CHAPTER 23

Connecting the Oceans and Human Health

While marine animals and plants are most commonly used as sources of food, they also produce a vast array of chemical compounds that can be developed into products with beneficial medical and industrial uses. However, marine organisms, such as bacteria, algae, and viruses, can also be sources of human illness. Although these microorganisms exist naturally in the ocean, human actions can lead to ocean conditions that greatly increase their growth, harming the health of humans, marine species, and ecosystems. Significant investment must be made in developing a coordinated national research effort to better understand the links between the oceans and human health, with research aimed at discovering new drugs and other useful products derived from marine organisms, and detecting and mitigating outbreaks of disease and other harmful conditions. Efforts must also be aimed at improving public awareness about how pollution and waste can contribute to the spread of seafood contamination and disease, and can decrease the diversity of species that provide new bioproducts.

Understanding the Links between the Oceans and Human Health

The topics generally included under the umbrella of Oceans and Human Health, such as harmful algal blooms and pharmaceutical development, may at first seem to be unrelated, but they are actually inextricably linked. The health of marine ecosystems is affected by human activities such as pollution, global warming, and fishing. But in addition, human health depends on thriving ocean ecosystems. A better understanding about the many ways marine organisms affect human health, both for good by providing drugs and bioproducts, and bad by causing human ailments, is needed.

The oceans sustain human health and well-being by providing food resources and absorbing waste from areas of human habitation. For many years, the ocean's carrying capacity for meeting both these needs was assumed to be limitless. As we know today, this is not true. Scientists have reported that excessive human releases of nutrients and pollution into the ocean, and a subtle, yet measurable, rise in ocean surface temperatures are causing an increase in pathogens, primarily bacteria and viruses.[1,2] These environmental conditions can also promote excessive growth of microscopic algae, some of which can produce toxins that are released into the water and air, and become concentrated in the tissues of fish and shellfish. When these toxins are ingested or inhaled by humans, they present health risks ranging from annoying to deadly.

On the other hand, thousands of new biochemicals have been discovered in marine organisms, such as sponges, soft corals, mollusks, bacteria, and algae. Furthermore, scientists believe only a fraction of the organisms that live in the ocean have been documented, underscoring the vast potential of the oceans as a source of new chemicals.[3] These natural products can be developed not only as pharmaceuticals, but also as nutritional supplements, medical diagnostics, cosmetics, agricultural chemicals (pesticides and herbicides), enzymes and chemical probes for disease research, and for many other applications. Based on existing pharmaceutical products, each of these classes of marine-derived bioproducts has a potential multibillion-dollar annual market value.

The use of marine organisms as models for human systems has also advanced biomedical research. The diversity of life found in the oceans offers vast opportunities for the discovery of organisms that can be used to investigate biological processes analogous to those found in humans. Of particular interest are primitive vertebrates. Studies on the biology of these animals may offer insights into the evolution and physiology of humans and other organisms. Although some of the most familiar marine animal models have been used by researchers for decades, increased understanding of human biology can be gained by continuing to examine new marine organisms.

A 1999 National Research Council (NRC) report recommended a renewed effort to understand the health of the ocean, its effects on humans, and possible future health threats.[4] In a 2002 report, the NRC also emphasized the beneficial value of marine biodiversity to human health, noting that underexplored environments and organisms—such as deep-sea environments and marine microorganisms—provide exciting opportunities for discovery of novel chemicals.[5]

Currently, two national programs are designed to enhance our understanding of the ocean's role in human health. The first is a joint program between the National Institute of Environmental Health Sciences (NIEHS) and the National Science Foundation (NSF) called the Centers for Oceans and Human Health. The Centers promote interdisciplinary collaborations among biomedical and ocean scientists, with the goal of improving knowledge about the impacts of the oceans on human health. The second is the National Oceanic and Atmospheric Administration's (NOAA's) Oceans and Human Health Initiative, which will coordinate agency activities and focus funding on ocean and health issues such as infectious diseases, harmful algal blooms, environmental indicators, climate, weather and coastal hazards, and marine biomedicine.

In addition to these broad interdisciplinary programs, several other existing programs focus on one or more specific subtopics. For example, ECOHAB (Ecology and Oceanography of Harmful Algal Blooms), a program created by NOAA and NSF, provides a scientific framework designed to increase our understanding of the fundamental processes leading to harmful algal blooms. Other agencies, including the Centers for Disease Control (CDC), U.S. Environmental Protection Agency (EPA), and Food and Drug Administration (FDA), administer research and management programs that address different aspects of the links between the oceans and human health.

Maximizing the Beneficial Uses of Marine-derived Bioproducts

The marine environment constitutes the greatest source of biological diversity on the planet. Representatives of every phylum are found in the world's oceans, and more than 200,000 known species of invertebrates and algae have been documented. With so many organisms competing for survival in the challenging ocean environment, it is not surprising that many organisms produce chemicals that provide some ecological advantage. Animals and plants synthesize natural biochemicals to repel predators, compete for space to grow, and locate

The oceans are the last great frontier for biomedical research. We have learned much from the life on land, but it is now time to access the wealth of information in the sea.

