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CRS Report for Congress

Oil in the Ocean: The Short- and Long-Term Impacts of a Spill

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OIL IN THE OCEAN: THE SHORT- AND LONG-TERM IMPACTS OF A SPILL

SUMMARY

This report describes the short- and long-term impacts of an oil spill. The short-term impact is the incident as generally portrayed immediately following the spill, and the long-term impact is the life cycle of the spilled oil itself. Not surprisingly, the impacts are often different. The media presentation is commonly one of a catastrophic occurrence, and a major oil spill is indeed that. Media coverage also tends to focus on the more emotional aspects of destruction to the local environment, to which irreparable harm is often claimed. Rarely does media coverage convey the fact that oil is a natural substance, and that natural processes, over time, will do much to remove it.

Oil that is spilled or seeps naturally into the ocean is eventually accommodated by natural physical, chemical, and biological processes, including spreading, evaporation, solution, emulsification, tar lump formation, photochemical oxidation, microbial degradation, uptake by organisms, and sedimentation and shoreline stranding. Factors particular to each spill influence the effectiveness of these processes, and determine the severity of the ecological impact. Although human intervention can help to make a shoreline look clean, it has rarely been very effective in removing oil, and improper clean-up methods can be detrimental to the ecological restoration of the area. Historically, it has been unusual for more than 10 to 15 percent of the oil to be recovered from a large spill.

The life cycles of six major oil spills were chosen for examination because they occurred sufficiently long ago for long-term effects to have become apparent and for attention from the media to have long subsided. Because they are still being studied, the *Exxon Valdez* and the *Mega Borg* incidents are not discussed. The six events chosen are the Santa Barbara and Ixtoc I blowouts and the *Argo Merchant*, *Burmah Agate*, *Alvenus*, and *Amoco Cadiz* tanker spills. Each event received extensive media coverage at the time and are still thought of by many as major environmental catastrophes. In fact, the environmental damage and socioeconomic consequences were relatively modest, and, as far as can be determined, of relatively short duration.

The longest residence time spilled oil appears to have in the marine and coastal environment is generally less than a decade--often much less. The major ecological impact comes at the time of the spill or within the first few months. Beyond a few months, most oil is reduced to tarry residues or is chemically detectable in sediments and resident organisms, which may be of scientific interest, but in terms of further ecological impact, likely to be fairly insignificant. Short-term impacts on marine animal life are dramatic but recovery of species populations in almost every case studied has been swift.

Because many physical and biological processes in the marine and coastal environment are poorly understood, it is difficult for scientists to measure the full impacts of an oil spill and sometimes the results appear contradictory.

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INTRODUCTION

Crude oil is made by nature and has long been part of the environment. Oil forms largely from the burial and transformation of marine organisms under heat and pressure over geologic time. Most of the oil that ever formed was not trapped in reservoirs, but seeped to the surface where it was decomposed, digested, and recycled. Many of these seeps are small, but many are not. A significant amount of this seepage and recycling occurs in the marine environment. Although difficult to quantify, it is estimated that on the order of 1.5 million barrels of oil enter the oceans from natural seeps each year, and even this amount may be an order of magnitude too low.[1] In any event, oil has been common to the oceans for hundreds of millions of years, long before the advent of humans. When oil seepage or oil spills occur, natural organisms and natural chemical processes act to decompose it. For example, an average liter of seawater normally contains about ten hydrocarbon decomposing bacteria, but after an oil spill their population densities can reach 50 million per liter.[2]

As it comes out of the borehole, crude oil has never been of much practical use. In a refinery, this unpretentious raw material is converted into hundreds of products and chemicals essential to maintaining the quality of life in modern society. Some of these refined products are less common and more toxic than crude oil and are also commonly transported by tanker. A spill of refined products can differ considerably from a spill of crude oil, as will be shown.

Human activities involving oil in the marine environment include drilling for and producing crude oil offshore and transporting both crude oil and refined products by tanker. These activities rarely take place in a pristine environment. Human beings have had an impact on the ocean, particularly coastal areas for many years. Consequently, a return to pre-spill conditions can easily mean a return only from a very disturbed to a less disturbed condition. In addition, "normal" or "baseline" conditions are not static because the environment is dynamic and constantly changing, not only from human disturbance, but also from natural change. Many physical and biological processes are occurring in the marine and coastal environment that are only poorly understood. For these reasons, it is particularly difficult for scientists

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[1] National Research Council. Oil in the Sea: Inputs, Fates, and Effects. National Academy Press, Washington, D.C., 1985, 601 p.

[2] Coastal Zone Management, June 20, 1990, p. 7.

to measure the full impacts of an oil spill and sometimes the results app(contradictory.

A major oil spill is both tragic and (as long as the world is based larg on a petroleum economy) inevitable, because no technology is with(environmental cost and none is fail-safe. A recent study performed for t State of Alaska determined that a catastrophic spill in the Valdez tanl trade, similar in magnitude to the *Exxon Valdez* spill in Prince William Sou (the *Exxon Valdez* spilled 258,000 barrels), would occur on the average of o1 every 13 years, or about once every 11,600 transits, under the circumstan that existed prior to the spill.[3] Thus, by those estimates, the *Exxon Val* spill occurred within the predicted time frame. Improvements alre(accomplished, and further improvements to be accomplished, will likely exte the average recurrence interval considerably.

Following the *Exxon Valdez* spill, leaders in the House and Sen. announced that comprehensive oil pollution liability and compensat. legislation was a priority. There appears to be a general consensus amc the Administration, Congress, and the oil industry that such legislation necessary. Subsequently, the House has passed H.R. 1465 and the Sen passed S. 686, which are now in conference (the conferees reached agreem on July 26, 1990). These bills would internalize the immediate costs pollution cleanup and damages within the oil-handling industry (althou ultimately they would be borne by consumers). Also the bills would o financial protection to a number of industries and businesses affected b spill, including the fishing and recreation industries that are characterized many small participants and are subject to natural and seasonal variatio In addition to providing a framework for dealing with a spill event after occurs, the legislation also addresses spill prevention through technology operational requirements and safety provisions. These include establishment of an oil spill research and development program and tan operation and design regulations including provisions relating to alcohol drug abuse, access to the National Drivers Registry, and requirements double hulls. Taxing provisions to establish a $1 billion compensatory fu were passed as part of the Reconciliation Act (P.L. 101-239, Section 75 (For a summary of the issues addressed in the differing provisions of House- and Senate-passed bills, see **CRS Issue Brief 89082, Oil Polluti Liability and Compensation Legislation After the *Exxon Valdez* Spill.**)

It is possible to think of an oil spill as having two life cycles. One the short-term life cycle generated by the human environment, including media and other interests (primarily affected individuals, State and lo governments, and environmental groups); the other life cycle is biogeochemical cycle of carbon and its compounds in the natural environme

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[3] Spill: The wreck of the *Exxon Valdez*. Report of the Alaska Oil S Commission, Jan. 1990, Executive Summary, p. 4.

The former is generally given great attention; the latter is rarely considered outside of the technical and scientific literature. Consequently, the perceived impact of an oil spill may be little related to what ultimately happens to the oil or to the interaction that the oil has on the affected area, but rather to what is said about the event at the time. This is significant because the public and policy decision makers can be influenced by perceived impacts of events.

FACTORS THAT DETERMINE THE SEVERITY OF THE ECOLOGICAL IMPACT

A great number of factors, individually or in combination, govern the effects that an oil spill may have on marine life. Some spills may have a relatively minor effect compared to others which may be much more locally damaging. The biological damage that results depends largely on the following factors:

1. The dosage of oil and the duration of the exposure;
2. The type of oil involved, particularly with respect to its content of the more toxic aromatic compounds;
3. Whether the oil is in a fresh, weathered or emulsified form;
4. Whether a coastal, estuarine or open ocean area is involved, and whether it is a nesting or wintering ground for sea birds, migration route, etc.;
5. Natural environmental stresses imposed by meteorological or oceanographic parameters such as fluctuations in salinity, water temperature, wind conditions, etc.;
6. The season of the year with respect to whether organisms are dormant or actively feeding and reproducing;
7. Whether adult or juvenile forms are involved;
8. Whether the oil is in solution, suspension, or absorbed onto particulate material;
9. Distribution in the water column, such as whether plankton, pleuston, nekton or benthos are involved and which species;
10. The effects of oil on competing biota;
11. The ecosystem's previous history of exposure to oil or other pollutants; and

12. Clean-up procedures, if any, that have been used, and, particularly, whether chemical agents have been used.[4]

Oil Dosage

Many of these factors are interrelated. The dosage of oil an area receives depends primarily on the size of the spill and the elapsed time before it is dispersed. Physical constraints on the spill, such as embayments, do not allow oil to disperse rapidly and, thus, effective dosage will be increased. The portions of the oil that sink, float, and dissolve also determine the dosage. In general, the biological damage is much more severe if the spill occurs in a coastal or estuarine environment, especially if the intertidal zone is affected, than if it occurs in the open ocean. This greater damage occurs because there are generally many more diverse habitat types and numbers of organisms in the near-shore areas and because of the presence of the sensitive juvenile stages of many species. By comparison, the reported biological damage in the open ocean has been minimal, with the most visible impacts related to oiled seabirds and marine mammals. Although only a few studies have been conducted, no evidence has been found that plankton populations have been significantly altered by oil spills on the high seas.[5] Even if a large number of algal cells were affected during a spill, regeneration time of the cells (9 to 12 hours), together with the rapid replacement by cells from adjacent waters, would likely obliterate any major impact on a pelagic phytoplankton community.[6]

Type of Oil

Offshore spills can involve both crude oil and refined products. While OCS production spills would primarily involve crude oil, tanker spills could involve either crude oil or refined products. Generally, refined products such as fuel oil or gasoline have greater concentrations of toxic components than crude oil, and spills of refined products would likely have a greater ecological impact. However, because lighter refined products such as fuel oil or gasoline are more volatile than crude oil, the visual impact of the spill will be of shorter duration and the likelihood of shoreline impacts will be less. The greater biological impact from refined products has been cited as one reason

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[4] IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). Impact of Oil on the Marine Environment. Reports and Studies No. 6. Published by the Food and Agriculture Organization of the United Nations, Rome, 1977, p. 54.

[5] National Research Council. Oil in the Sea: Inputs, Fates, and Effects. National Academy Press, Washington, D.C., 1985, p. 442.

