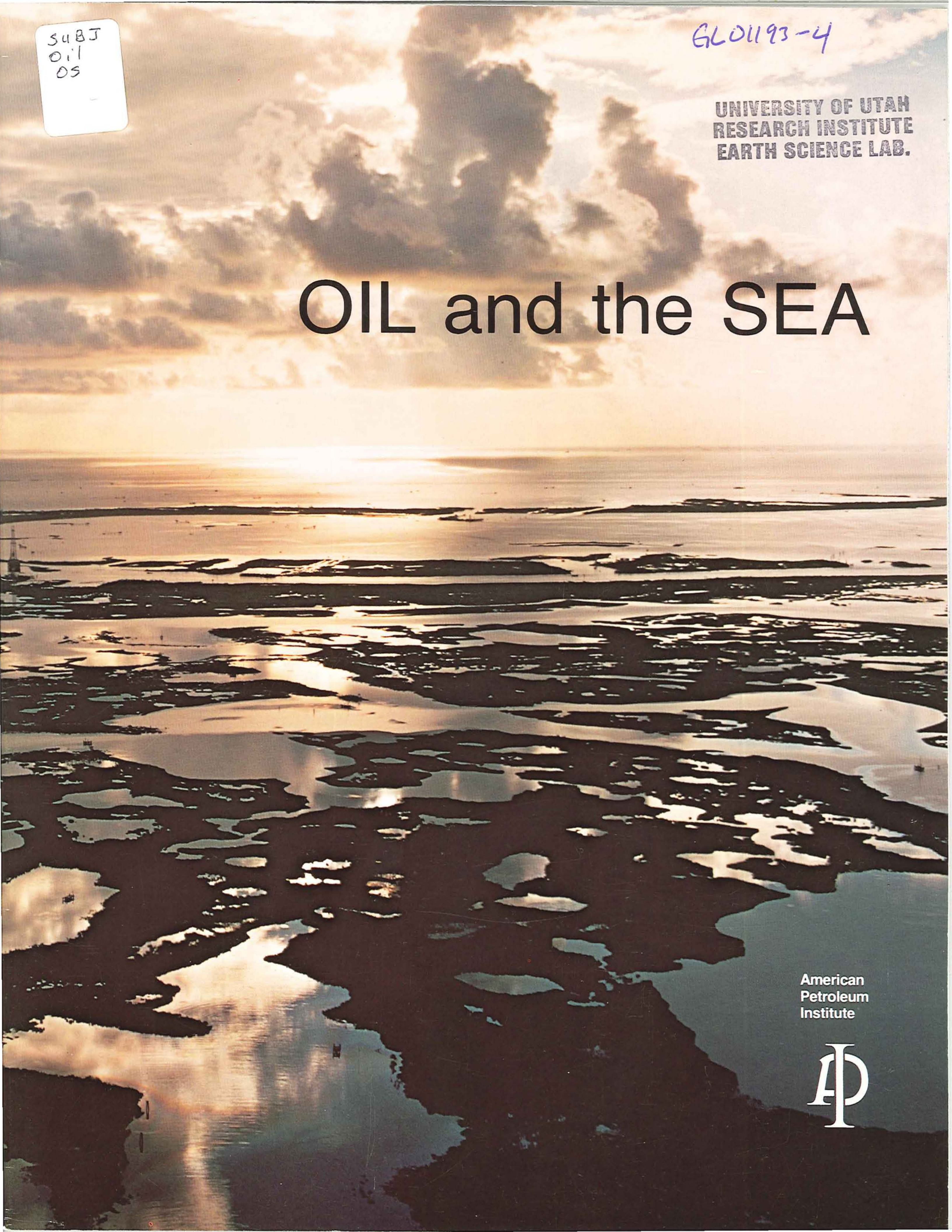


OIL and the SEA

American
Petroleum
Institute

TABLE OF CONTENTS

Technical support and guidance for the research projects presented in this report are provided by the American Petroleum Institute's Committee on Fate and Effects of Oil in the Environment, a group of oil industry scientists, and by the Institute's Environmental Affairs Department. The current roster of the Committee appears on page 19. Questions regarding individual projects and related matters should be addressed to:

Environmental Affairs Department
American Petroleum Institute
2101 L Street, N.W.
Washington, D.C. 20037

Attn. J. R. Gould

I. OIL AND MARINE LIFE: LABORATORY STUDIES

BATTELLE, PACIFIC NORTHWEST LABORATORIES

Principal Investigator:

B. E. Vaughan
Battelle, Pacific Northwest Laboratories
Sequim, Washington

The case of DDT concentration in the natural food chain led the American Petroleum Institute to focus on whether oil taken up internally, or ingested, by marine life might be retained permanently, concentrated, or passed to food chains, possibly posing a health hazard to human beings. This concern led to the first research project entered into by the Institute's Committee on Fate and Effects of Oil in the Environment.

The Institute engaged Battelle, Pacific Northwest Laboratories, a private research organization, to develop tests suitable for examining the potential threat of spilled oils to marine life. Battelle's work was fruitful. It developed improved bioassay procedures applicable, for example, to larval vs. adult stages and to flow-through vs. static exposures to oil. It developed more specific hydrocarbon analytical measurements. And it directed attention to the importance of the way oil fractions may be distributed in the water column.

Battelle scientists found, contrary to a widely held theory at the time, that a filter feeder, the Pacific oyster, quickly purged itself of the oil that it had taken up. This observation was based on examination of petroleum fractions in muscle, gonad, and whole oyster. They also found that the lethal effect of oil on various marine organisms depended on both the concentration of oil in the water column and the length of an organism's exposure to oil. Toxicity effects varied significantly among types of oil and types of organisms. In follow-on studies involving exposure to hydrocarbons, Battelle scientists showed that finfish also purged themselves when returned to oil-free seawater.

As a result of Battelle's work, a substantial body of data indicates that ingested oil is not accumulated and passed to higher organisms through the food chain.

The two-year study involved marine animal embryonic and larval life stages of Pacific oysters and Dungeness crab, two unicellular algae, various eggs and larval forms, and 11 selected fish. The selection of these animals was based on their potentially high sensitivity to oil, their economic importance, or their significance in the food web system.

The study used a No. 2 fuel oil and two crude oils, a South Louisiana and a Kuwait. A high aromatic No. 2 fuel oil was chosen because its expected relatively high toxicity would represent a "worst case." The three oils chosen for this and subsequent studies are typical of oils transported and used in large quantities in the United States.

These oils, along with a Bunker C oil, were later established as API Reference Test Oils for biological studies. They have been made available to the scientific community through a repository established at Texas A&M University. Wide use of the same oils by researchers, of course, affords a basis for comparison of results of biological studies among various laboratories.

The Battelle scientists concluded:

- In laboratory tests, this No. 2 fuel oil is more toxic than is the South Louisiana or Kuwait crude oil.
- A short exposure and low concentration of oil in the water are two factors that mitigate the consequences of oil exposure on marine life. There are other mitigating factors, for example, dilution, evaporation, and biodegradation.
- Depuration, the ridding of these hydrocarbons from an organism's tissues, is rapid after the test organism enters clean water.

CENTER FOR MARINE RESOURCES, TEXAS A&M UNIVERSITY

Principal Investigator:

J. W. Anderson
Biology Department
Texas A&M University
College Station, Texas

Even before Battelle-Northwest had completed its research on the effects of oil on marine organisms, the Institute contracted with Texas A&M University to repeat and verify some of Battelle's laboratory studies and to conduct new laboratory studies. The Institute also asked Texas A&M to design a series of studies to investigate oil under natural, as opposed to laboratory conditions.

The researchers used a Venezuelan Bunker C oil in addition to the same three oils that Battelle used. They examined the effects of these oils on a wide range of marine animals, seeking answers to such questions as: How toxic is each of the different kinds of oils? When marine animals absorb the pollutants, in which tissues do the pollutants accumulate? And how do various pollutant levels in the water and in the animal tissues affect the animals?

The Texas group first determined the effects of the four API Standard Reference Oils on six kinds of fish, shellfish, and plants. As indicated by earlier research, the refined oils carried by many tankers are more toxic than are crude oils. The study also identified specific refined oil components that apparently pose the greatest threat to marine life.

Detailed studies sought to find out how fast the animals absorb oil components from the water, how much oil the animals accumulate, and how fast they can release it when the pollution is gone from the water habitat. One series of studies showed that oysters, clams, brown shrimp, and grass shrimp in oil-contaminated water accumulated toxic naphthalenes more than other petroleum compounds. When placed in clean water, however, all of the animals released the pollutants over periods ranging from a few days to two months.

In a study of clams, the scientists concentrated on benzo(a)pyrene, an active carcinogen found in minute amounts in oil and known in chemical shorthand as BAP. Little was known about the accumulation or release of BAP and similar compounds. The scientists collected clams from Trinity Bay, Texas, and exposed them to BAP-contaminated water for 24 hours. When returned to clean water, the clams released 70 percent of the absorbed BAP within 10 days and the rest within 30 to 58 days.

As the scientists noted, petroleum is not the main source of BAP and similar compounds. These enter the air through processes such as forest fires, refuse burning, and coke production. Some of this airborne material, via rain, reaches rivers, lakes, and oceans. Some of the compounds may be synthesized by microorganisms, algae, and other marine plants. (See the summary of research in "PNA's in the Environment," below.)

The studies carried out at Texas A&M University also provided valuable information on how marine animals absorb and release pollutants. Brown shrimp, for example, rapidly accumulated naphthalenes in the digestive gland, while the shrimp's abdominal muscle contained the lowest concentration. The digestive gland required about 10 days to release the naphthalenes, while the edible muscle was cleansed after only one hour.

In summary, these laboratory studies support several hypotheses that are consistent with results of other independent studies:

- Exposed marine animals accumulate oil, but rapidly release it.
- When the marine animals have released the oil, they return to normal behavioral and physiological patterns.
- The growth rate of oysters and brown shrimp exposed to oil was not significantly different from the growth rate of animals in the control group not exposed to oil.
- The rapid release of oil by these small marine animals suggests that the amount of oil in marine animals does not increase up through the food chain. Larger animals at the top of the Sargasso Sea food chain were found to contain no higher levels of petroleum compounds than did the smaller animals lower in the food chain. Additionally, certain marine animals can metabolize petroleum compounds.

WESTINGHOUSE OCEAN RESEARCH LABORATORY

Principal Investigator:

J. M. Forns
Ocean Research Laboratory
Westinghouse Electric Corporation
Vineyard Haven, Massachusetts

Another study, conducted by Westinghouse's Ocean Research Laboratory, assessed the effects of oil on the larvae of the Maine lobster, one of the most important commercial shellfish. The American Petroleum Institute chose to initiate this approach because lobsters, from the egg through four larval stages, are part of the near-surface dwelling planktonic community that could be especially vulnerable either to an oil spill or to chronic oil leakage.

