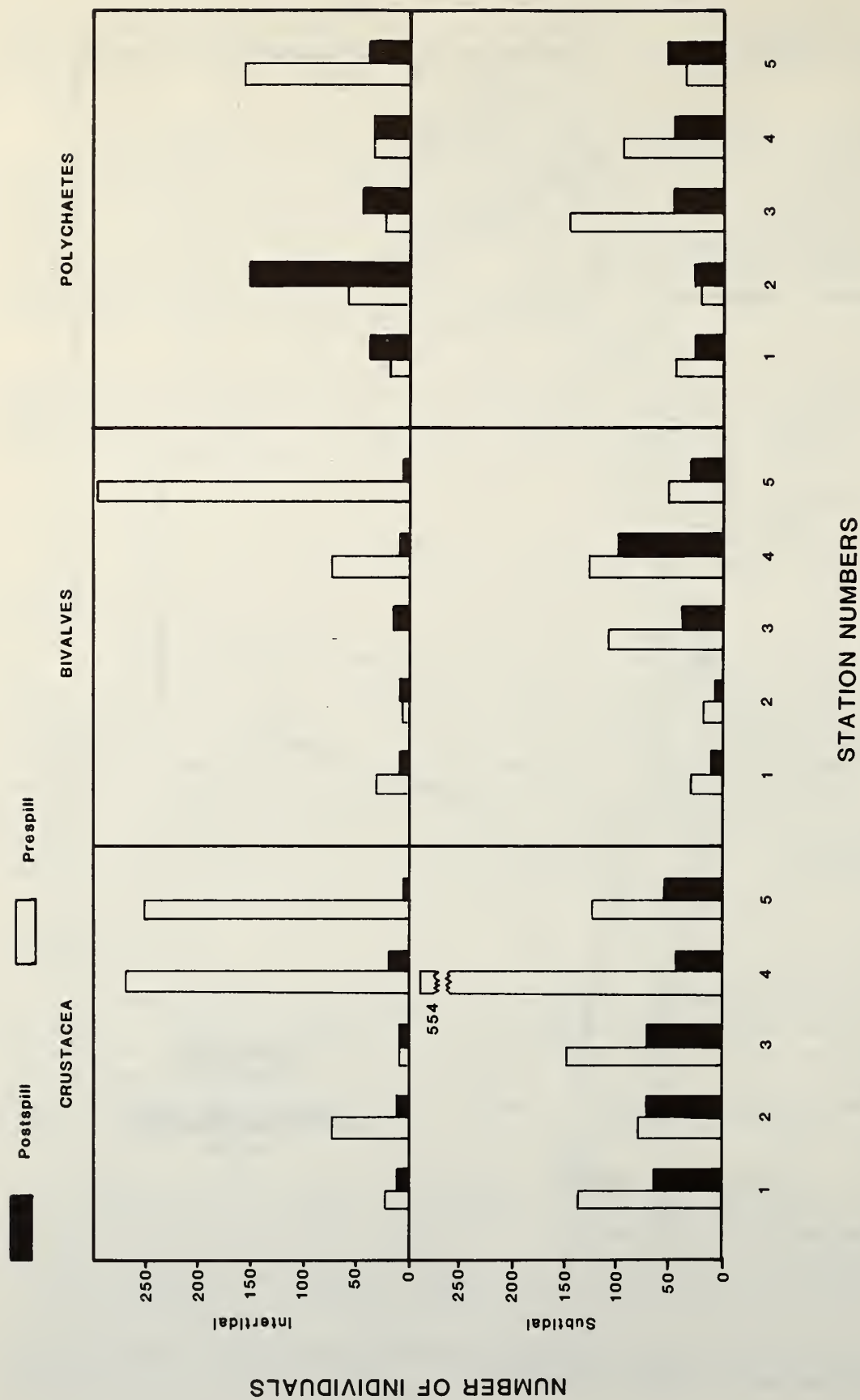
Figure 6.8 Population densities of individual macroinfaunal components for intertidal and subtidal zones at five site-intensive stations before and after spill impact. Results are expressed by major taxonomic groups for crustaceans, bivalves, and polychaetes. Crustaceans showed a consistent decrease between pre- and post-spill conditions all stations. Bivalves showed a consistent decrease in all but one site, intertidal site No. 3, which showed a slight increase. The response of polychaetes was variable, including increased densities at sites 1, 2, and 3 in the intertidal zone following spill impact.

Results showed a visible, though not significant, decrease in total faunal population densitites for the pooled intertidal zones (Figure 6.8). In separate comparisons of the upper, mid, and low intertidal zones, post-spill densities were only significantly (p < 0.05) decreased in the low intertidal zone (Table 6.6). Total post-spill densities at stations 1, 4, and 5 were decreased; but only at station 4 was the decrease significant (p < 0.05). Post spill total densities at stations 2 and 3 slightly increased (non-significant), perhaps due to the small total densities observed at these two stations. Additionally, post-spill sampling at stations 2 and 3 indicated a substantial (non-significant) increase in polychaete populations and a slight (non-significant) increase in mollusc populations (Figure 6.9). Post-spill crustacean population densities, consisting primarily of mole crabs and amphipods, were significantly (p < 0.05) decreased. Amphipods had the largest decrease in densities (in total numbers, per se); however, only mole crab densities were significantly (p < 0.05) decreased (Table 6.7).

The subtidal zone had a significant (p < 0.05) decrease in total population densities (Table 6.8). Crustacean densities were significantly (p < 0.05) lower in post spill samples (Table 6.7). Haustorid amphipods, which were the dominant macro-infauna in the subtidal zone, also had significant (p < 0.05) decreases in population densities in post-spill samples. Figure 6.9 shows that, with the exception of polychaetes at station 3, there was a slight decline in all post-spill subtidal populations. Populations in both the second trough and second sand bar had significantly declined from the pre-spill densities (Table 6.8).

In general, population densities declined from pre-spill to post spill measurements. Crustacean populations in both intertidal and subtidal zones were significantly changed in comparisons of July, pre-spill sampling to the September, post-spill sampling. However, several combined factors may have caused these changes. First, the IXTOC I oil may have impacted the communities. Second, the occurrence of a tropical depression and storm during the first half of September cleaned off the beaches, but at the same time reshaped the beach profile. The berm crest was flattened, as well as the rest of the beach, back to the foredune ridge. The tremendous agitation of sediment during that period may have affected both intertidal and subtidal populations. Little information was available on the effects of storms on beach infauna.

Third, seasonality may have played a role in population density. Loesch (1957) found a decline in the Donax population on Mustang Island, Texas, between August and October. Matta (1977), in a North Carolina barrier island beach infauna study, found seasonality affected all species with a decline occurring in the fall. Because the IXTOC I oil arrived at Texas in late summer and early fall, any one of these factors or any combination of the three may have been responsible for observed population declines.

TABLE 6.6 Test for significance of impact on species abundance, richness, and diversity of macro-infaunal communities at south Texas beaches. H = high M = mid, L = low, and COM = combined zones of the intertidal zone.

Station No.	Pre-Spill				Post Spill			
	H	M	L	COM	H	M	L	COM
	NUMBER OF INDIVIDUALS (N)							
1	1	7	73	81	3	30	13	46
2	3	64	63	130	0	151	8	159
3	2	6	18	26	4	51	3	58
4	207	61	103	371	6	33	11	50
5	303	396	9	708	4	26	7	37
Mean ($\bar{X}$)	103.2	119.4	53.2	263.2	3.40	58.2	8.40	70.00
Standard Deviation	127.6	136.7	35.1	251.7	1.96	47.0	3.44	45.01
U value (sig)					13.5^{NS}	13^{NS}	23*	18^{NS}
	NUMBER OF SPECIES (S)							
1	1	2	11	12	3	2	7	8
2	1	4	6	8	0	6	3	8
3	2	3	3	5	1	4	3	6
4	6	5	8	12	1	4	6	8
5	3	8	5	10	1	1	3	4
Mean ($\bar{X}$)	2:60	4.40	6.60	9.40	1.20	3.60	4.40	6.80
Standard Deviation	1.85	2.06	2.73	2.65	0.98	1.50	1.74	1.60
U Value (sig)					18.5^{NS}	15^{NS}	18^{NS}	19.5^{NS}
	DIVERSITY OF INDEX (DS)							
1	0.00	1.40	4.70	5.47	3.00	1.15	7.80	2.02
2	1.00	1.22	1.96	2.40	0.00	1.18	1.87	1.29
3	0.00	2.50	2.67	3.65	1.00	1.94	1.00	1.97
4	1.15	1.65	4.71	2.60	1.00	1.83	5.00	3.64
5	1.61	1.72	5.14	3.17	1.00	1.00	4.20	1.34
Mean ($\bar{X}$)	0.75	1.70	3.84	3.46	1.20	1.42	3.97	2.05
Standard Deviation	0.65	0.44	1.27	1.09	0.98	0.39	2.41	0.85
U value (sig)					11.5^{NS}	17^{NS}	14^{NS}	22*

*Significant ($p < 0.05$)
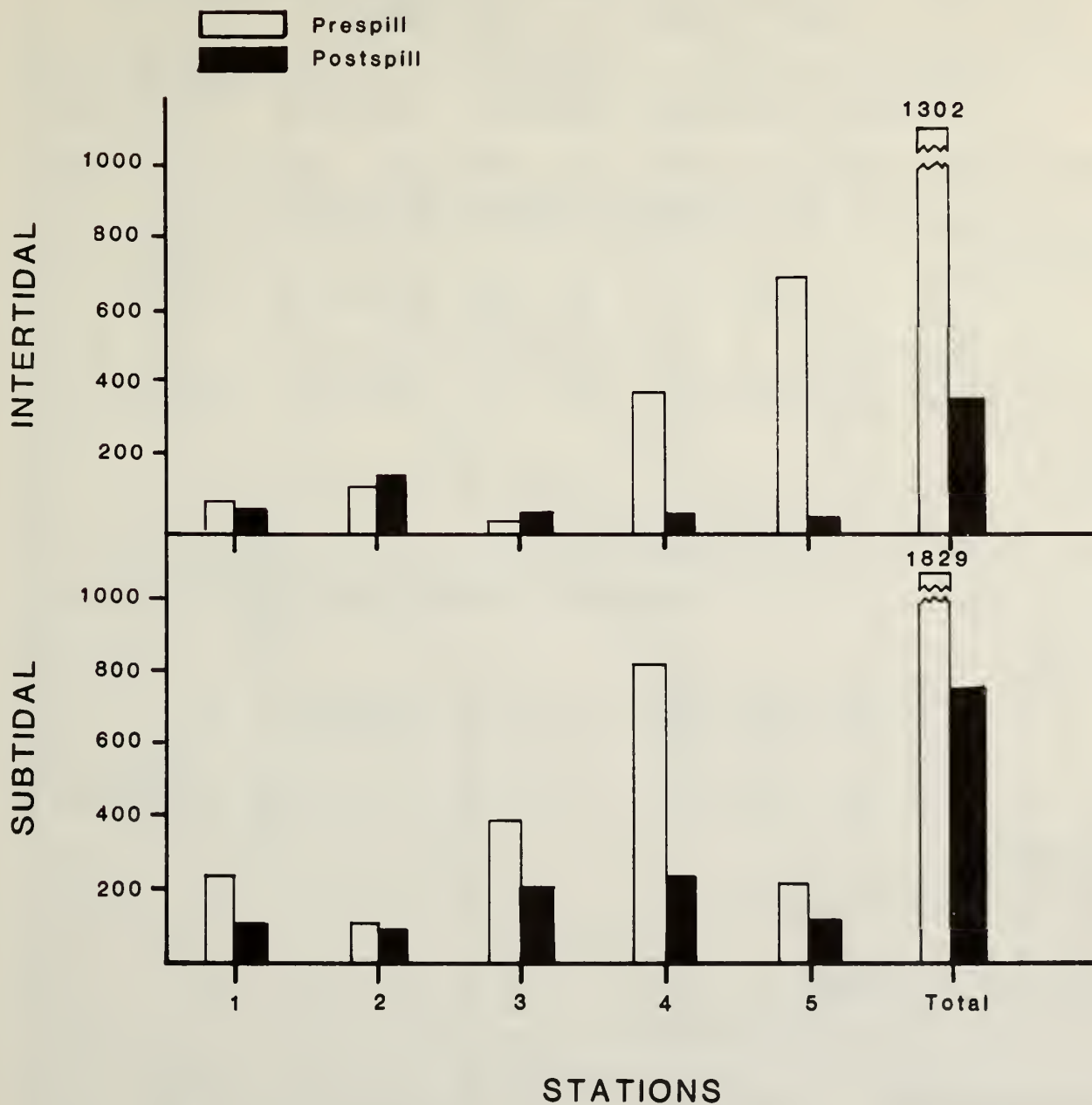
Figure 6.9 Total density of organisms at five site-intensive stations
where intertidal and subtidal macroinfauna were monitored. Data are
presented for pre-spill and post-spill periods. Intertidal stations
show variable but usually decreasing numbers in post-spill samples
while the subtidal zone consistently shows decreases in density of
macroinfauna.

TABLE 6.7 Test for significance of impact on abundance of dominant inter-
tidal macro-infaunal species at south Texas beaches. Stations 2 and 5
were not fully sampled because of inclement weather.

Station No.	Haustorius		Donax sp.		Scolopelis		Emerita sp.		Lumbrineris	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post

NUMBER OF SPECIES (N)

Station No.	Haustorius Pre	Post	Donax Pre	Post	Scolopelis Pre	Post	Emerita Pre	Post	Lumbrineris Pre	Post
Intertidal										
1	0	5	29	4	9	32	8	0	0	1
2	67	3	2	3	51	140	2	1	5	6
3	0	0	0	11	5	1	5	4	3	0
4	215	6	71	4	9	25	43	7	20	5
5	227	0	297	2	135	2	12	1	20	2
U value (sig)	17^{NS}		15^{NS}		11^{NS}		22^{*}		17^{NS}	

NUMBER OF SPECIES

Station No.	Haustorius Pre	Post	Donax Pre	Post	Scolopelis Pre	Post	Emerita Pre	Post	Lumbrineris Pre	Post
Subtidal										
1	42	0	28	8	3	6	2	7	2	6
2	71	20	15	6	10	1	2	4	3	19
3	23	5	108	35	1	3	9	3	117	33
4	321	0	124	98	3	8	4	12	48	25
5	29	3	49	27	8	8	7	2	9	10
U value (sig)	9^{*}		7^{NS}		1^{NS}		3^{NS}		6^{NS}	

*Significant (p < 0.05)

Upper Beach Faunal

The supratidal ghost crabs and the wrack-associated amphipods of the
south Texas sand-beach habitats were examined for impacts resulting from
IXTOC I oil. Impacts were observed incidental to studies of oil distri-
bution and geomorphology.

The ghost crab (Ocypode quadrata) is the dominant consumer of the
supralittoral portion of Texas exposed-sand beaches (Hill and Hunter, 1973).
Vertical distributions and relative abundances were measured within randomly
placed 1 m^2 triplicate grids at intervals along three beach transects (beach
stations 6, 7, and 8) before (25 July to August 1979) and during (2 September
1979) the impact of IXTOC I oil. During impact, oil coverage was moderate
to heavy.

TABLE 6.8 Tests for significance of oil impact on species abundance and richness of macroinfaunal communities at nearshore subtidal zones of Texas beaches. T = trough, B = bar, COM = combined zones, and * = significant (p < 0.05).

