

# POLLUTION IN THE OCEAN

Highlights of National Academies Reports

**THE NATIONAL ACADEMIES**  
*Advisers to the Nation on Science, Engineering, and Medicine*







# POLLUTION IS THE RELEASE OF UNDESIRABLE SUBSTANCES

into the environment. Many human activities—industrial production, burning of fossil fuels, agriculture, and product use, among others—generate pollutants that can find their way into the ocean. At one time, people thought that the vastness of the ocean could dilute pollutants enough to eliminate their impacts. It is now known, however, that some pollutants can significantly alter marine ecosystems and cause harm—sometimes deadly—to species from the top to the bottom of the food web.

Pollutants often originate far inland and are transported to the ocean via rivers or through the air. Pollutants of particular concern include petroleum, excess nutrients from fertilizers, debris, and industrial contaminants. Even noise, from such activities as shipping, seismic exploration, and sonar, can affect ocean life.

The good news is that through innovative science and technology, regular monitoring, environmentally-aware policies, and established treatment methods, some of the effects of pollution can be contained and reduced. Many important action steps have already been taken: “scrubbers” have been installed on coal power plants to reduce air emissions of pollutants; microorganisms are being used to break down pollutants in sewage; wetlands and buffer zones have been created along rivers and streams to absorb excess fertilizers; and oil dispersants are being used to treat oil spills.

Despite some successes in reversing hazardous effects of pollution, much work remains to be done to protect ocean health for future generations.



# OIL

The 1989 oil spill from the grounding of the oil tanker *Exxon Valdez*, still the largest such spill in U.S. history, is infamous for the devastation it caused to the fragile marine wildlife in Alaska's Prince William Sound. The tanker spilled approximately 11 million gallons of its 53-million-gallon cargo of crude oil, killing an estimated 900 bald eagles, 250,000 seabirds, 2,800 sea otters, 300 harbor seals and uncounted fish and invertebrates. Massive cleanup efforts removed much of the visible crude oil within a year, but the slow release of the remaining oil has continued to affect populations of local marine plants and animals to this day.

Although alternative energy sources are being pursued, oil is expected to remain the dominant fuel for at least the next couple of decades. Energy demands continue to rise as population increases and the developing world becomes more industrialized. Worldwide petroleum consumption is projected to rise sharply over the next few decades, with the largest rate of growth in China, India, and other developing Asian nations.

The Steller sea lion was among many marine animals coated with oil following the 1989 spill from the oil tanker *Exxon Valdez* in Alaska's Prince William Sound. (Image from the Exxon Valdez Oil Spill Trustee Council)

The National Research Council report *Oil in the Sea III: Inputs, Fates, and Effects* (2003) developed a new methodology for estimating petroleum inputs to the sea from both natural and human sources (see figure at right). Oil inputs from human activities are categorized as those that originate from: (1) petroleum extraction, exploration, and production activities; (2) petroleum transportation, including tanker spills and (3) petroleum use, including runoff from highways and discharges from recreational vehicles.





Accidental spills have been dramatically reduced with the advent of double-hulls on oil tankers and through new technology and safety training on oil platforms (shown above).

Although people often associate oil in the ocean with tanker accidents, natural seeps are the largest single source of oil in the sea, accounting for about 60 percent of the total in North American waters and 45 percent worldwide. Seeps form when crude oil oozes into the water from geologic formations beneath the seafloor. Oil and gas extraction activities are often concentrated in regions where seeps form.

### NEW TECHNOLOGIES HAVE REDUCED OIL POLLUTION FROM SHIPS AND PLATFORMS

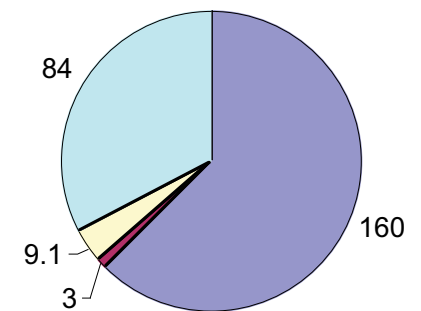
Historically, oil and gas exploration, petroleum production, and transportation-related spills have been significant sources of oil in the oceans. The second-largest marine spill in the world was a 1979 “blowout” of a Mexican exploratory oil well that released about 140 million gallons of crude oil into the open sea in the southern Gulf

of Mexico. During the past decade, however, improved production technology and safety training of personnel have dramatically reduced both blowouts and daily operational spills. Today, accidental spills from platforms represent about 1 percent of petroleum discharged in North American waters and about 3 percent worldwide.

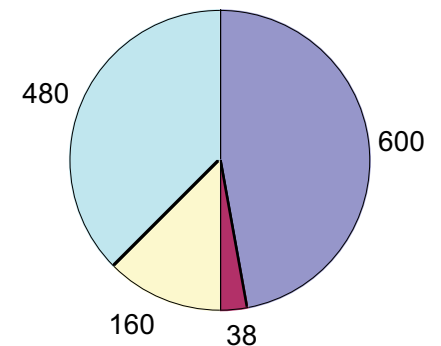
Although the amount of oil transported over the sea continues to rise, transportation-related spills are down. The U.S. Oil Pollution Act of 1990, enacted in response to the *Exxon Valdez* disaster, required older vessels to be phased out. Most tankers now have double-hulls or segregated tank arrangements that dramatically reduce spillage. Transportation spills now account for less than four percent of the total petroleum released in North American waters and less than 13 percent worldwide.

These pie charts show the relative contribution of the average, annual releases (1990-1999) of oil into the marine environment from natural seeps and from human activities associated with the extraction, transportation, and use of oil.

