Interagency Oceans and Human Health Research Implementation Plan:

A Prescription for the Future

By

The Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health

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Council on Environmental Quality
Office of Science and Technology Policy
Executive Office of the President

Dear Members of Congress and partners and friends in the ocean and coastal community:

We are pleased to transmit to you this report, ***Interagency Oceans and Human Health Research Implementation Plan: A Prescription for the Future***. This document describes the interagency program in Oceans and Human Health (OHH) and outlines areas of research emphasis for the next decade.

The Bush Administration's U. S. Ocean Action Plan committed to "develop a strategic research plan for oceans and human health." President Bush's Executive Order 13366 established the cabinet-level Committee on Ocean Policy to oversee the coordination of this effort, culminating in the release of this report. In 2004, the Congress passed the Oceans and Human Health Act, formally establishing the Interagency Program in Oceans and Human Health and the requirement for this report.

This Interagency OHH Research Implementation Plan summarizes work underway in OHH programs in the National Oceanic and Atmospheric Administration, the National Science Foundation, and the National Institute of Environmental Health Sciences, and provides synopses of ongoing related work in six other collaborating federal agencies (the Centers for Disease Control and Prevention, Environmental Protection Agency, Food and Drug Administration, Marine Mammal Commission, National Aeronautics and Space Administration, and U.S. Geological Survey). It establishes goals and priorities for Federal research that will most effectively advance scientific understanding of the connections between the oceans and human health.

The Plan was prepared by the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health, which was chartered through the Joint Subcommittee on Ocean Science and Technology of the National Science and Technology Council. This plan complements "*Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy,*" which was recently released by the Joint Subcommittee on Science and Technology, and provides a more detailed outline for implementation of a national OHH research, outreach and education program.

As pointed out by the U.S. Commission on Ocean Policy, the ocean can be a source of both health hazards and products to enhance human health and well-being. The activities outlined in this *Interagency Oceans and Human Health Research Implementation Plan* will ensure a vibrant, national research program targeted to minimize human health risks, maximize ocean benefits to humans, and maintain healthy and productive marine ecosystems and coastal communities.

Sincerely,

James L. Connaughton
Chair, Committee on Ocean Policy
Chair, Council on Environmental Quality

John H. Marburger,.III
Director
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Executive Summary

The ocean[1] provides numerous benefits to humankind, including seafood[2], pharmaceuticals and other natural products, recreational opportunities and aesthetic value, shoreline protection, waste assimilation, nutrient cycling, oxygen production, and drinking water[3]. The ocean also moderates climate and contributes substantially to the U.S. economy. However, the ocean poses risks when people are exposed to disease-causing organisms transmitted through or originating in the marine environment, toxins from harmful algal blooms (HABs) and other microorganisms, chemical contaminants, and when catastrophic events such as hurricanes and tsunamis occur.

Because the close connection between ocean ecosystem conditions and human health has long been recognized, several federal agencies have been working on oceans and human health (OHH)-related problems for many years. Ongoing activities and interagency collaborations have included programs related to seafood and drinking water safety, drug discovery, pollution effects and control, HABs and the toxins they produce, occurrence and transmission of disease-causing agents, and numerous others. However, the advent of named OHH programs, specifically the National Oceanic and Atmospheric Administration's (NOAA) Oceans and Human Health Initiative (OHHI) and the National Science Foundation (NSF) and National Institute of Environmental Health Sciences' (NIEHS) Research Centers of Excellence in OHH, has led to substantially increased progress in OHH research and its useful application, and in partnering among federal agencies, academia, states, and the private sector. Federal agencies collaborating on OHH research, in addition to NOAA, NSF, and NIEHS, include the Centers for Disease Control and Prevention (CDC), Environmental Protection Agency (EPA), Food and Drug Administration (FDA), Marine Mammal Commission (MMC), National Aeronautics and Space Administration (NASA), and U.S. Geological Survey (USGS).

To coordinate ongoing OHH research efforts and to ensure that federal investments in this emerging and important interdisciplinary scientific field are utilized as efficiently as possible, in 2004 the U.S. Congress passed the Oceans and Human Health Act that formally established the Interagency OHH Program. The Act also explicitly calls for this ten-year implementation plan and states that its purpose is to define "the goals and priorities for Federal research which most effectively advance scientific understanding of the connections between the oceans and human health, provide usable information for the prediction of marine-related public health problems, and use the biological potential of the oceans for development of new treatments of human diseases and a greater understanding of human biology."

In fall 2005, the Joint Subcommittee on Ocean Science and Technology (JSOST) of the National Science and Technology Council (NSTC) Committee on Science and the Committee on Environment and Natural Resources and the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI) established the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (IWG-4H). One of the IWG-4H's principal tasks has been to develop this implementation plan. This plan complements and expands upon the OHH-related priorities detailed in "*Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy*" prepared by the JSOST and published in early 2007, and provides a framework for implementation of a national OHH research and outreach program. It also summarizes work underway in NOAA's OHHI and the NSF-NIEHS Centers in OHH, and provides synopses of ongoing related work in the CDC, EPA, FDA, MMC, NASA and USGS (see Chapter 2 for details).

In preparing this implementation plan, the IWG-4H focused on three broad goals of the Interagency OHH Program.

1) Establish a research agenda focused on the highest priority areas and activities, the appropriate mix of supporting infrastructure, and the transition of research to useful application and outreach.

2) Promote a robust interdisciplinary approach that links marine and biomedical sciences to create

[1] The term "ocean" refers to open ocean, coasts (including bays and estuaries), coastal watersheds, and Great Lakes.
[2] The term "seafood" refers to all consumer seafood products as well as recreational and subsistence take including marine mammal subsistence harvest by Alaska Natives.
[3] The term "drinking water" refers to fresh water supplies derived from the Great Lakes or from coastal seawater via desalinization.

a fundamentally new OHH research community with the breadth of expertise required to address diverse human health questions within the complexity of ocean systems.

3) Establish and expand collaborative partnerships to develop and effectively use OHH information and products through technology transfer and training, and ensure inclusion of OHH-supportive data collection, integration, analysis, and modeling within the larger framework of national and international ocean observation efforts.

To accomplish our vision of a future where a healthy ocean allows people to benefit from a variety of ocean products and to swim, fish, or otherwise recreate in ocean waters and eat seafood without risk of exposure to disease-causing organisms and compounds, federal agencies and their academic and other partners should concentrate efforts where significant opportunities for advancement to improve and/or protect human health have been identified. These are:

1) Priority research dealing with pathogens, chemical contaminants, HABs, seafood safety, pharmaceuticals and other beneficial products and in cross-cutting areas such as epidemiology, sentinel species, genomics and related technologies, and social, behavioral and economic sciences.

2) Appropriate infrastructure to support research advances in such areas as linking to the ocean observing systems, data management and access, development of standards and standardized methods, and access to the sea.

3) Transition of research results to applications through targeted outreach and education activities and development of rapid response capabilities.

In addition, the IWG-4H identified the following six implementation actions that the federal agencies involved in the Interagency OHH Program will take to advance OHH research and application, leading to reduced health risks and increased health benefits for people.

Action 1. Work through existing OHH programs and partnerships.

Specifically work through existing NSF-NIEHS OHH Centers and NOAA's OHHI including OHHI Centers, external grants, scholars, and traineeships, and through collaboration with OHH-related activities in the CDC, EPA, FDA, MMC, NASA, and USGS.

Action 2. Target priority research in the following areas:

- Basic and applied studies of ocean ecosystems and processes that affect human exposure to health risks, including natural hazards, seafood consumption, and climate change.
- Discovery and development of new pharmaceuticals and other beneficial products.
- Epidemiologic studies and disease surveillance to elucidate acute, chronic, and emerging health effects and threats in humans and animals resulting from exposures to ocean waters, sediments, air, and seafood.
- Use of marine species and habitats as early warning indicators of existing and emerging threats to human, animal, and ecosystem health and as models for the study of human disease processes and toxicology.
- Development and improvement of conceptual and quantitative models that integrate environmental, biological, and epidemiologic data to produce new levels of understanding and predictive capacity.
- Economic and socio-cultural studies that advance understanding of how humans use and value the health benefits provided by the ocean.

Action 3. Support research infrastructure including:

- Ocean observing, including development, deployment, operation and maintenance of biological sensors and other biological data-collection tools.
- Cyberinfrastructure to enable data sharing, integration, archiving, analysis, and access for a broad range of OHH-related data.

- New standards and standardized methods for OHH research and research materials.
- Access to remote and at-sea platforms for the OHH program to accomplish crucial sampling activities.
- Core facilities in genomics/proteomics, marine microbiology, and analytical chemistry.

Action 4. Support transition of OHH research to application through outreach and education by:

- Strengthening cross-agency, cross-institution and cross-discipline collaboration and coordination to provide the framework to develop a fundamentally new interdisciplinary OHH research community.
- Providing OHH information, tools, technology, products, and training to support improved public health and coastal and marine resource decision-making.
- Providing opportunities for interdisciplinary training, research, and collaborations for graduate and post-doctoral students, health professionals, and scientists at early- to mid-career stages.
- Coordinating OHH outreach and education programs across agencies.
- Supporting interagency partnerships to enable rapid and coordinated response of OHH researchers to emergency situations.
- Promoting ocean stewardship and ocean and human health literacy.

Action 5. Improve coordination of OHH activities within and across agencies and internationally.

Much integration has been achieved by leaders and participants in the named NOAA and NSF-NIEHS OHH programs and related federal programs. However, for the Interagency OHH Program to continue to develop, long-term support for interagency coordination of OHH research and outreach is essential. To date, the IWG-4H has added appreciably to the positive interactions among OHH-related programs in a broad suite of agencies. The JSOST, through the IWG-4H, will continue to address interagency coordination issues.

Action 6. Provide for updates to the Interagency OHH Research Implementation Plan.

The OHH Act of 2004 requires that the Interagency OHH Annual Reports include a summary or copy of the implementation plan and any changes made in the plan. This provides a regular opportunity for the Interagency OHH community to update the plan.

These six actions will ensure a vibrant interagency program in OHH research and will result in better-informed policy decisions; discovery and application of natural products beneficial to humans; increased basic knowledge and enhanced understanding of human disease processes; improved understanding and communication about the benefits and risks of seafood consumption; increased economic returns due to decreased losses associated with beach and fishery closures, health care costs, and gains in the ocean natural products sector; and improved ocean stewardship and ocean literacy.

Chapter 1: A Vision for Oceans and Human Health Activities in Service to Society

America's ocean[1] provides a strong foundation for the nation's economy and the well-being and health of its citizens. The ocean impacts every person in the United States no matter whether they are among the more than 50 percent of the population living along the coasts or those residing inland. The U.S. has over 95,000 miles of shoreline and 25,000 miles of navigable waters. Its Exclusive Economic Zone (EEZ) is the largest in the world with 3.4 million square miles of open water, and is larger than the landmass of the entire country. Flanked by the Atlantic, Pacific, and Arctic Oceans, the Bering and Caribbean Seas, and the Gulf of Mexico, and threaded with coastal watersheds, America's ocean serves as a highway for maritime transport, a supplier of seafood[2] and other natural products, and a prime tourist destination. America's coasts also provide essential services such as shoreline protection, nutrient cycling, waste assimilation, climate moderation, and a buffer against natural and man-made disasters. Overall, these waters help drive an economic engine that provides over half the nation's gross domestic product and more than 60 million jobs annually.

While the ocean provides invaluable benefits to people, effects on coastal and ocean ecosystems from multiple stressors including population growth, land use, loss of biodiversity, habitat degradation, pollution, and natural processes are leading to increased health threats to both humans and marine animals. Escalating climate change can exacerbate a number of these stressors, including the spread of disease, toxins, and contaminants in the marine environment, with polar areas perhaps especially vulnerable. Addressing these threats requires sustained and targeted efforts from multiple disciplines and institutions, development and deployment of new technologies, effective transfer of critical information to environmental and public health managers and the general public, and a focus on prevention and prediction. Such efforts can best be carried out through a coordinated interagency program as envisioned by the U.S. Commission on Ocean Policy (USCOP) and required by the Oceans and Human Health Act of 2004 (see Appendix 1).

Healthy beaches sustain a booming coastal tourism industry, attract over a 100 million visitors each year and generate billions of dollars in revenue. Photo credit: T. Fowler

Vision for the Interagency Oceans and Human Health Research Program

Photo credit: M. Hollinger

A strong and well-coordinated Interagency Oceans and Human Health (OHH) Research Program will help ensure a healthy ocean where people can swim, fish, recreate, eat seafood and drink water[3] without risk of exposure to dangerous levels of disease-causing organisms, chemical contaminants, or biotoxins and can benefit from ocean-based pharmaceuticals and other natural products.

[1] The term "ocean" refers to open ocean, coasts (including bays and estuaries), coastal watersheds, and Great Lakes.
[2] The term "seafood" refers to all consumer seafood products as well as recreational and subsistence take including marine mammal subsistence harvest by Alaska Natives.
[3] The term "drinking water" refers to fresh water supplies derived from the Great Lakes or from coastal seawater via desalinization.

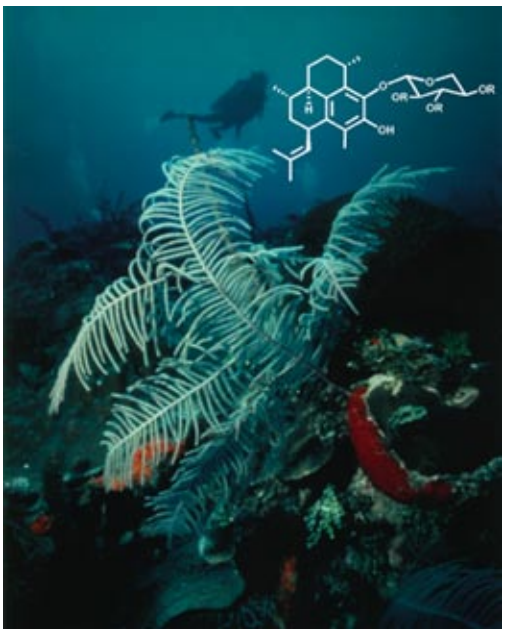
Value of the Ocean and Role in Enhancing Human Health, Well-Being and Quality of Life

The ocean provides many resources and services that directly benefit human health; seafood is among the most obvious. Seafood supplies high-quality protein, other essential nutrients, and certain healthful omega-3 fatty acids. Numerous studies have shown consumption of fish—especially fatty cold-water species such as salmon, mackerel, sardines, and herring—protects against cardiovascular disease and provides benefits for brain development in fetuses and children. Other studies suggest eating fish may also help protect humans against some cancers, asthma, diabetes, rheumatoid arthritis and other inflammatory diseases, Alzheimer's disease, depression, and macular degeneration. With commercial and recreational fisheries together generating about $80 billion in annual economic activity, plus the increasing importance of aquaculture and dominance of imported products in the U.S. marketplace, maintaining a safe and secure seafood supply is imperative.

The ocean also provides a medicine chest of marine-based pharmaceuticals and other natural products that can greatly enhance our quality of life and combat human illnesses. For thousands of years, terrestrial sources have provided nearly all drug discoveries but with 34 of 36 phyla represented in marine environments, compared to 17 on land, potential discoveries to benefit humankind seem boundless. Although only limited effort has yet been expended to discover ocean-source drugs, in part because of the necessity for long-term and high-risk investments, several marine-based products are already on the market, including a pain medication derived from the cone snail, and skin-care additives from the Caribbean sea whip used in cosmetic products. The National Cancer Institute has invested in discovery and development of anti-cancer drugs from the ocean, with over 30 in preclinical and clinical trials to treat a vari-

The term "seafood" also includes a variety of non-commercial, non-recreational marine life harvested for subsistence purposes by Alaska natives such as walrus and seal meat, seen here drying on a meat rack. Photo credit: G. Sheiflied

Wild caught and farm raised seafood have many health benefits such as providing a source of protein, essential nutrients and omega 3-fatty acids for people of all ages. Photo credit: D. Benetti



The oceans provide beneficial pharmaceuticals and products such as the Caribbean sea whip, Pseudopterogorgia elisabethae (Gorgonacae), that contains anti-allergenic and anti-inflammatory compounds used in many products as skin-care additives. Photo credit: V.J. Paul and with permission from The Oceanography Society

ety of cancers. These marine chemicals are produced by a variety of species, such as bacteria, sponges, ascidians, mollusks, bryozoans, and sharks. Other materials also in trial phases include potential anti-viral and anti-asthmatic drugs from sponges, anti-inflammatory compounds from corals, and treatments for Alzheimer's disease from marine worms. Nutritional supplements, chemical probes for medical research, enzymes, and other useful products are already being derived from the sea. Expanded development of new drugs from the sea is vitally important, but it must be conducted in a sustainable manner.

Healthy and functioning coastal ecosystems provide clean beaches and drinking water. Much of the coastal economy is powered by tourism, the fastest growing component of coastal business. Over a hundred million Americans and international guests visit our coasts annually, creating billions of dollars in positive economic impacts and millions of jobs. While tourism creates positive economic returns for coastal residents, they also derive benefits from living next to the water both in terms of property values and in promoting healthy community identity and socio-cultural relationships. This holds true for inland coastal communities as well, such as in the Great Lakes, which provide the additional benefit of supplying drinking water to over 40 million people. Finally, the ocean provides a number of marine species and habitats that can serve as sentinels that may offer early warnings about how the condition of ocean ecosystems may affect humans.

Living next to the water provides many benefits such as increased property values, daily aesthetics and general sense of well-being. Photo credit: G. Steele and F. Holland

Ocean Health Risks and Associated Economic Impacts

Ocean waters can also negatively impimpact human health and well-being by exposing humans to seafood-borne or waterborne illnesses that stem from harmful algal blooms (HABs), coastal and industrial pollution, wastewater, sewage, storm water inputs, and point and non-point source runoff from agricultural and animal production systems and other land uses (see Table 1).

For example, seafood may pose risks to consumers and subsistence harvesters because fish, shellfish, and other marine wildlife (e.g., marine mammals and seabird eggs) may accumulate heavy metals (including methyl mercury), persistent organic pollutants (such as PCBs), pesticides, and numerous other chemicals; toxins produced naturally from HABs and other harmful microorganisms; and pathogens (disease-causing organisms). Chemical contaminants can impact human reproduction, cause kidney and brain damage, and have adverse effects on endocrine function, neurobehavioral development, liver function, birth weight, immune responses, and tumor development. Pathogens and toxins sometimes associated with seafood may cause diarrhea, paralysis, amnesia, or death. Contamination of shellfish with pathogens and biotoxins is a continuing problem and every year results in closures of shellfish grounds to harvesting and warnings about shellfish consumption. Even though the FDA's "Fish and Fishery Products Hazards and Controls Guide" and NOAA's National Seafood Inspection Program have improved fishing, handling, and processing protocols to

Shellfish harvest and beach closures are widespread throughout the U.S. due to presence of harmful pathogens (disease-causing organisms) and HAB toxins. Photo credit: L. Younglove

Table 1. Ocean-Borne Health Threats to Humans.

Disease	Cause	Common Associated Vectors or Exposures	Common Signs and Symptoms
Microbe-related Illnesses			
Viral gastroenteritis	Norovirus	Fecal-oral transmission, possibly airborne, ingestion of contaminated food or water	Nausea, vomiting, diarrhea, abdominal pain, muscle aches, headache, general sense of tiredness, low-grade fever
Vibrio parahaemolyticus food poisoning	*Vibrio parahaemolyticus*	Ingestion of raw or inadequately cooked seafood or any food cross-contaminated by handling raw seafood, or by rinsing food with contaminated seawater	Watery diarrhea, abdominal cramps, sometimes with nausea, vomiting, fever, and headache. Occasionally, a dysentery-like illness is observed, with bloody or mucoid stools, high fever, and high white blood cell count
Vibrio vulnificus food poisoning and/or skin infection	*Vibrio vulnificus*	Food poisoning due to ingestion of raw or inadequately cooked seafood or any food cross-contaminated by handling raw seafood or by rinsing food with contaminated seawater. Skin infection due to coming into contact with contaminated seawater or raw seafood (e.g., oysters) particularly if open cut on skin	Food poisoning: vomiting, diarrhea, and abdominal pain. Skin infection: gangrene, sepsis including fever, chills, decreased blood pressure, and possible death (even in healthy people)
Salmonellosis	*Salmonella* serotypes including *S. typhimurium* and *S. enteritidis*	Ingestion of organisms in food derived from infected food animals or contaminated by feces of an infected animal or person	Acute enterocolitis (sudden onset of headache, abdominal pain, diarrhea, nausea, and vomiting)
Typhoid fever	*Salmonella typhi*	Ingestion of food or water contaminated by feces and urine of patients and carriers, ingestion of raw fish harvested from sewage-contaminated beds, raw fruits and vegetables fertilized with night soil, ingestion of milk contaminated with feces from infected person	Sustained fever, headache, general feeling of tiredness, anorexia, rose spots on the trunk, enlarged spleen, non-productive cough
Shigellosis	*Shigella* species (*S. dysenteriae, S. flexneri, S. boydii, S. sonnei*)	Direct or indirect fecal-oral transmission from a patient or carrier, ingestion of water or milk contaminated with feces from infected person	Diarrhea accompanied by fever, nausea, vomiting, cramps, and tenesmus (straining at bowel movement or urination)
Cholera	*Vibrio cholerae*	Ingestion of water contaminated with feces or vomitus of patients, ingestion of unrefrigerated food contaminated with feces from an infected person	Profuse watery stools, occasionally vomiting, rapid dehydration, acidosis and circulatory collapse
Yersinosis	*Yersinia enterocolitica, Yersinia pseudotuberculosis*	Ingestion of food or water contaminated with feces of infected person or animal	Enterocolitis, pain mimicking appendicitis, fever, headache, pharyngitis, anorexia, vomiting, post-infectious arthritis
Hepatitis	Hepatitis A virus (Enterovirus type 72)	Person-to-person via oral-fecal route, ingestion of food or water contaminated by infected food handlers, ingestion of raw or undercooked mollusks harvested from sewage-contaminated beds	Abrupt fever, general feeling of tiredness, anorexia, nausea, abdominal discomfort, followed by jaundice
Pneumonia (Legionnaire's disease, Pontiac fever)	*Legionellae* species	Airborne via aerosol-producing devices	Anorexia, general feeling of tiredness, muscle weakness, headache, rapidly rising fever, non-productive cough
Respiratory tract infections	Microbes	Inhalation of aerosols of contaminated water	Cough (productive and non), fever
External otitis media	Bacteria & viruses	Contact with contaminated water	"Swimmers ear"
Asceptic (viral) meningitis	Many viruses capable of producing meningeal features, *Coxsackievirus* Group B	Varies depending on virus involved; little evidence of water-borne transmission	Rapid onset of fever with signs of meningeal involvement, increased protein in cerebral-spinal fluid, rash resembling rubella

Table compiled by L. Backer and L. Fleming

Table 1. Ocean-Borne Health Threats to Humans (continued).

Disease	Cause	Common Associated Vectors or Exposures	Common Signs and Symptoms
Cryptosporidiosis	*Cryptosporidium* sp.	Fecal-oral, including person-to-person, animal-to-person, ingestion of water contaminated with feces of infected person or animal	Profuse watery diarrhea preceded by anorexia and vomiting, cramping abdominal pain, general feeling of tiredness, fever
Amoebic dysentery	*Entamoeba histolytica*	Hand-to-mouth transfer of feces, ingestion of water contaminated with amoebic cysts, ingestion of contaminated raw vegetables	Acute dysentery with fever, chills, and bloody or mucoid diarrhea
Giardia	*Giardia lamblia*	Hand-to-mouth transfer of cysts from the feces of infected individual, ingestion of water contaminated with cysts	Chronic diarrhea, abdominal cramps, bloating, frequent loose and pale greasy stools, fatigue, weight loss
Scombroid poisoning	Histamine-like toxins from bacterial overgrowth	Consumption of spoiled fish, particularly tuna and similar fish	Histamine-like reaction, rash, difficulty breathing, vomiting
Anasikiasis	*Anasikiasis* (nematode or round worm) *Gnathostoma* (helminth)	Consumption of raw fish (especially cod, herring, mackerel and salmon), and cephalopods (such as squid).	Asymptomatic, eosinophilia, abdominal discomfort, intestinal hemorrhage, granulomatous reaction, allergic reactions
Diphyllobothriasis	*Diphyllobothriasis* (fish tapeworm)	Consumption of raw fish (particularly preparation of gefilte fish but also raw Pacific salmon)	Asymptomatic, megaloblastic anemia (secondary to vitamin B12 deficiency), eosinophilia
Skin infection	*Stapholococcus aureus*	Skin contact with contaminated water and/or sand	Skin infection, sepsis, toxic shock syndrome, and death (the latter in very rare cases)
Harmful Algae-related Illnesses			
Amnesiac shellfish poisoning (ASP)	Domoic acid	Bivalve shellfish, primarily scallops, mussels, clams, oysters & possibly fish	Vomiting, diarrhea, abdominal pain and neurologic effects (confusion, memory loss, disorientation, seizure and coma)
Diarrheic shellfish poisoning (DSP)	Okadaic acid & dinophysistoxins	Bivalve shellfish, primarily scallops, mussels, clams, oysters	Diarrhea, abdominal pain, chills, headache, fever
Neurotoxic shellfish poisoning (NSP)	Brevetoxins	Bivalve shellfish, primarily mussels, oysters, scallops, & possibly fish	Tingling and numbness of lips, tongue, and throat; muscular aches; dizziness; reversal of the sensations of hot and cold; diarrhea and vomiting
Paralytic shellfish poisoning (PSP)	Saxitoxins	Scallops, mussels, clams, oysters, cockles & certain herbivorous fish (e.g., pufferfish), and crabs	Paresthesias of mouth and lips, weakness, dysphasia, dysphonia, respiratory paralysis, diarrhea, nausea, vomiting
Ciguatera fish poisoning	Ciguatoxins, maitotoxin, scaritoxin	Large reef fish (e.g. grouper, red snapper, amberjack, barracuda [most common])	Abdominal pain, nausea, vomiting, diarrhea followed by paresthesias, reversal of hot/cold, pain, weakness. Can proceed to bradycardia, hypotension, increase in T wave abnormalities. Symptoms may persist for up to years.
Azaspiracid shellfish poisoning (AZP)	Azaspiracid	Bivalve shellfish	Nausea, vomiting, liver damage
Florida red tide respiratory irritation	Brevetoxins	Aerosolized seawater	Acute eye irritation, acute respiratory distress (nonproductive cough, rhinorrea), asthma exacerbation
Blue green algae (Cyanobacteria)	Anatoxins, axitoxins, icrocystins, nodularins, cylindrospermopsins	Direct contact with water, inhaling aerosols, drinking water, and possibly seafood	Skin and eye irritation, nausea, vomiting, respiratory distress, liver damage

Table 1. Ocean-Borne Health Threats to Humans (continued).

Disease	Cause	Common Associated Vectors or Exposures	Common Signs and Symptoms
Marine Creatures			
Fugu and pufferfish poisoning	Saxitoxin, Tetrodotoxin	Consumption of certain species of pufferfish	Paresthesias of mouth and lips, weakness, dysphasia, dysphonia, respiratory paralysis, diarrhea, nausea, vomiting
"Sea bather's eruption" ("swimmer's itch" or "sea lice")	Larvae of jellyfish such as *Linuche unguiculata* (Thimble jellyfish); and *Schistosoma cercaria* (free-swimming flatworm found in Florida)	Skin contact	Itchy rash, hives, particularly along bathing suit lines; may be more severe in children; allergic reactions
Jellyfish stings	Jellyfish such as: *Cyanea capillata* (Lion's mane jellyfish), *Aurelia aurita* (Moon jelly), *Stomolophus meleagus* (Cannonball jellyfish), *Cassiopeia xamachana* (Mangrove upside-down jellyfish), *Pelagia noctiluca* (Purple jellyfish), *Chrysaora quinquecirrh*a (Sea nettle), *Carybdea alata* (Sea wasp), *Linuche unguiculat*a (Thimble jellyfish), *Drymonema dalmatinum* (Stinging cauliflower)	Skin contact with jellyfish, particularly the tentacles	Burning itchy rash, hives, rarely systemic reaction and even death; allergic reactions
Fire coral	Fire Coral such as: *Millepora complanata* (Blade fire coral), *Millepora alcicornis* (Branching fire coral), *Millepora squarrosa* (Box fire coral), *Tedania ignis* (Fire sponge), *Microciona prolifera* (Red moss sponge), *Fibulia nolitangere* (Poison bun sponge)	Skin contact with fire coral	Rash, itching, burning, allergic reactions
Sea urchin spines	Sea urchins such as: *Diadema antillarum* (Long-spined sea urchin), *Diadema setosum* (Black spiney sea urchin)	Penetration of skin by spine(s)	Skin puncture, pain, tenderness, secondary bacterial infections at site of puncture
Sting ray spines on tail	Sting ray	Penetration of skin by spine on tail	Skin puncture, pain, tenderness, secondary bacterial infections at site of puncture; allergic reactions; rarely death
Lionfish and scorpionfish spines	Lionfish and Scorpionfish such as: *Scorpaena plumieri* (Spotted scorpionfish), *Scorpaena grandiconis* (Plumed scorpionfish), *Scorpaenna brasiliensis* (Barbfish), *Pterois volitans* (Red firefish/Lionfish)	Penetration of skin by spine(s)	Pain, headache, nausea, confusion, fainting, death
Catfish spines	Catfish such as: *Arius felis* (Hardhead catfish), *Bagre marinus* (Gafftopsail catfish), *Galeichthys felis* (Common saltwater catfish)	Penetration of skin by spine(s)	Pain, swelling, numbness; rarely, fainting, reduced heart rate
Bites	Sharks and other predatory species such as wahoo, barracuda and seasnakes	Penetration of skin, muscle, bone, viscera by teeth	Pain, amputation, death

ensure safer seafood products, seafood poisonings are still under-reported and may be increasing in incidence and geographic distribution. For instance, during a period of unusually warm surface waters in 2004, oyster farms in Prince William Sound, Alaska, were devastated by an outbreak of a highly virulent form of *Vibrio parahaemolyticus*, resulting in 63 confirmed human cases plus others in marine mammals.

Humans can also be exposed to pathogens, biotoxins, or chemical contaminants by swimming or recreating in ocean waters or drinking tainted water. The CDC, EPA, and the Council of State and Territorial Epidemiologists maintain a collaborative surveillance system for collecting and reporting on the occurrence and cause of waterborne disease and outbreaks in drinking and recreational waters. However, outbreaks resulting from exposures to recreational waters, particularly marine waters, are often under-reported and/or misdiagnosed. Further, CDC concluded that the incidence of infections associated with recreational water use has steadily increased over the last several decades. Estimated increases in occurrence of gastrointestinal illness caused by swimming in contaminated waters at beaches in Orange and Los Angeles Counties, California correspond to an annual negative economic impact of $21 to $51 million. If one extrapolates from these results for just two counties to the more than 20,000 instances of closings and advisories annually at coastal and Great Lakes beaches, the public health costs associated with illnesses potentially occurring as a result of exposures on beaches could be staggering.

HABs are proliferations of microscopic algae that harm the environment and humans by producing toxins that accumulate in shellfish and fish and concentrate up the food chain. Such blooms occur naturally but have increased in number, frequency, and type in recent years. The biotoxins produced by HABs are not destroyed by cooking or other methods of food preparation and can cause serious illness and even death in humans. HABs have been a persistent problem in several areas of the country, including Alaska, with some documented human deaths caused by paralytic shellfish poisoning from consumption of contaminated shellfish. Other HAB toxins, such as domoic acid, could become more prevalent as a result of climate change. People can also be affected by inhalation of aerosolized HAB toxins while walking on the beach or from coming into direct contact with contaminated waters. Recent work by the CDC and OHH researchers found significant increases in reported respiratory symptoms among recreational beachgoers in Florida after a red tide (*Karenia* spp.) exposure. Another study showed emergency room visits related to respiratory diagnoses rose 54 percent in years when red tides occurred in coastal Florida. While probably significantly underestimated, the overall economic effects of HABs in the U.S. (not including freshwater outbreaks) are at least $82 million per year, with public health costs of illness accounting for 45 percent of the total, commercial fisheries impacts for 46 percent, local recreation and tourism impacts for 5 percent, and costs of coastal monitoring and management for 4 percent.

A red tide (Karenia brevis) bloom along a Florida beach impacts local tourism and can induce respiratory symptoms among beachgoers. Photo credit: P. Schmidt and with permission from TOS

Other ocean health threats include the prevalence of emerging chemical contaminants (ECC), such as drugs used to treat diseases in humans and domestic animals, flame retardants, stain repellants and non-stick coatings, and pesticides in aquatic environments. Numerous such compounds are rapidly accumulating in coastal waters, appear to be persistent, and some are concentrated as they move up the food chain, as has been documented in marine mammals that feed at a similar trophic level as humans. Possible effects on estuarine organisms include

Newly recognized emerging chemical contaminants such as flame retardants, used in furniture and electronics, are rapidly increasing in coastal waters, bio-magnify up the food chain and may affect the health of aquatic species and people.