Station No.	PRE-SPILL							POST SPILL						
	T1	B1	T2	B2	T3	B3	COM	T1	B1	T2	B2	T3	B3	COM
	NUMBER OF INDIVIDUALS (N)													
1	19	11	23	39	53	99	244	12	8	11	9	33	33	106
2	11	15	31	40	---	17	(114)	8	12	13	20	25	24	102
3	15	37	95	25	131	97	400	13	5	34	18	91	59	220
4	144	199	139	91	188	84	845	31	50	16	27	24	96	244
5	51	24	105	46	---	---	(226)	16	17	26	21	50	21	151
X̄	48	57.2	78.6	48.2	124	74.8	496.3	16	18.4	20	19	49.3	53	190
S.D.	55.9	79.9	49.9	25.1	67.8	39.1	311.9	8.9	18.2	9.7	6.5	36.3	32.2	73.7
U value								16^{NS}	16^{NS}	22^*	24^*	8^{NS}	11^{NS}	8.5^*
	NUMBER OF SPECIES													
1	6	5	8	12	13	19	25	7	6	6	3	7^*	10^*	18
2	4	5	6	3	--	6	12	6	5	6	9	9	10	22
3	5	8	7	3	16	14	21	5	3	5	8	15	15	23
4	8	14	13	13	16	15	28	5	10	7	7	8	11	22
5	11	8	13	18	---	--	26	9	9	12	10	17	11	27
X̄	6.8	7.4	9.4	9.8	15	13.5	24.6	6.4	6.6	7.2	7.4	10	11.5	21
S.D.	2.8	3.1	3.4	6.6	1.7	5.4	3.5	1.7	2.9	2.8	2.7	4.4	2.4	2.6
U value								12.5^{NS}	15^{NS}	19.5^{NS}	14^{NS}	8^{NS}	10.5^{NS}	7^{NS}

At heavily oiled station 6, a significant (p < 0.05) change (determined by the Mann-Whitney U-test) in vertical distributions of ghost crabs was observed. At moderately oiled station 8, a significant (p < 0.05) change was also observed, but at station 7 (also moderately oiled), no significant change in vertical distribution was noted. Therefore, it appears that ghost crabs are able to move higher up on the beaches following oiling, but the response varies between localities.

The amphipods, Orchestia and Talorchestia, are most commonly associated with beach wrack (usually the alga (Sargassum) on Texas sand beaches (Hedgpeth, 1953). Wrack-associated amphipods were observed in light concentrations under beach wrack before oil impact (July and August 1979), but were absent following impact at five or six transects that were revisited on 2 and 6 September 1979. This same loss of wrack-associated amphipods was noted during the PECK SLIP spill study of December 1978 (Robinson, ed., in press).

Infauna Laboratory Toxicity Analysis

In addition to field studies laboratory studies were concentrated on organisms living in outer coastal barrier island beach habitats because of the high probability that animals in these areas would be oil-impacted. One of the immediate questions faced was the potential toxicity of IXTOC I oil to marine biota inhabiting these areas.

The objective of these experiments was to quantitatively define the acute toxic effects of this oil on common invertebrates of the Texas coast, which were likely to be impacted in sandy beach environments. The acute toxic effects of IXTOC I oil on three species of invertebrates (a sandy beach bivalve, Donax variabilis; an intertidal, burrowing, detrital-feeding polychaete, Scolelepis texana; and a burrowing tidal crustacean, Emerita sp.) commonly found in beach habitats were measured in laboratory toxicity tests. Additionally, sublethal effects induced by oil-exposure, including behavioral and physiological changes, were measured. These lethal and sublethal studies provided useful information in predicting potential impacts to sand beach fauna.

Intertidal organisms and sediments used in this study were collected from the beaches of Mustang and St. Joseph Islands, using standard invertebrate collection techniques. Collected sediments were sieved through a 500-μ mesh sieve to remove macrofauna, and dried for 48 hours to kill any remaining fauna. Collected beach fauna were maintained in salinities of 34 °/oo and at a water temperature of 25°C.

Sediment selectivity tests. The bottom sections of 0.24 ℓ (½ pint) capacity milk cartons, cut 6 cm from the bottom, were filled with dried beach sediment that had been mixed with different concentrations of whole oil. The range of concentrations included controls (no oil in sediments), 0.1, 1.0, and 10.0 percent oil in sediment. The cartons containing control, 0.1, and 1.0 percent oiled sediment were placed randomly side by side in a 20-gallon aquarium. The 10 percent oiled sediments and unoiled sediments (controls) were placed in a separate, 10 gallon aquarium to prevent contamination of sediments at the lower oil-exposure concentrations (0.1 and 1.0

percent). The aquaria were slowly filled with beach water (34 ^{o}/oo salinity) to a depth of 12 cm over the surface of the sediments. Mole crabs (Emerita sp.) were introduced randomly over the water surface. The water was aerated and maintained at 25°C. One experiment was run for 24 hours and a second was run for 72 hours. At the end of each test, water was slowly drained to below the surface of the sediment containers. The contents of each carton were sieved through a 500-μ mesh sieve, and the living and dead mole crabs counted immediately.

The results of the 24-hour, sediment-selectivity tests suggested that mole crabs had a definite preference for the less oiled sediment. There was a significant ($p < 0.05$) difference between treatments as tested by one-way ANOVA for these 24-hour tests. Thirty-five percent of the crabs were observed in the control sediments, 28 percent in the 0.1 percent oiled sediments, 25 percent in the 1 percent oiled sediments, and 13 percent in the 10 percent oiled sediments. Less than 1 percent mortality was observed in all treatments over the duration of exposure, and no treatment showed significantly greater mortality than the controls.

The 72-hour, sediment selectivity tests indicated there were no significant ($p < 0.05$) differences in the selection of treated and control sediments by the mole crabs. No dead crabs were observed in the control sediment. Mortality was 1 percent in the 0.1 percent oiled sediments, and 2 percent in the 1.0 percent and the 10.0 percent oiled sediments.

Toxicity tests. Oil accommodated seawater (OAS) was prepared by shaking a 1 percent mixture of IXTOC I mousse (collected by the U.S. Coast Guard Cutter POINT BAKER) in seawater for 1 hour in an Eberbach shaker. After allowing this mixture to settle for 1 hour, the aqueous phase containing the 100 percent OAS fraction was siphoned off. This stock solution, which contained approximately 25 mg/ℓ total hydrocarbons, was used to prepare different exposure solutions for each of the toxicity tests. Calculated, treatment-exposure concentrations of OAS for each group of test animals were 0 (control), 5, 15, 30, and 60 percent. Water samples taken after 24 hours of exposure indicated a significant evaporation of hydrocarbons. Therefore, each test container of mole crabs, surf clams, and polychaetes had 25 percent of the water removed and replaced with a fresh mixture of exposure solution, daily.

Four groups (replicates) of mole crabs, surf clams, and polychaetes, consisting of 10 animals per group, were exposed to each treatment concentration. Mole crabs and polychaetes were placed in 11.4 cm finger bowls containing approximately 1.5 cm of sediment and 200 mℓ of 34 ^{o}/oo, aerated seawater. Surf clams were placed in 11.4 cm finger bowls containing 3 cm of sediment and 200 mℓ of 34 ^{o}/oo, aerated seawater. All tests were conducted at 25°C. Test animals were fed rotifers (Brachionus plicatilis) daily. Both survival and mortality were recorded daily for each finger bowl. Behavioral observations for mole crabs (burrowing versus nonburrowing before being presented a food source; feeding versus nonfeeding when presented a food source, and burrowing versus nonburrowing after being presented a food source); surf clams (continuously pumping, intermittantly pumping, or non-pumping after being presented a food source); and polychaetes (percentage of worms extended from burrow or on sediment surface; percentage of worms burrowing; and percentage of worms producing feces after being presented a food source) were recorded daily.

All experiments were conducted for 96 hours.

Mole crab. Percent mortality, percent survival, and percent behavioral activity (number of mole crabs exposed above the sediment following food stimulation) are recorded in Table 6.9.

No mortalities of mole crabs were recorded for any of the OAS treatments. However, unretrieved animals a well as pieces of mole crabs and molts may represent mortalities that could not be verified without an in-hand dead specimen. No acute, sublethal behavioral effects, as determined by mole crab activity observations, were measured in different treatments. Behavioral activity in both control and oil-exposed mole crabs decreased throughout the 96-hour period.

TABLE 6.9   Results of mole crab toxicity tests and behavioral studies.

Treatment (%)	% Mortality				% Survival 96-hr	% Activity after Food		# Visible Stimulation	
	24-hr	48-hr	72-hr	96-hr		24-hr	48-hr	72-hr	96-hr
Control	0	0	0	0	95	35	63	40	18
5 OAS	0	0	0	0	98	60	80	50	33
15 OAS	0	0	0	0	98	68	70	50	33
30 OAS	0	0	0	0	75	63	58	60	25
60 OAS	0	0	0	0	100	78	70	53	38

Surf clam. Results of surf clam toxicity tests and behavioral studies (number of surf clams with siphons extended and working, following food stimulation) are recorded in Table 6.10. No mortalities were recorded for any of the surf clams in the OAS treatments, while there was 8 percent mortality measured in the controls. All test animals were retrieved from the experiments. There were no significant sublethal effects measured in comparisons of behavioral activity observations in control and oil-exposed surf clams. Behavioral activity decreased throughout the 96-hour period in both control and oil-exposed surf clams. There were no behavioral differences measured between different OAS concentrations.

TABLE 6.10   Results of surf clam toxicity tests and behavioral studies.

Treatment (%)	% Mortality				% Activity after Food		# Visible Stimulation	
	24-hr	48-hr	72-hr	96-hr	24-hr	48-hr	72-hr	96-hr
Control	0	0	0	8	40	33	30	5
5 OAS	0	0	0	0	53	38	28	25
15 OAS	0	0	0	0	68	48	40	28
30 OAS	0	0	0	0	58	23	40	20
60 OAS	0	0	0	0	38	28	35	18

Polychaete.   Results of polychaete toxicity tests and behavioral stud-ies are listed in Table 6.11. Not all the test organisms were retrieved from the experiments. These unretrieved animals, as well as dead and decomposing body sections, may represent mortalities that could not be verified without an in-hand dead specimen. Survival in all OAS-exposure concentrations was not significantly different from control survival. The highest mortality (25 percent at 96 hours) was measured in the 15 percent OAS treatment. Sublethal effects as determined by polychaete burrowing activity could not be determined for any of the treatments. Burrow openings and fecal pellets around openings were recorded, but artifacts of the previous day's activity could not be distinguished from the current day's. In general, activity increased in all treatments after 48 hours, then decreased through 96 hours below the initial level.

Inspection of polychaetes after retrieval from experiments and before and during respiration measurements showed the 60 percent OAS-exposed organisms to be in poor condition, alive but motionless upon stimulation, and covered with mucus and attached sand grains and debris. The poly-chaetes from the control dishes, however, were robust, active, in good condition, and free of mucus and debris.

TABLE 6.11   Results of polychaete toxicity tests and behavioral studies.

Treatment (%)	% Mortality				% Survival 96-hr
	24-hr	48-hr	72-hr	96-hr	
Control	0	3	5	10	85
5 OAS	3	5	5	8	80
15 OAS	3	10	10	10	75
30 OAS	5	5	8	8	92
60 OAS	10	17	17	23	77

Oxygen consumption. Differences in the metabolic functions of control
and OAS-exposed populations of test organisms were determined by oxygen
consumption measurements to assess sublethal, physiological responses to
oil exposure. The following tests listed in Table 6.12 were conducted.
All organisms were acclimated to 25°C for 15 minutes. Respiration chambers
were filled with supersaturated, filtered seawater and held to a constant
temperature (25°C) in a circulating water bath. A Beckman model 0260
oxygen analyzer ($O_2/T°$) was used, and changes in oxygen ($\mu\ell\ O^2$) within the
respiration chamber were recorded every 5 minutes for the duration of the
measurements. Organisms were wet weighed to the nearest 0.001 g. Oxygen
consumption was calculated for each replicate in $\mu\ell\ O_2$ per g per hr.

TABLE 6.12   Laboratory design of whole animal respiration tests.

Organism	No. of Replicates	No. of Organisms/ Replicates	Duration of Measurement	Treatments Tested
Mole Crab	3	3	30 min.	Control, 60% OAS
Surf Clam	3	3	30 min.	Control, 60% OAS 60% OAS

Result of oxygen consumption ($\mu\ell\ O_2$ per g per hr.) measurements for
all organisms taken from each OAS concentration after 96 hours of exposure
are recorded in Table 6.13. The only measureable differences that were
shown to be signficiant ($p < 0.05$) between the control and any oiled treat-
ment were for the mole crab. There appeared to be a slight increase in
oxygen uptake in the oiled versus the control treatments for the surf clam,
but these differences were not significant. Oxygen consumption was slightly
(nonsignificant) lower for the polychaetes treated with 60 percent OAS than
for controls, which may possibly be a reflection of the poor physical
condition of these worms as noted in the toxicity results section.

It was not possible to determine the acute toxicity of IXTOC I oil (as
oil accommodated seawater) in the beach biota studied, at least at the
concentrations tested. The fauna examined appeared to show few, if any,
acute effects from oil exposure. This could be related to the physical
nature of the oil tested. However, the concentrations tested (1.25 to
15 ppm) in the lab should not be considered the same as the actual concen-
trations observed in the Gulf of Mexico and on Texas beaches.

TABLE 6.13   Oxygen consumption for experimental animals removed from
control and 60 percent OAS treatments after 96 hours of exposure.
Data are reported in $\mu \ell$ O_2 per g per hour.

		Treatment
Organism	Control	60% OAS
Mole Crab*	20.14	18.24
	24.88	18.47
	26.95	15.32
X	23.99	17.34*
Surf Clam	6.44	9.80
	10.12	13.36
	11.39	15.18
X	9.32	12.78
Polychaete	90.00	85.37
	142.86	90.90
X	116.43	88.14

*Significant difference from controls at $p < 0.05$.

Mortality was higher in the polycheates than in any other fauna tested
(although this was by no means significant). This may be related to poly-
chaetes being the only one of the three beach fauna tested that was a
surface-deposit feeder. The other two were both suspension feeders.
Feeding from the sediment surface, the polychaete may have ingested the
numerous micro-tar balls that were initially suspended in the OAS and later
settled to the sediment surface. This may help to explain the poor health
of the worms in higher treatment concentrations as noted in the results.

These acute tests did not evaluate any of the potential, sublethal,
biological effects of oil exposure on reproductive success, long-term
health of the organisms, accumulation of toxic substances, growth and
development, and histopathological conditions that may result from chronic
exposure to IXTOC I oil. What can be concluded from these acute tests was
that the fauna examined appeared to show very few acute effects from oil
exposure.

Effects Other Than Spilled Oil

As results of laboratory toxicity studies and field studies have
shown, there was some evidence for oil related impacts to sandy beach
habitats from the IXTOC I oil spill. In addition to oil-induced impacts,
other factors such as tropical storms and seasonality should also be con-
sidered to properly interpret these data.

Tropical Storms

South Texas was hit by a tropical depression 31 August to 1 September
1979. The tropical depression raised tide levels, removing beached oil and
pushing some of it up to the foredune line. However, the majority of the
oil was dispersed back into nearshore waters. The beachface was also
altered as the high winds and waves flattened it.

In mid-September, a tropical storm resulting from Hurricane Frederick
hit the south Texas coast. The storm surge was 1.2 m (4 ft) and winds
reached to 60+ knots. The beachface was completely flattened. This was
most noticeable at Big Shell where a 1.0 to 1.5 m berm normally found was
flattened. The oil on the fine-grain sand beaches was removed or pushed up
to the foredune ridge. The oil in the coarser mixed, sand shell beach at
Big Shell Beach was worked into the sediment, as well as removed. It was
not possible to determine what effect these storms had on the benthic
infauna of the intertidal and nearshore subtidal zones. Thus, it was
impossible to differentiate between impacts attributable to these two
storms from those resulting from the IXTOC I oil spill.