North American Marine Waters



Worldwide Marine Waters



- Natural Seeps
- Extraction of Petroleum
- Transportation of Petroleum
- Consumption of Petroleum

## PETROLEUM RUNOFF AND RECREATIONAL VEHICLE DISCHARGE HAVE A MAJOR ENVIRONMENTAL IMPACT

The conclusion of *Oil in the Sea III*, perhaps surprising to many, is that oil from individual cars and boats, lawn mowers, jet skis, marine vessels, and airplanes contribute the most oil pollution to the ocean. This includes land runoff from oil slicks on urban roads and hydrocarbons deposited from the atmosphere. According to the report's estimates, use-related oil pollution dwarfs that from oil and gas production activities, accounting for about 87 percent of the oil from human activity in North American waters.

Oil from individual cars and boats, lawn mowers, jet skis, marine vessels, and airplanes—from both direct inputs and runoff—accounts for most oil pollution in the ocean, dwarfing inputs from oil and gas production activities.



## THE IMPACT OF AN OIL RELEASE DEPENDS MORE ON ITS LOCATION THAN ITS SIZE

Similar to the real estate maxim, the impact of oil is not so much about the amount released but more about the “location, location, location.” Even a relatively small amount of petroleum can seriously harm marine life and habitat if it occurs in an area where the oil cannot be contained or dispersed. Unfortunately, many spills take place in coastal areas that are home to sensitive ecosystems such as mangroves and salt marshes that support a wide range of fish, birds, and animals—some of them endangered. In addition, car runoff and recreational vehicle discharges can occur in sensitive coastal environments. More than half of the oil pollution in North America is estimated to flow to coastal waters between Maine and Virginia, a region with densely packed urban areas.



Advances in technology are helping to reduce inputs of oil from vehicles. For a long time, some recreational vehicles, for example, outboard motorboats, used inefficient “two-stroke engines” that discharged significant amounts of oil into coastal environments. These engines began to be replaced with more efficient engines in 1990 when the U.S. Environmental Protection Agency (EPA) regulated “non-road engines” under the Clean Air Act.

### **CLEAN-UP STRATEGIES REQUIRE CAREFUL STUDY**

There are no easy solutions to cleaning up oil spills. Available methods include the use of biological agents that help break down the oil, use of materials that absorb oil, and gelling agents that make oil easier to skim from the surface. People also physically clean up spills by using high-pressure water hoses on shores and cleaning oil off of animals.

The National Research Council report *Understanding Oil Spill Dispersants: Efficacy and Effects* (2005) assesses the scientific questions related to the use of dispersants, a group of chemicals that act like soap to help dilute large oil spills. They work to reduce the oily contamination of wildlife and shoreline habitats by allowing the oil to be dispersed into the surrounding waters. However, in semi-enclosed coastal areas, the oil may not be diluted sufficiently by dispersants to reduce its toxicity to marine life.

The report concludes that decisions about whether and when to use dispersants require a very site-specific assessment of a complex array of variables, including the type and volume of the oil spill, and the weather, water depth, degree of turbulence, and relative abundance and life stages of marine species in the region. The report recommends that relevant state and federal agencies, industry, and international partners develop and implement focused studies to support decision making about the use and anticipated effectiveness of dispersants for a given spill.



A harmful algal bloom known as a “red tide” swirls around some islands in southeast Alaska. (Image from National Geographic)

## NUTRIENT POLLUTION

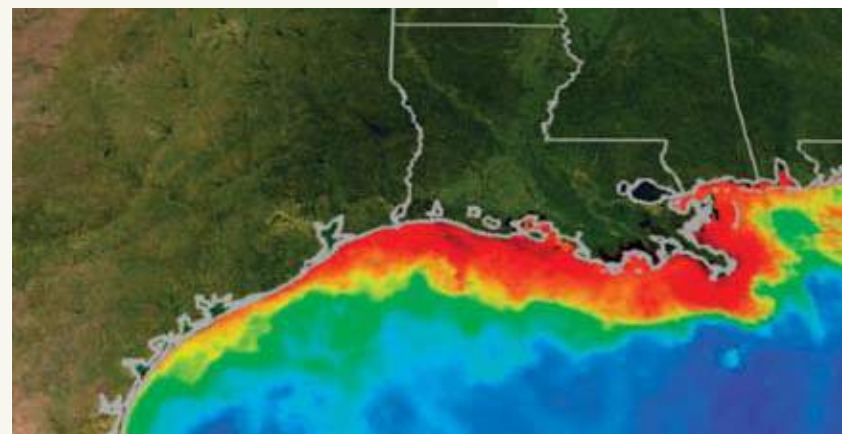
In spring and summer, oxygen levels in the Gulf of Mexico have become so low in a large area off the coast of Louisiana—sometimes spreading as far as the coasts of Texas and Mississippi—that most fish and shellfish cannot survive, creating what is known as a “dead zone.” Fish, shrimp, and crabs often flee, while less mobile bottom-dwellers such as snails, clams, and starfish may die. The phenomenon is attributed to excess nutrients—mostly from fertilizers—that flow down the Mississippi River and empty into the gulf.

Why are excess nutrients bad for marine life? All living things require nutrients containing nitrogen, phosphorus, and trace elements to sustain life. But if too much nitrogen and phosphorus find their way into the ocean, these nutrients fertilize the explosive growth of algae.

In recent summers, a large region of low oxygen water known as a ‘dead zone’ has spread across nearly 5,800 square miles of the Gulf of Mexico from the mouth of the Mississippi River all the way to the Texas coast. This colorized image is generated from NASA summertime satellite observations of ocean color. Reds and oranges represent high concentrations of phytoplankton and river sediment. (Image from NASA/ Goddard Space Flight Center Scientific Visualization Studio)

When these algae sink and die, their decomposition consumes most of the oxygen in the bottom water. Algal blooms not only affect fish, but can contribute to the loss of seagrass bed and coral habitats and to the deterioration of water quality.