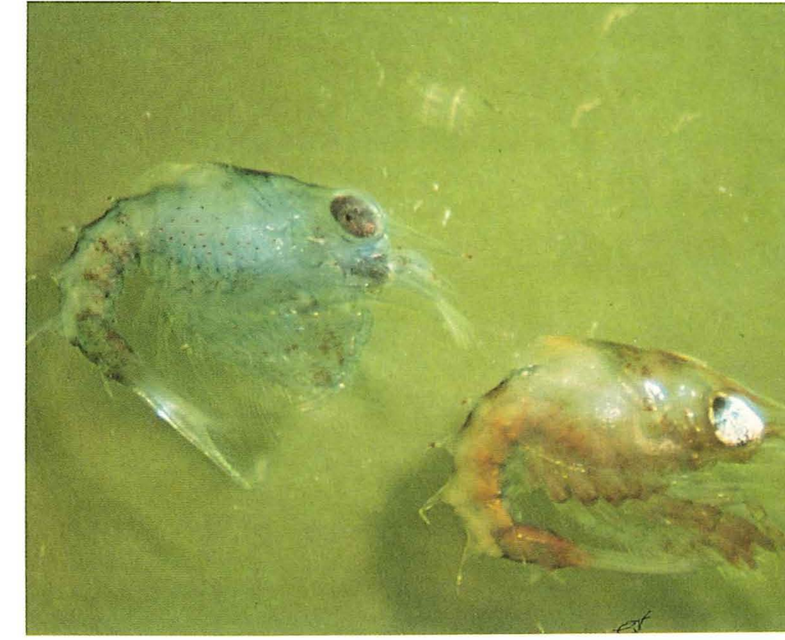
The Westinghouse researchers, in cooperation with the Commonwealth of Massachusetts, used the facilities at the Massachusetts State Lobster Hatchery to study the effects of South Louisiana crude oil on four larval stages of the lobster. The tests were conducted with naturally hatched animals in individual test chambers as well as in mass culture systems. The researchers introduced varying concentrations of oil into the water that flowed through the tanks. They varied the temperature of the water and the length of time the animals were exposed.

The animals were monitored six times a day for feeding behavioral characteristics, mobility, molting success, growth, and development times to reach the fourth larval stage. Researchers studied both the larvae and the chemical makeup of the hydrocarbons in the sea water. They found that the larvae exposed to 1.0 part per million (ppm) of crude oil in seawater had approximately 50 percent lower survival than did control larvae or those exposed to only 0.1 ppm crude oil in seawater.

Animals exposed to 0.1 ppm crude oil were active feeders, their movement was consistent, and they were aggressive. Larvae exposed to 1.0 ppm crude oil were depressed feeders, their motions were minimal, and they were generally lethargic.

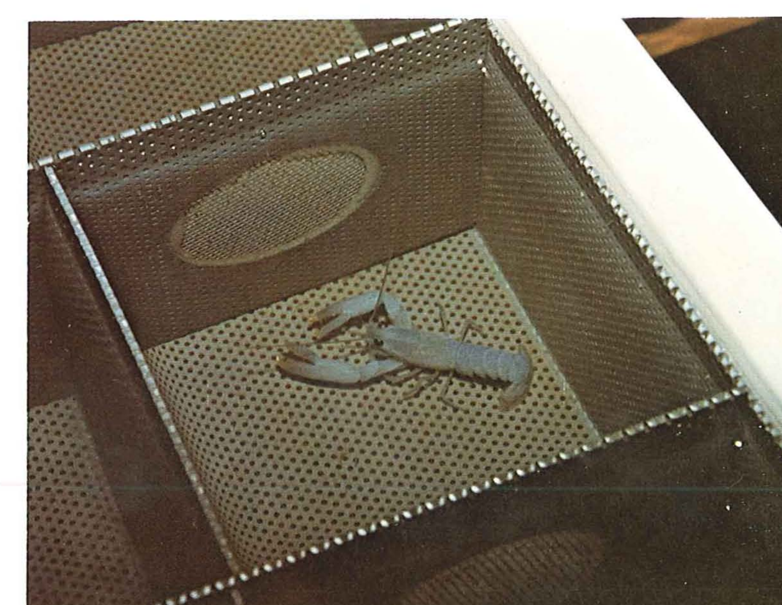
The time it took for the animals to develop was also directly related to the concentration of oil in the water. For almost all of the tests, the control larvae and the larvae exposed to 0.1 ppm oil reached the second stage of development within three days. They reached the third stage within six days. And they molted to the fourth stage within 12 days after hatching. Development times for the larvae exposed to 1.0 ppm crude oil were more than three days to molt to the second stage, seven days to reach the third stage, and at least 15 days to reach the fourth larval stage. The frequency of mortalities for both the control and the oil-exposed larvae was highest when the larvae molted to the second larval stage.

The most obvious effect on developing larval lobsters was the color the animals displayed after exposure to crude oil, especially those exposed to the 1.0 ppm crude oil. They turned from their normal, almost transparent pale blue color to varying shades of red, depending on the amount of oil exposure. Larvae which became completely reddened rarely survived the fourth stage. The almost transparent character of the typical larvae may serve to camouflage them from predators in the near-surface environment. The Bureau of Land Management of the U.S. Department of the Interior is continuing this work in a study of what happens to the "red" survivors.



First-stage lobster larvae, normal (pale blue) and oiled (reddish).

Normal lobster in holding tank.



II. OIL AND MARINE LIFE: FIELD STUDIES

EFFECTS OF OIL SPILLS

Texas Field Studies

Principal Investigators:

J. W. Anderson
J. M. Neff
Center for Marine Resources
Texas A&M University
College Station, Texas

In order to see whether laboratory results would apply under "real" conditions, Texas A&M University scientists repeated some of the tests described above in an experimental outdoor pond. In the pond, shrimp, clams, and oysters absorbed and released naphthalenes in much the same way that they did in the laboratory. More shrimp, however, died at lower pollution levels than predicted by laboratory data. Shrimp apparently behave differently in natural habitat, at night swimming up into the surface oil slick and thus coming into contact with a greater concentration of oil.

Other field studies were conducted in Trinity Bay, which is typical of many Gulf Coast bays and estuaries. It contains several oil fields and is important for recreational and commercial fishing. Indeed, sport fishermen and commercial shrimpers and crabbers often pursue their activities near the oil-well heads.

The scientists were especially interested in the rates that clams under and near an oil platform absorb and release the oil. Much is already known about clams. They can accumulate oil pollutants even where pollution levels are low. They play an important role in the Gulf Coast ecosystem. And they are found worldwide.

The results of this field study were consistent with those of the earlier laboratory experiments. When exposed to low-level pollution for 100 days, the clams absorbed naphthalenes in much the same way that they did under high-level pollution conditions for one day in the laboratory. Similarly, when transferred to clean water, the Trinity Bay clams released the naphthalenes within 30 to 58 days.

The evidence in this and other low-level pollution studies suggests that clams and other animals do not accumulate lethal levels of the pollutants. But additional study will be needed to learn the exact effects of chronic low-level pollution.

The Texas A&M group also studied the area around an oil-gathering platform in shallow water, six to eight feet deep. (In deep water, where most new offshore production occurs, the effects shown here are not observed.) At the platform, brine brought up with the produced crude oil is separated and returned to the bay. One 21-month study—completed in December 1975—examined the platform's effects on the variety and amount of marine animals on the bay bottom.

In general, both the variety and numbers of organisms increased with distance from the platform. Within 50 feet of the platform, a minute fraction of the total area surveyed, there was almost no bottom marine life. At 500 feet, the bottom life was less than normally would be expected. But at 1500 feet, the platform had no effect on bottom life.

Phytoplankton

Principal Investigators:

E. Mills
S.M. Ray
Texas A&M University
College Station, Texas

J.A. Strand
Battelle, Pacific Northwest Laboratories
Sequim, Washington

The basis of the food chain for marine animals is phytoplankton, the floating plant life in a body of water. Should petroleum harm the reproductive capacity of phytoplankton, it was theorized, repercussions might be felt by members higher in the food chain, thus affecting species consumed by humans.

When they exposed phytoplankton to water-soluble fractions of test oils, however, scientists at Texas A&M University found that the growth rate of the phytoplankton decreased. When the exposure to oil ended, the phytoplankton resumed a normal growth rate within a few days. The researchers concluded that once a spill is over, the surviving phytoplankton repopulate an area rapidly. They also found that phytoplankton recruited from nearby areas unaffected by the spill would disperse and rapidly re-establish a normal phytoplankton population.

In another American Petroleum Institute study at Battelle-Northwest, scientists found that oil at concentrations of less than one part per million actually stimulated the growth of phytoplankton. This finding is similar to the results of other observations in Alaska, France, Canada, and elsewhere. Even so, these results are speculative and require further confirmation.

Marshland

Principal Investigators:

M. E. Bender
R. H. Bieri
R. J. Huggett
H. L. Kator
Virginia Institute of Marine Science
Gloucester Point, Virginia

Public concern about drilling and producing in the Atlantic offshore regions and the possible effects of oil spills on the shoreline led to a study to measure the potential impact of an oil spill on the ecology of a fertile marshland. The study, conducted by the Virginia Institute of Marine Science, was designed to evaluate the effects of an oil spill in a marshland area not with laboratory experiments, but with a simulation of an oil spill in an actual marsh.

The Institute was able to get permission to conduct the spills at a Navy facility because the experiment was designed in such a way that the surrounding estuarine area would not be affected. The researchers selected a marsh-tidal stream system just off the York River in Virginia. There, they built retaining walls by imbedding corrugated composition board into the soil to form "pens," each measuring approximately 50 by 100 feet. The walls closed the pens off on three sides. The fourth side contained an opening below the water surface, allowing the tidal flow in and out of the test areas, but preventing surface oil from escaping.

In September 1975, the scientists released three barrels of fresh South Louisiana crude oil into each of two of the test area pens. They released three barrels of artificially weathered South Louisiana crude oil into two other pens. A fifth area was left free of oil to serve as a control.

The scientists evaluated the effects of crude oil on microbe populations to see whether the oil interfered with normal life processes in the marsh. Within several days, the oil-digesting bacteria had grown 20 to 40 times their normal numbers. These higher numbers lasted throughout a full year of observation. Other studies after accidental oil spills have shown similar increases in bacteria in beach sands.

Bacterial decomposition of such substances as chitin (part of the hard outer covering of crustaceans and insects) and marsh grasses is very important in maintaining a healthy ecological balance in biologically productive marshlands. The scientists detected no harmful effects on the microbes that normally decompose such important substances in the marsh. Non-oil digesting bacteria, fungi, and yeasts were present in their usual numbers.

Another significant observation of the study concerned the long-term effects of the fresh oil and the artificially weathered oil. Initially, the areas doused with artificially weathered oil showed greater incidence of fish toxicity. But the long-term effects of both oils on the biological communities that were monitored were almost identical.

During the sampling of various species over a three-year period, the Virginia group has found variations in the numbers of particular species. Factors in addition to the presence of oil appear to be operative. Severe winter weather, for example, appears to be a highly significant factor.

To date, scientists have found no simple answer to the question "How long does it take for a marsh to recover?" They have monitored a large number of species. In terms of variety and number of species and productivity as an ecosystem, the marsh has almost recovered. But a few species in the benthic, or bottom-dwelling, community are not yet so abundant as their counterparts in the control area. The project continues.

Scientists are shown deploying clams in the test pen for the York River marshland study.

One of the test pens immediately after the controlled introduction of oil.