Seasonality

Little is known about the seasonality of the beach infauna on south
Texas barrier island gulf beaches. Loesch (1957) documented a seasonal
decrease in Mustang Island Donax populations from August (peak) to September.
Thus, in addition to impacts resulting from IXTOC I oil and tropical storms,
seasonal variability in population densities must also be considered.

STUDIES OF OFFSHORE AND NEARSHORE ENVIRONMENTS AND ORGANISMS

Bioassay and toxicity tests of dominant and commercial species, in
addition to observations made during cruises, comprise the results of
offshore and nearshore environments and organisms.

Fisheries

Toxicity studies and bioassay of three commercial fish species were carried out to investigate potential acute toxicity of IXTOC I oil.

Seatrout Study

This study investigated toxicity levels and sublethal, respiratory metabolic effects of IXTOC I crude oil on the spotted seatrout (<u>Cynoscion nebulosus</u>), a sensitive, euryplastic species living in nearshore and estuarine environments, which is used commercially and recreationally (Wohlschlag and Wakeman, 1978; Wohlschlag and Parker, unpubl. data).

The specific aims of these studies were to use the spotted seatrout as a test organism for making preliminary determinations of:

1. Acutely toxic levels of IXTOC I oil on adult and fingerlings or underyearlings,

2. Metabolic results at active and standard (or resting) levels for detection of physiological scope diminution even though the chemical composition of the spill material could be considered unknown,

3. What levels of the spill material produce observable metabolic depression, and

4. Information of basic energetics data on a species of general importance in fishery and ecological considerations.

Spotted seatrout used throughout the study were captured near Port Aransas, Texas, by hook-and-line or seine. Capture temperature (30°C) and salinity (32 °/oo) were near test levels for respiration experiments, but toxicity test fish required additional acclimation to the lower (23°C) room temperature used. Fish were transported to the laboratory in insulated boxes and placed in indoor holding tanks for acclimation to the appropriate test condition. Fish that behaved abnormally or appeared unhealthy were discarded.

Samples of wellhead IXTOC I mousse were collected by the U.S. Coast Guard Cutter POINT BAKER. The preparation of oil spill material to produce a stock, "100 percent solution" in toxicity tests were done as follows: "mousse" collected by the U.S. Coast Guard Cutter POINT BAKER was blended with seawater from laboratory settling tanks with a salinity of 35 °/oo. No measured amounts of "mousse" were used; the procedure involved high-speed blending of the oil in water for 45 sec, after which the oil accommodated seawater (OAS) fraction was siphoned into a holding container. After enough of this solution was collected, it was diluted with two parts seawater to produce a 100 percent stock solution. Initially, the concentration of the stock was 27 mg/ℓ oil for the adult fish toxicity tests and 30.1 mg/ℓ for the fingerlings and underyearlings. Before the start and end of each test, samples of each appropriate dilution were taken for later chemical analysis.

Preliminary toxicity tests on adult C. nebulosus were conducted in 20-gallon, glass aquaria equipped with aerators. Six OAS dilutions were used (100, 50, 12, 12.5, 5, and 1 percent); control fish were maintained in a larger holding tank. Observations were recorded for 96 hours on each of these six tanks, each containing two fish of 100 to 200 g weight. All tests were conducted at room temperature (23°C) and a salinity of 35°/oo.

Fingerlings and underyearling fish tests were carried out in six 20-gallon aquaria at five dilutions (100, 50, 25, 12.5, and 5 percent) and one, oil-free control tank. Again, observations on behavior and toxicity were recorded for 96 hours. At the end of all experiments, fish were weighed and lengths measured. Specimens were then frozen for later inspection.

Respiration experiments were conducted at 28°C and 35°/oo. Fish were exposed to each OAS dilution in a temperature-controlled, circular tank for 48 hours before respiration measurements were made. Fish were starved during this period and a slow current was maintained within the circular tank to provide a stimulus for swimming so that active metabolism measurements could be made. The holding tank and respirometer tank were always well-aerated throughout experiments.

Active and resting metabolism rates were made in a 207-Blazka chamber (Blazka et al., 1960; Fry, 1971) as used by Wohlschlag and Wakeman (1978). No filtration system was used for these tests. Fish were maintained for 2 days swimming at low velocities (about one length (L/sec) before active measurements began. After swimming in the chamber at an intermediate speed for enough time to calm the fish, the velocity was increased gradually until the fish "broke" pace. At this instant, the velocity was lowered (usually quite slightly) to the highest possible velocity at which normal swimming persisted without breaking. With this "training" regimen, the maximum-sustained velocity could be reproducible for each fish. The U_{max} (total lengths/sec) swimming velocity was determined, after which each fish was tested for at least 1 hour for a consistent U_{max}. Following the 1 hour or longer runs, the fish were left in the chamber at intermediate and/or zero velocities, and oxygen measurements were made to detect any respiratory irregularities that could have resulted had the U_{max} been associated with undesirable anaerobic metabolism.

Oxygen consumption rates were measured by withdrawal of small samples for use in a Radiometer (Model E-5046) with a PHM 71 electrode equipped with acid-base analyzer. Following completion of a set of experimental, oxygen consumption measurements, the fish were removed and lengths and weights recorded. Along with lengths, weights, oxygen consumption rates, and swimming velocities (total lengths/sec), salinities were recorded to 0.1 ^{o}/oo and temperatures to 0.1°C. From this, a simple multiple regression was calculated at control and experimental conditions in the form

$$\hat{Y} = a + b_w X_w + b_v X_v$$

where

$\hat{Y}$ = expected O_2 consumption rate in $\log_{10}$ mgO_2 1 hr

a = constant

X_w = $\log_{10}$ weight in grams

X_v = L/sec

The various "b" values are the respective, partial regression coefficients. Similar procedures have been used by Wohlschlag and Juliano (1959), Wohlschlag and Cameron (1967), and others.

Temperature and salinity values remained near 28°C and 35 °/oo, respectively, and were not included in the regression calculations. Control data were acquired from a study on ocean-dumped, pharmaceutical wastes by Wohlschlag and Parker (in progress). Standard metabolic rates were determined from the appropriate, active regression equation using the Brett (1964) technique. This involves a line parallel to the active regression line through the lowest U_{max} value and using the "Y" intercept value as a realistic estimate of the standard rate.

The preliminary experiment to assess the toxicity of OAS to subadult fish in 20-gallon aquaria indicated that 100, 50, and 25 percent dilutions had a significant effect on behavior after 96 hours of exposure. At dilutions of 12.5, 5, and 1 percent, adverse effects usually appeared after 24 hours of oil exposure.

The second, preliminary experiment to assess 96-hour toxicity to fingerlings had similar, but more lethal, results. From these preliminary data, a 96-hour TLM level would be a range from 5 to 25 percent dilution (1.3 to 7.5 mg/ℓ). The smallest of the fish generally died first; this would indicate a critically susceptible size of smaller than about 10 g, although there may have been uncontrolled variables from one aquarium to the next.

The first experimental Blazka respiratory measurement attempts failed during acclimation (habituation) to a 5 percent OAS level, when some deaths occurred. Accordingly, the remainder of the results deal with respiratory metabolism measured under control or 1 percent OAS conditions in the Blazka apparatus.

The more definitive results from the Blazka chamber experiments yielded for control data:

$\hat{Y}$ = 0.06995 + 0.71242 X_w + 0.11192 X_v (Equation 1), where the average weight was 114 g, and the average of 14 determinations at U_{max} was 3.3 lengths/sec. Total N = 34.

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The data at 1 percent OAS were

$\hat{Y}$ = 0.87662 + 0.36468 Xw + 0.11381 X_V (Equation 2), where average weight was 164 g, and average of 10, U_{max} measurements was 2.8 lengths/ sec.   Total N = 27.

The following schedule of statistics for these equations are also useful (Table 6.14).

TABLE 6.14   Statistical parameters used in calculations of regressions.
     N = sample size; R = correlation coefficient

Equation No.	N	R	s_Y	s_{b_w}	P	s_{b_V}	P
1	34	0.92	0.07901	0.12416	0.001	0.0092	<0.001
2	27	0.77	0.13624	0.02123	0.001	0.0190	<0.001

Figure 6.10 is the plot of oxygen consumption rate of all control fish (calculated from Equation 1 and adjusted to the average weight of 114 g) against observed swimming velocities.   This equation is

$$\hat{Y} = 1.52522 + 0.11192 \; X_V$$

The Brett (1964) extrapolated standard metabolism rate was 29.17 mg O_2/hr or 256 mg O_2/kg/hr.

Figure 6.11 is the plot of the oxygen consumption of the experimental fish (calculated from Equation 2 and adjusted to the average weight of 164 g) against observed swimming rates.   This equation is

$$\hat{Y} = 1.68433 + 0.11381 \; X_V$$

Some pertinent notes on the condition of the fish in the Blazka chamber experiments are most revealing. Fish in the 1 percent solution showed no deterioration for the first 2 days of the acclimation and first 2 days of oil exposure. By the third day of oil exposure, fish in the Blazka chamber were more labored in their swimming motions and appeared to have equilibrium problems. Fish were definitely sluggish on the fourth day of oil exposure with an obvious prevalence of tail rot. Of the three fish remaining on day
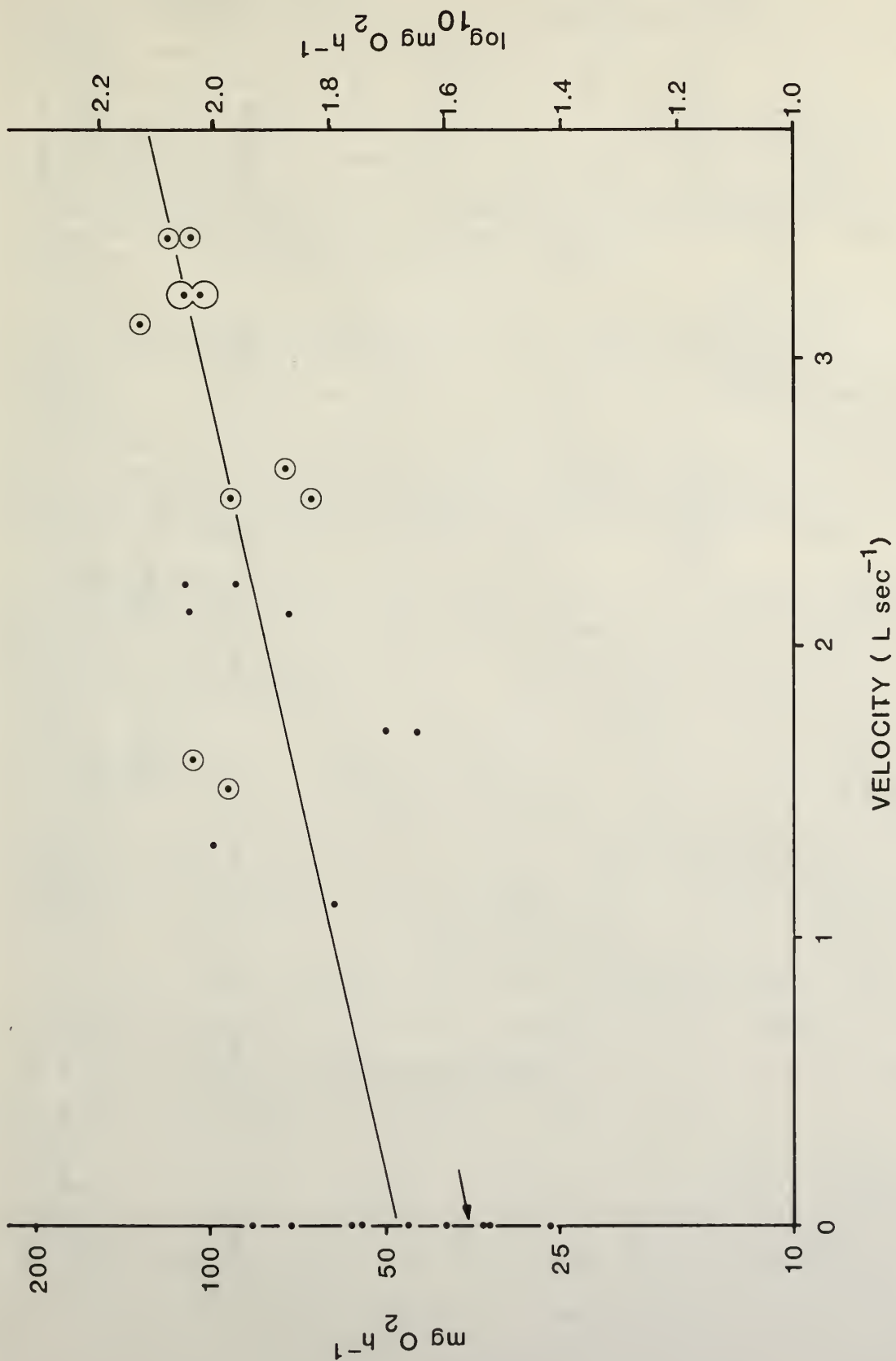
Figure 6.10 Calculated oxygen consumption rates for control seatrout at 114 g average weight plotted against observed swimming rates. Encircled points are for maximum sustained (U_{max}) swimming performances. Arrow (←) on Y axis indicates estimated standard rate.

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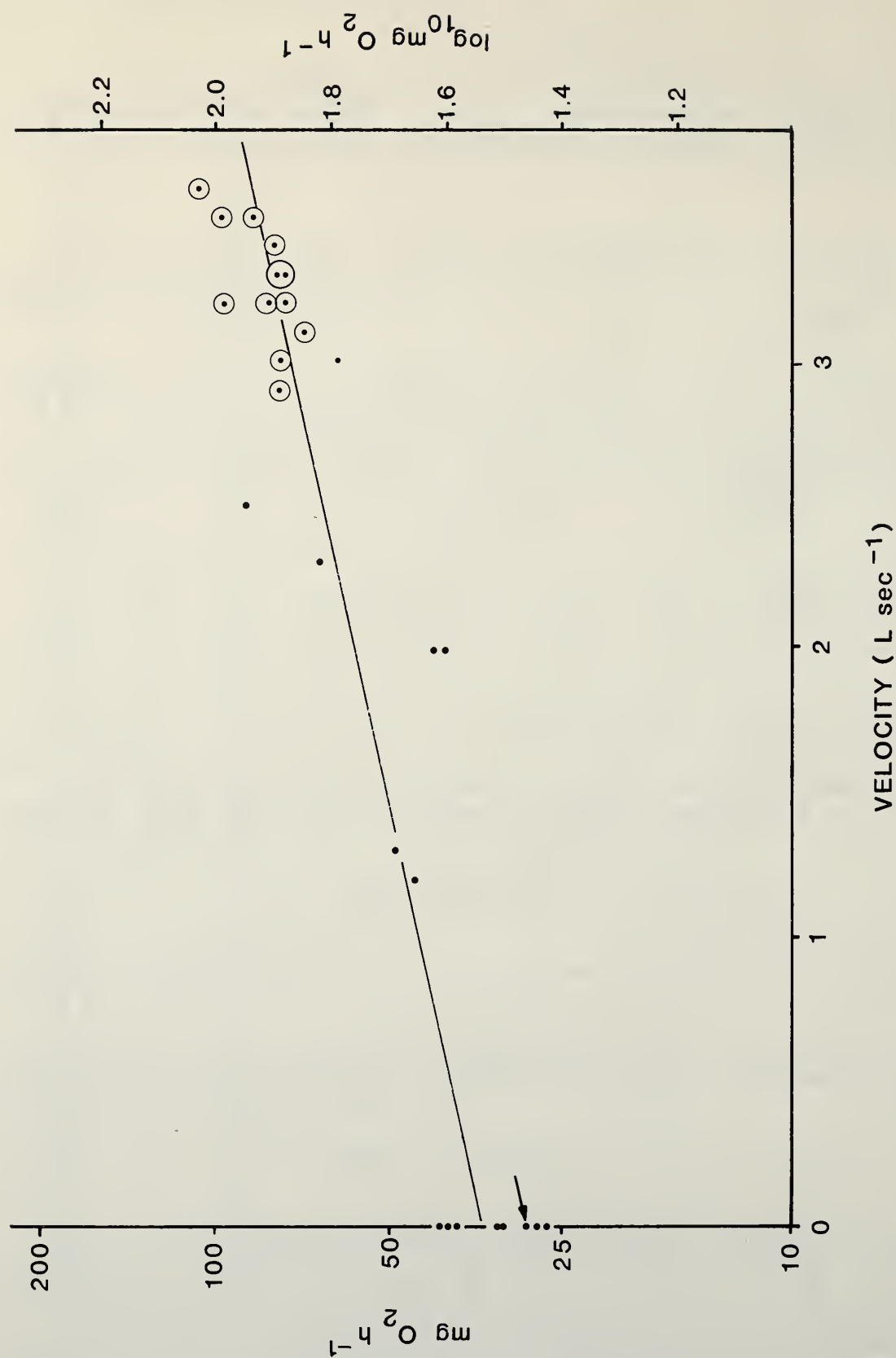
Figure 6.11 Calculated oxygen consumption rates for seatrout in 1 percent crude oil extract at 164 g average weight plotted against observed swimming rates. Encircled points are for maximum sustained (U_{max}) swimming performances. Arrow ($\leftarrow$) on Y axis indicates estimated standard rate.

