CHAPTER 16 BOX 1

PETROLEUM IN THE MARINE ENVIRONMENT

PETROLEUM

Almost every year, somewhere in the world, one or more oil tankers accidentally spill some or all of their cargo into the oceans. Tanker accidents (**Fig. 16B1-1a,b**) and oil well blowouts (**Figs. 16B1-1c,d,f, 16B1-2**) generate enormous public and media attention. These dramatic events provide gripping visual images of stranded and damaged ships; of thick black oil floating on the water and washing up on beaches; of oiled and dying or dead seabirds (**Fig. 16B1-1c**), otters, and other animals; and of frantic efforts to clean up the spilled oil (**Fig. 16B1-1d–f**). Consequently, tanker spills and oil platform blowouts are widely believed to be the major source of oil contamination and the most damaging form of ocean pollution. Neither of these beliefs is correct.

Sources of Petroleum Contamination

Sources of oil in the oceans include natural seeps from the seafloor and from terrestrial watersheds that drain to the oceans, large and small spills, and incidental releases by vessels and offshore platforms. In a 2007 report, the National Academy of Sciences reported that natural seeps are the major source of petroleum to the oceans both nationally and wordwide. According to the report,oil from individual cars and boats, lawn mowers, jet skis, marine vessels, and airplanes contribute the most anthropogenic oil contamination to the ocean both in the United States and globally. This oil enters the oceans through land runoff from oil slicks on urban roads and by deposition of hydrocarbons from the atmosphere. The report estimates that use-related oil pollution accounts for about 87 percent of the oil from human activity in North American waters, an amount that dwarfs the inputs from oil and gas production activities, In the period 1990-1999, the report estimated that worldwide natural releases of petroleum were fifteen times greater than releases from offshore oil platforms, and that oil transportation accidents (mostly spills from tankers) contributed about 4 times more oil to the oceans than oil platforms (**Fig. 16B1-3**).

Since the *Exxon Valdez* oil spill in Alaska in 1989, extensive efforts to reduce accidents and incidental oil releases from vessels and offshore oil platforms have substantially reduced the input from these sources, particularly in the United States. For example, no large spills from tankers have occurred since 2002 (**Table 16B1-1**)..In contrast, there has been relatively little success in reducing the inputs of oil through urban and river runoff or in incidental discharges from recreational and other vessels. Major spills such as the 2010 Deepwater Horizon explosion in the Gulf of Mexico still occur but they are now drastically less frequent that they were a decade or two ago.

Fate of Petroleum in the Oceans

When oil is spilled into the ocean, it spreads on the water surface to form a slick. The oil's fate then depends on several factors, including the oil composition, air and sea temperatures, concentrations of suspended sediment, presence of breaking waves, and whether the oil reaches a shore (**Fig. 16B1-4**).

Oil contains many different chemical compounds called **hydrocarbons**. Individual hydrocarbons differ widely in volatility, solubility, toxicity, and chemical properties. Crude oil composition depends on its source, and refined oil products are very different in composition from crude oil. Generally, refined oil products, such as gasoline and diesel fuel, contain a greater proportion of low-molecular-weight, more-volatile hydrocarbons, and these refined products are more toxic than crude oil.

After a spill, the volatile components of the oil evaporate into the atmosphere or are dissolved in the water. These volatile compounds are largely evaporated from the slick within a day or two. As volatile components are removed, the oil becomes more **viscous** and, unless the seas are rough, begins to aggregate into lumps. In rough seas, oil may be mixed with air and water to form a gummy suspension that resembles and is often called "chocolate mousse." The oil dissolves or forms lumps, called "tar balls," composed primarily of high-molecular-weight, less-volatile hydrocarbons, or the oil is attached to sediment particles and deposited. If the slick does not encounter a shore, it is eventually completely dissipated. If the slick does reach a shore, oil clings to any substrate as an oily film. Once ashore, the oil film persists until it is washed off, buried in sediments by continuous strong wave action, or slowly decomposed by bacteria.

Because oil is a naturally occurring material, many decomposers are able to use hydrocarbons as food. Consequently, oil spills are eventually "cleaned up" naturally. The severe damage to birds and mammals and to **intertidal epifauna** and **infauna** that provides gripping television coverage after a spill is generally limited to relatively small stretches of shore. Even the most severely damaged shores normally recover and are almost indistinguishable from their original condition within a few years to a decade after the spill.