A "Worst Case" Situation

Principal Investigator:

A. D. Michael
Marine Biological Laboratory
Woods Hole, Massachusetts

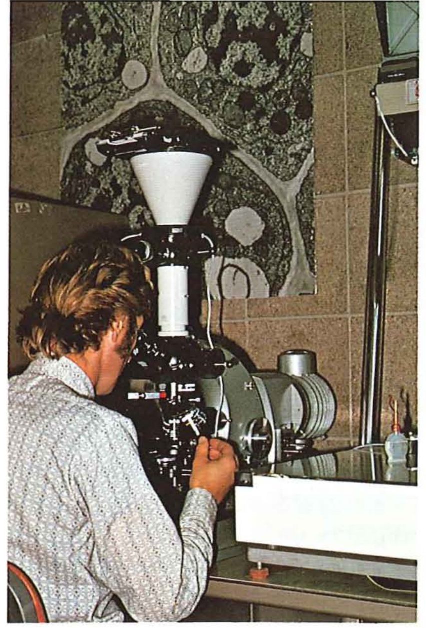
In terms of the severity of environmental effects, one of the worst oil spills in the U.S. occurred at West Falmouth, Massachusetts, in September 1969. The spill was relatively small, some 4,000 barrels. But it was a high-aromatic No. 2 fuel oil. This and other conditions combined to create severe effects. The oil was spilled near the entrance to West Falmouth harbor. Heavy surf pounded most of the oil ashore a few miles north of West Falmouth, affecting the Wild Harbor River and marsh, a boat basin, and the beach adjacent to the river mouth.

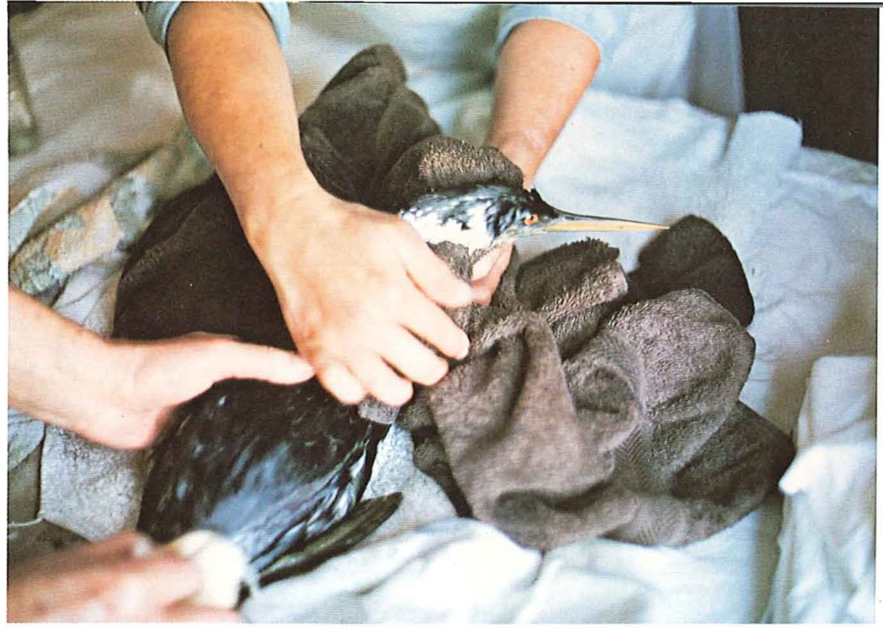
Recognizing the importance of learning more about the long-term effects of an oil spill in such a "worst case" situation, the American Petroleum Institute contracted for a study with the Marine Biological Laboratory at Woods Hole, Massachusetts. The Woods Hole researchers took samples of the sediment at monthly intervals at each of eight stations. Some of the fuel oil spilled in September 1969 was still detectable in the sediment of the offshore stations, all three marsh stations, and the boat basin station as late as April 1973. The number of species found at the sampling stations varied. Basically, more species were counted at the offshore stations than at the marsh stations. And more were counted at the marsh stations than at the boat basin.

The first results showed that the affected marsh station had significantly fewer individuals than did the control marsh station. But there was a noticeable increase in the animal populations during the course of the research at the affected station. By 1974 the differences were not significant. At the boat basin station the number of marine individuals was very low, and no trends were evident. And at the offshore stations there was considerable variance in the number of individuals, but none of the figures showed significant trends. One result in the study of the diversity of the species at the stations was a significant improvement in one of the offshore stations from 1973 to 1974.

The scientists also noted that the rate of recovery of most of the organisms that live in the areas tested had leveled off by the time the study was started, but that some recovery continued during the course of the research. In spite of the conditions which created severe effects from this spill, the area continued to recover and, with the exception of a few small areas, animal populations reached the levels of the control stations.

A view of the estuarine area, one of three areas affected by the West Falmouth oil spill.





Above left: A scientist uses an electron microscope to examine the effect of ingested oil on the gut tissue of a duck.

Above right: Cleaning the oiled plumage of a Western Grebe.

Marine Birds

Principal Investigator:

W. N. Holmes
University of California
Santa Barbara, California

Underwater animals are not the only forms of life that are affected by oil in water. Sea birds, for example, can become covered with oil. Their ability to fly may be impaired, and in attempting to preen their plumage they may ingest oil.

A great deal of research has been done to improve techniques for removing oil from birds' plumage. Scientists from the University of California at Santa Barbara set out to investigate the effects of ingested oil on marine birds. The intent of their project was to explore the physiological and pathological effects of different hydrocarbons present in oil so that a meaningful program of therapy for contaminated birds could be developed.

They worked on the theory that one of the possible systemic effects of ingesting crude oil may have something to do with impairment of the internal salt-and-water balance that marine birds must maintain. Their theory proved correct. They concluded that oil affected the bird's salt gland and interfered with its ability to separate fresh water from seawater. And, as hoped, much that was learned became the basis for treatment of oil-contaminated birds.

Other stress factors—for example, the restraint and handling of wild species, the inhalation of noxious fumes from solvents used to clean the birds, and the loss of natural properties of the cleansed feathers—must also be considered in treating oiled waterfowl. Knowledge of these and other factors has increased the successful rehabilitation of oiled birds.

A manual on cleaning and rehabilitating oiled waterfowl is available from the American Petroleum Institute.

Oil-in-Water Research: A Study Strategy

Workshop at Gurney's Inn, Montauk, L.I., New York
Sponsored by: American Petroleum Institute
Bureau of Land Management
National Oceanic and Atmospheric Administration

API co-sponsored a workshop with the National Oceanic and Atmospheric Administration and the Bureau of Land Management. The workshop was designed to provide marine scientists with a study strategy to determine the environmental effects of an oil spill. The workshop gathered current knowledge from experienced oil spill researchers and led to a publication which represents their consensus.

The conference covered such topics as:

- Managing information, including data handling and exchange, statistics, and sample tests;
- Chemical methods of analysis, centering on the identification and quantification of various petroleum fractions;
- Methods for collecting, preserving, and analyzing samples of oil and water; and
- Methods for analyzing oil in sediments and in tissues.

The workshop also developed the first comprehensive reference work on how scientists should perform studies on the environmental effects of spilled oil. It is "Oil Spill Studies: Strategies and Techniques," available as Publication No. 4286 from the American Petroleum Institute.

EFFECTS OF CHRONIC EXPOSURE

Chronic Exposure to Natural Petroleum Seeps

Principal Investigator:

D. Straughan
Allan Hancock Foundation
University of Southern California
Los Angeles, California

In some parts of the world, oil seeps out of the ground naturally. Sir Francis Drake, for example, caulked his ships with natural tar when he sailed around the world in the 16th Century. This natural petroleum "pollution" has co-existed with a viable ecosystem for eons. Off the California coast, near Coal Oil Point in the Santa Barbara Channel, is an area with a natural oil seep. Estimates of the total seepage there range from 50 to 100 barrels per day. This condition provides scientists with a unique opportunity to study the long-term effects of chronic exposure of marine organisms to petroleum.

The American Petroleum Institute contracted with the Allan Hancock Foundation at the University of Southern California to compare organisms from Coal Oil Point with organisms not chronically exposed to natural oil seepage. This study encompassed most segments of the environment, most invertebrate groups, and most habitat types.

The study, which took two years to complete, concluded that, for most species examined, chronic exposure to oil from natural seeps does not affect the health of local marine animals in any significant way. The conclusion is based on the following findings:

- In the subtidal soft bottom, there was no change in faunal populations in the oil spill area that could be directly attributed to the presence of petroleum hydrocarbons in the sediment.
- At Coal Oil Point, no adverse effects of chronic exposure to petroleum were demonstrated in studies on reproduction and size in the mussel.
- No adverse effects were found in the population and reproduction of abalones and sea urchins. Some young sea urchin larvae indicated an increase in tolerance to the low concentrations of the dissolved components of Santa Barbara crude oil. Low numbers of abalone were attributed to overfishing.
- No malformations were observed in the several thousand animals that were examined both externally and by dissection.
- The distribution of petroleum hydrocarbons at Coal Oil Point was patchy in both the sediments and the organisms. The mussel, for example, was the only species with petroleum hydrocarbons in all samples that were taken. In some cases, animals contained hydrocarbons, but others of the same species did not. For instance, only some abalone contained petroleum hydrocarbons.
- Hydrocarbons occurred in some tissues and not in others. No hydrocarbons were recorded in the muscle tissue, the part that is eaten, of either abalones or Pacific Coast lobsters, but were found in the reproductive and digestive systems of both. The muscle portion of sea urchins and mussels, on the other hand, did contain petroleum hydrocarbons.
- The rate of brooding in stalked barnacles covered by oil decreased, but the rate in two species of sedentary barnacles remained unchanged by chronic natural exposure to oil.

Another study conducted by the same investigator addressed the effects of an oil well blowout that occurred in the Santa Barbara Channel in January 1969. This study, not funded by the American Petroleum Institute, is interesting in that its objective was to determine the immediate effects of oil pollution, as well as any possible longer-term hazards. The study concluded:

- It was often difficult to isolate the effects of oil pollution from other phenomena.
- Damage to flora and fauna in the Santa Barbara Channel was much less than predicted.
- The area was recovering well.

A follow-up study at Coal Oil Point has been completed. It concentrated on one organism, the mussel, its community structure, and its relationships with other animals in its ecosystem, such as algae and worms. The researchers, who conducted a careful data collection, have concluded that the data do not show a clear distinction between the mussel community structure in oiled areas and in areas free of oil.

A natural submarine seep near Coal Oil Point in the Santa Barbara Channel. The hilt of the diver's knife in the foreground indicates the size of the escaping petroleum globule just beyond.

The Hilda-Hazel Project

Principal Investigator:

J. Isaacs
Institute of Marine Resources
Scripps Institution of Oceanography
University of California
La Jolla, California

In another study involving chronic exposure to petroleum, this time resulting from human activities, scientists from the Southern California Coastal Water Research Project under the direction of the Scripps Institution of Oceanography conducted a series of field surveys to document the diversity, health, and abundance of marine life around the 25-year-old oil producing platforms Hilda and Hazel in the Santa Barbara Channel. At the two platforms, which stand about one and a half miles apart, with a control area between them, scientist-divers equipped with television and 35mm cameras documented the abundance and diversity of fishes and invertebrates.

On the platform structures themselves, the divers found heavy growth up to four feet thick—attached mussels, anemones, corals, starfish, and other invertebrates. Under the platforms, on the cutting piles, or tailings resulting from the original drilling of the wells, similar heavy growth occurred.

Great numbers of fish swam under the platforms—20,000 to 30,000 of some 45 species. This was 20 to 50 times more fish than were found in the control area, which also has a soft mud bottom, but has no platform. Some 290 species of mammals, birds, fish, and invertebrates were seen on or under the platforms or were found in samples of sediments.

Levels of metal and petroleum hydrocarbons in the platform fish and invertebrates showed no increase over a group of control animals, except for vanadium in the rockfish. No adverse effects on the fauna were observed. The high abundance of fish and the presence of huge mussels are clear indications that the presence of platforms does not inhibit marine life and indeed provides additional habitat not otherwise to be found in the area.

