Oil in the Ecosystem

Oil pollution has been a human problem for most of this century, but it took the grounding of the tanker *Torrey Canyon* and the blowout of the well off the coast of Santa Barbara to draw public attention to the major problems that can arise in the production and shipping of petroleum. A fivefold increase in oil production is expected by 1980, and the potential for large-scale pollution can increase even faster because of changes in drilling location and shipping practice. Knowledge of how oil affects the environment is fragmentary and gives only dim clues about what to expect in the future.

The problems involved in oil studies are complex. Crude oil is not a single chemical but a collection of hundreds of substances of widely different properties and toxicities. Paul Galtsoff of the Bureau of Commercial Fisheries at Woods Hole, Massachusetts, stated recently that "oil in sea water should be regarded not as an ordinary pollutant but as a dynamic system actively reacting with the environment."

Viewing the problem of oil this way, one finds that biologists present an essentially unified account of how oil came to be an important part of the environment and that they can give a rough outline of the way oil interacts with the rest of the ecological system. However, it is still impossible to predict the behavior of specific oil spills, and little is known about the long-term effects of oil in the marine environment.

Most current research is directed toward the immediate problem of handling oil spills. There is little prospect that detailed ecological studies will increase dramatically in the near future, but plans are being considered for the establishment of broad-based environmental-monitoring programs.

Oil at Sea

In 1966, 700 million tons of oil—about half the world's total ocean tonnage—were shipped in 3281 tankers. In the best of worlds, this oil would remain in that part of the "ecological" system of interest only to humans—wells, tankers, refineries, and, finally, furnaces and machines. It is difficult to estimate just how far short we are of living in the best of worlds, but Max Blumer of Woods Hole Oceanographic Institution estimates that somewhere between 1 million and 100 million tons of oil are added to our oceans each year.

The major sources of this oil are handling errors, leaks from natural deposits, tanker and barge accidents, and illegal tanker bilge washings. Normal techniques of transferring oil to small coastal tankers, barges, and shore facilities result in a chronic source of coastal oil. The total amount of oil from this source is unknown, but the Massachusetts Division of Natural Resources says that, in Boston Harbor alone, a spill involving several tons of oil can be expected every third week. Less frequent, but more spectacular, are leaks from offshore deposits. These can occur naturally, but they have been associated with drilling operations since the 1930's, when fields in the Gulf of Mexico were opened. The biggest loss associated with the more than 9000 offshore wells was the million-gallon blowout early this year off the California coast near Santa Barbara. Tanker accidents are similar to well blowouts in that an occasional major catastrophe highlights a constant source of contamination. The grounding of the *Torrey Canyon* off the southwest coast of England in March 1967 was simply the most dramatic example of a type of accident that, on a worldwide basis, occurs more than once a week. Finally, deliberate dumping of bilge washings adds a considerable, but unknown, amount of oil to the oceanic environment. In 1962 Shell Oil Company developed a method to separate oil from such washings, and there is a tacit international agreement to use the method; however, shipmasters find the procedure inconvenient, and the dumping practice continues.

Although our oil resources are not unlimited, a quick look to the future indicates that pumping and shipping operations will continue to expand for the next few decades. The continental shelves of North and South America, Africa, and Australia all have oil. Seismic profiling has indicated the probable presence of oil in the North Sea, Persian Gulf, and Indonesia, and large deposits have been discovered in Alaska and Canada.

Oil from these new sources will be transported through pipelines and by gigantic tankers. Construction has already begun on a road that will be used to build the 800-mile, 48-inch, 900-million-dollar pipeline from Alaska's North Slope to Valdez Bay, an ice-free port on the Gulf of Alaska. The large United States merchant vessel S.S. *Manhattan* was specially strengthened for travel in ice and fought her way through the Canadian Arctic in September. If such trial runs are judged successful, a fleet of six, quarter-million-ton vessels will be built for year-round service. (The *Torrey Canyon*, considered a large ship at the time of her grounding, had a displacement of 127,000 tons.)