Recovery and recolonization are generally faster on rocky or other high-energy shores where physical processes limit the extent of oil accumulation during the spill and maximize its removal and dispersion into the open ocean in the post spill period. Low-energy shores, particularly wetlands, recover more slowly because oil can accumulate more easily and sediments into which it is mixed often have low concentrations of oxygen, an element that some bacteria need in order to decompose the hydrocarbons. Because both bacterial decomposition and evaporation are reduced at low temperatures, oil spills may persist longer and recovery may be slower in high-latitude environments than in warmer regions.

Effects of Major Spills

One of the largest oil spills from a tanker accident occurred in Brittany, France, in 1978 (**Table 16B1-1**). The tanker *Amoco Cadiz* (**Fig. 16B1-1b**) spilled its entire cargo of more than 200,000 tonnes of oil over several days after it hit a rock 13 km offshore and broke up. This was more than six times the amount of oil spilled in the *Exxon Valdez* accident in Alaska in 1989. Strong currents rapidly spread the oil slick along the Brittany coast, and strong wave action prevented at-sea cleanup efforts from recap-

FIGURE 16B1-1 Oil spills provide spectacular images that ensure media coverage. (a) The *Exxon Valdez* tanker 48 h after it ran aground on Bligh Reef in Prince William Sound, Alaska, in 1989. The tanker is still leaking some oil, and it is surrounded by a boom that has been placed on the water surface in an attempt to contain this oil so that it can be collected. (b) The *Amoco Cadiz*, Brittany, France, 1978. (c) A rescuer tries to capture an oiled Pelican after the 2010 Deepwater Horizon spill in the Gulf of Mexico. Rarely do heavily oiled birds survive even when cleaned up. (d) A boom skimmer toed by two small boats corrals surface oil so it can be burned. Controlled burns need only low cost equipment and are one of the most effective spill clean-up techniques. (e) High-pressure water hoses are used to wash oil off a Naked Island beach in Prince William Sound one week after the *Exxon Valdez* oil spill. (f) Cleaning up Gulf of Mexico beaches after the Deepwater Horizon spill. Aggressive beach clean-up often causes more environmental damage than would occur if the beach were left to clear naturally.

turing much of the oil. Within a few days, 300 km of shore was affected by oil. Oil entered a number of low-wave-energy and low-current-energy estuaries and other embayments, where it accumulated in large quantities.

The biological impacts of the *Amoco Cadiz* spill were immediate, dramatic, and severe. More than 7000 seabirds, mostly diving birds such as cormorants, were oiled and died. The **plankton** biomass was substantially reduced for at least 2 months after the accident, and mortalities of benthic organisms, including **sea urchins,** clams, and **amphipods,** were massive. The major commercial species of the area, oysters, survived but were heavily contaminated and thus unfit for human consumption for many months. The rooted vegetation in coastal **salt marshes** and the **fauna** of intertidal mud-flats were severely damaged. In contrast, only a small number of fishes were reported killed within the immediate vicinity of the wreck (about 10 km). Commercial flatfishes, including plaice and sole, showed no significant changes in population, although their average size in the spill year was somewhat below average, presumably because of the reduction in biomass of the juveniles' plankton food.

In the weeks and months after the *Amoco Cadiz* accident, extensive cleanup and oil removal efforts were made, especially in the low-energy estuarine environments. Visible signs of oil persisted in the water for as long as 6 months and in sediments for more than 3 years. However, all but very limited areas, such as the mudflats, were repopulated with most or all of their original species within several years. Some mudflats were subject to increased erosion caused by the loss of their vegetation, and oil contamination still could be detected in the mud-flat sediments more than a decade after the spill. Nevertheless, this massive spill, which occurred in a particularly vulnerable area with extensive and important tidal wetlands and estuaries, caused severe ecosystem disruption in only a limited area, and the system recovered almost totally within a decade. This experience has been repeated in many other spills, including the *Exxon Valdez* accident (**Fig. 16B1-1a**), the huge *IXTOC* platform spill (**Fig. 16B1-2b**), and the massive deliberate spill by Iraq in the Persian Gulf during the Gulf War in 1991.

