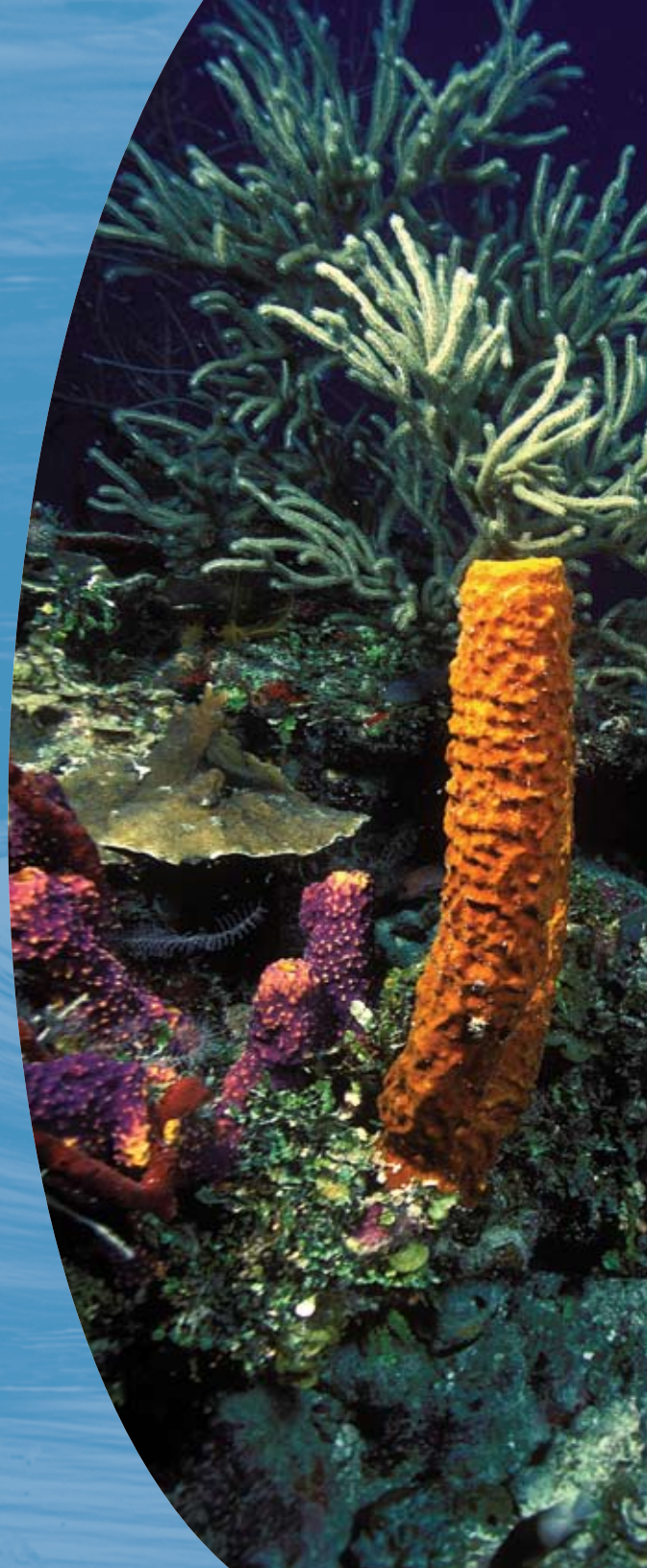
OCEAN SCIENCE SERIES

OCEANS AND HUMAN HEALTH

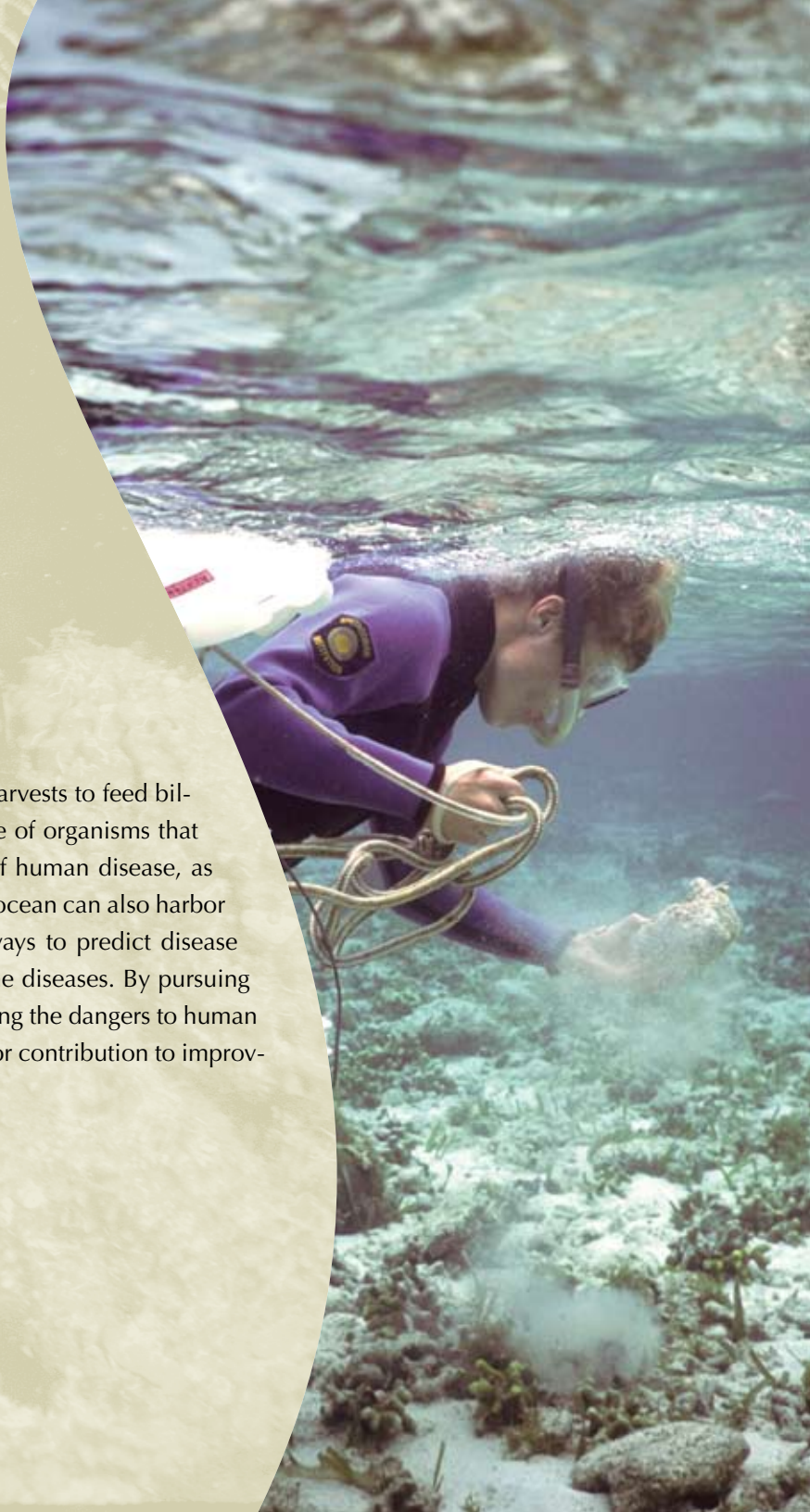
Highlights of National Academies Reports