[6] Ibid., p. 404.

for the severity of the observed effects of the well-studied West Falmouth, MA spill in 1969, which released about 4,000 barrels of No. 2 fuel oil into the waters of Buzzards Bay, and surrounding marsh areas (near Woods Hole Oceanographic Institution). No. 2 fuel oil is enriched in aromatics, some of which are created in the refining process. On the other hand, studies of a large fuel oil spill (54,000 barrels) in Japan's Inland Sea in December 1974 indicated no evidence of lasting damage.[7] The Inland Sea seemed particularly vulnerable to contamination because it is relatively shallow and circulation is restricted, but data indicated that populations of marine organisms and water quality returned to normal after three months.

No. 2 fuel oil was also involved in the spill of the Greek-flagged tanker *World Prodigy* which ran aground on Branton Reef just outside of Narragansett Bay, Rhode Island on June 23, 1989. The spill released approximately 6,900 barrels of fuel oil into the coastal waters of Rhode Island. Some shoreline impact occurred and the Rhode Island fishing industry was disrupted for at least a week, but the majority of the oil evaporated. Two weeks after the spill occurred the general scientific consensus was that any longer-term damage would be minimal due to the rapid dissipation of the oil and timely cleanup response.[8]

Fresh Versus Weathered Oil

The longer a spill is exposed and weathered before it enters a sensitive area, the fewer harmful compounds it will contain. Generally, the lighter and more soluble compounds, which are the more toxic, are removed and degraded early in the weathering process, as will be shown in the following section on the geochemical life cycle. Heavy tarry residues have much less severe biological impact.

Location and Natural Environmental Stresses

The climatic conditions and location of a spill area influence the ecological impact. The effects of oil spilled in a cold marine environment, such as the North American Arctic, might be much more serious and long lasting than in a more temperate area for the following reasons:

1. Cold temperatures do not permit rapid evaporation of aromatics in oil, thus allowing more of these toxic hydrocarbons to enter solution

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[7] Chemical and Engineering News. No Lasting Damage From Japanese Oil Spill, Oct. 20, 1975, p. 13.

[8] U.S. Congress. Senate. Committee on Environment and Public Works, Subcommittee on Environmental Protection. Three Recent Oil Spills. Hearing, July 13, 1989, U.S. Govt. Print. Off., Washington, 1989, p. 62.

in sea water even though the solubility of these compounds is lower at low temperatures;

2. The rate of bacterial degradation and other processes of weathering are comparatively slower at very cold temperatures; and

3. The marine biota of polar regions are generally long-lived, have low reproductive potentials, and do not have wide-ranging dispersal stages.[9]

On the other hand, biodiversity is lower and fewer species would be affected. In general, however, recovery from an oil spill in polar regions would likely be slow.

Another reason that the location of a spill is an important factor in determining the impact is that biota vary greatly from area to area. For example, the habitat of the East Coast of the United States is geologically and ecologically quite different from the West Coast, and the Louisiana coastal environment is not like that of Alaska. Different organisms react to oil pollution in different ways. What kills one species may have little or no effect on another, thus upsetting prey and predator relationships.[10] Individuals within a species may differ--eggs, larvae, and newly molted individuals have different sensitivities to the same level of pollution.

Location is also important in terms of the physiography and physical energy of the area. For example, a spill off a low-energy marshy area can have much longer lasting effects than a spill on a high-energy rocky coastline. Oil from the *Amoco Cadiz* that entered quiet backwaters was still present in sediment two years later, whereas by that time oil was no longer found in the sediment of some of the more energetic offshore areas.[11]

The season of the year a spill occurs is an important factor. Most marine organisms show natural seasonal variations that are related to yearly cycles as well as year to year variations. For example, if a spill occurs during the season when sea birds are nesting, bird mortality would be much higher than at other times the year. If a spill enters an estuary when salmon smolts are going to sea or during a salmon run, much more severe impacts are

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[9] Boesch, D. F., C. H. Herschner, and J. H. Milgram. Oil Spills and the Marine Environment. Ballinger Publishing Co., Cambridge, MA, 1974, 114 p.

[10] IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution, Impact of Oil on the Marine Environment, p. 54.

[11] Gundlach, E. R., P. D. Boehm, M. Marchand, R. M. Atlas, D. M. Ward, and D. A. Wolfe. The Fate of *Amoco Cadiz* Oil. Science, July 8, 1983, p. 122-129.

likely.[12] Larvae that float near the surface of the water, and newly set oyster spats will probably be killed if a spill occurs during this stage of their life cycles, whereas these organisms are less vulnerable during later stages of development. Had the January 1969 blowout spill at Santa Barbara, CA happened earlier, some nursing pups of sea lions and elephant seals may have succumbed after ingesting oil coating their mothers teats, and sea bird populations would have been greater (likely resulting in more mortalities).[13]

Oceanographic and meteorological factors such as wind conditions and currents in the spill area vary from day to day, and may drive floating oil either onshore or offshore. Currents and wave action combine to spread and dilute the spilled oil, thus reducing its potential impact. On the other hand, wave action may intensify problems especially near shore, as apparently occurred at West Falmouth. At West Falmouth, onshore winds churned oil with sediments and drove the oil ashore into the surrounding marshlands. The oiled sediments and marshlands then became a reservoir of oil for several years.[14] Recognizable chemical components of the fuel oil persisted in the sediments for at least 8 years.[15]

At Santa Barbara, the spill occurred during a period of heavy storms that brought flood waters bearing great amounts of sediment into the coastal waters. The sediment-laden fresh water provided an adsorptive surface for the spilled oil causing much of it to settle to the bottom rather than reaching shore.[16] Sedimentation is advantageous to intertidal life because this may prevent the oil from reaching the intertidal zone, but it may be detrimental to benthic life.[17]

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[12] National Academy of Sciences, Ocean Affairs Board. Petroleum in the Marine Environment. National Academy Press, Washington, D.C., 1975, p. 83.

[13] Boesch, et. al., Oil Spills and the Marine Environment, p. 38.

[14] Blumer, M., H. L. Sanders, J. F. Grassle, and G. R. Hampson. A Small Oil Spill. Environment, v. 13, no. 2, 1981, p. 1-12; and Sanders, Howard L. The West Falmouth Spill. Oceanus, fall 1977, p. 15-24.

[15] National Research Council, Oil in the Sea: Inputs, Fates, and Effects, p. 551.

[16] Drake, D. E., P. Fleischer and R. L. Kolpack. Transport and Deposition of Flood Sediment, Santa Barbara Channel, California. In Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill 1969-1970, v. 2, R. L. Kolpack ed. Allan Hancock Foundation, 1971, p. 181-217.

[17] Blumer et. al., A Small Oil Spill, p. 1-12.

Damages Due to Clean Up

An improper method of cleaning up an oil spill can increase the impact of oil pollution rather than diminish it. At sea, mechanical methods are considered the least damaging to the environment. These methods include the use of booms and skimmers or the spreading and retrieval of absorbent material. Sinking agents acting in the same way as naturally turbid water, transfer the effects from intertidal coastal areas to offshore bottom-dwelling fauna, and may extend the duration of the impact. The use of dispersants is controversial and has been shown to be helpful in some cases and harmful in others, depending on the toxicity of the dispersed oil and the nature of the particular organisms one is intending to protect. Low-toxicity dispersants have the advantage of preventing oil from washing ashore, soiling beaches and killing intertidal organisms, but pose an additional burden on the assimilative capacity of the marine environment. (For a discussion of cleanup technologies see **CRS Report For Congress, 90-146 SPR, Oil Spill Response Technologies.**)

Onshore, cleaning a soiled marsh area may prolong its recovery rather than aiding it. Scrubbing soiled rocky coastlines with hot water to restore their beauty may be done at the sacrifice of the surviving organisms along the shoreline. Providing nutrients to soiled areas to stimulate natural bioremediation is a new technique that would take longer than scrubbing to achieve a clean substrate but is less environmentally damaging.

With such a complex interaction of variables, it is not possible to predict accurately the severity of the ecological impact of an oil spill. However, it would appear predictable that long-term effects, if any, would be minimal. Further insight into the latter can be gained, however, by examining the fate of petroleum in the marine environment.

THE BIOGEOCHEMICAL LIFE CYCLE OF OIL IN THE OCEAN

When petroleum enters the ocean, it immediately begins to undergo a series of weathering and biological processes that distribute the material in the environment and alter its physical and chemical nature. The ultimate result of these processes is the complete removal of essentially all traces of the original crude oil and the geochemical recycling of the carbon. The time involved in this chemical recycling process can range from a matter of minutes and hours for the removal of some components of crude oil to a few years for other components. Figure 1 summarizes the fate of oil in the ocean superimposed with a general indication of the time frame of each process. The width of the lines generally indicates when that process is primarily operating and its relative magnitude compared to the others.

In general, during the aging of a spill in the open ocean, the relative influence of the various dispersive and degradative processes shifts from rapid physical effects to slower chemical and biochemical modifications. Initially the

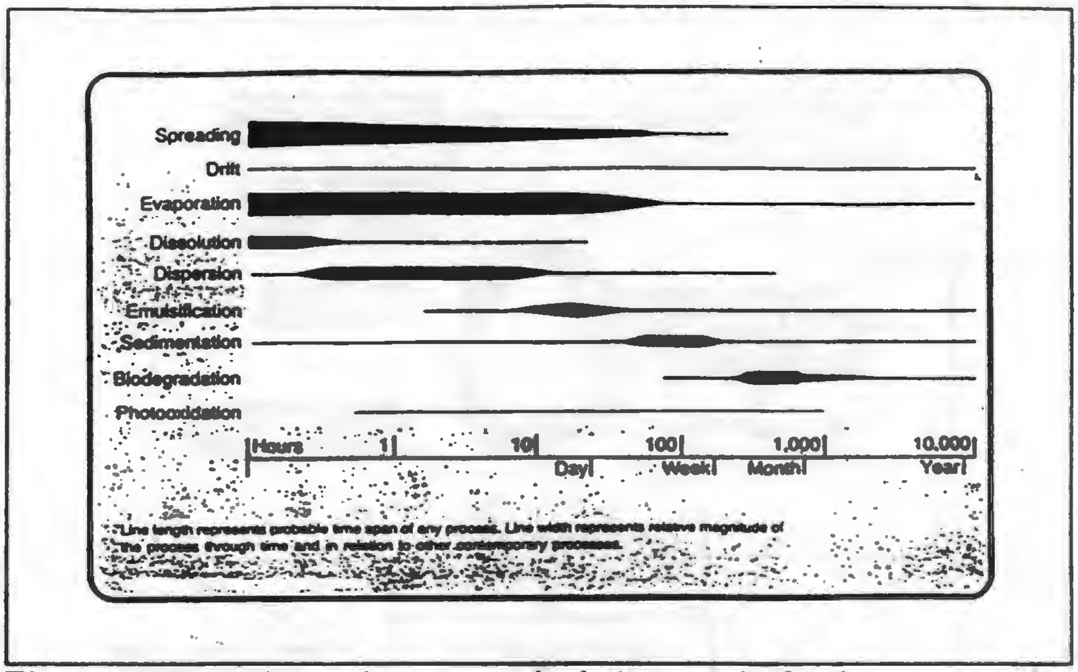

Figure 1. Approximate time span and relative magnitude of processes acting on spilled oil.
Source: Exxon Production Research Company

oil spreads rapidly through the combined action of gravity and surface chemistry. As the surface to volume ratio increases there is greater exposure to air, sunlight, and sea water. Spreading, evaporation and solution are the primary physical dispersive processes while photoxidation and biological degradation begin to assume a more dominant role as exposure time increases. Eventually, a relatively mature phase is reached when more refractory or resistant tarry residues predominate. Figure 2 is a stylized representation showing various pathways without attempting to quantify reaction rates. Reaction rates are poorly known as they depend on much the same interacting variables that determine the severity of the ecological impact described previously.

