Web Supplement 28.6.5

28.6.5 **Microorganisms**

Pathogen pollution is the introduction of disease-causing agents as a direct or indirect consequence of human activities. The incidence of disease resulting from pathogen pollution appears to be increasing in both humans and marine organisms. At least some of this increase is due to global climate change, which has expanded the range of many species. Pathogenic microbes include bacteria, protozoans, and viruses. Parasitic worms are another common disease agent.

The infective agents whose source is external to the ocean are termed *pollutogens*. Pathways of transport of pollutogens into the ocean include: (1) discharge of treated and untreated sewage including bilge pumping, (2) stormwater runoff, (3) groundwater seeps, (4) aeolian dust, and (4) off-loading of ballast water. Humans are exposed to pollutogens through skin contact and ingestion of contaminated seafood. Consumption of shellfish is particularly problematic as these filter feeders concentrate pathogens in their tissues. Since shellfish tend to live in estuaries, their exposure to pollutogens is high, especially following rain events, because stormwater runoff mobilizes contaminants from domesticated animal feces, broken sanitary sewer system pipes, and dysfunctional septic tanks. These same sources can contaminate groundwater and thereby eventually seep into the coastal waters. While sewage treatment can reduce pathogen levels, not all microbes are removed, so even treated effluents are a potential pollutogen source. Because of the extensive use of antibiotics, pathogenic bacteria are becoming increasingly antibiotic resistant and prevalent in treated effluents.

Diseases caused by ingestion of pathogens in seafood are listed in Table W28.3. Some of these pathogens are native to the ocean, but their numbers and geographic range appear to be expanding. Shellfish beds are now closely monitored and closed for harvesting when pathogen concentrations are high. In some locations, precautionary closings are declared after sufficiently high amounts of rainfall. Screening of water and tissues for all possible pathogens is too time consuming and costly. Instead, contamination levels are estimated by culturing water samples for groups of organisms commonly found in fecal material, i.e., total coliforms, fecal coliforms, fecal streptococci, *E. coli*, and *Enterococcus*. These bacteria are called pollutogen indicators because they are present

Table W28.3 Food-Borne Illness and Disease.

Bacterial pathogens associated with raw and processed seafood

- *Salmonella* spp.
- *Clostridium botulinum*
- *Listeria monocytogenes*
- *Vibrio cholerae* OI
- *Vibrio cholerae* non-OI
- *Vibrio parahaemolyticus* and other vibrios
- *Vibrio vulnificus*

Parasites that are sometimes found in raw seafood

- *Anisakis* sp. and related worms
- *Diphyllobothrium* spp.
- *Nanophyetus* spp.
- *Eustrongylides* sp.
- *Acanthamoeba* and other free-living amoebae
- *Ascaris lumbricoides* and *Trichuris trichiura*

Viruses that sometimes contaminate raw seafood

- Hepatitis A virus
- Hepatitis E virus
- Rotavirus
- Norwalk virus group
- Other viral agents

Natural toxins that are sometimes found in seafood

- Ciguatoxin (ciguatera poisoning)
- Shellfish toxins (PSP, DSP, NSP, ASP; see Table W28.2)
- Scombrotoxin (scombroid fish poisoning)
- Tetrodotoxin (pufferfish)

Source: *From FDA/Center for Food Safety and Applied Nutrition, April 5, 2006. Foodborne Illness and Seafood, http://www.cfsan.fda.gov/~mow/sea-ill.html.*

in the fecal material of animals. *Enterococcus* is considered to be more specific for pathogenic fecal contamination and is the indicator of choice for assessing swimming safety in marine waters. More detailed source tracing of the pathogens can be performed using genetic markers.

While the pollutogen indicators are not in themselves necessarily harmful to humans, they are relatively easy to test for and indicate the likely presence of harmful pathogens. They also "die-off" after release from their host at approximately the same rate as the harmful pathogens found in human sewage. Water-quality criteria for the pollutogen indicators are based on an operationally defined threshold. This is typically defined as the number of microbial colonies that grow on an inoculated medium incubated at a particular temperature for a specified length of time. Thus, this screening technique does not measure the in situ concentration of the microbes. It also requires a fairly long incubation time, on the order of 18 to 24 h. Depending on the culturing and detection methodology, results are reported as colony forming units (CFU), most probable numbers (MPN), or cells per unit volume. Water quality standards are expressed as organism densities. For example, the U.S. EPA has established a single sample maximum allowable density of 104 *Enterococci* per 100 mL for designated beach areas.

Evidence from epidemiological studies has demonstrated that bathing and swimming in marine waters contaminated with pollutogens causes an increased incidence of enteric and respiratory disease. Incidence increases with increasing concentration of the pollutogen indicator. An increased incidence occurs even in waters that meet current standards for safe recreational contact. When waters contain densities of 104 *Enterococci* per 100 mL, the U.S. EPA estimates that 19 of 1000 swimmers will become ill. Such illnesses goes unnoticed because minor cases of gastroenteritis are rarely treated by physicians or reported to health authorities. Symptoms of gastroenteritis include vomiting, diarrhea, stomachache, nausea, headache, and fever. The major pollutogens causing swimming-related disease are listed in Table W28.4. Viruses are believed to be the most

Table W28.4 Pathogens and Swimming-Associated Illnesses.