Above right: A school of rockfish, which are commonly found in abundance in waters around offshore platforms.

Right: A heavy encrustation of barnacles and mussels on one of the submerged legs supporting an offshore production platform. The diameter of the steel leg, 18 inches, is doubled by the encrustation.

Two scientists, their equipment on the rocks behind them, observe the tidal pools along Devonshire Bay, an area typical of much of Bermuda's shoreline.

Bermuda Shoreline

Principal Investigators:

C. D. Gebelein
N. G. Maynard
A. Zsolnay
Bermuda Biological Station for Research
St. George's West, Bermuda

Pelagic tar, or tarballs formed on the open sea, are found over the surface of most of the world's oceans roughly in proportion to existing tanker traffic. In order to study the effects of these tarballs on intertidal plants and animals, the American Petroleum Institute selected Bermuda as the site. The islands of Bermuda, located in the Sargasso Sea, act as a passive "net" that collects floating matter from a twenty-mile wide area of ocean. Chemical analyses of the floating residues indicate that weathered oil is derived primarily from tanker washings and bilge discharges, practices that are diminishing with the increasing application of new technology.

The Bermuda Biological Station for Research already possessed some baseline data on the islands' flora and fauna which facilitated a study on the effects of oil pollution on marine animals. The amount of tar balls washing up on Bermuda's beaches has increased in the past ten years, and a chronic level of hydrocarbon pollution now exists on the shores. It should be noted that the shores are virtually free of other pollutants that would complicate a study of this type.

Bermuda Station researchers found that tar does not adhere to vertical shores. But on sloping shores, tar coverage can be high because the tar lumps are thrown up on the rocks where the heat from the sun melts them before waves wash them back to sea. Most of the permanently attached tar is deposited above the normal high tide level in the splash zone. No significant amount of tar was observed on the rocks or plants and animals below the splash zone in the intertidal area, where the majority of the flora and fauna are located. The potential effect of the permanently attached tar on sea life is thus limited.

In the high splash zone where there is the greatest accumulation of tar, there was little direct correlation between tar coverage and the size of the populations of the two high intertidal snails that were studied. An exception was that at one heavily tarred sampling site, one of the snail populations was observed to have a reduced population. This appeared to be space competition induced by the tarring, rather than a direct toxic effect.

In the intertidal zone itself—the area between the high and low tide marks—population levels remained normal. At almost every location studied, there appeared to be no correlation between the amount of tar present and the population levels of any intertidal animals.

Size frequency studies showed that one species of barnacle and two species of snail, on average, were smaller at the stations with the highest tar coverage. The reason for this phenomenon is not fully understood, but may be associated with the increased chance that these animals have of being smothered by large tar particles. In the low splash zone, there was no correlation between tar coverage and population size of either of two major species which live and graze in the area.

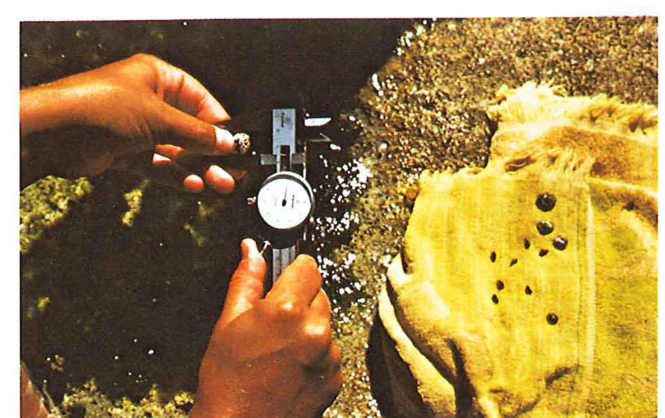
Tidal pools in the intertidal zone are the ecosystem with the highest abundances of animals. They are also natural catchment basins for small floating particulate hydrocarbons or tar balls. The browsing hermit crabs, snails, and limpets were uncontaminated. So were several bottom browsers. These animals, the scientists speculated, either selectively avoid the tar particles or do not assimilate the tar even if it is ingested.

The filter-feeding mussels in the pools contained significant levels of hydrocarbon materials, suggesting that the concentrated hydrocarbons in the pools are present in sufficient quantities to be ingested with the food particles. In two of the three sets of tidal pools that were tested, samples of algae were found to have relatively large quantities of hydrocarbons.

Reproductive potential is a sensitive indicator of the effects of pollution on the environment. The scientists found no correlation between the reproductive potential of any organism and the amount of tar coverage on the shore. All of the animals studied reproduced normally in response to seasonal patterns. The scientists regarded this normal reproduction by every species on the shore as significant.

Right: Collecting and counting marine animals at a vertical station on the Bermudan shore.

Below: Taking field measurements of small invertebrates that live in Bermudan tidal pools.



EFFECTS OF OIL AND DRILLING MUDS ON CORAL REEFS

Principal Investigators

T. J. Bright
J. M. Neff
Texas A&M University
College Station, Texas

Drilling muds are formulated in such a way as to serve a number of functions. They lubricate and cool the drill bit, lift cuttings from the hole, control well pressures, control wall properties of the borehole to prevent caving in, permit the taking of satisfactory electric measurements downhole, and minimize corrosion in the string of drill pipe. Some quantities of used drilling muds enter the marine environment during offshore operations. It should be noted that in a very short time, at a distance of 100 meters, these muds are diluted at least a thousandfold.

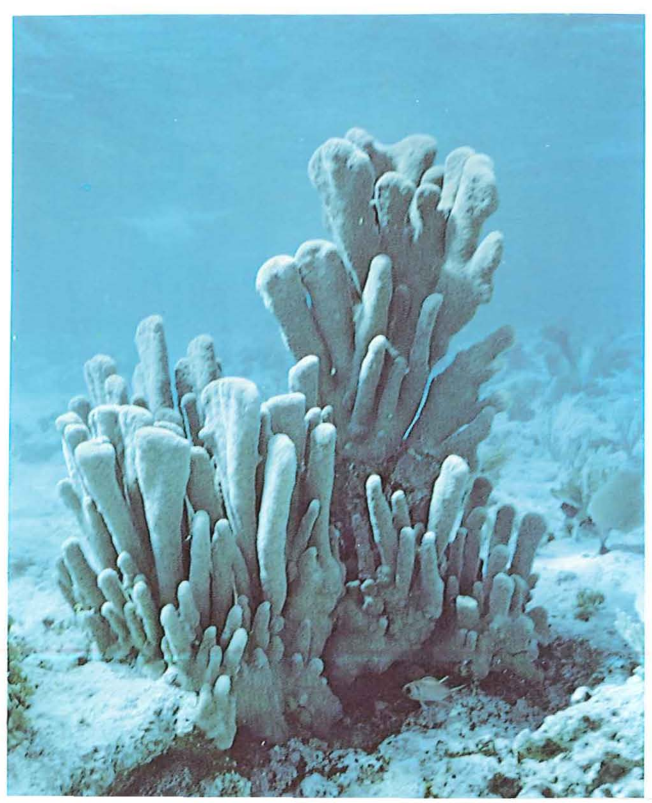
As the amount of drilling for offshore oil increases, questions arise about the potential impact of drilling muds on the marine environment. More than 500 trade-named mud products are used currently. But these represent only about 45 compounds, and only about a dozen are used to drill the typical well.

Using time-delay underwater photography of coral that had been contaminated with whole, undiluted drilling mud, Texas A&M scientists observed corals engaging in a pulsing action which shed the drilling mud. They were, however, unable to observe the same action in the laboratory. Here, tests showed that in concentrated doses, some undiluted drilling muds are toxic to corals and affect their ability to cleanse themselves.

In another laboratory experiment, corals were maintained in natural sea water in large glass aquaria. South Louisiana crude oil was layered on the surface of the water, but the coral colonies were not allowed to come in direct contact with the floating oil. Later, the corals were placed in aquaria containing coral reef butterfly fish. These fish characteristically feed on the mucus which corals produce to protect themselves from environmental hazards and which may be a means of hydrocarbon release by contaminated corals.

Butterfly fish were chosen for the study to determine whether any toxic substance on coral reefs would get into the mucus, be consumed by the fish, and get into the food web. The fish were allowed to eat the mucus that had been produced by oil contaminated corals for several hours. Subsequent analysis showed small amounts of naphthalenes in several organs of the fish. No information was obtained about the persistence of hydrocarbons in the tissues of oil-contaminated fish. As noted in the summaries elsewhere in this report, however, other species of fish very rapidly metabolize and cleanse themselves of hydrocarbons.

The ability of reef corals to tolerate grazing and predation and to compete for space is dependent in large part on their growth rate. It follows that depressed coral growth rates due to oil pollution could have a long-term deleterious effect on the whole coral reef community. Preliminary investigations have been undertaken to determine the effect of that fraction of fuel oil which is soluble in water on the rate of skeletal calcium deposition by one species of branching coral.



*Pillar coral (*Dendrogyra cylindrus*), a rare and distinctive species found in Caribbean waters.*

One of the many platforms producing crude oil and natural gas from America's offshore lands.

THE EFFECT OF DRILLING MUDS ON MARINE ANIMALS

Principal Investigator:

J. M. Neff
Texas A&M University
College Station, Texas

As noted above, some quantities of used drilling muds enter the marine environment during offshore operations. To find out what happens both to organisms on the ocean floor and to those in the surrounding waters when drilling mud enters their environment, the American Petroleum Institute funded a study by Texas A&M University.

The researchers studied muds that had been used for drilling at great depths because the high temperatures encountered in such drilling can alter the physical and chemical composition of the muds. Animals of various species taken from different parts of the Gulf of Mexico were placed in aquaria and exposed to these used drilling muds for periods ranging from four to 60 days. The deaths of the animals at different concentrations of the drilling mud in seawater were logged.

For tests with suspended sediment, different quantities of drilling mud were added to a series of cylindrical all-glass aquaria containing seawater. Such test organisms as fish, shrimp, oysters, and clams were exposed to the suspended muds for a minimum of 96 hours. Mortalities were noted, and at the end of the exposure period survivors were examined for possible tissue damage.

In other tests involving the exposure tanks, the mud was present as layers of different thicknesses on top of natural sediments. Marine crustaceans and mollusks accumulated some chromium, but there is a possibility that the chromium is associated with mud in the digestive tract or on body surfaces. In any case, the organisms lose the chromium when placed in fresh seawater.

Other conditions of the chromium, mud, overlying water, and tissues of mud-exposed animals are still to be determined. The project is scheduled for completion in 1979, at which time final conclusions will be reported. A similar study on the effects of used drilling muds on marine animals in cold water is now in progress at Bowdoin College in Maine.

III. THE FATE OF OIL

CREATING A COMPUTER MODEL

Principal Investigator

R. L. Kolpack
N. B. Plutchak
Environmental Geology Program
University of Southern California
Los Angeles, California

The first project at Battelle-Northwest dealt with the *effects* of oil in a marine environment, or what happens to marine organisms affected by oil in the sea. The *fate* of oil, or what happens to the oil itself once it is spilled into the ocean, was the subject of another set of studies conducted in the early stages of the American Petroleum Institute's fate and effects research program.

University of Southern California researchers designed their project to follow a typical oil spill in the marine environment. They began by surveying existing oil spill literature, reviewing more than 10,000 data sources. They evaluated 550 studies to determine "mass balance" relationships and to identify gaps in existing knowledge.

As their work proceeded, the investigators saw the need for a more exact method of expressing the information they had gathered. They proposed the creation of a mathematical model of an oil spill that could be expressed in computer language. It would then be possible to express simultaneously not only the various stages that a spill might go through, but also the numerous factors that affect those stages.