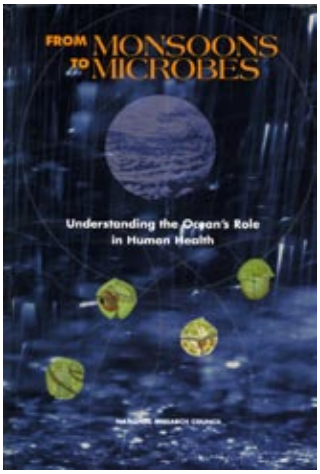
cancer; impacts to reproductive physiology, early development, immune function, and metabolism; and other species-specific effects that could impair healthy ecosystem functioning. The health effects of human exposures to these chemicals via the complex circulation of environmental contaminants through air and water are not well understood and a coordinated approach to assessing the effects of these exposures is needed.

Coastal population densities are two–five times higher than inland, and coastal land is being consumed for urban development three–six times as fast as the rate of population growth, resulting in major and permanent alterations to coastal ecosystems. These trends appear to be accelerating, with potentially serious impacts on the long-term health of coastal ecosystems and the people who live, work and recreate there. The latest assessments of coastal-ecosystem condition can be found in the National Coastal Condition Report II (NCCR) prepared by the EPA with contributions from NOAA, the U.S. Fish and Wildlife Service (USFWS), and the USGS. The report, using data from the period 1997–2000, rated U.S. coastal waters as generally fair, with some poor areas, in terms of water quality, sediment contamination, and status of biological resources. Relatively few areas were rated good, and little improvement was noted over the previous assessments in NCCR I, which used data from 1990–1996.

U.S. coastlines are highly desired locations for residents and visitors with rates of urban development much higher than the national average, resulting in significant alterations to coastlines and impacts to coastal ecosystem resiliency. Photo credit: R. Kresge

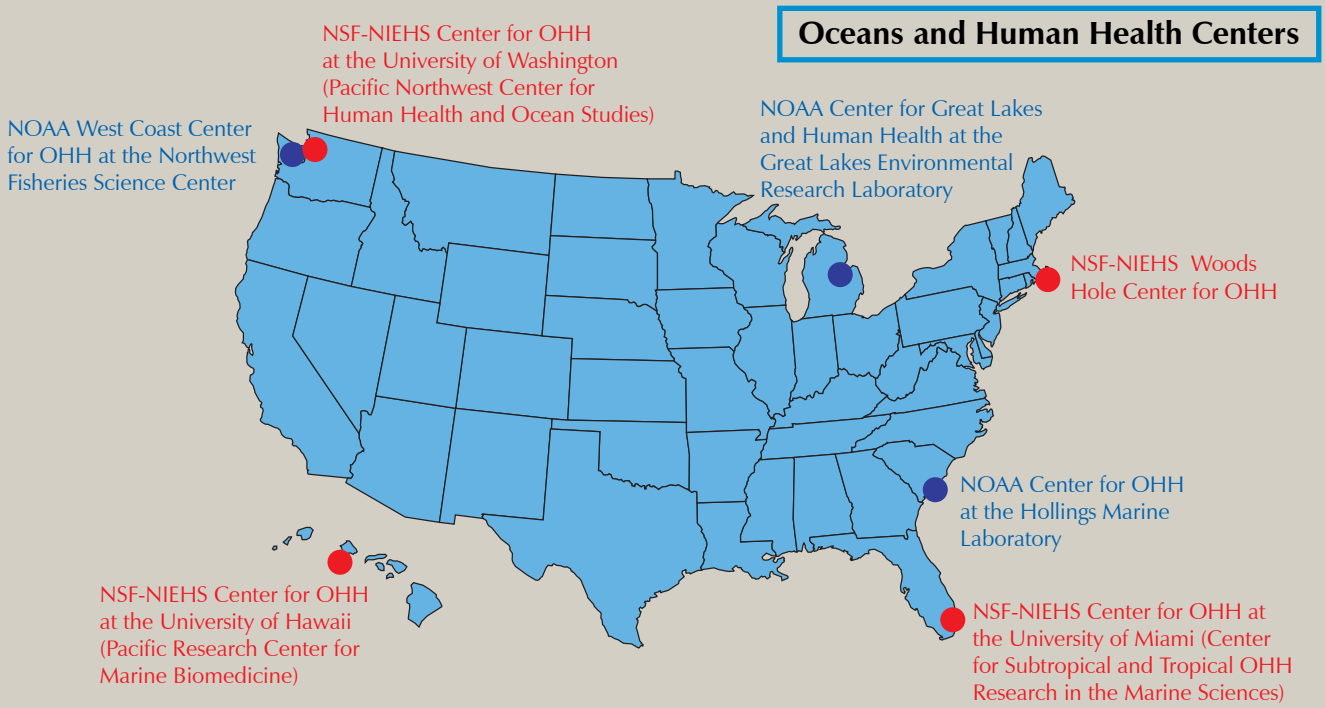
Brief History of the Interagency Oceans and Human Health Program

Widespread recognition that the ocean plays an important and growing role in affecting human health was sparked when the U.S. sponsored an OHH-themed pavilion at the 1998 World's Fair in Lisbon, Portugal, followed soon thereafter by publication of the National Research Council's (NRC) 1999 seminal report, *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health*. Subsequent NRC reports, such as *Under the Weather: Climate, Ecology and Infectious Disease* (2001) and *Marine Biotechnology in the Twenty-First Century: Problems, Promise, and Products* (2002), and workshops led by NSF, NIEHS, and NOAA further substantiated the need for action at the federal level. Together, these activities and reports highlighted the importance of OHH activities and coordination among federal agencies.



NSF and NIEHS joined forces, held a community workshop in December 2001, and issued a Request for Proposals in November 2002 for the establishment of academic centers for OHH. For NOAA, Congress appropriated funding beginning in FY 2003 for the agency to establish an Oceans and Human Health Initiative (OHHI) to "coordinate and focus agency activities on critical areas of concern and identify critical gaps in coverage, and … to be used for critical research and projects aimed at closing identified gaps." Congress directed NOAA to consult with NSF and other federal agencies, establish NOAA Centers of Excellence in OHH, create a national advisory panel, and support competitive external grants, distinguished scholars, and trainees in OHH. NOAA sponsored a community workshop in October 2003 to solicit input for development of its OHHI.

The NSF and NIEHS jointly awarded five-year OHH Center grants to four academic institutions in May 2004. NOAA selected its three OHH Centers of Excellence via an internal peer-reviewed competition a few months later, followed by initiation of its external OHHI grant program. Also in 2004, the USCOP released its final



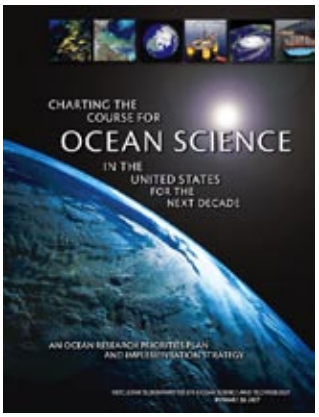
Adapted from TOS.

report, which spoke to the importance of a national OHH program. In December 2004, Congress passed the OHH Act (see Appendix 1) and established an Interagency OHH Research Program to "… improve understanding of the role of the oceans in human health" and officially authorized NOAA's OHHI. The Administration's *Ocean Action Plan* response to the USCOP report also included a commitment to "…develop a strategic research plan for oceans and human health."

Requirement for an Interagency OHH Research Implementation Plan and Coordination with the National Ocean Research Priorities Plan

This Interagency OHH Research Implementation Plan was prepared pursuant to requirements of the OHH Act of 2004. The Plan builds upon the institutionalized and formally named "OHH" programs of NOAA, NSF, and NIEHS and the expressed interest of other agencies with a wealth of OHH-related activities, including the CDC, EPA, FDA, MMC, NASA, and USGS. As stated in the OHH Act, the purpose of the Implementation Plan is to establish "the goals and priorities for Federal research which most effectively advance scientific understanding of the connections between the oceans and human health, provide usable information for the prediction of marine-related, public health problems, and use the biological potential of the oceans for development of new treatments of human diseases and a greater understanding of human biology." The OHH Act also directed the National Ocean Research Leadership Council to ensure that ocean and coastal observations provide useful information necessary to reduce marine public health problems.

This Interagency OHH Research Implementation Plan was developed by the Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health (IWG-4H). In fall 2005, the Joint Subcommittee on Ocean Science and Technology (JSOST) of the National Science and Technology Council (NSTC) Committee on Science and the Committee on Environment and Natural Resources and the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI) established the IWG-4H. The ICOSRMI and JSOST are planning and coordinating bodies under the President's cabinet-level Committee on Ocean Policy. This document presents a comprehensive interagency effort to coordinate and enhance OHH-related research over the next decade. It complements and expands upon the "Enhancing Human Health" theme described in *"Charting the Course for Ocean Science*



in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy", prepared by the JSOST pursuant to the Administration's *Ocean Action Plan*. Numerous participants in the Interagency OHH Program contributed to the development of the "Enhancing Human Health" theme, which highlights four OHH-related research priorities:

- Understand sources and processes contributing to ocean-related risks to human health.
- Understand human health risks associated with the ocean and the potential benefits of ocean resources to human health.
- Understand how human use and valuation of ocean resources can be affected by ocean-borne human health threats and how human activities can influence these threats.
- Apply understanding of ocean ecosystems and biodiversity to develop products and biological models to enhance human well-being.

"Charting the Course for Ocean Science" also identifies four near-term priorities to be pursued over the next two to five years to initiate rapid progress toward the 20 ocean research priorities highlighted in the plan. One of the near-term priorities is the development of new sensors that will, among other things, provide essential information to enable forecasting of ocean-related risks to human health and safety, including those associated with pathogens, HABs, extreme weather events, natural disasters, and changing ocean conditions.

Goals for the Interagency OHH Research Implementation Plan

This plan focuses on coordinated federal activities that will foster "interdisciplinary research among the ocean and medical sciences, and coordinated research and activities to improve understanding of processes within the ocean that may affect human health and exploration of the potential contribution of marine organisms to medicine and research," as required by the OHH Act of 2004. The Interagency OHH Program will focus on the following broad goals:

Establish an OHH research agenda focused on the highest priority topics and activities - including the appropriate mix of infrastructure to allow scientists to develop a requisite understanding of ocean-system properties and processes; assess, predict, and prevent human health risks and impacts; and discover and develop new marine bio-products that benefit mankind. This research agenda must also incorporate economic and socio-cultural dimensions, as well as epidemiologic approaches, into a fuller understanding of ocean-human health linkages. It should capitalize on further development and application of advances in such areas as genomics, proteomics, metabolomics, analytical chemistry, microbiology, source tracking, aquaculture, use of biological sentinels and indicators, and other new or improved approaches for tracking movements of pathogens, toxins, and chemical contaminants through the environment.

Promote a robust interdisciplinary OHH research approach - that links marine and biomedical sciences to create a fundamentally new and dynamic research community with the breadth of expertise required to address diverse human health questions within the complexity of ocean systems

Establish and expand collaborative partnerships - that link academic, federal, state, and private researchers with public health workers, environmental/natural resource managers, and multiple user groups to facilitate the acquisition of OHH information and its application through technology transfer and training. Such partnerships will ensure inclusion of OHH-supportive data collection, integration, analysis, and modeling within the larger framework of national and international ocean observation efforts.

Expected Benefits to the Nation from OHH Research

The interagency OHH planning effort has identified seven major benefits that will accrue to the United States as a result of continued and coordinated research in OHH, accompanied by rapid application of research findings to real-life situations involving health threats to humans and potential for development of health-enhancing products.

1) **Improved policy decisions that reduce health risks and help ensure healthy and productive marine ecosystems and people via enhanced monitoring and health surveillance for humans and wildlife -** These activities include developing and employing a range of biosensors, models, databases, and predictive tools to provide early warning and other information for management, control, and prevention by resource and public health managers and policy-makers. Connecting data from new biosensors for pathogens, contaminants, HABs, and toxins with data from ocean and coastal observing systems and new epidemiological studies of human disease will enable significant advances in protecting the public from ocean-borne health threats. In addition, implementation of sophisticated techniques for surveillance of disease in ocean wildlife populations will substantially decrease the risk to humans from diseases that may jump from animals to humans, such as avian influenza.

2) **Discovery and application of marine-based pharmaceuticals and other beneficial natural products -** A broad effort to discover, test, develop, and market new products, including drugs, from the ocean will result in improved human health, enhanced private sector returns, increased employment opportunities, and development of a new ocean business sector based on renewable resources and novel ecologies and chemistries.

3) **Increased basic knowledge -** A strong Interagency OHH Research Program will produce significant advances in basic scientific information and thereby provide a stronger foundation for understanding and preventing health threats to humans and managing coastal development and land to minimize adverse environmental and health impacts on people and coastal ecosystems.

4) **Enhanced understanding of human disease processes -** This program will develop and utilize new mechanistic and conceptual models derived from marine species and marine sentinel organisms and habitats. These models will enable major advances in understanding a broad range of human-disease processes, resulting in improvements in prevention, intervention, and treatments to protect human health.

5) **Improved understanding and communication about comparative benefits and risks of seafood consumption -** Coordinated interagency work will allow the nation to maximize health benefits and minimize risks from the consumption of seafood and will provide essential information to empower consumers and subsistence users to make well-informed individual choices about seafood.

6) **Increased economic returns -** Application of OHH research results is expected to lead to decreased economic losses related to beach closures, lowered risks for exposure of people to health risks from ocean waters and related health care costs, and maintenance of coastal property values through enhanced ability to minimize occurrences of ocean health threats. In addition, major new business development in a burgeoning ocean natural products sector should lead to increased economic returns.

7) **Improved ocean stewardship and ocean literacy -** Effective communication of the effects of the oceans on human health and vice versa will enable a well-informed public to act as stewards of coastal and marine ecosystems, thereby reducing or preventing human health risks and maximizing human health benefits.

Coordination of oceanographic research across agencies, such as at-sea sampling, will provide many benefits to the U.S. Photo credit: NOAA Northwest Fisheries Science Center (NWFSC)

Chapter 2: Existing Agency OHH Programs and Related Activities

The OHH Act of 2004 established "…a national research program to improve understanding of the role of the oceans in human health" and stated that such a program "will build on and complement the ongoing activities of the National Oceanic and Atmospheric Administration, the National Science Foundation, and other departments and agencies." NOAA, NSF, and NIEHS have specifically authorized research activities focused on OHH, and several other agencies have missions related to OHH issues (e.g., CDC, EPA, FDA, MMC, NASA, USGS). Current OHH activities of individual agencies, as well as some important interagency collaborations, are summarized in this chapter. Excellent examples of interagency collaboration include the OHH program's responses to Hurricane Katrina, the Massachusetts Bay HAB event, and epidemiologic studies of health effects of aerosolized Florida red tide toxin, as described herein. More information on interagency OHH program activities will be presented in the OHH Annual Report, to be published in the near future.

Named OHH Programs (NSF, NIEHS and NOAA)

NSF and NIEHS

In June 2000, NSF and NIEHS began discussions about a collaborative program with the goal of bringing together the expertise of the medical community and the ocean science community to create "Centers of Excellence" where OHH problems would be addressed in an interdisciplinary research context (see Appendix 2: Agency Prospectus for NSF). HABs, water- and vector-borne diseases, and the search for marine pharmaceuticals were identified as foci for the initial OHH effort. In December 2001, the agencies convened a workshop involving 24 scientists, representing a broad range of relevant expertise, to outline the scientific issues and discuss strategies for implementation of an interdisciplinary initiative. NSF and NIEHS used recommendations from this workshop to develop an Interagency Request for Applications (RFA) to fund several OHH Centers. These agencies received proposals in March 2003 and, after subsequent peer review, they funded four centers in 2004.

NSF and NIEHS expressed an overarching vision for their OHH Centers in the call for applications:

> *"The field of oceans and human health currently represents a gap between the two participating agencies missions. As such, it also represents a logical opportunity for partnership. Together, NSF and NIEHS plan to bridge this gap and promote state-of-the-art, interdisciplinary research that unites the oceanographic and medical communities, allows for cross-fertilization of ideas and technologies, and provides more comprehensive insight of the potential risks and benefits to human health generated by the oceans."*

The four NSF-NIEHS centers are in their fourth year of operation and have collaborated with a number of non-affiliated academic institutions, formed working partnerships with several federal agencies (CDC, EPA, USGS, USDA, Naval Research Lab [NRL], NOAA) and state and local heath departments, grassroots groups, and others. To date, Center activities have involved more than 60 senior researchers, more than 10 postdoctoral researchers, and more than 40 graduate students and undergraduates. Already, at least 40 publications have resulted from the Centers' research activities, and there have been many presentations of OHH activities at national and international scientific meetings. The combined investment for NSF and NIEHS for the present five-year duration of the Centers' awards is approximately $25M.

A brief overview of Center projects, partnerships, some initial successes, and education and outreach efforts is provided here.

NSF-NIEHS Woods Hole Center for Oceans and Human Health (WHCOHH)

The mission of the WHCOHH is to improve public health through enhanced understanding of how oceanic processes affect the distribution and persistence of human pathogens and toxin-producing organisms. The Center is a partnership that includes the Woods Hole Oceanographic Institution (WHOI), the Marine Biological Laboratory, and the Massachusetts Institute of Technology. WHCOHH researchers study the distribution of biological agents in temperate coastal ocean waters that may negatively impact human health.

Two research projects focus on blooms of toxic dinoflagellates of the genus *Alexandrium*. *A. fundyense* is responsible for paralytic shellfish poisoning (PSP), and *A. ostenfeldi*i is associated with an emerging toxin threat. One project explores the extent of natural genetic diversity within *Alexandrium* in the Gulf of Maine and will develop genetic markers capable of distinguishing among the different *Alexandrium* genotypes. A second coordinated project is developing a suite of population-dynamics models to explain or predict the distribution of *Alexandrium* genotypes within the Gulf of Maine. These HAB projects build on previous studies funded by NSF and NOAA. Results from the WHCOHH HAB-focused projects will provide a comprehensive understanding of toxic *Alexandrium* bloom dynamics which is required to model and predict human exposure to toxin through harvested shellfish. One of the initial successes of the combined HAB projects was the mapping of a massive red tide that occurred in Massachusetts Bay in May of 2005 (see Box 1).

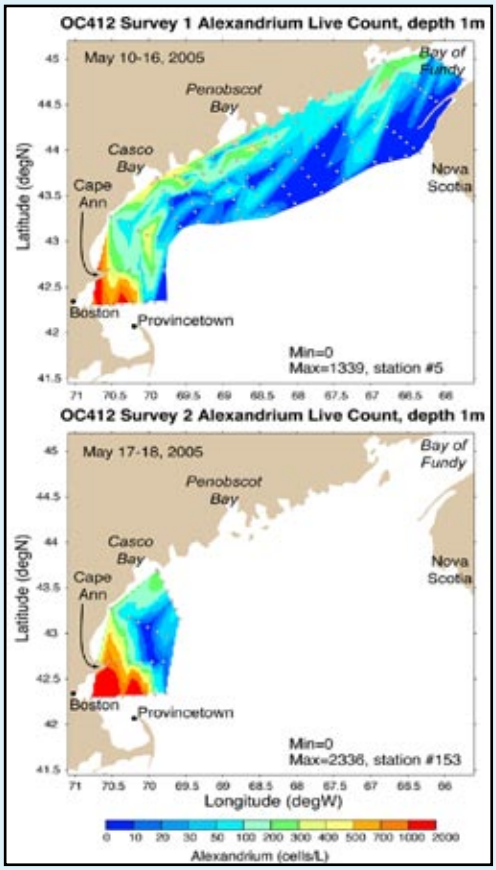
The two other WHCOHH projects address the distribution of pathogens in coastal waters. The first examines the diversity, distribution, and persistence of human pathogens in the coastal marine environment of Mt. Hope Bay, Mass., an estuarine environment heavily impacted by humans. These initial studies will assist in establishing and validating a water quality model for Mt. Hope Bay and a model system for identifying and preventing human health problems from water-borne pathogens in other coastal environments (see Box 13). The second project examines the ecology and evolution of two important human bacterial pathogens, *Vibrio vulnificus* and *V. parahaemolyticus*, in the Plum Island estuary, Mass.. This project is expected to yield major insights into what determines the presence of pathogens in coastal waters and what environmental factors select for the presence of pathogenicity traits in bacteria. These in-depth studies of pathogens are among the first to examine the dynamics and diversity of human pathogens in coastal waters on multiple spatial and temporal scales.

Pilot projects are augmenting ongoing research and extending research in the areas of natural toxins and natural bioactive compounds. A genomics core facility at WHCOHH provides DNA-sequencing services, microsatellite analysis, and computational support to Center investigators and collaborators.

Researchers at WHCOHH are cooperating with the USGS, NRL, and USDA. HAB research has included

Box 1: Massive Red Tide in Massachusetts Bay

In May 2005, with funding and other support provided by NOAA and NSF and in collaboration with other agencies (see Box 45), researchers at the WHCOHH applied cutting-edge marine field instrumentation and biochemical technology to study and map the largest outbreak of red tide in Massachusetts Bay in more than 30 years. The research team used in-water sensors (including those operated by the Gulf of Maine Ocean Observing System), state-of-the art shipboard optical and molecular biological techniques, and coupled ecological-physical models to characterize the initiation and development of a bloom of *Alexandrium fundyense*, the major red tide species in the Gulf of Maine. These combined capabilities, organized under the umbrella of the WHCOHH, enabled the researchers to characterize the development of this toxic bloom in real time. Scientific understanding of what factors initiate red tides in the region is benefiting resource managers charged with monitoring shellfish for threats to human health. The team's discovery and tracking of this bloom helped prevent serious public health consequences.



Alexandrium concentration mapped from shipboard measurements.

international collaborations with the National Research Institute of Fisheries and Environment of the Inland Sea in Hiroshima, Japan, and participation by a WHOI researcher in a new European Commission-U.S. collaborative project.

NSF-NIEHS Center for Oceans and Human Health at the University of Miami (Center for Subtropical and Tropical Oceans and Human Health Research in the Marine Sciences [UMCOHH])

The primary mission of the UMCOHH is to focus innovative interdisciplinary scientific research on OHH issues affecting the subtropical and tropical oceans. The Center's partners include Florida International University, Florida Department of Health, University of Florida, Nova Southeastern University, CDC, University of North Carolina at Wilmington, Mote Marine Laboratory, Florida Poison Information Center at Miami, Lovelace Respiratory Institute, and NOAA.

One important study is investigating the use of microbial indicators of human health effects in subtropical beaches and other recreational marine waters. This research incorporates modeling of the physical oceanographic environment with the characteristics of microbes causing or indicating public health problems on beaches. The goal of this project is to discover basic, predictive indicators of coastal contamination, including residence times and transport pathways of pathogenic and indicator microbes in coastal systems.

A second research project focuses on discovery and characterization of new HABs. Many species of dinoflagellates, cyanobacteria, and other algae produce toxins that are not presently noticed as harmful to humans because those species generally do not occur in dense-enough concentrations to produce harmful quantities of toxins or because they are in areas of the ocean where humans are not exposed to the toxins. However, circumstances are likely to change, with the possibility that these previously unrecognized toxin producers could become important threats to human health (see Box 2). Another HAB-related project is using a functional genomics approach to examine toxin production by the Florida red tide organism, *Karenia brevis* (see Box 33).

Box 2: Discovery of New Toxic Algal Species

Over the past few decades, multiple species of harmful algal organisms with newly discovered toxins have appeared, possibly due to increased nutrient loading in coastal waters. Many other species of marine algae also may produce toxins, but they have not yet been recognized because they do not occur in high-enough concentrations or are not located where they can cause problems to humans and other animals at present. However, it is highly likely that some of these algae will become HABs in the future, and that low concentrations of their toxins already occur in ocean food webs and ecosystems.

Researchers at UMCOHH maintain subtropical and tropical algal cultures to screen for existing and emerging HAB species. Photo credit: K. Rein

The UMCOHH is examining numerous algal species from subtropical and tropical waters for the production of a variety of types of HAB toxins. For this exploratory work, the Center has developed automated methods for isolating viable single cells using flow cytometry. To date, researchers have isolated 67 uni-algal cultures. Genomic sequences indicate that many of these isolated strains are previously undescribed HAB species. Preliminary screening has already indicated that at least 22 of these isolates, representing an as-yet unknown number of species, are potentially toxic to humans and other organisms.

The CDC and NOAA are organizational partners at the University of Miami OHH Center. UMCOHH personnel also collaborate with NIEHS researchers at NIEHS Marine and Freshwater Biomedical Sciences Center and the NIEHS-funded Florida International University-University of Miami Advanced Cooperation in Environmental Health Research Program. In addition, the UMCOHH collaborates with the University of North Carolina, Wilmington, the CDC, Florida Department of Health, Mote Marine Laboratory, Lovelace Respiratory Institute, the Florida Marine Research Institute and other partners in an ongoing NIEHS-funded project to investigate human and animal exposures to and health effects of aerosolized Florida red tide toxin (see Box 25).

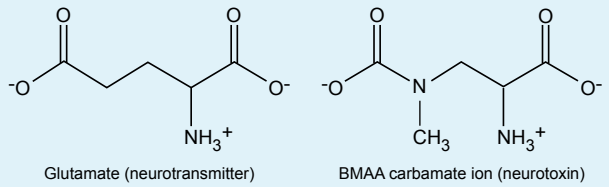
NSF-NIEHS Center for OHH at the University of Hawaii (Pacific Research Center for Marine Biomedicine, PRCMB)

PRCMB builds on the University of Hawaii's research strengths in oceanography and tropical medicine and its location in the center of the largest ocean on Earth. Through the collaboration of an interactive milieu of oceanographers and medical researchers, the PRCMB is conducting hypothesis-driven, interdisciplinary research on HABs, water- and vector-borne diseases, and marine-derived pharmaceuticals and probes, in the thematic context of tropical coastal waters and small islands. In conducting its programs, PRCMB is partnering with other universities; federal, state, and local agencies; and the private sector.

The PRCMB's HAB-related work is focused on ciguatera fish poisoning, attempting to develop methods to detect ciguatera poisons and determine what is responsible for the variability of ciguatera toxins in nature (see Box 22). Another research project is studying local water quality and human health effects from water-borne pathogens. Specifically, this project is attempting to identify useful indicator organisms for sewage contamination of Hawaiian (tropical) coastal waters, developing a procedure to use mollusks to monitor water for viruses, and monitoring beach environments for staph bacteria (*Staphylococcus aureus*) virulence genes to determine what portion of the bacterial population represents a human health risk. The health effects of these pathogens in coastal waters are being determined based on the numbers of virulence characteristics they exhibit and the exposure and susceptibility of human populations. A third research project deals with exploring the ocean for sources of new pharmaceuticals and biochemical probes and discovering new, biologically active natural products. The Pharmaceutical Lead and Probe Discovery Program and the PRCMB Core Facility for the Culture and Characterization of Marine Microbes are working closely on the discovery of novel bioactive compounds. This process begins by taking samples from Hawaii's various marine environments, ranging from the nutrient-poor waters of the open ocean to the nutrient-rich environments of Kaneohe Bay. The PRCMB core facility is using innovative, high-throughput culturing techniques to generate pure cultures of heretofore unculturable marine microbes and is providing marine microbe culture and characterization support for all the Center's research projects. Screening of cyanobacterial cultures has led to the discovery of the widespread occurrence of a neurotoxic amino acid (see Box 3).

Box 3: Cyanobacterial Neurotoxin Discovered at PRCMB

In April 2005, researchers at the University of Hawaii's Center for OHH, in conjunction with colleagues at the Institute for EthnoMedicine and elsewhere, reported that a neurotoxin, ß-N-methylamino-L-alanine (BMAA), is produced by all known groups of cyanobacteria in freshwater, marine, and terrestrial environments. Previous investigations of this neurotoxin in the cyanobacterial symbionts of cycad palm trees in Guam led researchers to hypothesize that BMAA is the probable cause of the high incidence of amyotrophic lateral sclerosis/parkinsonism dementia complex (ALS/PDC) among the Chamorro people. In Guam, human exposure to high quantities of BMAA results from unique components of the traditional Chamorro diet, including cycad tortillas, flying foxes, and possibly other feral animals. The ubiquity of cyanobacteria in diverse terrestrial and aquatic environments suggests that ingestion of BMAA, with consequent potential health threats, may occur through even less esoteric routes, including direct consumption of cyanobacteria or cyanobacterial hosts, bioaccumulation in food chains, or exposure to cyanobacteria-contaminated water supplies.



BMAA chemical structure. High exposures to BMAA may be linked to the occurrence of Lou Gehrig's and Parkinson's disease.

At PCRMB, the ciguatera HAB project collaborates with the NOAA marine toxin facility in South Carolina in characterizing the ciguatera toxins. There is also close coordination with the Hawaii Department of Health and the Hawaii Aquaculture Development Program to share information about ciguatera-toxin problems in Hawaii waters. This project also provides algal material to the Cancer Research Center of Hawaii, an NIH/National Cancer Institute facility at the University of Hawaii, to screen for interesting bioactive compounds. The Center's water-borne pathogen project has collaborated with the Division of Environmental Quality, the Watershed Division of the City and County of Honolulu, the Hawaii Department of Health, CDC, EPA, Staub Clinic and Hospital, Queens Medical Center, and the Surfrider Foundation. The Pharmaceutical Lead and

Pharmacological Probe Discovery research project has formed a working partnerships involving NOAA's Center for Oceans and Human Health at the Hollings Marine Laboratory and with Diversa Corporation, a biotechnology company based in San Diego, CA (see Box 23).

NSF-NIEHS Center for OHH at the University of Washington (Pacific Northwest Center for Human Health and Ocean Studies, PNW H2O)

The goal of the PNW H2O is to elucidate relationships between marine processes and public health consequences of HABs, by focusing specifically on the toxic diatom *Pseudo-nitzschia*. Studies are being conducted on *Pseudo-nitzschia* dynamics and human impacts in two major representative ecosystems, the Puget Sound estuary and Washington's Pacific coast. The Center is exploring underlying differences between the coastal environments in the Pacific Northwest and Puget Sound. The Center is composed of a multidisciplinary research team that includes researchers from universities as well as state and federal government agencies, with organizational partners that include the University of Washington, Institute for Systems Biology, Washington State Department of Ecology, Washington State Department of Health, and NOAA's Northwest Fisheries Science Center and its West Coast Center for Oceans and Human Health (WCCOHH).

One research project is focused on the physical, chemical, and biological factors that promote blooms and toxin release from *Pseudo-nitzschia* cells by coupling molecular and genomic techniques with environmental data. This project's objectives are to identify nearshore and offshore environmental factors that influence the dynamics and toxicity of *Pseudo-nitzschia* blooms (see Box 4). This project is using genomic techniques to examine the genetic variations among *Pseudo-nitzschia* populations and to determine the underlying mechanisms of toxin production (see Box 34). This project builds on results obtained from previous funding from NSF through the Ecology and Oceanography of HABs (ECOHAB) and the Biological Oceanography Program.

A second PNW H2O project seeks to develop a predictive understanding of the factors that regulate the uptake and accumulation of toxic domoic acid in benthic bivalve mollusks. Researchers are attempting to model the transport of toxic algae from offshore waters to nearshore benthic organisms and determine the rate of accumulation and retention of the toxin in local benthic organisms, with special emphasis on commercially harvested species (see Box 20).

A third research project examines the specific molecular mechanisms that account for the toxicity of domoic acid in humans and other vertebrates. This project studies how age affects susceptibility to this neurotoxin and the health risks posed by low-level chronic exposure to domoic acid (see Box 30).

The fourth project focuses on human exposure to domoic acid. Project investigators are partnerning with regional populations to better understand dietary behaviors that contribute to increased exposure and to understand factors that may define "at risk" populations. Such factors can include concurrent dietary exposures, age, cultural practices, and geographic proximity to contaminated shellfish. The human exposure studies provide the link between the Center's basic research on mechanisms of toxicity and environmental domoic acid contamination (see Box 24).

Box 4: Detecting the Toxic Diatom *Pseudo-nitzschia* in Puget Sound Waters

Pseudo-nitzschia species differ in the amount of toxin they can produce, yet differentiating species in a seawater sample is difficult or impossible with traditional microscopy. To predict toxic events, it is essential to be able to rapidly identify blooming species. Using a DNA-based technique known as ARISA, the species in a sample can now be "fingerprinted" and easily identified.

Pseudo-nitzschia diatoms produce high concentrations of domoic acid during algal blooms which can poison marine mammals and humans who eat contaminated shellfish. Photo credit: P. von Dassow

Resources include real-time environmental monitoring, a biosensor development core facility (joint with the university's Genome Sciences), a neurobehavioral facilities core that conducts animal neurobehavioral studies, and a bioinformatics core that provides statistical and other bioinformatic support critical for translation of findings across disciplines.

Outreach, Education, and Training at the NSF-NIEHS COHH

Outreach

The NSF-NIEHS OHH Centers undertake a number of outreach efforts:

- They maintain public Web sites that can be accessed individually or through a link at WHCOHH, http://www.whoi.edu/science/cohh/index.htm.
- They have regular seminar programs where OHH-related topics are presented. These are generally targeted to the local academic community, but most are open to the interested public.
- They have developed outreach materials in collaboration with local Centers for Ocean Sciences Education Excellence (COSEE).

Some Center activities are specifically directed toward local outreach. For example, one pilot project at the WHCOHH provides information about northeast HABs to the public and stakeholders in response to a bloom. The PNW H2O at the University of Washington conducts outreach efforts to strengthen partnerships with local Native American Tribes and Asian Pacific Islander communities.

