Marine Swimming–Related Illness: Implications for Monitoring and Environmental Policy

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There is increasing evidence that environmental degradation may be contributing to an increase in marine-related diseases across a wide range of taxonomic groups. This includes a growing number of reports of both recreational and occupational users of marine waters developing gastrointestinal, respiratory, dermatologic, and ear, nose, and throat infections. The duration and type of exposure, concentration of pathogens, and host immunity determine the risk of infection. Public health authorities may not be able to accurately predict the risk of waterborne disease from marine waters due to the limitations of conventional monitoring, as well as erroneous perceptions of pathogen life span in marine systems. Pathogens undetectable by conventional methods may remain viable in marine waters, and both plankton and marine sediments may serve as reservoirs for pathogenic organisms, which can emerge to become infective when conditions are favorable. In this paper we address the environmental factors that may contribute to illness, the types of associated economic costs, the issues of water quality monitoring and the policy implications raised by the apparent rise in incidence of marine water-related illnesses. *Key words*: disease surveillance, marine ecosystems, waterborne disease. *Environ Health Perspect* 109:645–650 (2001). [Online 19 June 2001]
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Beach closings and illness after exposure to marine water may be increasing in frequency (*1*,*2*). In the United States from 1988 to 1994, there were over 12,000 coastal beach closings and advisories (an increase of 400% over that period), with over 75% of the closings due to microbial contamination (*3*). Although not all cases can be traced to anthropogenic discharges, the belief that marine pollution has no significant impact on health must now be challenged (*4–6*). Infectious diseases and toxin-related illness may be caused by enteric pathogens or chemicals that enter the marine environment from terrestrial ecosystems (e.g., through fecal contamination from a number of point and diffuse sources) (*7*). Alternatively, indigenous organisms (and biotoxins) that may have increased in number or virulence as a result of ecologic imbalance (*8*,*9*) can cause negative health effects. Anthropogenic inputs to the coastal environment may be contributing to both terrestrial and marine stress (*8*).

Anthropogenic pressures on coastal environments. Population growth in coastal areas is increasing at a rate double that of population growth worldwide. It is estimated that billions of gallons of treated and untreated wastewater are discharged daily into the world's coastal waters. In developing nations, 90% of untreated sewage from urban areas is dumped into streams and oceans (*10*). In addition, runoff from heavy rains can worsen water quality. Increased bacterial, viral, and toxin contamination may be associated with watershed pollution, loss of wetlands (which naturally filter out pollutants), and overfishing (which decreases predation). Heavy loadings of organic and inorganic nutrients change the ecologic balance, stimulating nuisance organisms (*11*) and in some cases affecting the virulence of indigenous species (*12*).

The literature suggests a global increase in the frequency, magnitude, and geographic extent of harmful algal blooms (HABs) over the past two decades, leading to toxic and anoxic conditions (*13*). A strong correlation exists between HABs and the degree of coastal pollution (*14*). Global factors also affect the plankton; for example, warm sea surface temperatures increase photosynthesis and metabolism (*15*), and may contribute to the growth of tropical and temperate species in higher northern and southern latitudes. Extreme conditions may spur blooms that are extensive enough to cause anoxic zones in shallow estuaries such as the Chesapeake Bay. In the Laguna Madre in Texas, a bloom persisted for over 8 years after an abnormally cold period led to a fish kill that stimulated a rare "brown tide" organism similar to the *Aureococcus anophagefferens*, which is found in the Northeastern United States (*16*).

In addition to the microenvironment created by plankton, there is evidence that inert material (e.g., bottles, tires, plastics) supporting biofilms may provide protective niches for bacteria and viruses, prolonging their marine survival (*17*). Sediments are also thought to be reservoirs for certain pathogens. For example, indicator bacteria (fecal coliforms and enterococci) and *Vibrio parahaemolyticus* survive in high numbers in sewage-polluted intertidal sediments (*18*). Fecal coliforms have been isolated from marine sediments beneath a deep ocean dumpsite off New York (*19*). *Aeromonas hydrophila*, with similar virulence factors to isolates from human diarrhea cases, has been isolated from marine sediments in southern Italy (*20*). Where sediments can be readily resuspended in high-energy coastal environments, they may be a significant source of pathogens to the water column (*7*,*18*). Survival strategies of pathogens in marine environments are discussed in more detail in a recent review by Ford (*21*).