Both the IXTOC spill and the Gulf War spill were estimated to be about the same size as the Deepwater Horizon spill in the Gulf of Mexico in 2010. Even just one year after the beginning of the Deepwater Horizon spill, the accumulating scientific data showed that the Gulf of Mexico was already well on its way to recovering from the spill and further studies suggest that any the long term damage will be minimal, except for degradation of the benthos in a limited are around the spill site, which has been found was most likely caused primarily by dispersant chemicals used to minimize the amount of floating oil. For example, the data show that Gulf fisheries catch rates were higher in 2011 than they were before the spill. This has been attributed by some scientists to be due to the fact that stocks were allowed to recover when fishing was banned in the oil affected area of the Gulf for several months. An equally valid hypothesis has been proposed that the improved fishing is due to the large pulse of additional food supplied by the microbial biomass that has been shown to have decomposed the spilled oil in the open waters of the Gulf so effectively that oil related compounds were back to normal (the Gulf has many ongoing natural seeps, so oil related compounds are never zero) background concentrations within months. Nevertheless, public pressure has demanded and required intensive future studies to identify the long-term impacts of the Deepwater Horizon spill. As in all past spills that have been studied, it is likely that changes will be observed in the Gulf ecosystem in future years that could possibly be caused by the spill or could alternatively be due to natural variation. In the meantime, the public and the media will almost certainly continue to almost totally ignore the annual occurrence of a human pollution caused "dead zone" in the Gulf of Mexico which has grown larger over the last several years and probably will continue to grow. The dead zone that now affects about 19,500 km^2 of the Gulf of Mexico and is almost certainly a far greater .cause of adverse ecosystem impact on the Gulf than the 2010 oil spill, especially since the dead zone is an ongoing and growing pollution problem that remains largely unaddressed.

Cleanup activities after a spill may be essential to remove as much oil as possible and speed natural recovery. However,