The proposed drilling activities will involve greater risks of major losses because work must be done at sea or in inhospitable northern latitudes. The use of large tankers will reduce the probability of collisions and groundings, but there are few port facilities for these giants, so the possibility of spills during transfers to smaller tankers or barges will be increased. Major accidents, of course, will be of colossal proportions.

Behavior in Water

After coming in contact with water, crude oil rapidly spreads into a thin layer and the lighter fractions evaporate. In protected areas the oil often becomes adsorbed on particulate matter and sinks, but in open seas it tends to remain on the surface where wind and wave action aid in further evaporation. Some oil dissolves in seawater and some is oxidized but the hundreds of species of bacteria, yeasts, and molds that attack different fractions of hydrocarbons under a variety of physical conditions are primarily responsible for oil degradation.

Bacteria found in open seas tend to degrade only straight-chain hydrocarbons of moderate molecular weight, so branched-chain hydrocarbons of high molecular weight in the form of tarry chunks may persist for a long time. In still waters, a series of complex events results in almost complete degradation. In 1950, Soviet microbiologists showed that, after the lighter fractions of oil spilled on the Moskva River evaporated, the remaining oil was adsorbed by particles and sank. Bottom-dwelling microorganisms produced a new mixture of organic substances that were carried to the surface with bubbles of methane and other light gases. The new compounds again were adsorbed, sank, and the cycle was repeated. A number of cycles, repeated over several months, were necessary to degrade most of the oil.

Studies on the thoroughness of degradation have produced conflicting results. Research at Terrebonne Bay, Louisiana, in 1966 showed that essentially complete degradation occurs within a period of several months. Oil has been a consistent pollutant in the Bay since the 1930's, but analysis of bottom mud showed that significant concentrations of petrochemicals could be found only in areas that had received oil relatively recently. However, studies in the French Mediterranean, which will be discussed later, indicate that important chemicals are persistent in bottom sediments.

There is now a considerable body of literature on the interactions of microorganisms and petroleum products, most of it based on laboratory studies and much of it dating back to Soviet work in the 1930's and American work in the 1940's. However, these studies are scarcely past the descriptive stage, and, even when combined with field studies, they are not adequate for predicting the course of degradation of an oil spill.

Oil and Marine Life

The most visible victims of ocean oil are sea birds. It is impossible to even guess how many are killed each year, and about the only thing known for sure is that, once oiled, very few birds survive. After the *Torrey Canyon* disaster, 5711 oiled birds were cleaned off; apparently 150 of them returned to health and were released, but banding counts of these indicate that at least 37 died within the first month after release. Similar figures were obtained from French efforts at bird rehabilitation after the same disaster, and few of the 1500 diving birds cleaned after the Santa Barbara blowout survived.

It is believed that most deaths are the result of diseases, such as pneumonia, which attack the birds after they are weakened by the physical effects of the oil (feather matting, loss of buoyancy, flying difficulty, and others). However, the high death rate of cleaned birds is unexplained, so long-term toxicity of the oil cannot be ruled out.

The major studies of the effects of oil spills on species other than birds have produced a wide variety of results. Dr. Robert Holmes, the first director of a major study after the Santa Barbara blowout, has stated that plankton populations were unaffected, and, although his remark was challenged at the Massachusetts Institute of Technology symposium where it was made, it is generally agreed that visible damage to organisms other than birds has been relatively light.

On the other hand, in what is probably the best "before and after" study of a major spill, it was conclusively shown that almost the entire population of a small cove was killed by dark diesel oil from the tanker *Tampico Mara*. In March 1957, the tanker grounded at the mouth of a small, previously unpolluted cove on the Pacific coast of Baja California, Mexico, and, until destroyed by the sea, it blocked most of the cove's entrance. All signs of oil disappeared sometime between November 1957 and May 1958, but the ecology of the cove was radically changed. A few species returned within 2 months, but 2 years had elapsed before significant improvements were noted. Four years after the accident, sea urchin and abalone populations were still greatly reduced; and, at the last observations in 1967, several species present 10 years earlier had not returned.