Exposure scenarios. There is increasing evidence that rates of marine-associated infections are proportional to the duration of exposure (*22*) and pollution level (*22–25*). While submerged, swimmers are exposed to pathogens, toxins, and irritants that can easily enter the ears, eyes, nose, and mouth, as well as the anus and genitourinary tract. The skin is directly exposed to infectious agents and chemicals through swimming or working in polluted waters. This exposure can lead to a variety of health problems, including dermatitis and skin infections or deep tissue and blood infection through open cuts. In addition, there is strong evidence that dermal sorption is an important route of exposure to toxins (*26*,*27*). The health significance of percutaneous absorption of contaminants is unclear. It could, however,

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be highly significant over long exposure periods. Almost 100% of a swimmer's body is exposed to toxins in the water; therefore, dermal sorption could result in rapid dissemination of toxins through the systemic system, with health consequences ranging from immune suppression to acute toxicity (*27*).

Churning surf may aerosolize toxins or pathogens, providing respiratory tract exposure (*28*). Likelihood of infection also depends on individual susceptibility; for example, acquired immunity may protect an individual from marine-associated infection. Children appear to be at greater risk than adults (*29,30*), and tourists without prior immunity may be at particularly high risk per exposure (*2,31*). However, among local populations, the poor are at highest risk overall because they tend to swim at periurban, polluted beaches and may have both poorer diets and weaker general health. As expected, immunocompromised persons are also a high-risk category for infectious disease (*32*).

Several studies have attempted to define the levels of risk following exposure to different concentrations of pathogens and indicator organisms in recreational waters (*22–24,29,31,33–38*). In this paper we focus on marine-related infectious disease hazards, explore the environmental factors that may lead to illness, address the problems with water quality standards, and discuss the environmental policy implications.

Infectious Agents and Mechanisms of Survival

Bacteria. It is becoming increasingly clear that the concept that enteric pathogens die quickly when exposed to sea water may not be accurate (*39*). The determinants of bacterial growth and survival in marine waters are salinity, temperature, predation, sunlight (ultraviolet), toxic chemicals, and nutrients (*40*). The more favorable ranges of these determinants for microbial growth can often be found in estuaries (*41*). Indeed, the high nutrient content found in some coastal waters can override the stresses of suboptimal salinity and/or temperature, prolonging bacterial survival (*42*).

Some gram-negative organisms adapt to low-nutrient environments through reductive division; that is, with no change in total biomass, more organisms develop, but at a greatly reduced metabolic rate (*43*). Under unfavorable conditions, bacteria can enter a dormant state. In response to cold or reduced nutrients, *Vibrio cholerae* can shrink to 1/300th its size and persist in a dormant form for extended periods, growing again with conducive environmental conditions (*44,45*). Colwell and colleagues showed that *V. cholerae* could become nonculturable on routine culture plates, but remain viable, and could regrow under appropriate conditions (*45*). Additionally, *Escherichia* spp. (*46*), *Salmonella* spp. (*47*), *Legionella* spp. (*48*), *Campylobacter* spp. (*49*), and *Shigella* spp. (*45*) demonstrate "viable but nonculturable" (VNC) states. Despite being undetectable by conventional culture plate methods, VNC organisms have been demonstrated to have clinically virulent potential, and could be present in marine systems (*43*).