Education and Training

The NSF-NIEHS OHH Centers provide educational opportunities and training to postdoctoral researchers, graduate students, and undergraduates as an integral part of the awards made to the Centers. Additional undergraduate participation at the Centers is encouraged with Research Experiences for Undergraduate Students ([REU]; see Box 5) supplemental awards to all Centers. Already, over ten postdoctoral researchers and more than 40 graduate students and undergraduates have been involved in Center research activities during their first three years of operation. Postdoctoral researchers and students receive training and experience in a number of fields, including physical, chemical, and biological oceanography; remote sensing; genomic techniques; bioinformatics; epidemiology; toxicology; marine biology; fisheries; statistics; and microbial ecology. In addition to formal education, students gain interdisciplinary training from participating in regular seminar programs and workshops organized at the Centers.

Box 5: NSF Undergraduate REU at the Four NSF-NIEHS Oceans and Human Health Centers

Beginning in 2004 and continuing for five years, two undergraduates per year work closely with researchers in the NSF-NIEHS OHH Center projects, mentored by the lead project researcher. Students have the opportunity to participate in field sampling and environmental modeling, write reports and publications, and conduct literature searches in specific research areas. They are encouraged to write and present their research at appropriate scientific meetings.

REU students get the opportunity to work directly with OHH researchers in the lab and field. Photo credit: S. Lovelace

NOAA's Oceans and Human Health Initiative (OHHI)

NOAA is the nation's lead civilian ocean agency; its vision is "an informed society that uses a comprehensive understanding of the role of the ocean, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions." Based on this vision, and a series of reports that called attention to the role of the ocean in affecting human health, Congress appropriated funds to NOAA beginning in 2003 to establish its Oceans and Human Health Initiative (OHHI). OHHI tackles critical issues, such as "are our waters safe to swim in and to drink[3]" and "is our seafood safe to eat," and how we can guard against growing and emerging health impacts while taking advantage of the many benefits the ocean provides.

The OHHI was officially authorized by the OHH Act of 2004 to coordinate and implement NOAA's research and activities related to the role of the oceans in human health and provide support for agency Centers of Excellence in OHH, external research grants, distinguished scholars, traineeships, and a national advisory panel. The OHH Act specified the scientific scope for the OHHI as research related to the agency's mission, including the use of marine organisms as indicators for marine environmental health, ocean pollutants, marine toxins and pathogens, HABs, hypoxia, seafood testing, identification of potential marine products, biology and pathobiology of marine mammals, marine genomics, marine environmental microbiology, ecological chemistry, and conservation medicine. The OHHI was directed to coordinate with the OHH programs of the NSF, NIEHS and other federal agencies and departments.

The mission of the OHHI is to improve understanding and management of the ocean, coasts and Great Lakes to enhance benefits to human health and reduce public health risks. The OHHI investigates relationships between environmental stressors, coastal condition, and human health to maximize health benefits from the ocean, improve the safety of seafood and drinking waters, reduce beach closures, and detect emerging health threats. In order to accomplish its mission, the OHHI catalyzes innovative and interdisciplinary OHH research; fosters and facilitates strong partnerships among agencies, academia and the private sector on OHH; and develops and delivers useful tools, technologies and environmental information to public health and natural resource managers, decision-makers and the public.

The goals of the OHHI (see Box 6) are to: (1) lead development of early warning systems to forecast threats and predict long-term risks to human health throughout U.S. coastal and Great Lakes waters; (2) investigate and optimize health benefits from the sea; and (3) help develop a robust oceans and human health community working across disciplines and institutions to improve public health.

OHHI Programmatic Structure

NOAA's OHHI includes competitively awarded internal Centers of Excellence in OHH, external research and internal capacity-development grants, distinguished scholars, and traineeships. Of the funds appropriated to the OHHI, at least 50 percent must be expended in support of the external grants, distinguished scholars, and traineeships. A national advisory panel comprised of top marine and biomedical scientific experts helps guide the development and future direction of the OHHI. The OHHI is founded on partnerships among scientists, public health decision-makers and natural resource managers, and across agencies and academia. All of these program elements work together to accomplish OHHI's mission by coordinating research, outreach, education, and data management within OHHI, across NOAA, and with other agencies to strengthen OHH capacity through partnerships and interdisciplinary research and training.

The OHHI conducts research in nearly every coastal region in the United States, with over 75 OHHI Center-based scientists, 26 external and seven internal grants recipients, and two Distinguished Scholars, working across a multitude of local, state, federal, and academic partnerships. Already, OHHI research activities have resulted in over 80 peer-reviewed scientific publications and have been highlighted at more than 50 scientific conferences, workshops, and other meetings. The OHHI strengthens NOAA's capability to conduct and deliver cutting-edge OHH research and directly supports the "One NOAA" approach and its mission, "To understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social and environmental needs." It also supports three of NOAA's four mission goals: "To protect, restore and manage the use of coastal and ocean resources through ecosystem-based management; to understand climate variability and change to enhance

Box 6: NOAA's OHHI Goals and Strategic Objectives

Goal: Early Warning Systems

Lead the development of early warning systems to forecast threats and predict long-term risks to human health throughout U.S. coastal and Great Lakes waters

Strategic Objectives:

- Develop methods, tools, and technologies to predict ocean-related public health risks from pathogens, chemical pollutants, and toxins
- Characterize impacts of coastal ecosystem change, in response to natural factors and environmental stressors such as climate change, land-use and pollution, on ecosystem goods and services related to human health
- Use sentinel species and habitats as integrative indicators of ocean health threats to humans
- Develop and integrate data, tools and technologies applicable to human health into ocean observing systems
- Engage public health and natural resource managers and decision-makers in order to develop and deliver useful products and services
- Evaluate prototype early warning systems and their components for readiness and plan for transition to operations
- Evaluate utility and value of early warning systems and their components to identify, mitigate, and reduce public health risks and related economic and socio-cultural impacts

Goal: Benefits from the Sea

Investigate and optimize health benefits from the sea

Strategic Objectives:

- Assess health benefits and risks of seafood consumption through partnerships with fishery and aquaculture communities
- Partner with subsistence communities to document and evaluate the benefits and risks of marine food products for health promotion and socio-cultural value
- Develop and transfer technology to enhance the healthful characteristics of seafood and minimize ocean-related contamination of seafood
- Increase and leverage partnerships to discover and develop pharmaceuticals, molecular probes, bioactive compounds, and other marine natural products through innovative and ecologically sound exploration and laboratory approaches
- Develop and transfer, to other researchers and the private sector, useful aquatic biomedical models to enhance understanding of human disease processes and provide other health benefits
- Characterize and estimate public health related economic, socio-cultural and broader health benefits (and risks) of coastal and marine resources
- Evaluate utility and value of tools, technologies and information transferred to managers, decision-makers, and other partners

Goal: OHH Community

Develop a robust oceans and human health community working across disciplines and institutions to improve public health

Strategic Objectives:

- Provide opportunities and institutional mechanisms to support interdisciplinary OHH research such as Centers of Excellence, traineeships, early career and distinguished scholar awards, grants and research collaborations
- Partner with the OHH programs of the NSF and NIEHS, as well as other interested agencies, to stimulate scientific interest in OHH across broad institutional and disciplinary boundaries
- Identify key end-users and their needs in order to develop and deliver useful OHH tools, technologies and information
- Communicate findings to decision-makers, managers, scientists and the public
- Provide OHHI information to ocean education programs and media outlets for use in promoting ocean literacy and stewardship
- Partner with other agencies to enable a rapid and coordinated OHH community response to ocean and coastal public health emergencies

society's ability to plan and respond; and to serve society's needs for weather and water information."

NOAA's Centers of Excellence for Oceans and Human Health

Pursuant to the OHH Act of 2004, NOAA designated three national Centers of Excellence in OHH within the agency through an internal competitive process. These Centers, designed to enhance NOAA's internal OHH research capacity, include multi-institutional partnerships with non-NOAA elements and are located in three of NOAA's six line offices – NOAA's Ocean Service, NOAA Research, and NOAA Fisheries. All three Centers are a combination of agency, academic, and other relevant partners, with nearly half of each Center's funding going to its external partners, in addition to the amounts provided to the external community via the OHHI grants, scholars, and traineeships. Combined, the OHHI Centers are working on at least 50 projects through 22 institutional partnerships. In addition to their scientific work, each Center has dedicated outreach personnel and activities, advisory groups, and data management efforts. Also, the directors of the three NOAA OHHI Centers and the four NSF-NIEHS OHH Centers meet at least annually with key staff to share scientific information and research findings, identify opportunities for collaboration, and initiate synthesis and assessment of the implications and application of their research findings.

NOAA Center of Excellence for Oceans and Human Health at the Hollings Marine Laboratory (HML), Charleston, South Carolina

This Center is developing new methods and approaches to identify and characterize chemical and microbial threats to marine ecosystems and human health and to evaluate the health responses of marine organisms to stress (see Box 7). To accomplish these objectives, the Center at HML supports four core research areas: (1) source tracking of marine pathogens; (2) emerging chemical contaminants; (3) applied marine genomics; and (4) monitoring, assessment, and prediction. In addition, scientists at HML are evaluating techniques to determine human health benefits and risks associated with cultured and wild seafood, and to assess the levels and variability of chemical contaminants and beneficial fatty acids in representative finfish and crustaceans.

Pathogen Source Tracking: Scientists are developing novel techniques and sensors for rapidly detecting and tracking marine microbes of public health concern, including bacteria, viruses, protozoan parasites, and HAB species. These tools will be useful for rapidly assessing health risks for humans who recreate in coastal waters or consume shellfish. The technologies allow the sources of microbes to be identified, instead of relying on indicators for contamination, and will provide managers the ability to rapidly respond to beach and shellfish contamination (see Box 26).

Environmental Chemistry: Scientists are conducting research to identify and understand the potentially harmful effects to humans of a variety of chemical contaminants that reach estuaries and the ocean. Cutting-edge laboratory methods and equipment are used to study the fate and effect of compounds of emerging concern, such as new pesticides, herbicides, fire retardants, pharmaceuticals, and personal care products. Development and use of new analytical techniques help identify and quantify the problems, while field, laboratory, and mesocosm experiments allow scientists to look at effects of sublethal concentrations of target contaminants on sentinel marine and coastal species (see Boxes 17 and 21).

Genomic Applications: An interdisciplinary genomics effort allows HML scientists to evaluate physiological responses of organisms to environmental stress from pathogens, toxins, and contaminants at the molecular level. The purpose of the genomics program is to provide insights into the physiological status of organisms and to translate this into an understanding of overall population health. Development of this technology for key marine species, including the bioinformatic tools to interpret the complex data, will provide an additional tool for monitoring and assessing ecosystem health (see Box 32).

Monitoring, Assessment, and Prediction: Scientists are evaluating the performance of environmental quality and public health indicators developed by other OHHI program elements using southeastern tidal creeks as sentinel habitats. Findings are used to develop approaches for simultaneously monitoring and assessing the ecological condition and public health status of coastal environments (see Box 29).

HML is operated as a partnership comprised of NOAA, the National Institute of Standards and Technology (NIST), the South Carolina Department of Natural Resources, the College of Charleston, and the Medical

Box 7: Development of Tools to Rapidly Detect and Identify Harmful Marine Organisms

Scientists at HML have developed cutting-edge technologies to rapidly detect and determine the source of waterborne pathogens such as *E. coli*, viruses, and protozoa that can cause disease in humans. Some of these harmful microorganisms are indigenous in coastal waters, while others are introduced through agricultural and wastewater inputs, storm water run-off, and the excrement of domestic and wild animals. Current technologies are slow and rely on indicators of the harmful marine organisms. These new methods can rapidly assess the actual presence of pathogens in coastal oceans and pin down their source. Also, in response to the need of public health and environmental managers to quickly screen for the presence of harmful algal species, HML researchers have developed a new technology to simultaneously detect multiple algal species. Known as SIVCA (Species Identification via Chimeric Amplification), this technology is a vast improvement over existing methods. It requires less time and expertise to operate, and is cheaper. In just a year and half, these tools have gone from concept to field trials with hopes of having the technology broadly available to local public health professionals within the next several years. With these advanced DNA technologies in hand, managers will be equipped to determine when beaches are safe for swimming and seafood safe to eat, and to mitigate pollution at its source.

OHHI researchers are developing new DNA-based technologies for public health and resource managers to rapidly detect and determine the source of harmful algal species and waterborne pathogens such as E. coli, viruses, and protozoa. Photo credit: S. Lovelace

University of South Carolina. This unique arrangement integrates basic, applied, and biomedical scientists into multidisciplinary research teams and establishes programs that link environmental conditions in the coastal zone to human health and socio-economic well being.

In addition, HML maintains a Center-wide data management program to develop the information technology, infrastructure, and expertise required to share, synthesize, integrate, and archive the data and information produced by the Center, its partners, and other collaborators. The education and outreach program communicates and transfers the Center's knowledge and technology to natural resource and public health managers, scientists, regulatory agencies, local decision-makers, university students, teachers, and the public.

NOAA Center of Excellence for Great Lakes and Human Health (CEGLHH) at the Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan

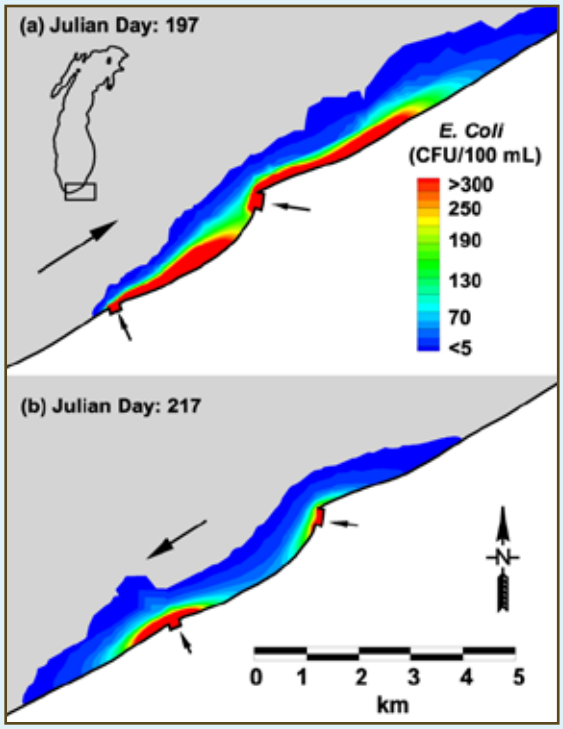
This Center focuses on understanding the inter-relationships among the Great Lakes ecosystem, water quality, and human health. The Center employs a multidisciplinary approach to understand and forecast coastal-related, human health impacts for natural resource and public policy decision-making, and develop tools to reduce human health risks associated with three research priority areas: beach closures, HABs, and drinking water quality.

Many processes and events influence the sources, transport, and loading of pollutants, bacteria, and nutrients to the Great Lakes, such as land use and weather. Defining and forecasting these relationships are the primary goals of the Center. Research is concentrated on providing predictions of coastal water quality that can be used directly to reduce risks to human health associated with recreational exposure and human consumption of Great Lakes water. Main research foci include: (1) bacterial and microbial pollutant sources and loadings; (2) pathogen/virus transport (see Box 14); (3) microbial research; (4) nearshore transport; and (5) HABs (see Box 18). The research includes laboratory work, field experimentation, and computer modeling.

The Center is housed within and led by the NOAA Great Lakes Environmental Research Laboratory (GLERL), but is comprised of multiple federal agencies, universities, and public health networks. GLERL's partners

Box 8: New Beach Forecast Model for the Great Lakes

NOAA's CEGLHH and the USGS teamed up to implement a forecast model that can predict recreational beach conditions in the Great Lakes to enable public health officials and beach managers to better manage beaches and reduce health risks. Project SAFE (Swim Advisory Forecast Estimate) is a model that predicts bacterial counts for *E . coli* based on rainfall, wave heights, and the direction of lake currents, to determine when counts are high enough to threaten human health. This model is one of the first recreational water health forecasting system in the country and does not rely on time-consuming sampling that tells beach managers today that they should have closed the beaches yesterday. CEGLHH provided numerous inputs to help develop and sustain the model, ranging from technical support to hydrological data and financial support. The lab also provides the necessary daily forecast on lake currents and wave heights. This model became operational during summer 2006 in Indiana's Lake Michigan beaches and effectively predicted *E. coli* concentrations. Predicted bacterial counts were posted through hypertexts in local newspapers, the USGS and Project SAFE Web sites, and were sent to beach managers, Gary Sanitary District, and Indiana Department of Environmental Management by 10 AM each day, which gave beach managers enough time to inform the public of beach advisories or closures. Project SAFE, in conjunction with the onset of rapid sampling techniques, will greatly improve the prediction and detection of harmful microorganisms such as *E. coli* in the Great Lakes and could serve as a model for application in other coastal regions of the United States.



Dangerous levels of bacteria, such as E. coli (shown here in red and orange), can be predicted using one of the first operational forecast models to allow for daily updates to Great Lakes beach managers.
Photo credit: P. Mantha and J. Rose

include Michigan State University, EPA Chicago, USGS, EPA Athens, GA, Florida Institute of Oceanography, NOAA Beaufort Laboratory, NOAA NOS Silver Spring, Michigan Sea Grant Extension, University of Michigan, and the Great Lakes Human Health Network.

CEGLHH uses a multidisciplinary approach to translate scientific information and research into materials to aid public health officials, beach and coastal zone managers, drinking water operators, local and tribal governments, and communities in making sound environmental decisions (see Box 8). In addition, CEGLHH works to assess user needs by collaborating with stakeholder groups (see Box 11). Outreach activities are coordinated through the well-established Great Lakes Sea Grant Extension Program and include a broad range of activities, such as needs assessment workshops, a public access Web site, newsletters, information-sharing partnerships, publications, public presentations and training workshops.

NOAA West Coast Center of Excellence for Oceans and Human Health (WCCOHH) at the Northwest Fisheries Science Center, Seattle, Washington

This Center has strong research programs with proven track records in a wide range of scientific fields (e.g., climatology, oceanography, microbiology, genetics and molecular biology, immunology, ecotoxicology, neurotoxicology, developmental biology, plankton ecology, physiology, and marine mammal ecology). The WCCOHH conducts its research through four core programs: (1) pathogens, viruses, and bacteria; (2) chemical contaminants and biotoxins (see Box 19); (3) marine mammals and fish as sentinel organisms (see Box 31); and (4) climate impacts. Key priorities for the Center include sharing data and research results with other institutions and the public, fostering the exchange of information among diverse communities, including other OHH programs, and providing educational opportunities.

Box 9: Risk Assessment Tools to Detect Pathogenic *Vibrios* in Seafood

Scientists at the WCCOHH at the Northwest Fisheries Science Center have developed a rapid DNA test to measure pathogenic strains of *Vibrio vulnificus*, which are capable of causing fatal infections in people who consume raw shellfish. Although molluscan shellfish, such as oysters, can harbor hundreds of individual strains of this naturally occurring marine bacterium, it has long been recognized that only a low percentage of strains are capable of causing life-threatening infections in people. This has been a major obstacle to being able to rapidly determine the actual safety of shellfish for human consumption. Until the identification of the genetic marker targeted by this DNA-based method, there has been no tool available to differentiate the pathogenic *V. vulnificus* isolates from the majority of non-pathogenic environmental strains. The USDA and FDA have recently used the method to survey market oysters to assess the relative percentage of pathogenic *V. vulnificus* strains in shellfish. Furthermore, this technology has led to a university-federal government collaboration to carry out the genome sequencing of several *V. vulnificus* strains, which will then be used to identify the genes or other factors that cause some *V. vulnificus* strains to be more pathogenic than others. Such advanced predictive technologies will enable public health managers to better determine the safety of seafood and not indiscriminately close shellfish beds based only on identifying *V. vulnificus* without differentiation between being pathogenic or non-pathogenic strains.

Using new DNA tools, pathogenic Vibrios can be distinguished from non-harmful strains, enabling better management of shellfish beds and securing the safety of shellfish such as oysters. Photo credit: M. Strom

The WCCOHH's research will (1) provide a better understanding of how pathogens and toxins, both natural and human-made, interact with and affect shellfish and fish, (2) enhance the development of tools to identify direct risks that contaminated shellfish pose to consumers, and (3) develop methods to forecast and mitigate threats to human health. Conversely, indirect effects to human health can be realized by understanding the health of sentinel species, like fish and marine mammals. In addition WCCOHH's research will provide a better understanding of the transmission dynamics of infectious diseases and their interactions with other stressors, such as toxins and environmental variability (see Box 9).

Key partners of the WCCOHH include the University of Washington (PNW H2O Seattle, WA), Institute for Systems Biology (Seattle, WA), Oregon State University (Corvallis, OR), the Marine Mammal Center (Sausalito, CA), the University of California, Davis (Davis, CA), and NOAA's Alaska Fisheries Science Center (Seattle, WA). Also, the WCCOHH has external collaborations with researchers affiliated with the University of Florida and the National Research Council, Canada.

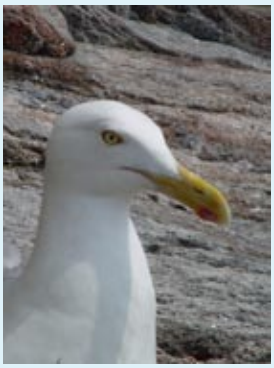
WCCOHH educational and outreach activities emphasize OHH products and services, strengthen awareness of our connection to the oceans, and increase environmental stewardship. Specific activities include participation in major scientific conferences, educator workshops, annual investigator meetings, and local community events; development of a newsletter and interactive Web site; and sponsorship of an educator at sea and student travel to a national conference.

OHHI External Research Grants

The OHHI External Grants Program engages the non-federal research community in investigations that directly complement NOAA's ongoing OHHI activities. NOAA is the only agency that has a targeted external research grant opportunity in the OHH arena. In keeping with the OHH Act requirements, only non-federal applicants are eligible to apply for funds allocated to this program element. The grants are structured to provide useful information for public health and natural resource managers related to NOAA's OHHI mission (including Centers). Grantees must demonstrate the ability to perform and sustain interdisciplinary and applied research and execute outreach and data management plans.

Box 10: Zoonotic Disease Surveillance: Using Seabirds and Marine Mammals to Detect Health Threats

An OHHI external grant recipient at the Woods Hole Oceanographic Institution, along with colleagues and partners at Cornell University, Tufts Cummings School of Veterinary Medicine, and the Cape Cod Stranding Network, are addressing worldwide concerns about animal vectors of human disease (zoonoses) by learning more about the role of marine mammals and seabirds as reservoirs for disease. This team investigated the prevalence of zoonotic bacteria, parasites, and viruses in the southwestern Gulf of Maine in whales, dolphins, seals, gulls, eider ducks, and loons and screened a total of 116 normal and diseased individuals from live captures, fishery bycatch, or beach strandings. Representatives of 79 of approximately 200 potentially zoonotic pathogens worldwide were detected in the marine organisms. Infectious agents associated with diarrhea and other chronic diseases such as brucellosis (which can cause fever, sweats, headaches, back and joint pains, physical weakness and infections of the central nervous systems or lining of the heart) were detected in 26 percent of the cases. Other particularly noteworthy findings included detection of a Brucella-like agent in birds for the first time, a broad array of pathogens in a deep-diving beaked whale, and marked antibiotic resistance patterns in bacteria from live, bycaught, and stranded marine mammals and birds.



Harbor seals and sea birds can carry human diseases and provide clues about how the spread of current and emerging threats in the oceans can affect human health. Photo credit: M. Moore

Through 2006, the OHHI External Grants Program has received over 260 proposals in response to its Requests for Applications and has granted 26 competitive awards to investigators at academic institutions throughout the United States: Northeast (9), Southeast (includes the Gulf of Mexico) (7), Pacific Northwest (2), Southwest (3), Great Lakes (3), and Pacific Islands (2). Topically, work supported by the grants covers the full OHHI scientific scope, including research on ocean-related pathogens (see Boxes 10 and 15), toxins, chemical contaminants, benefits and risks of seafood consumption, sentinel species, marine natural products, and the effects of multiple ecosystem stressors on OHH. Regular Principal Investigator meetings provide opportunities for external grantees and NOAA scientists to compare findings, share information and work plans, and develop new collaborations.

OHHI Internal Capacity Development

In addition to external grants, the NOAA OHHI has supported some small competitive awards within NOAA through its Internal Capacity Development Program. This program element is designed to stimulate OHH activities across NOAA, catalyze cross-NOAA collaboration on OHH issues, capitalize on existing strengths, and take advantage of the OHH-related scientific capacity residing in NOAA entities outside the Centers. Focus areas for this peer-reviewed competition resulted from an internal NOAA OHH workshop in May 2004, which drew together scientists working on oceans and health issues throughout the agency. In contrast to the external grant program, these funds are directed toward internal NOAA research projects, though outside collaboration is possible. In 2005, 21 proposals were received, seven were awarded. These awards have focused primarily on sensor development, chemical contaminants, sentinel species, and bioinformatics.

OHHI Distinguished Scholars

The Distinguished Scholars Program builds NOAA's capacity by bringing world-renowned scientists to work with NOAA on cutting-edge ocean and health sciences and their application, and by recognizing forward-looking scientific leadership in the emerging interdisciplinary OHH scientific field. Proposals are reviewed based on scientific merit, collaboration with NOAA, and ability to add significantly to NOAA's OHH research capabilities. Based on a peer-reviewed competition, the OHHI awarded its first two Distinguished Scholars grants in 2006 to Dr. Rita Colwell (University of Maryland at College Park and Johns Hopkins University Bloomberg School of Public Health and former Director of the National Science Foundation) and Dr. Phillip Roberts (Georgia Institute of Technology). Dr. Colwell is focusing on application of genomic technologies for disease surveillance in the marine environment and the development of integrated, global observations for disease surveillance. She is working with the OHH Center at the HML and with the OHHI Program Management Team. Dr. Roberts is focusing on improving models for pathogen forecasting in nearshore environments in the Great Lakes. He is working principally with the OHH Center at GLERL.

OHHI Traineeships

NOAA's OHHI Traineeships are designed to build a new cadre of scientists working in the OHH field that are trained across disciplines and institutions to improve public health. These awards provide cross-disciplinary training opportunities, build institutional support for OHH research and application, enhance communication with public health and natural resource managers, stimulate scientific advances in OHH, and acquaint young researchers with NOAA OHH research. OHHI traineeships will be awarded on a competitive basis for pre-doctoral students and post-doctoral researchers who will become actively involved in OHH research.

OHHI Public Information and Outreach

The OHHI Public Information and Outreach Program strives to engage and involve public health and natural resource managers and decision-makers, and the broader OHH scientific community in the application of OHHI research. This program helps to disseminate and communicate OHHI research findings, assessments, tools, and technologies to managers and decision-makers, other users, and the public (see Box 11). Public information and outreach activities are conducted at both the national level and through the OHHI Centers. Each Center has a coordinator who develops partnerships, leverages resources, and organizes and implements targeted activities. Also, all OHHI grant recipients are required to have an outreach component. Program activities are conducted in consultation with other federal agencies and in cooperation with regional Sea Grant College Programs, as well as with appropriate state and local partners. Activities range from workshops, training opportunities, internships, seminars, scientific meetings, and other public events, to the development of Web sites, informational products, and curricula. This program also helps to enhance public literacy and understanding about the effects of the oceans on human health, promote ocean

Box 11: Needs Assessment Workshop to Help Direct Beach Health Research

In November 2005, the CEGLHH partnered with the USGS, EPA, and Great Lakes Beach Association to host a workshop to identify needs and concerns of beach managers, public health officials, and other stakeholders. The workshop's purpose was to define research priorities for addressing recreational water quality issues in the Great Lakes related to beach closures due to pathogen pollution or HABs. All Great Lakes states were represented among the over 40 participants. Workshop outcomes included establishment of a steering committee to ensure implementation of assessed needs, a beach management training course, a training video on the use of models to predict bacteria levels, and a standardized sanitary survey tool to identify contamination sources at beaches.

Needs assessment workshops help identify OHH tools and information beach and seafood managers can use to reduce human health threats. Photo credit: S. Joseph

stewardship, and build a new cadre of interdisciplinary OHH professionals. (See Box 41).

OHHI Data Management

To ensure maximum consistency, access, and use of data derived with OHHI funding, the OHHI established a Data Management Working Group, which includes active participation of experts from each of the OHHI Centers and the OHHI Program Office. This group is designing a seamless, distributed OHHI data/metadata infrastructure to provide access to data and related information products by OHHI researchers, the general scientific community, and operational user communities (e.g., public health and natural resource managers, homeland security). Specific data management objectives include developing and implementing policies and protocols throughout the OHHI and in coordination with other OHH programs, such as the NSF-NIEHS OHH Centers, to maximize access and minimize duplication. Also, the Data Management Working Group will coordinate with other NOAA data management activities such as IOOS, the Data Management Integration Team, and other ocean, coastal, and public health surveillance systems to develop long-term useful data streams for monitoring and analysis. The goal of the OHHI data management policy, in principle, is to allow free and open access to the research community but still provide scientists a restricted initial access period for the analysis, research, and publication of their data. Proper acknowledgement and citation of all data used will be required in publications. OHHI is making arrangements to ensure that "orphan" data sets (i.e., smaller regional networks and local observations that may not be routinely saved or readily available) will be archived.

OHHI Partnerships

Partnerships at the federal, state, local, and eventually international levels are critical elements of the OHHI. To ensure synergy and avoid unnecessary duplication, the OHHI works very closely with several other NOAA programs and with numerous other federal agencies, including all of those represented on the IWG-4H. Most state and local partnerships are developed at the regional level through the OHHI Centers of Excellence and/or by the external grant investigators.

Understanding the connections between marine animal health and human health, and identifying key species as "sentinels" of potential human health impact, requires a close working relationship with NOAA's Marine Mammal Health and Stranding Response Program (MMHSRP). This Program focuses on marine protected species and marine animal stranding. The collaboration includes joint research, planning, and funding, as well as post doctoral training.

The OHHI works closely with the ECOHAB (Ecology of Harmful Algal Blooms) Program (supported jointly by NOAA, NSF, EPA, NASA and ONR) and NOAA's MERHAB (Marine Emergency Response to Harmful Algal Bloom) Program, with a principal focus on work related to the human health impact of HAB-related biotoxins. Within NOAA, the programs coordinate research planning and funding of external research grants.

In addition to the OHHI, NOAA has several programs that have at least some focus on science and technology related to marine natural products and pharmaceuticals. The Ocean Exploration (OE) Program will be taking samples of opportunity during ship runs, and may also offer competitive research grants. One of the National Undersea Research Program (NURP) Centers has expertise in marine pharmaceuticals research, development, and sample archiving. In previous years, the National Sea Grant College Program has provided grants to support research on natural products from the sea, including pharmaceuticals. In addition to its role as an OHHI Center, HML has capabilities in marine natural product analysis. The OHHI is leading an internal NOAA effort to coordinate approaches to the discovery and identification of new marine natural products and pharmaceuticals. The NIH National Cancer Institute is also part of this planning process.

The OHHI collaborates and coordinates activities with the NSF-NIEHS, including annual meetings of the directors of all seven OHH Centers. The OHHI also works with EPA at the national and regional levels on beach and water quality management and with the USGS on regional issues related to beach management and risk forecasting and at the national level on marine animal health and surveillance issues. The OHHI connects with CDC through joint research planning and the transfer of research results to the public health community.

Although the OHHI's main focus is on the United States, it has supported a bit of international work related to malaria in Africa. Collaborations with other international health and Earth science organizations could be strengthened in future years.

Related OHH Programs in Other Agencies

The **Centers for Disease Control and Prevention (CDC)** is one of the 13 major operating components of the Department of Health and Human Services (HHS). Since it was founded in 1946 to help control malaria, CDC has remained at the forefront of public health efforts to prevent and control infectious and chronic diseases, injuries, workplace hazards, disabilities, and environmental-health threats. CDC applies research findings to improve people's daily lives and responds to health emergencies (see Appendix 2: Agency Prospectus).

CDC is conducting studies to collect data that will improve public health decision-making and responses to ocean-borne health threats. Since 1998, the Health Studies Branch at the National Center for Environmental Health (NCEH) has been funded to support a cooperative agreement with six eastern seaboard states relative to the harmful alga, *Pfiesteria piscicida*, and more recently other HABs. The program includes biological research, environmental exposure assessments, human disease surveillance, clinical evaluations of ill people, environmental monitoring, and the development of state HAB response plans. NCEH participates in collaborative HAB-related research activities with other federal agencies, universities, and state and local public health agencies and developed the HAB-related Illness Surveillance System (HABISS) (see Box 25). An ongoing epidemiological study involving a partnership between CDC and NIEHS demonstrated that people exposed to aerosolized HAB toxin (specifically brevetoxin associated with Florida red tides) experience respiratory problems and that these problems are of special concern for people with asthma. The CDC team developed toxin assays and other methods and produced a targeted public health protection program based on its findings. CDC is also leading partnership studies investigating human exposures to freshwater HAB toxins in the Great Lakes region.

In related work, CDC is building a National Environmental Public Health Tracking Network that will provide scientific information on environmental exposures and adverse health conditions as well as the possible spatial and temporal relations between them. This network will include exposures and health effects of marine origin. Other OHH-related activities include service on the National HAB Committee and the National Advisory Panel for NOAA's OHHI, both of which help focus OHH research efforts.

CDC's National Center for Infectious Diseases (NCID) conducts various surveillance programs for food- and water-borne diseases reported by state health agencies and in cooperation with the USDA and the FDA. This surveillance includes illnesses caused by *Vibrio* bacteria (most of which are attributable to consumption of contaminated seafood) and marine toxins, which account for about four percent of the food-borne disease reports. NCID is working with NCEH to improve waterborne disease surveillance and also collaborates with the EPA to assess public health risks from water-related recreational activities, which include recreational exposures to toxins, contaminants and pathogens.