Although toxicity studies in the ocean have been limited to a few large spills, considerable laboratory work has been done to determine the lethal concentrations of a number of chemicals on various species. Most toxic are the aromatic hydrocarbons (for example, benzene, toluene, and the xylenes), and investigators have recently shown that the low-boiling, saturated hydrocarbons are more toxic than formerly believed. The destructiveness of the *Tampico Mara* grounding was probably due to the saturated hydrocarbons, and it has been shown that aromatic hydrocarbons used to dissolve detergents in the effort to disperse oil from *Torrey Canyon* caused much of the damage. When a spill occurs at sea, a large portion of both these classes of compounds evaporates before reaching shore. This is probably the main reason that the Santa Barbara blowout was not more disastrous to shore life other than birds.

Biochemical Studies

Just enough is known about the higher-boiling, saturated hydrocarbons and the high-boiling, aromatic hydrocarbons to indicate that more study is needed. Saturated, higher-boiling compounds occur naturally in both crude oil and marine organisms, so they are probably not toxic; but work reported this year indicates that these compounds may affect the behavior of sea animals.

Blumer points out that very small amounts of certain chemicals are used by many species of sea animals as behavior signals in the vital activities of food finding, escaping from predators, homing, and reproduction. He has shown, for example, that starfish are attracted to their oyster prey by chemicals in concentrations of a few parts per billion. The responsible chemicals have not been identified, but Blumer believes that in many cases they may resemble the high-boiling, saturated hydrocarbons found in petroleum products. Because of the extreme sensitivity of the response and the similarity of the animal and petroleum chemicals, he thinks it is possible that pollution interferes with chemically stimulated behavior "by blocking the taste receptors and by mimicking natural stimuli."

Studies on chemically stimulated behavior of marine animals are in such an early stage that ideas about the role of sea oil in the process can only be considered speculative. However, the speculation indicates that the consequences—altered behavior of entire populations of commercially valuable species—are so serious that the matter deserves early attention.

Another matter still in the speculative stage, but with potentially hazardous consequences, is the significance of high-boiling, aromatic hydrocarbons. Crude oil and crude oil residues contain alkylated 4- and 5-ring aromatic hydrocarbons similar to those found in tobacco tars, but little is known about their role in the marine environment.

In 1964 Lucien Mallet, a French marine chemist, reported the presence of 3,4-benzopyrene, a known carcinogen, in sediments of the French Mediterranean. Concentrations ranged from

5.0 parts per million at a depth of 8 to 13 cm to 0.016 part per million at 200 cm. Similar concentrations have been found in other waters that had been polluted for a long time. Near the port of Villefranche, 3,4-benzopyrene in concentrations from 0.025 to 0.04 part per million have been found in plankton.

Benzopyrenes can be formed by algae, and they occur naturally in many soils in concentrations ranging from parts per million to parts per billion; thus their presence in marine sediments may not be cause for concern. However, the detection in sea cucumbers of concentrations that were slightly greater than those in the bottom sediments where these animals feed indicates that benzopyrenes in the marine environment may find their way into the food chain.

Pollutants tend to enter the food chain more easily and to pass through it with fewer changes in aquatic environments than they do in terrestrial environments. They can be introduced in solution through bottom sediments and even in dispersed droplets that are ingested by the numerous filter feeders that constitute an important part of aquatic food.

The presence of DDT in Lake Michigan's coho salmon drew public attention to the fact that some hydrocarbons pass through the aquatic food chain relatively unchanged. Work at Woods Hole has demonstrated that the ratios of olefinic hydrocarbons in zooplankton to those in livers of basking sharks and herring that feed on the plankton are so constant that they can be used to determine the feeding grounds of these species.