—Dr. William Fenical, *Director, Center for Marine Biotechnology and Biomedicine, Scripps Institution of Oceanography, testimony to the Commission, April 2002*

potential mates. Scientists have shown that these chemicals can also be developed as human pharmaceuticals and used for other biomedical and industrial applications (Table 23.1).

Despite these potential benefits, the U.S. investment in marine biotechnology is relatively small. Japan, the world leader in this field, has spent between $900 million and $1 billion a year for the last decade and has said it intends to significantly increase this investment in the future. About 80 percent of the Japanese investment comes from industry, with the remainder from government. By contrast, U.S. public investment in marine biotechnology research and development in 1996 was around $55 million, and U.S. industry investment is estimated at approximately $100 million annually. Yet even with this limited funding, U.S. marine biotechnology efforts since 1983 have resulted in more than 170 U.S. patents, with close to 100 new compounds being patented between 1996 and 1999.[6]

Specific Applications

Pharmaceuticals

Since the 1970s, scientists have been isolating and characterizing molecules from ocean organisms that have unique chemical structures and bioactivities. In recent years, several of these compounds have undergone clinical testing in the United States as potential treatments for cancer. Progress has also been made in finding treatments for other human ailments, including infectious diseases, cancer, chronic pain, and arthritis.

Molecular Probes

Several marine-derived compounds, explored initially as potential pharmaceuticals, are available commercially as molecular probes. These probes are special chemical compounds that researchers can use to study important biochemical processes. Their value in resolving the complexities of diseases has often outweighed their economic and medicinal value as commercial pharmaceuticals. Moreover, molecular probes often offer attractive opportunities for commercialization, with revenues generated in a shorter time than pharmaceuticals because lengthy regulatory approvals are not required for research that does not involve human subjects.

Nutrients

Marine-derived nutritional supplements, or "nutraceuticals," present a relatively new opportunity for research and development in the application of natural marine products to human health issues. Nutritional supplements from plants have been used for years, including commonly known products such as St. John's wort, ginseng, and echinacea. A few products from marine sources are also commercially available such as xanthophylls from algae, which are used in nutritional supplements and vitamins for their antioxidant properties. Although the use of marine natural products in nutritional supplements is limited at this time, it represents a large potential market.

Industrial Uses

In addition to medicinal uses, chemicals produced by marine organisms have a wide array of industrial applications. For example, some marine organisms, such as limpets, produce adhesive proteins that hold them strongly to surfaces against the pull of tides and waves. Currently, researchers are examining the chemistry of these adhesives to produce new glues that work in wet environments. Cold-water marine microorganisms are being studied because of chemicals they produce that can be used as detergents. These chemicals could help produce commercial detergents that are more effective in cold water. Many sedentary marine organisms produce anti-fouling chemicals that prevent algae and bacteria from clinging to their surfaces. Researchers are investigating these chemicals as potential paint additives for ship hulls. If effective, these chemicals could reduce the need for traditional anti-fouling paints that contain high levels of heavy metals, which can contaminate

Box 23.1 Special Focus on Microbial Diversity

Microorganisms comprise a larger biomass than any other form of life on Earth. In addition, they are the most diverse group of organisms on the planet, having evolved to survive in almost all environments. In the ocean they are the basis for food webs, even in areas that would not normally be capable of sustaining life.

For example, in the deep ocean environment with no light and few nutrients, chemosynthetic bacteria thrive on the methane present in frozen gas hydrates. Near deep-sea hydrothermal vents where temperatures can rise to over 300 degrees Celsius, bacteria are capable of using hydrogen sulfide and carbon dioxide as their only nutrients and producing enough organic compounds to support whole vent communities, including tubeworms, fish, crabs, shrimp, clams, and anemones.

However, microorganisms have not evolved simply to synthesize molecules for food; they have also been shown to produce a wide array of chemicals for other purposes. Understanding how these organisms survive, both individually and symbiotically, and why they produce such unique chemistry, is essential to understanding their therapeutic and technological potential. Yet, only a small percentage of these organisms have been documented, largely due to difficulties in culturing organisms from such unique habitats. An expanded search for new microbes in the ocean based on cooperation among a number of multidisciplinary government programs could yield exciting results.

bottom sediments. Several other applications of marine-derived substances are currently in development, such as reaction enzyme catalysts and biochemicals used for detoxifying chlorinated hydrocarbons and other pollutants.

Encouraging Interdisciplinary Marine Biomedical Research

Past U.S. efforts to discover marine biomedicines were of the collect-and-test type, with little attention given to the evolutionary, environmental, and molecular biology of the species being tested. However, to realize the greatest rewards for research investments, each species' ecological, genetic, and physiological information will need to be examined to understand how they adapt to environmental conditions. The unique diversity and adaptations of marine life can help scientists understand the evolutionary development of biochemical signals that regulate cell cycles and control resistance against diseases and infections.