Knowledge in this form is important for three reasons. First, such a model helps in defining research needs. Second, it aids in predicting whether, and how much of, a given oil spill will reach the coast or an environmentally sensitive area. And third, the state and concentration of the oil at a given time and place can be ascertained, thus assisting in predicting the effects that the oil might have on marine life.

The University of Southern California researchers created a highly sophisticated three-dimensional model designed to consider not only the physical movement of an oil spill, but also changes in oil concentration and composition over a period of time, taking into account such environmental, chemical, and physical factors as temperature, sea state, oil dispersion, biodegradation, evaporation, and solution. The model is an advanced tool that should prove of value to others working in this field. The principal investigator plans publication of complete details on the model.

CONTROLLED OIL SLICKS ON THE OCEAN

Principal Investigators:

E. E. Johanson
J. C. Johnson
JBF Scientific Corporation
Wilmington, Massachusetts

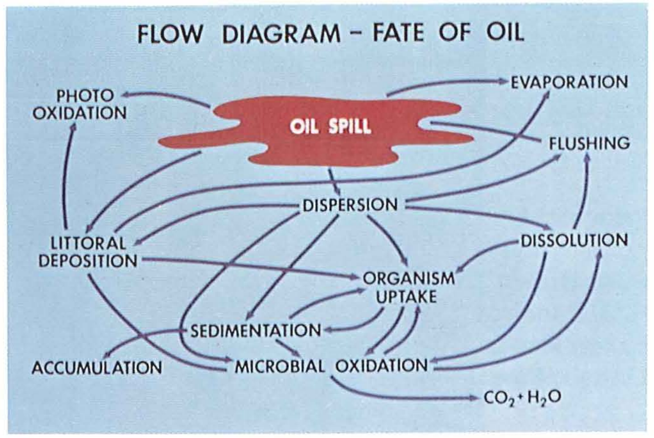
Most open water oil spill research has been done by researchers hurriedly assembling and traveling to spill sites to monitor the physical, chemical, and biological effects. Consequently, there is relatively little information on the behavior of a spill during its first hours.

To remedy this deficiency, the American Petroleum Institute commissioned JBF Scientific Corporation to produce and monitor small, controlled crude oil slicks on the open ocean. JBF scientists made four spills, each consisting of approximately 440 gallons of crude oil. They released light and heavy crude oils in both calm and rough seas.

The scientists made each spill from a research vessel and tracked it by vessel and aircraft for up to two days. Of special interest was the chemical behavior of various fractions in the oils, especially low molecular weight, soluble hydrocarbons that have a relatively high toxicity. They performed detailed chemical analyses on samples of the oil and on the waters at five and ten feet below the oil. They identified specific hydrocarbon fractions and their concentrations, toward relating such data to the potential biological effects such fractions might have in water.

Chemical analyses of the water under the oil slicks showed that, in all cases, low molecular weight hydrocarbons were not detectable in the water samples taken more than 20 minutes after the spills. Further examination showed that oils undergo a rapid weathering process in the early hours after a spill, losing in the process certain hydrocarbon fractions by dissolution and evaporation.

Studies of the hydrocarbons in the water samples showed that concentrations increased in the waters under the slicks soon after the spills occurred, but decreased rapidly. Concentrations returned to background levels in about four hours. The fact that concentrations of hydrocarbons in the water column drop rapidly indicates that toxic concentrations are not maintained very long under oil slicks and therefore that the impacts on marine life present under slicks should not be substantial.



Schematic of major factors affecting oil in the marine environment.

USING DISPERSANTS ON OIL SPILLS

Principal Investigators:

J. C. Johnson
R. Neal
JBF Scientific Corporation
Wilmington, Massachusetts

G. C. Grant
H. L. Kator
P. L. Zubkoff
Virginia Institute of Marine Science
Gloucester Point, Virginia

D. T. Boyles
British Petroleum Research Center
Middlesex, England

Knowledge of the physical and chemical behavior of crude oil slicks under natural conditions is now being used as the basis for a study of oil spill dispersants. Researchers are determining how effective chemical dispersants are in accelerating the processes that break up and dissipate oil in open water. The results of these tests will be used to:

- Compare hydrocarbon levels in the water resulting from oils that have and have not been dispersed.
- Establish the effectiveness of various types of chemical dispersants.
- Evaluate techniques for applying dispersants from aircraft and surface vessels.
- Determine the physical and chemical behavior of ocean oil spills that have been chemically dispersed.
- Determine whether significant adverse biological effects result from the use of chemical dispersants.

Such information will provide an on-scene coordinator with the information he needs to decide whether to use dispersants on an oil spill and, if so, how to use them effectively. It will help fill in the gaps in knowledge that presently make it difficult for administrative agencies to review and evaluate dispersant regulations. Finally, additional information should make it easier for dispersant and equipment manufacturers to improve their products and their application methods.

In November 1978, a study of the fate and biological effects of chemically dispersed oil was undertaken under the sponsorship of the American Petroleum Institute. Four spills of 440 gallons of crude oil were made approximately 30 miles off the coast of New Jersey. Each spill was treated with a dispersant applied by helicopter. The water column was sampled throughout the spill area and at various depths, the samples being studied both for oil content and effect on marine organisms.

The entire testing operation was monitored by various government agencies. In airplanes fitted with sophisticated imaging equipment, agency personnel overflew the site to record the spread and trajectory of the spills before and after application of the dispersant. The data obtained by the various investigators are now being analyzed and correlated. Conclusions will be published upon completion of this work, and additional work is planned for the near future.

IV. HEALTH ASPECTS OF OIL SPILLS

PNA'S IN THE ENVIRONMENT

Principal Investigators:

R. A. Brown
R. J. Pancirov
Exxon Research and Engineering Company
Linden, New Jersey

Since some PNA's, or polynuclear aromatic hydrocarbons, are carcinogenic, the American Petroleum Institute commissioned this study of the current knowledge about PNA's in the marine environment. The Exxon investigators reviewed the capability of scientists to measure the presence of carcinogenic PNA's in petroleum and in marine animals, at concentrations as low as one or two parts per billion. They showed how advanced analytical techniques apply to the actual measurement and compilation of concentrations of PNA's. This information is useful in determining what petroleum products contain PNA's in what quantities and in tracing their presence, if any, in the food chain.

The new methods of chemical analysis used in this study assist in investigating the carcinogenicity of PNA's and in determining the origin of PNA's through chemical "fingerprints." Through other research, it has become clear that the vast majority of PNA's, and especially carcinogenic PNA's, originate from combustion. They are widely present in the environment, including soils and marine sediments, and have evidently been present since geologic times.

BAP, or benzo(a)pyrene, is one of the carcinogenic PNA's present in the earth's environment. It is estimated that approximately 1,350 tons of BAP enter the environment in the United States as a result of man's activities each year. Of this amount, 600 tons originate from refuse burning, 500 tons from heat and power generation, 200 tons from the production of coke, 20 tons from the operation of motor vehicles, and 20-30 tons from crude oil, including both man's input and natural oil seeps into oceans.

The investigators also looked into the question of whether the PNA's found in food products are a result of the natural combustion process or whether they result from contamination. Their studies suggested that the particular types of PNA's found in flounder, oysters, and clams derive from combustion sources—for example, forest fires—rather than from petroleum.

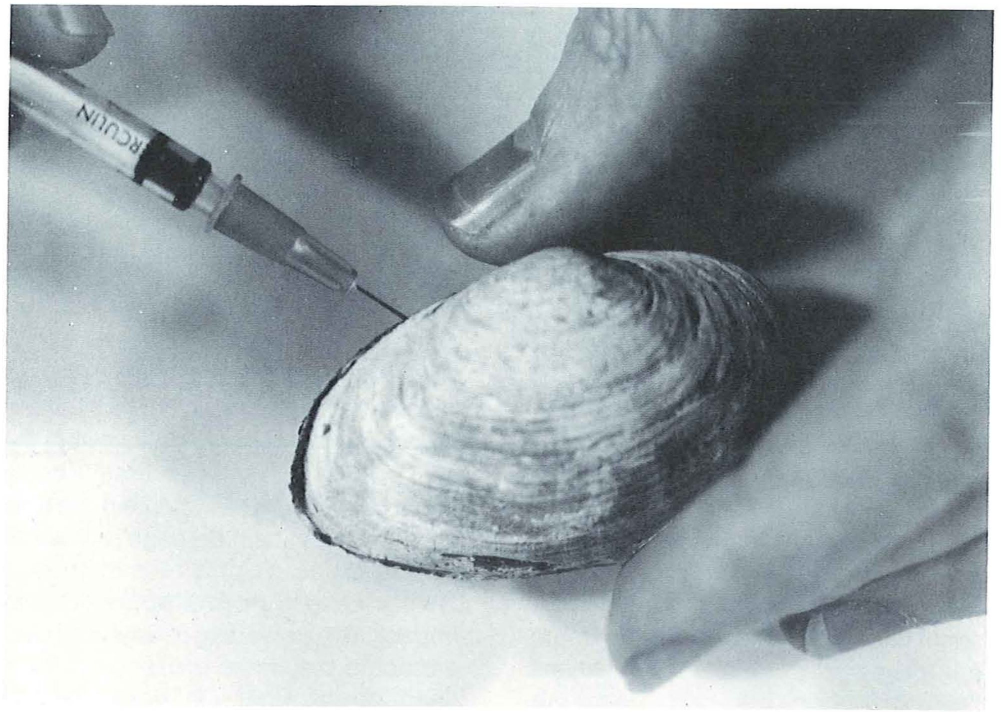
PNA's present in the environment can undergo chemical changes. They are especially sensitive to photochemical degradation by sunlight. PNA's are also susceptible to biological degradation by bacteria.

Different types of PNA's vary in their acute toxicity. Naphthalenes, for example, appear to be toxic to certain marine animals, whereas BAP was found not to be lethal at the highest concentrations tested.

Marine organisms ingesting PNA's do not retain them, but purge themselves when placed in clean water. Some sea animals, such as mussels, depurate hydrocarbons unchanged. Others, such as fish, metabolize them. Similar results have been obtained in shrimp, clams, and oysters.

A review of this work is contained in American Petroleum Institute Publication No. 4297.

Shown is an example of the highly sophisticated type of equipment used to measure and identify PNA's at a concentrations as low as one or two parts per billion.



The bleeding technique for diagnosis of abnormal cell growth enables scientists to keep clams alive and, thus, follow the course of the disease.

ABNORMAL CELL GROWTHS IN SOFT-SHELL CLAMS

Principal Investigators:

C. W. Brown
R. S. Brown
S. B. Saila
University of Rhode Island
Kingston, Rhode Island

A 1971 oil spill into Long Cove in Searsport, Maine, prompted New England researchers to look into the possible effects the oil might have on the clams in the area. Their study uncovered the fact that some of the clams in the area evidenced tumorous cell growth patterns. Since one implication was that the oil might have been responsible for these abnormalities, the American Petroleum Institute felt compelled to look into the question.

Because of its biostatistical and histopathological capabilities, the University of Rhode Island was chosen to undertake a wide-ranging study of abnormal growths in clams. The scientists picked 14 sites, ranging from Canada south to the Chesapeake Bay. The study involved examining samples of clams for a large number of disease conditions and gathering environmental data from the sample sites. Some sites have been examined at different times of the year to permit assessment of seasonal effects.