The CDC's National Institute for Occupational Safety and Health is responsible for conducting research and making recommendations for the prevention of work-related injuries and illnesses, including those associated with commercial seafood harvesting.

The **U.S. Environmental Protection Agency (EPA)** is an independent federal agency whose mission is to protect human health and the natural environment. EPA develops and implements federal regulations to protect human health and issues non-regulatory health advisories to warn the public about levels of contaminants in the air, land, and water, including marine waters, that can cause harm.

The EPA Office of Research and Development (ORD) has initiated a multi-year planning effort for priority research. Several of the EPA multi-year plans (MYPs) pertain directly to OHH or OHH-related topics, including drinking water, water quality, human health, human health risk assessment, and global change. All MYPs can be accessed online at http://epa.gov/osp/myp.htm. Research efforts of particular relevance to OHH include studies on how water-borne contaminants may affect swimmers and beachgoers. For example, ORD conducted epidemiological studies on three freshwater (Great Lakes) beaches to evaluate molecular methods for determining when beaches should be closed due to pathogen contamination. Related studies were initiated in the Gulf of Mexico in 2005, but these were prematurely terminated by Hurricane Katrina impacts. A new EPA supported OHH-related research program, being developed through the agency's National Center for Environmental Research, will evaluate relationships between changes in biodiversity and human health.

Domestically, EPA participates in numerous interagency partnerships with OHH-related themes, including: with NOAA, ONR, and NASA in the (ECOHAB) Program; with NIEHS' National Toxicology Program to evaluate toxicity of contaminants in drinking water; with CDC on surveillance of water-borne diseases; with the U.S. Army Corps of Engineers for wetland conservation and restoration; and with NOAA and NSF to evaluate Hurricane Katrina's impacts on Gulf of Mexico coastal waters. EPA representatives serve on the National HAB Committee and on the National Advisory Panel for NOAA's OHHI.

EPA's international programs help protect the environment along our common borders with Mexico and Canada, reduce global environmental threats such as marine pollution and toxic chemicals, integrate environmental protection with international trade and investment, and exchange innovative practices and technologies. These activities not only help sustain the health of the global ocean, but also improve environmental quality across the nation. In addition, EPA provides U.S. leadership related to international marine pollution issues.

The **Food and Drug Administration (FDA)** of the Department of Health and Human Services ensures the safety of food and drugs available to consumers, and is the agency primarily responsible for approval of pharmaceuticals. While essentially a regulatory agency, the FDA conducts and encourages research to support its mission.

The FDA has several OHH-related research programs, many at the Center for Food Safety and Applied Nutrition (CFSAN), pursuant to its responsibility for the safety of shellfish and other seafood. CFSAN's goals are to understand the risks and develop cost-effective strategies for addressing those risks and practical tools for implementing those strategies, so that the FDA can minimize risks and maximize benefits of seafood consumption. One CFSAN concern is improper handling of seafood products, which can allow them to decompose. Some forms of decomposition can lead to the formation of toxins that cause human illness and, in general, decomposition lowers the value of increasingly scarce marine resources. CFSAN conducts research to establish time/temperature parameters for harvest, transportation, and storage of seafood that will ensure its wholesomeness, and develops methods for detecting decomposed seafood. In addition, absorption of the volatile mono- and bicyclic aromatic hydrocarbons from petrochemical contamination leads to "petrochemical taint." CFSAN research on petrochemical contamination will introduce and advance chemical analytical methods for the detection and quantification of petrochemical taint in seafood.

In the mid-1990s, the FDA implemented a Hazard Analysis Critical Control Point (HACCP) program for the seafood industry to analyze hazards, identify and monitor critical control points, establish preventive measures, establish corrective actions to be taken when monitoring shows that a critical limit has not been met, and verify that the system is working and documented properly. The FDA published the Fish and Fishery Products Hazards and Controls Guide to assist processors in the development of HACCP plans; this guide is updated periodically to reflect advances in science-based knowledge regarding seafood hazards. The safety features of FDA's seafood HACCP regulations have also been incorporated into NOAA's National Seafood Inspection Program.

Research on marine toxins includes development of toxin-detection methods, characterization of toxins and emerging vectors of toxins, and exploration of better strategies for managing the risk of natural toxins in seafood. The latter includes the Signal Environmental And Plankton Observations in Real Time (SEAPORT) program (see Box 42) and participation in preparation of major HAB reports.

Aquaculture is a rapidly growing industry worldwide, contributing significantly to the global food supply. Because of industry expansion and trends toward high-intensity aquaculture, diseases frequently occur in farm-raised fish or shellfish. Many of these diseases can be addressed with drug therapy. Therapeutic drugs and chemicals are available to the global industry for treating disease, but their use raises several concerns, including the development of resistant strains of microorganisms, environmental impacts of drug residues, and drug residues in products. Regulations governing aquaculture drug use vary from country to country, so the detection of residues in a product is important for ensuring compliance. The FDA has identified a priority list of aquaculture drugs and chemicals for analytical-method development in specific applications based on food safety and the extent of known use within the global aquaculture industry.

Pathogenic microorganisms present in the aquatic environment can be accumulated by shellfish, posing a serious risk to consumers of raw or inadequately cooked

shellfish. The majority of shellfish-associated illnesses are attributed to enteric viral pathogens. Research on pathogenic viruses and bacteria is conducted by the Office of Seafood (OS) and Office of Applied Research and Safety Assessment (OARSA). Current OS research activities focus on: (1) the ecology of indicator microorganisms of fecal pollution in estuarine waters and their interaction with shellfish and (2) the development of methods for the extraction and detection of enteric viruses in shellfish tissue. Findings will be evaluated to determine if shellfish growing-area classifications are suitable for indicating the presence of enteric viruses and to determine if any of the indicator organisms could be used to predict the risk of viral contamination. Research conducted by OARSA seeks to identify and characterize virulence determinants/genes of food-borne pathogens, such as marine *Vibrio* species. This work will help lead to development of gene-based tests that are specific for pathogenic organisms, thus allowing regulatory action to be narrowly focused on actual risk, the removal of contaminated food from the marketplace and steps to prevent future contamination.

In its role in approving pharmaceuticals, the FDA's Center for Drug Evaluation and Research (CDER) has approved some marine-derived drugs.

The **Marine Mammal Commission (MMC)** is charged with developing, reviewing, and making recommendations on domestic and international actions and policies of all federal agencies with respect to marine mammal protection and conservation, including the health and stability of marine ecosystems upon which the mammals depend (i.e., ocean health) and the health of native subsistence harvesters and consumers of marine mammals (i.e., human health).

With respect to the OHH-related activities, the MMC is particularly interested in: (1) the relationship between measures of ocean health and marine mammal biology, ecology, population dynamics, and unusual mortality events; (2) the efficacy of using marine mammals as sentinels of ocean and human health; (3) the potential communication of diseases from humans and domestic or feral animals to marine mammals; (4) the potential for marine mammals to communicate diseases to subsistence hunters and others who may come into contact with marine mammals; and (5) the relationship among ocean health, contaminant loads in marine mammal tissues, and the health of subsistence hunters.

Although the MMC has supported some research projects relevant to the five issues listed above, it does not have the resources to establish a research program focused solely on OHH issues. Historically, MMC supported some of the earliest work on responses to marine mammal stranding events and participated in the development of a specimen bank of marine mammal tissue samples that can be used in various health-related studies. Currently, MMC participates in a NOAA Fisheries working group on marine mammal unusual mortality events. In addition, the MMC sponsored both a workshop dealing with prevention of potential viral epidemics in Hawaiian monk seals and an assessment of the risk of illness and injury among marine mammal workers and the public who may come into contact with stranded animals. Fifty percent (243/483) of respondents reported suffering an injury caused by a marine mammal; 23 percent reported having a skin rash or reaction. Common marine mammal, work-related illnesses included conjunctivitis, several types of dermatitis, and "seal finger" (apparently a mycoplasma infection). Severe illnesses were less common, but included tuberculosis, leptospirosis, and brucellosis.

The **National Aeronautics and Space Administration (NASA)** is an independent federal agency whose mission is to pioneer the future in space exploration, scientific discovery, and aeronautics research. NASA uses observations and modeling to help answer scientific questions about the ocean and its role in the Earth system.

NASA's OHH activities include basic Earth science research and the extension of NASA Earth science research results to operational partner agencies' public health and coastal management decision-support tools in areas including toxic HABs. NASA supports a cooperative agreement between NRL and Applied Coherent Technologies, Inc. to support NOAA HAB activities through the Research, Education and Applications Solution Network (REASoN) project, which integrates measurements from NASA and NOAA satellites, available coastal observations, and coastal ocean model outputs into the NOAA HAB Bulletin and NOAA Harmful Algal Blooms Observing System (HABSOS). NASA's Ocean Biology and Biogeochemistry research program, through their ECOHAB partnership with other federal agencies, funds basic HAB research on optical propreties of *Karenia brevis* and its detection in the Gulf of Mexico, mycosporine-type amino acids as markers for harmful dinoflagellates, and the coupled biological and physical dynamics of HABs in waters off of the Pacific

Northwest. NASA's Applied Sciences Public Health Program supports projects to enhance partner agencies' decision-support tools with NASA Earth science research results for societal benefit. The Applied Sciences Public Health Program will be expanding its OHH activities by participating in the NASA Research Opportunities in Space and Earth Sciences (ROSES) solicitation in FY07 and encouraging proposals related to OHH. In the past, NASA has also partnered with NOAA, EPA, NSF, and EPRI (formerly the Electric Power Research Institute) in the multi-agency Climate Variability and Human Health program.

The **U.S. Geological Survey (USGS),** a bureau of the U.S. Department of the Interior, provides reliable scientific information to describe and understand Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life.

The USGS conducts a diverse range of programs and activities that provide OHH-related research and information products. Many of these investigations are leveraged by support from partnering among federal and local government agencies, and they address OHH-related issues such as impacts of storms, tsunamis, earthquakes, landslides, climate change, and sea-level rise on coastal communities, as well effects of contaminants, biotoxins, and pathogens on humans.

USGS programs monitor the quality and quantity of water in the nation's rivers, including water and constituent delivery to estuarine and coastal ecosystems; evaluate the sources and mechanisms of contaminant production and delivery; and develop methods to predict and manage beach conditions. In marine, coastal, and Great Lakes environments, the USGS also investigates the condition of wetland, estuarine, coral, and offshore marine habitats and the health of shorebirds and water birds, sea ducks, pelagic seabirds, marine mammals, sea turtles, and fish stocks. These studies provide a means to observe early warning of issues that may affect human health, such as loss of the role of ecosystems in maintaining a healthy coastal environment, depleted food sources, or emerging environmental contaminants, which are of specific concern to the OHH programs. The USGS also uses remote sensing to monitor coastal land-use changes, studies the connection between people and those changes, and provides information that can be used to address the consequences of those changes, including information related to human health. In conducting these studies, the USGS works with a wide range of federal, state, and local agencies.

OHH International Partnerships

Many of the individual agencies collaborate, to varying degrees, with international organizations and countries on work related to the OHH topics covered by this interagency program. While these relationships have evolved over time, and some are well established, an important next step will be to further develop and expand existing relationships and improve flow of environmental data and health information worldwide. Key international organizations with whom the Interagency OHH Program may interact include: International Atomic Energy Agency (IAEA); World Organization for Animal Health (OIE); World Health Organization (WHO); Food and Agriculture Organization of the United Nations (FAO); International Whaling Commission (IWC); Global Earth Observation System of Systems (GEOSS) including the Group on Earth Observations (GEO); United Nations Educational, Scientific and Cultural Organization (UNESCO), including International Council for the Exploration of the Sea (ICES); Intergovernmental Panel on Harmful Algal Blooms of the International Oceanographic Commission (IOC); North Pacific Marine Science Organization (PICES); Arctic Council and its Arctic Marine Assessment Program (AMAP); the International Geosphere-Biosphere Programme (IGBP); and countries with whom the United States has multi-bilateral environmental and research agreements.

Chapter 3: Opportunities for Major Advances in OHH Research and Application

This chapter is the first comprehensive effort to address ongoing OHH research work and priorities at national and interagency levels. It describes the breadth of priority on-going activities that will advance OHH research and application in the nine agencies engaged in the Interagency OHH Program. The lists presented here were developed by the IWG-4H based in part on input received via several pathways, including the JSOST-sponsored Ocean Research Priorities Plan Public Workshop in Denver, CO (April 2006), special meetings of the NOAA and NSF-NIEHS OHH Center Directors and other representatives in Honolulu, HI (February 2006) and Seattle, WA (April 2006), and a variety of written materials provided by numerous experts in their respective OHH fields. The opportunities for advancement are organized under three sub-headings: (1) Research Priorities; (2) Infrastructure; and (3) Transition of Research to Application, and include highlights of selected agency activities (see Box 12). Further prioritization is provided in Chapter 4.

Box 12: Primary Areas for Advancement in the Interagency OHH Research Program

Research Priorities

Research Areas:
- Pathogens
- Chemical contaminants
- Harmful algal blooms
- Seafood safety
- Pharmaceuticals and other beneficial products

Cross-Cutting Areas:
- Epidemiology
- Sentinel species/habitats and biological models
- Genomics and other "omics" technologies
- Social, behavioral and economic studies
- Climate change

Infrastructure

- Linking to ocean observing systems
- Data management and access
- Standards and standardized methods
- Access to the sea: platforms for OHH sampling and exploration

Transition of Research to Application

- Outreach and education for the Interagency OHH Research Program
- Rapid response capabilities

Priority Research Areas

Pathogens, Potential Pathogens, and Indicators

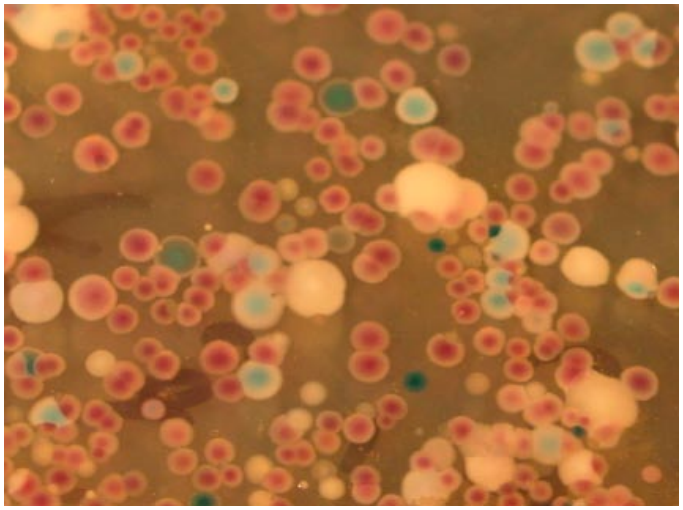
Ocean and estuarine ecosystems can directly and indirectly impact the extent to which humans are exposed to disease-causing organisms known as pathogens, including bacteria, viruses, protozoa, and fungi. One of the most significant ocean health threats to humans is exposure to recreational waters and drinking water contaminated with pathogens (see Boxes 13, 14). Sources of pathogens in ocean waters may include run-off from agricultural and animal production systems into estuaries, rivers, and creeks; wastewater inputs associated with sewage discharge, leaking septic systems, and stormwater run-off from urban and suburban areas; and discharges of ship ballast waters. Currently, the EPA, CDC, and Council of State and Territorial Epidemiologists track food-borne diseases and outbreaks. However, the system is passive and compliance with the request to report outbreaks is incomplete. Thus, the number of food- and water-borne disease outbreaks is likely under-reported. In addition, because many of the illnesses associated with food and water contamination have symptoms in common with other illnesses, such as the flu, they are often misdiagnosed.

Pathogen research in coastal environments has advanced considerably under the Interagency OHH Program, and in response to the Beaches Act of 2000, which directed the EPA to develop new technologies to rapidly measure water quality and improve understanding of the relationship between water quality and health of swimmers. Other advances from work in the NOAA and NSF-NIEHS OHH programs and in several other agencies have resulted in expanded capabilities to detect, identify, determine the source of, and eventually forecast the occurrence of pathogens in coastal waters, shellfish, and drinking waters (see Boxes 15, 16). These advances in patho-

gen research will likely lead to development of new biological sensors that can be incorporated into ocean observing systems. Also, advancements in DNA technologies have allowed for discovery of genetic factors associated with virulence of *Vibrio* and other bacteria, so that harmful strains can be identified and researchers can differentiate human from nonhuman sources of contamination. When fully developed, new tools based on these advances will provide faster and more reliable information to protect consumers from contaminated seafood (see Seafood Safety Section).

Much recent pathogen research has focused on advancements in methods that allow for rapid detection and source identification of harmful microbial organisms in water and shellfish tissues. Traditional methods for detection are based on indicator bacteria rather than direct identification of enteric pathogens. These approaches are labor intensive, applicable only to a limited number of pathogens, and do not provide information about pollution sources. The OHH program has ongoing research aimed at detecting and determining the source of pathogens in recreational waters (whether from wildlife, domestic animals, or humans) accurately, rapidly, and inexpensively. Results from this work will greatly improve our ability to protect both public health and shellfish operations in coastal environments. Also, work supported by the OHH programs and others has led to a new understanding of soils and sediments, including beach sands, as reservoirs and sources of beach bacterial contamination.

Despite these advances, a number of scientific hurdles remain. Application of DNA-based techniques for rapid detection, quantification, and tracking is severely limited by the lack of suitable concentration methods for initial isolation of microbes from large volumes of water and other complex environmental samples. Targeted research in this area should enable rapid development and deployment of a wide range of microbial sensors as part of ocean observing systems. While the ability to forecast the need for beach and fishery warnings/closures has advanced, much more robust models are needed to evaluate the transport and fate of pathogens in aquatic systems and to understand the roles of sediments as reservoirs. Reliable prediction of the fate and transport of pathogens is essential to support decisions about beach closures, inform the design of structures for combined sewer outfalls and water intakes, and address soil and sediment as sources of pathogens.



Vibrio bacteria are pathogens known to cause gastroenteritis and septicemia in humans from ingestion of undercooked or contaminated seafood. Colonies of Vibrio parahaemolyticus appear mauve color while V. vulnificus and V. cholerae appear turquoise blue on this agar plate. Photo credit: B. Robinson

Colonies of fungi (which may be pathogenic) are isolated from the upper respiratory tract (blowhole fluid) of wild bottlenose dolphins from Charleston, South Carolina and grown on this agar plate. Photo credit: P. Morris

OHH research should be aimed at how pathogenesis and virulence are linked to ecosystem variables, including seasonal variability in water temperature, water chemistry, algal blooms, climate cycles, and global climate change. For example, sea surface temperatures along the Gulf Coast have been found to account for over 50 percent of the variability in concentrations of disease-causing *Vibrio* bacteria. Also, some evidence connecting coastal environmental degradation to human health threats is emerging, such as an apparent link between

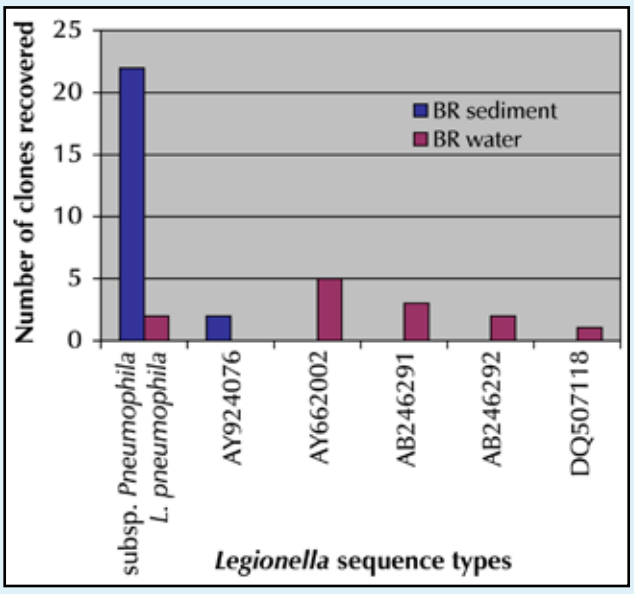
metal contamination of coastal waters and proliferation of antibiotic-resistant bacteria, which in turn could pose additional risks to humans exposed to pathogenic bacteria in coastal waters. These kinds of associations require much further study. Improved disease surveillance would allow earlier detection of outbreaks, making it possible for public health officials to respond more rapidly to avoid or control them, mitigate exposures, and decrease the number of people who become ill.

Major opportunities for advancement related to waterborne pathogens require integration of OHH research and activities with epidemiology, public health, resource management, and risk communications (see Epidemiology and Outreach and Education sections) and include the following:

- Conduct basic and applied research about known and emerging human and marine animal pathogens, their transport and occurrence, including development and use of models and predictive and preventive capabilities related to disease trends.
- Determine how the prevalence and virulence of pathogens are linked to coastal and oceanic ecosystem variables, including seasonal variation, water temperature, water chemistry, algal blooms, climate cycles, and trends in global climate change.
- Improve molecular techniques to allow for rapid, direct, and simultaneous detection of multiple harmful marine organisms and incorporate into ocean observing systems.
- Improve techniques for concentrating microbes from large volumes of water and other environmental samples to allow more effective use of molecular and other modern pathogen detection methods.
- Develop standards, standard methods, and centralized culture collections, such as mixed cultures and other biological materials specifically relevant to OHH research (see Standards and Standardized Methods section).
- Develop risk assessment tools with the ability to integrate effects of multiple ecosystem stressors on pathogen presence, fate, and transport, and use sentinel species and wildlife disease surveillance to elucidate and predict potential human health outcomes.

Box 13: NSF-NIEHS OHH Center Studies Human Pathogens in Mt. Hope Bay, Massachusetts

Mt. Hope Bay, Massachusetts has been heavily impacted by human activity, resulting in significant pollution due to thermal effluents, sewage outfalls, and the effects of past industrial activities. Scientists at the WHCOHH are sampling bay waters for the presence of a wide range of human pathogens and examining the potential role of thermal and sewage input on persistence of these pathogens. Their work is the first to document the presence and diversity of *Legionellae*, the group of bacteria that cause Legionnaire's disease, in the marine environment. While many of the genetic sequences recovered are similar to those obtained from freshwater environments, they also detected the human pathogen (*L. pneumophila*) in Mt. Hope Bay samples. Microbial diversity assessed using genomic techniques revealed that the largest number of potential human pathogens were in sediment samples rather than in the water column.



Diversity of the Legionella sequence types, known to cause Legionnaire's disease that were recovered in the water vs sediment in Mt. Hope Bay, Mass.. Photo credit: R. Gast

Box 14: Pathogens Detected through Groundwater Quality Investigation

A major tourist destination of Lake Erie, South Bass Island, also known as the "Key West of the Midwest," was the source of groundwater contamination that sickened 1,450 people during summer 2004. A scientific team at Michigan State University, part of the CEGLHH, sampled 16 drinking water wells on the island and found the groundwater contaminated with multiple fecal-associated pathogens. The CEGLHH developed and implemented a Lake Erie hydrodynamic model that showed a complex water movement pattern around the island preceding and during the time of the outbreaks. Analyses of model runs demonstrated that the massive contamination of drinking water wells was the result of heavy rains in May 2004 that contributed to higher groundwater levels, coupled with unique water movements that transported sewage and pathogens from public and private sewage treatment systems to drinking water wells. As a result of this investigation, the Ohio EPA and Department of Health are addressing the wastewater issue and supplying the island with fully treated drinking water.

Almost 900 Visitors Report Becoming Sick Following Island Trip

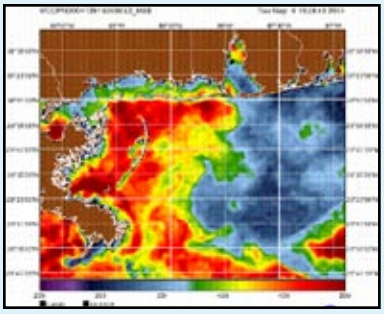
Bad Water Might Be Source of Outbreak: Testing of samples could help identify problem

August 24, 2004, Columbus Dispatch

Scientists used hydrodynamic models to map the source of drinking water contamination to failing septic tanks coupled with heavy rainfall on South Bass Island, OH. Photo credit: S. Joseph

Box 15: Tracking Pathogens from Space: Risk Assessments to Predict Seafood Contamination

Scientists at the University of Southern Mississippi, with support from NOAA's OHHI External Grants Program, are using sea surface temperature, chlorophyll, and turbidity data collected by satellite to develop and test a surveillance system for at least two disease-causing marine bacteria, *Vibrio parahaemolyticus* and *V. vulnificus*. Until now, these harmful marine organisms have been difficult to detect because sample collection is labor and resource intensive, making it difficult to predict potential outbreaks. People who eat raw or undercooked seafood (e.g., oysters) containing high levels of these naturally occurring bacteria or whose open wounds are exposed to seawater containing high levels of these bacteria may become ill. Symptoms range from mild gastrointestinal illness to more serious and sometimes lethal infections especially in immunocompromised persons. By harnessing the technological capabilities of satellites, in combination with application of molecular biological detection methods, it may be possible to better predict and prevent human disease associated with food-borne or recreational water exposures.



Presence of the pathogen Vibrio parahaemolyticus can be predicted per gram of oyster meat based on remotely sensed data collected by satellites such as sea surface temperature (high levels shown in red). Photo credit: J. Grimes

Box 16: Beach Conditions "Nowcast" for Huntington Beach, Lake Erie

During summer 2006, the USGS and the Cuyahoga County Board of Health instituted and tested a system to quickly estimate bacteria levels and provide beach advisories to swimmers headed to Huntington Beach in Bay Village, Ohio. By 9:30 each morning, a Nowcast estimate of bacterial levels was posted, enabling the public access to advisory information before they left for the beach. Estimates are made using a computer model calibrated especially for Huntington Beach, which takes into account current weather and environmental conditions. Nowcast information for Huntington Beach is available on the Web at http://www.ohionowcast.info/, and the general methodology is available for possible use at other beaches (http://pubs.water.usgs.gov/tm6b5/).

Chemical Contaminants

Chemical contaminants are ubiquitous in aquatic environments and can pose risks to humans either via consumption of contaminated seafood or from contact with polluted waters. Urbanized estuarine watersheds are well documented to have elevated contaminant levels in their sediments, water, and associated biota. Until recently, the majority of research has focused on the effects of metals and persistent organic pollutants such as methyl mercury, pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and oil spills. EPA's Oil Spill Program, NOAA's Office of Response and Restoration, and the U.S. Coast Guard coordinate oil- and chemical-spill prevention and response capabilities in coastal waters. A number of agencies conduct contaminant monitoring programs in coastal areas, such as EPA's Environmental Monitoring and Assessment Program and National Coastal Assessment Program, NOAA's National Status and Trends Program, and USFWS National Wetlands Inventory, as well as Great Lakes information from the State of the Lakes Ecosystem Conference. Data collected from these monitoring efforts are used as the basis for the National Coastal Condition Report, a multi-agency effort led by the EPA to assess the condition of waters, sediments, and biota around the entire coastline of the United States.

Chemical contaminants which stem from industrial processes, household activities and vehicles are released into coastal watersheds through sewage outfalls, runoff and other point and non-point discharges.

Although successful programs monitor many of the chemical contaminants in our waters, many other potentially dangerous chemicals are not monitored routinely because of lack of methodologies for detection and quantification and/or lack of information on potential hazards posed to aquatic ecosystems and humans. Recent research has shown that very low levels of PAHs affect fish heart function, raising questions about potential for increased heart disease in people exposed to PAHs, perhaps even through air pollution (see Sentinel Species, Habitats, and Biological Models section). Also, studies are necessary to investigate the balance between the health benefits of eating seafood versus the risks associated with increased exposure to methyl mercury and other contaminants in seafood (see Seafood Safety section).

In recent years, OHH researchers have begun to investigate how increased levels of emerging chemical contaminants (ECCs), such as flame retardants, stain repellants and stick-resistant coatings, human and animal-use pharmaceuticals, and pesticides in aquatic environments, could affect ecosystem and human health. These ECCs are released into coastal watersheds through upland runoff from both urbanized and agricultural lands, sewage discharges, industrial releases, atmospheric transport, and aquaculture. Some ECCs have the potential to bioaccumulate and can be transferred throughout food webs. One group of ECCs that could be addressed through OHH research is the class of brominated flame retardants. Flame retardants have been reported to cause neurological effects in mammals and reduced growth and survival of juvenile fish. These compounds have not been monitored widely in estuaries, and little information is available regarding their toxicity in estuarine species. Additionally, the potential for transfer of these contaminants to humans consuming seafood products has not been well characterized, although humans are known to accumulate them.

Other ECCs of concern include perfluorinated compounds (PFCs) which contain chemicals with unique properties to make materials stain- and stick-resistant such as non-stick pan coatings, fabric stain repellants, microwave popcorn bags, pizza boxes, fire-fighting

foam, and some cosmetics products. PFCs are resistant to breakdown and are turning up in unexpected places around the world, including humans and marine wildlife. Recent studies of sea turtles have shown PFCs surpassing PCBs in concentration. PFCs are persistent, bioaccumulate and can cause tumors and toxicities to the liver, reproductive, developmental, and immune systems of rats, mice, and monkeys. The effects on humans have not been observed or are inconclusive.

The increasing prevalence of pharmaceuticals in aquatic ecosystems could have widespread effects on marine organisms because pharmaceuticals are biologically active and may cause significant unintended responses even in minute quantities (e.g., endocrine-disrupting reproductive impacts). These compounds also may be transferred to humans through consumption of fishery products. In addition, the release of antibiotics to the environment may favor the development of resistant strains of pathogenic bacteria or lead to alterations in the composition of natural microbial communities, which in turn may have severe consequences for both human and ecosystem health.

The effects of pharmaceuticals and personal care products in the marine environment are less studied compared to freshwater but already show similar effects such as the feminization of male marine fish.

Additional ECCs that warrant further research include a wide variety of insecticides, fungicides, and herbicides used to control insect, weed, and fungal pests associated with crops, turf grass, and ornamental plants and new anti-fouling compounds used to limit marine growth on boat hulls (see Box 17). Although modern pesticides are typically less persistent than earlier classes of pesticides, many are acutely toxic to a variety of non-target estuarine species. Because of the way they are applied, they may enter the environment in the form of repetitive pulses at concentrations sufficient to cause toxicity in non-target species. New compounds enter the market every year and their toxicity to most estuarine species is often unknown. Thus, analytical, toxicological, and ecological methodologies to document and quantify their concentrations and potential effects in estuaries are essential.

The number and diversity of both common chemical contaminants and ECCs that may impact human or coastal ecosystem health are tremendous and represent an important focus of the Interagency OHH Program. Major opportunities to advance understanding of chemical contaminants in coastal waters include the following:

- Conduct basic research and monitoring to provide baseline information to identify and prioritize known and emerging chemical contaminants.
- Develop, validate, and standardize analytical methods for the detection of these contaminants in estuarine and marine waters, sediments, and tissue samples (see also Standards and Standardized Methods section).
- Develop sensitive indicators (biomarkers) of ECC effects in estuarine and marine environments.
- Regularly monitor estuarine and marine ecosystems, seafood, and humans to determine the presence and distribution of ECCs.
- Evaluate ECC hazards to estuarine and marine biota and especially to humans who may be exposed via multiple pathways.
- Develop improved models and risk assessments to inform management and public health authorities.

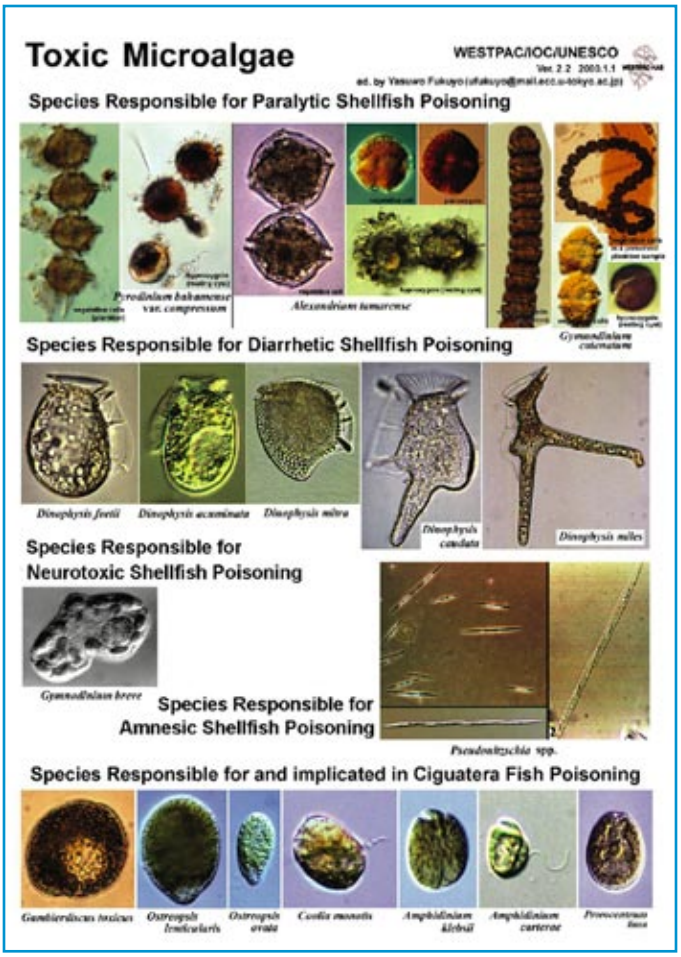
Harmful Algal Blooms

Blooms of various kinds of algae occur commonly and naturally in coastal waters, estuaries, lakes, and ponds. Some, typically referred to as HABs, have harmful effects or produce potent natural toxins that cause mild to severe disease and even death among a variety of aquatic species and humans exposed to them *via* consumption of contaminated seafood or other avenues (Table 1). Several reports highlight global increases in frequency and intensity of HABs, leading to more closures of beaches and fishing grounds and associated economic losses. Recent work with dolphins and manatees has documented that some deaths of these marine mammals occurred as a result of their consumption of toxin-contaminated fish and seagrass, raising the specter of potentially increased dangers to human and animal consumers of seafood. Also, OHH research has documented an association of pathogenic bacteria with HABs.