Historically, structural limitations inherent in the federal agencies made it difficult to undertake truly multidisciplinary science. NSF restricted funding for biomedical research because it is the primary focus of the National Institutes of Health (NIH), creating difficulties in establishing combined environmental and biomedical research programs. Likewise, NIH has generally supported direct medical research, thus precluding ancillary studies of systematics, ecology, and species distributions. Until a few years ago, the NIH's ocean pharmaceutical programs had been very narrow, focusing almost exclusively on discovering and developing new anti-cancer drugs. Thus, the very structure of the federal scientific support system has been counterproductive to establishing the type of multidisciplinary programs required to advance the broader field of marine natural product discovery and development.

Based on recommendations from the National Research Council and others, in the last two years, new approaches for supporting marine bioproduct development have been established that allow the necessary cross-disciplinary research to occur, including the NIEHS–NSF and NOAA programs mentioned earlier. However, increased participation and cooperation from other federal agencies, including EPA, the Office of Naval Research (ONR), the National Aeronautics and Space Administration (NASA), CDC, FDA, and the Minerals Management Service (MMS), each of which brings particular expertise and perspectives, will also be helpful.

Table 23.1 The Bounty of the Sea

This table highlights some of the chemicals and biological materials isolated from marine organisms that are in use or being developed.

Application	Original Source	Status
Pharmaceuticals		
Anti-viral drugs (herpes infections)	Sponge, *Cryptotethya crypta*	Commercially available
Anti-cancer drug (non-Hodgkin's lymphoma)	Sponge, *Cryptotethya crypta*	Commercially available
Anti-cancer drug	Bryozoan, *Bugula neritina*	Phase II clinical trials
Anti-cancer drug (mitotic inhibitor)	Sea hare, *Dolabella auricularia*	Phase I clinical trials
Anti-cancer drug (tumor-cell DNA disruptor)	Ascidian, *Ecteinascidia turbinata*	Phase III clinical trials
Anti-cancer drug	Ascidian, *Aplidium albicans*	Advanced preclinical trials
Anti-cancer drug	Gastropod, *Elysia rubefescens*	Advanced preclinical trials
Anti-cancer drug (microtubule stabilizer)	Sponge, *Discodermia dissoluta*	Phase I clinical trials
Anti-cancer drug	Sponge, *Lissodendoryx sp.*	Advanced preclinical trials
Anti-cancer drug	Actinomycete, *Micromonospora marina*	Advanced preclinical trials
Anti-cancer drug (G2 checkpoint inhibitor)	Ascidian, *Didemnum granulatum*	In development
Anti-cancer drug	Sponge, *Jaspis sp.*	In development
Anti-inflammatory agent	Marine fungus	In development
Anti-fungal agent	Sponge, *Trachycladus*	In development
Anti-tuberculosis agent	Gorgonian, *Pseudopterogorgia*	In development
Anti-HIV agent	Ascidian	In development
Anti-malarial agent	Sponge, *Cymbastela*	In development
Anti-dengue virus agent	Marine crinoid	In development
Molecular Probes		
Phosphatase inhibitor	Dinoflagellate	Commercially available
Phospholipase A2 inhibitor	Sponge, *Luffariella variabilis*	Commercially available
Bioluminescent calcium indicator	Bioluminescent jellyfish, *Aequora victoria*	Commercially available
Reporter gene	Bioluminescent jellyfish, *Aequora victoria*	Commercially available
Medical Devices		
Orthopedic and cosmetic surgical implants	Coral, mollusk, echinoderm skeletons	Commercially available
Diagnostics		
Detection of endotoxins (LPS)	Horseshoe crab	Commercially available
Enzymes		
Polymerase chain-reaction enzyme	Deep-sea hydrothermal vent bacterium	Commercially available
Nutritional Supplements		
Polyunsaturated fatty acids used in food additives	Microalgae	Commercially available
Pigments		
Conjugated antibodies used in basic research and diagnostics	Red algae	Commercially available
Cosmetic Additives		
Cosmetic (anti-inflammatory)	Gorgonian, *Pseudopterogorgia elisabethae*	Commercially available

Source data combined from:

Pomponi, S. A. "The Bioprocess-technological Potential of the Sea." *Journal of Biotechnology* 70 (1999): 5–13.

Pomponi, S. A. "The Oceans and Human Health: The Discovery and Development of Marine-derived Drugs." *Oceanography 14* (2001): 78–87.

National Institutes of Health, National Cancer Institute, Natural Products Branch, Frederick, MD.

Jordan, M.J., and L. Wilson. "Mining the Ocean's Pharmacological Riches: A Lesson from Taxol and Vinca Alkaloids." In *Marine Biotechnology in the 21st Century.* Washington, DC: National Academy Press, 2001.

Recommendation 23–1

The National Oceanic and Atmospheric Administration, National Science Foundation, National Institute of Environmental Health Sciences, and other appropriate entities should support expanded research and development efforts to encourage multidisciplinary studies of the evolution, ecology, chemistry, and molecular biology of marine species, discover potential marine bioproducts, and develop practical compounds.