Viruses. The work of Paul (*49*) and others suggests that viruses are extremely abundant in marine systems. Because the etiologic agent is not identified in a high proportion of gastrointestinal infections, viruses may be a chief cause of swimming-associated diseases (*32*). Several strains of morbilliviruses have been associated with illness and death in marine mammals (*50*). The potential for human illness is evident; only 20 copies of poliovirus or echovirus are required for infection to occur (*51*). Viruses survive longer in sea water than do bacteria (*52,53*); they are also more likely to survive sewage treatment processes than are bacteria (*54*). Seyfried et al. (*55*) found that, after sewage treatment, 40% of the chlorinated effluent samples contained viruses. In addition, enteroviruses were detected in over 40% of waters deemed safe for recreational use by fecal coliform standards (*56*). Although consumption of raw seafood is often implicated in cases of hepatitis A and Norwalk virus gastroenteritis (*57*), infection with these viruses from direct exposure to fecally contaminated water may also be possible.

Protozoa. As with viruses, there is little information on pathogenic protozoan survival in marine waters. Routes of exposure are primarily through ingestion of seawater; although the potential is there, few reports associated gastrointestinal illness with exposure to protozoa-contaminated sea water (*58*). Viral and protozoal infections from marine waters represent an area of research that clearly requires further work, both in terms of recognition of etiologic agents and in providing a higher level of awareness among health care providers.

Plankton reservoir. Since 1960, researchers in Bangladesh have noted an association between seasonal blooms of freshwater algae and plants and toxigenic *V. cholerae* (*59–62*). More recently, an indirect link has been suggested between coastal algal blooms and cholera epidemics (*63–65*), although this link is criticized as speculative (*66*). However, researchers have shown a strong link between plankton and aquatic bacteria, and a number of planktonic species concentrate pathogens within their mucilaginous sheaths and eggs (*43,67*). During blooms, the number of pathogens may be amplified to reach infectious doses (*43*), and many planktonic species themselves can persist for years as cysts at the bottom of estuaries; survival of human pathogens within these cysts is currently unknown (*21,68*). Whether plankton serve as a reservoir for viruses and protozoa remains an open question.

Infections and Illness Associated With Exposure to Marine Waters

Gastrointestinal, respiratory, dermatologic, and ear, nose, and throat infections are not uncommon after recreational or occupational uses of water, but clinicians seldom elicit information regarding potential exposures when interviewing patients with these complaints.

Prospective studies. The strongest evidence linking infectious diseases to marine water activities comes from prospective epidemiologic studies. The first prospective study showed increased morbidity in swimmers compared to nonswimmers, particularly in children under 10 years of age (*29*), but sampling and reporting biases were present in the study, and confounding factors were inadequately addressed.

In the late 1970s, Cabelli et al. (*23*), in a landmark prospective cohort study, reported a linear relationship between the incidence of gastroenteritis among swimmers and marine bacterial counts. Between 1973 and 1978, participants were recruited at beaches from three U.S. locations—New York, Lake Pontchartrain, Louisiana, and Boston, Massachusetts—and were contacted by telephone days after going to the beach. Swimming status was self-selected, not randomly assigned, and symptoms were self-reported. The mean proportion of swimmers with gastrointestinal symptoms was 6.8% versus 4.6% in nonswimmers. When enterococcal concentrations were above 1/100 mL, relative risk increased linearly, reaching 4.0 with concentrations of 1,000/100 mL ($p < 0.001$). The frequency of gastrointestinal symptoms was inversely related to the distance from known sources of municipal wastewater (*23*).

Similar studies have been replicated in Egypt, Israel, South Africa, France, the United Kingdom, Australia, and Hong Kong (*22,24,38,68–71*) (Table 1). In the study in Sydney, Australia, Corbett et al. (*22*) found that as many as one out of three swimmers became ill within 10 days of swimming in polluted waters [relative risk (RR) = 2.2, $p < 0.001$]. In addition to gastroenteritis, infections of the eye, ear, respiratory tract, or skin have been associated with marine exposure (note that all studies have relied on self-reported symptoms) (*22,24,29,37,70,71*).