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

SOCIETIES RELY HEAVILY ON THE OCEAN

for many of their needs, not the least of which is providing rich harvests to feed billions of people on Earth each day. The ocean is also a key source of organisms that are beginning to yield new and potent drugs for the treatment of human disease, as well as new products for use in biotechnology. Unfortunately, the ocean can also harbor disease-causing agents. Ocean research offers promising new ways to predict disease outbreaks and to help reduce the risks associated with waterborne diseases. By pursuing the medical promises hidden within the ocean, while also managing the dangers to human health found in this new frontier, ocean scientists can make a major contribution to improving human health in the twenty-first century and beyond.



EXPLORING THE PROMISES OF OCEAN SCIENCE

The ocean benefits human health and well-being in immeasurable ways. The nutritional benefits of eating fish, rich in protein and omega-3 fatty acids, make the ocean an indispensable—but not unlimited—source of healthy food. Ocean science is revealing many other ways the ocean can benefit human health, from providing new sources of drugs to helping unravel many of the mysteries of human disease.

THE OCEAN IS THE MOST PROMISING FRONTIER FOR SOURCES OF NEW DRUGS

In 1945, a young organic chemist named Werner Bergmann set out to explore the waters off the coast of southern Florida. Among the marine organisms he scooped from the sand that day was a Caribbean sponge that would later be called *Cryptotethya crypta*. Back in his lab, Bergmann extracted a novel compound from this sponge that aroused his curiosity.

The chemical Bergmann identified in this sponge, spongothymidine, eventually led to the development of a whole class of drugs that treat cancer and viral diseases and are still in use today. For example, Zidovudine (AZT) fights the AIDS virus, HIV, and cytosine arabinoside (Ara-C) is used in the treatment of leukemias and lymphomas. Acyclovir speeds the healing of eczema and some herpes viruses. These are just a few examples of how the study of marine organisms contributes to the health of thousands of men, women, and children around the world.

New antibiotics, in addition to new drugs for fighting cancer, inflammatory diseases, and neurodegenerative diseases (which often cannot be treated successfully today), are greatly needed. With drug resistance nibbling away at the once-full toolbox of antibiotics, the limited effectiveness of currently available drugs has dire consequences for public health.

Compounds with medical potential have been found in several species of marine sponges, such as this bright orange sponge. (Image from Harbor Branch Oceanographic Institution, Fort Pierce, Florida)

Historically, many medicines have come from nature—mostly from land-based natural organisms. Because scientists have nearly exhausted the supply of terrestrial plants, animals, and microorganisms that have interesting medical properties, new sources of drugs are needed.

Occupying more than 70 percent of the Earth's surface, the ocean is a virtually unexplored treasure chest of new and unidentified species—one of the last frontiers for sources of new natural products. These natural products are of special interest because of the dazzling diversity and uniqueness of the creatures that make the sea their home.

One reason marine organisms are so interesting to scientists is because in adapting to the various ocean environments, they have evolved fascinating repertoires of unique chemicals to help them survive. For example, anchored to the seafloor, a sponge that protects itself from an animal trying to take over its space by killing the invader has been compared with the human immune system trying to kill foreign cancer cells. That same sponge, bathed in seawater containing millions of bacteria, viruses, and fungi, some of which could be pathogens, has developed antibiotics to keep those pathogens under control. Those same antibiotics could be used to treat infections in humans.

Sponges, in fact, are among the most prolific sources of diverse chemical compounds. An estimated 30 percent of all potential marine-derived medications currently in the pipeline—and about 75 percent of recently patented marine-derived anticancer compounds—come from marine sponges.

Marine-based microorganisms are another particularly rich source of new medicines. More than 120 drugs available today derive from land-based microbes. Scientists see marine-based microbes as the most promising source of novel medicines from the sea. In all, more than

A cone snail uses its powerful venom to kill a fish. Prialt, an effective medication for managing chronic pain in AIDS and cancer patients, was derived from the venom produced by this type of snail. (Image from Kerry Matz, University of Utah, Salt Lake City)

20,000 biochemical compounds have been isolated from sea creatures since the 1980s.

Because drug discovery in the marine frontier is a relatively young field, only a few marine-derived drugs are in use today. Many others are in the pipeline. One example is Prialt, a drug developed from the venom of a fish-killing cone snail. The cone snails produce neurotoxins to paralyze and kill prey; those neurotoxins are being developed as neuromuscular blocks for individuals with chronic pain, stroke, or epilepsy. Other marine-derived drugs are being tested against herpes, asthma, and breast cancer.

The National Research Council report *Marine Biotechnology in the Twenty-First Century* (2002) concluded that the exploration of unique habitats, such as deep-sea environments, and the isolation and culture of marine microorganisms offer two underexplored opportunities for discovery of novel chemicals with therapeutic potential. The successes to date, which are based upon a very limited investigation of both deep-sea organisms and marine microorganisms, suggest a high potential for continued discovery of new drugs.

The Hawaiian bobtail squid has a unique mutually beneficial (symbiotic) relationship with the bioluminescent bacterium *Vibrio fischeri*. (Image from M. J. McFall-Ngai and E. G. Ruby, University of Hawaii; National Science Foundation)

MARINE ORGANISMS PROVIDE MODELS FOR UNDERSTANDING HUMAN BIOLOGY

Among the most fascinating aspects of ocean science is the use of marine creatures as models for unraveling the mysteries of basic biochemical and physiological processes.

Scientists have made many remarkable discoveries by studying marine life. For example, the big purple slug offers researchers clues about learning and memory. The toadfish teaches lessons about balance and equilibrium. The spiny dogfish shark and the horseshoe crab provide a glimpse of the mechanics of vision.

Study of such animals as sea stars, sharks, and sea squirts has enormously enhanced our understanding of how the human body fights diseases. Likewise, studying sea ur-

BIOLUMINESCENT BACTERIA FROM THE SEA SHED LIGHT ON SOME HUMAN DISEASES

The mysteries of nature are typically unraveled through detailed investigations designed to answer a specific question. Sometimes, however, amazing revelations come about unexpectedly. Such is the story behind an intriguing bioluminescent bacterium named *Vibrio fischeri*.

Vibrio fischeri enjoys an exquisite, mutually beneficial (symbiotic) relationship with the Hawaiian bobtail squid as well as other marine animals. By producing light, the bacterium helps its host lure prey, scare enemies, or attract mates. In return, the host provides the symbiotic bacteria with nutrients.