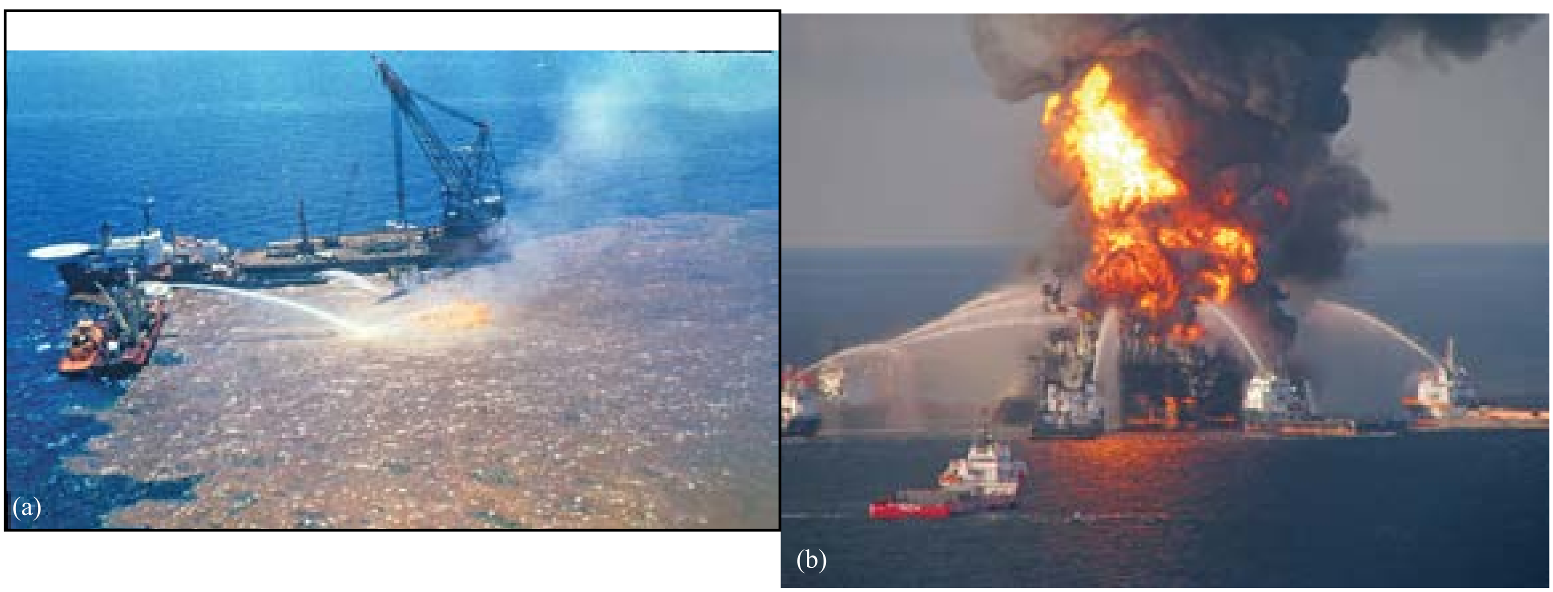

FIGURE 16B1-2 Major oil spills from the offshore oil industry are rare but dramatic events. (a) This spectacular blowout and fire at the IXTOC oil rig in the Gulf of Mexico in 1979 resulted in a continuous release of oil that lasted for several months before the well was finally closed (b) The Deepwater Horizon rig burns before it sank in the Gulf of Mexico, April 2010.

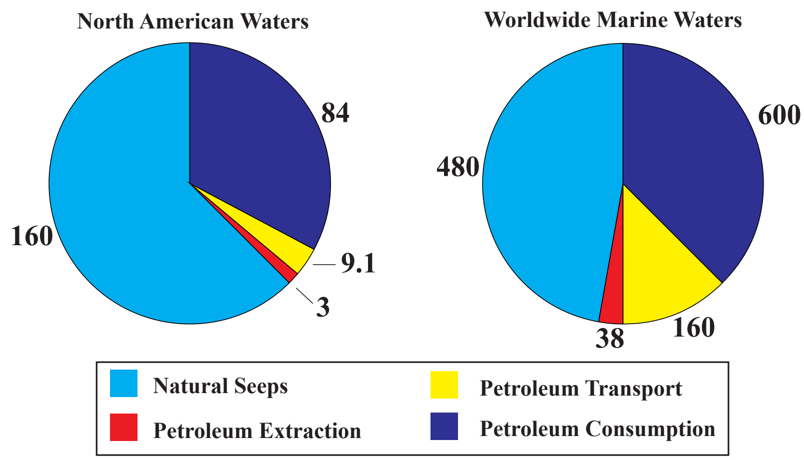

FIGURE 16B1-3 There are many sources of oil contamination of the marine environment. According to a 2007 National Academy of Sciences report, while incidental releases during petroleum release at the consumption stage , for example, from automobiles, far exceeds the inputs from spills and other releases during the production and transportation of petroleum, especially in the Unites States.

if cleanup is too aggressive and protracted, the environmental benefit of the additional actions quickly diminishes, and extending the "cleanup" beyond a certain point can cause more damage than would otherwise occur. Generally, it is beneficial to skim up and remove as much floating oil as possible and to mop up oil from the shore that can be easily removed without disturbing the sediment. In addition, oil can be washed back into the water to be skimmed and removed, but only from high-energy beaches and rocky areas where the high-pressure water jets used for cleaning essentially simulate extended strong wave action.

Other cleanup efforts, including aggressive removal of oiled sediment from low-energy environments and extended efforts to remove oil from below the surface of coarse sand or gravel beaches, are costly, provide little or no environmental benefit, and in some instances, cause additional **ecological** damage and retard recovery. In isolated wild areas, such as Alaska's Prince William Sound, the extended presence of people and their cleanup activities on beaches can have adverse effects on shorebirds, terrestrial wildlife, and **marine mammals.** In addition, the use of chemicals