Kay et al. (*25*) conducted the only randomized controlled swimming exposure trial, involving over 1,200 adults at four sites around the UK coast between 1989 and 1992. Non-water–related confounding factors (including high-risk food consumption) were similar between swimmers and nonswimmers. Gastroenteritis was reported in 14.8% of swimmers (RR = 1.5, p = 0.01). The risk to swimmers increased with fecal streptococci levels, with gastroenteritis rates reaching 30.4% when the count was above 80/100 mL (RR = 3, $p < 0.05$). Interestingly, swimmers acquired symptoms on days when bacterial indicator levels were acceptable, supporting information that bacterial indicators are inadequate surrogates for pathogens, including viruses, protozoa, and even bacteria (*32,72–74*). Attempts to determine the etiologic agents in symptomatic swimmers were unsuccessful (*75*), and no attempts were made to demonstrate viral pathogens in seawater.

Outbreaks and case reports. There are numerous case reports of infectious diseases acquired from recreational and occupational use of marine waters (*76–98*) (Table 2), and many of these are benign. We focused on the more serious or unusual manifestations.

A 1982 outbreak of gastrointestinal illness affected New York, New York, police and fire department scuba divers who had been diving in Manhattan's sewage-contaminated Hudson and East Rivers. The Centers for Disease Control and Prevention (CDC) (*58*) reported that either *Entamoeba histolytica* or *Giardia lamblia* were isolated from the water and from 60% of the symptomatic divers. In the earlier part of this century, typhoid was linked to swimming in New York and New Haven harbors (*94,95*).

Marine vibrios are increasingly recognized as human pathogens. Although cholera diarrhea has not been linked to swimming, a case of *V. cholerae* non-01 cystitis associated with swimming in Chesapeake Bay (USA) was reported (*99*). Cases of central nervous system and wound infections and osteomyelitis have resulted from injuries exposed to *Vibrio alginolyticus* in salt water (*100,101*). Roland (*102*) attributed a case of leg gangrene with sepsis necessitating above-the-knee amputation to *V. parahaemolyticus* exposure in New England coastal waters. Although disease from *Vibrio vulnificus* is more commonly associated with shellfish ingestion by individuals with hepatic compromise (*76,77*), Tison and Kelly (*103*) reported the case of a previously healthy woman who developed *V. vulnificus* endometritis secondary to sexual activities in sea water. *V. vulnificus* also causes serious wound infections and fatal septicemia (*104*).

Mycobacterium marinum, the "fish tank granuloma" organism found in fresh and sea water, primarily causes superficial wound infections. However, cases of septic arthritis, keratitis, and osteomyelitis (rarely) have been reported in fishermen (*105–107*). One case of tenosynovitis progressing to tendon rupture and permanent loss of hand function was reported by Hoyt et al. (*108*).

Erysipelothrix rhusiopathiae, a gram-positive bacillus found in fresh and salt water, causes erysipeloid, which is characterized by well-demarcated skin plaques. Dissemination, although unusual, has led to septic arthritis, osteomyelitis, brain abscess, and endocarditis (*78,79*).

Marine water-related disease is not always infectious. Swimmer's itch is a papulovesicular dermatitis acquired worldwide from the cercaria of *Microbilharzia variglandis* and other avian schistosomes. These free-swimming cercaria penetrate human skin, causing local eruptions. Outbreaks have been reported from Delaware and Connecticut (*80*). "Seabather's eruption" or "sea lice" is a self-limited dermatitis caused by *Linuche unguiculata* (jellyfish) and *Edwardsiella lineata* (sea anemone) larvae that become trapped under bathing suits and secrete toxins causing a maculopapular rash (*81*). Outbreaks have been reported from the Caribbean, Florida, and Long Island, New York (*81–84*).

Many HAB biotoxins have known neurotoxic effects. Examples include amnesic shellfish poisoning, paralytic shellfish poisoning, and neurotoxic shellfish poisoning (NSP) (*1,2*). The effects of these three on humans are primarily associated with consumption of contaminated shellfish. The "red tide" toxin produced by *Ptychodiscus brevis*, once aerosolized, induces cough, rhinorrhea, watery eyes, and sneezing in normal hosts and wheezing and exacerbation in asthmatics (*109,110*). NSP, an example of the impact of biotoxins on humans, is caused by *Gymnodinium breve* releasing brevetoxins that can form toxic aerosols (by wave action) and then produce respiratory asthma-like symptoms (*13*). Also, dermatitis caused by algal toxin has been reported in Hawaii (*85–87*).