These efforts should include:

- a strong focus on discovering new marine microorganisms, visiting poorly sampled areas of the marine environment, and studying species that inhabit harsh environments.
- encouragement for private-sector investments and partnerships in marine biotechnology research and development to speed the creation of commercially available marine bioproducts.

Managing Marine Bioproduct Discovery and Development

Based on the potentially large health benefits to society, the federal government should encourage and support the search for new bioproducts from marine organisms, known as bioprospecting. However, before wide-scale bioprospecting proceeds in federal waters, requirements need to be established to minimize environmental impacts. Planning and oversight will help ensure that public resources are not exploited solely for private gain and will help protect resources for future generations.

Individual states regulate the collection of marine organisms quite differently, sometimes requiring an array of research permits to collect organisms and licenses to gain access to particular areas. Regulations that ban the removal of specific organisms, such as corals and other sensitive species, often exist in both state and federal protected areas. In protected federal waters, such as national marine sanctuaries, research permits are required for all collections. However, bioprospecting outside state waters and federal protected areas is unrestricted, except for certain species subject to regulation under existing legislation, such as the Endangered Species Act. Both U.S. and foreign researchers, academic and commercial, are free to collect a wide range of living marine organisms without purchasing a permit and without sharing any profits from resulting products.

On land, the National Park Service has successfully asserted the government's right to enter into benefit sharing agreements in connection with substances harvested for commercial purposes in Yellowstone National Park. The National Park Service is in the process of conducting a full environmental impact statement on the use of such agreements for benefit sharing in other parks. This practice could serve as a model for the management of bioprospecting in U.S. waters.

Similar to other offshore activities, bioprospecting in federal waters will require appropriate permitting and licensing regulations to protect public resources while encouraging future research. Furthermore, when allocating use of federal ocean areas for bioprospecting, it is important that consideration be given to other potential uses of those areas, including oil and gas exploration, renewable energy, and aquaculture. A proposal for better coordinated governance of offshore uses is discussed in detail in Chapter 6.

Reducing the Negative Health Impacts of Marine Microorganisms

A host of microorganisms exist in marine waters, filling their roles in the ecosystem and generally causing no problems to humans. However, the number and distribution of marine pathogens can change over time due to many environmental factors. Human impacts, such as pollution or climate change, can produce even greater fluctuations that threaten the health of humans, marine organisms, and the marine ecosystems on which we all depend.

Harmful Algal Blooms

The term harmful algal bloom (HAB) is used to describe destructive concentrations of particular algal species in ocean waters. These blooms are sometimes called red tides because the high algal density can make the ocean surface appear red, but they may also be green, yellow, or brown, depending on the type of algae present.

The Nature of the Problem

The underlying physical, chemical, and biological causes for most harmful algal blooms are not well understood, but an increase in distribution, incidence, duration, and severity of HABs has been documented within recent decades (Figure 23.1). In many areas, increases in nutrients in coastal waters, from point and nonpoint sources of pollution, and higher numbers of invasive species released from ships' ballast water mirror the increase in HAB events, suggesting a possible causal connection.[7,8] However, others have suggested that the apparent increase in HAB events is simply a result of more frequent and effective monitoring. Additional research is needed to understand why blooms form in a specific area, how they are transported, and what causes them to persist.

HABs become a health concern when they produce high concentrations of potent toxins in ocean waters. When these toxins are concentrated in fish and other seafood consumed by humans, they can lead to paralytic, diarrhetic, neurotoxic, or amnesic shellfish poisoning. Most of these toxins cause harm only if ingested; however, some enter the air from sea spray and can cause mild to severe respiratory illnesses when inhaled. These health effects are not restricted to human populations; fish, birds, and marine mammals also fall victim to red tide poisoning. The Great Lakes and large estuarine systems are also affected by HABs. Lake Erie continues to experience blooms of a blue green alga called *Microcystin sp*. This alga is capable of producing toxin compounds called microcystins that have been implicated in bird and fish kills and can result in gastrointestinal problems in humans.

Annually, HABs are believed to cost the nation's fishing and tourism industries more than $50 million directly, with a likely multiplier effect that pushes the total economic loss to $100 million.[9,10] This can be catastrophic to low-income fishing communities, as witnessed in Maryland in 1997 during an outbreak of *Pfiesteria piscicida* (a species of dinoflagellate) associated with widespread fish kills.[11] Tourism was hurt by news coverage of seafood poisonings, and reports of red tides had a swift and chilling effect on oceanside resort visits, beach-going, and boating. Aquaculture can also be severely damaged by HABs, which can cause rapid fish kills and result in harvesting moratoria.