Pathogenic Agent	Disease
Bacteria	
Campylobacter jejuni	Gastroenteritis
E. coli	Gastroenteritis
Salmonella typhi	Typhoid fever
Other *Salmonella* species	Various enteric fevers (often called paratyphoid), gastroenteritis, septicemia (generalized infections in which organisms multiply in the bloodstream)
Shigella dysenteriae and other species	Bacterial dysentery

(Continued)

Table W28.4 *(Continued)*

Pathogenic Agent	Disease
Vibrio cholera	Cholera
Yersinia spp.	Acute gastroenteritis (including diarrhea, abdominal pain)
Aeromonas hydrophila	Dysenteric illness, wound infections, gastroenteritis, septicemia
Helicobacter pylori	Chronic and severe inflammation of the stomach, increased likelihood of developing gastric cancer
Viruses	
Adenovirus	Respiratory and gastrointestinal infections
Coxsackievirus (some strains)	Various, including severe respiratory disease, fever, rash, paralysis, aseptic meningitis, myocarditis
Echovirus	Various, similar to coxsackievirus (evidence is not definitive except in experimental animals)
Hepatitis	Infectious hepatitis (liver malfunction); also may affect kidneys and spleen
Norwalkvirus	Gastroenteritis
Poliovirus	Poliomyelitis
Reovirus	Respiratory infections, gastroenteritis
Rotavirus	Gastroenteritis
Calicivirus	Gastroenteritis
Protozoa	
Balantidium coli	Dysentery, intestinal ulcers
Cryptosporidium	Gastroenteritis
Entamoeba histolytica	Amoebic dysentery, infections of other organs
Giardia lambia	Diarrhea (intestinal parasite)
Isospora belli and Isospora hominis	Intestinal parasites, gastrointestinal infection
Toxoplasma gondii	Toxoplasmosis
Cyclospora	Gastroenteritis

Source: *After Natural Resources Defense Council (2006).* Testing the Waters 2006: A Guide to Water Quality at Vacation Beaches*, p. 10.*

common culprit. In addition to causing gastroenteritis and respiratory illnesses, they are responsible for hepatitis, and ear, nose, and throat problems. Other pathogens include bacteria, amoebae, and protozoans.

The U.S. EPA is in the process of upgrading water-quality standards for bathing. Some of the problems with the current standards have been mentioned, such as the lack of specificity for viruses and long lag time between sampling and generation of results. The former is worrisome as viruses are less efficiently removed during sewage treatment and they are more resistant than bacteria to degradation by sunlight. They are also pathogenic at far lower concentrations. The microbial bathing standards are also problematic in that they were developed to address the risk of contracting gastroenteritis and, hence, do not address other health issues such as rashes, earaches, respiratory infections, or hepatitis. Furthermore, the standards are based on studies in which exposures were mostly to point-source discharges of municipal effluents. In many coastal areas, nonpoint sources of pollutogens are far more important and likely to be different in composition from the point sources. Another factor that has been neglected is the likelihood that sediments, including beach sands, harbor viable reservoirs of pollutogens. These benthic pollutogens can get injected into bathing waters by stormwater runoff, wind mixing, and tidal currents.

As shown in Figure W28.3, the number of swimming advisories posted at marine beaches has increased. This is partly due to increased reporting, but clearly illustrates the widespread nature of pollutogen contamination in U.S. recreational waters. In NYC, implementation of various control measurements has resulted in a decrease in waters too contaminated for swimming (Figure W28.4). In less urbanized areas, reduction in pollutogen contamination is going to require implementation of nonpoint-source controls.

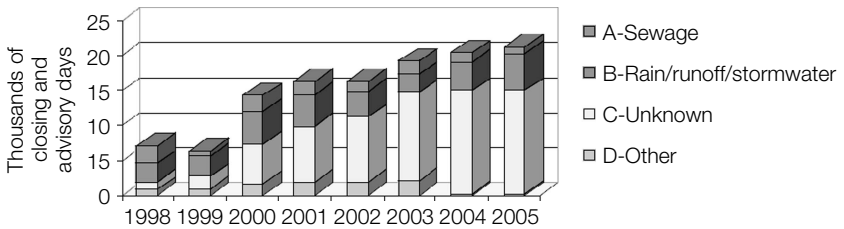

FIGURE W28.3

Number of days that marine beaches in the United States were reported as closed or under a swimming advisory due to bacterial contamination during 1998 to 2005. The sources of this contamination are also shown. Totals shown are greater than annual totals because more than one pollution source may have contributed to each closing/advisory. Key: (A) Sewage spills and overflows, (B) polluted runoff, stormwater, or preemptive due to rain, (C) unknown, and (D) other sources (including those with no source information provided). *Source*: From Natural Resources Defense Council (2006). *Testing the Waters 2006: A Guide to Water Quality at Vacation Beaches*, p. xii.