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five, one died; one failed to swim faster than 1.6 lengths/sec and was afflicted with tail rot, gill lesions, and coughing spasms; while the last fish swam weakly at only 1.5 lengths/sec. During the 7 days, there was no perceptible deterioration with U_{max} values showing no trend downward.

The initial trials that indicated a 1 percent OAS concentration was significantly toxic were apparently misleading, inasmuch as cumulative effects did not become evident until after 4 days. Just what protocol should be used for evaluating delayed reactions to unknown toxins at unknown concentration is unclear because relative concentrations, exposure time, and effects in the open ocean are unknown.

McKeown and March (1978) have observed severe damage to gills in rainbow trout (Salmo gairdneri) exposed to Bunker C oil. Minchew and Yarbrough (1977) found fin erosion in Mugil cephalus exposed to 4 to 5 mg/ℓ crude oil in estuarine pond ecosystems. Sinderman (1978) reviewed the recent literature on the generalized nature of fin rot occurrences in degraded estuarine and coastal systems. The coughing response has been shown to be directly related to concentrations of toxic substances (Barnett and Toews, 1978; Carlson and Drummond, 1978; and others). Any of these, or other similar deficiencies, would be expected to suppress metabolic scope.

From the descriptions of the preliminary, toxicity tests and the Blazka chamber respiratory experiments, there was no obvious, biological clue about a sufficient concentration or a proper exposure interval. Whatever the identifications of toxic materials are, it was apparent that a 5 percent extract was acutely toxic within 2 days. In about 7 days, the 1 percent dilution may be considered acutely toxic. Whether the acute toxicity depends upon bioaccumulation past a threshold concentration, or upon the progressive breakdown of a biochemical system once a toxin, or combination of toxins, initiates a degradational process, should provide a focal point of interest in future experiments. Such experiments should provide contrasting acute and sublethal chronic toxicity levels wih the sublethal levels low enough to: (1) allow for flow-through experiments conducted at a continuously added, constant pollutant level, and (2) detect further degradation, if any, by a single initial addition of the pollutant.

The experimental concentration of the pollutants in this study yielded what might be ordinarily expected of sublethal levels. The Blazka respirometer experiments, as summarized by Equations 1 and 2 and the plotted, processed data in Figures 6.10 and 6.11, show that the variability of the controls is considerably less with high "R" multiple correlation and low standard error of the regression, s_v. The greater variability of the plotted data for oil exposed fish in Figure 6.11 shows up at $X_v = 0$ and at the maximum-sustained (encircled) values when compared with Figure 6.10 for

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control data. The greater variability of standard error (s_{b_w}) for the b_w of the control (0.12 compared with 0.02) was unclear, although similar ranges of standard errors are common and may be associated with the relatively smaller average size, $\bar{X}_w$ = 114 g, and the smaller range of weights for the control fish.

Average weights of 114 g for controls in Equation 1 and 164 g for 1 percent IXTOC I samples in Equation 2 reveal somewhat emphatically the differences between control and experimental metabolic levels when the average maximum activity is decreased from 3.3 lengths/sec to 2.8 lengths /sec, or to 85 percent of the maximum-sustained value.

At 114 g, Equation 1 yields 704 mg/O_2 kg/h at maximum activity, Xv = 3.3 lengths/sec. From Figure 6.10, extrapolated from the minimum, active level of this zero (standard) level by the Brett (1964) method, the standard rate is 256 mg O_2/kg /h. The difference, or scope, was 448 mg O_2/kg/h (704 to 256).

At 164 g, Equation 2 (1 percent IXTOC I) yields at X_v = 2.8 lengths/sec, 614 mg O_2/kg/h, which was considerably depressed. A corresponding Brett type of extrapolation yielded a standard rate of 214 mg O_2/kg/h, somewhat lower than the control as might be expected for continuously stressed fish. The difference from 614 to 214 of 400 mg O_2/kg/h was a scope which was about 89 percent of the control values.

The depression in the b_w coefficient in Equation 2 (0.36 compared with 0.71) in Equation 1 indicates that polluted waters adversely and selectively affects the larger fish. This has been repeatedly observed both in current studies by Wohlschlag and Cameron (1967), Kloth and Wohlschlag (1972),and others. For this study, an extrapolation from Equations 1 and 2 to a larger size, say 500 g, was instructive. For control fish, the scope is (460 to 167) = 293 mg O_2/kg/h with X_w = 500 g and X_v = 2.8 lengths/sec. Thus for a 500 g fish, the oil-exposed fish have a scope value that was about 67 percent of the control fish.

Clearly, the implications are that even these low concentrations of chemical toxicants in the 1 percent solution of the mousse-water phase can have a severe effect on the overall metabolism of organisms. In fisheries, the disappearance of larger members with exploitive stresses is well known, but little work has been extended to show if natural or pollution stresses

at very low, sublethal levels can have the same utlimate effect (i.e., the older and larger members tend to disappear from a population structure while the younger and smaller members survive), providing some recruitment is maintained.

Redfish Study

The redfish (Sciaenops ocellata) is one of the most important commercial and sport fishes in Texas waters. Redfish generally spawn around the mouths of tidal inlets on the Texas coast in the late summer and early fall. Oil from IXTOC I blowout was in Texas waters, not only while adult redfish were spawning, but also while the early larval stages were developing. This study was to determine the effect of IXTOC I oil on redfish eggs and larvae, which are very sensitive and susceptible stages to deleterious perturbations in the life cycle.

To determine the toxicity of IXTOC I crude oil on the eggs and newly hatched larvae of the redfish, three different tests were conducted using three forms of IXTOC I crude oil. In all cases, the eggs and larvae were obtained from captive redfish which were induced to spawn, using light and temperature manipulation to simulate natural conditions. All tests were performed in 32 ^{o}/oo seawater, maintained at 26°C.

In the first of these tests, a 1 percent concentration (25 to 30 ppm) of oil accommodated seawater (OAS) was used. This solution was prepared by agitating IXTOC I crude oil and filtered seawater for 2 hours and then allowing it to settle for 2 hours. The water, which was relatively free of large oil globules, at the bottom of the container was decanted off and used as OAS. Concentrations of 0 (control) to 100 percent seawater/OAS were prepared. Fifty, one-day-old redfish eggs were placed in each of the 11 different concentrations and allowed to stand without aeration. After 24 hours, the emerging larvae were counted.

The second experiment was conducted in the same manner as the first with the following modifications. The OAS was filtered using a 0.45μ Millipore filter, and the water-soluble fraction (WSF) was retained. Twenty-five, 1-day-old redfish eggs from a different spawn were used in Experiments 1 and 3. These were placed in mixtures of 0 (control) and 50 to 100 percent WSF and filtered seawater. The number of live and dead larvae and unhatched eggs were recorded.

In the third experiment, 500, 16-hour-old redfish eggs were placed in 1 ℓ of unfiltered seawater to which 4 g of IXTOC I mousse had been added. The mixture was maintained with gentle aeration. Another mixture of 9 g of mousse to 1 ℓ of water was prepared, aerated vigorously, and maintained at room temperature. Five hundred, 1-hour-old redfish eggs were added, and the number of live larvae were counted after 24 hours. Live and dead larvae were counted in the 4 g/ℓ preparation, while only live larvae were counted in the 9 g/ℓ preparation. Experiments using mousse were repeated 1 week later, using eggs 14 hours old, but modified in that after 24 hours,

the total number of live larvae, live deformed larvae (body bent dorsally and/or a large unabsorbed yolk sac), dead larvae, and unhatched eggs were counted.

Only live larvae were counted in Experiment 1 (Table 6.15). It was therefore impossible to ascertain the effect of the OAS on redfish eggs. Hatch percentage of nearly 100 percent was observed in other eggs from this same spawn. This, along with the short time (<1 hour) the eggs were subjected to the OAS before hatching, indicates that the 38 percent mortality in the control (0 percent) was an expression of normal mortality in 24-hour-old redfish held in this manner. Forty-eight to 52 percent mortality above control mortality was observed between 50 and 100 percent OAS/seawater mixture.

Live and dead larvae were used in Experiment 2 (Table 6.16). No dead larvae were found in the control or 50 percent WSF; 64 to 94 percent mortality was experienced between 60 and 100 percent WSF.

A large percentage (80 percent) of the 127 live larvae treated with 4 g of IXTOC I mousse in Experiment 3 were either deformed, unresponsive to tactile stimuli, or moved very slowly. There were a large number (250) of dead larvae that were highly deformed. Many of the larvae were brown and retained a large yolk sac, indicating that death occurred very shortly after hatching. After 24 hours, only five live larvae were found in the 9 g mousse/water mixture. Many of the unhatched eggs were observed floating in mousse that had accumulated at the water surface.

TABLE 6.15 Survival of redfish larvae after 24 hours in OAS (oil accommodated seawater).

OAS (%)	Live Larvae (No.)	Mortality (%)
0 (Control)	31	38
10	26	48
20	17	66
30	13	74
40	13	74
50	7	86
60	9	82
70	8	84
80	7	86
90	5	90
100	5	90

TABLE 6.16 Survival of redfish eggs and larvae after 24 hours in WSF
(water-soluble fraction).

WSF (%)	Live Larvae (No.)	Dead Larvae (No.)	Unhatched Eggs	Mortality (%)
0 (Control)	16	0	7	0
50	22	0	3	0
60	17	2	4	11
70	6	16	2	73
80	8	14	2	64
90	6	19	0	76
100	2	19	0	94

In the repeat of the mousse experiment using 14-hour-old eggs, the total number of eggs and larvae observed after 24 hours was lowest in the highest oil concentration (Table 6.17). This was probably due in part to the unhatched eggs being entrapped in the mousse and were thus not counted. Mortality was highest in the 9 g treatment where 96 percent of the larvae accounted for were dead or live deformed; 89 percent of the larvae accounted for in the 4 g treatment were dead or live deformed. After 48 hours, all larvae in the oiled beakers were dead, while living fish were still observed in controls.

TABLE 6.17 Survival of redfish eggs and larvae after 24 hours in two
IXTOC I crude oil mousse/seawater mixtures.

Mousse/1 ℓ seawater (g)	Live (No.)	Live (%)	Live Deformed (No.)	Live Deformed (%)	Dead (No.)	Dead (%)	Unhatched Eggs (No.)	Unhatched Eggs (%)	Total
0 (Control)	298	(67)	17	(4)	115	(26)	15	(3)	445
4	32	(7)	394	(85)	18	(4)	20	(4)	464
9	3	(1)	89	(28)	214	(68)	8	(3)	314

The water-soluble fraction (WSF) of IXTOC I crude oil was more acutely toxic than the oil accommodated seawater (OAS) fraction, since higher mortality was observed at a lower concentration in the WSF than in the OAS. The mousse mixture of 9 g/ℓ water was more toxic than a mousse mixture of 4 g/ℓ water. The large number of deformed larvae in the lower concentration of mousse indicated that possibly even this mixture would chronically cause 100 percent mortality after an extended period of exposure.

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Brown Shrimp Study

The brown shrimp (Penaeus aztecus) is a commercially important species, making up a large portion of the shrimp fisheries along the Texas coast. Adult shrimp migrate out of lagoons and estuaries into offshore coastal waters to spawn. Ocean currents brought IXTOC I oil into Texas coastal waters during this period of migration, and impact to the Texas shrimp fisheries was feared.

The purpose of this study was to investigate the effects of IXTOC I oil on adult brown shrimp in laboratory bioassays in an attempt to predict potential impacts to the brown shrimp fisheries.

Toxicity tests and burrowing behavior. Four groups (replicates) of shrimp, consisting of eight animals per group, were exposed to four different treatment concentrations consisting of 5, 15, 30, and 60 percent oil-accommodated seawater (OAS) fractions of IXTOC I oil. An additional group was maintained in oil-free seawater as a control. These animals were placed in aquaria containing approximately 4 cm of sediment in 14.5 ℓ of 27 ^{o}/oo aerated seawater. Animals were not fed. the tanks were sealed with black, polyurethane plastic to simulate darkness. Each tank was censused at the end of each 24 hours, for a 96-hour period. Dead shrimp were recorded and removed from the tanks. Shrimp behavioral activity was monitored daily by subjecting each tank to sunlight for 30 minutes to stimulate burrowing activity and recording the number of burrows. Initial observations indicated best results were obtained by limiting exposure to sunlight to 5 minutes, due to problems of reburrowing during the 30-minute period. Thus, the period of sunlight exposure was reduced to 5 minutes. After 96 hours of oil exposure, tests were ended.

Percent mortality for the shrimp at the various treatment levels are listed in Table 6.18. All test animals were retrieved from the experiments. There was no significant difference in mortality observed between controls and oil-exposed shrimps. The highest mortalities (9 percent at 24 to 96 hours) occurred in the highest exposure concentration (60 percent OAS).

TABLE 6.18 Mortality observed in adult shrimp exposed to four different OAS* concentrations for 96 hours.

| Treatment | % Mortality | | | |
(% OAS)	24-hr	48-hr	72-hr	96-hr
Control	3	6	6	6
5	3	3	3	3
15	0	0	0	0
30	3	3	3	3
60	9	9	9	9

*oil-accommodated seawater

After 96 hours of oil exposure, shrimp were exposed to light for
5 minutes and percent burrowing was recorded as listed in Table 6.19.
There was no significant difference in burrowing behavior observed between
controls and experimental shrimp, after 96 hours of oil exposure.   In
oil-exposed shrimp, approximately 50 percent of those above the sediment
would burrow within the 5 minute exposure to light.   Then the number of
burrowed shrimp was highest in the 30 to 60 percent OAS treatments, both
before (71 percent) and after (93 percent) exposure to light (5 minutes).

Oxygen consumption.   Differences in metabolic function of control and
oil-exposed populations of adult brown shrimp were determined by measuring
whole animal oxygen consumption.   The following tests were run as indicated
in Table 6.20.   All organisms were acclimated to 25°C for 15 minutes.
Respiration chambers were filled with supersaturated,

TABLE 6.19   Burrowing activity observed in control and 96-hour oil-exposed
shrimp before, during, and at the end of 5 minutes of exposure to sun-
light.