Vibrio fischeri helped scientists unravel the phenomenon of "quorum sensing," which has ultimately led to a remarkable new strategy for combating bacterial infections. Quorum sensing describes the phenomenon of how bacteria count, or sense, the abundance of fellow bacteria. In the case of *Vibrio fischeri*, the bacterium will only emit light when they are dense enough to make a difference in providing light for the host squid. When a quorum of *Vibrio fischeri* is reached, they signal each other to manufacture the enzyme that makes them glow in the dark.

Unfortunately, quorum sensing in other types of bacteria are also responsible for many of the diseases that plague humankind. They cause cholera and food poisoning, and infiltrate the lungs of children with cystic fibrosis. When disease-causing bacteria reach a quorum they form slimy, adhesive biofilms and produce toxins, repelling immune responses and making people sick.

Along with an understanding of how quorum sensing bacteria make people sick, however, comes new insight on how to treat bacterial infections. Researchers have developed an entirely new class of antibiotics that can disrupt the signaling system of microbial communities or disperse biofilms after they form. Best of all, because these drugs do not directly kill the bacteria, the bacteria may be less likely to develop resistance.

These and other studies at the forefront of drug discovery for the twenty-first century had their genesis in a microbial phenomenon discovered serendipitously through the study of marine organisms. Just think: What other surprises might come from the sea?

chins has revolutionized understanding of how cells divide, which is paving the way for exciting new research into the diagnosis and treatment of cancer.

These are just a few of the marine organisms that have had a powerful influence on medical research. Using marine animals as models of human physiological processes is helping researchers better understand and treat a wide array of diseases and offer the potential to decipher many more.

MARINE PRODUCTS ARE BEING USED AS RESEARCH TOOLS AND IN INDUSTRY

Another crucial application of marine products is their use as research tools. Some marine products, for example, allow scientists to "see" inside a cell by means of proteins that glow in the dark. In the laboratory, these fluorescent proteins help researchers track biochemical processes and understand disease. Aequorin, a bioluminescent compound found in some jellyfish, was used to illuminate the calcium activation wave that occurs when a sea urchin egg is fertilized. Fluorescent marine compounds, such as the green fluorescent protein found in squid, are widely used in biomedical research to diagnose diseases, to study cellular processes essential to cancer research and to monitor genetic modification of organisms. Such fluorescent proteins can illuminate processes that would otherwise require complex biochemical measurements in order to be observed.

In addition to their value as research tools, a number of marine-derived products are already in use in agriculture, in industry, in cosmetics, and even in nutritional supplements. For example, organic fertilizers made

Aequorin is a bioluminescent compound found in some jellyfish. Scientists can use this compound to illuminate biological processes. (Image from Dr. Osamu Shimomura, Marine Biological Laboratory, Woods Hole, Massachusetts)

THE SURPRISING SQUID

One of the biggest surprises in using animal models has come from the nerve cells of the squid. This animal's nerves are so enormous—an estimated 1,000 times larger than those of vertebrates—they were not immediately recognized as nerves. Because of their incredible size, scientists can easily insert electrodes directly into the nerve cells, allowing them to study the cells' electrical properties. These studies have opened the door to many medical breakthroughs in diagnosing and treating nerve disorders.

Photograph from NOAA

This marine organism, *Pseudopterogorgia elisabethae*, is the source of potent anti-inflammatory compounds. (Image from William Fenical, Scripps Institution of Oceanography, San Diego, California)

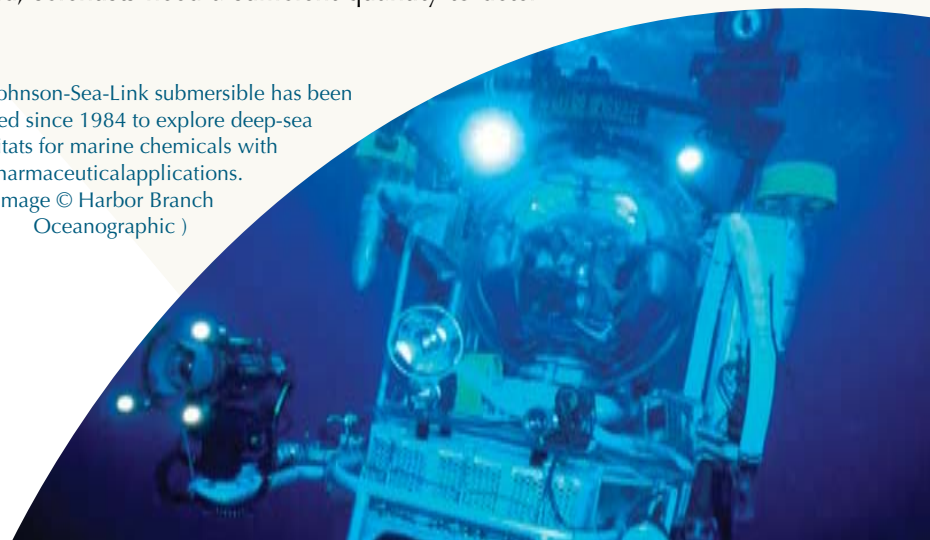
from seaweed extract and fish emulsion serve a role in sustainable agriculture, while an exceptional adhesive made by the common blue mussel *Mytilus edulis* improves the adherence of paint. An anti-inflammatory chemical from the sea fan is used in Estée Lauder's skin care product Resilience. A compound called docosahexaenoic acid (DHA)—a fatty acid essential for proper mental and visual function—was discovered in a marine microalga, *Cryptocodinium cohnii*. This compound currently is marketed as a nutritional supplement in baby formula in more than 60 countries around the world.

Because marine organisms have evolved a variety of unique chemicals that are not found among land creatures, the sea presents a rich source of tools for improving our understanding, not only of ocean environments, but also of human health and well-being.