Obviously, studies should be conducted to see what concentrations of 3,4-benzopyrene and other potentially dangerous hydrocarbons must be in seawater or sediments before they are introduced into the food chain and whether the chemicals persist as they pass through the chain.

Priorities

Although the possible ill effects of long-term oil pollution point to the need for more studies on the complex chemical-biological relationships of oil and the environment, there is still work to be done on the immediate effects of oil spills. Dale Straugh, who now directs the large Santa Barbara study, said in a telephone interview that oil spills will undoubtedly continue and that much of the research effort should concentrate on methods of handling them.

Present alternatives are (i) to "corral" the oil and hold it at sea, (ii) to pick it up mechanically, or (iii) to treat it chemically so it will emulsify, dissolve, or sink. None of these methods is particularly successful, and research on all of them is continuing. The major requirement for further development is engineering and chemical knowledge, but biological expertise is necessary in some areas.

It is primarily biological studies, especially those after the *Torrey Canyon* incident, that precipitated the government decision not to use chemical treatment when the shore area is used as a source of fresh water or as a beach, or when it is necessary for commercially valuable species. Toxicity tests of chemicals developed to treat oil are now routinely conducted, and the Federal Water Pollution Control Administration is developing a standard procedure for such tests. This action was prompted in part by reports that a dispersal agent, Corexit, used at Santa Barbara was more toxic than earlier tests indicated.

The step beyond toxicity tests is a giant one of determining subtle and long-term effects of sunken, dissolved, or dispersed oil. Biological knowledge has advanced far enough to cast doubt on any sinking or dispersal scheme, but not far enough to rule them out or to provide unquestionably safe alternatives. This task would require difficult, long-term studies on the complex interactions of oil, seawater, and marine life, and there is nothing on the horizon to indicate that these studies will progress rapidly enough to play a large role in decisions about methods of handling oil spills.

Another area in which biological knowledge could be helpful is in simply monitoring the oil that enters the oceans and determining, at least by sampling, its effects. On this horizon there seems to be some light. Several studies designed to determine the feasibility of establishing broad-based centers for environmental study are now in progress.

Early in September, after the announcement by the National Science Foundation of the availability of funds, the Ecological Society of America and the Washington, D.C., firm of Peat, Marwick, Mitchell, and Company, signed a contract for the first part of a feasibility study on the formation of a National Institute of Ecology. The study will consider information-collecting, environmental-monitoring, and possibly graduate-education functions. An international organization with similar functions is being considered by the International Biological Program under the auspices of the International Scientific Union. The next step for this effort was to be determined this week after Frank Blair of the United States, Bengt Lundholm of Sweden, and N. N. Smirnov of the Soviet Union had met in London to discuss the results of their consultations with various individuals and groups involved with worldwide ecological problems. Finally, as the result of a conference in Paris last September, the United Nations charged UNESCO with the formation of a "Man and the Biosphere" program. National governments were to submit statements discussing their part in the program by 30 August, and in October or November technical groups will meet to discuss specific actions. The director general will then have the duty of developing a plan on the basis of their reports and submitting it to the UNESCO Executive Board next year.

It is too early to know how these programs will fit together, or even if all of them will be pursued, but Blair thinks it is reasonable that the International Biological Program might form the backbone of overall scientific capability; the National Institute of Ecology, in addition to its own special capabilities, would form the United States arm of the international program; and UNESCO would function in tactical matters (for example, obtaining agreements among governments) and, hopefully, would provide financial support.

Whatever final form these organizations take, it is not likely that they will have specific research programs for oil studies. However, the systematic monitoring of the oceans, including their oil content, is a necessary step toward development of the capability of determining the worldwide consequences of effects that at present can be measured only in the laboratory or in relatively small field studies.

—ROBERT W. HOLCOMB