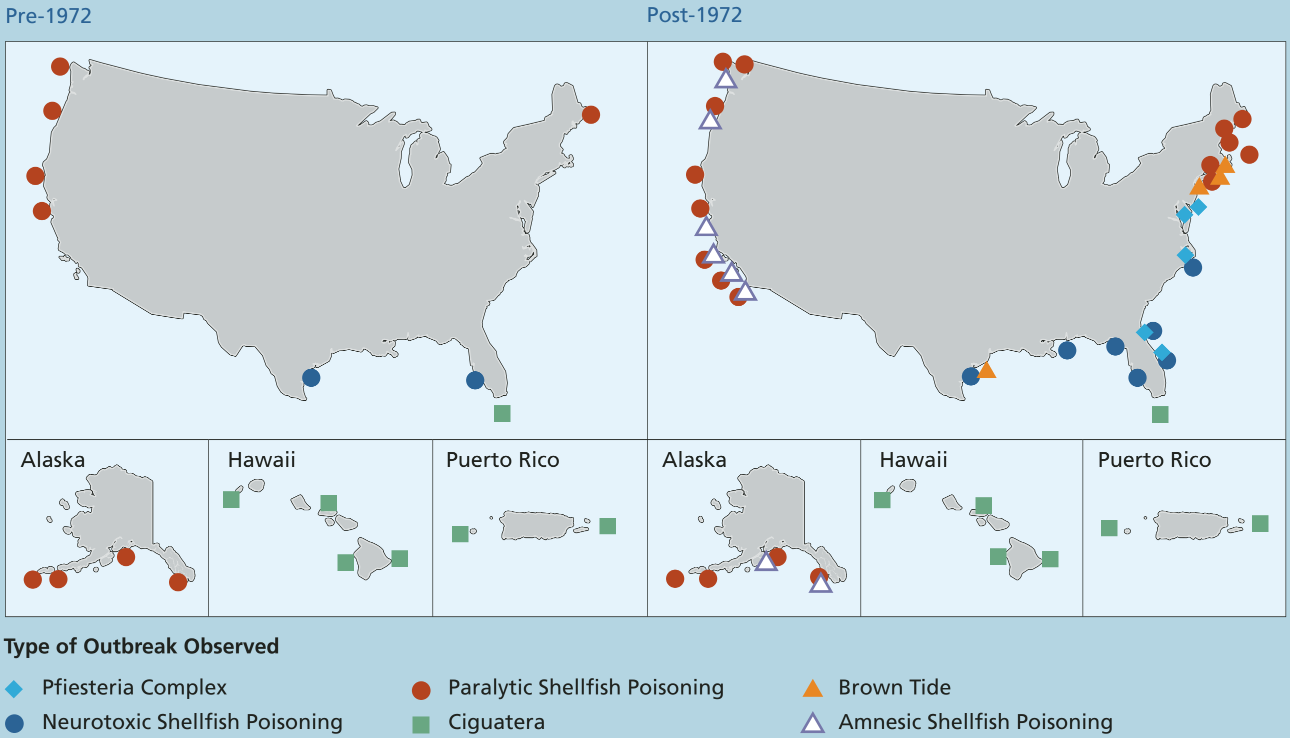
HABs are of particular concern in areas where the water contains high concentrations of dissolved nutrients. These areas are incubators for many types of algal blooms, nontoxic as well as toxic. The nutrients create conditions for rapid growth of large and dense algal blooms. When the algae die, their decomposition consumes the dissolved oxygen that other organisms need for survival.

Improving Understanding, Detection, and Prevention

HABs constitute significant threats to the ecology and economy of coastal areas. While the preferred course of action is prevention, effective treatments are also needed. The current availability of biological, chemical, or physical treatments is extremely limited. The ecology of each bloom is different, and the required environmental conditions are not completely understood for any particular algal species.

The most likely and immediate solution for reducing the number and severity of HABs is to control nutrient inputs to coastal waters. (Nutrient pollution is further discussed in Chapter 14.) Prevention may also be strengthened through careful facility siting decisions and tighter controls on invasive species. However, for better long-term management, a comprehensive investigation of the biology and ecology of HABs will be needed to increase our understanding of options for prevention, prediction, and control.

Figure 23.1 Harmful Algal Blooms on the Rise



Outbreaks of harmful algal blooms and related events, such as fish kills and marine mammal mortalities, have become more prevalent over the past thirty years. This can be attributed to many causes, including increases in nutrient runoff that enhance the growth of these types of organisms. However, a portion of the rise in reported bloom events may simply reflect better detection methods and more observers.

Source: National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution, Woods Hole, MA.

Better coordination would help leverage the relatively few but successful HAB research programs currently being supported by the federal government (such as ECOHAB, MERHAB—Monitoring and Event Response for Harmful Algal Blooms; NOAA's National Marine Biotoxin program and HAB sensor development and forecasting program, and efforts supported by the CDC, states, and others).

Improved monitoring techniques are also essential in mitigating the harmful impacts of HABs. Sampling directly from the natural environment can help researchers compile an overall HAB picture, laying the foundation for predictive modeling and forecasting. Numerous monitoring programs already exist, many of which are funded by state governments. However, routine field sampling, combined with laboratory analysis, is expensive and time consuming, and becomes more so as greater numbers of toxins and pathogens are discovered over larger geographic areas. Monitoring technologies that can be stationed in aquatic environments and continually measure for HABs are urgently needed. (Chapters 15 and 26 include broader discussions of national monitoring and observing needs.)