Box 17: NOAA's OHHI Develops New Methods to Identify and Measure Toxicity of Antifouling Pesticides

Many new antifouling agents have been created and widely used to prevent settlement and growth of marine organisms on submerged surfaces of vessels. While such compounds have clear commercial benefits, numerous questions concerning unintended impacts of new antifouling agents in ocean environments have been raised. OHH researchers at the HML developed a sensitive liquid chromatography-mass spectrometry method to detect several currently used antifouling agents. Monitoring studies were initiated in several locations including South Carolina, Puerto Rico, and California. A parallel laboratory evaluation of the potential toxicity of one such agent, Irgarol 1051, to several key estuarine organisms, including grass shrimp and clams, indicated that these animals were relatively unaffected by the chemical. However, algae were found to be very sensitive to Irgarol 1051 at concentrations similar to those measured in the environment during the monitoring studies. Impacts to algae at the base of estuarine food chains could seriously affect higher-level consumers.

Scientists study the toxicity of chemicals on various marine species, including pesticides and anti-fouling compounds painted on boats. Photo credit: S. Lovelace



Many species of algae are responsible for producing harmful algal bloom toxins. Photo credit: With permission from TOS and source: http://dinos.anesc.u-tokyo.ac.jp/Jpeg/index.htm

On the other hand, some HAB toxins may hold promise for development of new pharmaceuticals or other useful products (see Pharmaceuticals and Other Beneficial Products section).

For over a decade, the National Plan for Marine Biotoxins and Harmful Algae has guided U.S. HAB research and has led to considerable progress in understanding blooms and their toxins. In 2005, a new 10-year research plan (*HARRNESS, Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015*) identified four broad areas for focused research: (1) bloom ecology and dynamics, (2) toxins and their effects, (3) food webs and fisheries, and (4) public health and socioeconomic impacts. An associated report, *Harmful Algal Research and Response: A Human Dimension Strategy*, outlines some of the social, behavioral, and economic studies needed, and the *National Assessment of Efforts to Predict and Respond to Harmful Algal Blooms in U.S. Waters*, provides rec-

ommendations dealing with prediction and control of HAB events.

Prior to existence of the Interagency OHH Program, Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (amended in 2004) and put into motion an Interagency HAB research effort. Thus, the Interagency OHH Program will complement the ongoing federal agency HAB activities, with primary, although not exclusive, focus on documenting and understanding direct and indirect HAB-related health threats to humans and marine animals, collaborating to conduct epidemiological studies, new sensor technologies, and opportunities for beneficial uses of HAB toxins (see Boxes 18-20).

Major opportunities for advancement within the Interagency OHH Program include the following:

- Develop, test, deploy, and validate new or improved sensors for rapid, accurate, and inexpensive identification and quantification of multiple HAB species and HAB toxins in the environment, with particular emphasis on incorporating such sensors into ocean observing systems.
- Increase accuracy and timeliness of estimates of the concentration and distribution of waterborne harmful algae and toxins. Identify more accurate indicators of risk to humans and animals and improve measurement techniques to reduce the time between sample collection and the availability of results.
- Collaborate to develop and test new models that combine health and environmental surveillance data to produce useful forecasts and risk assessments for HAB-related health impacts and assess the capabilities of the ocean observing systems to support public health decision-making.
- Improve understanding of modes of action and health effects of HAB toxins in animals and humans to develop better health warnings and treatments.
- Investigate the occurrence and significance of observed associations of pathogens such as bacteria and viruses with HABs in ecosystem and human health contexts (see also Pathogens section).

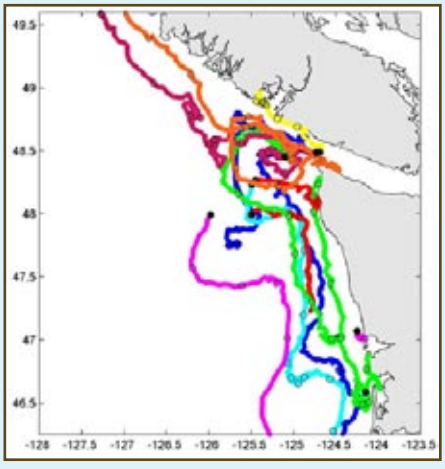
Box 18: NOAA's OHHI Develops PCR Assay to Determine Toxicity of *Microcystis* Blooms in the Great Lakes

Microcystis is a particularly harmful alga in the Great Lakes. Much more information is needed about factors that trigger blooms of this organism and when such blooms become toxic and thus pose risks to humans. Researchers at NOAA's CEGLHH developed a biochemical assay to quickly identify whether colonies of *Microcystis* were capable of producing toxins and to help identify which blooms are particularly threatening to recreational beaches and drinking water sources in the Great Lakes.

Microcystis harmful algal bloom in western Lake Erie and the infamous Microcystis "shake" taken from a water sample. Photo credit: T. Bridgeman

Box 19: NOAA's OHHI Tracks HABs on the West Coast

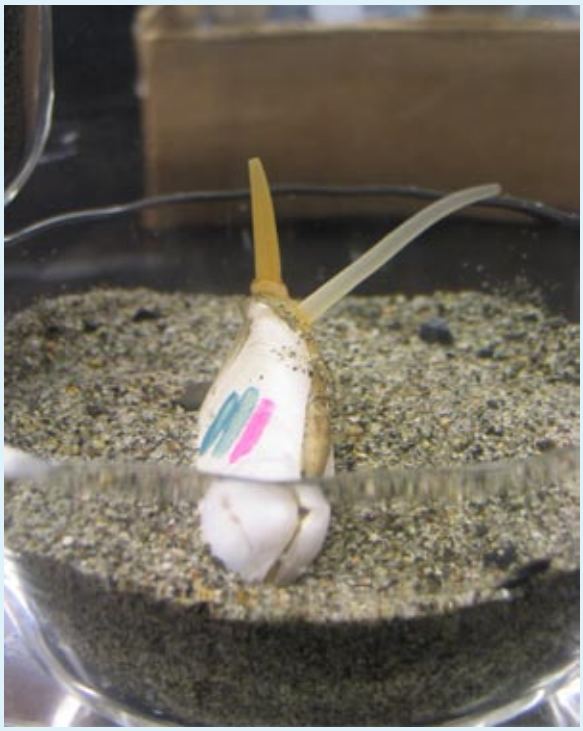
NOAA's WCCOHH, in collaboration with the ECOHAB Pacific Northwest Program, deployed drifters in the Juan de Fuca eddy, a known HAB "hot spot" off the Washington coast. These drifters track the movements of the toxic patches, providing an early warning of need for coast-wide closures of recreational, commercial, and tribal subsistence razor clam fisheries.



Drifters deployed during the September 2005 ECOHAB Pacific Northwest cruise track movement of harmful algal patches as seen here in the Juan de Fuca eddy region. Photo credit: V. Trainer

Box 20: Bivalves and Food Web Transfer of Domoic Acid in Washington Waters

Laboratory studies are being conducted at the NSF-NIEHS Center for Oceans and Human Health at the University of Washington (PNW H2O) to determine how various species of harvestable shellfish (including local species of clams, oysters, and mussels) differ in the rates they feed on the toxic alga, *Pseudo-nitzschia*. The feeding rate may influence the amount of domoic acid toxin retained in the shellfish tissue. Preliminary results suggest that mussels and oysters consume *Pseudo-nitzschia* at higher rates than clams found in Puget Sound, and at substantially higher rates than razor clams found along Washington's coast. It has been shown previously that mussels purge domoic acid from their tissues quickly, whereas razor clams take a long time to purge the toxin. The high feeding rate of mussels and oysters found in Puget Sound, combined with the ability of mussels to quickly purge toxin from their tissues, may be related to the decreased frequency of beach closures for *Pseudo-nitzschia* in Puget Sound. Data from these experiments will be combined with a model currently being developed to track the offshore to onshore water movement to predict the impacts of *Pseudo-nitzschia* blooms on the intertidal shellfish in Puget Sound.



Feeding rates of shellfish such as clams might affect the amount of domoic acid toxin retained in the tissues. Photo credit: E. Dusek

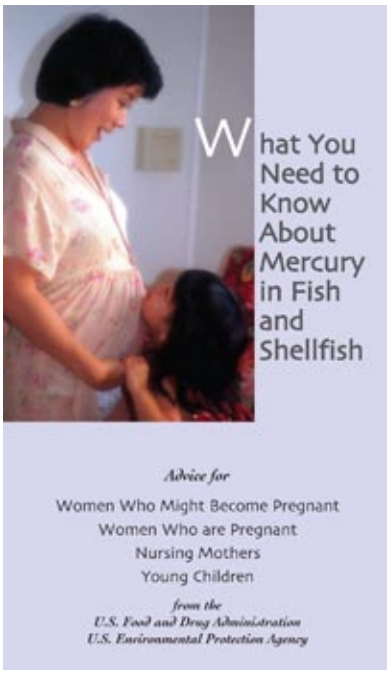
Seafood Safety

The health benefits of eating seafood are well known. Fish are an important source of high quality protein and other essential nutrients and contain omega-3 fatty acids, which have a variety of benefits. Yet seafood is also known to pose some health risks to humans if it is contaminated with pathogens or biotoxins, or accumulated heavy metals, organic pollutants, and ECCs.

NOAA, with additional support provided by the FDA, asked the Institute of Medicine of the National Academies (IOM) to review evidence on the benefits and risks associated with seafood consumption. The IOM released its findings in October 2006 and confirmed seafood is rich in nutrients, low in saturated fats, and should be incorporated more into the American diet to reduce the risk of early death by heart disease and stroke. Furthermore, the IOM found pregnant and nursing mothers and children should consume some seafood because of the significant benefit to cognitive development and association with higher IQ in newborns and children. At the same time as the release of the IOM study, a meta-analysis by Harvard School of Public Health researchers found reductions in death rate from heart disease among those who ate at least one to two servings of fish per week. A significant opportunity for the Interagency OHH Program is to determine the full range of health benefits from fish consumption, such as learning how much fish must be consumed to achieve these benefits, the active components in fish that protect humans from disease, and the mechanisms by which such protection occurs.

Contrasting with the benefits of fish consumption are risks associated with contamination by pathogens, toxins, and chemical pollutants (see Box 21). For example, contamination of fish with mercury and the potentially harmful effects of mercury on brain development pose a significant problem in communicating the balance of risks and benefits to the public and especially to women of child-bearing age. Pregnant women and nursing mothers should consume some fish to realize the benefits, but they should not eat certain fish species, which contain high levels of mercury. One opportunity for the OHH Interagency Program is to assist in standardizing risk and benefit analysis across agencies to ensure that recommendations and health advisories do not provide confusing or conflicting information to the public.

The need for risk and benefit analysis of seafood also applies to aquacultured products, as the majority of U.S. seafood comes from international sources, with nearly half the imports from aquaculture. The increasing proportion of aquacultured fish raises additional concerns about the amount of beneficial omega-3 fatty acids in the fish versus the chemical contaminant loads stemming from the feeds used to grow fish. Research is needed to identify and develop more plant- or microbe-based components to replace meal and oil in aquaculture feeds. Such replacement could address concerns related to both the sustainability of the wild fish stocks exploited for production of meal and oil and the levels of chemical contaminants these products may contribute to aquaculture feeds. Current research within NOAA's OHHI is developing technologies to produce competitively priced aquacultured seafood with enhanced beneficial fatty acid profiles and safe contaminant levels. Improving the nutritional characteristics of aquacultured seafood is an area where enhanced research within the Interagency OHH Program could result in major benefits for the public and a competitive edge for U.S. aquaculture producers in the global seafood market.



FDA, EPA and many states communicate the risk of eating certain fish high in mercury content to pregnant and nursing women, children and the general public. Source: http://www.epa.gov/mercury/advisories.htm

Development of better detection methods and forecasting capabilities for pathogens and toxins are underway (see Box 22), as are new approaches to destroy or make harmless pathogens and toxins in seafood and to educate the public about seafood consumption. Such capabilities are being developed within the Interagency OHH Program and can be addressed through targeted research, technology development, and implementation of monitoring protocols combined with new technology and communication tools. In addition, the National Aquatic Animal Health Plan, a cooperative effort of the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture, NOAA Fisheries of the U.S. Department of Commerce, and the USFWS of the U.S. Department of the Interior working together under the Joint Subcommittee on Aquaculture, is being developed to protect cultured and wild aquatic animal products from disease and ensure availability of diagnostic and certification services.

Although some benefits and risks of consuming fish are well established, continued research is needed to more fully understand the human health benefits and risks of seafood consumption and develop better approaches to ensure the high quality, safety, and sustainability of the nation's seafood supply.

Several major opportunities for advancement that could produce significant health benefits and reduced health risks for American seafood consumers include the following:

- Cooperate with the National Aquatic Animal Health Plan and Task Force to focus on major animal health research topics of mutual interest.

- Expand development of assays, sensors, microarrays, and other techniques to detect and quantify levels of specific contaminants of concern (pathogens, harmful algal toxins, chemical pollutants) in seafood from all sources, including marine wildlife harvested by subsistence users, that can be applied in the field and used by industry (e.g., fishers, fish markets, fish wholesalers and restaurants, etc.) and public health workers (see Pathogens, Chemical Contaminants and HABs sections).

- Examine seafood safety in an ecosystem context, including the role of anthropogenic factors, climate cycles, and climate change in pathogenesis, toxicity, and contamination of seafood, and develop and implement models linking environmental data to seafood contamination to build predictive and risk assessment capabilities.

- Determine the full range of health benefits from fish consumption, coupled with focused studies on which seafood components provide benefits and the biological mechanisms of those benefits. Specific research targets might include determining preferred levels and ratios of particular fatty

acids in fish flesh and to what extent the selenium content of fish flesh may offset potentially harmful effects of mercury contamination.

- Standardize comparative risk assessments that consider both beneficial and negative characteristics of specific types or sources of seafood in order to reconcile recommendations and health advisories and effectively communicate to the public.
- Evaluate new ways to enhance the levels of beneficial omega-3 fatty acids and reduce chemical contamination in aquacultured fish and fish feeds, including the use of materials derived from plants and microbes to substitute for fish meal and oil as basic components of fish feeds.

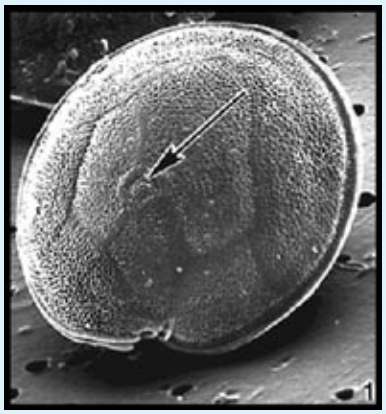
Box 21: NOAA's OHHI Investigates Benefits and Risks of Seafood Consumption

NOAA-supported researchers at the HML measured the chemical contaminant levels and fatty-acid content of samples of red drum (a popular marine fish) from a range of domestic and imported sources, including both wild and cultured fish. The results, interpreted in terms of both human health risks and benefits, suggest that fatty acid ratios and contaminant loads vary widely according to source and in some instances may pose a health hazard. A similar investigation of shrimp from 62 domestic and foreign sources is currently underway. HML scientists are using information derived from these studies to develop and test aquaculture technologies that will permit economically competitive production of seafood with certifiably safe contaminant levels and enhanced, beneficial fatty acid profiles.

Red drum are harvested from wild populations, and are also farmed. Scientists are analyzing fish tissues to see how contaminant loads vary by source. Photo credit: S. Lovelace

Box 22: NSF-NIEHS Ciguatera Studies

Ciguatera poisoning is a HAB-related illness caused by the consumption of fish, usually more tropical species, that have become contaminated with ciguatoxins produced by a dinoflagellate, *Gambierdiscus spp.* Research conducted by OHH researchers at the PRCMB is pursuing improved strategies to predict ciguatera outbreaks and prevent human poisonings arising from the consumption of ciguatoxic fish. Ecological efforts include the collection and analyses of fish, algae, and environmental data from coastal sites throughout the Hawaiian archipelago, and physiological studies that focus on the identification of conditions that trigger and promote the production of ciguatoxins by the dinoflagellate. Work is also underway to improve analytical methods to detect ciguatoxin at the extremely low levels that are known to cause poisonings in humans. Analyses have shown that between 12–17 percent of the fish sampled from Hawaiian coasts are ciguatoxic. Collaborative research has identified a novel ciguatoxin congener in Hawaiian fishes named CTX-H. The isolation and purification of this material is being used to develop improved detection methodologies needed to prevent ciguatoxic fish from reaching the consumer. In addition to *Gambierdiscus toxicus*, the species of dinoflagellate thought to produce ciguatoxin, two entirely new species of *Gambierdiscus* have tentatively been identified in Hawaiian waters.



Gambierdiscus toxicus (shown here) produces ciguatoxins which can accumulate in tropical reef fish via the food web and can cause illness in seafood consumers. Source: http://www.nmnh.si.edu/botany/projects/donoglag/Taxa/Gtoxicus.htm

Pharmaceuticals and Other Beneficial Products

For thousands of years, humans have used natural products from the land to treat diseases. Over time, humans learned how to isolate bioactive and other useful chemical components from plants and microorganisms, particularly bacteria and fungi. These discoveries eventually led to synthesis and mass production of purified medicines and other beneficial products. The discovery of penicillin in the late 1920s was arguably the single most important medical advance of the 20th century, and altogether over 120 antibiotics and other drugs originally derived from soil microbes are still in use today. Yet, despite a growing problem of antibiotic resistance, the global drug industry is not emphasizing continued exploration for and development of a new generation of safe and effective antibiotics for human use.

The sea squirt Ecteinascidia turbinata grows on mangrove roots and offers powerful anti-cancer compounds. Photo credit: With permission from The Oceanography Society

The potential for ocean resources to provide new sources of drugs and beneficial products, including some perhaps as transformational as the discovery of penicillin, is just beginning to be widely appreciated. Pioneering research began as early as the 1960s, including efforts supported by NOAA's National Sea Grant College Program, NIH's National Cancer Institute, the NSF, and other agencies, and some truly remarkable discoveries have been made (Table 2). However, major programs focused on discovery and development of drugs from the sea have not materialized. Recent advances in molecular biology, high-throughput cultivation of microorganisms, growing knowledge and exploration of deep-sea environments and chemosynthetic ecologies, and understanding of the ocean's incredible biodiversity, along with mounting problems of drug-resistant pathogen strains and increased incidences of some kinds of cancers, have resulted in new interest in the oceans from a pharmaceutical/natural products standpoint. For example, spongouridine and spongothymidine, compounds derived from a sea sponge, prompted the development of the synthetic anti-leukemia drug cytarabine (Cytostar®), and two very important anti-viral drugs (Acyclovir and AZT, which are used to treat Herpes and HIV infections, respectively, were based on the same natural marine sponge compounds.

A veritable host of marine species have demonstrated potential to yield useful compounds. These include microorganisms, principally the bacteria and fungi, but also algae, corals, mollusks, and fish. Several of these are already in clinical trials to treat cancers, tumors, inflammation, Alzheimer's disease and for use with bone implants, cosmetics and food additives (Table 2). Limited but promising studies indicate that some HAB toxins may have potential to treat cancer and pain in humans or may be used broadly as chemical tools for biomedical research. Also, there is growing private-sector interest in working with novel-disease organisms isolated from marine mammals and other marine animals to determine their potential for use in developing new compounds for human applications (see Box 23).

The advent of new, extremely sensitive analytical capabilities (including powerful nuclear magnetic resonance and mass spectral instruments) has opened the field to the discovery of highly active metabolites that exist in such low concentrations that they were previously beyond reach. In addition, the ability to mass culture toxin-producing algae, bacteria, and fungi under highly controlled and safe conditions allows for production of sufficient quantities of toxin for experimentation and testing. The availability of appropriately equipped biosafety laboratories opens new opportunities for beneficial advancements in the discovery and development of therapeutics based on materials from the sea. Coupling these laboratories with new remotely operated and in situ devices that allow sampling of very small quantities of biological materials from extreme and novel environments, without risk of introducing pathogens or invasive species, offers great potential for new discoveries.

Major opportunities for advancement include the following:

- Examine genetic, species, and molecular diversity within extreme marine habitats (e.g., thermal vents, seamounts, deep sediments, and cold seeps) using ecologically sound methods and evaluate these environments as sources of bioactive compounds.

Table 2. Status of Marine-Derived Natural Products in Clinical and Preclinical Trials.

Compound	Source	Disease	Comment
Bryostatin 1	Bryozoan (a sessile marine animal, also called moss animal) *Bugula neritina*	Cancer	Now in combination therapy trials; licensed to GPC Biotech by Arizona State University
TZT-1027	Synthetic Dolastatin isolated from the sea hare (a type of sea slug)	Cancer	Also known as Auristatin PE and Soblidotin; in trials
Cematodin	Synthetic derivative of Dolastatin 15 isolated from the sea hare	Cancer	Some positive effects in melanoma; in trials
ILX 651, Synthatodin	Synthetic derivative of Dolastatin 15 isolated from the sea hare (a type of sea slug)	Cancer	For melanoma, breast, and non-small cell lung cancer
Ecteinascidin 743	Ascidian *Ecteinascidia turbinate* (mangrove tunicate)	Cancer	Licensed to Ortho Biotech (J&J/Jansen Pharmaceuticals); in trials
Aplidine	Ascidian (sea squirt) *Aplidium albicans* (Mediterranean tunicate)	Cancer	Dehydrodidemnin B; made by total synthesis; in trials
E7389	Marine sponge *Lissodendoryx sp.*	Cancer	Eisai's synthetic halichondrin B derivative; breast and lung; in trials
Discodermolide	Deep-water marine sponge *Discodermia dissoluta*	Cancer	Licensed to Novartis by Harbor Branch Oceanographic Institution; in trials
Kahalalide F	A marine invertebrate, Mollusk *Eylsia rufescens* and the feather haired alga *Bryopsis sp.*	Cancer	Licensed to PharmaMar by University of Hawaii; in trials
Zalypsis	Synthetic safracin B; derivative from marine bacteria	Cancer	PharmaMar (based on saframyin molecule); in trials
ES-285	Stimpson's surf clam, *Spisula polynyma*	Cancer	A protein involved with functioning of the nucleotide guanosine triphosphate important in metabolism; in trials
KRN-7000	an Okinawan sea sponge, *Agelas mauritianus*	Cancer	An agelasphin derivative; in trials
Squalamine	Spiny dogfish (shark) *Squalus acanthias*	Cancer	Anti-angiogenic activity; in trials
Æ- 941 (Neovastat)	Shark (spiny dogfish and hammerhead shark) cartilage	Cancer	Defined mixture of < 500kDa from cartilage; anti-angiogenic; in trials
NVP-LAQ824	Synthetic derived from a marine sponge	Cancer	Derived from psammaplin, trichostatin and trapoxin structures; in trials
E-7974 (Eisai)	Marine natural product hemiasterlin synthetic derived from marine sponges	Cancer	Carboxylate-end modified hemisasterlin; in trials
Salinosporamide A (NPI-0052)	Marine bacterium *Salinispora tropic*a	Cancer	Proteasome inhibitor Nereus Pharma; in trials
GTS-21 (aka DMBX)	Marine worm	Alzheimer's	Licensed to Taiho by the Univeristy of Florida; in trials
IPL-576,092 (aka HMR-4011A)	Marine sponge *Petrosia contignata*	Anti-asthmatic	Derivative of contignasterol; Inflazyme Pharma; in trials
IPL-512,602	Derivative of 576092 from marine sponge *Petrosia contignata*	Anti-asthmatic	With Aventis. No further data as of 8/2005
IPL-550,260	Derivative of 576092 from marine sponge *Petrosia contignata*	Anti-asthmatic	With Aventis. No further data as of 8/2005
Ziconotide (aka Prialt)	Cone shell species (Mollusk) from the Pacific Ocean *Conus magus*	Neuropathic pain	Licensed by Elan to Warner Lambert; approved by FDA 12/28/04; launched in U.S. and Europe in 2005
CGX-1160	Cone shell species (Mollusk) also known as 'anbonia' from Pacific Ocean *Conus geographus*	Pain	Cognetix and Elan Corporation (Ireland); in trials
ACV1	Cone shell species (Mollusk) also known as Queen Victoria Cone from Pacific Ocean *Conus victoriae*	Pain	Metbolic Pharma (Australia)(06/2006), conotoxin Vc1.1; in trials

(Adapted from Fenical, 2006. Oceanography 19(2):110-119).

- Develop improved mass-culture methods to allow large-scale production of marine microbes, HAB species, and other organisms that produce compounds of interest for the development of pharmaceuticals and biochemical probes.

- Conduct focused studies to understand the chemical structures and functional relationships between algal toxins' toxicities and their effects, and these toxins' potential as beneficial products, such as new therapeutics and reagents (see HAB section).

- Investigate novel microbial diversity associated with corals and other organisms, including understanding their mechanisms of chemical "warfare" and defense, as well as symbiotic interactions that may result in the generation of bioactive metabolites/chemicals with potential utility in development of drugs and other beneficial products.

- Evaluate more thoroughly the widespread distribution of marine-based neurotoxins and their possible links to health of humans, fish, and birds; mechanisms of action; and potential applications to treat or prevent disease (see HAB and Epidemiology sections).

- Make available methods and materials to rapidly and accurately screen newly isolated compounds for bioactivity (e.g., ability to affect tumors, inhibit bacterial growth) and develop more sensitive and selective bioactivity-screening approaches.

- Establish mechanisms to archive portions of bioprospecting samples (including DNA for subsequent metagenomic studies) in order to conserve samples collected with federal funds as national resources (see also Standards section).

- Enhance collaborations and partnering among the marine biological, oceanographic, and biomedical communities and with the private sector.

- Access vessels and other platforms for ecologically sound exploration and sampling of poorly known marine environments and at locations where the potential for discovery of promising compounds is high (see "Access to Sea").

- Establish long-term mechanisms (e.g., the NOAA and NSF-NIEHS OHH Centers) to support drug and product discovery demonstration efforts over the extended time periods necessary to move from the ocean to the laboratory to commercial products.

- Implement consistent intellectual property procedures across federal agencies involved in OHH research.

Box 23: Pharmaceuticals from the Sea

In 2004, Diversa Corporation signed a biodiversity access and collaboration agreement with the University of Hawaii to cultivate novel bacteria associated with marine animals, sea grasses, and ocean sediments from Hawaiian samples. This discovery effort was co-funded by NOAA's OHHI and the NSF-NIEHS OHH Center at the University. This collaborative agreement provided a unique opportunity to integrate Diversa Corporation's high throughput culturing (HTC) technology with Hawaii's unique biodiversity and expertise in marine natural products chemistry. Samples of the sponge *Mycale armata* were collected from Kaneohe Bay, off Oahu, along with sediments sampled from various locations. Screening results revealed that five of the HTC bacterial isolates obtained from the sponge exhibited anti-microbial activity and four had anti-cancer activity. These findings indicate this strategy has great potential for discovering new drugs from the sea.

Bacteria associated with the sponge Mycale armata have been discovered by OHH scientists to exhibit anti-microbial and anti-cancer activity. Photo credit: S. Coles

Cross-Cutting Areas

Epidemiology

Epidemiologic research is a valuable tool to assess direct positive and negative impacts to human and animal health stemming from the oceans, coasts, and inland waters. Epidemiologic studies address the human part of the OHH equation by investigating diseases in human and animal populations most likely to be exposed to, or affected by, water-borne pathogens, and by observing and assessing naturally occurring disease patterns. The goals of epidemiologic research are to define the underlying characteristics of populations that make them susceptible to specific exposures and measure the associations between these population characteristics and environmental exposures. The results from epidemiologic studies can be used to assess cause and effect by examining the exposure-disease association, including its strength, consistency among studies, and whether or not the association makes sense from a biological standpoint (see Box 24).

A number of acute and chronic illnesses affecting humans and other animals are caused by ocean-based threats, such as infectious diseases and poisonings associated with chemical contaminants or algal toxins. Extreme coastal weather events, such as hurricanes, can put large populations at risk for exposure to harmful microbes, injury, and possibly death. Environmental epidemiology can help refine our knowledge of these public health threats, allow us to uncover emerging threats as they appear, and, ultimately, prevent human exposures to ocean-borne threats before they can cause disease.

Populations of interest to epidemiologists focused on OHH issues include those involved in seafood harvesting and handling, seafood consumers, environmental workers, individuals who work and play on or near the water, and coastal communities, especially indigenous peoples who rely on seafood for a substantial proportion of their diet. Other populations that may be particularly at risk from ocean-related exposures include children and people with compromised immune systems. In addition to directly assessing these populations of interest, aquatic animal health events can be evaluated to identify potential new human health threats (see Sentinel Species section).

Environmental epidemiology requires cross-disciplinary collaboration with experts from fields such as medicine, public health, epidemiology, toxicology, experimental design, analysis of environmental and clinical samples/specimens, data management, and statistical analysis (see Boxes 25, 26). Public health surveillance is the systematic collection of health data that are then used to generate hypotheses about causal relationships, assess disease trends, and serve as the basis for public health protection activities. Of particular interest to the Interagency OHH Program, the CDC has developed HABISS a HAB-illness surveillance system (see Box 27) that can be used as a model for examination of other environmental health threats. As pointed out in the Ocean Research Priorities Plan and Implementation Strategy, "Ocean data and modeling should be integrated with assessments and epidemiologic studies to define exposures and focus risk assessments." One way to do this would be to build upon HABISS with participation by multiple agencies.

Opportunities to advance understanding of the scope of public health threats posed by the ocean and to improve public health protection include:

- Implement and enhance epidemiologic studies to characterize public health risks from pathogens, toxins, and chemical contaminants from the oceans and coastal waters (see Pathogens, Contaminants, and HABs sections).
- Characterize diseases associated with ocean-borne risks to improve diagnosis and treatment, reporting, and public health surveillance.
- Acquire, integrate, and interpret environmental data applicable to epidemiologic studies and disease surveillance systems at the right temporal and spatial scales and correlate with epidemiologic data (see Ocean Observing Systems section).
- Make improvements to disease surveillance to detect emerging human and animal health issues.
- Continue to support CDC's existing HAB-related Illness Surveillance System, including involvement of local health practitioners to the greatest extent feasible (see HAB section).

- Use epidemiologic data to help design and implement models to track and predict ocean-driven health events.
- Improve the transfer and applicability of relevant medical information from animal health studies and response investigations to the public health community.
- Conduct epidemiologic studies on direct and indirect effects of climate variability on the geographic and temporal distribution of ocean-borne human and animal health threats.

Box 24: Studies of Human Exposure to Domoic Acid

The Pacific Northwest is a unique location for the study of exposure to domoic acid because there are many diverse regional populations that consume a lot of shellfish. At the NSF-NIEHS Center for OHH at the University of Washington (PNW H2O), investigators have partnered with Native American populations who reside, harvest and consume shellfish in the PNW where domoic acid concentrations in razor clams, crabs and other shellfish have closed usual and accustomed areas of harvest. The University of Washington Center has also collaborated with the Washington State Department of Health and other partners to characterize dietary consumption, including specific information about shellfish, among Asian and Pacific Islander populations whose diets are traditionally high in locally harvested shellfish.

Subsistence and recreational harvesting of razor clams provides an important source of protein and socio-cultural activity for communities. Photo credit: C. McKay

Box 25: NSF-NIEHS Center and CDC Epidemiologic Studies Related to HABs

The NSF-NIEHS Center for OHH at the University of Miami is collaborating with CDC, the Florida Department of Health, other universities, and private research laboratories to conduct epidemiologic studies of people exposed to aerosolized brevetoxins during Florida red tide events. The collaborative research program includes using animal models of asthma to provide a new level of understanding of the biological underpinnings of the effects observed in people. Study results have provided the basis for a further collaboration with NOAA to use human data to predict the effects of Florida red tides on coastal communities. Understanding the entire process from formation of the aerosols to the physiologic basis of the induced health effects has provided the foundation for an effective community outreach and education programs to prevent exposures and mitigate the public health impact from Florida red tide events.