The following sections consider the physical, chemical, and biological processes that operate during the life cycle of an oil spill. The physical and chemical processes involved include spreading, solution, evaporation, emulsification, photochemical oxidation, tar lump formation, and sedimentation. Biological processes include degradation by microorganisms and uptake by larger organisms with subsequent metabolism, storage, and discharge. In addition, concerns that have been raised over the possibility of food chain magnification are reviewed.

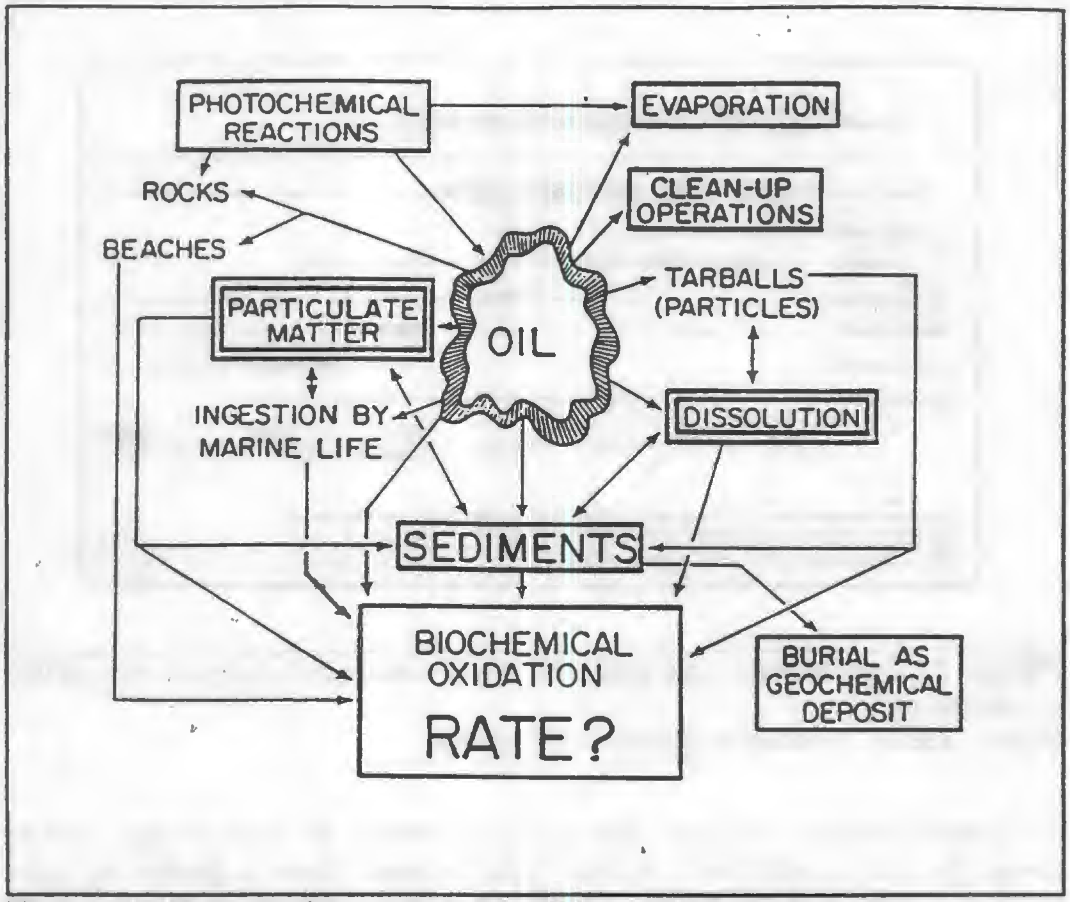

Figure 2. Fate of oil inputs to the marine environment.
Source: Oceanus, v. 20, no. 4, Fall 1977.

Spreading

Spreading begins as soon as petroleum is released into the ocean. Ultimately the area occupied by an oil slick is dependent on the volume spilled. Initially the physical process of spreading is controlled by gravitational effects which are influenced by wind, waves, and currents. After a few hours, the chemical and physical nature of the oil such as viscosity and surface tension become the controlling factors on the extent of spreading. The polar, surface-active constituents, containing nitrogen, oxygen, and sulfur, are influential in spreading a spill into very thin layers that approach monomolecular dimensions at the edges of the slick. Even massive spills eventually spread into thin layers and become fragmented by wind and waves into patches and windrows.

Spreading is important in the life cycle of a spill in that it greatly increases the surface area of the oil, thereby increasing its exposure to air, sunlight, and underlying water. This enhances the rate and effect of the other processes. However, spreading also reduces the effectiveness of mechanical recovery equipment.

Evaporation

Evaporation is the process in which low to medium weight crude oil components with low boiling points volatilize into the atmosphere. Evaporation is greatly enhanced by spreading. The rate of evaporation is greatest during the early stages of a spill. It appears that most hydrocarbons of around twelve carbon atoms or less are lost through evaporation within the first few days, with heavier hydrocarbons, up to twenty carbon atoms, evaporating over a few weeks. Through the selective processes of evaporation, aided by solution, the specific gravity of the oil increases. As evaporation progresses crude oil begins to resemble Bunker C (heavy) oil in composition. As a spill matures further, these processes contribute to the formation of thick sludge, tar balls, and eventually to sinking if the residual oil becomes denser than sea water.

For the Ixtoc I blowout, evaporation was the predominant weathering mechanism, resulting in a nearly equal loss of saturated and aromatic hydrocarbons with low boiling points.[18] Total evaporation loss is difficult to measure. Indirect evidence from compositional changes and laboratory studies indicate that 20 to 40 percent of an "average" crude oil spread over the sea surface can be removed by evaporation. Researchers studying the *Amoco Cadiz* tanker spill estimated that about 30 percent of the oil was removed through evaporation.[19]

Solution

Solution is the physical process by which the low molecular weight hydrocarbons, as well as some of the more soluble nonhydrocarbon constituents, enter the water column. The water soluble fractions of crude oil include light alkanes, such as propane, through isopentane and the light aromatics, benzene, toluene, and xylene. The acute toxicity of an oil is largely related to its soluble di- and tri-aromatic hydrocarbon content.[20] Even though solution starts as soon as the oil is released into the sea, it can continue for a long period as more soluble degradation products continue to be formed from biological and chemical oxidation. The rates at which soluble

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[18] Boehm, P. D. et. al. Physical-Chemical Weathering of Petroleum Hydrocarbons from the Ixtoc I Blowout--Chemical Measurements and a Weathering Model. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 453-460.

[19] Gundlach, E. R. et al., The Fate of *Amoco Cadiz* Oil, p. 122-129.

[20] IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution, Impact of Oil on the Marine Environment, p. 25.

components are removed from crude oil are poorly known. Over short periods of time, evaporation will remove highly soluble components more rapidly than solution. Evaporative weathering causes an equivalent depletion of saturated and aromatic compounds with low boiling points, whereas solution preferentially depletes low-boiling aromatics relative to saturated compounds, because of the much greater solubilities of the aromatics. Over a longer period, the solution rate will decline because of the lower solubility of the remaining high molecular weight components.

Emulsification

Most of the components of petroleum are relatively insoluble in seawater and in rough seas tend to form emulsions. Emulsions are of two types: oil-in-water emulsions where fine particles of oil are incorporated into the seawater, and water-in-oil emulsions where the floating emulsion contains 30 to 80 percent water. The latter are formed particularly from heavy crudes and are commonly referred to as "mousse." Emulsification promotes solution of the more soluble components by increasing surface area contact between oil and water. The eventual fate of oil-in-water emulsions appears to be dissolution in the water column or association with particulate matter and eventual biodegradation or incorporation in sediments. Mousse has been suggested as a source of pelagic tar lumps. Mousse can sink or become stranded on shore before degradation is completed.

Tar Lump Formation

The weathering processes described above can lead to the formation of residual lumps of tar which are much slower to degrade. These have been observed in the open ocean and can be a particular annoyance when washed up on beaches. At this stage of the weathering process, very little material lighter than 15 carbon atoms remains. Most tar lumps consist of paraffinic hydrocarbons of up to forty carbon atoms, and frequently contain waxy inclusions. These remain fairly persistent in the marine environment. For example, it was estimated that five to ten percent of the pelagic tar found in the eastern Gulf of Mexico four years after the Ixtoc I blowout originated from that event.[21]

Sedimentation and Shoreline Stranding

For residual fractions of crude oil to sink before reaching shoreline areas, the density must increase sufficiently. This generally occurs through loss of lighter components by evaporation and dissolution and/or sorption of liquid or dissolved components onto denser particulate material. Sedimentation is

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[21] Oil Spill Intelligence Report, v. VI, no. 24, June 24, 1983.

dependent on the availability of dense particulate matter to act as nuclei. This process can be especially important in removing petroleum from the water column in near shore areas or estuaries where there is generally a high concentration of suspended sediment. The chemistry of interactions with particulate material depends on the locale and the composition of the materials. Fine grained clay minerals can remove dissolved petroleum through absorption and adsorption. Sorption increases with salinity and decreases with temperature. Rough seas in shallow waters also stir up sand, silt, clay, and shells on which petroleum can be absorbed or agglomerated.