Treatment (% OAS)	% Burrowed Initially	% Burrowing w/in 5 min.	% Burrowing at end of 5 min.
Control	41	42	75
5	31	59	59
15	47	59	69
30	77	43	90
60	71	50	93

TABLE 6.20   Laboratory design of brown shrimp respiration experiments.

No. of Shrimp	No. of Organisms/ Replicate	Duration of Measurement	Treatment Tested
3	1	20 min.	Control, 15 & 60% OAS

filtered seawater and held to a constant temperature (25°C) in a circulating
water bath.   A Beckman model 0260 oxygen analyzer ($O_2/T°$) was used, and
changes in oxygen ($\mu\ell$ $O/_2/g/hr$) within the respiration chamber were recorded

every 5 minutes for the duration of measurements. Organisms were weighed wet to the nearest 0.001 g. Oxygen consumption was calculated for each replicate in $\mu\ell$ O_2/g/hr, and are recorded in Table 6.21. There were no significant (p < 0.05) differences measured between controls and any oil-exposed shrimp. There appeared to be a slight increase in oxygen uptake in the oiled compared with control shrimp, but these differences were not significant.

TABLE 6.21 Whole animal respiration rates ($\mu\ell$ O_2/g/hr) in adult Brown Shrimp acutely exposed to IXTOC I oil for 96 hours.

Oil Exposure Concentration	Whole Animal Respiration ($\mu\ell$ O_2/g/hr)				
	Mean	S/N	N	Statistical Significance*	P value*
Control	1.34	0.16	3	--	----
15% OAS	1.61	0.15	3	NS	0.40
60% OAS	1.45	0.12	3	NS	0.70

*determined by Mann-Whitney U-test

Marine Mammals

Little information is available concerning the distribution and natural history of marine mammals in the Gulf of Mexico. Davis (1974) describes 18 species of marine mammals that have been sighted in the Texas coastal waters. The only common nearshore resident is the bottled-nosed dolphin (Tursiops truncatus) which inhabits the inlets and the gulf near the inlets. The spotted dolphin (Stenella altenuata) is a pelagic species found farther offshore.

Porpoises were observed swimming in oil during two of the cruises. On Cruise FSU-1 (Florida State University) in July 1979, porpoises were seen riding the ship's wake as it went through tar ball fields and windrows. During the R/V WESTERN GULF cruise (22-23 August 1979), porpoises were observed surfacing in oil sheen and, in one case, in mousse-coverd water. No marine mammal mortalities were observed during the spill.

Marine Turtles

Five species of marine turtles have been reported along the Texas coast. The most commonly observed marine turtle is the Atlantic loggerhead (<u>Caretta</u> <u>caretta</u>). The other common species observed along the south Texas coast is the Kemp's ridley (<u>Lepidochelys</u> <u>kempi</u>). This endangered species, at one time, used Padre Island sand beaches as egg-laying areas. In a joint effort with Mexico, the NMFS and National Park Service are trying to reestablish Padre Island as a nesting area for the Kemp's ridley.

Two Atlantic green turtle (<u>Chelonia</u> <u>mydas</u>) carcasses were recovered from the foreshore, approximately 32 to 33 miles (51 to 53 km) south of Malaquite Beach. The partially decomposed carcasses were covered with oil. They were frozen and delivered to the U.S. Fish and Wildlife Service. A dead Kemp's ridley turtle was also turned in to the U.S. Fish and Wildlife Service. The carcasses were sent to the Patuxent Research Center for autopsy. Preliminary autopsies indicated there was no apparent cause of death other than oil contamination. There was little evidence of oil ingestion. The results of tissue analyses will better define these findings.

Zooplankton and Benthic Amphipods

During the impact of the Texas coast by IXTOC I oil, much concern was focused on potential effects of pelagic zooplankton and benthic infaunal invertebrates. Impacts to zooplankton were expected from floating oil slicks and sheens, while impacts to benthic invertebrates were expected from sinking oil and tar balls.

Two series of experiments were carried out on the acute toxicity of oil accommodated in seawater (OAS) made from the spilled IXTOC I oil. In one experiment, mixed natural zooplankton were exposed to OAS for 96 hours. A vital staining method was employed to distinguish dead from living individuals. In another experiment, a benthic amphipod, <u>Parhyale</u> <u>hawaiensis</u> (Dana), was acutely exposed to OAS. Results from these tests were used to predict potential impacts to zooplankton and benthic infauna.

Juvenile amphipods (one month old) used in the toxicity tests were obtained from stock cultures maintained at the Port Aransas Marine Laboratory of the University of Texas since 1976. They were kept in seawater (30 percent) filtered by glass fiber fish flake. Following the acclimation period, juvenile amphipods were exposed to the following OAS dilutions of 50, 40, 30, 20, 10, and 1 percent. Forty individuals were divided into two equal replicate groups and placed in 200 ml of each OAS dilution. An additional group of juvenile amphipods were similarly divided and maintained in oil-free seawater as a control. Mortality was observed for 7 days. Test medium was gently bubbled with air and not renewed during the experimental period.

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Zooplankton were collected at the Port Aransas Marine Laboratory pier and acclimated in seawater of 30 °/oo, at a room temperature of 24°C for 2 days, before the experiments began. Zooplankton were fed with a mixture of algae comprised of Dunaliella tertiolecta and Isochrysis galbana during both acclimation and exposure periods. Following acclimation, replicate samples of zooplankton were exposed to five OAS concentrations of 40, 30, 20, 10, and 1 percent. An additional group of zooplankton were maintained in oil-free seawater as a control. At the end of 96 hours of exposure, 10 mℓ of neutral red were added to each jar which contained 1 ℓ of test medium, and the zooplankton were then prepared following the procedures suggested by Crippen and Perrier (1974). To obtain percentage of survival for each sample, subsamples of at least 300 individuals were counted, identified, and determined for their status of living and dead animals.

OAS stock solutions used in all toxicity tests were prepared in the following manner. Oil was layered on the top of filtered seawater in a 4 ℓ aspirator bottle with a tube outlet near the bottom and shaken on an Eberback Shaker at low speed (260 excursions/min) for 2 hours. The lower portion OAS was drained after a 2 hour settling period and used as a stock OAS.

The chemical composition and the total amount of oil suspended and dissolved in seawater were analyzed at the time the experiment began. The prepared OAS stock contained 27 mg/ℓ of oil. Therefore, a 50 percent dilution would contain approximately 14 mg/ℓ of oil.

All experiments were maintained under the conditions of room temperature of 24°C (±2°C), and at salinity of 30 °/oo. Animals were also fed daily during all experiments.

At all test concentrations, ranging from 1 to 50 percent OAS, all individuals survived 7 days of exposure, except that two amphipods died at day seven in 40 percent OAS (Table 6.22). Additionally, there was no mortality observed in controls. Amphipods were actively moving and had no signs of abnormal behavior when compared with controls.

TABLE 6.22 Average percent survival of Parhyale hawaiensis in oil accommodated seawater (OAS).

Exposure Time		OIL CONCENTRATION OF OAS					
(hours)	Control	1%	10%	20%	30%	40%	50%
24	100	100	100	100	100	100	100
48	100	100	100	100	100	100	100
72	100	100	100	100	100	100	100
96	100	100	100	100	100	100	100
120	100	100	100	100	100	100	100
144	100	100	100	100	100	100	100
168	100	100	100	100	100	95	100

Zooplankton used in the toxicity study were typically a natural endemic to Texas coastal waters during the summer. The calanoid copepod, Acartia tonsa, comprised 65 percent of the test population. Other copepods that made up the remaining four most abundant species were Paracalanus crassirostris (26.3 percent), Oithona colcarva (6.6 percent), Corycaeus amazonicus (0.6 percent), and Eucalanus monachus (0.5 percent). These four species together with A. tonsa comprised more than 99 percent of test zooplankton populations.

Survival of copepods at all test concentrations were high, being ≥ 75 percent (Table 6.23). No significant trend in mortality was correlated to the concentration of OAS tested. Highest mortalities of copepods were recorded in sample 1 of both controls and 1 percent OAS. The reasons for this were not apparent, but judging from the mortality at the higher concentrations of OAS, it may be related to some effect caused by some unknown artificial factors rather than the toxicity of oil.

TABLE 6.23 Average percent survival of coastal zooplankton in oil accommodated seawater.

	Control	OIL CONCENTRATION				
		1%	10%	20%	30%	40%
Sample 1	47	65	82	91	96	80
Sample 2	87	88	83	81	76	83
Sample 3	67	76.5	82.5	86	86	81.5
Mean	67	76.5	82.5	86	86	81.5
S/N	11.6	6.6	0.3	2.9	5.8	0.9
N	3	3	3	3	3	3

These two studies indicated that the OAS of the spilled IXTOC I oil was not acutely toxic to the two kinds of crustaceans tested, possibly because this oil has been weathered for a long time. Thus, the most toxic components such as benzenes and napthalenes may have already evaporated to the extent that the residual components were no longer acutely toxic to these two marine invertebrates (amphipods and copepods). Previous studies (Lee et al., 1978) have indicated that weathered oil was much less toxic than fresh oil.

Chemical analysis of the test oil also showed that only a small amount of oil was dissolved into seawater and this total water soluble fraction was less than 3 mg/ℓ (K. Winters, pers. comm.). The water soluble fractions of a few oils have been characterized. Anderson et al. (1974) reported 23.75 ppm for south Louisiana crude oil, 21.65 ppm for Kuwait crude oil, and 5.28 ppm for a No. 2 fuel oil. Winters et al. (1976) have quantified

another four EXXON fuel oils, including 16 ppm for Montana, 19 ppm for Baytown, 14 ppm for New Jersey, and 9 ppm for Baton Rouge.

In general, the toxicity of either oil in seawater or water soluble fractions was positively related to the concentrations of aromatics such as benzenes and naphtalenes, generally found in the water soluble fractions (Anderson et al., 1974; Byrne and Calder, 1977) and the total amount of organics present in seawater (Lee, unpubl. data). Thus, the toxicity varies from one oil to another depending upon concentrations and toxic properties of the aromatic fractions of the particular oil. Toxicity also varied among animals. For example, the 96-hr-LC_{50} of a No. 2 fuel oil was about 3.0 ppm (OAS) and 3.5 ppm (WSF) for the grass shrimp, Palaemonetes pugio. Under the same test conditions, the 96-hr-LC_{50} for the post larvae of the brown shrimp, Penaeus aztecus, was 9.4 ppm (OAS) and 4.9 ppm (WSF), respectively (Anderson et al., 1974). For the two taxa (copepods and amphipods) tested in this present study, estimated values of 96-hr-LC_{50} were above the concentrations tested (13.5 mg/ℓ). Obviously this weathered IXTOC I oil was far less toxic than either south Louisiana crude or certain No. 2 fuel oils.

SUMMARY OF BIOLOGICAL STUDIES

Inlets and Lagoons

The only significant oil impact observed to inlets or lagoons was on 28-29 August 1979, when approximately 12 metric tons (86 barrels) of IXTOC I mousse impacted approximately 900 m of fringing marsh that bordered Lydia Anne Channel inside the Aransas Pass. Measurable effects upon animals were minimal as were effects to lightly oiled marsh grasses. Moderately oiled marsh grasses exhibited stress symptoms, but plant growth continued. Small, scattered areas of heavy oiling resulted in dead or dying marsh vegetation. Tides and wave action had dispersed much of the oil from these areas by 11 September 1979. Physiological bioassays with IXTOC I oil (in the form of mousse) did not immediately inhibit photosynthesis or respiration of representative nearshore plankton samples and seagrasses.

Sand Beaches

Aerial counts of wading and shorebirds indicated fewer birds were present during the period of heaviest oiling. Following heavy seas due to a tropical depression (31 August to 1 September 1979), an influx of birds occurred. A mid-September tropical storm that resulted from Hurricane Frederic removed much of the oil from the beaches, and the number of birds using the beach areas increased dramatically.

Ground surveys of oiled beaches revealed the following. Wading and shorebirds responded directly to oil concentrations on the beach in four ways: (1) birds avoided heavily oiled beaches; (2) birds avoided more heavily oiled parts of the beach, being more common on the back beach rather than the foreshore during periods of heaviest oil; (3) oiled birds spent less time feeding and more time resting; and (4) the entire bird population showed a decrease in size. This was interpreted as abandonment of sand beaches, because following the storm's removal of oil from beaches, bird populations returned to former numbers and reinvaded previously oiled foreshores.

Ground observations of wading and shorebirds indicated that the oiled birds never exceeded 10 percent, peaking during periods of heaviest beach oiling. Eighty-two (82) birds were more than 75 percent oiled; these were judged as unlikely to survive. Few dead birds were found; however, removal by predators may have accounted for this.

Physiological bioassays of birds related to the endangered peregrine falcon and whooping crane showed reduced fitness (lethargy, weight loss, and increased mortality), although the toxicity of IXTOC I oil to these species was judged low when compared with other crude oils.

Site-specific studies of the infaunal communities at sand beaches before and after oiling indicated that the subtidal zone experienced a significant change in population size following oiling. Densities of subtidal crustaceans (mostly mole crabs and amphipods) were greatly reduced. Changes in other subtidal infauna were more variable, although the trend was toward reduced numbers, especially at the second trough and bar. The intertidal infauna did not show an overall population decrease, however. Intertidal crustaceans populations were significantly reduced as was infaunal community diversity.

Ghost crabs avoided oil on the lower beach by migrating farther up the beach in some cases; however, at one moderately oiled transect, no significant change in distribution was measured. The response of wrack-associated amphipods was also variable, although they disappeared at five of six transects following oiling.

Laboratory bioassays with IXTOC I oil (in the form of mousse) had minimal effects on mole crabs, surf clams, or polychaetes in acute exposures. This may support results of field studies that indicate a limited impact to infauna.

Effects Other Than Oil

Population decreases may have been affected by a tropical storm that hit the Texas coast in September 1979. The beach was reworked back to the foredune ridge. The berm crest was flattened. Seasonality may have also had an effect on the decrease in population. Peak summer populations would be decreasing during September. This was documented for Donax sp. (Loesch, 1957) and may also hold true for other beach fauna.

Offshore and Nearshore Environments

Toxicity studies and bioassays were conducted on three commercially important species. The spotted seatrout was sensitive even to low levels of oil contamination. Symptoms, such as equilibrium problems, sluggishness, tail rot, and coughing spasms, were observed in tests using 1 percent OAS.

Redfish eggs and larvae were tested in OAS, WSF, and two different mousse/seawater fractions. WSF was more acutely toxic than the OAS or mousse/seawater fractions. Of concentratons >50 percent WSF, mortality of larvae increased rapidly from 11 percent dead (60 percent WSF) to 94 percent dead (100 percent WSF). OAS, WSF, and mousse/seawater fractions were deleterious to redfish larvae and eggs.

Brown shrimp were more resistent to the oil than were the fish. The highest mortality was 9 percent at the 60 percent OAS concentration. There was no significant difference in survival between the control and oil-exposed shrimp.

Though porpoises swam in oil sheen and on an occasion in mousse, no mortalities or abnormal behavior was observed on any research cruise.

Three oiled turtles which were found dead were turned over to the U.S. Fish and Wildlife Service. Autopsies at the Patuxent, Maryland, laboratory could find no causes other than oil for the deaths. Tissue analysis will further define this.

Toxicity tests were conducted on zooplankton and benthic amphipods. The OAS, even at 50 percent concentration had little effect on the short-term survival of the amphipods. There was 100 percent survival at all test levels except the 40 percent concentration, which had a 95 percent survival rate. In tests conducted in concentrations from 1 to 40 percent OAS, zooplankton had a 75 percent or greater survival rate. Control survival was 67 percent and was not significantly different from test animals. Tests on both the zooplankton and amphipods indicated that the IXTOC I oil was not acutely toxic to either one.