Over the past 30 years, scientists, coastal managers, and public policy makers have come to recognize that nutrient pollution is a significant problem for the coastal regions of the United States. There are problem areas on all the coasts and also in freshwater lakes, but they are particularly prominent along the mid-Atlantic coast and the Gulf of Mexico. In addition, the algae in some blooms (e.g., red tides) are harmful, containing toxins







that can contaminate shellfish and kill marine life. A single harmful algal bloom, if it takes place during the wrong season, can cost a region millions of dollars in lost tourism or lost seafood revenues.

### CAUSES OF NUTRIENT POLLUTION ARE COMPLEX AND SITE SPECIFIC

The National Research Council report *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution* (2000) concludes that the key to addressing coastal nutrient problems is to understand that nutrients come from activities in the watersheds that feed coastal streams and rivers. The majority of the nutrient pollution flowing into the sea can be attributed to agriculture, primarily runoff of dissolved nitrogen and phosphorus from fertilizers applied to agricultural fields, golf courses, and lawns. Most of the remainder comes from sewage treatment plant discharges, septic system leaks, industrial discharges, and even deposits from the air of nitrogen released by the combustion of fossil fuels or in vapors from fertilizers or manure.

During the last half of the 20th century, the amount of nitrogen discharged by the Mississippi River has tripled, and phosphorus loads may have increased as well. A 1999 report from the National Oceanic and Atmo-

spheric Administration (NOAA) concluded that, left unabated, nutrient pollution could impair two out of three estuaries examined in the study by 2020. *Clean Coastal Waters* calls for a national strategy to combat nutrient pollution, with involvement from the local to the federal level.

Unfortunately, there are no easy-to-use and reliable methods to determine the sources of nutrients flowing into coastal waters. Direct sampling is costly and time-consuming. Resource managers often turn to 'proxies' to estimate nutrient inputs. For example, land-use data provide information about agriculture, industrial activities, and housing developments that influence trends in nitrogen and phosphorus inputs from runoff. Population data can be used as an indicator of the amount of nitrogen in the atmosphere from fossil fuel combustion.

### IMPACTS OF HARMFUL ALGAL BLOOM IN CAPE COD

In 2005, shellfish beds in the Massachusetts Bay and Cape Cod Bay areas were shut down for weeks as a result of an intense bloom of toxic algae *Alexandrium* (also known as red tide). Usually, ocean currents and winds keep the algae blooms from coming too close to the coastline, but that year, a high occurrence of winds blowing from the ocean back onto land moved the bloom toward the coast. Luckily, scientists discovered the bloom in time to prevent people from harvesting and eating shellfish that contained toxins. A number of factors contributed to this massive bloom including increased stormwater runoff from heavy spring rains that carried nutrients into the bays.



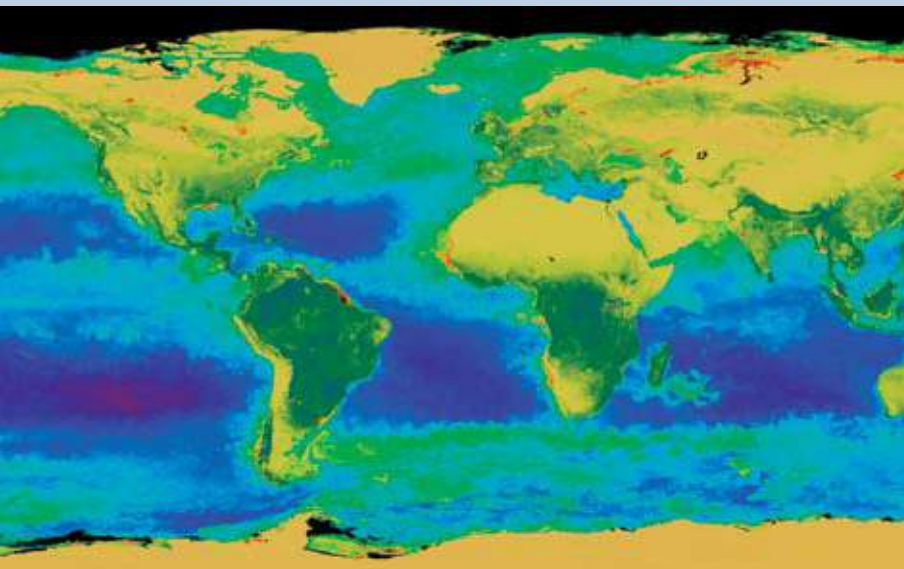
Photo Source: USDA's Natural Resources Conservation Services

## USING SATELLITES TO HELP MONITOR HARMFUL ALGAL BLOOMS

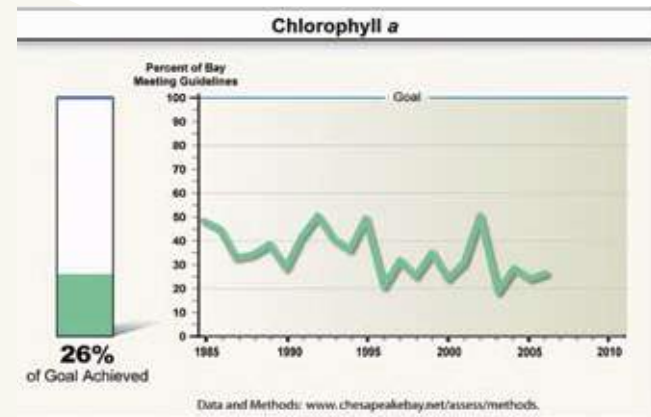
NASA's SeaStar spacecraft, launched in 1997, carries an instrument called the Sea-viewing Wide Field-of-View Sensor or "SeaWiFS." SeaWiFS measures ocean color, which can help scientists identify harmful algal blooms and other high concentrations of material on the sea's surface. Ocean color observations made from Earth's orbit provide a viewpoint impossible from ship or shore.