The further movement and fate of oil in bottom sediments is poorly understood. A succession of chemical studies following the barge spill of No. 2 fuel oil in Buzzards Bay, Massachusetts, in 1969, showed that oil trapped in subtidal sediments continued to expand in areal extent for several years after the spill.[22] Presumably various suspension and resedimentation processes occurred aided by current movement and reworking of surface sediments. In addition, there was an extremely slow rate of degradation of the fuel oil in the sediments with recognizable components present more than eight years later.[23]

Investigations following the *Amoco Cadiz* spill off the coast of France confirmed that oil persistence in subtidal sediments appeared to correlate with the physical energy of the particular site and the type of sediment. For example, of a total of 56,000 barrels of crude oil hydrocarbons estimated to have become incorporated into subtidal sediments in the Bay of Lannion and the Bay of Morlaix during the first month of the spill, only 13,000 barrels were present four months later. After an additional year this had declined to less than 6,000 barrels and little or no oil remained in the sediment after two and one half years.[24] On the other hand, fine grained sediments in lower wave energy, sheltered interior areas of Aber Wrac'h were still found to contain oil after three years, and the heavily-oiled marsh areas, in general, took an additional 2 to 5 years to recover fully.

Shoreline stranding is one of the more distressingly visible intermediate fates of petroleum from an offshore spill. Recovery times depend on the extent of the initial impact, the persistence of the oil, inherent factors of the biological community governing its resiliency, and the extent of biological interactions such as predation, parasitism, and competition. In the case of the high-energy rocky shores at Santa Barbara, California, recovery time was on the order of weeks to a few months, whereas soft-bottom offshore areas and marsh ecosystems such as Ile Grande, France were affected for several

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[22] Sanders, Howard L. The West Falmouth Spill--*Florida*, 1969. Oceanus, v. 20, no. 4, fall 1977, p. 15-24.

[23] Ibid., p. 24.

[24] Gundlach, E. R. et. al. The Fate of Amoco Cadiz Oil. Science, v. 221, July 8, 1983, p. 122-129.

years. Oil presumably from the Ixtoc I spill, in the form of tar mats consisting of sediment and mousse, was periodically uncovered by storm action along the south Texas coast for about a year. A field experiment of the persistence of stranded crude oil and mousse on seven shores around the coast of Great Britain showed that the residence times ranged from a few days to one year.[25]

Photochemical Oxidation

Photochemical oxidation is the process whereby energy from sunlight in the presence of oxygen transforms hydrocarbons into oxygenated compounds (e.g., carboxylic acids, benzoic acid, alcohols, ketones, phenols), with the general result that the oxidation products are more soluble in water than the original compounds. Some products have been found in the laboratory to be more toxic than the parent compounds. Observers studying the *Amoco Cadiz* spill (a tanker spill off the coast of France in 1978) found photooxidation products in environmental samples similar to those found in laboratory studies. The rate of oxidation of hydrocarbons varies with their chemical nature. In photochemical processes, the optical density of the oil, particularly in the ultraviolet, is an important variable. Investigators have made experimental studies of the actual decomposition rates of slicks by photolysis. It was found that photolysis can initiate sufficient oxidation to decompose a thin slick in a few days.[26]

Microbial Degradation

As the residence time of oil in the ocean increases, biological processes begin to operate and rapidly gain in significance. Hydrocarbon decomposing microorganisms are ubiquitous. Over 90 species of microorganisms (bacteria and fungi) capable of subsisting on petroleum and, therefore, capable of degrading it by biological oxidation, have been identified.[27] Microbial processes also transform hydrocarbons to more soluble oxidized products, which eventually are completely oxidized to carbon dioxide and water.

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[25] Little, D. I. and D. L. Scales. The Persistence of Oil Stranded on Sediment Shorelines. In Proceedings, 1987 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4452, 1987, p. 433-438.

[26] National Academy of Sciences, Petroleum in the Marine Environment, p. 48.

[27] IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution, Impact of Oil on the Marine Environment, p. 29.

The extent of microbial degradation in the sea is dependent upon water temperature and on the absence or dilution of certain volatile fractions in the spill which are bacteriocidal in high concentrations. Nutrient limitation, specifically by nitrates and phosphates, is another major factor in the effectiveness of microbial degradation of petroleum in the marine environment. This was evidently the case following the Mexican Ixtoc I spill, where biodegradation was nearly inoperative in the open ocean. The primary reason appeared to be related to the low concentration of nutrients in the underlying water. This contrasts with other spills, such as the *Amoco Cadiz* tanker incident, where microbial degradation played a significant role, removing 73,000 barrels of oil while still at sea.[28]

Physical factors limit oil decomposing bacteria from removing more than about one-third of spilled crude oil within 100 days.[29] These limitations include (1) the presence of only about 10 hydrocarbon decomposing bacteria in an average liter of seawater prior to a spill, (2) the dwindling availability of oxygen as the spill area grows, and (3) the lack of oil/water boundary action (where microbial degradation occurs) in areas of low wave action. Oil decomposing bacteria multiply after a spill occurs, reaching peak densities of 50 million per liter, but growth is slow at first. Microbial degradation is also temperature dependent; it takes approximately four times longer at 4°C than at 18°C.[30]

Uptake By Organisms

Petroleum hydrocarbons become available for uptake by marine organisms as dissolved or dispersed materials, absorbed onto particulate material, or as small floating tar balls. Hydrocarbons enter the marine food web by several routes: direct uptake of dissolved or dispersed material, ingestion of the contaminated particulate material, or passage into the gut of fish which gulp or drink water.[31] A considerable portion of petroleum is absorbed onto particulate matter.

In some cases the biota may be severely affected by the presence of oil, but they are not a major reservoir for spilled oil. However, they may act as temporary storage sites or transfer points. Marine animals are also not major

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[28] Gundlach, E. R. et. al. The Fate of *Amoco Cadiz* Oil, p. 122.

[29] LeBlanc, Leonard A. Advanced Technology, Why Oil Decomposition Rates Are Hard to Improve. Offshore, Apr. 1990, p. 17.

[30] Ibid.

[31] IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution, Impact of Oil on the Marine Environment, p. 38.

factors in influencing the distribution of spilled oil. After petroleum hydrocarbons are taken up by an organism, they may be excreted unchanged, metabolized, or stored with possible elimination at a future time. Excreted fecal matter containing oil is generally more dense than seawater, hence there is some distribution of petroleum hydrocarbons through the water column and sedimentation from grazing organisms.

An additional concern that has been raised in association with the uptake of petroleum hydrocarbons by marine organisms is that of biological magnification. It has been suggested that petroleum hydrocarbons transfer through marine food webs, becoming more and more concentrated, in a manner similar to that of other persistent chemicals. Some researchers have found that many marine organisms may accumulate petroleum hydrocarbons in their tissues, and that a certain portion may persist throughout the life of an organism. However there is very little evidence, if any, of increased accumulation in the higher predatory members of the food web.[32]

On the other hand, another aspect of oil in the marine environment is its "benefit" as a source of food. When oil is biodegraded, primarily by microorganisms, it serves as a source of nourishment at the bottom of the food chain. Other organisms grazing on the oil ingesters are nourished by them, as are further predators along the food chain. Thus, in this respect, oil is no more of a pollutant than any other organic material serving as a source of food. In fact, there are chemosynthetic ecosystems based on petroleum oozing from deepwater seeps in the Alaminos Canyon area on the Texas continental slope east of Galveston.[33] The photosynthesis that these ecosystems with their succession of predators depend on is not today's sunlight, but the photosynthesis that occurred millions of years ago, which helped create the petroleum.

THE SHORT-TERM IMPACT

A major oil spill is a major media event at the time of its occurrence. This section will examine the life cycles of six major oil spills that occurred

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[32] Connell, D. W. and G. J. Miller. Petroleum Hydrocarbons in Aquatic Ecosystems--Behavior and Effects of Sublethal Concentrations: Part I, CRC Critical Reviews in Environmental Control. Dec. 1980. Reported in Minerals Management Service, Final Environmental Impact Statement, Proposed Apr. 1984 North Atlantic Outer Continental Shelf Lease Offering, p. 286; and National Research Council. Oil in the Sea: Inputs, Fates, and Effects. National Academy Press, Washington, D.C., 1985, p. 6.

[33] Ocean Science News, Apr. 10, 1990, p. 6.

sufficiently long ago for their "long-term"[34] effects to have become apparent and for their attention from the media to have long since subsided. The six events are the Santa Barbara and Ixtoc I blowouts and the *Argo Merchant, Burmah Agate, Alvenus* and *Amoco Cadiz* tanker spills. All of these were major spills, and except for the *Amoco Cadiz*, which foundered off the coast of France, all affected U.S. waters (even though the Ixtoc I blowout occurred in Mexican waters). Each of the events received extensive press and television coverage at the time and are still widely recalled as major environmental catastrophes that caused considerable socioeconomic loss. In fact, the environmental damage and socioeconomic consequences were relatively modest, and, as far as can be determined, of relatively short duration.

The News Media and Damage Perceptions

A number of investigators have probed the influence on the public of media coverage of oil spills and other events. For example, investigators studying the Santa Barbara spill concluded that the frequency and nature of reporting an oil spill could be predicted on the basis of the geographical proximity of the media to the event.[35] They also showed that an occurrence receives much coverage close to its date of origin, and subsequent related happenings received comparatively little nonlocal coverage.

Initial reporting often focuses on the more "newsworthy" elements of events, e.g., the threat to the health or environmental values of society. For example, media coverage of medical wastes found on beaches on Long Island and northern New Jersey in July 1988 caused beach scares resulting in more than $1 billion in lost revenues to other resort areas in which no wastes were found.[36] In the case of an oil spill, investigations and follow-up studies of actual effects take time, and results often are not available until a year or more has passed. Press coverage of these results is generally minimal and, to a large extent, confined to the more scientific literature. The *Argo Merchant* incident serves as an example.

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[34] For the purpose of this report, "long-term" is defined to be several years or on the order of a decade or more.

[35] Molotch, H. and M. Lester. Accidental News: The Great Oil Spill as Local Occurrence and National Event. American Journal of Sociology, v. 81, no. 2, 1975, p. 235-258.