SCIENTISTS FACE CHALLENGES IN EXPLORING UNIQUE OCEAN HABITATS

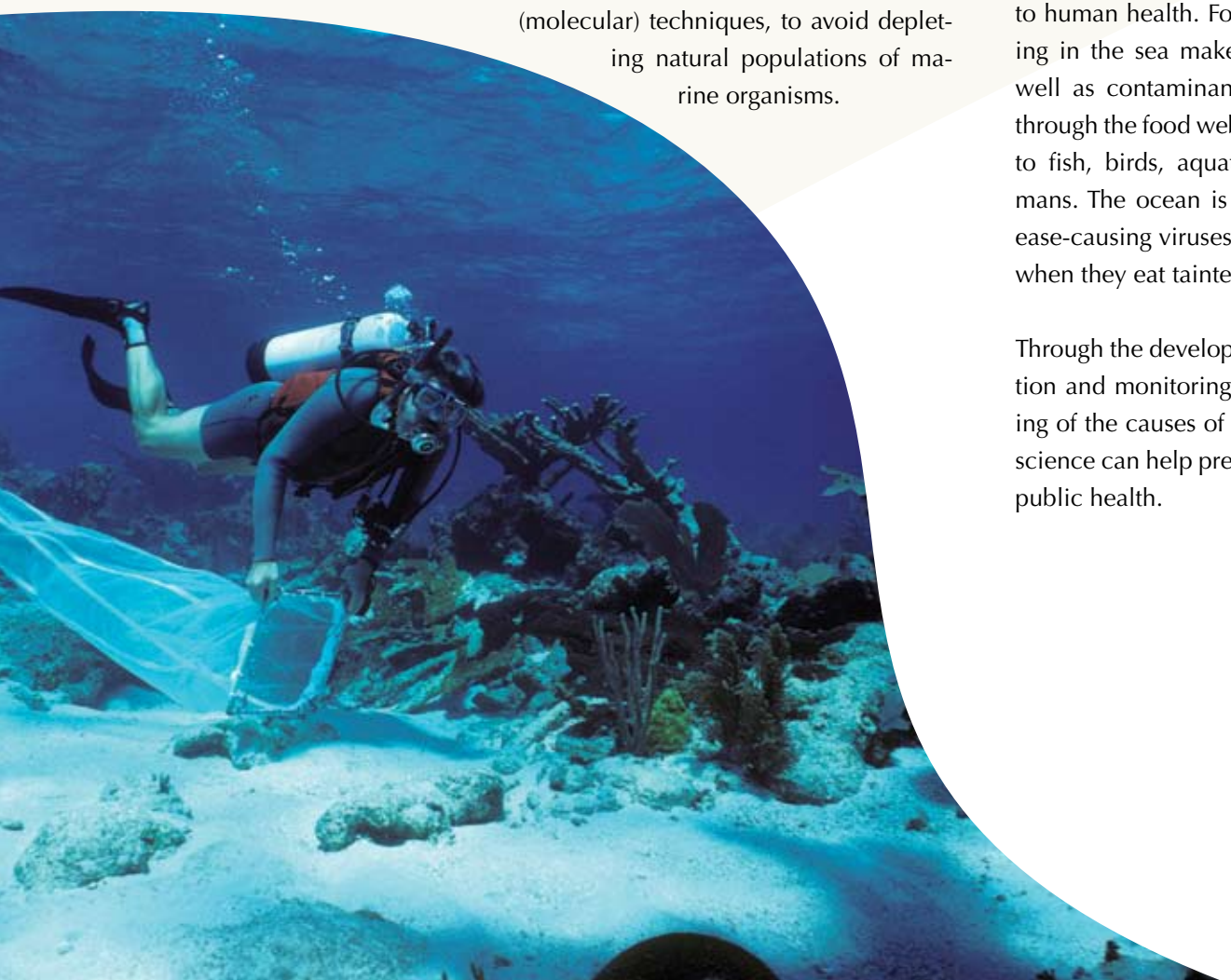
The ocean is the most promising source of new drugs, yet there are multiple challenges in marine exploration. At the heart of the challenges to ocean science lies the problem of the rights of a country to its genetic resources, in general, and the intellectual property rights of commercially promising discoveries, in particular. Complex legal and political issues involved with collecting marine resources in the territorial waters of other countries can present a major obstacle for researchers.

Another challenge that researchers face is obtaining a sufficient quantity of new marine-derived chemicals. On one hand, scientists need a sufficient quantity to deter-



The Johnson-Sea-Link submersible has been used since 1984 to explore deep-sea habitats for marine chemicals with pharmaceuticalapplications. (Image © Harbor Branch Oceanographic)

mine whether a new chemical has medical potential. On the other hand, protecting marine natural resources is essential. Exploitation of marine plants, animals, and microorganisms must be avoided to ensure that marine ecosystems and populations are not adversely impacted. The National Research Council report *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health* (1999) recommends that scientists pursue new ways to produce marine chemicals in a sustainable manner, such as aquaculture, cell culture, and recombinant (molecular) techniques, to avoid depleting natural populations of marine organisms.



FIGHTING OCEAN-RELATED THREATS TO HUMAN HEALTH

Unfortunately, the ocean harbors dangerous toxins and disease-causing agents that can present serious threats to human health. For example, some types of algae living in the sea make toxic chemicals. These toxins, as well as contaminants such as mercury, can move up through the food web, transferring dangerous substances to fish, birds, aquatic mammals, and, ultimately, humans. The ocean is also home to several types of disease-causing viruses and bacteria that make people sick when they eat tainted seafood.

Through the development of more effective threat detection and monitoring systems and a deeper understanding of the causes of ocean-related health threats, ocean science can help prevent disease outbreaks and improve public health.

(Right) In this satellite image, bloom of the toxic alga *Karenia brevis* is visible along the west coast of Florida. (Image from Jacques Descloitres, NASA)

THE THREAT OF HARMFUL ALGAL BLOOMS

Microscopic marine algae called phytoplankton serve a similar role in the sea as do plants on land. Through photosynthesis, these tiny organisms create the foodstuffs that form the base of marine food webs. Some species, however, produce substances that are toxic to humans. Algal toxins can interfere with neural processes, causing paralysis, amnesia, nausea, diarrhea, and respiratory distress, depending on the specific toxin produced. Most of these effects are not permanent, but the effects of some toxins may persist for years, and severe cases may be deadly.

Harmful algal bloom (HAB) events have spread to all regions of America's coastline. (Image from NOAA COP/National HAB Office-WHO1)

In addition to producing toxins, phytoplankton can multiply, or "bloom," in such enormous numbers that when they die, the decay processes deplete the water of oxygen, causing fish and other sea creatures to flee or perish. Harmful algal blooms—also known as red tides—may present a serious threat to the health of humans and marine ecosystems alike.

Algal toxins persist even when seafood is thoroughly cooked. According to the Centers for Disease Control and Prevention (CDC), marine toxins are tasteless and odorless, and, unlike pathogenic bacteria and viruses, they are usually not destroyed by cooking. To date, no antidotes to algal toxics are available.

Surprisingly, some toxic algae, such as *Karenia brevis*, can sicken vacationers on the beach who never even enter the water. Toxins from *K. brevis* can become airborne within tiny droplets of seawater, which can cause asthma-like symptoms when inhaled. This presents a serious public health risk. Affected beaches often must be closed, and, as a result, local economies suffer. Winds may carry airborne toxins inland, possibly affecting the people living in coastal communities. The amount of *K. brevis* toxin necessary to cause severe coughing and sneezing is almost undetectable using current chemical technologies.

THE INCIDENCE AND GEOGRAPHIC SPREAD OF ALGAL BLOOMS IS INCREASING

Harmful algal blooms occur in all of the world's oceans and in all climatic regions. During the past three decades, the recorded incidences of harmful algal blooms have increased significantly. Now, virtually all coastal regions of the United States are subject to this threat.