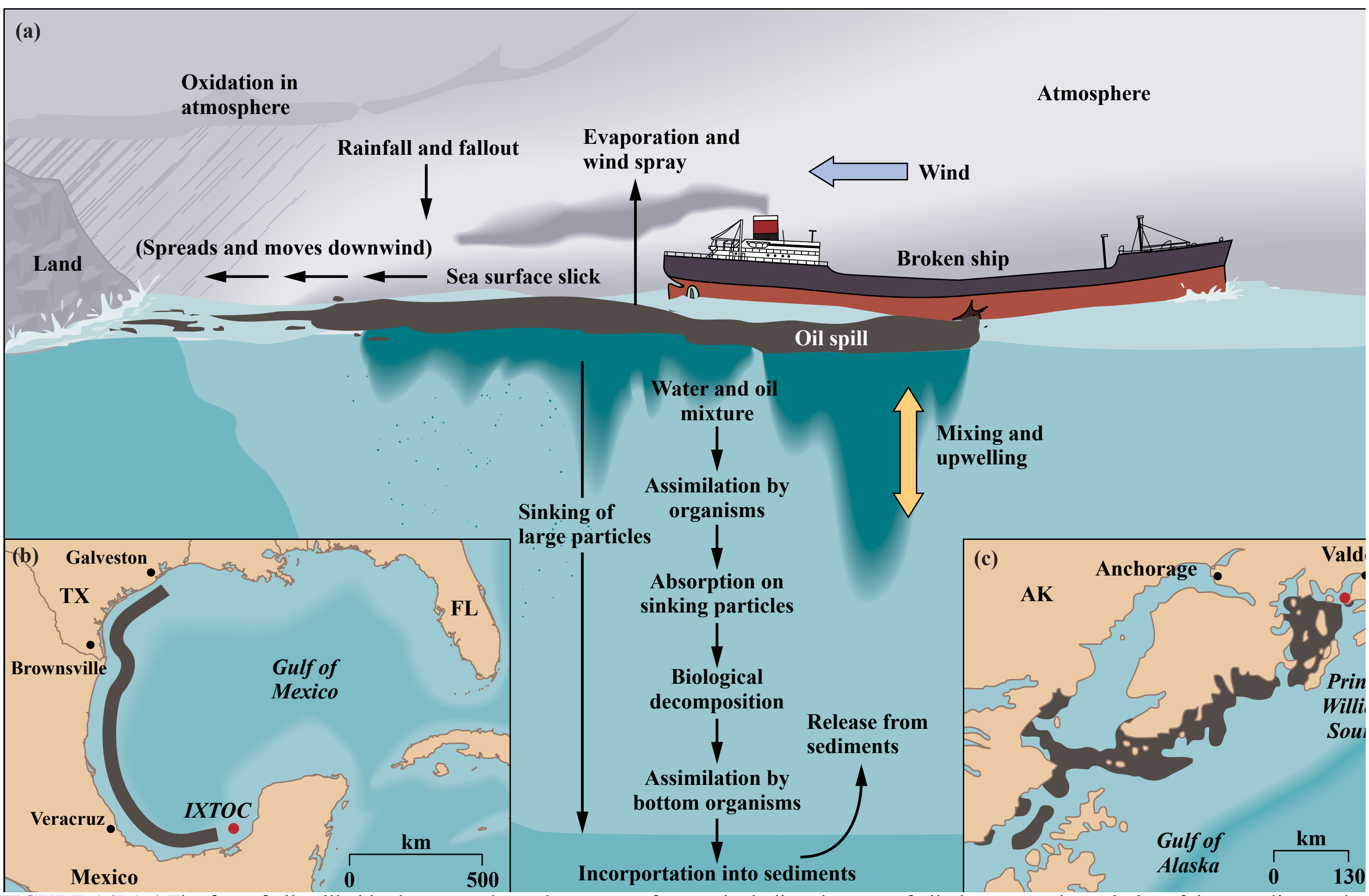

FIGURE 16B1-4 The fate of oil spilled in the ocean depends on many factors, including the type of oil, the type and proximity of the coastline, and the extent of wave energy. (a) Some oil evaporates quickly, but most coagulates to form tar balls or is adsorbed by particles and sinks to the sediments. The oil is eventually decomposed, primarily by bacteria. Oil spills generally do not cause lasting environmental damage, unless the oil reaches an ecologically sensitive shoreline, especially in high latitudes where oil degrades slowly because of the low temperature. (b) Areas affected by oil after the 1979 blowout of the IXTOC well, which took several months to cap. (c) Areas affected by oil after the 1989 *Exxon Valdez* accident.