CONCLUSIONS

IXTOC I oil failed to impact large areas of marshlands. Small amounts of oil that entered inlets appeared to have little or no measureable effects on the productivity of marshes and inlets. This was observed following the impact of IXTOC I oil to a salt marsh, and also through physiological bioassays on representative phytoplankton and seagrasses.

During the period of heaviest oiling of beaches, population densities of wading and shorebirds remained low. Substantial increases in bird populations occurred after the natural removal of oil from beaches by tropical storms and with an influx of newly arriving migratory bird species.

Birds were observed to avoid oiled portions of beaches and to move to other habitats during periods of heaviest oiling. No more than ten (10) percent of the bird population utilizing beaches was oiled at any time and few carcasses were found. Physiological bioassays were run using weathered IXTOC I oil on birds related to the peregrine falcon and the whooping crane. It was concluded that neither peregrines nor whooping cranes would be affected by the consumption of oil-contaminated prey.

Monitoring of infaunal populations at oiled beaches indicated measurable changes in the population size. Total population densities were significantly reduced in the lower intertidal zone and in the second bar and trough of subtidal habitats. Numbers of crustaceans (mole crabs and amphipods) were significantly lowered in both zones following the oil spill. It was difficult to distinguish the effects of the oil spill from natural factors, especially storms and natural population variations. Results of acute (96 hour) toxicity tests, exposing IXTOC I oil to dominant infaunal organisms, indicated no significant mortality. These results support the findings of field studies, thus suggesting that IXTOC I oil was not acutely toxic to beach fauna, although sublethal effects (significantly decreased respiration rates and avoidance behavior) were observed in oil-exposed mole crabs.

Results of acute toxicity tests, conducted on subtidal amphipods and zooplankton, suggested that IXTOC I oil was not toxic to these species.

Additional toxicity tests conducted on adult redfish, seatrout, and brown shrimp, indicated that IXTOC I oil was not acutely toxic to these commercially important fisheries species. However, high mortalities were observed in larval and juvenile fish species tested. Toxicity was greatest in larval redfish as many deformities in eggs and larvae were observed. Comparisons of redfish larval, toxicity, indicated that the oil accommodated seawater (water soluble fraction plus small oil microdoplets of mousse) fraction was more toxic than the water soluble fraction of the IXTOC I oil. Additional redfish larval tests indicated that the mousse fraction was nearly 100 percent toxic. The results of the studies may suggest that toxicity to redfish larval may be due to smothering rather than chemical toxicity per se, since the mousse and oil-accommodated seawater fractions were more toxic than the water soluble fraction. High mortalities were also observed in juvenile seatrout. In open water situations such as the Gulf of Mexico, adult organisms may be able to avoid contaminated areas; however, impacts to eggs, larvae, and juveniles would occur in heavily oiled areas.

All toxicity tests were conducted using the POINT BAKER mousse sample of the IXTOC I oil, which did not contain high concentrations of many aromatic oil fractions such as napthalene, methyl napthalene, dimethyl napthalene, and trimethyl napthalene (Ed Overton, Univ. of New Orleans, New Orleans, Louisiana; personal communication). These compounds are acutely very toxic to many adult marine organisms. The small amount of toxicity observed in tests with adults may have resulted from the very small concentrations of these toxic aromatic compounds in the POINT BAKER mousse.

The effect of IXTOC I oil on marine mammals are preliminary at this time. General indications are that there were no observable effects to marine mammals found during the different research cruises conducted at various times during the spill.

Initial findings indicated that sea turtle mortalities were possibly oil-related. However, preliminary findings suggest that incidences of mortality were rare and isolated cases.

These supportive ecological studies have indicated that IXTOC I oil did visibly impact considerable shoreline areas in South Texas. Field studies conducted at marshes and beaches suggest that IXTOC I oil may have caused: (1) significant population shifts and avoidance by major wading and shorebird species at heavily oiled beaches; (2) subtle reductions of infaunal population densities throughout the intertidal beach habitat, with significant declines occurring only in the lower intertidal zone and the second bar and trough of subtidal habitats; major population declines were only observed in two species of crustaceans [mole crabs (intertidal) and amphipods (subtidal)]; (3) minor impacts to marsh vegetation were observed; and (4) minor impacts to marine turtles and mammals were observed. However, it was difficult to distinguish the effects of spilled oil from effects from natural factors such as tropical storms, seasonality, and normal population variation.

Laboratory studies conducted using POINT BAKER mousse samples of the IXTOC I oil indicated that: (1) acute exposures of the oil-accommodated seawater fraction were not acutely toxic to dominant beach infauna such as mole crabs, surf clams, and polychaete worms, although significant sublethal physiological effects and avoidance behavior were observed in mole crabs; (2) acute exposures of the oil-accommodated seawater fraction to subtidal amphipods and zooplankton were not toxic; (3) acute exposures of the oil-accommodated seawater, water soluble, and mousse fractions to redfish larvae, were toxic, with highest toxicity being observed in the mousse and oil-accommodated seawater fractions (rather than the water soluble fraction); (4) acute exposures of the oil-accommodated seawater fraction to seatrout indicated significant toxicity in juvenile fish, but no toxicity in adult-sized fish; and (5) acute exposures of the oil-accommodated seawater fraction to brown shrimp were not toxic. Laboratory studies indicated that IXTOC I oil was not acutely toxic to the adult, marine organisms tested. These laboratory findings tend to support results from field studies which indicated that IXTOC I oil caused only limited impacts to beach infauna and other marine organisms.

Results of subtidal amphipod and zooplankton toxicity tests were inconclusive in that both species were resistant to low concentrations of oil tested. However, effects of higher concentrations than those tested are unknown.

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APPENDICES

A

BEACH PROFILE STATIONS TO MEASURE OIL DISTIRBUTION AND BIOLOGICAL IMPACT

Erich R. Gundlach, Kenneth J. Finkelstein,
Daniel D. Domeracki, and Geoffrey I. Scott

During the time IXTOC I oil was impacting the Texas beaches, extensive aerial photographs and taped observations were made during almost daily helicopter overflights. These records determined oil distribution along the shoreline and recorded oil transport and dispersal processes. The preparation of an oil-concentration map for the entire impacted coastline was a major objective of each flight.

In addition, 103 field stations were established and visited between 17 July and 10 October, 1979. The are shown in Figure A.1. Many of these stations, particularly those in the oil-impacted areas, were revisited several times. Two types of stations were established:

> Profile stations: 65 total, set up along exposed and lagoonal beaches to permit geomorphic and biological characterization of all habitat types.

> Photo stations: 38 total, especially along each of the three major inlets, set up for rapid determination of oil concentrations, obvious biological impact, and habitat type.

At each of the profile stations, the following work was completed:

1. The topographic profile of the beach was measured; concurrently, notations were made of all relevant changes to the beach, including the nature and occurrence of the oil and biological impact. Permanent stakes were set to mark the location of the profile.

2. Sediment size was estimated along the profiles.

3. Trenches were dug to determine the distribution of buried oil. Each trench was sketched and photographed in detail.

4. A sketch was drawn to show general coastline geomorphology, resident biota, and surficial oil distribution. Several examples are given in the discussion of oil impact (see Chapter 2, Part II).

5. The beach was photographed in detail.
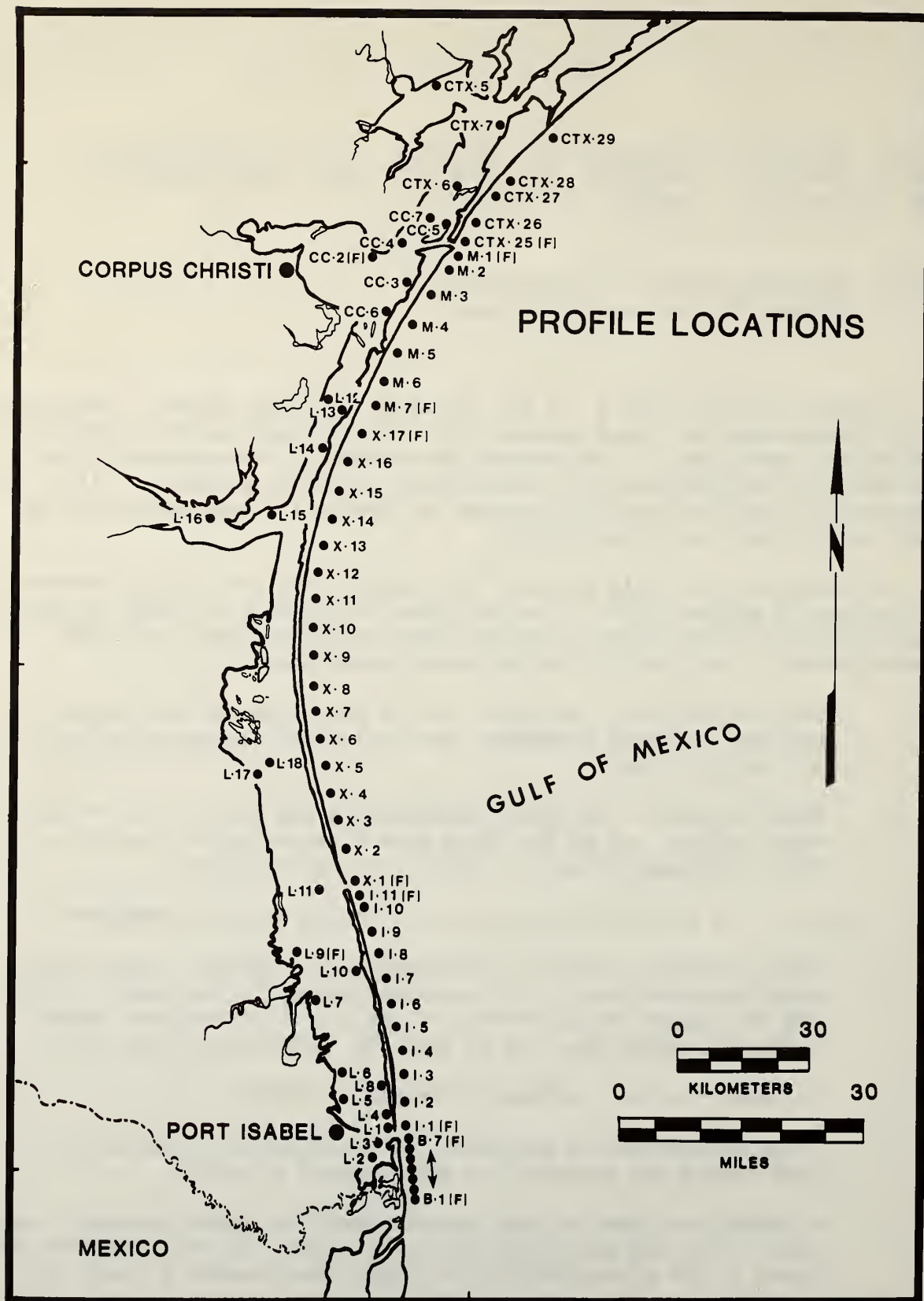
Figure A.1   Location of profile stations along the south Texas coast.
Sites surveyed before oil impact provided baseline data to monitor
ecological and physical changes.

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6. Biological observations were made as follows:

    a. Macroflora and macroepifauna were censused by projecting a 20-grid square over a randomly selected 1 m² area in each interval. These censuses were taken at random within the interval and recorded in grid per taxon units. Macroflora counts were later converted into percent coverage while macroepifauna were recorded as number of individuals of each taxon per 0.25 m²

    b. Macroinfauna were censused with triplicate can cores driven straight into the substrate along the upper, middle, and lower beachface. Infaunal samples were field-sieved with 1-mm mesh, or bagged for lab sorting. Samples for lab analysis were fist narcotized with propylene phenoxethol, stained with rose bengal, preserved in 10 percent formalin, and then bagged and labeled.

7. Various samples of sediment biota were collected for possible chemical analysis as described in a later section.

At photo stations, the site was visually inspected, photographed, trenched, and sketched. Observations were recorded in a field notebook and on recording tape. Chemical, biological, and sedimentary samples were taken when deemed necessary.

CALCULATION OF OIL QUANTITY ALONG THE SHORELINE

At each profile station, a topographic profile was measured, during which the surface oil concentration (in percent) was estimated for each sample interval by the three members of the field team. The thickness of oil in each interval was measured. Based on surface concentrations, the amount of oil coverage was determined to be very light, light, moderate, or heavy as designated in Table A.1.

Table A.1 Oil coverage of an 8- to 10-m Intertidal Zone

Very light	10 percent
Light	10 to 24 percent
Moderate	25 to 64 percent
Heavy	65 percent

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Examples of light, moderate, and heavy concentrations are shown in Figures 2.14 to 2.18.

In addition to surface oil coverage, subsurface oil was examined and measured (thickness and extent) by trenching. The total oil along the shoreline was then calculated as follows:

Surface oil was calcuated by the following formula:

LWD x %C x SG x %0

yields grams (per meter length
of oiled beach)

where (for each interval along the beach profile):

L = length of beach oiled in cm - calculations are made for
    100-cm (1 m) interval, and then multiplied by the entire
    stretch of beach characterized as light, moderate, or
    heavy.

W = width of oiled zone in cm.

D = thickness of oil in cm (0.3 to 0.4 cm was common).

%C = percent of surface area covered by oil (in decimal units).

SG = specific gravity of the oil in g/cm^3 (assumed to equal 1.0).

%0 = percent oil in mousse in decimal units (assumed to be 0.4;
    40 percent oil, 60 percent water).

Example: Station STX-4C, Mustang Island, 20 August 1979.

100 x 140 x 0.4 x 0.05 x 1.0 x 0.4 =	112 g
100 x 130 x 0.4 x 0.05 x 1.0 x 0.4 =	104 g
100 x 400 x 4.0 x 1.00 x 1.0 x 0.4 =	64,000 g
100 x 600 x 4.0 x 0.95 x 1.0 x 0.4 =	91,200 g
	155.4 kg

Total length of heavily oiled zone = 500 m x 155.4 kg = 77.7
metric tons (1000 kg = 1 metric ton = 1 long ton = 2200 lbs)

Buried oil was calculated by the following formula:

$LL_b T_b$ x   %0   x   SG

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where:

L = length (cm) of oiled beach at each sample interval.

L_b = length (cm) of buried oil-sediment layer measured
perpendicular to shore.

T_b = thickness (cm) of the buried layer.

%O = percent oil within the layer (assumed to be 10 percent).

SG = specific gravity (g/cm^3) of the oil.

As noted previously, units are in centimeters and grams.

OIL/SEDIMENT SEPARATION CALCULATIONS

A chemical separation of oil from sediment was done in selected samples
from temporary cleanup piles on Mustang and North Padre Islands to arrive
at an estimate of the quantity of oil removed during cleanup. The calcula-
tion involved the following steps.

1. Oil was removed from each weighed 150-gram sample by a 36-hour
    Soxhlet extraction, using 50-50 methanol-benzene solvent.

2. Solvent was removed with a rotary evaporator for 15 hours.

3. The remaining oil was weighed.

4. A 20-mℓ sample of clean sediment was weighed to determine bulk
    density (includes pore space) of the sand.

5. Percentage oil by weight was converted to percentage oil by
    volume by the formula:

$$\frac{\text{oil weight: (specific gravity, 0.94 g/cm}^3)}{\text{weight clean sand: (bulk density, 1.41 to 1.54 g/cm}^3)}$$

6. Percentage oil by volume was multiplied by the measured volume of
    oil-sediment layer at each cleanup storage site to determine
    total volume oil.

7. Total volume of oil was multiplied by the oil specific gravity to
    obtain the total weight of oil at each sample site.