To cover larger areas, monitoring data collected from remote sensing platforms are essential. NOAA is currently developing and testing techniques to forecast HAB occurrence and movement using satellite sensors. The complementary development and deployment of satellites and moored sensors will provide even greater coverage, cross-referenced ground truthing, and more frequent site-specific sampling. These elements will add up to better data sets for monitoring of HABs. As more data are collected on HAB occurrences, researchers will be able to more accurately predict future outbreaks by using advanced computer models and taking into account the physical and biological conditions leading to HABs.

Marine Bacteria and Viruses

Bacteria and viruses are present everywhere in the ocean; in fact, each milliliter of seawater contains on average 1 million bacteria and 10 million viruses. While only a small percentage of these organisms cause disease in humans, they pose a significant health risk. Humans become exposed to harmful bacteria and viruses primarily by eating contaminated seafood (especially raw seafood) and by direct intake of seawater.

Many, if not most, occurrences of high concentrations of pathogens in the ocean and Great Lakes are the direct result of land-based human activities. Pollution and urban runoff lead to nutrient-rich coastal and ocean waters that provide ideal conditions for the growth and reproduction of these microorganisms. With ever-increasing numbers of people living in coastal areas, along coastal watersheds, and inland along rivers that ultimately drain into the ocean, waste and pollution have increased to a level that creates negative environmental and human health-related consequences.

A comprehensive and integrated research effort is needed to further explore the relationship between human releases of inorganic and organic nutrients to coastal waters and the growth of pathogenic microorganisms in the ocean. Rapid monitoring and identification methods need to be developed so officials can warn populations at risk when unhealthy conditions are present. Integration of these new methods into moored biological sensors, the Integrated Ocean Observing System (IOOS, discussed in Chapter 26), and the national monitoring network (discussed in Chapter 15) will allow for continuous data collection, and be particularly helpful in areas of high recreational or seafood harvesting activity. This effort must include the input from the state, regional, tribal, and local organizations that will implement localized monitoring programs and address public education issues associated with marine bacteria and viruses.

Contaminated Seafood

Contaminated seafood is one of the most frequent causes of human disease contracted from ocean and fresh waters, whether due to pathogenic or chemical contamination. Chemicals, such as mercury and dioxins that exist as environmental contaminants and are concentrated in fish through bioaccumulation, continue to be a health concern for humans, especially in terms of reproductive and developmental problems. In addition, harmful algal blooms and pathogen outbreaks are becoming more common in local waters, increasing the risk of seafood contamination. In addition to domestic sources, Americans are importing more seafood than ever before.[12] These imports often come from countries whose public health and food handling standards are lower than in the United States.

To protect the safety of the nation's seafood, rapid, accurate, and cost-effective means for detecting pathogens and toxins in seafood are needed. As these techniques are developed they can be incorporated into seafood safety regulations and surveillance efforts, particularly inspections of imported seafood and aquaculture products.

Implications of Global Climate Change

In addition to the direct effects of human activities, marine microorganisms' survival and persistence are also strongly affected by environmental factors. In particular, global climate change has the potential to significantly alter the distribution of microorganisms in the ocean. Pathogens now limited to tropical waters could move toward the poles as sea-surface temperatures rise.

For example, the bacterium that causes cholera (*Vibrio cholerae*) has been implicated in disease outbreaks fueled by the warming of coastal surface water temperatures. The intrusion of these warmer, infected waters into rivers can eventually lead to mixing with waters used for drinking and public hygiene. An indirect relationship has also been noted between climate change phenomena associated with the Bay of Bengal and the incidence of cholera in Bangladesh. As the temperature in the Bay of Bengal increased, plankton growth accelerated, which in turn created ideal growth conditions for bacteria such as *Vibrio cholerae*.[13]

Mass mortalities due to disease outbreaks have also affected major life forms in the ocean. The frequency of epidemics and the number of new diseases in corals, sea turtles, and marine mammals have increased. It is hypothesized that some of these outbreaks are linked to climate change. Not only are new pathogens possibly present due to changes in water temperature, but temperature changes can also stress marine organisms, making it harder for them to fight infections.[14] More research is needed to understand the links among climate change, pollution, marine pathogens, and the mechanisms of disease resistance in marine organisms.

Progress through Research and Technology Development

Better understanding about the links between oceans and human health will require a commitment of research funds to discover the fundamental processes controlling the spread and impacts of marine microorganisms and viruses. In addition, closer collaboration between academic and private sector scientists and federal agencies (including NIH, NSF, NOAA, EPA, ONR, NASA, CDC, FDA, and MMS) will be needed to better examine these issues.

Recommendation 23–2

The National Oceanic and Atmospheric Administration, National Science Foundation, National Institute of Environmental Health Sciences, and other appropriate entities, should support expanded research efforts in marine microbiology and virology.