In field experiments, healthy and diseased clams have been transplanted in an effort to assess the effects of the environment on disease and growth. In addition, a laboratory study is now in progress to determine whether the disease can be transmitted under controlled conditions.

The study includes microscopic examination of clam tissue and an effort to correlate the disease with environmental contaminants by careful chemical and analytical studies. In the course of this research, one very useful technique was used. It involved sampling the blood of a clam while keeping the clam alive, thereby allowing scientists to follow the course of the disease.

Using this technique in a series of laboratory studies involving specially designed flow-through equipment, the Rhode Island group demonstrated (1) that the disease is not caused by oil and (2) that it can be communicated from one clam to another, even in the absence of pollutants.

This is probably the first scientific demonstration of a communicable disease in shellfish. It should be noted that the disease may be aggravated by stress arising from such causes as heat, metals, or oil. In statistically designed field studies, it has also been found that the disease is prevalent in areas unpolluted by oil. Further laboratory and field studies are in progress.

CONCLUSION

The American Petroleum Institute believes that the fate and effects research summarized in this report, *Oil and the Sea,* is an important contribution to man's understanding of what really happens when petroleum and petroleum products get into the marine environment. Part of that contribution to what is a growing body of knowledge consists of the development of methodologies that previously did not exist, of new tools for probing difficult and complex questions of tremendous interest to modern, industrialized society. And part consists of finding answers—and the beginnings of answers—to some of those difficult questions.

Development of the methodologies began in the laboratories of Battelle-Northwest and continued at such other independent research organizations as Battelle-Columbus and Texas A&M University. The methodologies make possible the accurate analysis and measurement of oil in water and sediments and in the tissues of marine animals. Closely related to these tools are the Reference Test Oils for biological studies made available by the Institute in the repository at Texas A&M University. These reference oils provide a common basis for comparing the results of biological studies, no matter where they are conducted. Also related is the procedural work of the workshop co-sponsored by the Institute, Bureau of Land Management, and National Oceanic and Atmospheric Administration at Montauk, Long Island. The seminar provided scientists everywhere with the first comprehensive reference work on preferred ways to conduct research on the effects of oil spills in the marine environment.

As to the substantive findings of the individual research projects sponsored by the Institute—along with research conducted by others in the same area—it is now possible to conclude that the greatest damage to the environment occurs when (1) spilled oil reaches a confined shallow body of water, such as a small bay; (2) the oil is a refined oil, such as home heating oil or diesel fuel; and (3) a storm or heavy surf pounds the oil into the bottom sediments. Spills involving all three of these conditions simultaneously do occur, as was the case at West Falmouth in 1969, but they are rare.

Areas subjected to severe spills of this kind apparently take several years to recover. Just how long cannot be determined at this time. But areas subjected to less severe spills appear to recover rapidly, as demonstrated by the experience following the Santa Barbara spill in 1969 and the San Francisco Bay spill in 1971. Spills occurring well offshore or on the open sea cause the least significant damage to marine life, whether the oil is a crude oil or a refined product. And chronic, low-level exposure to oil appears to have no significant impact. The University of Southern California researchers noted that in the presence of the natural crude oil seepage at Coal Oil Point, the stalked barnacle showed impaired reproduction potential. But both external examination and dissection of all other resident marine animals examined showed no change in the total biomass of the area and no abnormal growth in individual organisms.

Of equal importance is another conclusion to be drawn from the Institute's research—namely, that marine organisms generally purge themselves of ingested oil and do not pass contamination up the food chain for ultimate consumption by human beings.

As is the case with any branch of science, answering existing questions about the fate and effects of oil in the marine environment more often than not raises additional questions. For example, crude and refined oils are toxic, but in what quantities and over what exposure times? How can chemical dispersants best be used to combat oil spills? And what happens when oil reaches ocean sediments, both to the oil itself and to sediment organisms?

These questions and others remain and must be answered. As noted at the outset of *Oil and the Sea,* it is the job of the petroleum industry to help meet this country's current and future energy needs by finding and producing oil where it occurs, refining it, and transporting it to where it is needed—and to do so as efficiently and as safely as possible. The American Petroleum Institute's research in this and other environmental areas therefore will continue.

COMMITTEE ON FATE AND EFFECTS OF OIL IN THE ENVIRONMENT AMERICAN PETROLEUM INSTITUTE

A. H. Lasday, Chairman
Texaco Inc.

R. C. Allred, Vice Chairman
Continental Oil Company

G. P. Canevari
Exxon Research & Engineering Company

V. F. Coty
Mobil Research & Development Corporation

E. B. Cowell
British Petroleum Company, Ltd.

W. F. Gusey
Shell Oil Company

J. P. Marum
Standard Oil Company (Indiana)

C. D. McAuliffe
Chevron Oil Field Research Company

E. W. Mertens
(Chairman, 1971-78)
Chevron USA

J. P. Ray
Shell Oil Company

J. L. Siva
Atlantic Richfield Company

F. T. Weiss
Shell Development Company

PUBLICATIONS RESULTING FROM THE INSTITUTE'S FATE AND EFFECTS RESEARCH PROGRAM

American Petroleum Institute. 1977. Oil Spill Studies: Strategies and Techniques. Proceedings of a Workshop, Montauk, L.I., New York, February 24-26, 1976. API Publication No. 4286. American Petroleum Institute, Washington, D.C., 101 pp.

Anderson, J.W. 1973. Uptake and Depuration of Specific Hydrocarbons from Oil by the Bivalves *Rangia cuneata* and *Crassostrea virginica.* In: Background Papers for a Workshop on Inputs, Fates and Effects of Petroleum in the Marine Environment. NSF Ocean Affairs Board, Airlie, Virginia, May 21-25, 1973. National Science Foundation, Washington, D.C., pp. 690-708.

Anderson, J.W. (ed.). 1975. Laboratory Studies on the Effects of Oil on Marine Organisms: An Overview. Technical Report by Texas A & M University, Center for Marine Resources. API Publication No. 4249. American Petroleum Institute, Washington, D.C., 70pp.

Anderson, J.W. 1977. Responses to Sublethal Levels of Petroleum Hydrocarbons: Are They Sensitive Indicators and Do They Correlate with Tissue Contamination? In: Wolfe, D.A. (ed.) Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, New York, N.Y., pp. 95-114.

Anderson, J.W. 1977. Effects of Petroleum Hydrocarbons on the Growth of Marine Organisms. In: McIntyre, A.D. and K. Whittle (eds.) Petroleum Hydrocarbons in the Marine Environment. Rapp. P. – v Reun. Cons. Int. Explor. Mer. *171,* 157-165.

Anderson, J.W. and R.D. Anderson. 1975. Oil Bioassays with the American Oyster *Crassostrea virginica* (Gmelin). In: Proceedings of the National Shellfisheries Association (in press).

Anderson, J.W., R.C. Clark and J.J. Stegeman. 1974. Petroleum Hydrocarbons. In: Proceedings, Marine Bioassays Workshop, Montauk, L.I., New York. Marine Technology Society, Washington, D.C., pp. 36-75.

Anderson, J.W., J.M. Neff, B.A. Cox, H.E. Tatem and G.M. Hightower. 1974. Characteristics of Dispersions and Water-soluble Extracts of Crude and Refined Oils and Their Toxicity to Estuarine Crustaceans and Fish. Mar. Biol. *27,* 75-88.

Anderson, J.W., J.M. Neff, B.A. Cox, H.E. Tatem and G.M. Hightower. 1974. Effects of Oil on Estuarine Animals: Toxicity, Uptake and Depuration, Respiration. In: Vernberg, F.J., and W.B. Vernberg (eds.) Pollution and Physiology of Marine Organisms. Academic Press, New York, N.Y., pp. 285-310.

Anderson, J.W., J.M. Neff and S.R. Petrocelli. 1974. Sublethal Effects of Oil, Heavy Metals and PCBs on Marine Animals. In: Khan, M.A.Q. and J.P. Bederka, Jr. (eds.) Survival in Toxic Environments. Academic Press, New York, N.Y., pp. 83-121.

Anderson, J.W. and J.M. Neff. 1976. Accumulation and Release of Petroleum Hydrocarbons by Edible Marine Animals. International Symposium on Recent Advances in the Assessment of the Health Effects of Environmental Pollution, Paris, Vol. III, pp. 1461-1469.

Anderson, J.W., D.B. Dixit, G.S. Ward and R.S. Foster. 1977. Effects of Petroleum Hydrocarbons on the Rate of Heart Beat and Hatching Success of Estuarine Fish Embryos. In: Vernberg, F.J., A. Calabrese, F.P. Thurberg and W.B. Vernberg (eds.) Physiological Responses of Marine Biota to Pollutants. Academic Press, New York, N.Y., pp. 241-258.

Anderson, R.D. 1975. Petroleum Hydrocarbons and Oyster Resources of Galveston Bay, Texas. Proceedings, Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., pp. 541-548.

Anderson, R.D. and J.W. Anderson. 1973. Uptake and Depuration of Petroleum Hydrocarbons by the American Oyster, *Crassostrea virginica* Gmelin. Proc. Natl. Shellfisheries Assoc. *64* 1-2.

Anderson, R.D. and J.W. Anderson. 1975. Effects of Salinity and Selected Petroleum Hydrocarbons on the Osmotic and Chloride Regulation of the American Oyster, *Crassostrea virginica*. Physiol. Zool. *48* (4), 420-430.

Armstrong, H.W., K. Fucik, J.W. Anderson and J.M. Neff. 1977. Effects of Oilfield Brine Effluent on Benthic Organisms in Trinity Bay, Texas. Final Report by Texas A & M University, Center for Marine Studies. API Publication No. 4291. American Petroleum Institute, Washington, D.C., 81 pp.

Armstrong, H.W., K. Fucik, J.W. Anderson and J.M. Neff. 1979. Effects of Oilfield Brine Effluent on Sediments and Benthic Organisms in Trinity Bay, Texas. Mar. Environ. Res. (in press).

Becker, C.D., J.A. Lichatowich, M.J. Schneider and J.A. Strand. 1973. Regional Survey of Marine Biota for Bioassay Standardization of Oil and Oil Dispersant Chemicals. Research Report by Battelle, Pacific Northwest Laboratories. API Publication No. 4167. American Petroleum Institute, Washington, D.C., 108 pp.

Bender, M.E., E.A. Shearls, R. P. Ayres, C. H. Hershner and R. J. Huggett. 1977. Ecological Effects of Experimental Oil Spills on Eastern Coastal Plain Estuarine Ecosystems. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 505-509.

Bieri, R.H., V.C. Stamoudis and M.K. Cueman. 1977. Chemical Investigations of Two Experimental Oil Spills in an Estuarine Ecosystem. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 511-515.

Blaylock, J.W., P.W. O'Keefe, J.N. Roehm and R.E. Wildung. 1973. Determination of n-Alkane and Methylnaphthalene Compounds in Shellfish. Proceedings, Joint Conference on Prevention and Control of Oil Spills, Washington, D.C. American Petroleum Institute, Washington, D.C., pp. 173-177.

Cox, B.A. 1975. Responses of the Marine Crustaceans *Mysidopsis almyra* Bowman, *Penaeus aztecus* Ives and *Penaeus setiferus* (Linn.) to Petroleum Hydrocarbons. Ph.D. Dissertation, Texas A&M Univ., August 1975, 167 pp.

Cox, B.A., J.W. Anderson and J.C. Parker. 1975. An Experimental Oil Spill: the Distribution of Aromatic Hydrocarbons in the Water, Sediment, and Animal Tissues Within a Shrimp Pond. Proceedings of Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., pp. 607-612.