Recently a dinoflagellate (*Pfiesteria piscicida*) has been implicated as a causative agent in massive fish kills along the East Coast of the United States, especially in the estuaries and coastal zones of North Carolina (*11*). The fish kills usually occur during periods of warm temperatures and usually precede unusually low levels of dissolved oxygen. Human exposure to pathogen biotoxin leads to a number of neurologic problems, including memory loss and learning difficulty. Changes to the environment may have increased the toxicity of this predator toward a wide variety of fish (*2*).

Costs. Human exposure to biotoxins has been linked to a number of neurologic problems, including memory loss and learning difficulty. Coastal contamination can be costly not only to infected individuals but to entire communities Direct costs include diagnosis, treatment, investigation of outbreaks, and subsequent monitoring. Indirect costs can include lost wages and productivity, as well as losses to seafood industries, recreational activities, and tourism. For example, the oyster beds that were the livelihood of a Florida town were shut down because of harmful algal blooms, *Vibrio*, and viral contamination (*111*). Direct exposure to red tides (e.g., blooms of the toxic phytoplankton *Gymnodinium breve*) can cause eye and respiratory distress and skin irritation. Massive fish kills also result, covering beaches with rotting fish carcasses. In addition, toxins produced by the organisms rapidly accumulate in shellfish. For example, there was an estimated $60 million in losses after a *Pfiesteria* outbreak in 1997 (*2*).

Table 1. Prospective coastal water exposure studies.

Author (Reference)	Year published	Location	Symptoms
Stevenson (*29*)	1953	United States	ENT, GI, Resp
Cabelli et al. (*23*)	1982	United States	GI
El Sharkawi and Hassan (*69*)	1982	Egypt	GI
Foulon (*70*)	1983	France	Derm, eye, GI
Fattal et al. (*68*)	1987	Israel	GI
Cheung et al. (*24*)	1990	Hong Kong	Derm, GI
Balarajan et al. (*71*)	1991	United Kingdom	GI
Corbett et al. (*22*)	1993	Australia	GI, Resp, eye, ear
Kay et al. (*25*)	1994	United Kingdom	GI

Abbreviations: ENT, ear, nose, and throat; GI, gastrointestinal; Resp, respiratory; Derm, dermatologic.

Table 2. Infections associated with marine water exposure.

Infection	References
Dermatologic	(*76–93*)
Vibrio cholerae non-01	
Other vibrionaceae	
Mycobacterium marinum	
Erysipelothrix rhusopathiae	
Cercarial dermatitis	
Sea lice	
Algal dermatitis	
Gastrointestinal	(*32,58,76,88–90,94,95*)
Vibrio cholerae	
Other vibrionaceae	
Salmonella typhi	
Entamoeba histolytica	
Giardia lamblia	
Respiratory	(*88,89,96*)
Other vibrionaceae	
Francisella philomiragia	
Sepsis	(*32,77,79,88–90,97,98*)
Other vibrionaceae	
Francisella philomiragia	
Erysipelothrix rhusopathiae	

Marine Water Quality Monitoring

Recreational water quality standards are controversial, variable by locale, and sometimes even nonexistent (*112,113*). Even with monitoring, reporting is often inadequate. Even in the United States, municipalities do not always close beaches when standards are violated. Worldwide, there is no agreement on the best indicators of public health risks from contaminated marine waters. For example, the United States currently monitors enterococcus or coliforms, Hong Kong monitors *Escherichia coli*, and the United Kingdom monitors fecal streptococci. Of course, the range of viral, bacterial, and protozoan pathogens of anthropogenic origin is enormous, and it would be impossible to identify an indicator for all risks. Additionally, indicators of fecal pollution cannot predict infectious or noninfectious diseases caused by indigenous organisms.