to disperse and dissolve oil can be damaging because such chemicals can be more toxic and persistent than the oil. Burning the oil as soon as possible after a spill or as oil reaches the surface from an ongoing spill (such as Deepwater Horizon) and then skimming off what does not burn may well produce better overall protection for the environment, but that option is never considered to be viable due to the inevitable public and media reaction that would be generated by "sensational" video of the burning oil. About 7,500 tonnes of dispersants were used in the 2010 Deepwater Horizon spill. It is likely that future research will show that the dispersants, while minimizing floating oil and perhaps oiling of beaches, caused significant, perhaps more serious damage than would have occurred without their use. For example, without the dispersants oil (and dispersant) concentrations near the seafloor would have been much lower except immediately surrounding the well and perhaps the reported damage to deep water corals at substantial distances from the well would not have occurred.

Unfortunately, public pressure often requires that everything possible be done to clean up all the oil after a spill. As a result, spill cleanups often continue beyond the point at which many technical specialists believe they should be ended. Large sums of money are wasted in cleanup that yields no environmental gain or is even detrimental. Nature is very efficient at cleaning up oil spills within a few years. Our role should be to remove as much oil as possible quickly, and then let nature take its course. However, in some instances, naturally occurring hydrocarbon-degrading bacteria, or nutrients that encourage the growth of such bacteria, might be beneficially added to the oiled ecosystem to help nature heal itself.

Whether we should attempt to rescue, clean, and rehabilitate oiled birds and marine mammals in an oil spill area is debatable. For example, efforts to clean and rehabilitate sea otters after the *Exxon Valdez* spill are estimated to have cost more than $80,000 for each animal that was captured and eventually returned to the ocean (a total of only 197 animals). Estimates are that only about one-half of those animals survived a year after reintroduction, and many that did survive would probably have survived without cleaning because they were so lightly oiled. Mounting an animal cleanup program after a spill is emotionally satisfying, provides good material for the media, and provides those responsible for the spill with the ability to claim that they are making every effort possible to minimize the damage. However, almost all such efforts have proven ineffective.

Environmental scientists generally accept that even major oil spills do not cause lasting and widespread destruction of ocean ecosystems. However, concerns remain that major oil spills may have long-term adverse effects on some fish and other species because of the **chronic toxicity** of some of the more persistent hydrocarbons, particularly **polyaromatic hydrocarbons (PAHs)**. For example, the unusually

TABLE 16B1-1 Large Oil Tanker Spills

Tanker	***Date***	***Location***[a]	***Amount of Oil Spilled (tonnes)***[b]
Atlantic Empress	1999	Off Tobago	287,000
ATB Summer	1991	700 n.m. off Angola	260,000
Castillo de Bellver	1983	70 n.m. off Cape Town, South Africa	257,000
Amoco Cadiz	1978	Brittany, France	223,000
Haven	1991	Genoa, Italy	144,000
Odyssey	1988	700 n.m. off Nova Scotia, Canada	132,000
Torrey Canyon	1967	Scilly Isles, United Kingdom	119,000
Sea Star	1972	Gulf of Oman	115,000
Irenes Serenade	1980	Navarino Bay, Greece	100,000
Urquiola	1976	La Coruña, Spain	100,000
Hawaiian Patriot	1977	320 n.m. west of Hawaii	95,000
Independenta	1979	Istanbul, Turkey	95,000
Jakob Maersk	1995	Leixões, Portugal	88,000
Braer	1993	Shetland Isles, United Kingdom	85,000
Khark 5	1989	120 n.m. off Morocco, Atlantic	80,000
Prestige	2002	Off the Spanish coast	77,000
Aegean Sea	1992	La Coruña, Spain	73,000
Katina P.	1992	Off Maputo, Mozambique	72,000
Sea Empress	1996	Milford Haven, United Kingdom	72,000
Nova	1985	75 n.m. off Khark Island, Persian Gulf	70,000
Sinclair Petrolore	1960	Off Brazil	60,000
Epic Colocontris	1975	60 n.m. northwest of Puerto Rico	60,000
Corinthos	1975	Marcus Hook, Philadelphia, USA	53,000
Assimi	1983	60 n.m. off Masqat, Oman	52,000
Metula	1974	Strait of Magellan, Chile	50,000
Andros Patria	1978	Off Cape Finisterre, Spain	50,000
World Glory	1968	90 n.m. off Durban, South Africa	48,000
Pericles GC	1983	200 n.m. off Doha, Qatar	46,000
British Ambassador	1975	Pacific Ocean	44,000
Ennerdale	1970	Off Port Victoria, Seychelles	41,000
Mendoil II	1968	340 n.m. off Washington State, USA	40,000
Wafra	1971	Off Cape Agulhas, South Africa	40,000
Juan A. Lavalleja	1980	Arzew, Algeria	40,000
Trader	1972	Off southwestern coast of Greece	37,000
Exxon Valdez	1989	Prince William Sound, Alaska, USA	37,000
Thanassis A.	1994	200 n.m. off Manila, Philippines	37,000
Burmah Agate	1979	Galveston, Texas, USA	36,000
Napier	1973	Off Guamblin Island, Chile	35,000