[36] Schmitt, Eric. A Summer to Forget on the Jersey Shore. New York Times, Sept. 2, 1988, p. B1, B2.

Argo Merchant

On December 15, 1976, the Liberian-registered tanker *Argo Merchant* grounded on the Nantucket Shoals off Massachusetts. Heavy seas during the subsequent week caused the ship to break up, releasing 183,000 barrels of No. 6 residual fuel oil. Attempts to burn the oil were unsuccessful. The heavy oil formed a large slick, which eventually moved out to sea and dispersed. The estimated costs of response to the accident were $2.7 million.

In a study of media coverage of the *Argo Merchant* grounding and oil spill, researchers found that public perceptions of local damages presented an interesting and intriguing paradox. There is general agreement among post-spill investigations on the absence of serious economic damages (aside from the ship and cargo) resulting from the *Argo Merchant* incident. Persons in the area economically dependent on tourism, water transportation, and commercial fishing generally reported a good year.[37] Fortunately, pollution damage was also small.[38] There was little evidence of impact on marine fauna or phytoplankton and it was concluded that the spill had little effect on coastal and marine bird populations off the New England coast.[39]

At the time, EPA Administrator, Russell E. Train, described the event as "the biggest oil spill disaster on the American coast in our history"[40] and Governor Michael S. Dukakis asked President Ford to declare southeastern Massachusetts a disaster area to qualify it for Federal relief funds.[41] Television coverage featured the visual image of the grounded tanker and the subsequent oil slick.

As the slick broke up and moved out to sea, television coverage was greatly reduced. While a complete assessment of the environmental damage

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[37] Rappaport, Allen, L. H. Zincone, Jr., and Peter Fricke. The Media and Oil Spills: Does the Press Influence Damage Perceptions? In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 707.

[38] Milgram, Jerome. Being Prepared for Future *Argo Merchants*. MIT Sea Grant Program, Report no. MITSG 77-10, Apr. 1977, p. 13; and Oil Spills: Problems and Opportunities. The MIT/Marine Industry Collegium, Opportunity Brief no. 9, July 1977, p. 9; and The Washington Post, Dec. 15, 1977, p. A 8.

[39] National Research Council. Oil in the Sea: Inputs, Fates, and Effects. National Academy Press, Washington, D.C., 1985, p. 557-561.

[40] The New York Times, Dec. 22, 1976, p. 1.

[41] The Washington Post, Dec. 22, 1976, p. A 3.

is impossible to obtain, there seems to be general scientific consensus that classifying the incident as an ecological catastrophe had no factual basis.[42]

The paradox that researchers found when conducting a survey of area residents approximately one year after the spill occurred was that substantially over half still believed that the *Argo Merchant* spill had caused significant economic or ecological damage.[43] An analysis of the press coverage showed that it had shifted from an initial position of little or modest damage to one of catastrophe or major disaster, returning to a position of modest or no damage when the oil moved out to sea. This led to the conclusion that once the press portrays a possibility for, or existence of, substantial damages, the subsequent withdrawal of such claims evidently does not alter the perceptions of extensive damage held by a large part of the population.[44]

Again, it should be pointed out that the scientific literature is not without apparent contradiction. Commonly, one investigation reports findings indicating damage of one sort or another, while another study looking at other variables associated with the same event will report different conclusions. These apparent paradoxes are also illustrated in the following case examples.

Santa Barbara

On the 28th of January 1969 on Platform A in the Santa Barbara Channel about six miles southeast of Santa Barbara, California and in 190 feet of water, an incident occurred. The incident, with its widespread media coverage, did much to alter public attitudes toward offshore oil and gas development.

Four wells had already been drilled from the platform and the fifth well, A-21, was nearing completion. Federal requirements for the well had been altered to approve shorter sets of casing pipe than the minimum previously required. On the morning of January 28, the well had reached 3,479 feet and the crew began to pull the drill pipe to run a log (make down-hole instrument readings). As the crew broke out the eighth stand (segment) of drill pipe, fluids from the well blew out through the drill pipe.

The crew attempted to close the blowout preventer inside the well bore hole, but without success. The pressure was so great that some of the

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[42] See for example, Abelson, P. H. Oil Spills. Science, Jan. 14, 1977, p. 137.

[43] Rappaport, et al., The Media and Oil Spills: Does the Press Influence Damage Perceptions? p. 707-712.

[44] Ibid., p. 711.

equipment failed and the efforts of the crew were hampered by the slick mud-oil-gas mixture and constant danger of fire. After about 15 minutes, the crew succeeded in closing the well using the blind rams of the blowout preventer. However, this was only the first stage of the blowout.

The closure of the well resulted in a huge buildup of pressure within the overlying strata above the oil formation, but where the well had not been cased. Within 30 minutes after closing the well at the top of the casing, oil and gas began to erupt from the seafloor about 800 feet east of the platform. This eruption eventually spread along a zone from 250 feet west of the platform to more than 1,000 feet east of the platform. Faults in the rock formations penetrated by oil and gas under pressure probably helped serve as a conduit. Efforts to control the spill were only marginally successful and seepage from the seafloor still continues at a rate of around 365 barrels annually (comparable to a number of natural marine seeps in the area.)[45] The initial spill was variously estimated at 10,000 to 77,000 barrels (the Minerals Management Service uses the higher figure) with subsequent seepage of over 28,000 barrels. Containment and cleanup efforts were extensive at the time and, in some cases, led to controversy regarding their overall benefit and efficacy.

The full impact of this spill on the marine and coastal environment is not possible to determine for a number of reasons including: (1) lack of pre-spill information on organisms and populations to provide a reference frame; (2) unusually high runoff from coastal areas which lowered salinity and increased turbidity, thus, masking the effects of the oil spill; (3) unseasonably low temperature further stressing the ecosystem; and (4) many natural seeps in the area which masked any potential long-term effects that could be attributed to the spill.

Among the more visible impacts were the bird mortalities. The California Department of Fish and Game reported the loss of 3,686 birds due to oiling during the first four months of the spill. This is generally regarded as a minimum figure due to unknown numbers lost at sea. Others placed the estimated bird mortality at between 6,000 and 15,000.

Other detrimental impacts were most evident in the intertidal zone where barnacles and surf grass were damaged by physical smothering. Studies indicated that damage to intertidal life was generally proportional to the amount of oil received. In some areas, the local population of acorn barnacles was destroyed, but recolonization readily occurred. Gooseneck barnacles were damaged to a somewhat lesser degree. Some algae were slightly damaged. Kelp was little harmed. However, mysid shrimp that live among the kelp may

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[45] Natural seepage in the Santa Barbara Channel is estimated at 14,600 to 244,500 barrels annually from more than 2,000 seeps. See U.S. Department of the Interior, Minerals Management Service. Federal Offshore Statistics: 1988. OCS Report MMS 89-0082, p. 96.

have been harmed or caused to vacate their usual habitat during the heavy oiling.[46] Investigators noted limited damage among anemones, abalones, spiny lobsters, mussels, limpets, periwinkles, and starfish. Burrowing fauna generally escaped severe harm. Fish did not appear greatly harmed by the oil, and spawning occurred normally for most species. No fish kills were observed or reported. The limited number of mortalities of marine mammals which were observed at the time of the spill could not be conclusively attributed to effects of the oil.

Some reports suggested spiny lobster and certain finfish harvests may have been depressed for one to several years following the incident. It is difficult to ascribe a cause/effect relationship between the blowout pollution and this observation.[47] Natural variations in populations of living organisms are such that an abnormal perturbation, such as might occur in response to spilled oil, can only be detected if it is especially extreme. Some of the observed changes in marine biota populations may be more generally related to natural environmental change or reflect the effects of developmental activities onshore. Bird populations did not appear to incur any long-term changes in either behavior or habitat use and most showed signs of recovery by the summer following the event.[48]

The physical impacts of the oil spill dissipated long ago, but the residual psychological scars remain for the local population, and the entire Nation as well. Environmental policy analysts have credited this spill, a discrete physical event, as a major catalyst that precipitated the "environmental decade" of the 1970s. While this attribution may be excessive, a portion of the public still associates negative aspects of offshore oil development with the Santa Barbara oil spill.

The actual effects of the blowout appear to have been limited in both time and extent. Declines in local tourism, shore use, and property values were painful but transitory. Coastal uses rapidly returned to pre-spill levels after the oil was off the beaches. Tar continues to be found on beaches. Although this is known to be from marine seeps, it is frequently perceived by some to be primarily from offshore petroleum development.

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[46] Dept. of Biological Sciences, University of California. Santa Barbara Oil Spill: Short-term Analysis of Macro-plankton and Fish. Prepared for Office of Water Quality Research, Environmental Protection Agency, Contract no. 14-12-534, Feb. 1971, p. 55.

[47] Mielke, James E. and Eugene H. Buck. Offshore Oil Spills: Is the Shoe Bigger Than the Foot? Congressional Research Service Review, Apr. 1985, p. 16.

[48] Easton, Robert. Black Tide: The Santa Barbara Oil Spill and Its Consequences. Delacorte Press, New York, 1972, p. 264.

Campeche Bay/Ixtoc I

On June 3, 1979, the Ixtoc I exploratory well in the Bay of Campeche, Mexico, in 167 feet of water, blew out. The trouble began on June 2 when at a depth of 11,857 feet, the well started to lose drilling mud into the rock formations being penetrated. Loss of drilling mud creates an unstable condition since the weight of the mud balances the underground pressure as a defense against blowouts. Despite this problem, the crew drilled further until circulation was totally lost at 11,890 feet.

Several unsuccessful attempts were made to regain circulation, but as the well appeared stable, the crew decided to seal it by withdrawing the drill pipe and inserting a plug. At 3:30 a.m. the well blew out crude oil and natural gas through the drill pipe and caught fire. The explosion and fire destroyed the platform and damaged the stack of drilling pipe and well casing that extended to the seafloor; thus began the largest marine oil spill in the history of offshore drilling or tanker transportation.

About three weeks after the blowout, an attempt was made to close the blowout preventer valves which were still intact on the seafloor under the ruptured pipe. The valves closed but the extremely high pressure caused oil to leak outside the well casing below the blowout preventer. Several attempts were made, with some success, to decrease the flow of oil by forcing large numbers of lead and steel balls into the well head. Next a funnel-shaped "sombrero" was placed over the well head to collect the oil, but this was not very successful, and was eventually damaged in rough seas and removed from the site. Rough seas also hindered other containment and oil recovery efforts.