Traditionally, total and thermotolerant coliforms have been most widely used as indicators of fecal contamination; however, they have been shown to have shorter survival times than certain pathogens (e.g., *Salmonella typhimurium* and *Yersinia enterocolitica* in cold waters) (*114*). In addition, they give no indication of health risks from protozoa and viruses. For example, indicator bacteria seldom correlate with human enteric virus distribution in seawater (*115*). *E. coli* has also been shown to rapidly enter the VNC state in marine waters (*46*). In an epidemiologic study, Cabelli et al. (*33*) analyzed sea water for coliforms, enterococci, *Pseudomonas*, and *Clostridium* as possible indicators. Excess gastrointestinal illness in swimmers correlated with enterococci levels. As a result, the U.S. Environmental Protection Agency's (U.S. EPA) 1986 ambient bacteriological water quality report (*116*) suggested that 35 enterococci/100 mL related to a risk of 19 illnesses/1,000 swimmer days. Certain U.S. states have subsequently adopted enterococci monitoring of recreational waters. However, very few other countries monitor for enterococci.

Bacteriophages are considered to be potentially useful for predicting the likelihood of human enteric viruses in recreational water (*117*). The human specific *Bacteroides fragilis* heat shock protein 40 (HSP40) bacteriophage has received some attention as a potential water quality indicator (*118*); however, further research is necessary to correlate presence of this virus in marine waters with specific public health risks.

In addition to monitoring indicator organism levels, environmental risk factors may be useful in predicting disease events. Algal blooms (and the environmental conditions to which they are linked) may be a potential example because they can reflect anthropogenic activity (nutrient enrichment) and they may also harbor pathogenic organisms (*1*). It is also important to realize that pathogens may be present in high numbers in sediments, and they may be easily suspended by activities of swimmers (*21*). To protect public health, it may be necessary to begin monitoring coastal sediments for pathogens. This may become easier as advances in molecular techniques continue to be made.

Conclusions and Recommendations

There are increasing reports of disease related to exposure to the marine environment. There is a clear need for increased surveillance and monitoring of coastal ecosystem health.

Surveillance. Marine water quality standards based on culture techniques for bacterial indicator organisms are considered poor indicators of the risk from VNC bacteria, protozoa, and viruses (*72*). Techniques have been developed for the rapid enzymatic detection of fecal pollution (*119*); however, they currently target indicator organisms and not the pathogens themselves, which may therefore give false positive results due to enzymes produced from plants and algae (*120*). VNC pathogens can be detected by alternative methods such as polymerase chain reaction (PCR), fluorescent antibody techniques (*46,121,122*), or a rapid monoclonal antibody test.

Immunofluorescence staining seems to be the most efficient method for identifying protozoan cysts (*123*). Viruses are particularly difficult to detect because large quantities of water are usually necessary for concentration of particles, although specialized filters are being developed to optimize viral recovery. A reverse transcriptase PCR has been used to detect poliovirus, rotavirus, and hepatitis A virus in wastewater and ocean water (*124*). However, further research is necessary because inactivated virus can also be detected with PCR (*125*).

Advances in both molecular and cell culture techniques now make it possible to detect presence, viability, and infectivity of certain pathogens, at least under controlled conditions. Source tracking is also possible through molecular fingerprinting. A relatively recent beach closing that attracted considerable media attention occurred in the spring of 1999 at Huntington Beach, California, due to elevated coliform levels (*126*). Authorities were criticized for not taking advantage of the new technologies that could have been used to determine sources of contamination. This highlights the need for a mechanism to transfer developing technologies from the research laboratory to state and local agencies.