Data from SeaWiFS have been incorporated into the EPA's Advanced Monitoring Initiative program, conducted in partnership with NOAA and the Naval Research Laboratory to give early warning of harmful algal blooms. The pilot program located a bloom in the Gulf of Mexico of the potentially harmful alga *Karenia brevis* by detecting the marine plant's optical signature. The program demonstrated that data from SeaWiFS can be integrated into a successful operational effort, by helping states to identify potential trouble spots and redirect monitoring and management efforts accordingly.

Following three years of continual data collected by the SeaWiFS, NASA produced this image of the amount of chlorophyll present in the oceans, and the amount of vegetation on land. Purple and blue represent low levels of chlorophyll, while green, yellow, and red indicate progressively higher concentrations. On land, brown pixels show areas of little vegetation, while blue-green represents dense.



Measuring the concentrations of nutrients alone is not sufficient to understand the causes of nutrient pollution in a given water body. Whereas added phosphorus is usually the cause of eutrophication in freshwater lakes, additional nitrogen is in the culprit in most coastal marine ecosystems. The reason for the difference is that algal growth is limited by the nutrient that is in the shortest supply, referred to as the "limiting nutrient." In marine environments, algal growth is usually held in check because nitrogen is in limited supply relative to the other essential nutrients in the water. When additional nitrogen inputs enter these marine environments—for instance, when heavy winter and spring precipitation wash fertilizers and other nitrogen-containing compounds to the coast—algal blooms can occur.



Scientists use several measures to assess the health of the Chesapeake Bay. Measures of chlorophyll concentration are used to monitor algal growth, an indicator of nutrient over-enrichment. Throughout the summer of 2006, scientists estimated that only about 26 percent of the Bay's waters had chlorophyll concentrations that met goal levels. About 37 percent of the Bay had dissolved oxygen levels necessary to protect resident aquatic life. Only 7 percent of the Bay's waters had acceptable water clarity—a result of both algal growth and suspended sediments from rivers or those stirred up by storms. Large-scale reductions in the amount of nutrients flowing into the Bay would, over time, improve these measures. (Figures courtesy Chesapeake Bay Program)

Furthermore, not all coastal areas respond to increased nutrients in the same way. For example, although nitrogen concentrations tend to be higher in much of the Delaware Bay than in the Chesapeake Bay, the former has relatively fewer problems with algal blooms, probably because the water is more turbid and dark, which limits light and inhibits algal growth even when excess nutrients are present.

### INPUT REDUCTION AND EFFECTIVE MONITORING ARE KEY TO FIGHTING NUTRIENT POLLUTION

Although much progress has been made in the United States in controlling *point sources* of pollution—that coming from distinct points such as sewage or industrial pipelines—it is the *nonpoint sources*, which include urban runoff, agricultural runoff, and atmospheric deposition, that are of current concern. Although sewage inputs are the dominant problem in a few coastal areas, nonpoint source pollution causes the most damage nationally.

Central to the recommendations in *Clean Coastal Waters* is that a national strategy should set reasonable goals for improvement and expand monitoring of coastal waters to make sure goals are being met. Long-term monitoring and assessment programs help managers to (1) establish what the “baseline” nutrient levels should be; (2) determine where nutrient over-enrichment is most acute; and (3) measure whether or not actions to reduce nutrient run-off have been effective. The report recommends that a national assessment survey be conducted every 10 years to determine the extent of nutrient problems and the effectiveness of efforts to combat them.

Nutrient inputs can be reduced by improvements in agricultural practices, reductions in atmospheric sources of nitrogen, and improved treatment of municipal wastewater, among other means. Other promising strategies include the creation of regional stormwater control facilities, use of wetlands as nutrient sinks (absorbers), and biological treatment. Many of these actions are best addressed at the local level, but a truly national strategy must challenge federal, state, and local agencies to work together, and to create partnerships with academic and research institutions.

### SUCCESS IN TAMPA BAY

By focusing on source reductions, nutrient pollutants and their adverse effects can sometimes be reversed. In Tampa Bay, Florida, nitrogen loads from high population growth and industrial developments in the 1960s and 1970s resulted in rapid algal growth and a depletion of native seagrass populations. By 1972, 72 percent of the seagrass populations had been lost compared to earlier estimates. Strategies that began in 1980 to reduce nutrients were effective in reducing nitrogen inputs from sewage treatment plants by 50 percent. Within five years, algal concentrations in Tampa Bay began to decrease and the seagrass populations slowly began to return. In more recent years, the increased fossil fuel combustion from increased population in Florida has been contributing nitrogen from the atmosphere, again threatening water quality.





## INDUSTRIAL CONTAMINANTS

Sediments contaminated with pollutants are widespread in U.S. coastal waters. Industrial, agricultural, household cleaning, gardening, and automotive products and wastes regularly end up in coastal waters. Industries that are located in or upstream of urban ports discharge wastes directly into waterways. Dense populations contribute contaminants through sewage discharges, automobile emissions, and other waste generating activities. Stormwater runoff also carries contaminants from distant sources.

For many years, U.S. power companies and the electrical industry used compounds known as polychlorinated biphenyls (PCBs) to insulate electrical transformers and other equipment. PCBs were also used as fluids in industrial equipment in many manufacturing sectors. By the 1970s, it was recognized that PCBs were toxic to wildlife and humans, causing damage to the reproductive, neurological, and immune systems at high exposures. As a result, PCBs were banned in the late 1970s. Nevertheless, these compounds still persist in the environment

because they break down very slowly. Ongoing cleanup efforts have cost millions of dollars.