Lifeguards are probably one of the populations most highly exposed to aerolized brevetoxins (K. brevis) because of their lengthy stays on beaches; some wear masks during harmful algal blooms. Photo credit: L. Backer

Box 26: Multi-Agency Epidemiologic Studies Related to Water-Borne Illnesses

EPA is collaborating with the CDC and the USGS to conduct a series of epidemiologic studies to assess the occurrence of water-borne illnesses among beachgoers. In 2003 and 2004, the research focused on Great Lakes beaches and was to expand to Gulf of Mexico beaches in 2005, but this aspect was interrupted by Hurricane Katrina. Current plans are to conduct epidemiologic investigations along Atlantic and Pacific coastal beaches in collaboration with NOAA. For each study, nearly 8,000 volunteers report on their activities and health status after visiting the beach and EPA collects and analyzes water samples to assess exposure to water-borne pathogens. In addition, beginning in summer 2007, NOAA's OHHI will participate in a recreational waters epidemiological investigation organized by the Southern California Coastal Water Research Project in collaboration with an epidemiologist at the University of California, Berkeley. This partnership represents a rare opportunity to apply novel pathogen detection technology developed under the OHHI to water samples that will be collected simultaneously with health data.

Box 27: CDC's Harmful Algal Bloom-Related Illness Surveillance System (HABISS)

HABISS is a web-based modular system to collect and store data on human health, animal health, and environmental data in one place. This system combines environmental data with human and animal disease surveillance information and provides the basis for developing powerful new tools for the prediction, control, and prevention of adverse health effects associated with the ocean.

Collection of environmental data is combined with other epidemiologic data sets in HABISS and made available for more comprehensive analyses of human health threats.
Photo credit: L. Backer

Sentinel Species/Habitats and Animal Models

A variety of marine species and habitats are excellent indicators or sentinels of environmental stress and potential health threats for humans; they provide information about what is happening in the environment that may affect humans and animals. In-situ studies of sentinel species and habitats provide a means to assess cumulative or integrative effects of chemical contaminants, microbes, or toxins in food webs, animal systems, or ecosystems. Such sentinel species and habitats may be considered in at least three categories: (1) wildlife or habitats that tend to concentrate contaminants, toxins, and/or pathogens from their environment and thus may provide more biologically relevant indicators of exposure or effects than water sampling alone (e.g., filter-feeding bivalve mollusks such as oysters, clams, mussels); (2) wildlife with diets and/or physiologies at least partially similar to those of humans may demonstrate early indications of potential health effects (e.g., marine mammals, such as the California sea lion, bottlenose dolphins, and sea birds) (see Box 28); and (3) habitats encompassing key ecosystem components and subjected to high pollution exposure, thereby indicating potential effects at systems or community levels (e.g., tidal creek habitats which serve as first repositories and impact zones for terrestrial runoff and adjacent land use, Box 29).

Specific organisms or habitats may be excellent sentinels for particular questions whereas others may be sentinels for broader surveillance purposes. In most cases, they not only indicate the presence of a threat but can provide information about the possible risks or effects in the ocean environment. Ocean sentinels may provide a wealth of information to managers in addition to the mere presence of the organisms or chemicals of concern.

While sentinel species and habitats provide many advantages over routine water and sediment sampling, they also have important limitations. For example, migratory species such as some marine mammals may integrate environmental conditions over a large area, but may not provide information about specific localities or point sources of exposure. Sedentary species such as oysters and specific local habitats like tidal creeks may give a very accurate picture of localized effects of contami-

Marine mammals such as dolphins, manatees, sea lions and otters provide important clues as to how the health of ocean ecosystems may affect human health. Photo credit: With permission from TOS

nants, toxins, and pathogens, but gaining a picture of more widespread impacts may require sampling of similar point source sentinels in numerous locations. While these characteristics of specific sentinel systems may appear to be drawbacks, they actually demonstrate the great diversity of animals and habitats that can potentially serve as sentinels for environmental threats. The appropriate choice of a sentinel will allow us to sample at several trophic levels and scales to develop better understanding of how contaminants, toxins, and pathogens may be transferred, bioaccumulated, and/or biomagnified through food chains that may include humans at the top. Because they integrate the broad range of environmental conditions to which they are exposed, sentinel species and habitats may give a much better picture of the cumulative health effects of degraded coastal ecosystems than any other measure. They also provide unique opportunities to study how disease-causing materials may be transferred directly from organism to organism and from mother to offspring, and the kinds of impacts associated with such transfer, including cellular and gene-level responses and disease pathogenesis. Such studies may be costly to conduct in animal models in the laboratory and are likely impossible to conduct in people. Thus, use of a broad array of sentinels may be a highly effective means of unraveling ocean health threats to humans.

Monitoring the health of sentinel habitats such as tidal creeks. Photo credit: S. Lovelace

Numerous marine organisms already serve as informative animal models for investigations related to human physiology and mechanisms of disease processes (see Boxes 30, 31). Perhaps best known are the squids and sea hares, studies of which have generated much of our basic knowledge about how the human nervous system works, and sea urchins, which are outstanding models for the study of biological development. A variety of fish species are used to investigate genetic influences on development and disease processes, kidney function, cancers, and many other health-related issues, and there are many other species of both vertebrates and invertebrates that provide crucial information related to human health. Marine organisms also may serve as models for understanding human diseases associated with marine-borne pathogens or biotoxins and may suggest new treatments or products. Because life in the sea is so diverse, it is certain that we will find many other species with characteristics that make them excellent subjects for observation and experimentation. The end result will be a better understanding of disease processes that affect humans and ways to alleviate human pain and suffering or reduce disease in people.

Significant opportunities for advancement using sentinel species and habitats, and marine biological models include the following:

- Use surveillance systems to collect, analyze, and interpret information on exposures to and effects of pathogens, toxins, and chemical contaminants in priority sentinel species in specific regions, such as marine mammals, bivalve mollusks, sea

birds, selected fishes, and perhaps others (see Epidemiology section).

- Integrate information gained from studies of sentinel species and habitats with data from environmental observations and human epidemiologic studies to understand, predict, mitigate, and prevent ocean-borne health risks to humans, including both well-known and emerging threats and cumulative impacts of multiple stressors (see Epidemiology and Linking to Ocean Observing Systems sections).

- Optimize existing marine-animal models and identify and develop new organismal models for investigations that lead to improved understanding of human disease processes and health effects.

- Use findings from sentinel species such as marine mammals to design targeted laboratory experiments that will elucidate health risks to humans and ways to mitigate or avoid such risks.

- Use genomic and proteomic tools, including microarrays, for (a) rapid detection of multiple species of pathogens and HABs and identification and quantification of toxins; (b) integration into surveillance systems for sentinel species and habitats; and (c) research to unravel mechanisms of ocean-related health effects in sentinel species (e.g., marine mammals) that are particularly indicative of likely human effects (see also Genomics section).

- Investigate roles of marine mammals, seabirds, and perhaps other species as dispersal mechanisms for enteric organisms or antibiotic-resistant bacteria in the marine environment and as vectors of known and emerging disease threats to humans.

- Conduct research and monitoring to understand the sources, fates, effects, and human health threats of contaminants, pathogens, and toxins in sentinel habitats, including their possible roles as reservoirs of such threats; effects on ecosystem productivity, function, and resilience; and the potential use of sentinel habitats in ocean observing systems (See Linking to Ocean Observing Systems section).

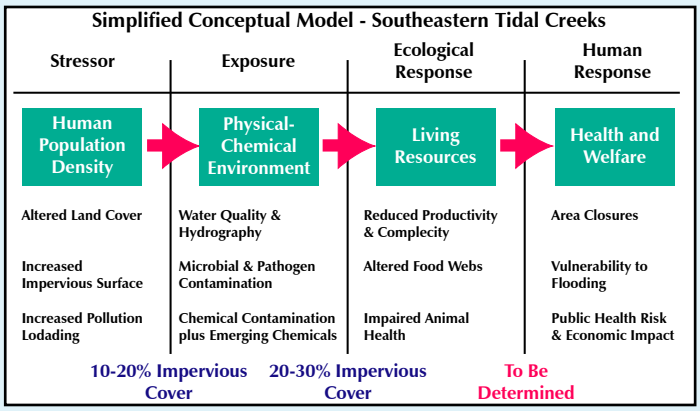
Box 28: California Sea Lions as Sentinels for HAB Exposure

In 1998, the strandings of sea lions along the California coast led to an intense investigation of the roles HABs play in marine mammal strandings. That event and numerous others demonstrated that domoic acid, a biotoxin produced by diatoms, can have acutely lethal and sublethal effects on marine organisms and can cause serious illness and death in humans. Some California sea lions that survived exposure to domoic acid have suffered seizures even long after the toxin was no longer detectable in their bodies. Some have also been shown to have permanent brain damage, abnormal behaviors, cardiac lesions, and reproductive problems (premature parturition, abortion, neonatal death, poor neonatal survival, and high levels of toxins in amniotic fluid). Through studies of the California sea lions, we are learning much about mechanisms of action, pathogenesis, and individual and population-level effects of domoic acid on organisms. This information will lead to better understanding of human risks and health effects that may result from exposure to domoic acid. In addition, studying what the dead marine mammals ate provided important information on the transfer of domoic acid through the food web (e.g., from sardines to mole crabs to sea lions). Understanding exposure pathways increases our knowledge of potential risks to animals and humans. Since 1998, there have been numerous other stranding/mortality events of marine mammals and sea birds caused by domoic acid along the California coast and elsewhere in the United States. Information gained from sentinel species such as the California sea lion allowed us to better understand mechanisms of action, low dose chronic exposure effects, and food web pathways and to initiate appropriate actions to protect people from this ocean hazard.

California sea lions and people share the same coastal waters and both eat at the top of the food web. Understanding exposure pathways and responses in marine mammals increases our knowledge of similar human health risks. Photo credit: T. Rowles

Box 29: Tidal Creeks as Sentinel Habitats

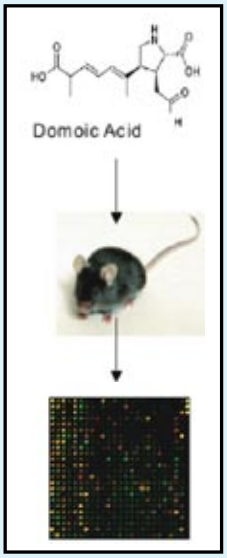
Work by OHH researchers at NOAA's HML suggests that small tidal creeks may provide early warning of impaired ecosystem conditions and risks to public health and welfare. Tidal creeks are the primary connection between the land and estuaries and the first recipient of much of the runoff from adjacent highlands. These areas exhibit impairment years in advance of deeper open estuarine habitats and provide early warning of ecological and public health threats. HML scientists have found clear relationships between the level of watershed development, the ecological integrity of the creeks, and exposure risks to humans, including risk of exposure to potentially pathogenic bacteria. This research is being expanded to include sites in National Estuarine Research Reserves throughout the Southeast.



Conceptual model of linkages between altered land cover and the condition of tidal creek ecosystems based on a preliminary synthesis of previous work. Photo credit: F. Holland

Box 30: Animal Models in Toxicology and Mechanism of Action - Characterization of Domoic Acid

Researchers at the NSF-NIEHS Center for OHH at the University of Washington are interested in characterizing the molecular and cellular processes that occur following exposure to domoic acid. Animal models are used in the evaluation of domoic acid and its effects on brain developmental processes in both prenatal and postnatal phases. Specifcally, two different in-vitro cell culture systems have been established: primary mouse neuronal precursor cells (from prenatal midbrain tissues) and a cerebellar granule neuronal cell culture (from post natal brain tissues). Use of these cell cultures has allowed for the examination of critical cellular process and responses, including proliferation, differentiation, oxidative stress, cytotoxicity, and apoptosis. Characterizing the mechanism of action through animal models will assist in the identification of susceptiblity factors that can potentially define "at risk" populations, and help inform public health protection activities.



Microarrays are used to measure changes in gene expression, as shown here in an animal model using mice to help characterize molecular and cellular responses to domoic acid exposure. Photo credit: M. Vredevoogd

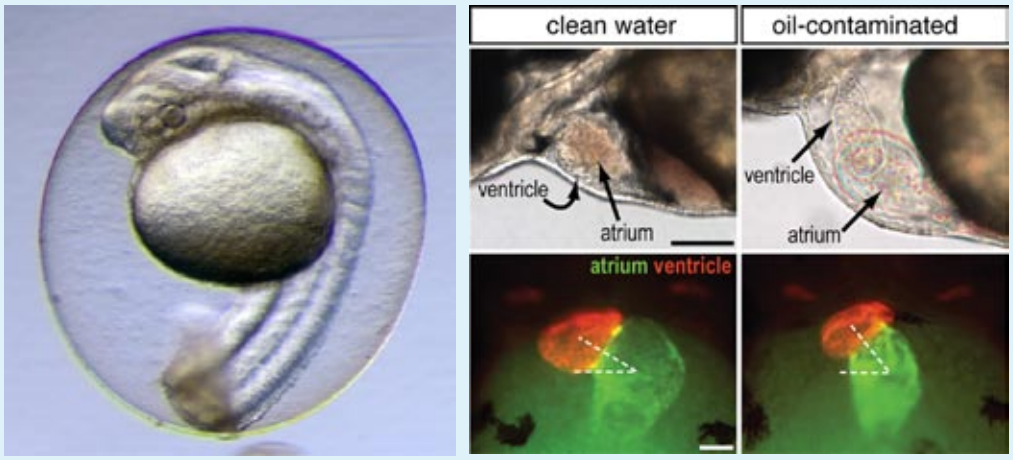
Genomics and Other "Omics" Technologies

The field of genomics is the study of organisms' genes and how they function. Genomics has revolutionized biology, leading to broad advances in biomedicine and many other fields and to the development of countless new commercial products. Not surprisingly, genomics technology is fundamental to OHH research. All seven of the OHH Centers have genomics facilities as core elements of their programs, and genomic tools are essential components of many of the research grants supported by OHH programs. In fact, many if not most of the new approaches to development of sensors for detecting pathogens and biotoxins use genomic-enabled technologies. In addition to their value in identifying pathogenic organisms, molecular tools can even detect genetic changes in pathogens that may make them more or less virulent and thus more or less likely to be a problem to humans (see Boxes 32, 33). Other related "omics" sciences, such as proteomics (the study of what proteins are produced or not as a result of gene activity and the roles of those proteins in life functions) and metabalomics (the metabolic consequences of an organism's physiological and biochemical processes), are also important for OHH research.

In response to the needs of researchers, public health officials and environmental managers to screen aquatic environments for the presence of many different harmful algal species rapidly and simultaneously, OHH scientists at the HML have created a new technology, SIVCA (see Box 7). The new technique amplifies small, fluorescently

Box 31: Use of Aquatic Biomedical Models to Assess Human Health Risk

Scientists at NOAA's WCCOHH refined an aquatic biomedical model using zebrafish to evaluate effects of polycyclic aromatic hydrocarbons (PAHs) on heart function. PAHs are chemical contaminants derived from fossil fuels, vehicle exhaust, and tobacco smoke and are highly abundant in air pollution and ubiquitous in the marine environment. Largely as a result of the Exxon Valdez oil spill, studies on the health impacts of PAHs in fish were undertaken. Research documented malformations in fish embryos, and reduced growth rates and survival to adulthood, even at very low exposure concentrations. Humans are exposed (via air pollution) to PAH mixtures with compositions very similar to those found in weathered Exxon Valdez oil. The OHH researchers used the zebrafish model to test toxicity of PAHs and found that these pollutants had significant effects on the heart, disrupting cardiac rhythm and contractility. Based on similarities between zebrafish and human hearts, the researchers suggest that PAHs may contribute to the increased heart disease-related mortality/morbidity in humans associated with air pollution. This work also demonstrates how fish can be used as both sentinel species to indicate ecosystem level and human effects of PAHs, and as biomedical models.



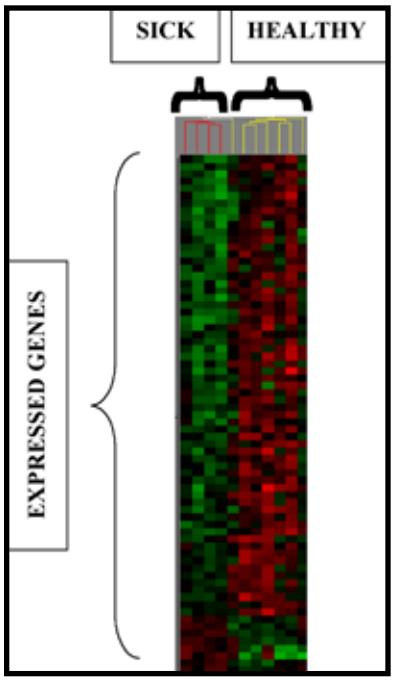
Using a zebrafish human health model, researchers found that PAHs disrupted cardiac function. Normal and abnormal heart development in larvae is shown in control embryos grown in clean water and exposed embryos grown in oil contaminated water. Photo credit: J. Incardona and N. Scholtz

Scientists use genomics as a tool to track changes in gene function and regulation as an indicator of organism health in response to a variety of stressors. Photo credit: S. Lovelace

labeled fragments of DNA from each of the target organisms, enabling their detection even at extremely low concentrations. The quick realization of SIVCA is a testament to the ready collaboration across disciplines within the OHH program.

Genomic tools such as microarrays, genetic bar-coding, and shotgun sequencing, provide highly sensitive means for identifying changes at cellular and molecular levels and for identifying both known and previously unknown species of pathogenic and other marine organisms. They also provide powerful tools for defining the health status of marine organisms as well as the sources of pathogens. OHH researchers are currently using such techniques to probe discrete molecular- and cellular-level responses in marine organisms that are elicited from the direct effects of one or more stressors to generate diagnostic profiles. These cellular responses can precede ecosystem-level responses by days to perhaps as much as years, providing an "eco-genomic" basis for development of early warnings and the implementation of management strategies that might prevent or mitigate the threat before it becomes a problem (see Box 34).

OHH scientists are also conducting toxicological studies aimed at identifying and understanding cellular responses to environmentally relevant exposures to marine toxins, pathogens, and chemical pollutants, including pharmaceuticals and flame retardants. These studies reveal levels of exposure (dosage) that may cause harm (response). Advances in genomics and proteomics allow researchers to investigate subtle changes that may occur at the molecular level following exposures to chronic, low levels of toxins, pathogens, or chemical contaminants. Over the long term, integration of genomic information with ecological and health effects data will enhance the sensitivity of ecosystem models and lead to a deeper understanding of the basic physiology and biochemical mechanisms of pathology for both marine animals and humans.



Genes are expressed differently in sick and healthy dolphins. In this expression profile, green indicates a gene is turned off and red indicates a gene is turned on. Photo credit: A. Mancia

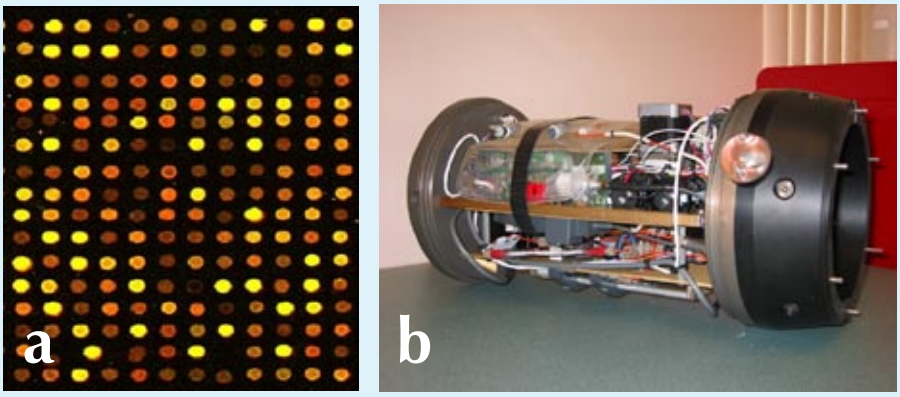
Genomics research produces huge amounts of data requiring robust computer and bioinformatics infrastructure for access, analysis, integration, and storage. The Moore Foundation is supporting a new program, Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis, or CAMERA, which is developing essential computational infrastructure for genomic investigations of marine microbes. Access to similar infrastructure can improve the OHH Centers' abilities to link and analyze genomic, environmental, and public health data sets and upload large genomics data sets to the National Center for Biotechnology Information where they can be accessed by other researchers. Important progress in this area has been made within the OHH program (see for example, www.marinegenomics.org), but much remains to be accomplished (see Data Management section).

Major opportunities for application of genomics to advance the broad suite of OHH research activities include the following:

- Enhance genomics core facilities in existing OHH Centers, including coordination among Centers and expanded collaboration with OHH researchers outside the Centers and develop improved cyber infrastructure and association with bioinformatics experts (see Data Management section).
- Develop or improve, demonstrate, and validate genomics-enabled sensor technologies that rapidly, accurately, reliably, and inexpensively identify and quantify bacteria, viruses, and HAB organisms of public health concern in ocean and coastal waters, including their relative pathogenicity or toxicity.
- Apply comparative genomic, proteomic, and metabolomic approaches to understand effects of exposures to chemical contaminants, pathogens, and toxins at the molecular level in marine organisms and mechanisms of toxicity and disease processes so as to gain new insights into how humans may respond to ocean health threats.
- Apply genomic tools to diagnose and improve understanding of disease processes in sentinel species and habitats and their occurrence in response to specific environmental perturbations (see Sentinel Species/Habitats section).
- Enhance gene sequencing and mapping efforts for a broad array of sentinel and model marine species to provide a foundation for understanding biological responses to environmental perturbations.
- Use genomic, proteomic, and metabalomic tools to identify new bioactive compounds with potential for commercial development and understand how they function (see Pharmaceuticals and Other Beneficial Products section).

Box 32: NSF-NIEHS Study - The Genomics of Florida Red Tides

OHH researchers at the University of Miami are attempting to gain a better understanding of the physiology and ecology of the Florida red tide organism, *Karenia brevis*, using a functional genomics approach. The objective of this work is to identify the genes that affect bloom initiation, development, maturation, and toxin production. Thousands of genes were isolated from *K. brevis* cells and used to create microarrays for assessing gene expression under various environmental conditions. With this approach, the reactions of many genes can be measured separately at one time on a single glass slide. To complement the laboratory studies, a new instrument, the *BreveBuster*, developed at the Mote Marine Laboratory, was used to identify and measure populations of *K. brevis* in natural settings. The investigators anticipate that combining data obtained from the microarrays with those collected in the field using the *BreveBuster* will allow them to determine what genes are important for cellular processes such as the production of brevetoxin.



a) Microarrays contain microscopic spots of DNA samples with each spot representing a different gene. The intensity of dye in each spot is used to quantify the expression of each gene in a sample, for example in seawater. (b) The BreveBuster is a submersible device that assesses the presence of a red tide by identifying and counting Kareina brevis. Photo credit: a. D. Crawford, b. G. Kilpatrick

Box 33: Gene-Environment Interactions

The NSF-NIEHS-funded PNW H2O Center in Seattle is bringing scientists from multiple disciplines together to explore interactions between genes and the environment using novel techniques. In one project, researchers are examining the effects of domoic acid on cells from mice lacking enzymes that are important in protecting cells from oxidative stress. Another study is using whole genome sequencing to identify genes that cause the alga *Pseudo-nitzchia* to produce domoic acid. This project is also using expressed sequence tags (ESTs) to identify cellular pathways associated with toxin production.

Box 34: NOAA's OHHI Develops Microarray Tools to Measure Organism Health and Exposure

To quickly monitor and assess the hazards to human health posed by eating shellfish and by residential, commercial, and recreational activities in the coastal and marine environment, OHH scientists at the HML have developed new and powerful tools based on advances pioneered in the Human Genome Project. These tools, called gene chips or "microarrays," permit the simultaneous measurement of the expression of thousands of genes. Analyses of gene expression can provide a sensitive and accurate diagnosis of the health of an organism and its exposure to infectious agents or chemical contaminants that may pose risks to human health. A national and international collaboration with researchers on the Atlantic, Gulf, and Pacific coasts, as well as in Norway and France, has generated a microarray with 30,000 DNA spots to measure gene expression in oysters. This microarray tool has been made available to the research community and is currently being used in studies of oysters as sentinels of human exposure to bacterial infection and heavy metal contamination.

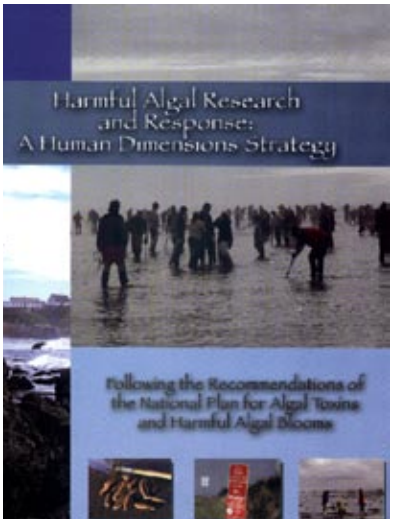
Samples are taken of oyster blood to monitor oyster health status using genomic-based tools. Photo Credit: N. Burnett

Social, Behavioral, and Economics Research

The affect of the health of the ocean on humans can encompass both positive and negative economic and socio-cultural impacts including gained and lost revenue and value associated with seafood harvesting, recreation and tourism and other potential impacts to subsistence and social activities. In the U.S., in the case of HABs alone (not including freshwater outbreaks), the economic effects are conservatively estimated at $82 million per year, with public health costs of illness and commercial fisheries impacts accounting for more than 90 percent of this total. On the other hand, the potential economic value of new pharmaceuticals and other natural products from the sea could be in the billions of dollars annually.

Social, behavioral, and economic (SBE) research helps decision-makers optimize beneficial uses of coastal and ocean resources while mitigating and adapting to public health, socio-cultural, and economic impacts of stressors from the oceans. SBE-focused studies that relate the health of the oceans to human health are relatively sparse at all scales, from local to national. Also, little is known about the SBE effects associated with human exposures to contaminated seafood, drinking and recreational waters, and the cumulative impacts and interactions of altered environments and non-point source pollution.

A 2006 multi-agency report, *Harmful Algal Research and Response: A Human Dimensions Strategy (HARR-HD)*, builds on the national HAB plan (*HARRNESS*) to put forth SBE research needed to improve HAB mitigation. This report provides a framework for human-dimensions research in the Interagency OHH Program as well. Opportunities to advance SBE research related to oceans and human health should focus on work in three major areas: (1) economic and socio-cultural values and impacts; (2) mitigation and adaptation; and (3) integrated decision-support tools that improve policy actions made by decision-makers. Further actions include the following:



- Building on the National Ocean Economics Program and other related efforts, estimate the net economic value associated with public health benefits that humans derive from the ocean, including the economic potential related to the discovery of biomedical compounds and other products.

- Assess, monitor, and forecast economic impacts (including both market and non-market valuation) and socio-cultural impacts (e.g., disruption to cultural subsistence practices, loss of recreational opportunities, and disruption to family and community relationships) related to health threats in coastal waters.

- Estimate total economic costs for illnesses related to ocean exposures, including out-of-pocket expenses due to infection and willingness to pay to avoid being exposed to diseases, contaminants, or toxins.

- Estimate the marginal benefits and costs for specific policy options designed to prevent, control, or mitigate ocean risks to human health, and determine the value of information provided that helped lead to successful actions.

- Assess, monitor, and forecast economic and socio-cultural consequences of resource management decisions designed to improve human health and welfare.

- Evaluate actual utility of OHH information to target audiences (e.g., assess how the public and officials use and value information provided from OHH research).

- Evaluate and improve the efficacy of risk-communication approaches (e.g., beach or fishery closures, seafood advisories, and public science forums) for promoting human behaviors that mitigate ocean impacts on human health and welfare (see Outreach and Education section).

- Identify human populations most susceptible to ocean-related health threats, with a focus on the importance of physiological traits, behavioral fac-

tors, occupation, economic status, and socio-cultural status, in influencing exposure and susceptibility, and assess the vulnerability of affected populations.

- Develop a suite of integrated epidemiologic/economic models that include social, behavioral, economic, and health impacts associated with human exposure to pathogens, toxins, and chemical contaminants from ocean and coastal waters (see Pathology, Contaminants, HABs, and Epidemiology sections).

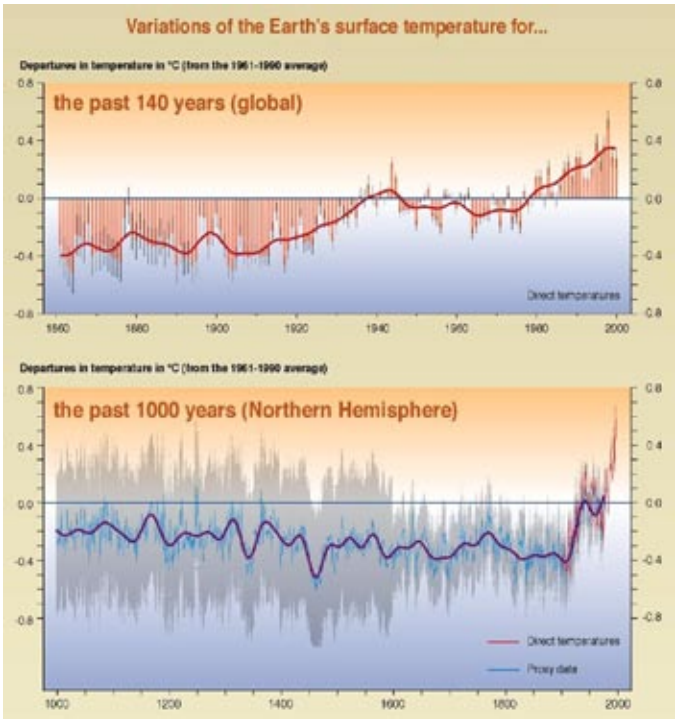
- Conduct needs assessments and collaborate with resource managers, public health professionals, public service groups, and other users in developing and transitioning research applications (see Outreach and Education section).

- Develop information products and other tools that assist policy- and decision-makers in evaluating risks and benefits of various actions, including measures of uncertainty associated with the expected risks and benefits.

Climate Change and OHH

There is strong scientific consensus that Earth's climate is changing and that these changes are affecting both human and natural systems. The Interagency OHH Program can contribute to increased understanding of climate effects on ocean-related threats to human health. Among other things, shifts in ocean currents and changes in ocean temperature and global precipitation patterns may affect the distribution and prevalence of marine microbes, human and animal diseases and disease vectors, HABs and their biotoxins, and food from the sea. The effects of climate changes on distribution and bioaccumulation of chemical contaminants in marine food webs are also poorly understood and may be significant for vulnerable populations of both humans and animals. Thus, climate change is a cross-cutting issue for ocean health risks.

Ongoing OHH activities within the NSF-NIEHS and NOAA Centers and elsewhere are well positioned to contribute to understanding how climate change will affect oceans and human health. Two existing OHH Centers are focused on OHH concerns in tropical and subtropical systems, while the geographic location of others



Over the last 60 years the Earth's surface temperatures have been higher than any other time in the last 1,000 years. Increases in sea surface temperature can influence the proliferation, spread and occurrence of diseases and HABs. Source: http://www.ipcc.ch/present/graphics/2001syr/large/05.16.jpg

allows a focus on temperate to northern systems. It is likely that climate change will result in warmer temperature and expansion of subtropical climates into temperate regions and some temperate expansion into northern waters. Thus, current research targeting HABs, pathogens, and other ocean health risks will contribute to an understanding of the broader effects of climate change on ocean ecosystems and health risks. In addition, ocean observing systems that include collection of OHH-related information (see "Linking to Ocean Observing Systems"), along with robust database development (see "Improvements in Data Management and Access"), will provide the time series data helpful for addressing climate issues within an OHH context.

Specific opportunities for the Interagency OHH Research Program to contribute to advances in understanding effects of global climate change, based on existing programs and utilizing ocean observing systems and data management tools, include the following:

- Determine how the prevalence and virulence of pathogens, HABs, and contaminants are linked to

ecosystem variables, including trends in global climate change.

- Include climate change information in epidemiological and disease surveillance studies for known and emerging ocean-borne human health threats.
- Consider the roles of climate cycles and change in the uptake and accumulation of pathogens, toxins, and contaminants in seafood.
- Integrate climate change data in development of models and other predictive tools.

Infrastructure

Linking to Ocean Observing Systems

EPA, NASA, NOAA, NSF, USGS, the U.S. Navy, and other federal agencies are investing significant resources in the development of national-level ocean environmental observatories. In some cases (e.g., NSF) the priority is for research, while other agencies' priorities include a variety of missions in addition to research. Currently, there are more than 40 coastal observing systems covering much of the U.S. coastline. They are operated independently or jointly by various federal, academic, state, and industry entities, and they encompass a wide range of observing and monitoring technologies, including fixed and free-floating buoys, cabled underwater stations with sensors, autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), remote-sensing technologies, satellites, and various kinds of sensors mounted on vessels, satellites, and aircraft (see Boxes 35-38).

To provide data at the temporal and spatial scales needed, many of the observing systems are being organized into the U.S. Integrated Ocean Observing System (IOOS) that will be managed through a number of Regional Associations (RAs). These RAs are working together under a federation concept, with federal oversight to further the seven societal goals adopted by the IOOS. The IOOS goals are: (1) improve predictions of climate change and weather and their effects on coastal communities and the nation; (2) improve the safety of maritime operations; (3) mitigate the effects of natural hazards more effectively; (4) improve national and homeland security; (5) reduce public health risks; (6) protect and restore healthy coastal ecosystems more effectively; and (7) enable sustained use of ocean and coastal resources.

The need to acquire OHH-related observations as an integral part of ocean observing systems was underscored by the USCOP. Possible mechanisms by which the IOOS could address its goal of reducing public health risks were the subject of an interagency workshop, *Public Health Risks: Coastal Observations for Decision Making and Management*, held in January 2006. This workshop concluded that the IOOS could make vital contributions to public health management and play a major role in developing opportunities for protecting human health by linking OHH activities and programs with ocean observing systems.