The frequency of harmful algal blooms is also increasing. *K. brevis*, for instance, repeatedly causes red tides along the coast of Texas and the southwest coast of Florida, delivering a blow to the Gulf Coast economy every year. According to some estimates, this species alone causes economic losses of roughly $50 million per year between human illness and downturns in shellfish, finfish, recreation, and tourism.

From Monsoons to Microbes identifies the need for closer monitoring of algal blooms to help resolve why harmful algae are increasing in frequency and range. Closer monitoring will also allow earlier notification of public health authorities so that they can act to reduce exposure of the public to algal toxins.

DETERMINING THE CAUSES OF HARMFUL ALGAL BLOOMS SHOULD BE A HIGH RESEARCH PRIORITY

Although red tides have received much attention, the conditions that provoke toxic algal blooms remain largely mysterious, and individual blooms may be triggered by different causes. The characterization of the life cy-

Better tracking helps health officials protect the public from exposure to toxic algae. One method of preventing exposure is to temporarily close beaches or fishing areas. (Image from Woods Hole Oceanographic Institution)

A POSITIVE SIDE OF TOXIC ALGAE?

Although harmful algal blooms are a significant threat to human health, their story has a surprising positive side as well. A team of researchers recently discovered that the toxic alga *K. brevis* produces an anti-toxin chemical that can actually blocks the effects of the *K. brevis* toxins on the human respiratory system. Even more astounding, the researchers found that this chemical, called brevenal, helps to break up mucus in the lungs of cystic fibrosis patients. This promising new medical discovery is one positive outcome of research focused on toxic algae.

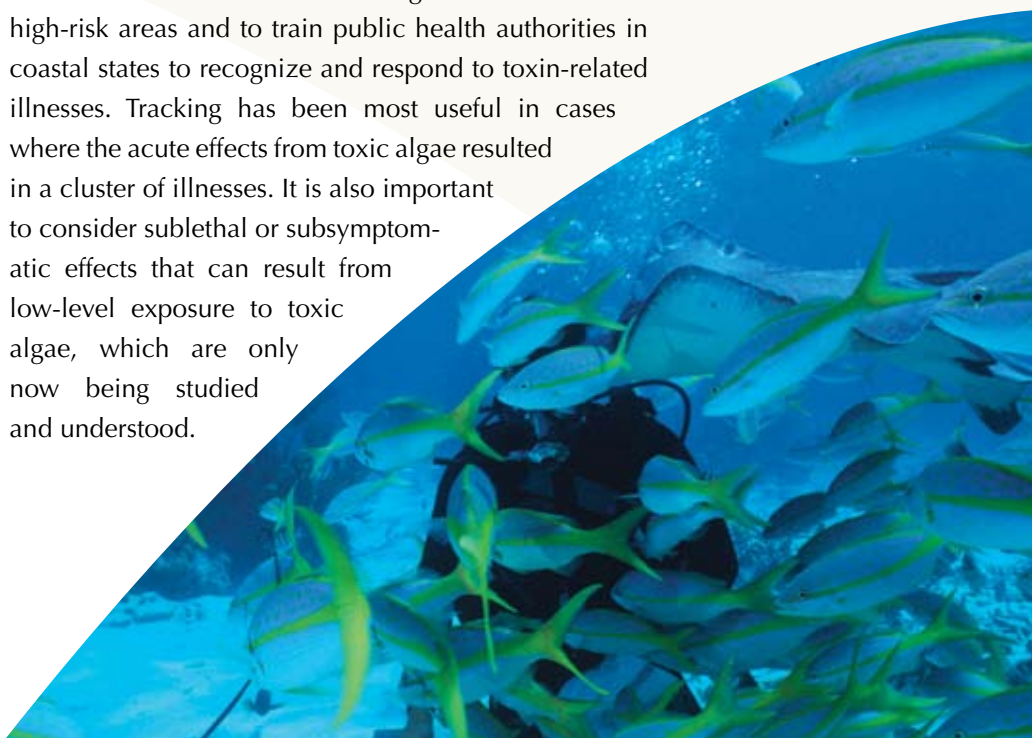
cles of many harmful algal species is critical in allowing scientists to understand the root causes of blooms and to identify ecological controls on bloom dynamics. *From Monsoons to Microbes* concludes that improved methods are needed to identify the toxic algal species that make people sick. There is also a need to determine the physical, chemical, and biological factors that promote algal growth in order to improve the ability to predict, manage, and potentially prevent harmful algal blooms.