These efforts should include:

- the discovery, documentation, and description of new marine bacteria, algae, and viruses and the determination of their potential negative effects on the health of humans and marine organisms.
- the elucidation of the complex inter-relations, pathways, and causal effects of marine pollution, harmful algal blooms, ecosystem degradation and alteration, emerging marine diseases, and climate change in disease events.

New technologies are needed for improving biological and biochemical sensors that can continuously monitor high-risk sites. These sensors must be quick and accurate so that information can be communicated to resource managers and the coastal community in a timely manner. It is also important to incorporate site-specific and satellite sensor data into the national monitoring network, discussed in Chapter 15, and the IOOS, discussed in Chapter 26. (Additional information about chemical and biological sensor needs is presented in Chapter 27.) Federal and private support will be particularly needed to develop monitoring and mitigation technologies that can be implemented at state and local levels where these outbreaks occur.

Recommendation 23–3

The National Oceanic and Atmospheric Administration, National Science Foundation, National Institute of Environmental Health Sciences, and other appropriate entities should support the development of improved methods for monitoring and identifying pathogens and chemical toxins in ocean and coastal waters and organisms.

This effort should include:

- developing accurate and cost-effective methods for detecting pathogens, contaminants, and toxins in seafood for use by both state and federal inspectors.

- developing *in situ* and space-based methods to monitor and assess pollution inputs, ecosystem health, and human health impacts.
- developing new tools for measuring human and environmental health indicators in the marine environment.
- developing models and strategies for predicting and mitigating pollutant loadings, harmful algal blooms, and infectious disease potential in the marine environment.

Increasing Federal Coordination on Oceans and Human Health

Several existing programs, including the NIEHS–NSF and NOAA programs, could form the nucleus of a fully integrated, national oceans and human health program to address the many issues discussed in this chapter. Most existing programs already involve significant interagency cooperation, which is essential for effectively examining issues that cross federal agencies' jurisdictional lines and for coordinating multidisciplinary biomedical research. Any truly national effort to address the varied roles of the oceans in human health will need to incorporate innovative basic and applied research with environmental regulations, coastal management, biosecurity, and homeland security.

Recommendation 23–4

Congress should establish a national, multi-agency Oceans and Human Health Initiative to coordinate and sponsor exploration, research, and new technologies related to examining the connections among the oceans, ecosystem health, and human health. The National Oceanic and Atmospheric Administration's Oceans and Human Health Initiative and the National Institute of Environmental Health Sciences–National Science Foundation Centers for Oceans and Human Health should be expanded and coordinated as the basis for this initiative.

The new Oceans and Human Health Initiative should:

- be implemented through both competitively awarded grants and support of federally-designated centers with federal, state, academic, and private-sector investigators eligible to compete for funding.
- work with the National Ocean Council to review other relevant agency programs and suggest areas where coordination could be improved.
- transfer new technologies into management programs that protect human health and the health of ocean and coastal ecosystems.

Implementing Human Health Protections

In addition to achieving a better understanding of the links between the oceans and human health, improvements in management are also needed. Most often this means protecting seafood safety and maintaining clean coastal waters and beaches.

Seafood Safety

Seafood consumption in the United States is rising. Americans ate about 15.3 pounds of seafood per person in 1999, compared to only 12.5 pounds in 1980. This is generally considered a positive development for public health as the vast majority of seafood available to the American public is wholesome and nutritious. However, as consumption rises, so does the possibility of public health problems from contaminated seafood, including: biological hazards from bacteria and viruses; chemical hazards from toxins, such as ciguatoxin and tetrodotoxin; and other contaminants such as mercury.

The FDA is responsible for ensuring the safety of seafood sold within the United States, including imported seafood products. NOAA also monitors seafood through the Seafood Inspection Program that provides voluntary, fee-for-service monitoring of domestic and foreign manufacturers, processes, and products.

In 1997, based in part on a National Research Council report on seafood safety, [15] the FDA implemented the Hazard Analysis and Critical Control Point (HACCP) system. The HACCP system requires both U.S. producers and foreign importers to analyze potential hazards in preparing, handling, and packaging seafood and implement plans to control these hazards. However, a 2001 study concluded that several problems existed with implementation of the HACCP system, both internationally and domestically.[16] While the FDA has been working to address these concerns, full implementation and enforcement will be needed to ensure seafood safety. New seafood testing methods, which are faster and more cost-effective, can be used in conjunction with HACCP regulations to further ensure seafood safety.

Aquaculture products make up a significant portion of the seafood sold within the United States and they are accompanied by specific health concerns that must be monitored. Cultured organisms are often more prone to disease than wild stocks. To protect against these diseases, high concentrations of pharmaceuticals can be used, but these chemicals may then appear in surrounding waters, and be concentrated in marine organisms that are consumed by people.