The inclusion of robust nearshore and inshore observing networks that can provide data of immediate utility to people living, working and recreating along our coasts will ensure that IOOS is relevant to public health concerns. Automated monitoring of coastal environments could facilitate the examination of broad-scale patterns of pathogenic organism distributions, and could provide real-time or near-real-time data at spatial and temporal scales that are not possible with current monitoring methods. Biological sensors that could be located on buoys, AUVs, ROVs, and other platforms (including satellites) to gather accurate and timely data on pathogens, chemical contaminants, and HABs are essential elements for an operational IOOS. The Interagency OHH Program includes excellent work on the development of a variety of biological sensors. However, much remains to be done, and there are many opportunities to further develop these and other technologies for eventual deployment as part of regional and national aquatic observing systems.

Although some biological sensors exist, most of the specific interest for OHH research are still under development, in contrast to the increasing availability and sophistication of instruments for obtaining physical oceanographic and atmospheric measurements. A variety of these (e.g., acoustic Doppler current profilers, surface current radar, satellite-tracked surface drifters, submerged drifters, moored thermistors, and conductivity probes), as well as a range of other oceanographic and meteorological sensors, will be included in the IOOS and will provide essential information for interpreting biological observations. In addition, hydrological data (e.g., rainfall, runoff, streamflows, water temperature and color, currents, soils) provide essential input for hydrographic models that may be employed to forecast transport and distribution of pathogens, chemical contaminants, HABs, and toxins in estuarine, coastal, and Great Lakes envi-

ronments. Implementation of the National Water Quality Monitoring Network, as called for in the *Ocean Action Plan*, and its linkage to the IOOS will improve estimates of land-based inputs of water, sediments, nutrients, and contaminants and their fates once they enter estuarine and coastal environments and will provide crucial information to enhance understanding and forecasting of ocean health threats.

Across the board, technological advances are expected to result in increasingly rich and complex data streams that will produce a broad variety of physical, chemical, and biological information. Major foci for development include enhancements to facilitate networking of disparate sensors and platforms, processes, and infrastructure for combining very different data sets and advanced data management, integration, modeling, and synthesis techniques. Data Management and Communications (DMAC) is one of the highest-priority areas of the IOOS (see Improvements in Data Management and Access section).

Federal agencies are also planning, operating, or participating in other large-scale, coastal and open-ocean observing systems and networks such as the NSF-supported Oceans Observatories Initiative (OOI – See Box 36) and the National Ecological Observatory Network (NEON). The OOI will be operated by and for researchers and driven by basic research questions related to how the earth-ocean-atmosphere system works, while NEON is envisioned as a continental-scale system of sensor networks, experimental infrastructure, and remote sensing linked to a computational, analytical, and modeling facility. As OOI and IOOS mature, the design and output of each will benefit the other, and the technological advances expected from NEON are likely to be applicable to ocean and coastal observations important for addressing OHH-related issues.

The next generation of NASA's Earth-observing satellites will include the Ocean Surface Topography Mission (extends the collection of sea surface topography data), Aquarius (measures global sea surface salinity), and the Global Precipitation Mission (measures the variability of global precipitation to advance knowledge of the Earth's water/energy budget). These satellites will provide oceanographic and hydrographic observations of even greater temporal and spatial resolution than currently available.

Major opportunities for advancement by linking the Interagency OHH Program with ocean observing systems include the following:

- Increase participation in the IOOS regional associations by coastal managers, public health practitioners, and stakeholders responsible for beach and shellfish management to help optimize observing-system capabilities that provide useful human health-related information products.

- Develop and incorporate sensors for pathogens, indicator microorganisms, harmful algae, toxins, other contaminants, and water quality into the observing systems at local to regional scales to acquire essential data for public health protection.

- Develop and provide multi-sensor data products in near-real-time for public health applications (e.g., detection, fate and transport of pollutants/pathogens, and blooms) and develop new and improved information products to support beach and shellfish-bed opening and closure decisions.

- Collect data in nearshore environments where the majority of the public's interaction with coastal waters occurs; record environmental observations at locations, and temporal and spatial scales particularly relevant to the population dynamics of waterborne pathogens and harmful algae.

- Monitor migratory species, including seabirds, fish, and marine mammals, to improve assessments of the health of these species and their potential to serve as vectors for, or indicators of, threats to human health.

- Strengthen efforts to make collection of epidemiologic, public health, and animal health surveillance data integral parts of the ocean observing systems, including the archiving of both environmental and health surveillance information to enable retrospective analyses (see Epidemiology section).

- Collect physical and remotely sensed oceanographic and hydrographic data, including stream and river flow, non-point-source runoff, and their chemical constituents for estuarine and coastal areas and make these data readily available to

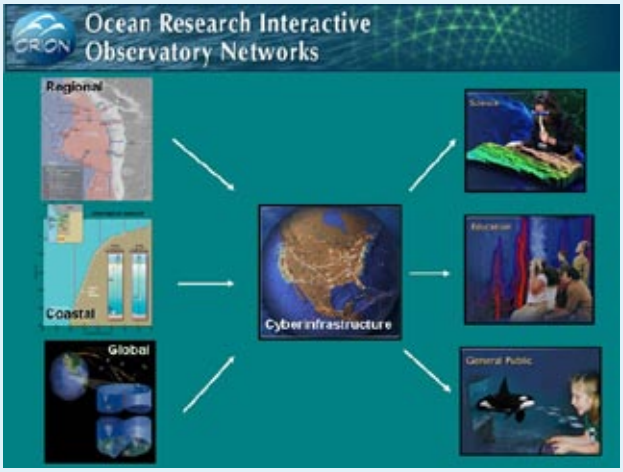
Box 35: IOOS and Public Health

Designed to be user-driven and provide output in forms and rates useful to decision-makers, the IOOS will link a wide variety of remotely sensed observations and other data collection methods, data management, and modeling to provide useful products on local to global scales, for example, from the local scale of beaches and shellfish beds to the global scale of an El Niño event. Remote-sensing capabilities include satellite-, aircraft- and land-based sensors, power sources, and transmitters. Direct sensing includes use of platforms (e.g., ships, buoys, gliders), in-situ sensors, power sources, sampling devices, laboratory-based measurements, and transmitters.

Ocean observing systems link data collected from multiple platforms such as ships and in-situ monitoring stations with remote sensing capabilities from satellites, submersibles and aircrafts. Source: Ocean.US

Box 36: A Conceptual Diagram of the NSF Oceans Observatory Initiative (OOI)

The OOI will have three observational components: coastal observatories; a regional cabled observatory; a global system of relocateable moorings for open ocean settings at high and low latitudes. Cyberinfrastructure will link OOI to research and education applications. OOI will provide infrastructure to enable hypothesis-driven basic oceanographic and geophysical research by fostering specialized observations, instruments and activities for the purpose of answering basic research questions. The high-speed, interactive communication capabilities of OOI will open entirely new avenues for student and public audiences to interact with and understand the ocean.



Source: NSF

researchers for use in model development and testing.

- Develop and provide data and information needed to quantify relationships between changes in land use and land-based inputs to coastal waters, and changes in public health risks.

- Continue development and deployment of Earth science satellites for collection of essential oceanographic and hydrographic observations at greater temporal and spatial resolution than currently available (see Box 37).

- Following recommendations of the international Group on Earth Observations, work with the World Meteorological Organization and other international bodies to explore how observing systems may respond to needs of the public health community by collecting, providing, and validating remotely sensed environmental measurements relevant to human health, including the possible initiation of pilot projects integrating Earth observation, health, epidemiologic, and socio-economic data.

Box 37: NASA Earth Observing Research Satellites - Critical Components of Ocean Observing Systems

NASA's Earth Science Division works to understand global, integrated Earth system science, including the response of the oceans to natural variations and human-induced changes. To this end, NASA developed and deployed a constellation of Earth-observing research satellites named Aqua, Aura, Terra (provides data on ocean properties including ocean chlorophyll and sea-ice cover) GRACE, Jason, QuikScat, TRMM, and others, along with aircraft and surface-based sensors. Essential oceanographic observations are collected from satellites such as Jason (collects sea surface topography data), GRACE (acquires data on variations in Earth's gravity field due to ocean currents and exchanges between ice sheets/glaciers and the oceans; its measurements yield vertically integrated ocean circulation), and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on Terra and Aqua. NASA also created the world's largest data and information system for collection, processing, archiving, and distributing Earth-observing satellite data.

Box 38: NASA MODIS

The Terra and Aqua Earth observing satellites acquire data on ocean chlorophyll fluorescence. Anomalies in ocean chlorophyll fluorescence are used in the detection of HABs.

This MODIS image from July 8, 2005, shows a potential harmful bloom in the Baltic Sea. Photo credit: NASA

Improvements in Data Management and Access

OHH is a broad interdisciplinary field not limited to databases within a single scientific domain, such as estuarine ecology or animal physiology, but instead encompasses aspects of oceanography, ecology, genomics, human health, and numerous other fields. Each of these disciplines has advanced, often program specific databases, oriented toward their specific needs. These data archives may be available online but are not necessarily integrated with or linked to other program-specific databases. Similarly, public health databases relevant to the OHH community reflect the breadth of public health science from the molecular level to individual and population studies and cover a broad range of health effects. The capability to access and link such data from disparate agencies and programs is critical for retrospective analyses and determining trends in ecosystem condition and human health.

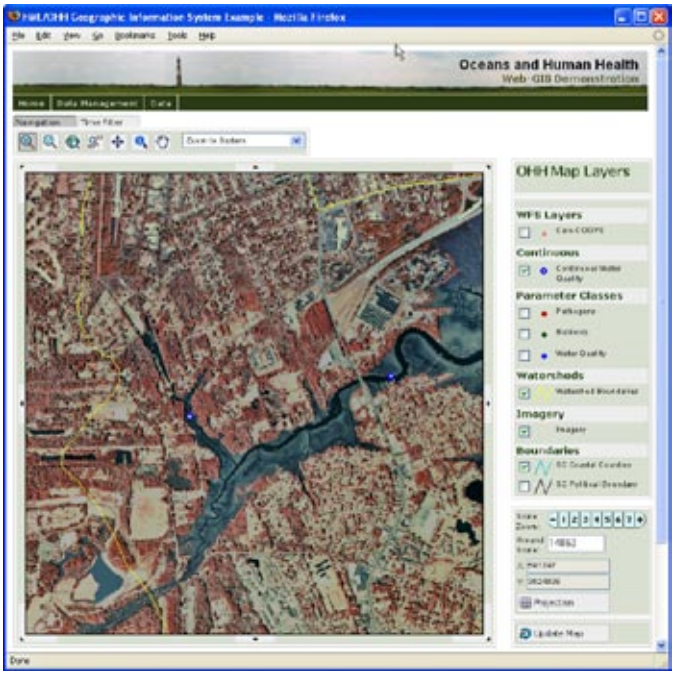
Massive volumes of data are already being collected from observing platforms, satellites, genomics investigations, various public health studies, and these streams will continue to expand exponentially. Because data management is so central to the entire ocean observing system, the IOOS DMAC community is developing Web-based networking capabilities to meet the IOOS-specific needs. The *Guide for IOOS Data Providers* presents a draft of the IOOS Data Policy (available on the Ocean. U.S. Web site), along with the most recent (2006) guidelines for IOOS data and metadata interoperability standards and best practices. These will be a valuable resource for the OHH since the developing OHH data structure which should link seamlessly with the IOOS (see Linking to Ocean Observing Systems section and Box 39).

Although progress is being made on the broad scale, the OHH community must establish a common "language" for its database requirements and determine what data need to be accessed, as well as the requisite "metadata"

(i.e., the who, what, where, when, why, and how of the data itself). The Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDM) is widely used for geospatial data, and should be applicable to some OHH data. According to the DMAC, the IOOS will initially use the FGDC Content Standard, and any applicable supplemental profiles (i.e., the Biological Data Profile, Shoreline Profile), as its standard for metadata. However, the OHH research community may have to invest considerable effort to develop procedures to crosswalk any other data standards in use with the FGDC and CSDM standards.

Sharing data across disciplines is fundamental to advancements in OHH research and predictions. Data must be capable of being easily accessed and shared electronically. These requirements suggest a data-sharing system that engages a diverse spectrum of data providers and users. A number of integrating technologies show potential for use with OHH data. For example, a multi-federal partner program at Oak Ridge National Laboratory is leading the development of SensorNet, a framework that ties together sensor data from all over the country to create a real-time detection and alert system for various threats, whether chemical, radiological, biological, nuclear, or explosive. Although the SensorNet effort is primarily focused on homeland security, the technology could be adapted to integrate data from estuarine, coastal, and ocean monitoring systems and other data streams in the Interagency OHH Program. Similarly, "grid" technology allows users to share distributed and heterogeneous computing resources in many research areas from remotely sensed data and climate modeling to bioinformatics and analyses of human disease. In addition, metadata and disparate databases need to be integrated in a manner that allows for automation. The developing Semantic Web provides a common framework allowing data to be shared and reused across application, enterprise, and community boundaries.

Acquiring and assimilating the necessary data into products useful to decision-makers, and increasing the knowledge base of the public at-large with regard to the connection between ocean health and human health are critical. The basic technical challenge is how to best apply modern information technology to effectively link numerous, distributed databases of variously formatted data. This effort will include determining minimal standards for long-term data archiving and implementing ways by which users can readily discover data, determine their availability, and easily gain access and use the data. An additional challenge is to foster understanding among the interested communities that the limitations of resources likely to be available to data providers will restrict the ability to make all data equally accessible and linkable all of the time.



OHH data are assimilated into common databases where multiple inputs can be layered, such as in these Geographic Information Systems (GIS) maps which are used to help managers make informed decisions. Photo credit: D. White

Major opportunities to enhance OHH data management include the following:

- Conduct interagency and community workshops to identify databases with high relevance to OHH research and their structures/content across disciplines, perform a baseline data needs assessment, define overall OHH database requirements, and provide recommendations on how best to create the OHH architecture to complement other ongoing data management efforts (e.g., under IOOS).

- Engage the public health community in OHH data management planning. This dialog will enable development of standards and processes, allowing data important for public health to be accessed, transported, and integrated into models and products for risk assessment that are useful to public health officials and the general public (see Outreach and Education section).

- Develop and implement essential cyber infrastructure to enable data sharing, integration, analysis, and access, with a particular focus on processes for linking and sharing environmental, genomic, and epidemiological data.

- Coordinate data management and access activities with the IOOS DMAC to ensure compatibility (see Linking to Ocean Observing Systems section).

- Develop and validate coupled physical-pathogen transport models for nowcasting risks and forecasting changes in risks with known accuracy.

- Develop and improve nearshore circulation models that link land-based inputs and nearshore processes with better offshore boundary condition information. Incorporate pathogen and algal biology into these models.

Box 39: NOAA's OHHI Develops Models to Incorporate Numerous Data Layers

NOAA's CEGLHH is developing a refined model to incorporate numerous data layers to predict the hydrodynamics of the Great Lakes and assist public health forecasting. In the Great Lakes, one of the biggest issues relating to human health is exposure of bathers and other beach users to bacteria stemming from creeks and rivers that convey surface runoff and combined sewer overflow discharges. Relevant data layers include information related to hydrodynamic processes (e.g., wind speed and direction, water temperature, current speed and direction, topography, biological contaminants, and chemical contaminants). These data layers are being combined in a GIS-based model to predict bacterial concentrations on recreational beaches.

Standards and Standardized Methods

Establishing data validity is the driver behind the development and use of standards for physical, chemical, and biological measurements as well as for data management and bioinformatics (see Improvements in Data Management and Access section). Standards are an integral component of monitoring programs important to protecting human and environmental health. For example, EPA's water quality standards define the goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants.

Methods and procedures must be validated and standardized, particularly when they are to be used in regulatory or management contexts. Professional associations, such as the AOAC International, usually validate analytical procedures. AOAC has a Marine and Freshwater Toxins Task Force devoted to accelerated validation of methods for analysis of HAB toxins. Similarly, the ISSC has established a Laboratory Methods Review Committee to help validate methods for ensuring the safety of shellfish intended for human consumption.

Another aspect of establishing credible measurements involves establishing procedures to produce comparable data. The National Institute of Standards and Technology (NIST) coordinates a number of performance-based quality assurance (QA) programs in micronutrient measurement, marine monitoring, marine mammal analyses, and other areas. These programs have resulted in dramatic improvement in quality and comparability of data. Although often overlooked, other tools historically used for QA are archived sample and tissue banks, including NIST's Environmental Specimen Bank, CDC's sample banks from disease outbreaks, and the National Cancer Institute's bank of bioactive materials. By maintaining subsets of samples collected by ongoing research and monitoring programs, specimen banks play an increasingly important role in assuring the quality of analytical results and in providing historical materials for comparison with new samples.

New and emerging ocean health threats dictate a need to enhance and/or expand existing standards and methodologies. Although Certified Reference Materials are readily available for analysis of well-known contaminants, few standards are obtainable by researchers working with more recently recognized chemicals of concern (such as brominated flame retardants, fluorinated compounds, and

Removing samples from a liquid nitrogen vapor phase freezer in the Marine Environmental Specimen Bank maintained by NIST. Photo Credit: R. Pugh

metabolites of pharmaceutical compounds). Work is currently underway in this area by OHH and NIST researchers, but a great deal remains to be done before these compounds can be analyzed routinely. Another critical issue is the need for a better understanding of the quality of microarray results to support studies on gene expression. NIST, in collaboration with OHH researchers, is beginning to develop standards for the production and generation of genomic microarrays, including protocols for performance and analysis.

Targeted efforts to improve and validate measurements and standards are needed for pathogens, pathogen source tracking, HAB toxins, and pharmaceuticals. Although several methods may help identify and differentiate bacteria from human and wildlife sources, uniform standards that would make each method more proficient and reliable, especially as they are applied in different watersheds, are lacking. Similarly some brevetoxins, which are produced by the HAB species *Karenia brevis*, can be detected by an enzyme-linked immunosorbent assay (ELISA) method in biological samples; however, ELISA of biological samples is not currently a certified method for detection of brevetoxin.

Credibility of measurements resulting from OHH research will hinge on careful documentation of procedures used, quality assurance efforts, validation, and standardization of material and methods. There are many opportunities for advancement of OHH research in this area, including the following:

- Develop partnerships among the Interagency OHH Program, NIST, and others as appropriate to establish standards and standard protocols for emerging chemical contaminants, HAB toxins, pathogens, genomic microarrays, and ELISA procedures for OHH research and management uses.

- Develop, validate, and distribute specific standards for DNA extraction techniques (see Rapid Response Capabilities section).

- Expand performance-based QA activities across the Interagency OHH Program and implement national standards and protocols for measurements, data management, communications, and modeling.

- Improve and validate sample processing procedures to quickly and efficiently isolate and concentrate microbes from large volumes of water so as to enhance use of genomic techniques for rapid detection, quantification, and tracking of microbial pathogens (see Pathogens section).

- Develop new procedures and opportunities for long-term storage and archiving of isolates and mixed culture collections, particularly of HAB organisms and other microbes and pathogens (including viruses). Establishing centralized collections that all researchers could access would facilitate assay optimization and comparisons (see HABs section).

- Improve infrastructure needed to protect human health during HAB events and for research on HAB impacts. Make available certified toxin standards and radiolabeled toxins, protocols, and methods for toxin analysis, and increase capacity for rapid analysis of known toxins and identification of unknown ones (see HABs section).

- Expand specimen and sample banks to ensure maintenance of appropriate materials to evaluate apparent emerging health threats in the marine environment, including mechanisms to archive and provide access to bioprospecting samples (see Pharmaceuticals and Other Beneficial Products section).

- Conduct workshops to assist regulatory agencies in the development of appropriate pollution standards and indicators to protect coastal and ocean water quality and prevent threats to human health caused or exacerbated by ocean pollution.

Access to the Sea to Support OHH Sampling and Exploration

Much data can be collected efficiently through platforms such as satellites, but a great deal of OHH research also relies on direct collection from ocean sediments, water columns, sea surfaces and the water-air interface. In nearshore waters, samples for public and environmental health monitoring programs may be collected by wading, from docks, piers, and jetties, or with the use of small- to medium-sized boats. In addition to sensors placed on buoys and satellites, ROVs and AUVs increasingly provide new tools for both sampling and observing in shallow to very deep seas. However, for many studies, specialized research vessels are used, in some cases to transport, deploy and operate ROVs, AUVs, buoys, and sensors (see Linking to Ocean Observing Systems section).

The primary access for academic scientists to marine research vessels is through the University-National Oceanographic Laboratories System (UNOLS). Both agency and university researchers can also take advantage of a limited number of mission-dedicated research vessels operated by federal agencies, particularly NOAA. However, their cruise missions are generally planned at least a year in advance, and are used to support ongoing agency research and monitoring objectives, as well as OHH activities. The Interagency OHH Program depends on using assets from the UNOLS system, NOAA and perhaps other agencies, and smaller, local vessels when appropriate.

Because many OHH activities are near the shore, small (< 130 feet) and intermediate-size (130-180 feet) vessels are often the most cost-effective platforms. In some cases, depending on the specific work and location, academic and/or state/local institutional vessels can be employed, principally for collecting samples that are returned to shore-based labs for analysis. These platforms are generally not amenable to long, deep-water cruises, where large scientific parties are required to support broad cross-disciplinary projects, or to carry out studies where a considerable amount of sample processing and analysis is to be carried out onboard, including bioprospecting for useful marine products.

Most, if not all, of the present NOAA and NSF-NIEHS OHH Centers utilize some form of vessel support. Currently the NSF-NIEHS Centers at the Woods Hole Oceanographic Institution and the University of Miami currently are budgeted to support cruises on UNOLS vessels. For these two Centers, using a mix of UNOLS ships and institutional vessels has proven to be a cost-effective mechanism to address sampling needs. The other Centers have leveraged ship time on other projects and/or have received logistic support from local partners or used smaller, less-specialized vessels depending on their needs. In addition, NOAA Centers may submit ship use requests to the NOAA Fleet Council, but generally requests must be submitted one to two years in advance.

Opportunities to provide access to the sea for OHH researchers include the following:

- Anticipate and include ship costs as part of supported research activities in OHH research projects.
- Identify, in a timely fashion, long-term needs for vessels, other platforms, and specialized equipment to support OHH research activities.
- Anticipate platform needs for OHH researchers to enable rapid response to episodic events such as HABs and hurricanes (see Rapid Response section).

Transition of Research to Application

Outreach and Education

The USCOP *"An Ocean Blueprint for the 21st Century"*, the NSTC JSOST *"Charting the Course for Ocean Science in the U.S. for the Next Decade"*, and other recent reports have emphasized the importance of outreach and education to improve the nation's science and ocean literacy and achieve healthy oceans and people. Similarly, the OHH Act of 2004 requires the Interagency OHH Research Implementation Plan to "establish goals and priorities for Federal research which… provide usable information for the prediction of marine-related public health problems and the use of the biological potential of the oceans for development of new treatments of human diseases and a greater understanding of human biology." The Act also places specific responsibility for information dissemination and outreach on NOAA.

Carefully targeted and coordinated outreach and education efforts can result in three critical outcomes for the nation:

1) Use of oceans and human health information and products by resource and public health managers to make decisions that help ensure healthy and productive marine ecosystems and people (see Box 40);

2) A dynamic, diverse, and interdisciplinary workforce with competencies critical to advancing oceans and human health research, both now and in the future (see Boxes 41 and 42); and

3) A well-informed public that understands the effects of the oceans on human health and acts as a steward of coastal and marine ecosystems, thereby preventing and reducing human health risks and maximizing human health benefits (see Box 43).

It is critical that resource and public health managers help guide OHH research needs and in turn be able to understand, access, and use information, tools, technologies, and products produced by the OHH research community to make informed decisions. Strengthening partnerships and dialogue between these managers and the OHH research community will enable effective development, transfer, and use of OHH information.

Researchers and outreach specialists communicate important OHH findings to multiple audiences including the scientific community, beach and seafood managers, and the public. Photo credit: S. Lovelace

Development of a new generation of interdisciplinary scientists who are comfortable working at the nexus of ocean sciences and health sciences and able to integrate data and approaches across fields is also critical. This new cadre of undergraduate, graduate, and post-doctoral students must be trained in effective communication and partnering with multiple user groups, as well as in science. Because people learn in a variety of places from formal academic settings (such as schools) to informal locations (such as aquariums, zoos, and even their own homes), OHH education materials, activities, and practitioners must be equally diverse. Expanded efforts with the media can also increase visibility and public awareness of linkages of human health to ocean stewardship. Accomplishing the OHH outreach and education outcomes will require a dynamic, performance-based program, with effective evaluation and assessment mechanisms.

The OHH programs in NOAA and NSF-NIEHS have initiated outreach and education activities that communicate and deliver OHH information, tools, and products to a broad range of users, the media, and the public; assess information and product needs of managers and educators; and provide diverse training opportunities for students, teachers, and scientists. Other agencies involved in OHH issues, such as the CDC, EPA, FDA, NASA, MMC, and USGS conduct various outreach and education activities to inform managers and the public about ocean-related human health risks.

Major opportunities to advance outreach and education for the Interagency OHH Program include the following:

- Ensure coordination of OHH-related outreach and education activities within and among agencies in the Interagency OHH Program and leverage existing outreach-education partnerships such as the Centers for Ocean Sciences Education Excellence (COSEE), the National Sea Grant College Program, the National Oceanographic Partnership Program (NOPP), and the Interagency Working Group on Ocean Education.

- Effectively communicate with, respond to needs of, and provide appropriate OHH information, tools, technology, products, and training to resource and public health managers and other users to support improved public health and coastal and marine resource decision-making.

- Establish, maintain, support, and enhance partnerships among governments and management bodies; academia; nongovernmental organizations; professional societies; informal outreach and education facilities, including aquaria, museums, and zoos; and the private sector to communicate OHH information and products to diverse audiences and to derive information from monitoring efforts involving the public.

- Sustain and enhance the development of undergraduate, graduate, and post-doctoral students pursuing OHH-based careers; encourage scientists in the early stages of their careers to pursue interdisciplinary OHH research by supporting fellowships, traineeships, and other opportunities, such as interagency exchange programs for researchers and managers.

- Expose a wider cross section of students to interdisciplinary OHH ocean sciences and inspire youth to pursue ocean-related careers by providing professional development opportunities to educators, developing more avenues for underrepresented and underserved students, and promoting partnerships and resources to support OHH curriculum development.

- Provide information for the preparation of updated clinical medical guides and training that describe ocean-derived illnesses in humans and sentinel species (including pathology, diagnostic methods, and available treatment options) and make them widely available to public health officials,

Box 41: Teachers at Sea and in the Lab

To improve integration of OHH topics in high school curricula, NOAA's OHHI Centers partnered with the Armada Project and COSEE to host educators on research cruises and in laboratories. Educators worked side-by-side with scientists to learn more about OHH topics and research methods.

Science teachers get the opportunity to work with OHH reseachers in the field, as shown here in the tidal creeks of SC. Photo credit: S. Lovelace

Box 40: Public Health and Florida Red Tide - From Remote Sensing to Poison Information

In a unique collaboration, the Florida Department of Health (FDOH), CDC, and its public and private partners have established a linked network of public health information coupled with exposure and disease surveillance on Florida red tides. NOAA (coastwatch.noaa.gov/hab/bulletins_ns.htm) and Florida Wildlife Research Institute (866-300-9399) produce weekly reports of the presence and location of Florida red tide blooms based on remote sensing and water monitoring that are available by phone and on the Web, while Mote Marine Laboratory (MML) has developed real-time beach condition reporting (http://coolgate.mote.org/redtide/). This exposure information is linked to South Florida Poison Information Center Hotline (888-232-8635), which provides 24 hour toll free health information in multiple languages with funding and backup by the CDC, FLDH, and a NSF-NIEHS funded Center at the University of Miami. The University of Miami, CDC, FDOH, MML, and a nongovernmental organization, START (http://www.start1.com), have developed beach signage, museum displays, information cards, healthcare provider information, public health recommendations and response plans, and a traveling exhibit to communicate up-to-date information to Florida's tourists and residents.

Web sites such as Solutions to Avoid Red Tide (START) are important tools to increase public awareness of ocean health risks and build support for increased monitoring, regulation and prevention of health threats.

primary health care providers, veterinarians, and emergency response personnel (see sections on Pathogens, HABs, Epidemiology, and Chemical Contaminants).

Box 42: Student and Volunteer Environmental Monitoring Efforts

A number of observing and monitoring efforts, such as FDA's SEAPORT and NOAA's Southeast Phytoplankton Monitoring Network (SEPMN), routinely use information provided by public volunteers. This approach not only helps build an ocean stewardship ethic in the public at large and involves students and the public directly in research, it also provides a wealth of useful information to better track the occurrence of health threats in the oceans. SEAPORT uses networks of volunteers to gather information that state shellfish programs can use to focus toxicity monitoring on times, locations, and toxins of greatest concern, thus making the overall program more effective and less expensive than would otherwise be possible. Similarly, SEPMN unites over 65 volunteer groups with scientists to monitor marine phytoplankton community and HABs in the southeast. The majority of volunteer groups include teachers and students in grades 5 through 12; however, universities, aquariums, parks and recreational facilities, and environmental and citizen groups participate as well. To date, over 40 HAB events have been identified and valuable data has been generated on species composition and distribution in southeastern coastal waters.

Students can be actively engaged in water quality monitoring, as a fun, educational, and valuable activity.
Photo credit: C. Dolan

Box 43: OHH Featured on The Weather Channel and in the LA Times

In 2005, NOAA partnered with The Weather Channel to produce an OHH special that aired nationally and highlighted research at NOAA's OHHI Centers. The Weather Channel continues to run this program occasionally, improving public awareness of OHH issues. In 2006, the LA Times produced a five-part series of feature articles on the crisis in the seas entitled, "Altered Oceans." Two of these articles were informed in part by a number of NOAA conferences related to marine mammal health and HABs, including a symposium at the 2006 American Association for the Advancement of Science (AAAS) involving OHH researchers focused on the effects of diseases and toxic algal blooms on sentinel species and coastal residents.

The LA Times series "Altered Oceans" by Kenneth R. Weiss, Usha Lee McFarling and Rick Loomis focused on several OHH themes and has won many awards including the Pulitzer for Explanatory Reporting. Source: LA Times

Rapid Response Capabilities

For decades, state, federal, and local authorities have implemented disaster planning and responded to physical, infectious, chemical, and weather-related events. Since the terrorist attacks of September 2001, significant federal, state, and local efforts have been made to improve emergency readiness, planning, and response. Federal efforts have been developed under the National Response Plan and are continuing under the National Preparedness Goal. Although such planning has been triggered by the threat of terrorism, the strategic goal has been to enhance ongoing response planning and capabilities for all hazard events from small local occurrences to disasters of national significance. These hazards include natural catastrophes such as hurricanes, outbreaks of marine- related diseases in humans or animals, and HABs, as well as human-caused disasters such as oil spills or hazardous chemical leaks. Numerous partners are involved in responses to these events at local, state, regional, and national levels, and a major goal has been to integrate these numerous players into a cohesive response network that can be managed (i.e., using the National Incident Management System) and expanded or contracted depending on the circumstances. The Interagency OHH Program can enhance these response capacities by providing additional scientific expertise in marine and human health-related sciences and laboratory capabilities to handle the surge of samples that often accompanies environmental disasters.

Participants in the Interagency OHH Program have engaged in both response planning and capacity building over the last three years and have been directly involved in responding to some recent high profile events, such as Hurricane Katrina and the 2005 HAB event in New England waters, specifically in Massachusetts Bay (see Boxes 44 and 45). In these situations, the Interagency OHH Program provided additional scientific support and increased laboratory analytical capacity to the primary responding federal, state, and local agencies. Federal agencies can provide unique expertise and capabilities to assist or lead activities to prepare for, respond to, or recover from an event. Often a federal emergency response is in response to a request from an affected state and may involve such entities as the CDC, EPA, FDA, FEMA, NOAA, USCG, and others. However, each agency's response is mission-dependent and their capa-

Box 44: Interagency Response to Assess Environmental Impacts of Hurricane Katrina

In August 2005, Hurricane Katrina devastated the north-central Gulf of Mexico coast. Federal, state, and local agencies along with non-profit organizations and citizens rushed to aid the area. EPA, FDA, NASA, NOAA, NSF, and USGS initiated an integrated response to assess environmental impacts of Katrina throughout the affected region, with much of the effort directed towards characterizing the magnitude and extent of coastal contamination. Response activities were conducted using EPA's vessel *OSV Bold,* NASA's Experimental Advanced Airborne Research LiDAR sensor, NOAA's *R/V Nancy Foster*, the NSF-supported UNOLS vessel *Cape Hatteras*, and FDA small boat teams. Specific objectives included measuring chemical and microbial contaminants in water, sediments, and fish and shellfish tissues to assess ecological impacts and potential threats to human health. OHH researchers from NSF-NIEHS Centers, Louisiana State University, and NOAA responded to concerns about pathogens and indicator organisms in soil around New Orleans, Lake Ponchartrain, and nearshore waters following the dewatering of New Orleans, and completed a comprehensive study of pathogenic viruses, bacteria, and protozoa as well as fecal indicator organisms in the area. Also, the University of Washington OHH Center developed and distributed to returning residents an informational flier that included important messages about anticipated hazards from multiple sources inside and outside of their homes.

Hurricane Katrina Photo credit: NASA

bilities differ. Identification of capabilities and capacity for response within the research elements of the Interagency OHH Program would provide response agencies with additional resources when needed.