The measure that finally capped the well on March 23, 1980, was the pumping of mud into two adjacent wells that were drilled directionally into the producing formation to link into the Ixtoc I well. These wells had been started in mid-June and July. After the mud caused the flow of oil and gas to cease, the Ixtoc I well was sealed with several cement plugs. During the 290 days that the spill continued, approximately 3,500,000 barrels of oil entered the Gulf of Mexico.[49]

Dispersants were selectively applied by aircraft to oil masses that threatened Mexican resources. Of special concern was the area extending 20 to 25 miles from shore along 1,000 miles of Mexican coast in major shrimping locations.[50] The use of dispersants kept oil from coming ashore on Mexican

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[49] Jarnelov, Arne, and Olof Linden. Ixtoc I: A Case Study of the World's Largest Oil Spill. Ambio, v. 10, no. 6, 1981, p. 299-306.

[50] Lindblom, Gordon P., Bruce D. Emery, and Ing. Miguel A. Garcia Lara. Aerial Application of Dispersants at the Ixtoc I Spill. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 259-262.

beaches until hurricane Henri arrived in late September and grounded the aircraft. At that time, oil stranded on the Yucatan shoreline, but lagoons were protected from oiling by the rapid outflow of fresh water from heavy rains. Field investigations indicated that the chemicals effectively dispersed the oil from the surface into the upper 10 feet of the water column by which it rapidly became diluted to low concentrations below acute toxicity thresholds. Limited biological studies during and following the spill did not reveal adverse effects.[51] Shrimp landings in subsequent years were unchanged or greater than previous yearly catches.

Impacts on U.S. resources were limited by the distance oil traveled from the site of the Mexican blowout. An estimated 30,000 to 70,000 barrels of the calculated 3.5 million barrels spilled reached Texas beaches.[52] Loss of the more volatile and soluble components through extensive weathering of the oil during travel time to Texas waters decreased the potential for detrimental impacts since these components are generally more toxic. Impacts on Mexican resources are incompletely known due to limited study and availability of results from such investigations as were conducted.

Reports indicate that few shrimp in Mexican and U.S. waters were tainted by settling oil debris. Along Padre Island, Texas, the percentage of total birds with any signs of oil on their feet or plumage never exceeded 10 percent; 82 birds were found with up to 75 percent of their bodies covered with oil and judged unlikely to survive.[53] Studies found decreasing populations of benthic fauna following the incident, but these circumstances could not be conclusively linked to the Ixtoc accident since minimal deposits of hydrocarbons were found in associated sediments.[54] No reports of long-term impacts on resources in U.S. or Mexican waters have been identified.

Most of the impact to the Texas beaches occurred between August and mid-September 1979. During this time business in the recreational and tourist

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[51] National Research Council. Using Oil Spill Dispersants on the Sea. National Academy Press, Washington, D.C., 1989, p. 320.

[52] Bedinger, C. A., Jr., and C. P. Nulton. Analysis of Environmental and Tar Samples from the Nearshore South Texas Area after Oiling from the Ixtoc I Blowout. Bulletin of Environmental Contamination and Toxicology, v. 28, no. 2, Feb. 1982, p. 166.

[53] Chapman, Brian R. Effects of the Ixtoc I Oil Spill on Texas Shorebird Populations. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 461-465.

[54] Boehm, Paul. Ixtoc Oil Spill Assessment: Executive Summary. Energy Resources Co., Inc., Cambridge, Mass., Apr. 1982, p. 22-24. NTIS PB82-197773.

industries in the South Padre Island area dropped significantly.[55] Dispersants were not used by the United States. By the end of 1980, the only known remanents of oil from Ixtoc I were scattered patches of tar mats along the Texas barrier island beaches.[56] Because of the numerous natural seeps in the area similar patches appear every year, but they were more numerous and extensive in 1980, and analysis showed that some originated at Ixtoc.

Cleanup costs on the Texas beaches exceeded $4 million. The estimated total cost of capping the well and containing the environmental damage, including lost oil revenues, amounted to $219 million.

Burmah Agate

On November 1, 1979, a collision of the Liberian-registered tanker, *Burmah Agate*, and the Liberian-registered freighter, *Mimosa*, produced the largest oil spill in U.S. waters up to that time. The accident occurred off the coast of Texas about five miles southeast of the Galveston Entrance Channel. The *Burmah Agate* was loaded with 397,800 barrels of Nigerian crude oil. The collision ruptured the starboard midship tanks resulting in a fire and explosions that left 33 dead. The ship settled on the bottom in 44 feet of water with its deck awash. Eventually, 24 of the 36 tanks were ruptured, releasing about 250,000 barrels of oil, much of which was consumed in the fire that continued to burn out of control for over two months. Over 150,000 barrels of oil were eventually salvaged from the forward tanks before the ship was refloated and towed to Brownsville, Texas for scrap. Another 6,700 barrels of oil/water emulsion were recovered from the water. Because of the predominance of offshore winds during the first month of the spill, most of the oil not consumed by the fire was dispersed offshore. Of the approximately 62,000 barrels of oil that were released and not burned, 2,100 eventually reached shore.

Beach impacts directly attributable to the spill occurred as far as 290 miles from the wreck. Prevailing winds and currents moved the oil toward the southwest. The first oil came ashore 155 miles southwest of the wreck. The heaviest oiling occurred between November 19 and 21 when up to 1,500 barrels beached along the western half of Galveston Island. Cleanup was initially by manual labor and front-end loaders. Eventually, the primary

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[55] U.S. Congress. House. Committee on Merchant Marine and Fisheries and Committee on Public Works and Transportation, Subcommittee on Water Resources. Blowout of the Mexican Oil Well Ixtoc I. Hearings, 96th Cong., 1st Sess., Corpus Christi, Texas, Sept. 8 and 9, 1979, p. 108-118.

[56] Gundlach, E. R., K. J. Finkelstein, and J. L. Sadd. Impact and Persistence of Ixtoc I Oil on the South Texas Coast. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 477-485.

method of beach cleanup involved pooling the oil by hand and picking it up with vacuum trucks. The latter method considerably reduced the amount of sand removed from the beach. By the end of the spill, a total of 1,500 cubic meters of oiled sand and 1,930 barrels of oil, water, and sand mixture were recovered from the beaches. Coastal processes aided the rapid recovery of Galveston beaches.[57]

The only known marsh impact occurred when approximately 5 barrels of oil coated about 1300 feet of marsh fringing Smith Point in Galveston Bay. Because of the relatively small area affected, no cleanup was attempted. It was thought that any human disturbance to the marsh area might be more detrimental than the relatively limited amount of oil. Over $850,000 was spent on onshore cleanup efforts. Offshore impacts were not reported.

Alvenus

On July 30, 1984, the British-registered tanker, *Alvenus*, grounded in the Calcasieu River Channel entrance about 11 miles south-southwest of Cameron, Louisiana. The vessel's hull buckled and fractured vertically on both sides and across the cargo tank tops discharging approximately 65,500 barrels of Venezuelan crude oil over a 6-day period. The grounding was later attributed to a combination of vessel squat and isolated channel shoaling. Attempts to contain and recover the oil at sea were ineffective because of rough seas and lack of adequate equipment for the magnitude of the spill.

Precautions were taken to prevent the outbreak of fire by continuously pumping inert gas into the ruptured cargo tanks. Decks were also covered with foam, and electrical power in the damaged area was shut off. Oil continued to flow from both sides of the ship. A major concern was the numerous aircraft employed by the news media, which at times flew within 50 feet of the stricken vessel, prompting the Coast Guard to request the Federal Aviation Administration to impose a restricted airspace over the vessel.[58] Approximately 284,000 barrels of crude oil remained onboard the *Alvenus* and were salvaged.

The spilled oil formed a 75-mile-long slick that traveled west from the wreck for over 100 miles, arriving on Texas beaches on August 3 and 4 along

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[57] Thebeau, Larry C. and Timothy W. Kana. Onshore Impacts and Cleanup During the *Burmah Agate* Oil Spill--November 1979. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 144.

[58] Alejandro, Anthony C. and Jack L. Buri. M/V *Alvenus*: Anatomy of a Major Oil Spill. In Proceedings, 1987 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4452, 1987, p. 27.

the west end of Galveston Island. Cleanup crews encountered a major problem when a large portion of the slick approached the shoreline, absorbed suspended solid particles, and sank in the nearshore surf zones. The oil became trapped between sand bars not more than 100 feet from shore, in water too deep for heavy land-based equipment and too shallow for floating recovery equipment. Cleanup crews had to wait until the oil beached, a process that took several weeks. The continued re-oiling of the beach required repeated recleaning of the beach area.

An effort was made to minimize the amount of sand removed from the beaches. Sand contaminated with an oil concentration greater than 10 percent (heavily oiled) was classified as waste and removed from the entire beach area. Moderately contaminated sand was relocated and spread in the back beach area adjacent to existing sand dunes. Lightly oiled sand was spread in the non-tidal, mid beach area. Analyses of the oil-contaminated sand indicated that the weathered oil contained no toxic components and that water-soluble fractions were no longer present, thus minimizing further leaching. There was no evidence of leaching from the oiled sand that was spread on the beaches above the tidal zone.

During the beach cleanup, conflict arose over who owned the contaminated beach sand. The State wanted the sand removed from the beach front while the land owners wanted it either left where it was or moved to the dune line seaward of the vegetation line. The amount of sand eventually removed from the beaches was roughly equivalent to the amount that would be removed by a small winter storm.

The Federal Scientific Support Group debated the merits of mechanical cleaning, which might kill organisms that survived smothering, versus letting the oil remain. From the onset of the spill, there were extensive discussions regarding the feasibility of dispersing the viscous Venezuela crude oil and the potential environmental damage, but dispersants were not used. It was concluded that available dispersants would not have significantly reduced the surface area of the spill, altered the location of the shoreline impact, or reduced the net damage to natural resources. Despite mechanical cleanup, the economic damage was great since the Galveston's resort beaches were heavily oiled during the height of the tourist season.

Booms prevented any significant quantity of oil from entering the inland hatchery environments of East Bay, Galveston Bay or West Bay. No significant lasting environmental damage was documented as a result of the *Alvenus* oil spill.[59] The oil was known to have a smothering effect on some marine organisms in the area; however, the Scientific Support Group determined that the affected organisms were a minor loss to the local ecosystem which soon recovered. Other than algae growing on rocks, most of the organisms in the area are transient and able to move to a more suitable

[59] Ibid., p. 31.

habitat. Several dead crabs, fish, and rays were found but these mortalities could not be directly attributed to the oil spill. The crabs, for example, were mostly female and may have expired normally after spawning.[60] Throughout the beach-cleaning period, fishing and shrimping activities continued offshore.