Surrogate markers of pollution may also be appropriate predictors of public health risk from both pathogens and toxic species. For example, satellite imaging has been used to target areas for sampling to detect phytoplankton blooms related to paralytic shellfish poisoning (*127*). Biomarkers in sentinel organisms are beginning to be used in ecologic risk assessment. Many organisms produce chemical, physiologic, or behavioral responses to chemical, microbiologic, and physical stresses (*128*). These biomarker responses are used as indicators of ecologic health. Integration of this information with more traditional measurements of nutrient status and pathogen indicators may provide overall prediction of public health risk.

Further research is necessary to fully validate the molecular methods and biomarker approaches mentioned above. It is beyond the scope of this review to discuss in detail the current state of development of these techniques. However, once optimized, they should provide the basis for a far more comprehensive evaluation of human health risk than can currently be achieved by use of traditional indicator approaches. An upcoming report of a recent American Academy of Microbiology Critical Issues Colloquium on "Re-evaluation of Microbial Water Quality: Powerful New Tools for Detection and Risk Assessment" (*129*) will provide further information.

Beyond these local measures, there is a clear need for national and international monitoring of marine disease events and environmental conditions. For this to be possible, a number of basic requirements must be met. There must be a standardized system (i.e., an online database) for global collection and storage of information. This information must then be organized and distributed; this database can then be used to correlate disease events with environmental conditions, allowing a quantitative study of environmental risk factors for disease events, estimates of the cost of environmental degradation, and yearly global environmental health assessments (*2*).

For complete information to be collected, it is crucial that clinicians be educated to increase awareness of marine-related illness, to ask the appropriate questions of patients related to routes of exposure, and to report minor infectious disease of unknown etiology. In addition, information about environmental health as it correlates with disease must be included in traditional medical education.

Public health policy and regulations. To treat, and eventually prevent, waterborne disease, both reporting and active surveillance systems must be implemented. Uniformity on a national and international scale is needed in both standards and enforcement measures. Marine water-related illness highlights the interconnectedness of ecosystem health and human health, and health surveillance needs to be integrated with marine ecosystem monitoring. A number of research groups are beginning to attempt to integrate ecologic and human health.

The importance of monitoring and research on the health of the world's oceans is beginning to be recognized by the National Oceanic and Atmospheric Administration and the Global Environment Facility of the World Bank, among other national and international agencies (*130*). As a result, there are programs that are beginning to monitor changing states of large marine ecosystems, but the process is slow.

The recently completed Health Ecological and Economic Dimensions of Global Change (HEED) Program identified policy initiatives that attempt to alleviate current downward trends in marine health (*2*). The report highlights the need for a reduction in the eutrophication of the coastal environment. There is evidence that an excess nutrient supply in coastal systems is greatly reducing biodiversity in marine ecosystems. For example, the main sources of nitrogen, a key nutrient in eutrophication, are sewage (point source), fertilizers (nonpoint source), and aerosols (from fossil fuel combustion). To deal with this problem, a number of steps should be taken. There should be an increase in acreage of buffer zones to increase filtration of runoff water. An increase in the efficiency of city disposal systems and a reduction in the use of fertilizers can reduce nutrient loads. Finally, regulations to reduce nitrogen oxides emissions from utilities and transport are also needed.

Environmental regulation cannot be merely a local or even a national issue; international, enforceable regulations are needed. Current international agreements on marine and coastal issues (e.g., the United Nations Convention on the Law of the Sea) must be strengthened and enforced (*130*). International agreements must be reached on critical issues, including fishing, waste release, coastal degradation, and carbon dioxide release.

A number of success stories can serve as models for the design of these reporting systems and programs. For example, remediation efforts following the Sydney study led to improvements in water quality (*131*). These efforts included the installation of extended ocean outfalls for each of the three sewage treatment plants in Sydney, releasing sewage beyond the continental shelf and dramatically cleaning up the beaches (*132*).

Priorities and policies must be set at both regional and international levels (*32*). A multidisciplinary approach is needed to integrate medicine and public health concerns with coastal zone management. For this approach to be successful, local populations must be involved in participatory management schemes and educated to the importance of preserving marine ecologic health. To preserve public health, we must ultimately address the policies that determine the health of the environment and the preservation of living marine resources (*64*).

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