Dennis, J.V. 1974. A Second Oil Pollution Survey of the Southeast Florida Coast. API Publication No. 4231. American Petroleum Institute, Washington, D.C., 36 pp.

Dillon, T.M., J.M. Neff and J.S. Warner. 1978. Toxicity and Sublethal Effects of No. 2 Fuel Oil on the Supralittoral Isopod, *Lygia exotica*. Bull. Environ. Contam. Toxicol. *20,* 320-327.

Dixit, D., and J.W. Anderson. 1977. Distribution of Naphthalenes within Exposed *Fundulus similus* and Correlations with Stress Behavior. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 633-636.

Ernst, V.V., J.M. Neff and J.W. Anderson. 1977. Effects of the Water-soluble Fraction of No. 2 Fuel Oil on the Development of the Estuarine Fish, *Fundulus grandis* Baird and Girard. Environ. Pollut. *14,* 25-35.

Forns, J.M. 1977. The Effects of Crude Oil on Larvae of Lobster *Homarus americanus.* Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 569-573.

Fucik, K.W., H.W. Armstrong, and J.M. Neff. 1977. The Uptake of Naphthalenes by the Clam *Rangia cuneata*, in the Vicinity of an Oil Separator Platform in Trinity Bay, Texas. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 637-640.

Fucik, K.W., and J.M. Neff. 1977. Effects of Temperature and Salinity on Naphthalenes Uptake in the Temperate Clam, *Rangia cuneata* and the Boreal Clam, *Protothaca staminea*. In: Wolfe, D.A. (Ed.). Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, New York, N.Y., pp. 305-312.

JBF Scientific Corporation. 1976. Final Report. Physical and Chemical Behavior of Crude Oil Slicks on the Ocean. API Publication No. 4290. American Petroleum Institute, Washington, D.C., 98 pp.

Jessee, W. 1976. The Effects of Water Temperature, Tidal Cycles, and Intertidal Position on Spawning in *Mytilus californianus* (Conrad). M.A. Dissertation, Humbolt State College, Arcata, California.

Kolpack, R.L., B.J. Mechalas, T.J. Meyers, N.B. Plutchak and E. Eaton. 1973. Fate of Oil in a Water Environment, Phase I. Final Report, Vol. I. A Review and Evaluation of the Literature. API Publication No. 4212. American Petroleum Institute, Washington, D.C., 27 pp.

Kolpack, R.L., T.J. Meyers, J.L. Batton, D.E. Drake and N.B. Plutchak. 1973. Fate of Oil in a Water Environment, Phase I. Final Report. Vol. II. Annotated Bibliography of Selected Literature. API Publication No. 4213. American Petroleum Institute, Washington, D.C., 166 pp.

Laughlin, R.B., Jr., L.G.L. Young and J.M. Neff. 1977. A Long-term Study of the Effects of Water-soluble Fractions of No. 2 Fuel Oil on the Survival, Development Rate and Growth of the Mud Crab *Rhithropanopeus harrisii* (Gould). Mar. Biol. *47,* 87-95.

Martella, T. 1974. Some Factors Influencing Byssus Thread Production in *Mytilus edulis* (Mollusca: Bivalvia) Linnaeus, 1758. Water, Air and Soil Pollution *3,* 171-177.

Maynard, N.G., C.D. Gebelein and A. Zsolnay. 1977. The Effects of Pelagic Hydrocarbons on the Rocky Intertidal Flora and Fauna of Bermuda. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 499-503.

Neff, J.M. 1974. Oil Pollution and Shellfish. In: Proceedings of the Eighth National Shellfish Sanitation Workshop, New Orleans, Louisiana, January 16-18, 1974, pp. 72-76.

Neff, J.M. 1975. Accumulation and Release of Petroleum-derived Aromatic Hydrocarbons by Marine Animals. Preprints, Div. of Petrol. Chem., A.C.S., *20* (4), 839-850.

Neff, J.M. (ed.) 1979. Responses of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. Final Report by Texas A&M University, Center for Marine Resources. American Petroleum Institute, Washington, D.C. (in press).

Neff, J.M., and J.W. Anderson. 1975. An Ultraviolet Spectrophotometric Method for the Determination of Naphthalene and Alkylnaphthalenes in the Tissues of Oil-contaminated Marine Animals. Bull. Environ. Contam. Toxicol. *14,* 122-128.

Neff, J.M., and J.W. Anderson. 1975. Accumulation, Release and Distribution of Benzo(a)pyrene-C^{14} in the Clam *Rangia cuneata*. Proceedings, Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., pp. 469-472.

Neff, J.M., J.W. Anderson, B.A. Cox, R.B. Laughlin, Jr., S.S. Rossi and H.E. Tatem. 1976. Effects of Petroleum on Survival, Respiration and Growth of Marine Animals. In: Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. American Institute of Biological Sciences, Arlington, Virginia, pp. 515-539.

Neff, J.M., B.A. Cox, D. Dixit and J.W. Anderson. 1976. Accumulation and Release of Petroleum-derived Aromatic Hydrocarbons by Four Species of Marine Animals. Mar. Biol. *38,* 279-289.

Pancirov, R.J. 1974. Compositional Data on API Reference Oils Used in Biological Studies: A # 2 Fuel Oil, a Bunker C, Kuwait Crude Oil and South Louisiana Crude Oil. American Petroleum Institute, Washington, D.C., 24 pp.

Pancirov, R.J. and R.A. Brown. 1975. Analytical Method for the Measurement of Polynuclear Aromatic Hydrocarbons in Marine Tissue. Preprints, Div. of Petrol. Chem., A.C.S., *20* (4), 812-823.

Pancirov, R.J. and R.A. Brown. 1975. Analytical Methods for Polynuclear Aromatic Hydrocarbons in Crude Oils, Heating Oils and Marine Tissues. Proceedings, Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., pp. 103-113.

Pancirov, R.J. and R.A. Brown. 1977. Polynuclear Aromatic Hydrocarbons in Marine Tissues. Env. Science & Tech. *11* (10), 989-992.

Proceedings, Symposium on Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment, American University, Washington, D.C., August 9-11, 1976. American Institute of Biological Sciences, Arlington, Virginia, 578 pp.

Proceedings, 1969 Joint Conference on Prevention and Control of Oil Spills, New York, N.Y. American Petroleum Institute, Washington, D.C., 345 pp.

Proceedings, 1971 Joint Conference on Prevention and Control of Oil Spills, Washington, D.C. American Petroleum Institute, Washington, D.C., 544 pp. plus 45 pp. supplement.

Proceedings, 1973 Joint Conference on Prevention and Control of Oil Spills, Washington, D.C. American Petroleum Institute, Washington, D.C., 834 pp.

Proceedings, 1975 Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., 612 pp.

Proceedings, 1977 Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., 640 pp.

Proceedings of the Industry-Government Seminar on Oil Spill Treating Agents, April 8-9, 1970, Washington, D.C. API Publication No. 4055. American Petroleum Institute, Washington, D.C., 168 pp.

Rossi, S.S. 1976. Interactions Between Petroleum Hydrocarbons and the Polychaetous Annelid, *Neanthes arenaceodentata:* Effects on Growth and Reproduction: Fate of Diaromatic Hydrocarbons Accumulated from Solution or Sediments. Ph.D. Dissertation, Texas A&M Univ., May 1976, 75 pp.

Rossi, S.S. 1977. Bioavailability of Petroleum Hydrocarbons from Water, Sediments and Detritus to the Marine Annelid, *Neanthes arenaceodentata*. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 621-625.

Rossi, S.S., and J.W. Anderson. 1976. Toxicity of Water-soluble Fractions of No. 2 Fuel Oil and South Louisiana Crude Oil to Selected Stages in the Life History of the Polychaete, *Neanthes arenaceodentata*. Bull. Environ. Contam. Toxicol. *16,* 18-24.

Rossi, S.S., and J.W. Anderson. 1977. Accumulation and Release of Fuel Oil-derived Diaromatic Hydrocarbons by the Polychaete, *Neanthes arenaceodentata*. Mar. Biol. *39,* 51-55.

Rossi, S.S., and J.W. Anderson. 1977. Effect of No. 2 Fuel Oil and South Louisiana Crude Oil Water-soluble Fractions on Hemoglobin Compensation and Hypoxia Tolerance in the Polychaetous Annelid, *Neanthes arenaceodentata* (Moore). Mar. Sci. Commun. *3,* 117-131.

Rossi, S.S., and J.W. Anderson. 1978. Effect of No. 2 Fuel Oil Water-soluble Fractions on Growth and Reproduction in *Neanthes arenaceodentata* (Polychaeta: Annelida). Water, Air and Soil Pollut. *9,* 155-170.

Rossi, S.S., and J.W. Anderson. 1978. Petroleum Hydrocarbon Resistance in the Marine Worm *Neanthes arenaceodentata* (Polychaeta: Annelida) Induced by Chronic Sublethal Exposure to No. 2 Fuel Oil. Bull. Environ. Contam. Toxicol. *20,* 513-521.

Rossi, S.S., J.W. Anderson and G.S. Ward. 1976. Toxicity of Water-soluble Fractions of Four Test Oils for the Polychaetous Annelids, *Neanthes arenaceodentata* and *Capitella capitata*. Environ. Pollut. *10,* 9-18.

Rossi, S.S., and J.M. Neff. 1978. Toxicity of Polynuclear Aromatic Hydrocarbons to the Marine Polychaete, *Neanthes arenaceodentata*. Mar. Pollut. Bull. *9,* 220-223.

Sharp, J.R., K.W. Fucik and J.M. Neff. 1979. Physiological Basis of Differential Sensitivity of Fish Embryonic Stages to Oil Pollution. In: Vernberg, F.J., W.B. Vernberg and A. Calabrese (eds.) Marine Pollution: Functional Responses. Academic Press, New York, N.Y. (in press).

Strand, J.A., W.L. Templeton, J.A. Lichatowich and C.W. Apts. 1971. Development of Bioassay Procedures for Oil and Oil Dispersant Chemicals. Report to American Petroleum Institute, Committee for Air and Water Conservation. Battelle, Pacific Northwest Laboratories, Richland, Washington, 106 pp.

Straughan, D. 1974. Field Sampling Methods and Techniques for Marine Organisms and Sediments. In: NBS Special Publication 409, Marine Pollution Monitoring (Petroleum). Proceedings of a Symposium and Workshop Held at NBS, Gaithersburg, Maryland, May 13-17, 1974. National Bureau of Standards, Gaithersburg, Maryland, pp. 183-188.

Straughan, D. and D.M. Lawrence. 1975. Investigation of Ovicell Hyperplasia in Bryozoans Chronically Exposed to Natural Oil Seepage. Water, Air and Soil Pollution *5* (1), 39-48.

Straughan, D. 1976. Effects of Natural Chronic Exposure to Petroleum Hydrocarbons on Size and Reproduction in *Mytilus californicus Conrad.* Proceedings, Symposium on Pollution and Physiology of Marine Organisms, Milford, Connecticut, November 3-6, 1975. Academic Press, New York, N.Y., pp. 289-298.

Straughan, D. 1976. Sublethal Effects of Natural Chronic Exposure to Petroleum in the Marine Environment. Final Report, Allan Hancock Foundation, University of California. API Publication No. 4280. American Petroleum Institute, Washington, D.C., 119 pp.

Straughan, D. 1977. The Sublethal Effects of Natural Chronic Exposure to Petroleum on Marine Invertebrates. Proceedings, Joint Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana. American Petroleum Institute, Washington, D.C., pp. 563-568.