By mid-November, algae were again growing on rocks and groins and even growing over some oil that remained. Also, indigenous grasses were growing through the oiled sand in back beach areas.

Amoco Cadiz

On March 16, 1978, the Liberian-registered tanker, *Amoco Cadiz* grounded and broke up off the coast of Brittany, France and, over the next 15 days, spilled her entire cargo of 1,635,000 barrels of light Arabian crude oil. At the time of its occurrence, this was the largest oil spill the marine environment had experienced (and is over 6 times the size of the *Exxon Valdez* spill). The tanker suffered steering failure 8 miles north of the Ile d'Ouessant in the English Channel, and grounded on rocks at high tide within sight of shore. As the tide ebbed, the ship broke in two.

Approximately 90 percent of the cargo was lost in the first 11 days, during which time the winds averaged between 20 and 30 knots. The strong winds precluded most efforts at removing oil from the sea and soon drove the oil ashore along 250 miles of the French coast. The oil came ashore over a 4-week period, resulting in an almost continual oiling of the coastline. Less than 146,000 barrels were eventually recovered, most from beach and shoreline areas. A considerable portion of the oil that came ashore, and was not removed manually in the massive cleanup effort, eventually became buried in the sediments or entrapped in the low-energy salt marshes and estuaries. Efforts were made to remove oiled vegetation and sediments in some marsh areas with the expectation that recovery would be more rapid on clean subsurface sediments.

Attempts to combat the oil at sea included the use of about 3,000 tons of dispersant and some chalk, used as a sinking agent. Dispersant use was permitted only in water depths greater than 50 meters (164 feet) and only where no major marine resource would be endangered. Dispersants appeared to be used effectively in some instances and ineffectively in others. Effective use was limited by the broad aerial distribution of oil along the coast, the patchiness of the oil in windrows, and limited favorable weather conditions. The use of chalk as a sinking agent did not appear to be very effective and

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[60] Ibid., p. 32.

was objectionable on environmental grounds because of the smothering effect on bottom-dwelling organisms.[61]

While at sea, the oil underwent extensive evaporation and biodegradation so that the petroleum that stranded had changed in character from the original cargo. All of the oil that came ashore was in the form of some type of oil-water emulsion or "mousse," with the oil content ranging from 8 percent to 48 percent.

Of the 455,000 barrels of oil estimated to be on the shore at the end of March 1978, 67,500 barrels were estimated to be remaining one month later. The reduction was due to cleanup activities and the extensive biodegradation of the stranded oil. The affected shoreline areas included rocky coasts, recreational beaches, tidal estuaries, and coastal marshes. Figure 3 is a quantitative estimate of the disposition of the oil during the first month of the spill.

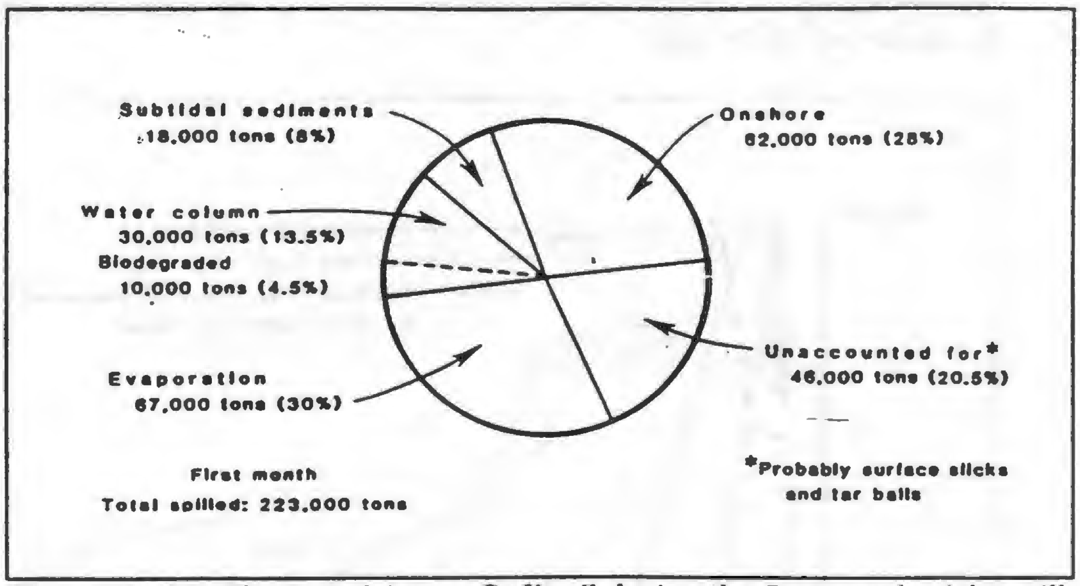

Figure 3. Distribution of *Amoco Cadiz* oil during the first month of the spill. *Source: Science, July 8, 1983.*

Since much of the coastline in the affected area is a resort area known for its beautiful pink granite, the cleaning of rocks, retaining walls, ramps, and boulders was considered of high priority for safety, aesthetic, and economic reasons. Most of this effort was accomplished through flushing with water and water-detergent mixtures under high pressure. Both hot and cold

[61] Hann, Roy W., Jr. Unit Operations, Unit Processes and Level of Resource Requirements for the Cleanup of the Oil Spill From the Supertanker *Amoco Cadiz*. In Proceedings, 1979 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4308, 1979, p. 154.

water were used, and, upon completion, the rock walls, ramps, and boulders appeared relatively clean. Sand blasting was tested, but was not recommended because of the high cost. The cleanup effort lasted several months, although some restoration activities extended into 1979 and beyond.

Because of its magnitude and impact on a range of coastal areas, including marshes in particular, the spill has been the subject of extensive ecological investigations. An initial three-year study of the effects of the spill was sponsored by Amoco Transport Company and conducted under the joint efforts of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) and the French Centre National Pour l'Exploitation Des Océans (CNEXO).[62] These studies were subsequently followed by several others. Figure 4 is a synthesis of data indicating the relative persistence of *Amoco Cadiz* oil in various environments over the first three years. Fate and effects studies were severely complicated, however, when on March 7, 1980 the tanker *Tanio* broke up 40 miles off the Brittany coast releasing over 50,000 barrels of oil into many of the same areas affected by the *Amoco Cadiz* spill.

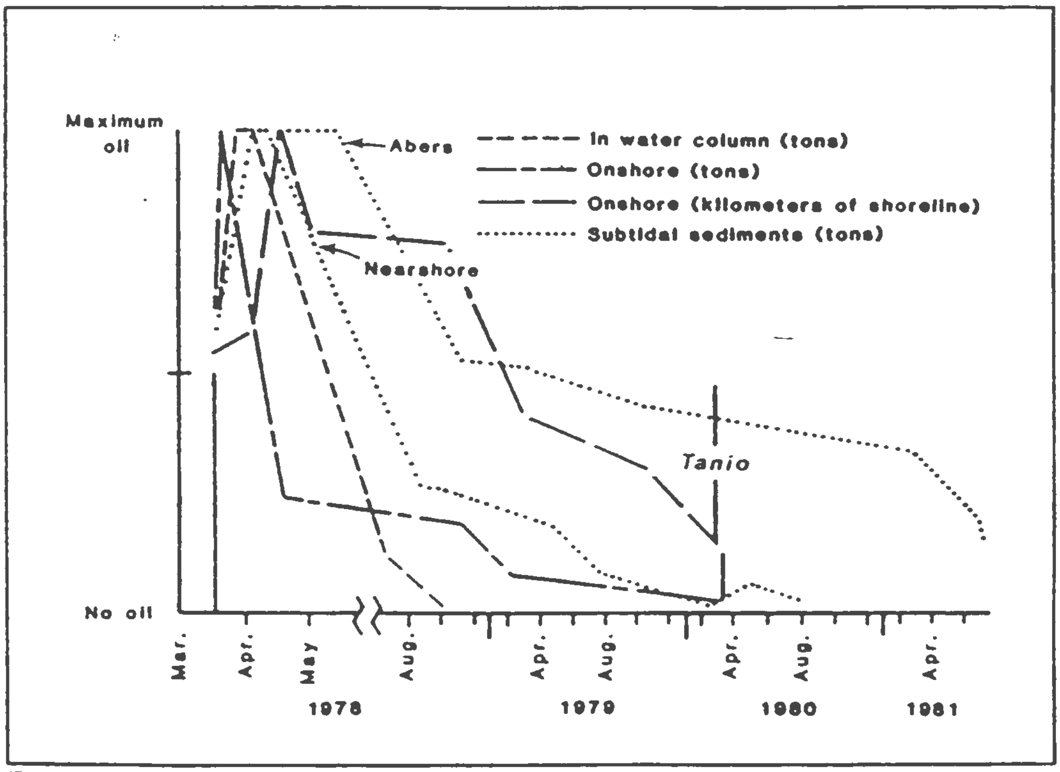

Figure 4. Relative persistence of *Amoco Cadiz* oil in various components, March 1978 through June 1981.
Source: Science, July 8, 1983.

[62] Ecological Study of the *Amoco Cadiz* Oil Spill. Report of the NOAA-CNEXO Joint Scientific Commission, Oct. 1982, 419 p.

The *Amoco Cadiz* spill affected the most exposed sites, such as rocky shores, the least. A variety of intertidal rocky shore animals were killed, but in general, rocky shores suffered little damage except where they were damaged from cleanup operations.[63] Sandy shores retained oil as buried layers for several years, but dead animals were found only immediately after the spill. Exposed intertidal mudflats had almost their entire fauna killed by oil from the water column until recolonization could occur. Decreases in biomass of phytoplankton were observed for several weeks in the immediate vicinity of the wreck and in the highly contaminated tidal rivers. In contrast, further from the wreck phytoplankton production was elevated, perhaps stimulated by either low levels of petroleum hydrocarbons or nutrient release from dead organisms.[64] Over 4,500 oiled birds were recovered dead, presumably from physical effects of the oil. A disastrous effect on the bird population had been feared, but it did not materialize, suggesting that the survival potential of seabirds, at least for the eastern North Atlantic populations, is quite good.[65] There was some mortality of fish in the vicinity of the wreck and some bottom-dwelling species showed evidence of fin rot with the percentage of individuals affected diminishing from 80 percent after 9 months to 10 percent after 20 months. However, it was also found by comparison to control areas, that the area oiled by the *Amoco Cadiz* spill was clearly not pristine before the spill.[66] For example, investigators found that 21 months after the oil spill, hydrocarbons (not all derived from the spill) were only one of three factors (the others were silver and mercury) associated with adverse effects on oyster populations in the area.[67] Although hydrocarbons from the spill were still found in oysters up to 27 months after the spill, there was little evidence of histopathological and biochemical damage.[68] At the same time, evidence of

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[63] National Research Council, Oil in the Sea: Inputs, Fates, and Effects, p. 561-566.