Contaminants can reach the ocean through atmospheric deposition. For example, mercury is released into the air when large quantities of coal and other fuels containing trace amounts of the element are burned, from the incineration of mercury-containing medical wastes, and from other human-induced sources. Ultimately, that mercury rains down into lakes, rivers, and the ocean. Once deposited in sediments, mercury may be con-





Burning fossil fuels releases mercury and other contaminants into the atmosphere. These contaminants eventually settle in bodies of water, where they are taken up by marine life. Consequently, they pose a risk both to marine ecosystems and human health.

verted by aquatic organisms into methylmercury, a more toxic form of the element.

Many contaminants stay in the environment for a long time and become more concentrated through the food chain. Among the most troubling contaminants are heavy metals, such as mercury and cadmium, and “persistent organic pollutants,” such as PCBs, dioxin, and DDT, which remain in the marine sediment for a long time. Marine life takes up such contaminants from polluted sediments. Because these contaminants are much more soluble in fat than water, they are excreted slowly

and build up in the tissues of fish and shellfish. They also accumulate in the tissues of people who eat contaminated fish.

Progress has been slow in reversing PCB contamination in the thirty years since they were banned. Physical removal of PCB-contaminated sediments by dredging or other methods has had limited success. Likewise, even though atmospheric levels of mercury have dropped from their peak levels in the 1980—thanks to regulatory actions including mandated mercury controls on coal power plants and more strict management of mercury wastes—mercury levels in fish remain high in many areas.

### **NUTRITIOUS BENEFITS OF SEAFOOD ARE JEOPARDIZED BY CONCERNS ABOUT MERCURY**

Fish and shellfish are excellent sources of protein and omega-3 fatty acids that offer a number of health benefits. However, eating fish may expose people to various contaminants, including methylmercury, which can be harmful to a person’s health if they are highly concentrated. Consumers are thus faced with the dilemma: choosing between the health benefits and possible risks from eating fish.

Weighing the risks and benefits of eating seafood can be confusing. Contaminants such as methylmercury have been found in some types of fish, and this presents a potential health risk. But eating seafood also has many demonstrated health benefits.



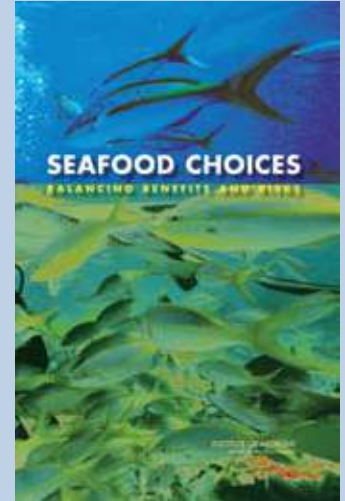
Exposure to methylmercury varies according to the kind of fish consumed and the region where the fish originate. Because methylmercury accumulates up the food web, higher concentrations are found in large fish (tuna and swordfish, for example) that are at higher levels on the food chain. Freshwater fish, including bass, walleye, and pickerel from sources in the United States can also contain significant concentrations of mercury as a result of airborne contamination.

The vast majority of Americans are not exposed to unsafe levels of methylmercury, but pregnant women who consume large amounts of predatory fish (e.g., swordfish, shark, tilefish, and king mackerel) may expose their developing fetuses to it. Prenatal exposures that exceed the established safe “reference dose” can cause an IQ deficit; abnormal muscle tone; or impaired motor function, attention, and visuospatial performance in the child.

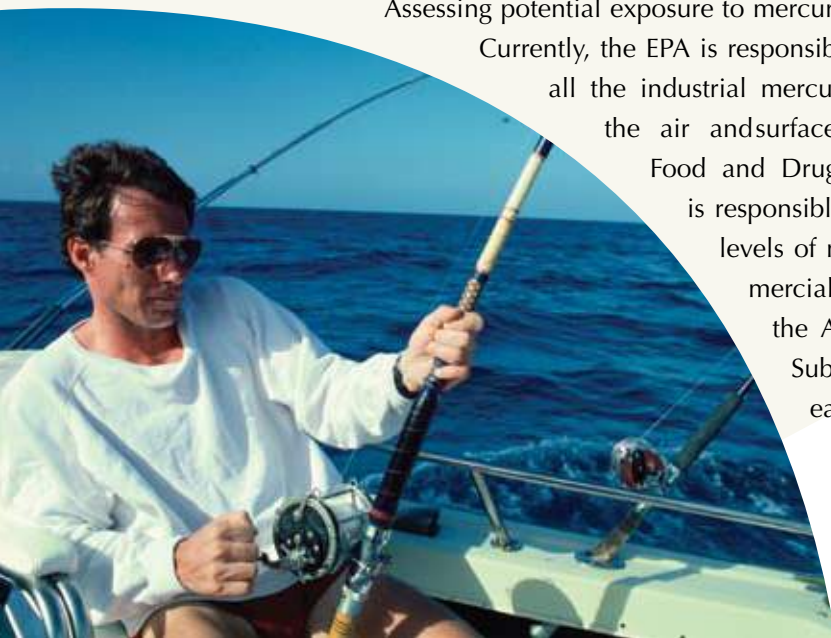
Assessing potential exposure to mercury is a challenge. Currently, the EPA is responsible for regulating all the industrial mercury released into the air and surface water; the U.S. Food and Drug Administration is responsible for monitoring levels of mercury in commercially sold fish; and the Agency for Toxic Substances and Disease Registry eval-