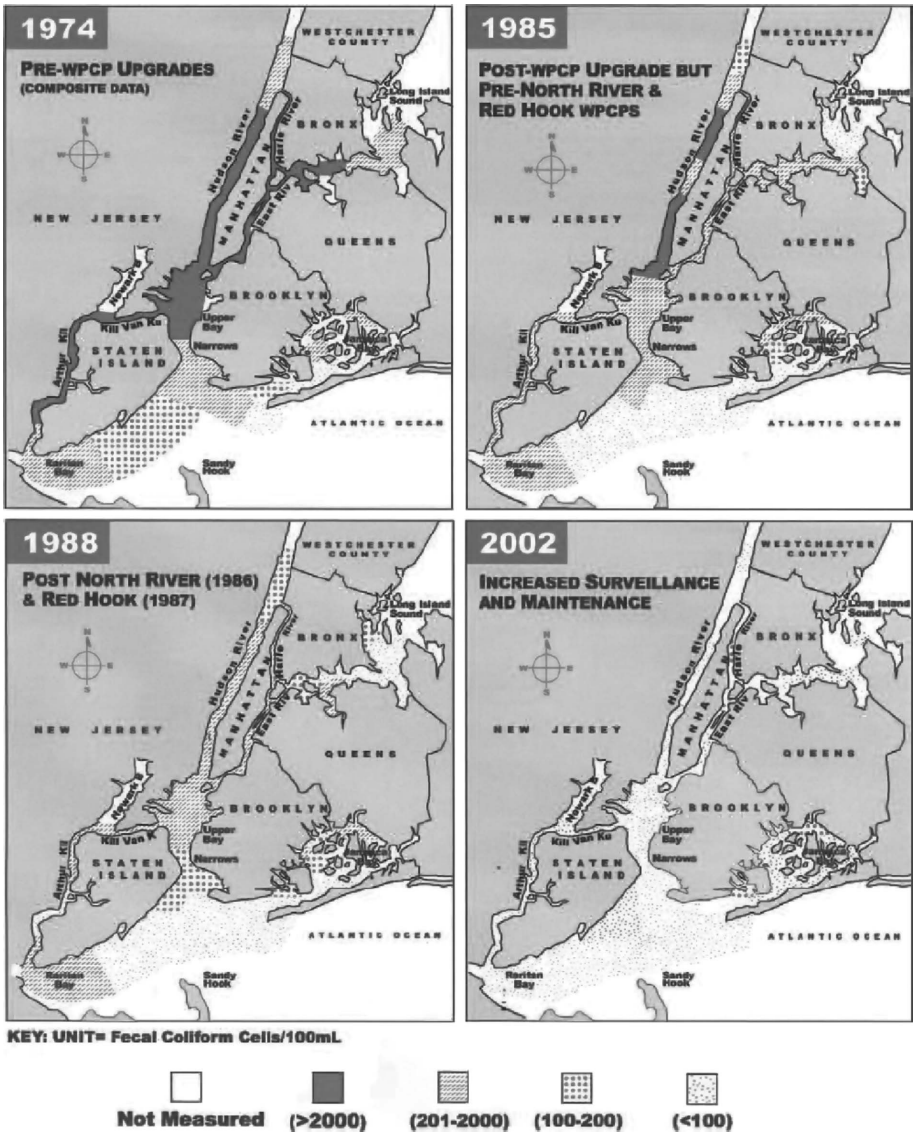

FIGURE W28.4

Summer geometric mean for fecal coliform in surface waters around New York City from 1974 to 2002 documenting water quality improvements following implementation of pollution control measures. Swimming water standard is $\leq$200 cells per 100 ml. (WPCP, water pollution control plant). *Source*: After NY Department of Environmental Protection (2003). New York City's Wastewater Treatment System, p. 15.

An increased incidence of infectious disease has been reported in a diverse group of marine organisms including corals, oysters, and marine mammals. The causes are also diverse. For example, a dramatic decrease in the sea otter population off the California coast is being ascribed to infection by the parasitic protozoan *Toxoplasma gondii*. Cats are the only animals that shed this parasite and do so through their feces, suggesting that cat feces are being transported into coastal waters either through nonpoint-source runoff or via disposal in sanitary sewer systems.

Some of the rise in marine disease appears to be a consequence of global climate change, with warmer waters expanding the range of marine pathogens, such as Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*), which infect oysters, and various *Vibrio* spp. The latter include *V. parahaemolyticus* and *V. vulnificus*, both of which can be fatal to humans. Climate also impacts how pollutogens behave in the marine environment. This has been observed in *Vibrio cholerae*, a human pathogen whose presence in the ocean is a result of poor sanitation. This bacterium survives outside its host by entering a dormant state, enabling its transport via currents. Outbreaks of cholera in coastal communities are correlated with increased water temperatures that are thought to "awaken" the bacterium from its dormant state. In marine mammals, an increased incidence of infectious disease has been attributed, in part, to a weakened immune system caused by exposure to chemical pollutants, such as heavy metals and persistent organic pollutants.