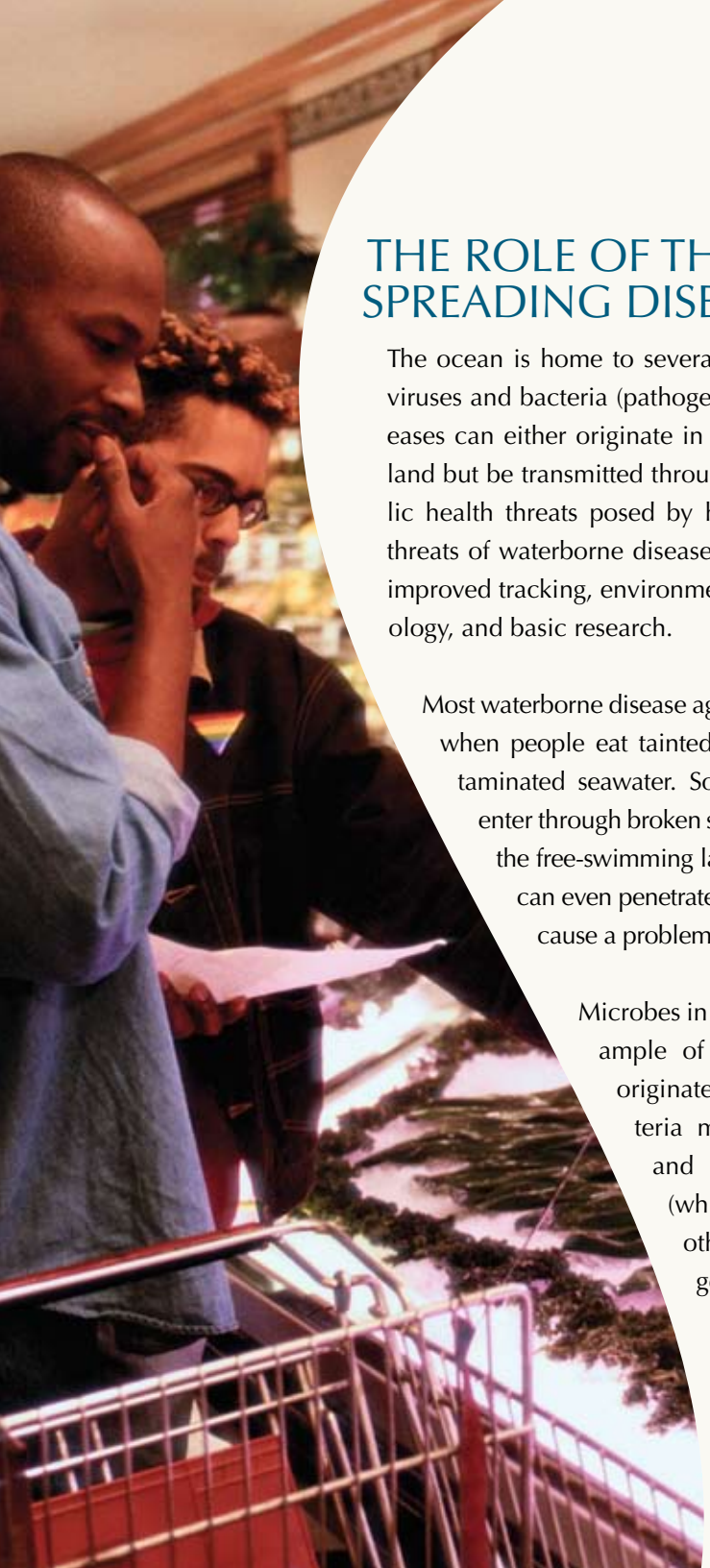
BETTER TRACKING CAN HELP PREVENT HUMAN EXPOSURE TO ALGAL TOXINS

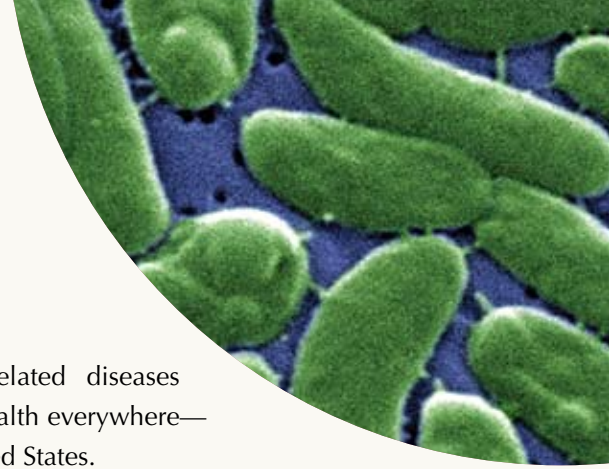
Scientists are now developing exciting new technologies for identifying algal blooms, including ways to spot them from space. Scientists have also been designing a number of promising tools to detect the presence of algal toxins rapidly and to track their route of transfer throughout the environment. Being able to predict when a harmful algal bloom will become dangerous for humans would make health officials better prepared to make management decisions that protect the public from exposure, such as temporary beach and fishing closures.

Epidemiology—the study of the occurrences of diseases in populations—can be used to identify disease "hot spots." By investigating what sick people have in common, scientists can often trace the cause of the problem, such as an algal bloom, and warn the public accordingly. Without such warnings, people can become ill and not know why. In many cases, illnesses related to marine toxins go unreported.

Epidemiological studies also alert the medical community to the presence of harmful algal blooms or other events so they recognize the symptoms in their patients. *From Monsoons to Microbes* concludes that there is a need both to document the incidence of toxin-related illness in coastal areas and among travelers who visit high-risk areas and to train public health authorities in coastal states to recognize and respond to toxin-related illnesses. Tracking has been most useful in cases where the acute effects from toxic algae resulted in a cluster of illnesses. It is also important to consider sublethal or subsymptomatic effects that can result from low-level exposure to toxic algae, which are only now being studied and understood.







THE ROLE OF THE OCEAN IN SPREADING DISEASE

The ocean is home to several types of disease-causing viruses and bacteria (pathogens). These waterborne diseases can either originate in the ocean or originate on land but be transmitted through seawater. Like the public health threats posed by harmful algal blooms, the threats of waterborne diseases can be reduced through improved tracking, environmental monitoring, epidemiology, and basic research.

Most waterborne disease agents enter the human body when people eat tainted seafood or swallow contaminated seawater. Some agents, however, can enter through broken skin or mucous membranes; the free-swimming larvae of avian schistosomes can even penetrate unbroken human skin and cause a problem called swimmer's itch.

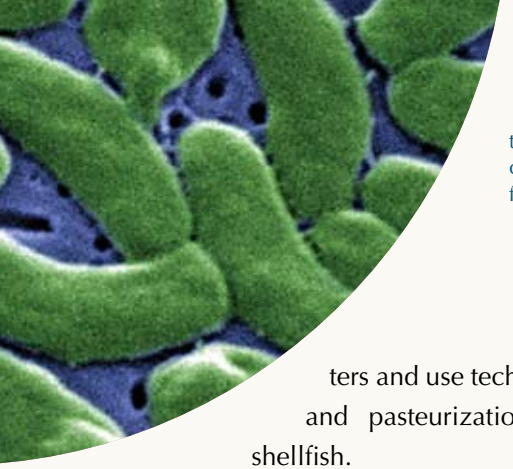
Microbes in the vibrio genus are an example of bacterial pathogens that originate in the ocean. These bacteria multiply in marine waters and include *Vibrio cholerae* (which causes cholera) and other life-threatening pathogens.

Although cholera occurs mostly in developing countries, vibrio-related diseases threaten human health everywhere—including the United States.

A major source of waterborne illness is seafood consumption. In the United States, the most common vibrio infections are caused by *Vibrio vulnificus* and *Vibrio parahaemolyticus*, and these infections occur most frequently in the Gulf Coast region. According to the CDC, about 59 percent of all vibrio infections in this country are food borne. Of these, 64 percent are directly linked to the consumption of oysters.

The CDC estimates that about 8,000 cases of mostly mild vibrio infections occur each year, but many people do not see a doctor, so their infections go unreported. The Gulf Coast reports the highest number of vibrio infections, with about 100–200 seriously ill individuals per year. These infections can be deadly in individuals who have a weakened immune system. Among those seriously ill who seek medical attention, *V. vulnificus* hospitalizes 93 percent, and 38 percent of these patients die.

The CDC suggests that people should avoid harvesting and consuming shellfish during warmer weather, when disease-causing bacteria are more likely to be present. It also suggests that people should thoroughly cook oys-



Vibrio vulnificus is one of the bacteria in the Vibrio genus that live in seawater and cause cholera and other diseases. (Image from CDC/ Colorized by James Gathany)

ters and use technologies such as irradiation and pasteurization to eliminate vibrio in shellfish.

Viruses, too, can be lethal, and even a single ingested virus can cause an infection. Rotaviruses, for example, are unusually robust and can be found in seawater that has been contaminated by sewage. Rotaviruses cause severe diarrhea in young children, killing an estimated 870,000 children in the world each year, mostly through their exposure to human sewage.