Tatem, H.E. 1975. The Toxicity and Physiological Effects of Oil and Petroleum Hydrocarbons on Estuarine Grass Shrimp *Palaemonetes pugio* Holthius. Ph.D. Dissertation, Texas A & M University, August 1975, 133 pp.

Tatem, H.E. 1977. Accumulation of Naphthalenes by Grass Shrimp. Effects on Respiration, Hatching and Larval Growth. In: Wolfe, D.A. (Ed.) Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, New York, N.Y. pp. 201-209.

Tatem, H.E., J.W. Anderson and J.M. Neff. 1976. Seasonal and Laboratory Variations in the Health of Grass Shrimp *Palaemonetes pugio:* Dodecyl Sodium Sulfate Bioassay. Bull. Environ. Contam. Toxicol. *16,* 368-375.

Tatem, H.E., B.A. Cox and J.W. Anderson. 1977. The Toxicity of Oils and Petroleum Hydrocarbons to Estuarine Crustaceans. Estuar. Cstl. Mar. Sci. *6,* 365-373.

Vaughan, B.E. (ed.) 1973. Effects of Oil and Chemically Dispersed Oil on Selected Marine Biota—A Laboratory Study. Final Report by Battelle, Pacific Northwest Laboratories. API Publication No. 4191. American Petroleum Institute, Washington, D.C., 118 pp.

Walker, J.D., R.R. Colwell and L. Petrakis. 1975. Bacterial Degradation of Motor Oil. J. Water Poll. Control Fed. *47,* 2058-2066.

Walker, J.D., R.R. Colwell and L. Petrakis. 1975. Microbial Petroleum Degradation: Application of Computerized Mass Spectrometry. Can. J. Microbiol. *21,* 1760-1767.

Walker, J.D., L. Petrakis and R.R. Colwell. 1975. Evaluation of Petroleum Degrading Potential of Bacteria from Water and Sediment. Appl. Microbiol. *30,* 1036-1039.

Walker, J.D., R.R. Colwell and L. Petrakis. 1975. A Study of the Biodegradation of a South Louisiana Crude Oil Employing Computerized Mass Spectroscopy. Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California. American Petroleum Institute, Washington, D.C., pp. 601-606.

Walker, J.D., L. Petrakis and R.R. Colwell. 1976. Comparison of the Biodegradability of Crude and Fuel Oils. Can. J. Microbiol. *22.*

Warner, J.S. 1974. Quantitative Determination of Hydrocarbons in Marine Organisms. In: NBS Special Publication 409, Marine Pollution Monitoring (Petroleum). Proceedings of a Symposium and Workshop Held at NBS, Gaithersburg, Maryland, May 13-17, 1974. National Bureau of Standards, Gaithersburg, Maryland, pp. 195-196.

Warner, J.S 1975. Determination of Sulfur-containing Petroleum Components in Marine Samples. Joint Conference on Prevention and Control of Oil Pollution, San Francisco, California, American Petroleum Institute, Washington, D.C., pp. 97-101.

Warner, J.S. 1976. Determination of Aliphatic and Aromatic Hydrocarbons in Marine Organisms. Analytical Chemistry *48* (3), 578-583.

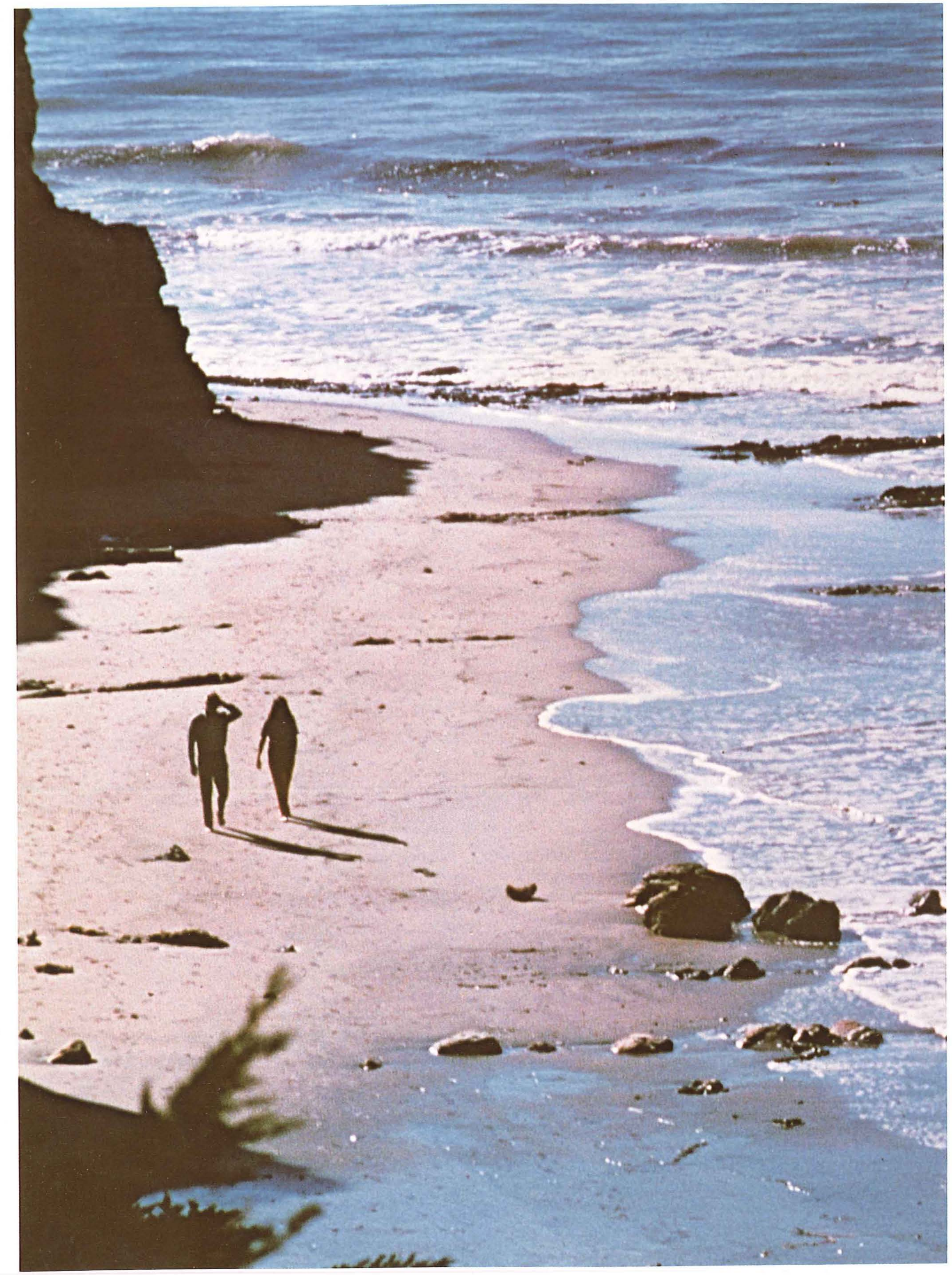
Warner, J.S. 1978. Chemical Characterization of Marine Samples. Final Report by Battelle, Columbus Laboratories. API Publication No. 4307. American Petroleum Institute, Washington, D.C., 36 pp.

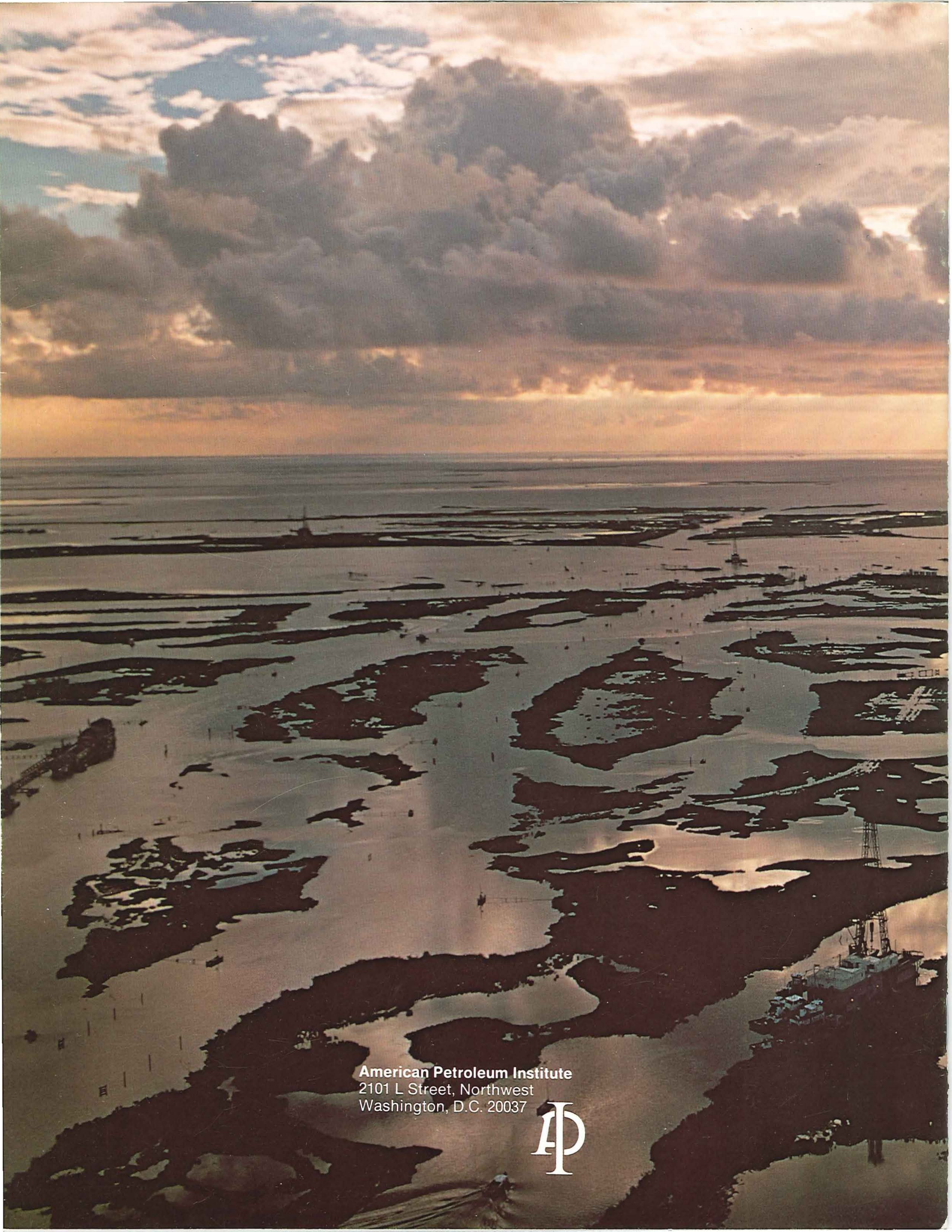
Young, J.P. 1977. Effects of Naphthalene and Phenanthrene on the Grass Shrimp *Palaemonetes pugio* (Holthius). Master's Thesis, Texas A&M Univ., August 1977, 67 pp.

Zsolnay, A. 1978. Lack of Correlation Between Gas-Liquid Chromatograph and UV Absorption Indicators of Petroleum Pollution in Organisms. Water, Air and Soil Pollution *9,* 45-51.

Zsolnay, A. 1978. The Weathering of Tar on Bermuda. Deep Sea Research *25,* 1245-1252.

2400-7/79-20M





American Petroleum Institute
2101 L Street, Northwest
Washington, D.C. 20037