## HOW MUCH FISH IS SAFE TO EAT?

The Institute of Medicine report *Seafood Choices: Balancing Benefits and Risks* (2006) concludes that seafood can be part of a healthy diet, particularly because it could replace other protein sources that are higher in saturated fat, such as beef or pork. Healthy adults and those already at risk for cardiovascular disease may reduce their risk by eating fish high in omega-3 fatty acids, but they should select from a variety of seafood to avoid the risk of exposure to contaminants from a single source. Pregnant women and young children can safely consume up to 2 age-appropriate servings (no more than 12 ounces total) of fish weekly and up to 6 ounces of albacore tuna weekly. However, they should avoid eating such predatory fish as swordfish, shark, tilefish, and king mackerel.



uates the potential risk of methylmercury to humans. All three agencies have used different risk assessment methods, data sets, uncertainty factors and guidelines to assess exposure to toxicants. The National Research Council report *Toxicological Effects of Methylmercury* (2000) identifies the most appropriate studies and approaches to assess the risk of methylmercury. It also recommends conducting an exposure assessment of the U.S. population to provide a more cohesive picture of the distribution of methylmercury nationally and regionally.



## ADVANCES IN SCIENCE AND TECHNOLOGY ARE NEEDED FOR THE MANAGEMENT OF CONTAMINATED SEDIMENTS

Approximately 14 to 28 million cubic yards of contaminated sediments must be managed annually in the United States (one million cubic yards is roughly equivalent to 200 football fields stacked one yard high). Progress in science and engineering has advanced the nation's ability to detect contaminants; the challenge now, however, is to foster similar advances in decision-making and clean-up strategies.

Dredging is one of the few options available for cleaning up contaminated sediments. However, the National Research Council report *Sediment Dredging at Superfund Megsites: Assessing the Effectiveness* (2007) concludes that, based on available evidence, dredging's ability to decrease environmental and health risks is still an open question. Such technical difficulties as underwater obstacles can prevent dredging equipment from accessing sediments, and dredging can uncover and re-suspend buried contaminants, adding to the amount of pollution people and animals are exposed to, at least in the short term. The report recommends that the EPA step up monitoring activities before, during and after cleanups to determine their effectiveness.

Controversies over the risks and costs of sediment management interfere with the need for regular dredging, maintenance, and construction in U.S. ports, which

support approximately 95 percent of U.S. foreign trade. Those controversies also hamper or sometimes completely halt clean-up plans at hundreds of contaminated marine sites. The National Research Council report *Contaminated Sediments in Ports and Waterways: Clean-up Strategies and Technologies* (1997) identifies a process for helping decision makers assess the trade-offs among the risks, costs, and benefits of dredging. The report urges that these trade-offs be presented to the public in an accessible format.

Dredging is one of the few options available for cleaning marine sediments, but its effectiveness in reducing environmental and health risks is still an open question. (Image from Dalton, Olmsted and Fluglevand, Inc.)





## NOISE

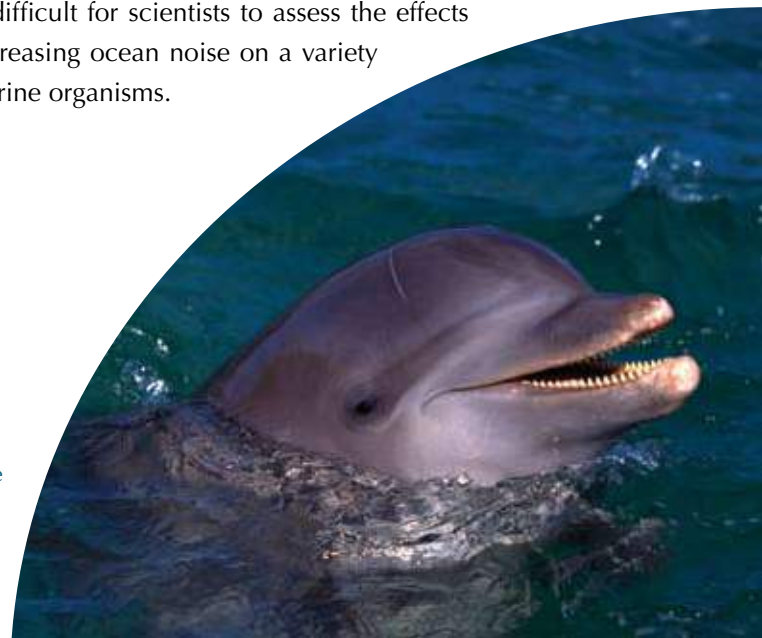
In one well documented incident in March 2000, whales suffered traumatic injuries and stranded themselves in the Bahamas after naval sonar was used nearby. Fourteen beaked whales and two minke whales became stranded during this event. Six of the beaked whales died. The U.S. Navy and the National Marine Fisheries Service (NMFS) reported that the extended use of their mid-range sonar likely initiated a sequence of events that culminated in internal bleeding. Autopsies revealed bleeding in the inner ears of three of the beached whales and around the brain of a fourth. It is not known how exposure to sonar resulted in internal bleeding.

For the 119 species of marine mammals, as well as for some other aquatic animals, sound is the primary means of sensing the environment and is used for communicating, navigating, and foraging. The ocean environment has always included an abundance of natural noises, such as the sounds generated by rain, waves, earthquakes, and other animals. However, a growing number of ships, oil exploration activities, and military and civilian use of sonar, are adding noise to the ambient sounds in the oceanic environment.