Understanding the epidemiology and causes of outbreaks of waterborne pathogens will allow better control of these outbreaks and will protect public health.

THE OCEAN CAN INFLUENCE HUMAN HEALTH EVEN HUNDREDS OF MILES INLAND

Many diseases are not directly present in seawater but are carried by other animals, called vectors, which can be influenced by changes in weather mediated by the ocean. Worldwide, changing weather and climate patterns affect the incidence of such diseases as malaria, yellow fever, hantavirus, and others that are transmitted by insects, mice, or other animals.

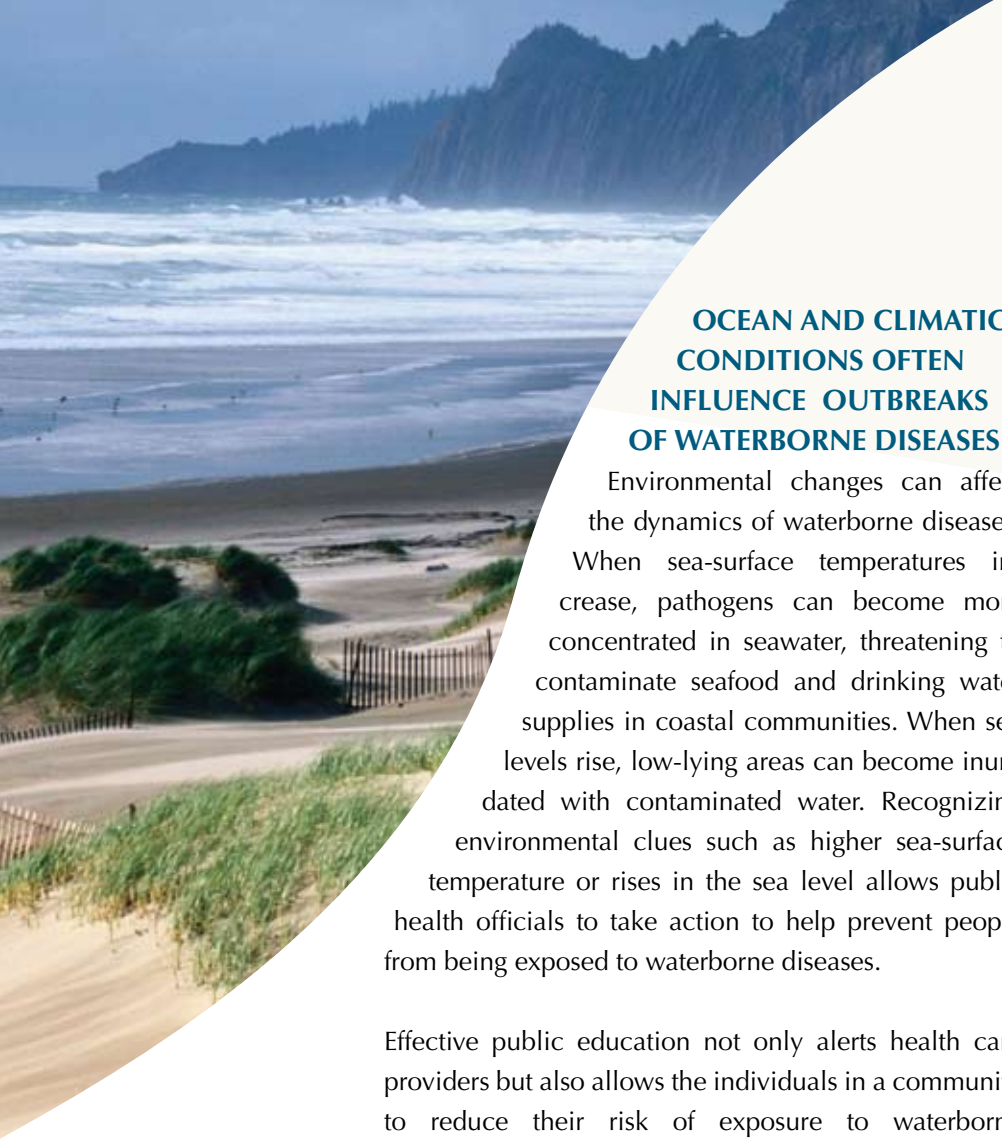
PUBLIC HEALTH EFFORT IN BANGLADESH

In tracking *V. cholerae* around the world since the 1970s, U.S. marine microbiologist Dr. Rita Colwell noticed that four to six weeks after the seasonal peaks in sea-surface temperatures in the Bay of Bengal, cholera outbreaks in Bangladesh increased dramatically.

Once she understood the effects of changes in sea-surface temperature on cholera incidence, Dr. Colwell was able to warn residents in a particular rural village of an impending outbreak by monitoring satellite data. She met with the women, teaching them how to filter pathogens from the family drinking water by placing four to eight layers of clean sari cloth over the mouth of the water pitcher.

Tests show that Dr. Colwell's filtration method removes about 99 percent of *V. cholerae*. A three-year study demonstrated a 50 percent reduction in cholera infections in villages where the women filter water through sari cloth.

Patients suffering from cholera in Bangladesh hospital. An American researcher, Dr. Rita Colwell, developed a simple water filtration method that has significantly reduced cholera infections in this region. (Image from D. J. Grimes)



OCEAN AND CLIMATIC CONDITIONS OFTEN INFLUENCE OUTBREAKS OF WATERBORNE DISEASES

Environmental changes can affect the dynamics of waterborne diseases. When sea-surface temperatures increase, pathogens can become more concentrated in seawater, threatening to contaminate seafood and drinking water supplies in coastal communities. When sea levels rise, low-lying areas can become inundated with contaminated water. Recognizing environmental clues such as higher sea-surface temperature or rises in the sea level allows public health officials to take action to help prevent people from being exposed to waterborne diseases.

Effective public education not only alerts health care providers but also allows the individuals in a community to reduce their risk of exposure to waterborne pathogens.

EL NIÑO LINKED TO HANTAVIRUS OUTBREAK IN THE SOUTHWEST UNITED STATES

El Niño is a shift in weather patterns that is caused by natural fluctuations in ocean dynamics. It brings unusually warm and wet weather to certain parts of the world, including the west coasts of North and South America.

Though it is an ocean-based phenomenon, the effects of El Niño can be felt far inland. In 1993, for example, an outbreak of hantavirus, which causes acute respiratory distress, occurred in the "four corners" area of New Mexico, Arizona, Colorado, and Utah. In retrospect, scientists observed that the unusually heavy rainfalls from the 1992–1993 El Niño led to an abundant food supply for deer mice—the most common reservoir of hantavirus in the southwestern United States. The abundance of food caused a population explosion among deer mice, which commonly live in and around houses and stables. The urine of these mice, which was infected with hantavirus, mingled with the dust in the air after drying. People who inhaled this infected dust got sick, and more than half of those infected died.