CHEMICAL AND SAMPLING AND CHAIN OF CUSTODY

Chemical and biological samples collected for chemical analysis between 17 July and 10 October 1979 were taped shut with signatures attached across seals to maintain chain-of-custody. The samples were frozen at $-17^{\circ}C$ and turned over to a NOAA representative responsible for all accumulated chemical and biological samples.

Chemical sampling from 26 September to 3 October was conducted using hexane-washed glassware. Glassware was washed with soap and tap water, rinsed three times in tap water, washed with reagent-grade hexane, and then a final time with nano-grade hexane. Caps were placed over aluminum foil previously baked at $260^{\circ}C$ for 2 hours.

B

MARINE CRUISES

Edward Overton

VALIENT Cruise (USCG) 16-21 July 1979

The cutter VALIENT cruise was undertaken to determine surface circulation on the Continental Shelf of the western Gulf of Mexico, and to establish the regime of water currents for increasing the accuracy of forecasting oil movements. During the 6-day cruise, the participants also collected samples along the leading edge of the slick before it entered U.S. territorial waters for analyses of the physical properties and chemical characteristics of the oil. They also observed and logged the occurrence of oil in the gulf water.

POINT BAKER Cruise (USCG) 27-28 July 1979

The POINT BAKER cruise sampled the leading edge of IXTOC I oil before oil patches entered U.S. territorial waters early in August 1979. The sample collected was for studies of short-term (acute) lethal and sublethal effects on local Gulf of Mexico biota, to be performed at University of Texas Marine Science Institute/Port Aransas Marine Laboratory (UTMSI/PAML). Also, a preliminary chemical characterization of the POINT Baker sample was completed and compared with analyses of other available samples of IXTOC I mousse or oil suspected to be of IXTOC I origin.

FSU-I, LONGHORN Cruise 26-31 July 1979

Cruise FSU-I, made aboard the LONGHORN (UTMSI/PAML) and sponsored by the NSF, was undertaken to install six deep-ocean current water arrays as part of the Florida State University project (under the direction of Wilton Sturges) to study the Western Boundary Current in the Gulf of Mexico (Amos, 1980). The cruise also served as a shake-down exercise in deployment and operation of a shipboard computer system coordinating STD casts, XBT profiles, and continuous sea-surface temperature sensors.

The LONGHORN departed Port Aransas, Texas, and proceeded to below the 24th parallel, off the Mexican coast, before turning north to return to Port Aransas. During the cruise, considerable amounts of oil were encountered and a log was maintained of these sightings. As the primary objectives of the survey did not include sampling spilled oil, only a few samples of opportunity was taken.

The most common form of oil encountered was tar balls ranging from pea-sized and smaller to about 20 mm in diameter. The tar balls were frequently aligned and concentrated in windrows. Some tar balls were observed sinking or suspended several centimeters below the surface, especially in windrows. Breakdown of the tar balls could be observed as a "wake" of sheen, often present behind the oil particles.

LONGHORN I (Mousse I) 4-8 August 1979

The LONGHORN I cruise was the initial search for the presence of IXTOC I oil in the water column off the southern Texas coastline, encompassing the region from Port Aransas south to the Mexican border (Amos, 1980). The cruise was initiated at a time when no IXTOC I oil had been sighted in U.S. waters, but was approaching rapidly from the south. An estimate of the amount of submerged oil was urgently needed by the spill response strike teams on the mainland so they could assess the potential effectiveness of booms being placed across various barrier island passes to protect the sensitive estuarine areas. Divers made visual observations and collected samples. Concurrent with the more immediate objective, a variety of samples were taken to begin investigation of the oil spill phenomena. Although the LONGHORN I was a relatively short and hurried cruise, several classes of samples were collected, including oblique plankton tows, whole water samples, filtered particulates, surface and submerged hydrocarbons (sheen, mousse, tar), and sediments. Physical oceanographic measurements included STD casts, XBT's, rosette samples, and current drifters.

LONGHORN II Cruise (Mousse II) 15-22 August 1979

The LONGHORN II cruise surveyed hydrocarbon concentration gradients along the Texas-Mexican coastline at the peak of IXTOC I impact in U.S. waters (Amos, 1980). The ship traversed the region from Port Aransas to approximately 150 miles south of the Mexican border. Continuous sea-surface observations were maintained and logged hourly. Divers were deployed frequently for subsurface observations. In mid-to-late August, oil was encountered throughout the entire cruise track and was rarely out of sight. Tar balls (1 to 3 cm in diameter) and, to a lesser degree, slightly larger conglomerants (up to 20 cm in diameter) were the common forms. Tar balls were found with or without associated sheen, depending on sea conditions, and were more often in windrows when a breeze was blowing (as was usual). A single large patch of heavy mousse was encountered and sampled at Station V-6A. While the LONGHORN occupied this station, an unidentified aircraft appeared and applied dispersant to the mousse patch.

Sampling stations were located along four transects (II-7 stations, IV-7 stations, V-8 stations, VI-3 stations) with the line of stations running roughly west to east from the inner Continental Shelf to the shelf/slope dropoff.

Physical oceanographic measurements included STD casts, rosette samples, XBT's, and surface current metering. Sampling included hydrocarbons (sheen, mousse, tar balls), whole and filtered water, pumped articulate filtrates, oblique plankton tows, and sediments. A few samples of biota were also retrieved.

Observations on the physical states of oil encountered were logged. Tar balls, more descriptively called tar flakes, were by far the most common form of oil sheen. Their median diameter was probably less than 3 cm and only rarely were they up to 20 cm wide; frequently, they were less than 1 cm in diameter. The tar balls occurred in patches, streaks and, most often, in windrows.

When the wind was calm or light the tar balls spread out over the surface and invariably a sheen patch formed. Tar balls could be seen "bleeding" irridescent wakes into the sheen, particularly in sunlight. Oil-produced sheen was never encountered without tar balls. Conversely, however, tar balls were often found without a surrounding sheen. As the wind increased, the patches of sheen broke up into smaller patches, then into wide streaks and finally into windrows. The stronger the wind, the less shiny was the surface of the slick and in winds of >20 knots, it was hard to tell whether or not a sheen was present.

When the tar balls were concentrated in windrows they could often be seen sinking, sometimes out of sight and at other times returning to the surface. When the winds were calm and the tar balls were in patches of sheen, they were never observed to sink.

Tar balls were seen beneath the surface by divers whenever there was oil on the surface. They were found mainly in the upper 10 feet, but were observed as deep as 65 feet. The concentration of oil below the surface was much lower than that on the surface. Particles were usually only a few millimeters in diameter and were almost always described as thin and flaky. No obvious change in particle density coincident with the thermocline was reported, but a general thinning out of particles with depth occurred.

Particles were found down to the nepheloid layer (turbid water zone found adjacent to the bottom), but not within the nepheloid layer, nor were they seen on the bottom by the divers at any station or found in any of the sediment samples.

Tar balls are tarlike pieces of oil, ranging from light-brown to black. After collection, they easily fused together, were sticky to the touch, and readily liquified in sunlight to a dark, viscous liquid.

Mousse is a semiliquid emulsion of (IXTOC) oil and sea water, presumably named for its color (milk-chocolate) rather than its texture. In the nomenclature adopted for the LONGHORN cruises "mousse" refers only to

the large patches of thick oil, still somewhat liquid, before it broke up
into tar balls. Other scientists have referred to tar balls as mousse
(indeed, tar balls may coalesce and in sunlight become mousse again).

The "Big Mousse Patch"

        At 1110 CDT, 18 August 1979, en route to station V-6, the LONGHORN
encountered a large area of heavy oil completely covering the sea surface.
It was reddish to chocolate-brown in color, highly viscid in texture, and
contained much debris. It was presumed that this was a classic example of
"mousse" and station V-6A was initiated. This was th only genuine mousse
encountered on the LONGHORN II cruise. A strong odor, described as like an
"old gas station," permeated the area. The mousse made a memorable sound
as it "slurped" against the side of the ship. When the surface of the oil
parted, several schools of small silvery fish and some sharks could be seen
swimming below perhaps due to the shade provided by the oil cover. Shortly
after the mousse was found, a DC-6 aircraft appeared and sprayed the patch,
presumably with a dispersant; after the spraying had ceased, the LONGHORN
steamed back into the mousse and found the area of the patch appeared
smaller, as if the oil had been "herded" by the chemical. Its texture was
now more liquid but the layer was thicker, although it was difficult to
judge exactly what the immediate effects of the spraying had been. Another
surface sample was taken, but due to the extremely noxious smell surrounding
the patch, making some of the crew feel ill, the LONGHORN retreated from
the mousse.

        The purpose for the EPA-sponsored OSV ANTELOPE cruise was to obtain
'ground truth' to accompany aerial observations of sheen and mousse in the
northwestern gulf, as well as to survey the water column and bottom for
accumulations of IXTOC I oil. Objectives as outlined in the cruise plan
were to:

    1.   Perform sea-level observations of surface oil, mousse, and sheen
          concentrations in conjunction with aerial overflights.

    2.   Evaluate the physical chemical phases that the oil has taken.

    3.   Examine subsurface distributions of oil.

    4.   Evaluate the concentrations and composition of the oil sheens,
          mousse, and tar on a real-time basis using spectrofluorometry.

    5.   Relate oil concentration observations to physical phenomena
          (water column structure, etc.).

    6.   Update the offshore distribution of oil to enable possible time
          of impacts on Texas and/or Louisiana to be estmated.

    7.   Examine the potential presence of toxic components in waters
          adjacent to and beneath mousse patches using in situ bioassays.

8. Investigate sediment and benthic samples, specifically in near-shore mixing areas and in the nepheloid zone, for petroleum hydrocarbons.

9. Examine selected species of fishes and invertebrates to determine potential body burden or food web uptake of petroleum hydrocarbons.

10. Obtain fresh-as-possible samples of water-borne mousse for examination for microbial degrading organisms and to add to better understanding of photo degradation steps.

The cruise comprised three legs with the ANTELOPE putting into port for several days between segments.

Leg I, 25 August to 27 August. The general cruise track was from Pensacola down to 28°00'N latitude to the Flower Garden reef and then up to Galveston, Texas. Samples of water, tar balls, oil slicks, oiled sargassum weed, and the water under tar ball and sargassum slicks were obtained.

No large slicks were observed during this leg of the cruise. Some hydrocarbons detected by on-board fluorimetry were attributed to either shipboard contamination or background from the multitude of offshore oil drilling platforms in the region.

Leg II, 29 August to 31 August. The cruise track of this leg started at Galveston, ran to the Flower Garden reefs, back near shore between Galveston and Corpus Christi, Texas, then south in response to a request from a Coast Guard overflight before coming into port in Corpus Christi.

Sediment samples were obtained, neuston tows were made, and a vertical upward tow was made using the bongo nets. Not all samples obtained on this leg were analyzed (due to personnel limitations), but no oil appeared in the analyses that were conducted. Neither was any oil observed on the sea surface that was thought to be of Mexican origin.

Leg III, 3 September to 8 September. Leg III of the cruise was scheduled to sample along three lower BLM transects that had been occupied by the LONGHORN two weeks earlier. Benthic and pelagic biological ocean monitors were obtained. The cruise covered the 3rd (second from most southern) BLM transect, and sampled at the most landward station of the 4th (most southern) BLM transect before being terminated early due to engine problems. At 26°08.6'N latitude and 97°06'W longitude, samples of water, mousse, degraded oil, water-borne tars and tar balls, and mousse, tars and tarred sediments from the beach were obtained for bacterial and chemical analyses.

R/V RESEARCHER/PIERCE Cruise, 11-27 September 1979

The NOAA ship RESEARCHER and a companion vessel, the G.W. PIERCE (Tracor Marine, under contract to NOAA) departed Miami, Florida, on 11 September to survey and sample in the region of the IXTOC I wellhead, Bay of Campeche, and to track the oil northward into U.S. territorial waters. Objectives of the cruise were to:

1. Determine the effects of physical, chemical, and microbial weathering of spilled oil in the marine environment on its chemical and physical properties.

2. Determine the fate of spilled oil in the marine environment.

3. Estimate the microbial degradative input to weathering of spilled oil.

4. Study the effect of spilled oil on bacterial and planktonic communities.

The vessels conducted coordinated operations in the vicinity of the well head, with the RESEARCHER sampling just outside the main plume of spilled oil and the surrounding vicinity, while the PIERCE occupied stations within the plume and in other areas with heavy concentrations of mousse. A helicopter carried by the RESEARCHER was used for reconnaissance flights to plan and coordinate sampling strategies and to observe the physical formation and mutation of the oil plume as it moved away from the IXTOC I well head. Small launches were deployed by the RESEARCHER for sea-level sampling of mousse, sheen, and air over slicks.

Microbiological investigations and sampling formed a significant part of the research efforts conducted during the joint cruise. Long-term incubation experiments were performed on-board the PIERCE to estimate potential bacterial degradative effects on the weather of mousse. Microcosm experiments conducted aboard the RESEARCHER served to measure assimilation of 14_C-labeled amino acids, hexadecane, and naphthalene, to estimate bacterial metabolic rates and uptake. Selective changes in species makeup of microcosm bacterial communities were also monitored and compared with the 'real-world' samples.

At a total of 46 stations occupied by the two vessels, extensive collections of many classes of samples were taken, including physical oceanographic measurements, microbiological samplings, and samples destined for detailed chemical analyses. The combined effort generated over 1,500 samples of all classes, with roughtly 800 of these for chemical assay. The PIERCE occupied 17 stations, most of which were in the immediate vicinity of the well head.

The RESEARCHER occupied 29 stations (excluding samples of opportunity), which fall into two groups:

1. Stations in the vicinity of the well head and below the 23rd parallel off the Mexican coastline.

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2. Stations comprising two sediment sampling transects made off the southern Texas coastline, one of which corresponds to the previous BLM-STOCS transect IV, for which there is prespill baseline data. Two additional stations, where more complete chemical sampling was peformed, were occupied offshore of Brownsville and Corpus Christi. Several samples of opportunity were taken from the beaches on either side of the U.S.-Mexican border.

The second group of RESEARCHER samples represents samples that could be applicable to a damage assessment program for the south Texas environments. Analysis of samples collected in the vicinity of the well head will provide much insight into weathering processes, and hopefully, provide an unequivocal characterization of IXTOX I oil. Their usefulness to damage assessment beyond this information is limited.

RESEARCHER Operations

Physical oceanographic measurements taken throughout the cruise consisted of STD profiles of all stations and XBT sections fired every 15 n mi when steaming in water depths exceeding 100 m. Sampling of the water column was coordinated with salinity and/or thermal profiles. Samples included whole and filtered water sediments, sediments, flotsam, and water and beached hydrocarbons.

Oil Dispersal Observations

During the time the vessels were near the IXTOC I well head (15-21 September), the well was on fire and putting out large volumes of crude oil on the sea surface. Flames from the well covered approximately 1 acre. Two relief well platforms, the AZTECA and INTEROCEAN II (of Houston), were near the well site, the AZTECA being located about 1/4 mile to the north and INTEROCEAN II about 1/4 mile east of the burning well head.

Upon our arrival on 15 September, the well output was to the northeast at about 055° true. Previous reports, through around 10 September, indicated that earlier output of the well had been to the west and northwest. The visible plume from the output extended northeast for at least 35 n mi. Output continued in this 055° direction until 20 September, when it started to swing to a more southerly heading. Upon our departure on 21 September, the output was roughly toward 145° true.