[64] Ibid., p. 564.

[65] Ibid., p. 574.

[66] Gilfillan, Edward S., David S. Page, Barbara Griffin, Sherry A. Hanson, and Judith C. Foster. The Importance of Using Appropriate Experimental Designs in Oil Spill Impact Studies: An Example From the *Amoco Cadiz* Oil Spill Impact Zone. In Proceedings, 1987 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4452, 1987, p. 503.

[67] Ibid., p. 507.

[68] Neff, J. M. and W. E. Haensly. Long-term Impact of *Amoco Cadiz* crude oil on oysters *Crassostrea gigas* and plaice *Pleuronectes platessa* from Aber Benoit and Aber Wrac'h, Brittany, France. In Ecological Study of the *Amoco Cadiz* Oil Spill. Report of the NOAA-CNEXO Joint Scientific Commission, October 1982, p. 269-327.

damage continued to be found in plaice (bottom-dwelling fish) in areas heavily affected by the spill, although substantial improvement was noted during that period.

Two years after the spill it was reported that there was no recovery at the most heavily oiled marsh areas. This led to predictions that several decades may be required for a return to prespill conditions by natural processes.[69] Others who studied the spill in the first 2 years suggested that if the oiled marshes were left untouched, spontaneous recovery may require centuries and recommended mass planting of marsh vegetation.[70] However, on the basis of further studies, it now appears that marshes that were oiled but had no cleanup were essentially restored by natural processes within 5 years, whereas in cleaned marsh areas, restoration took 7 to 8 years.[71] Marshes that had been subjected to extensive cleanup efforts experienced increased erosion of fine sediments and despite extensive artificial plantings, their restoration was delayed by 2 to 3 years. In Aber Benoit, an estuary heavily affected by the spill, the only measurable residues of weathered petroleum remaining after 8 years were found in isolated soft sediment locations that served as repositories for fine sediment from other parts of the estuary.[72]

In the months following the spill, journalists and individuals associated with affected localities and industries made numerous assertions about the extent of lost earnings in the fishing and tourist industries, and the extent of cleanup and restoration costs, property damage, and other effects. "Brittany will look like a desert" was one oft-repeated phrase. The magnitudes of the short-run and long-run physical, biological, and monetary damages as a result

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[69] National Research Council, Oil in the Sea: Inputs, Fates, and Effects, p. 566.

[70] Vandermeulen, J. H., B. F. N. Long, and L. D'Ozouville. Geomorphological Alteration of a Heavily Oiled Saltmarsh (Ile Grande, France) as a Result of Massive Cleanup. In Proceedings, 1981 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4334, 1981, p. 350.

[71] Baca, Bart J., Thomas E. Lankford, and Erich R. Gundlach. Recovery of Brittany Coastal Marshes in the Eight Years Following the *Amoco Cadiz* Incident. In Proceedings, 1987 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4452, 1987, p. 459-464.

[72] Page, David S., Judith C. Foster, Paulette M. Fickett, and Edward S. Gilfillan. Long-term Weathering of *Amoco Cadiz* Oil in Soft Intertidal Sediments. In Proceedings, 1989 Oil Spill Conference, sponsored by EPA, USCG, and API, American Petroleum Institute publication 4479, 1989, p. 401-405.

of the spill became questions of national and international focus and interest. Thus, the social costs of this oil spill were also well studied. The total economic costs to the world were estimated to range from about $190 million to $290 million (1978 dollars).[73] The largest components of the total cost were cleanup expenditures, losses to the oyster-culturing industry, and the loss of the tanker and cargo. The loss of recreational values were estimated to range from about $1.5 million to over $80 million depending on the unit values of losses assumed. The French Government and others originally sought $2 billion in damages, but Amoco's liability was considerably reduced because the judge found relatively little long-term ecological damage and recommended an award of $115.2 million.[74]

CONCLUSIONS

Since the first well was drilled over 130 years ago, petroleum has become society's major energy source. Petroleum and petroleum products have played a significant role in the progress of civilization. Materials made from petroleum are virtually everywhere. Petroleum production has been among the least damaging to the environment of any of the extractive earth resources industries. Yet no technology is without environmental cost and none is fail-safe.

An oil spill can be a devestating occurrence. However, past spills have not been long-lived events. For the most part, the longest residence time that spilled oil appears to have had in the marine and coastal environment was generally less than a decade--often much less. The major ecological impact has come at the time of the spill or within the first few months. Beyond a few months, most oil has been reduced to tarry residues or was chemically detectable in sediments and resident organisms, which may be of scientific interest, but in terms of further ecological impact, has proved to be fairly insignificant overall. Public impressions of socioeconomic and environmental damage that occurred and concerns over further ecological impacts have lasted much longer. The life span of the media coverage has been shorter than the major ecological impact of the spill, but probably of greater significance. With the possible exception of special environments, predictions of long-term effects have been largely unsubstantiated. Based on the evidence available, there has been no evident irrevocable damage to marine resources on a broad scale to justify serious allegations of unknown, but significant, long-term effects.

The short-term impact of a major spill can be devastating to the organisms in the immediate vicinity, including shellfish, finfish, marine

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[73] U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Assessing the Social Costs of Oil Spills: The *Amoco Cadiz* Case Study. July 1983, 144 p.

[74] Wall Street Journal, Mar. 28, 1989, p. A13.

mammals and waterfowl. Experience, thus far, however, would indicate that this has not made a noticeable impact on world population levels of any species. For species of shellfish, finfish, and waterfowl that are harvested, the mortality from an oil spill, so far as is known, has never come close to approaching the magnitude of the annual harvests.[75] Recolonization of an area temporarily polluted from oil appears to be rapid for most species.

A major short-term impact of a major spill is the visual impact created by an oiled shoreline and featured by the media coverage of the event. The media coverage typically includes heartrending scenes of oiled or dead birds and sea life, and oiled beaches. The portrayal is generally one of a major catastrophe.[76] While not minimizing the effect of an oil spill, it appears that the environmental damage has been less than one would surmise from immediate visual appearances or media coverage.

Nearly one year after the grounding of the *Exxon Valdez* the city of Valdez issued a press release appealing to the world's press "to avoid repeating errors and myths" in covering the spill anniversary. The press release noted that the loss of wildlife was a small fraction of existing populations in the sound and that most of the affected shoreline is remote and outside the area likely to be seen by seaborne tourists. On the other hand, the Alaska Coalition, an environmental group, marked the anniversary by calling on Congress to establish a memorial for the wildlife lost in the accident by declaring the entire Arctic National Wildlife Refuge a wilderness area.

Based on the record of past spill events, it would also appear that beyond a moderate human effort to clean up an oil spill, nature does a much better job than humans. In fact, in some instances, it would appear that massive physical cleanup efforts delayed the natural ecological restoration of the affected area although the appearance, particularly of rock and beach areas, may be improved sooner. This might raise the question of whether the cost to society of massive physical cleanup efforts is equal to the social and environmental benefit. In the case of the *Exxon Valdez* spill, the cost of cleanup to date has exceeded $2 billion (far more than has been expended on any previous spill), where most of the affected shoreline is "remote and outside the area likely to be seen by seaborne tourists." The unfortunate spill in Prince William Sound will, however, offer an opportunity to study the effects of a large oil spill in a subarctic environment. Whether the effects of the *Exxon Valdez* spill will match the experiences of spills in more temperate environments remains to be seen.

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[75] For example, about 300,000 waterfowl are taken each year during hunting season on Maryland's "eastern shore" alone.

[76] Yen, Marianne. Judge Sets $500,000 Bail for Disaster Unequaled 'Since Hiroshima'. Washington Post, Apr. 6, 1989, p. A1, A11.

Oil spills are not new events and many have been studied. Obviously, all of the possible physical oceanographic, socioeconomic, and environmental effects of an oil spill are not known, and further scientific study will be of value. On the other hand, from a public policy perspective, the major socioeconomic and environmental impacts of an oil spill are reasonably well known, and, on the basis of that knowledge, the major effects of a future spill should be fairly predictable.

Public policy decisions have to balance the overall needs and benefits to society of a particular action versus its costs and risk. For example, public policy decisions, such as whether to permit offshore drilling in a particular area, are properly based in part on a scientific assessment of the probability of spills from offshore production versus imported oil and the severity of the consequences. The experience of the past 50 years and the careful research of marine scientists now provide the basis for realistic estimates.

EPILOGUE

The oceans are ancient and throughout the course of time many sea-dwelling species have flourished and faded while new species have evolved. Now, for the first time, there is broad human concern for the well-being of the seas because, as no other creature before, human beings have the ability to alter a wide range of marine ecosystems dangerously and quickly. In the pursuit of food and living resources, humans have even threatened the survival and caused the extinction of many species. Fortunately, however, the oceanic environment is not fragile;[77] in fact, it is extrodinarily resilient. It has evolved through ice ages, global warming, bombardments of cosmic radiation, fluctuations of the sun, massive volcanic eruptions, and collisions of comets and meteors. Mass extinctions of species were associated with some of these events, but life forms continued to adapt, evolve, become more complex, and flourish.

Many physical and biological processes in the marine and coastal environment are only poorly understood. For these reasons, it is particularly difficult for scientists to measure the full impact of an oil spill and sometimes the results appear contradictory. To date, pollution from offshore petroleum activities has not appeared to be a significant threat to the survival of the various species. Nor is it, if compared to other activities and possible pollutants, likely to be ranked as a leading threat in this regard. Despite short-term media attention to the catastrophic nature of major spill events, the chemicals contained in petroleum have long been part of the marine environment and physical impacts are likely to be temporary in the dynamic natural flux of the coastal environment.

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[77] Fragile and environment are commonly linked together in media accounts of spill events.