THERE IS A GROWING NEED FOR RAPID, INEXPENSIVE TESTS FOR DETECTING WATERBORNE PATHOGENS

The CDC, the Environmental Protection Agency (EPA), and the Council of State and Territorial Epidemiologists maintain a collaborative surveillance system of waterborne disease outbreaks. This monitoring is instrumental in determining national and regional trends of various infections, which then helps to guide prevention programs throughout the country.

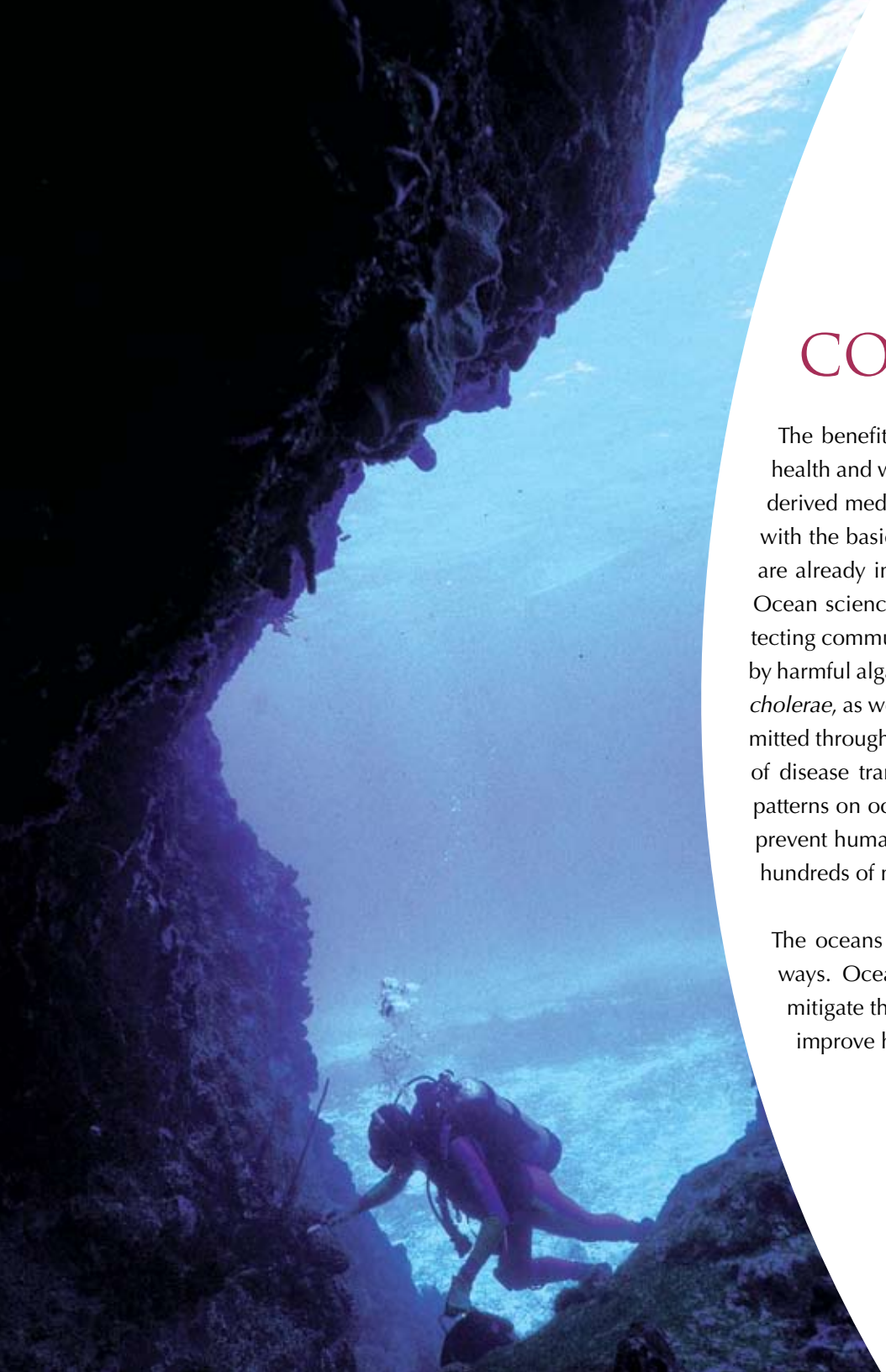
In 2000, the U.S. Congress passed the Beaches Environmental Assessment and Coastal Health Act to better protect seashore bathers from harmful pathogens. Of the 4,025 beaches monitored by the EPA in 2005, 28 percent were affected by advisories or closings.

In the United States, testing for coliform bacteria—the bacteria found in human or animal wastes—constitutes the cornerstone of all monitoring and regulatory programs. This testing has been effective in reducing exposure to waterborne disease outbreaks that arise from fecal contamination.

In addition to the bacterial contamination revealed in coliform tests, viruses can be transmitted by seawater. However, viral monitoring has not yet been included in the routine water quality tests. The EPA is working to design a water quality test that will identify both bacterial and viral threats and provide results within two hours so that beaches and oyster and clam-producing areas can be temporarily closed in a timely manner whenever necessary.

From Monsoons to Microbes emphasizes the need to apply newly developed tests to environmental monitoring and quality assessment, but it also notes that they must be field-tested for applicability in different geographic locations. If the field tests are successful, the new methods should be adopted by enforcement agencies as standard methods.

Thousands of beaches in the United States are routinely monitored for coliform bacteria, which indicate the presence of contamination by human or animal wastes. Positive coliform tests can result in temporary beach advisories or closings.



CONCLUSIONS

The benefits of oceans and ocean science for improving our health and well-being are enormous. The discoveries of marine-derived medicines, research tools, and other products, coupled with the basic and applied research leading to new discoveries, are already improving the lives of people all around the world. Ocean science is essential for developing effective ways of protecting communities from harmful toxins, such as those produced by harmful algal blooms, and dangerous pathogens, such as *Vibrio cholerae*, as well as the potential dangers from sewage leaks transmitted through the sea. Exciting new research on the mechanisms of disease transmission and the effects of climate and weather patterns on ocean-related threats can help public health systems prevent human exposure to illness—in coastal communities and hundreds of miles inland.

The oceans touch the lives of billions of people in countless ways. Ocean science can help us understand, predict, and mitigate the threats within the ocean and develop products to improve human health.

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

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Sponsored by: National Oceanographic and Atmospheric Administration's National Sea Grant College Program, National Science Foundation, The Whitaker Foundation, Minerals Management Service, Electric Power Institute.

From Monsoons to Microbes: Understanding the Ocean's Role in Human Health (1999)
Sponsored by: National Oceanic and Atmospheric Administration, National Institute of Environmental Health Sciences, National Aeronautics and Space Administration.

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