### **NOT ENOUGH IS KNOWN ABOUT NOISE IN THE OCEAN AND ITS EFFECTS ON MARINE MAMMALS**

Although the whales that were stranded present a tangible and potentially alarming picture of the potential effects of high-energy mid-frequency sonar, observations of the effects of most kinds of ocean noise on marine mammals and other aquatic organisms are quite limited. Potential effects include changes in hearing sensitivity and behavioral patterns and acoustically induced stress. Most existing data are short-term observations of marine mammal responses to human activity, making it very difficult for scientists to assess the effects of increasing ocean noise on a variety of marine organisms.

Some marine mammals, such as minke whales or bottlenose dolphins, may be harmed by noise pollution in the ocean.





## SIGNIFICANT SOURCES OF HUMAN-GENERATED OCEAN NOISE

**Transportation:** Ships and boats, aircraft, icebreakers, hovercrafts, and vehicles on ice

**Dredging and Construction:** Dredging, tunnel boring, and other operations

**Oil Drilling and Production:** Drilling operations and offshore oil and gas production

**Geophysical Surveys:** Air-guns, sleeve exploders, and gas guns

**Sonars:** Military systems, fish finders, and depth sounders

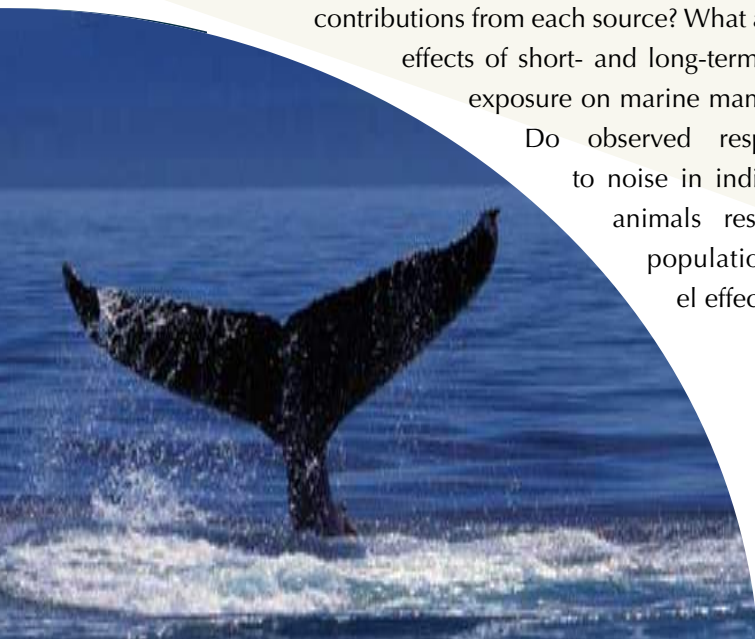
**Ocean Research:** Seismology, acoustic propagation, acoustic tomography, and acoustic thermometry

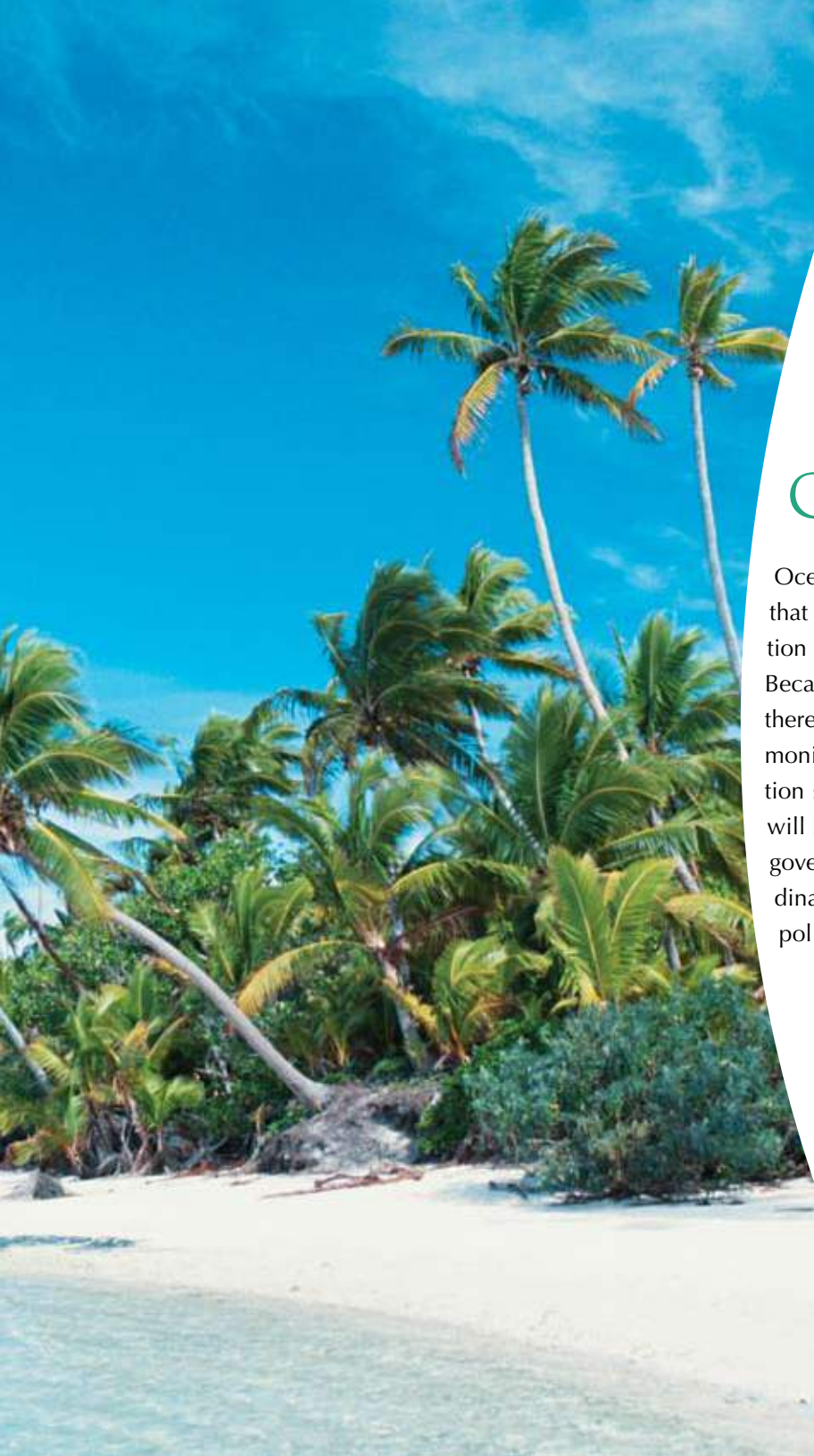
To identify problems that result from noise and to determine whether solutions are working, it is necessary to continually monitor the environment for changes in both ocean noise and marine mammal behavior. The National Research Council report *Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects* (2005) emphasizes the need to establish baseline knowledge and to conduct fundamental research to improve scientific understanding of the effects of noise on marine mammals. A long-term ocean noise-monitoring program over a broad range of frequencies needs to be initiated in coastal areas, marine mammal migration paths, foraging areas, and breeding grounds.