Based on the lessons learned from the Hurricane Katrina and HAB-event responses, opportunities for advancement include:

- Identify OHH research, analytical, diagnostic, and other response capabilities that could be brought to bear in emergencies and how they might be used to best complement and enhance established state, federal, and local agency disaster-response capacities.

- The Interagency OHH Program, working with NIST, federal response and regulatory agencies, and other entities, could lead efforts to develop and standardize techniques for specific marine analyses (e.g., DNA extraction) so as to improve the capacity for integrated interagency efforts in disaster responses (see Standards and Standardized Methods section).

- The Interagency OHH Program could help bring together key players (e.g., federal and state agency representatives, public health officials, academic researchers, constituents, and users groups) to evaluate different agency determinations of "safe levels" of various contaminants in seafood, water, sediments, and air and make recommendations for integrated and standardized risk communication after disaster events (see Seafood section).

Box 45: Integrated Response to the 2005 Paralytic Shellfish Poisoning Event in New England

From May to July 2005, the most severe bloom since 1972 of the microscopic toxic alga, *Alexandrium fundyense*, spread from Maine to Massachusetts, resulting in extensive commercial and recreational shellfish-harvesting closures to protect people from paralytic shellfish poisoning (PSP). Previous and current funding by a variety of programs, including the NSF and NOAA ECOHAB and MERHAB programs, the NCCOS Event Response, and the NSF-NIEHS WHCOHH (see Box 1), along with critical information provided by the Gulf of Maine Ocean Observing System buoys, allowed scientists in the region to provide maps of the bloom location and model predictions of bloom movement to management agencies responsible for ensuring safe shellfish. These information products helped state agencies focus limited resources on monitoring areas where new closures were needed or where reopening might be possible. The FDA and NOAA also used this information to make decisions regarding closure of offshore areas under federal jurisdiction. Thus, use of state-of-the-art field and laboratory techniques by OHH researchers allowed the bloom to be monitored in real time, enabling early warnings to public health and fishery managers. As a result of the coordinated assistance given by researchers at Woods Hole Oceanographic Institution, FDA, and NOAA, there were no reported human PSP illnesses, despite remarkably high toxicity in unmarketed shellfish products during this bloom.

Chapter 4: Implementing a Strong Interagency OHH Research Program

In developing this plan, the IWG-4H had extensive deliberations about the comprehensive lists of research, infrastructure and outreach priorities that comprise Chapter 3. Based on those discussions, and numerous interactions with OHH researchers and others during the information gathering efforts that resulted in those priorities, the IWG-4H distilled the following six implementation actions to ensure a vibrant Interagency OHH Program. These actions, and the priorities identified within them, will advance OHH research across a broad interdisciplinary and interagency front and transfer and apply OHH findings to reduce human health risks, maximize human health benefits, and ensure healthy and productive marine ecosystems.

Action 1: Work through Existing OHH Programs and Partnerships.

The OHH Act of 2004 stated that this Implementation Plan should "build on and complement the ongoing activities of the National Oceanic and Atmospheric Administration, the National Science Foundation, and other departments and agencies …" The existing formal programs encompass NOAA Centers of Excellence in OHH, the NSF-NIEHS Centers for OHH, and the NOAA OHHI's extramural research grants, traineeships, and distinguished scholars. Other agencies included in this plan are CDC, EPA, FDA, MMC, NASA, and USGS. Efforts of all these collaborating agencies and their current and future partners to conduct research targeted at the high priority topics (see Action 2 below), support OHH-related infrastructure (see Action 3), and conduct outreach, education, and application activities (see Action 4) will increase the ability of the Interagency OHH Program to reduce ocean-based risks to humans and develop new marine-derived products to improve human well-being.

Action 2: Target Priority Research.

Based on the numerous major opportunities for advancement of OHH science described in Chapter 3, and the respective interests, roles, and priorities of the various agencies as outlined in Table 3, highest priority should be given to six research areas:

Basic and applied studies of ocean ecosystems and processes that affect human exposure to ocean-related health risks, including development of new and improved sensors, assays, tools and methods for the assessment, monitoring and prediction of HABs and their toxins, known and potentially infectious diseases (including those that may be transmitted from marine animals to humans and from humans to animals), and ECCs. Such investigations should include assessments of the impacts of natural hazards, seafood consumption, and climate change on human exposure to health risks from the ocean and ways to reduce, mitigate or prevent such impacts.

Discovery and development of new marine pharmaceuticals and other products beneficial to humans. The ocean is the last frontier for new drug discovery, and because of its unparalleled biodiversity, it holds huge possibilities for new products that could improve and perhaps even revolutionize health care. Efforts should optimize acquisition, testing, characterization, and production of new marine bioproducts, including those produced through sustainable aquaculture. Work in this target area should emphasize ecologically sound methods and innovative public-private collaborations. Because of the lengthy lag time between initial discovery and product development, this work requires a long-term focus and commitment.

Epidemiological studies and disease surveillance, both short- and long-term, are necessary to document and elucidate acute and chronic health effects in humans and animals resulting from exposures to ocean waters, marine sediments, aerosols, and seafood. These investigations include collaboration with entities collecting environmental data and the integration of environmental and health data to document current and future levels of human disease resulting from ocean-based exposures, increase understanding of relationships among environmental factors and distribution/abundance of harmful agents, develop predictive models, and identify promising means to limit and prevent human exposures to these agents. This work also encompasses disease surveillance in marine mammals, seabirds, and other marine animals likely to harbor pathogens of potential danger to humans.

Table 3. Primary Roles of Agencies in Conducting and Utilizing Research in Priority Areas Identified in the Interagency Oceans and Human Health Research Implementation Plan (see Chapter 2).

Research Topic/Agency	NOAA	NSF	NIEHS	CDC	EPA	FDA	MMC	NASA	USGS
Pathogens	*RTSA	*RT	*RTS	RTS	*TSA	*RTSA	RA		RT
Chemical Contaminants	*RTSA	RT	RTS	A	*RTA	*RTSA	RA		RTS
Harmful Algal Blooms	*RTSA	*RT	*RTSA	*RTS	*RTA	*RTSA	RA	*RS	RT
Seafood Safety	*RTSA		RSA	S		*RTSA	A		
Pharmaceuticals & Other Beneficial Products	*RTA	*RT	*RT		*TA	*RTSA			
Epidemiology	*RTSA		RTSA	*RTSA	*RTS	*SA	A		
Sentinels	*RTSA			S		*RTSA	RA		
Genomics & Other "Omic" Sciences	*RTA	*RT	*RTS		*RT	*RTSA			
Social, Behavioral, Economic	*RTA	R	R		*R	*SA	A		
Climate Change	*RTSA	*RT		RT	*RSA		*RSA	*RS	RTS

R = Research, basic to applied (mission-specific) S = Surveillance and monitoring * = Current activity within OHH-related program
T = Tool and/or method development A = Application (use) and/or regulation

Use of marine species and habitats as early warning sentinels to indicate existing and emerging threats to human, animal and ecosystem health **and as models** for the study of human disease processes and toxicology.

Improving, developing, and testing conceptual and quantitative models that integrate a broad range of environmental, biological, and epidemiological data and produce new levels of understanding and predictive capacity related to ocean health threats.

Economic and socio-cultural studies that advance understanding of how humans use and value the health benefits provided by coastal and ocean waters and resources and how these uses and values are impacted by real and perceived health threats that these environments may pose.

Action 3: Support Research Infrastructure.

Like almost all interdisciplinary research efforts, the Interagency OHH Program requires the right mix of cutting-edge research and supporting infrastructure. Based on an assessment of the respective interests, roles, and priorities of the agencies participating in the OHH program (Table 4), supporting infrastructure includes:

The IOOS and other ocean observatories that contribute to the Global Earth Observing System of Systems. These observing systems are essential building blocks for synoptic collection of physical, chemical, and biological data related to ocean-based health threats, through sensors and other tools, and for integrating these data into useful and timely information products for decision-makers.

Computing, data management, and bioinformatic infrastructure to enable data sharing, integration, archiving, analysis, and access for a broad range of OHH-related data, including the large amounts of data derived from genomic and proteomic studies.

New standards and standardized methods for OHH research and research materials. This activity should include capabilities for sample and specimen archiving, including those obtained for new product discovery, and the rapid evaluation, validation, and implementation of new analytical and monitoring methods by researchers and federal regulatory and management agencies.

Access platforms that make ocean sampling, observations, and discovery possible, including research vessels, satellites, aircraft, buoys, AUVs, ROVs, and others, and dedication of sufficient time on these platforms for the OHH program to accomplish crucial sampling activities.

Table 4. Primary Roles/Interests of Agencies in Providing and/or Using Major Infrastructure for the Interagency Oceans and Human Health Research Implementation Plan (see Chapter 2).

Agency/Infrastructure	NOAA	NSF	NIEHS	CDC	EPA	FDA	MMC	NASA	USGS
Link to Observing Systems	*HP PU	*HP P	*HP U	HP PU	*HP	HP PU	HP U	*HP PU	HP P
Data Management, Access & Modeling	*HP PU	*HP P	*HP PU	HP PU	*HP	HP PU	HP U	*HP PU	HP P
Development of Standards	MP PU	*MP PU	MP PU	HP U	LP	HP PU	MP U	MP PU	MP PU
Access to Sea	*HP PU	*HP P	*HP PU	LP U	LP	HP U	LP U	MP U	MP U

HP = High Priority; MP = Medium Priority; LP = Low Priority
P = Provider and U = User; any agency could be one or the other or both
* = ongoing activity within the agency's OHH-related efforts

Core facilities in genomics/proteomics, marine microbiology and analytical chemistry. Sequencing centers and state-of-the-art microbiology laboratories, with associated computer processing, bioinformatics, and analytical capabilities, support "omics" research to advance understanding of health impacts and disease processes at the molecular level and the identification and quantification of pathogenic microbes. In addition, chemistry laboratories with the capacity to provide consistent measurements of an increasing number and variety of chemical pollutants at very low but biologically relevant concentrations (e.g., levels < 1 part per trillion) in water, sediment, air, and tissue samples will facilitate our efforts to address the associated human health concerns. These core facilities will allow rapid progress that may transform our understanding of disease processes and potential control, treatment, and prevention options.

Action 4: Support Transition of OHH Research to Application.

To fulfill the vision of the Interagency OHH Program, OHH research, information, and technology must be effectively transferred to the OHH research community, resource and public health managers, other users, and the public. Also, a national OHH research program will require training a new generation of scientists who are comfortable and equipped to work at the juncture of ocean and biomedical sciences and who are able to communicate with multiple and very different users. Based on an assessment of the respective interests, roles, and priorities of the agencies participating in the OHH program (Table 5), targeted and coordinated information, outreach, and education activities across the Interagency OHH Program should:

Strengthen cross-agency, cross-institution, and cross-discipline collaborations that provide the necessary framework to develop a fundamentally new interdisciplinary research community with the breadth of expertise required to address diverse human health questions within the complexity of ocean systems and ensure coordination of agency OHH-related communication and education efforts.

Provide opportunities for interdisciplinary training, research, and collaborations for graduate and post-doctoral students, health professionals, scientists at early- to mid-career stages, and scholars that will expose them to both ocean and health sciences and enable them to integrate data and approaches across fields and effectively communicate and partner with multiple user groups.

Provide OHH information, tools, technology, products, and training to support improved public health and ocean resource decision-making. A robust OHH research program, coupled with monitoring and surveillance, data sharing, and technology transfer, will lead to availability of a host of helpful products for use by decision-makers and the public. A targeted outreach effort will allow the OHH program to strengthen partnerships with managers and decision-makers, and effectively communicate with them and respond to their information and technology needs on a rapid, regular, and reliable basis.

Coordinate OHH communication programs across agencies. Although outreach is a particular responsibility of the NOAA OHHI, OHH information programs should be coordinated among mission and science agencies at all levels of government to enable rapid transfer and consistent communication of findings and tools to users, including a nationwide network of health care providers. This effort should encompass potential or emerging threats detected from human and animal disease surveillance, monitoring for safety of seafood and recreational and drinking waters, and identification of ocean-related health benefits.

Support interagency partnerships to enable rapid and coordinated response of OHH researchers to emergency situations such as may be associated with severe weather events, sewage, oil or chemical spills, and possible marine-derived disease outbreaks among both humans and animals. Findings must then be communicated effectively to the public.

Promote ocean stewardship and ocean and human health literacy by improving the visibility and public awareness of the relationships between oceans and human health and introducing OHH themes, activities, and materials within schools and in a variety of settings such as aquariums, zoos, and via the popular press and media.

Action 5. Improve Coordination of OHH Activities within and across Agencies and Internationally.

The OHH Act requires that "The President, through the National Science and Technology Council, shall coordinate and support a national program to improve understanding of the role of the oceans in human health." This program is to be carried out in consultation with the Interagency Task Force on Harmful Algal Blooms and Hypoxia established under section 603 of the Harmful Algal Blooms and Hypoxia Control Act of 1998 (HABHRCA). Currently, responsibilities for the duties of the Interagency Task Force on Harmful Algal Blooms and Hypoxia have been assigned to the IWG-4H, which is also responsible for development of this Interagency OHH Research Implementation Plan and the Interagency OHH Annual Report.

Much integration has been achieved on an ad hoc basis by the program leaders and participants in the NOAA and NSF-NIEHS OHH programs and through the work to date of the IWG-4H. The JSOST, through the IWG-4H, will continue to advance interagency coordination.

Action 6. Provide for Updates to the Interagency OHH Research Implementation Plan.

The OHH Act of 2004 requires that the Interagency OHH Annual Report include a summary or copy of the

Table 5. Primary Roles/Interests of Agencies in Transitioning OHH Research Results to Applications, Outreach and Education (see Chapter 2).

Agency/Transitions	NOAA	NSF	NIEHS	CDC	EPA	FDA	MMC	NASA	USGS
Outreach									
Transition of research results to products or applications	HP		*MP	HP	LP	*HP	MP	*HP	*HP
OHH advisory information to public health officials, resource managers & general public	*HP		*MP	*HP	*HP	*HP	MP	LP	*MP
Education									
Improve public understanding of ocean sciences, including OHH	*MP	*HP	*MP	LP	LP	*HP	MP	*HP	*MP
Professional training of undergraduate, graduate students & post-doctoral researchers	*HP	*HP	*HP	LP	LP	*MP	MP	*HP	LP
Rapid Response									
Assess health risks	*HP		*HP	*HP	*HP	*HP	HP		*MP
Follow up research	*HP	*HP	*HP	*HP	LP	*HP	HP	HP	*MP
Provide analytical resources	*HP	*MP	*HP	*HP	LP	*HP	HP		*HP

HP = High Priority; MP = Medium Priority; LP = Low Priority * = ongoing activity within the agency's OHH-related efforts

Implementation Plan and any changes made in the plan. Thus, this annual reporting mechanism provides a regular opportunity for the interagency OHH community to update the Implementation Plan. Programmatic support for interagency-sponsored workshops that would include the external research and stakeholder communities, as well as federal agencies, at 3-5 year intervals to examine progress and re-evaluate the Plan would also be beneficial.

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APPENDIX 1: Oceans and Human Health Act of 2004

TITLE IX—OCEANS AND HUMAN HEALTH ACT

SEC. 901. SHORT TITLE.

This title may be cited as the 'Oceans and Human Health Act'.

SEC. 902. INTERAGENCY OCEANS AND HUMAN HEALTH RESEARCH PROGRAM.

(a) COORDINATION- The President, through the National Science and Technology Council, shall coordinate and support a national research program to improve understanding of the role of the oceans in human health.

(b) IMPLEMENTATION PLAN- Within 1 year after the date of enactment of this Act, the National Science and Technology Council, through the Director of the Office of Science and Technology Policy shall develop and submit to the Congress a plan for coordinated Federal activities under the program. Nothing in this subsection is intended to duplicate or supersede the activities of the Inter-Agency Task Force on Harmful Algal Blooms and Hypoxia established under section 603 of the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (16 U.S.C. 1451 note). In developing the plan, the Committee will consult with the Inter-Agency Task Force on Harmful Algal Blooms and Hypoxia. Such plan will build on and complement the ongoing activities of the National Oceanic and Atmospheric Administration, the National Science Foundation, and other departments and agencies and shall-

(1) establish, for the 10-year period beginning in the year it is submitted, the goals and priorities for Federal research which most effectively advance scientific understanding of the connections between the oceans and human health, provide usable information for the prediction of marine-related public health problems and use the biological potential of the oceans for development of new treatments of human diseases and a greater understanding of human biology;

(2) describe specific activities required to achieve such goals and priorities, including the funding of competitive research grants, ocean and coastal observations, training and support for scientists, and participation in international research efforts;

(3) identify and address, as appropriate, relevant programs and activities of the Federal agencies and departments that would contribute to the program;

(4) identify alternatives for preventive unnecessary duplication of effort among Federal agencies and departments with respect to the program;

(5) consider and use, as appropriate, reports and studies conducted by Federal agencies and departments, the National Research Council, the Ocean Research Advisory Panel, the Commission on Ocean Policy and other expert scientific bodies;

(6) make recommendations for the coordination of program activities with ocean and human health-related activities of other national and international organizations; and

(7) estimate Federal funding for research activities to be conducted under the program.

(c) PROGRAM SCOPE- The program may include the following activities related to the role of oceans in human health:

(1) Interdisciplinary research among the ocean and medical sciences, and coordinated research and activities to improve understanding of processes within the ocean that may affect human health and to explore the potential contribution of marine organisms to medicine and research, including—

(A) vector- and water-borne diseases of humans and marine organisms, including marine mammals and fish;

(B) harmful algal blooms and hypoxia (through the Inter-Agency Task Force on Harmful Algal Blooms and Hypoxia);

(C) marine-derived pharmaceuticals;

(D) marine organisms as models for biomedical research and as indicators of marine environmental health;

(E) marine environmental microbiology;

(F) bioaccumulative and endocrine-disrupting chemical contaminants; and

(G) predictive models based on indicators of marine environmental health or public health threats.

(2) Coordination with the National Ocean Research Leadership Council (10 U.S.C. 7902(a)) to ensure that any integrated ocean and coastal observing system provides information necessary to monitor and reduce marine public health problems including health-related data on biological populations and detection of contaminants in marine waters and seafood.

(3) Development through partnerships among Federal agencies, States, academic institutions, or non-profit research organizations of new technologies and approaches for detecting and reducing hazards to human health from ocean sources and to strengthen understanding of the value of marine biodiversity to biomedicine, including—

(A) genomics and proteomics to develop genetic and immunological detection approaches and predictive tools and to discover new biomedical resources;

(B) biomaterials and bioengineering;

(C) in situ and remote sensors used to detect, quantify, and predict the presence and spread of contaminants in marine waters and organisms and to identify new genetic resources for biomedical purposes;

(D) techniques for supplying marine resources, including chemical synthesis, culturing and aquaculturing marine organisms, new fermentation methods and recombinant techniques; and

(E) adaptation of equipment and technologies from human health fields.

(4) Support for scholars, trainees and education opportunities that encourage an interdisciplinary and international approach to exploring the diversity of life in the oceans.

(d) ANNUAL REPORT- Beginning with the first year occurring more than 24 months after the date of enactment of this Act, the National Science and Technology Council, through the Director of the Office of Science and Technology Policy shall prepare and submit to the President and the Congress not later than January 31st of each year an annual report on the activities conducted pursuant to this title during the preceding fiscal year, including—

(1) a summary of the achievements of Federal oceans and human health research, including Federally supported external research, during the preceding fiscal year;

(2) an analysis of the progress made toward achieving the goals and objectives of the plan developed under subsection (b), including identification of trends and emerging trends;

(3) a copy or summary of the plan and any changes made in the plan;

(4) a summary of agency budgets for oceans and human health activities for that preceding fiscal year; and

(5) any recommendations regarding additional action or legislation that may be required to assist in achieving the purposes of this title.

SEC. 903. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION OCEANS AND HUMAN HEALTH INITIATIVE.

(a) ESTABLISHMENT- As part of the Interagency Oceans and Human Health Research Program, the Secretary of Commerce is authorized to establish an Oceans and Human Health Initiative to coordinate and implement research and activities of the National Oceanic and Atmospheric Administration related to the role of the oceans, the coasts, and the Great Lakes in human health. In carrying out this section, the Secretary shall consult with other Federal agencies conducting integrated oceans and human health research and research in related areas, including the National Science Foundation. The Oceans and Human Health Initiative is authorized to provide support for—

(1) centralized program and research coordination;

(2) an advisory panel;

(3) one or more National Oceanic and Atmospheric Administration national centers of excellence;

(4) research grants; and

(5) distinguished scholars and traineeships.

(b) ADVISORY PANEL- The Secretary is authorized to establish an oceans and human health advisory panel to assist in the development and implementation of the Oceans and Human Health Initiative. Membership of the advisory group shall provide for balanced representation of individuals with multi-disciplinary expertise in the marine and biomedical sciences. The Federal Advisory Committee Act (5 U.S.C. App.) shall not apply to the oceans and human health advisory panel.

(c) NATIONAL CENTERS-

(1) The Secretary is authorized to identify and provide financial support through a competitive process to develop, within the National Oceanic and Atmospheric Administration, for one or more centers of excellence that strengthen the

capabilities of the National Oceanic and Atmospheric Administration to carry out its programs and activities related to the oceans' role in human health.

(2) The centers shall focus on areas related to agency missions, including use of marine organisms as indicators for marine environmental health, ocean pollutants, marine toxins and pathogens, harmful algal blooms, hypoxia, seafood testing, identification of potential marine products, and biology and pathobiology of marine mammals, and on disciplines including marine genomics, marine environmental microbiology, ecological chemistry and conservation medicine.

(3) In selecting centers for funding, the Secretary will give priority to proposals with strong interdisciplinary scientific merit that encourage educational opportunities and provide for effective partnerships among the Administration, other Federal entities, State, academic, non-profit research organizations, medical, and industry participants.

(d) EXTRAMURAL RESEARCH GRANTS-

(1) The Secretary is authorized to provide grants of financial assistance to the scientific community for critical research and projects that explore the relationship between the oceans and human health and that complement or strengthen programs and activities of the National Oceanic and Atmospheric Administration related to the ocean's role in human health. Officers and employees of Federal agencies may collaborate with, and participate in, such research and projects to the extent requested by the grant recipient. The Secretary shall consult with the oceans and human health advisory panel established under subsection (b) and may work cooperatively with other agencies participating in the interagency program to establish joint criteria for such research and projects.

(2) Grants under this subsection shall be awarded through a competitive peer-reviewed, merit-based process that may be conducted jointly with other agencies participating in the interagency program.

(e) TRAINEESHIPS- The Secretary of Commerce is authorized to establish a program to provide traineeships, training, and experience to pre-doctoral and post-doctoral students and to scientists at the beginning of their careers who are interested in the oceans in human health research conducted under the NOAA initiative.

SEC. 904. PUBLIC INFORMATION AND OUTREACH.

(a) IN GENERAL- The Secretary of Commerce, in consultation with other Federal agencies, and in cooperation with the National Sea Grant program, shall design and implement a program to disseminate information developed under the NOAA Oceans and Human Health Initiative, including research, assessments, and findings regarding the relationship between oceans and human health, on both a regional and national scale. The information, particularly with respect to potential health risks, shall be made available in a timely manner to appropriate Federal or State agencies, involved industries, and other interested persons through a variety of means, including through the Internet.

(b) REPORT- As part of this program, the Secretary shall submit to Congress an annual report reviewing the results of the research, assessments, and findings developed under the NOAA Oceans and Human Health Initiative, as well as recommendations for improving or expanding the program.

SEC. 905. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated to the Secretary of Commerce to carry out the National Oceanic and Atmospheric Administration Oceans and Human Health Initiative, $60,000,000 for fiscal years 2005 through 2008. Not less than 50 percent of the amounts appropriated to carry out the initiative shall be utilized in each fiscal year to support the extramural grant and traineeship programs of the Initiative.

APPENDIX 2: Agency Prospectuses

The National Science Foundation (NSF) is an independent federal agency with a primary mission to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense. NSF provides approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. In many fields such as mathematics, computer science and the social sciences, NSF is the major source of federal backing.

NSF supports research efforts focused on Oceans and Human Health in an interagency partnership with the National Institute of Environmental Health Sciences (NIEHS). Four Centers for Oceans and Health (COOH) were established in 2004. The NSF-NIEHS COOH effort is managed in the Division of Ocean Sciences (OCE) by the Chemical Oceanography Program. NSF also participates in other Interagency activities with OHH themes, including: Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) (with NOAA, EPA, ONR, NASA); Ecology of Infectious Diseases (EID) (with NIH). NSF also supports basic research that addresses OHH Themes in various Directorates of the Foundation. Specific themes include harmful algal blooms (HABs) (Directorate of Geosciences/Division of Ocean Sciences), microbial ecology (primarily in the Directorates of Biology and Geosciences). The Directorate of Social, Behavioral, and Economic Sciences (SBE) also has identified the human dimensions of OHH as a future area of interest. The Division of Ocean Sciences supports education and outreach efforts in the ocean sciences through Centers for Ocean Science Education Excellence (COSEE) Program. Sea-going capability in support of academic research is primarily provided by the University-National Oceanographic Laboratory System (UNOLS). NSF provides approximately 70 percent of support for UNOLS operations. Oversight and support for UNOLS is provided by the Division of Ocean Sciences. The Foundation will implement two "Major Research Equipment and Facilities Construction (MREFC)" projects, the Ocean Observatories Initiative (OOI); and the National Ecological Observatory Network (NEON). These will provide research observatory capabilities in the marine and freshwater/terrestrial environments, respectively, and thus have a high potential to contribute to the developing OHH activities. The OOI is expected to be come operational in the coastal regions in the 2008-2012 time frame.

The Centers for Disease Control and Prevention (CDC) is one of the 13 major operating components of the Department of Health and Human Services (HHS). HHS is the principal agency in the United States government for protecting the health and safety of all Americans and for providing essential human services, especially for those people who are least able to help themselves. Since it was founded in 1946 to help control malaria, CDC has remained at the forefront of public health efforts to prevent and control infectious and chronic diseases, injuries, workplace hazards, disabilities, and environmental health threats. Today, CDC is globally recognized for conducting research and investigations and for its action-oriented approach. CDC applies research and findings to improve people's daily lives and responds to health emergencies—something that distinguishes CDC from its peer agencies. CDC supports research efforts related to OHH at many levels and through several internal units, including the Health Studies Branch at the National Center for Environmental Health (NCEH), the National Center for Infectious Diseases (NCID), and the National Institute for Occupational Safety and Health (NIOSH).

APPENDIX 3: List of Acronyms and Abbreviations

Act	Oceans and Human Health Act
ALS/PDC	Amyotrophic Lateral Sclerosis/ Parkinsonism–Dementia Complex
AMAP	Artic Marine Assessment Program
AOAC	Association of Official Analytical Chemists (now AOAC International)
ARISA	Advanced Reflectometer for Interface and Surface Analysis
AUV	Autonomous Underwater Vehicle
AZT	Azidothymidine (an antiretroviral drug)
BMAA	ß-N-methylamino-L-alanine (a neurotoxin amino acid)
CA	California
CAMERA	Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis
CDC	Centers for Disease Control and Prevention
CDER	Center for Drug Evaluation and Research within FDA
CEGLHH	NOAA Center of Excellence for Great Lakes and Human Health
CFSAN	Center for Food Safety and Applied Nutrition within FDA
COHH	Centers for Oceans and Human Health within NSF
COSEE	Centers for Ocean Science Education Excellence
CSDM	Content Standard for Digital Geospatial Metadata
CTX-H	a ciguatoxin congener derived from the dinoflagellate *Gambierdiscus*
DMAC	Data Management and Communications Plan
DNA	Deoxyribonucleic Acid
ECC	Emerging Chemicals of Concern
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms (multi-agency program involving NSF, NOAA, EPA, ONR, NASA)
EEZ	Exclusive Economic Zone
ELISA	Enzyme-Linked Immunosorbent Assay
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration
FGDC	Federal Geographic Data Committee
FLDH	Florida Department of Health
GA	Georgia
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GLERL	Great Lakes Environmental Research Laboratory (a NOAA Center of Excellence for OHH)
GRACE	Gravity Recovery and climate Experiment within NASA
GSAT	Global Situational Tool
HAB	Harmful Algal Bloom
HABISS	Harmful Algal Bloom-related Illness Surveillance System
HABHRCA	Harmful Algal Bloom and Hypoxia Control Act of 1998
HABSOS	NOAA's Harmful Algal Blooms Observing System
HACCP	Hazard Analysis Critical Control Point
HARR-HD	A report entitled, "Harmful Algal Research and Response: A Human Dimensions Strategy"
HARRNESS	Harmful Algal Research and Response National Environmental Science Strategy, 2005-2015
HHS	Department of Health and Human Services
HIV	Human Immunodeficiency Virus
HML	Hollings Marine Laboratory (NOAA Center of Excellence for Oceans and Human Health at the Hollings Marine Laboratory)
HTC	High Throughput Culturing
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Seas
ICOSRMI	Interagency Committee on Ocean Science and Resource Management Integration
IGBP	International Geosphere-Bioshere Programme
IOC	International Oceanographic Commission
IOM	Institute of Medicine of the National Academies
IOOS	Integrated Ocean Observing System
ISSC	Interstate Shellfish Sanitation Conference
IWC	International Whaling Commission
IWG-4H	Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health
JSOST	Joint Subcommittee on Ocean Science and Technology
LA	Los Angeles
LiDAR	Light Detection and Ranging; or Laser Imaging Detection and Ranging

Mass.	Massachusetts
MERHAB	Monitoring and Event Response for Harmful Algal Blooms program
MMC	Marine Mammal Commission
MML	Mote Marine Laboratory
MODIS	Moderate Resolution Imaging Spectroradiometer
MYP	Multi-Year Plan
NASA	National Aeronautics and Space Administration
NASA ROSES	NASA's Research Opportunities in Space and Earth Sciences
NC	North Carolina
NCCR	National Coastal Condition Report
NCEH	National Center for Environmental Health within CDC
NCID	National Center for Infectious Diseases within CDC
NEON	National Ecological Observatory Network within NSF
NIEHS	National Institute of Environmental Health Science within NIH
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOAA HABSOS	NOAA's Harmful Algal Blooms Observing System
NOAA OHHI Centers	NOAA'S Oceans and Human Health Initiative Centers of Excellence
NOPP	National Oceanographic Partnership Program
NOS	National Oceans Service within NOAA
NRC	National Research Council
NRL	Naval Research Laboratory
NSF	National Science Foundation
NSTC	National Science and Technology Council
NWFSC	Northwest Fisheries Science Center
NURP	National Underwater Research Program
OARSA	Office of Applied Research and Safety Assessment within FDA
OE	Ocean Exploration Program
OHH	Oceans and Human Health
OHH Act	Oceans and Human Health Act of 2004
OHHI	Oceans and Human Health Initiative
OIE	World Organization for Animal Health
ONR	Office of Naval Research
OOI	Ocean Observatories Initiative (within NSF)
OR	Oregon
ORD	Office of Research and Development with in EPA
OS	Office of Seafood within FDA
OSV	Ocean Survey Vessel
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Diethyl Ether
PCB	Polychlorinated Biphenyls
PICES	North Pacific Marine Science Organization
PNW	Pacific Northwest
PNW H2O	Pacific Northwest Center for Oceans and Human Health (funded by NSF-NIEHS at the University of Washington)
PRCMB	University of Hawaii Pacific Research Center for Marine Biomedicine (funded by NSF-NIEHS)
PSP	Paralytic Shellfish Poisoning
QA	Quality Assurance
RA	Regional Association
REASoN	Research, Education and Applications Solution Network
REU	Research Experiences for Undergraduate Students
RFA	Request for Applications
RFP	Request for Proposals
Rho-GTP	A protein involved with functioning of the nucleotide guanosine triphosphate important in metabolism
ROV	Remotely Operated Vehicle
R/V	Research Vessel
SAFE	Swim Advisory Forecast Estimate
SARS	Severe Acute Respiratory Syndrome
SBE	Social, Behavioral, and Economic
SC	South Carolina
SEAPORT	Signal Environmental and Plankton Observations in Real Time
SEPMN	Southeast Phytoplankton Monitoring Network within NOAA
SIVCA	Species Identification via Chimeric Amplification
sp.	species (singular)
spp.	species (plural)
START	Solutions to Avoid Red Tide
TOS	The Oceanography Society
TRMM	Tropical Rainfall Measuring Mission within NASA

UMCOHH	University of Miami Center for Subtropical and Tropical Oceans and Human Health Research in the Marine Sciences (funded by NSF-NIEHS)
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNOLS	University-National Oceanographic Laboratory System
U.S.	United States
USCOP	U.S. Commission on Ocean Policy
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UW	University of Washington
WA	Washington
WCCOHH	NOAA West Coast Center of Excellence for Oceans and Human Health at the Northwest Fisheries Science Center
WHCOHH	Woods Hole Center for Oceans and Human Health (funded by NSF-NIEHS)
WHO	World Health Organization
WHOI	Woods Hole Oceanographic Institute

APPENDIX 4: Joint Subcommittee on Ocean Science and Technology (JSOST)

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JSOST Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health (IWG-4H)
Paul Sandifer, Co-Chair, NOAA
Lorrie Backer, Co-Chair, CDC

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Stephen Weisberg, Vice-Chair
Debra Hernandez, Vice-Chair

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