States, territories, and tribes have a role in protecting their residents from the health risks associated with contaminated fish and seafood caught outside the commercial industry by issuing Fish and Wildlife Consumption Advisories, based on EPA guidance, for the general population as well as for sensitive subpopulations. These advisories inform the public that high concentrations of chemical contaminants—such as mercury, PCBs, chlordane, dioxins, or DDT—have been found in local seafood. The advisories include recommendations about limiting consumption of certain fish and seafood harvested from specified waterbodies.

Better seafood screening, processing regulations, and public advisories are only part of the solution. Proactive control of harmful algal blooms, bacteria, and viruses through reductions in point and nonpoint source water pollution and control of invasive species is needed to ensure a safe food supply. Shellfish are at particular risk of contamination because they feed by filtering large volumes of water. If that water is contaminated with bacteria or viruses, shellfish become carriers of these pathogens. When outbreaks occur, coastal areas may be closed to shellfishing, with serious economic consequences for fishing communities and repercussions for human health.

Chemical contaminants such as methyl-mercury can also enter aquatic environments through atmospheric deposition. These compounds can then accumulate in fish and other marine organisms. Limiting atmospheric deposition of environmental contaminants to protect coastal waters and the nation's seafood supply is discussed in Chapter 14.

Harmful algal blooms represent the most notorious marine hazard to both man and animal. They know no geographic bounds and appear to be increasing worldwide.

—Allen Dearry, *Chief, National Institutes of Environmental Health Sciences, testimony to the Commission, April 2002*

Coastal Water Quality

In addition to the danger of consuming contaminated seafood, human health can also be threatened by participating in recreational activities in or near unhealthy waters. Viruses are believed to be the major cause of swimming-associated diseases, but bacteria, harmful algal blooms, and microbial pathogens, such as amoebae and protozoa, also cause health problems in humans. Although recent programs at the federal and state levels have been put in place to address these problems, success has been limited. In 2003, more than 18,000 days of beach closings and swimming advisories were issued across the nation.[17] The number of such actions continues to rise, costing many millions of dollars a year in decreased revenues for tourism and higher health care costs.

Almost all coastal states monitor beach water quality by measuring levels of certain indicator bacteria. However, studies have shown that the presence or absence of these indicator species does not provide information about all possible threats. In particular, concentrations of marine viruses are not well characterized by indicator bacteria levels. Another problem with using microorganisms as indicators of contamination is the lag time between sample collection, test results, and public notice. During this time swimmers continue to be exposed to the contaminated water. As discussed above, improved testing technologies and a well-coordinated federal effort are essential to support state and regional implementation of appropriate monitoring. (A discussion of national monitoring needs is found in Chapter 15.)

Of course, coastal managers can best protect public health by maintaining clean coastal waters. Data indicate that most beach closings and advisories are due to the presence of microscopic disease-causing organisms that come from human and animal wastes.[18] These wastes typically enter coastal waters from combined sewer overflows, discharges of inadequately treated wastes from sewage treatment plants and sanitary sewers, septic system failures, or stormwater runoff from urban, suburban, and rural areas. Recommendations on limiting point and nonpoint source pollution in marine and freshwater environments are provided in Chapter 14.

Public Education and Outreach

Reductions in pollution from urban area runoff, sewage outflows, agricultural pesticides, and many other sources are needed to avoid creating harmful conditions in the oceans and Great Lakes. One important step in achieving such reductions is public education (Chapter 8). Ocean-related educational campaigns frequently focus on the impacts of pollution on marine animals. Signs stenciled on storm drains remind people that "dolphins live downstream." However, people must also become more aware that food supplies and recreational areas are also downstream.

Education campaigns should also inform people of the potential risks from fish and shellfish contaminated with bacteria, viruses, or chemicals. Timely and clear State Fish and Wildlife Consumption Advisories are one way to educate the public about health hazards from seafood. Better communication among the seafood industry, state officials, recreational fishermen, and consumers will also improve the effectiveness of seafood safety programs and help prevent outbreaks of seafood-related illnesses.

Regional Dimensions

Ocean-related risks to human health are usually specific to certain local or regional areas. Different species of algal blooms and bacteria are indigenous to particular regions, and both air and water quality are dependent upon localized human activities. Because of this, the regional ocean councils and regional ocean information programs, discussed in Chapter 5, are well placed to examine these issues and their potential cumulative effects and work toward management practices that best protect the health of the people in their region.

Regional ocean councils could coordinate the development of performance assessments—for example, by measuring the progress of point and nonpoint source control programs, monitoring introductions or eradications of invasive species, and tracking water quality—to complement the regional ecosystem assessments called for in Chapter 5.

Recommendation 23–5

The National Oceanic and Atmospheric Administration, Environmental Protection Agency, and Food and Drug Administration, working with state and local managers, should fully implement all existing programs to protect human health from contaminated seafood and coastal waters.

Particularly, the federal agencies should:

- incorporate new findings and technologies, especially those developed within the Oceans and Human Health Initiative, into monitoring and prevention programs.
- coordinate and increase interagency public education and outreach efforts in this area.

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