Crude oil could be observed to be boiling up at the surface near the well head and fire. It remained sharply delineated from the surrounding sea and there was little observable sheen around the edges. The plume of oil funneled out and widened. A short distance from the well head, significant amounts of sheen began to bleed off the edges of the still- solid plume of emulsified oil. Perhaps 10 miles (16 km) down plume, heavy patches of sheen appeared within the oil-mousse. Still farther down plume, the mousse became more patchy and streaked, with much sheen interspersed, and

when farther out, sheen began to predominate, with the mousse, now more solid in appearance, forming raft-like patches that tended to entrap and incorporate floatsam (weeds, bottles, etc.).

The entire surrounding sea appeared milky. But in areas where sheen predominated, there was an obvious, pronounced milky edge along the sheen patches (suspended sediments?, dispersants?, water soluble fraction?).

Pronounced color changes were observed to occur both diurnally and with increasing distance from the well head and for some distance down plume, the oil appeared chocolate brown. With increasing distance and/or sunlight the oil-mousse took on a brighter, richer, reddish-brown tone (which may have been attributable simply to better lighting). The color was not homogenous, but rather, a swirled appearance was evident. In some places, swirls of very bright orange oil were interspersed.

FSU-II Cruise (NSF), 13 October - 6 November

Cruise FSU-II, made aboard the LONGHORN (UTMSI/PAML) and sponsored by NSF, was undertaken to recover current meter arrays deployed during FSU-I the previous July. Several of these were refurbished and redeployed, while others were left on location. As described previously, the cruise track extended belo the 24th parallel into Mexican waters. A related objective was to measure the thermohaline structure of the water column via STD casts and XBT selections.

As on three previous LONGHORN cruises, surface observations were made for the presence of IXTOC oil and a few samples were retrieved for chemical assay. At the time of this cruise, the currents were no longer bringing oil ashore onto Texas beaches.

Tar balls were the major form of oil encountered during the FSU-II cruise. Sheen was observed only once. Tar balls were generally small, perhaps smaller than observed on the three previous LONGHORN cruises. They frequently occurred in windrows and together with Sargassum. At several locations, tar balls of considerably darker coloration were mixed with the more traditional mousse-colored balls. Occasionally these darker pieces had attached goose barnacles. When sampled, the darker "tar balls" were found to be small pieces of driftwood with goose barnacles growing on them. In contrast to the previous cruises, there were extensive areas where no oil was sighted.

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LONGHORN IV Cruise (USCG) 16 November - 13 December

        With the objective of surveying postimpact accumulations of
IXTOC I petroleum residues in Texas waters, UTMSI/PAML was contracted by
NOAA in November 1979 to conduct extensive samplings of offshore, nearshore,
and estuarine passes (Griffin, 1980).   This study area was bordered on the
north by Pass Cavallo and continued southward to Port Isabel.   This effort
culminated in a series of four cruises aboard the R/V LONGHORN, which
examined the various environmental zones by the following time-table:

        Southern stations-Port Mansfield, Port Isabel...16 to 20 November
        Middle Stations.........................30 November to 3 December
        Northern Stations and Pass Cavallo...............7 to 10 December
        Port Aransas...13 December

        A total of 131 nearshore/offshore and 12 channel stations were occupied,
with the study area divided into north, middle, and south sections (lettered
N, M, and S followed by sequential sample numbers).   Seaward stations were
located along the 15-, 30-, 60-, 120-, and 180-ft isobaths with approximately
5 miles between the 15-, 30-, and 60-ft stations and approximately 10 miles
between the 120- and the 180-ft stations.   By design, stations for the
offshore survey included several of the previous Bureal of Land Management-
South Texas Outer Continental Study (BLM-STOCS) program stations, as the
BLM-STOCS program constitutes a body of prespill baseline data for comparison.
The BLM-STOCS program sampled 25 stations among four transects with the
inner three stations of each transect reoccupied in this survey.   Samples
collected included hydrocarbons and macrobenthic organisms; sediments for
hydrocarbon and trace metal analysis; sediments sieved for infauna with a
subsample retained intact for particle size analysis; sediments for micro-
biology; and physical oceanographic measurements of bottom currents, surface
salinity and temperature, and bottom salinity and temperature.

                        BEACH SAMPLING ACTIVITIES FOR OIL

                        HAZMAT Team Initial Sampling Effort

        In mid-August, at thetime of initial impact along the southern Texas
coastline, NOAA/HAZMAT personnel collected beached hydrocarbons.   These
samples represented the first collected along Padre Island beaches that
were suspected of coming from the IXTOC I blowout.   One of these samples
(tar balls) was analyzed at UTMSI/PAML and reported by Parker (1979).

Research Planning Institute

Research Planning Institute (RPI) of Columbia, South Carolina, was
contracted by NOAA to conduct biological and geological sensitivity analyses
of the south Texas coastlne from Port Isabel to the Sabine River, including
the Laguna Madre. Concurrent with these efforts and following the sensitivity
analyses, samples of beach sediments, infauna, and beached tars were collected
at over 100 stations along the barrier islands and in adjacent coastal
lagoons, bays, and marshes.

URS - Post-Impact Samples of Beach Tars

In the latter part of November and early December 1979, Peter Sturtevant
(URS) collected various beached hydrocarbons along the Texas barrier islands.
that had been impacted by IXTOC I oils not removed by clean-up operations.
The rationale was to verify the identity of the hydrocarbons while also
attempting to sample various types of states of beached oils.

FISHERIES AND WILDLIFE SURVEY STUDIES

A cooperative program was formulated between Texas Parks and
Wildlife Department (TPWD), National Marine Fisheries Services (NMFS), and
Texas A&M University to conduct a joint research cruise to determine whether
shrimp and/or finfish caught near oil on the sea surface had been contaminated
or were otherwise unmarketable. Organoleptic tests (visual and oilfactory)
were performed by Food and Drug Administration (FDA) personnel upon catch
species, with only faint petroleum odors not sufficient to warrant production
rejection detected. Additionally, catch aliquots were sent to the FDA
Dallas laboratory for analyses of petroleum hydrocarbons, including polynu-
clear aromatics (PNA's). Other aliquots were sent to the NMFS Charleston
laboratory for further organoloeptic (taste) testing. Samples were scheduled
to be analyzed for oil contamination of gut contents by the NMFS Beaufort
Laboratory.

Fifty-five samples were collected at six stations. Standard 40-ft
shrimp trawls were used to collect all speciments. A used net was fished
in sheen-covered waters (stations 1 through 4) and a new net was fished in
waters having no apparent sheen (stations 5 and 6). A single mousse sample
was taken for reference.

Fisheries Products Monitoring - NMFS

The National Marine Fisheries Service (NMFS) undertook to monitor dockside catches of fisheries products for possible petroleum contamination along selected Gulf of Mexico ports. Shrimp were obtained from commercial boats beginning 1 August 1979 and weekly at five ports in Texas - Brownsville, Port Aransas, Freeport, Galveston, and Port Arthur - until the end of November. After that monthly samples were taken (except in the Galveston and Port Arthur areas, which remained on a weekly basis through 31 January 1980 in response to the BURMAH AGATE* spill). In late October, shrimp sampling began at several Louisiana ports: Cameron, Delcambre, Leeville, Houma, and Venice.

Also, in late December a weekly finfish collection was initiated at selected ports, dependent upon species availability. For Texas, this includes red snapper at Brownsville and flounder at Port Aransas. In Louisiana, spotted sea trout and red drum are taken at Leeville and Houma. All samples will be analyzed for traces of hydrocarbons in tissues.

Fisheries Products Monitoring - FDA

In August 1979, Food and Drug Administration (FDA) agents began monitoring fisheries products along selected Gulf of Mexico ports for possible petroleum contamination of commercial species. This project stemmed from legal mandates making FDA responsible for protecting consumers from contaminated and/or otherwise unmarketable fisheries products. Aliquots of commercial shrimp, shellfish, crab, and finfish species were obtained from domestic seafood processors and are awaiting analysis for polynuclear aromatic (PNA) contaminants.

No analyses have been completed to date, as FDA-approved methodology is under development. Further sample collection has been postponed until analyses begin, and at that time, collections will be resumed.

Patuxent Toxicity Studies

Several samples of oil were sent to the Patuxent National Wildlife Refuge for use in petroleum toxicity bioassays. A samples of oil taken near the wellhead by Oil Mop, Inc., was used in ingestion studies of the Americal kestrel to simulate exposure of perigrine falcons, an endangered species that winters in Texas. Also, samples of mousse and tar received

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*M/T BURMAH AGATE is a tanker which burned after a collision 11.3 km offshore of Galveston on 1 November 1979, spilling a major portion of the 290,000 barrel cargo.

from Padre Island beaches were slated for use in related studies. Results of these studies are forthcoming. In addition to oil samples, Patuxent received approximately nineteen birds and six sea turtles from spill-related mortality along the Texas coastline. These were autopsied and stored in freezers for possible future chemical analyses of tissues.

UTMSI/PAML Mussel Watch Program

In conjunction with the ongoing National Mussel Watch Program, a limited number of oyster samples were obtained at various inshore localities along the Texas coastline to detect a chronic increase, if any, in hydrocarbon content of local populations due to the influx of IXTOC I oil. Samples were collected by UTMSI/PAML after the IXTOC I impact in late September and early October at Port Isabel, East Matagorda Bay, Port Mansfield, and Port Aransas.

C

COMMON AND TAXONOMIC NAMES OF COASTAL BIOTA

PLANTS

COMMON NAME   SPECIES

<u>Alga</u>

   blue-green---<u>Lyngbia</u> <u>confervoides</u>

   other--<u>Sargassum</u>

<u>Grasses</u>

   saltgrass--<u>Distichlis</u>

   saltwater cordgrass------------------------------<u>Spartina</u> <u>alterniflora</u>

   sea ox-eye daisy---------------------------------<u>Borrichia</u>

   shoal grass--------------------------------------<u>Halodule</u> <u>wrightii</u>

   turtle grass-------------------------------------<u>Thalassia</u> <u>testudimum</u>

   widgeon grass------------------------------------<u>Ruppia</u> <u>maritima</u>

   other--<u>Cassia</u> <u>fascrulata</u>
                                                             <u>Panicuia</u> <u>ararum</u>,
                                                             <u>Salicornia</u>

Mangrove, black----------------------------------<u>Avicennia</u>

BIRDS

Cormorant, olivaceous------------------------------Phalacrocorax olivaceus

Crane, whooping------------------------------------Grus americana

Duck, black-bellied whistling----------------------Dendrocygna autumnalis

Duck, fulvous whistling----------------------------Dendrocygna bicolor

Duck, mottled--------------------------------------Anas fulvigula

Duck, redhead--------------------------------------Aythya americana

Egret, reddish-------------------------------------Dichromanassa rufescens

Falcon, peregrine----------------------------------Falco peregrinus

Goose, Canada--------------------------------------Branta canadensis

Goose, lesser snow---------------------------------(not found with lesser
                                                    prefix)

Goose, white-fronted-------------------------------Anser albifrons

Gull, laughing-------------------------------------Larus atricilla

Heron, little blue---------------------------------Florida caerulea

Oystercatcher, American----------------------------Haematopus palliatus

Pelican, brown-------------------------------------Pelecanus occidentalis

Pelican, white-------------------------------------Pelecanus erythrohynchos

Plover, snowy--Charadrius alexandrinus

Plover, Wilson's--------------------------------------Charadrius wilsonia

Skimmer, black---------------------------------------Rhynchops nigra

Spoonbill, roseate------------------------------------Ajaia ajaia

LAND MAMMALS

Bat--(not specific)

Coyote---Canis latrans

Fox, grey--Urocyon cinereoargeneus

Ground squirrel-------------------------------------(not specific)

Jackrabbit---(not specific)

Kangaroo rat---------------------------------------(not specific)

Skunk---Memphitis mephitis

MARINE MAMMALS AND TURTLES

Dolphins

bottle-nosed---------------------------------------Tursiops truncatus

bridled--Stennella frontalis

Marine mammals and turtles (cont'd)

rough-toothed-------------------------------Steno bredanensis

spotted-------------------------------------Stennella plagiodon

Manatee, West Indian------------------------Trichechus manatus

Seal, West Indian---------------------------Monachus tropicalis

Turtle, green sea---------------------------Chelonia mydas mydas

Turtle, hawksbill---------------------------Eretmochelys imbricata
                                              imbricata

Turtle, leatherback-------------------------Dermochelys coriacea
                                              coriacea

Turtle, loggerhead--------------------------Caretta caretta caretta

Turtle, Kemp's ridley sea-------------------Lepidochelys kempi

Whales, baleen

black right---------------------------------Baleana glacialis

blue--Balaenoptera musculus

common finback------------------------------Balaenoptera physalus

Whales, toothed

goose-beaked--------------------------------Ziphius cavirostris

gulf stream beaked--------------------------

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Marine mammals and turles (cont'd)

    killer, common-------------------------------Orcinus orca

    killer, false-------------------------------Pseudorca crassidens

    killer, pygmy-------------------------------Feresa attenuata

    pilot---------------------------------------Globicephala macrorhyncha

    sperm---------------------------------------Physteter catodon

    sperm, dwarf--------------------------------Kogia simus

    sperm, pygmy--------------------------------Kogia breviceps

FISHES

Croaker, Atlantic------------------------------Micropogonias undulatus

Drum, black-----------------------------------Pogonias cromis

Drum, red-------------------------------------Sciaenops ocellata

Flounder, southern----------------------------Paralichthys lethostigma

Killifishes-----------------------------------Adinia, Cypriniodon, Poeulia

Mackerel, king--------------------------------Scomberomorus cavalla

Minnow, sheepshead----------------------------Cyprinodon variegatus

Mullet--Mugil

Pompano---------------------------------------Trachinnotus carolinius

Redfish--Scianops ocellata

Sardine---Harengula pensacolae

Seatrout---Cynoscion nebulosis

Snapper, red--------------------------------------Lutjanus campechanus

SHELLFISH

Auger, Atlantic-----------------------------------Tereba dislocata

Bubble shell--------------------------------------Bulla striata

Clams

  coquina---Donas variabis

  razor---Tagebus plebius, Enis
                                                    minor

  other---Mulina lateralis,
                                                    Anomalacardia cumiemeris

Crabs

  blue--Callinectes sapidus

  fiddler---Uca

  ghost---Ocypodus quadrata

Shellfish (cont'd)

hermit---Clibinarius vittatus

mud---Rithropanopeus harrisi,
                                                   Neopanope texana texana,
                                                   Panopeius herbstii

mud (flat)--Eurypanopeus depressus

stone---Menippi mercenaria

Lucine, thick-------------------------------------Phacoides pectinatus

Nerite, virgin------------------------------------Neritina virginea

Shrimp

arrow---Tozeuma carolinensis

brown---

caridean--Hippolyte pleuracantha,
                                                   H. zostericola

grass---Paleomonedes sp.

pink--Penaeus duorarum

snapping--Alpheus heterochaelis

white---

other---Callianassa jamaicense
                                                   louisianensis

<u>Shellfish (cont'd)</u>

Snails

mud--<u>Polinicis duplicatus</u>,
<u>Nariarius vibex</u>

oyster drill--------------------------------<u>Thais hematostoma</u>

MISCELLANEOUS INVERTEBRATES

Beach hoppers--------------------------------<u>Orchestia</u>, <u>Talorchestia</u>

Keyhole urchin-------------------------------<u>Mellita</u>

Gastropods-----------------------------------<u>Pagrus longicarpus</u>,
<u>P. pollicaris</u>

Sand star------------------------------------<u>Astropecten</u>

Sea cucumber---------------------------------<u>Thyrone mexicana</u>

Worms

lug---------------------------------------<u>Arenicola cristata</u>

parchment---------------------------------<u>Chaetopterus variopedatus</u>

polychaete--------------------------------<u>Eteone heteropoda</u>, <u>Laeoeris</u>
<u>culveri</u>, <u>Scolopis squamata</u>

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