Note: For incidents in which some of the spilled oil burned, not all of the amount listed here was released into the ocean
[a]n.m. = nautical miles
[b]All values are estimates. Reports of amounts of oil spilled have varied for some spills

low numbers of salmon, **herring,** and other species returning to Prince William Sound in some (but not all) years after the *Exxon Valdez* spill raised suspicions that the low returns were in some way chronic effects of the spill. These returns are highly variable from year to year because of natural factors, such as climatic variations and disease outbreaks. Consequently, determining whether variations, such as those in Prince William Sound since the 1989 spill, are natural or related to the spill or to other anthropogenic factors is exceedingly difficult.

The difficulty is partly related to the lack of studies of year-to-year variability before the spill. After many years of intensive research following the *Exxon Valdez* spill, there is a consensus in the scientific community that, although some lingering long-term effects could be identified, many of these were caused by the aggressive cleanup efforts after the spill and that the sum of the effects that still remained a decade or more after the spill was far less significant than natural changes in the ecosystem (possibly related to the climate change associated with the Pacific Decadal Oscillation; **Chap. 7**).

A related issue is the widespread belief that if scientists are able to still find any trace of the spilled oil in the environment of a former spill location the area is still polluted. Scientists can detect incredibly low concentrations of hydrocarbons, far lower than the levels found naturally in many areas, and well below any known sublethal toxicity limit so, at worst these environments may be considered contaminated but there are no known lingering effects so they are no longer polluted.

Chronic Inputs

Many hydrocarbons are toxic to some species, even in small concentrations. PAHs especially have a range of toxic effects, including teratogenicity and carcinogenicity (**CC18**). Consequently, any chronic long-term impacts of oil contamination from sources other than spills are likely to be more serious and widespread than those of the much more dramatic spills. Nonspill contamination sources generally are highly concentrated in estuaries and the coastal zone, particularly near ports, harbors, and major cities. Hence, many scientists believe that greater research emphasis should be placed on the possible chronic effects of these other sources of oil in environmentally important coastal areas than on the massive research programs that follow major spills.

Lessons Learned

Several lessons can be learned from a careful review of oil pollution studies. Most importantly, the extraordinary public attention to and concern about major spills is misplaced. Recovery after such spills is relatively rapid, and their long-term effects are almost certainly less than effects of the much more widespread chronic oil contamination from other sources.

Second, although cleanup of oil from the area of a spill helps to speed recovery, cleanup must be limited and done carefully, because overly aggressive cleanup can cause more damage than the spill itself.

Third, public opposition to offshore oil drilling in U.S. waters may result in greater oil pollution because offshore production has been historically safer than tanker transport. Although the United States must ultimately reduce its use of oil, it cannot do so immediately. If we do not produce oil in continental United States, we must continue to produce it from offshore oil rigs, or import it in tankers and incur a greater risk of oil spills. If the imported oil is produced from offshore oil platforms in other countries the global environmental cost of using oil will include any oil spills from these platforms plus the transport risks

Finally, ecosystems are naturally variable, so after an oil spill or other major disturbance, appropriate actions may restore the ecosystem to a natural state, but the balance of species in this new state will be different from the preexisting natural state because ecosystems are in a constant process of change.

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