The National Research Council report *Ocean Noise and Marine Mammals* (2003) concludes that the impact of human noise on marine mammals is significant enough to warrant concern. Yet, many fundamental questions remain unanswered. For example, what is the overall level of noise in the ocean and what are the relative contributions from each source? What are the effects of short- and long-term noise exposure on marine mammals?

Do observed responses to noise in individual animals result in population-level effects?

While the number of commercial ships is increasing, newer ships are often quieter, making it difficult to estimate their contribution to ocean noise. (Image from NOAA)





## CONCLUSION

Ocean pollution is a diffuse, complex series of problems that are not easily addressed. Nevertheless, some pollution problems can and have been successfully addressed. Because of the value of science in dealing with pollution, there is a need to devote resources to research, improved monitoring, and the continued development of pollution source-reduction strategies and technologies. Efforts will be made more effective when actions at all levels of government—federal, state, and local—are better coordinated and when communications to the public about pollution sources and impacts are improved.

### About the National Academies

The National Academies—the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and the National Research Council—provide a public service by working outside the framework of government to ensure independent advice on matters of science, technology, and medicine. They enlist committees of the nation’s top scientists, engineers, and other experts—all of whom volunteer their time to study specific concerns. The results of these deliberations are authoritative, peer-reviewed reports that have inspired some of the nation’s most significant efforts to improve the health, education, and welfare of the population.

This booklet was prepared by the National Research Council based on the following reports:

*Sediment Dredging at Superfund Megasites: Assessing the Effectiveness* (2007)

Sponsored by: U.S. Environmental Protection Agency.

*Seafood Choices: Balancing Benefits and Risks* (2006)

Sponsored by: Department of Commerce, U.S. Food and Drug Administration.

*Oil Spill Dispersants: Efficacy and Effects* (2005)

Sponsored by: National Oceanic and Atmospheric Administration, Minerals Management Service, U.S. Coast Guard, American Petroleum Institute.

*Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects* (2005)

Sponsored by: National Oceanographic Partnership Program, National Oceanic and Atmospheric Administration, Office of Naval Research, National Science Foundation, Minerals Management Service.

*Ocean Noise and Marine Mammals* (2003)

Sponsored by: National Oceanographic Partnership Program, Office of Naval Research, National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Geological Survey.

*Oil in the Sea III: Inputs, Fates, and Effects* (2003)

Sponsored by: Minerals Management Service, American Petroleum Institute, Environmental Protection Agency, U.S. Geological Survey, Department of Energy, U.S. Coast Guard, National Ocean Industries Association, U.S. Navy, National Oceanic and Atmospheric Administration.

*Toxicological Effects of Methylmercury* (2000)

Sponsored by: U.S. Environmental Protection Agency.

*Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution* (2000)

Sponsored by: National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, U.S. Geological Survey, Electric Power Research Institute.

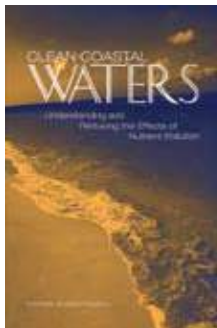
*Contaminated Sediments in Ports and Waterways: Clean-up Strategies and Technologies* (1997)

Sponsored by: Maritime Administration of the U.S. Department of Transportation.

These and other reports are available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242; <http://www.nap.edu>. Reports are available online in a fully searchable format.

For more information, contact the Ocean Studies Board at 202-334-2714 or visit <http://dels.nas.edu/osb>.

Copyright 2007 by the National Academy of Sciences.



In one way or another, every landform and creature on Earth reflects the presence of the oceans. Understanding the Earth's oceans is essential to our understanding of human history, the origin of life, weather and climate, medicines, the health of the environment, energy sources, and much more. Reports from the National Academies provide in-depth analysis and useful advice for policymakers and the general public on topics ranging from exploring the ocean's incredible biodiversity and resources to reducing threats to human safety from toxic algal blooms, contaminants, and coastal storms. This series is intended to help readers interpret information about the state of our oceans and better understand the role of ocean science.

Other booklets in this series include *Ocean Exploration*, *Marine Ecosystems and Fisheries*, *Coastal Hazards*, and *Oceans and Human Health*.

## **THE NATIONAL ACADEMIES**

*Advisors to the Nation on Science, Engineering, and Medicine*

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.

[www.national-academies.org](http://www.national-academies.org)