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# Apres le Deluge: Microbial Landscape of New Orleans After the Hurricanes

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COMMENTARY

# Après le déluge: Microbial landscape of New Orleans after the hurricanes

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Now would I give a thousand furlongs of sea for an acre of barren ground.
William Shakespeare, *The Tempest*

When storms of hurricane force unleash their power on natural systems, they can reset successional sequences and even change the structure of biological communities (e.g., refs. 1–3). Should that same power descend on a center of human population, the results can be deadly catastrophic. A recent and unforgettable example is the one-two punch delivered to New Orleans in August and September 2005 by hurricanes Katrina and Rita. Failure of levees within the city and the resultant flooding by waters from Lake Pontchartrain set the stage for a collapse of social norms and governmental order. Images of New Orleans' human misery after the storms have become iconic. After landfall of Hurricane Katrina, much was conjectured about potential public health repercussions of the storm (4). The arrival of Hurricane Rita 26 days afterward served only to compound the situation and increase such speculation. Fortunately, there were no large-scale outbreaks of serious communicable disease. There has been, however, increasing documentation of the storms' effects on the city's environment, especially in those low-lying areas that were under as much as 3 m of water. What are the concerns associated with the sediment, toxic chemicals, metals, and microbes mobilized by the hurricanes? In a recent issue of PNAS, Sinigalliano *et al.* (5) consider the poststorm "microbial landscape" of New Orleans and environs. They show that Lake Pontchartrain's microbial environment returned to prestorm (but not pristine) conditions 2 months after the hurricanes. Furthermore, they argue persuasively that the lake was not the source of fecal contamination in floodwater sediments; instead, the city's deficient sanitary infrastructure was responsible.

The study represents the efforts and expertise of investigators distributed among eight academic institutions and three National Science Foundation/National Institute of Environmental Health Sciences national centers. Sampling began and was most intensive during the 2 months after New Orleans was "dewatered," i.e., when floodwaters were pumped back into Lake Pontchartrain. Results cover the time span from October 2005 to December 2006. Thus, Sinigalliano *et al.* (5) did not sample floodwaters but instead tested water samples from Lake Pontchartrain and canals draining from the city into the lake. In addition, their article evaluates sediments deposited in private homes and those collected from sites around the city.

## Fecal Contamination During and After the Floods

Sinigalliano *et al.* (5) assayed for so-called "indicator organisms." In a public health context, these microorganisms indicate fecal contamination, which, in turn, may well signal the presence of pathogens. The criteria for indicator organisms are that they be proportional in abundance to the number of pathogens in water, viable in the environment at least as long as pathogens, easily detected, present in greater quantity than any pathogen, and absent unless water has been polluted with sewage or animal excrement (6). In analyses of wastewaters and recreational waters, the most widely accepted indicator organisms are bacteria ubiquitous in the mammalian gut, *Escherichia coli* and enterococci.

**Lake Pontchartrain's microbial environment returned to prestorm conditions 2 months after the hurricanes.**

In water samples collected immediately after the storm, other researchers had reported *E. coli* concentrations as high as $3 \times 10^7$ colony-forming units (cfu) per 100 ml (7). Consider this value in light of the Environmental Protection Agency's maximum single-sample exposure level of 235 cfu per 100 ml for freshwater beaches (8). In addition, species of *Aeromonas*, pathogenic bacteria not having origin in sewage, had been reported at densities up to $10^8$ per 100 ml (7). Clearly, the microbial burden of the floodwaters was very large. In contrast, after the floods had receded, Sinigalliano *et al.* (5) rarely found Lake Pontchartrain water to exceed the aforementioned Environmental Protection Agency exposure level, and then only at stations near the shoreline. Water samples from the canals, however, frequently exceeded the mark. With these data, Sinigalliano *et al.* start to make their case that the source of fecal contamination was not the lake waters that rushed over parts of the city when the levees broke. They strengthen and expand their argument with results of subsequent analyses, in which they found no statistical difference in the level of fecal contamination when comparing sediments from areas of the city that had or had not been flooded. They conclude that the source of microbial pollution was the discharge of fouled water from the city's interior, a health hazard well known before the passage of these hurricanes (9), and an unfortunate, if predictable, result of a defective municipal sewage system.

## Multiple Methods of Detection

A distinguishing aspect of the article (5) is the veritable cornucopia of microbiological methods Sinigalliano *et al.* used with both water and sediment samples. For traditional fecal-indicator bacteria, *E. coli* and enterococci, they used not only standard culture techniques but also recently developed "chromogenic" agars formulated to yield color-coded colonies, and in addition, real-time PCR, a culture-independent method. Furthermore, they adopted a similar comparative approach in analyzing samples for a suite of less-traditional fecal indicators, including F-specific RNA coliphage, viruses that use *E. coli* as their host, and the bacteria *Clostridium perfringens*, *Bacteroidales*, and *Bifidobacterium adolescentis*. They also assayed for pathogenic bacteria (*Vibrio* spp. and *Legionella*) and protozoa (*Cryptosporidium* and *Giardia*). Finally, they

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applied a genomic approach, a method based on BLAST scores, to evaluate the affinity of microbial assemblages in water and sediment samples against sequence libraries of pathogens, sewage-associated organisms, and microbes from uncontaminated aquatic environments.

As might be expected with multiple metrics, there were instances in which the data were not fully congruent. This investigation demonstrates the need to expand comparison of "new," or at least, nontraditional, indicators of fecal pollution with the widely accepted, traditional ones. Resolving disparities between the two groups clearly is a goal for public health microbiology.

## Broader Effects of the Storms

There is a final point about the study to recapitulate here. Sinigalliano *et al.* (5) found no evidence of an algal bloom in Lake Pontchartrain 6 weeks after the first storm. If floodwaters returned to the lake were contaminated with sufficient nitrogen and phosphorus, which are plant fertilizers, then growth of planktonic microalgae could be stimulated and dense concentrations of algae might develop. There was no increase in chlorophyll concentrations, however, and in fact, poststorm levels were lower than historical data. Sinigalliano *et al.* do not explain this result, but it suggests that nutrients either were insufficient to initiate and sustain a bloom, perhaps because of dilution with floodwaters, or were outside the range of nitrogen-to-phosphorous ratios necessary for algal growth. Alternatively, the suspended sediment load in the lake may have so reduced the penetration of sunlight that abundant algal production was precluded.

Although outside the purview of Sinigalliano *et al.*'s article (5), another type of microorganism, mold, certainly is on New Orleans' list of public health concerns. Schwab *et al.* (10) recently determined the concentration of airborne mold spores in a small number of private homes in the city. Those homes that had been flooded contained spores at densities of hundreds of thousands per cubic meter, extremely high values with potential for adverse health effects.

The article by Sinigalliano *et al.* (5) represents one of many efforts to address public health issues associated with exposure to microorganisms after the hurricanes. Sinigalliano *et al.* conclude that risks associated with exposure to Lake Pontchartrain water, other than in areas near the city's shoreline, are equal to those before the storms, probably because contaminated floodwaters pumped into the lake were overwhelmingly diluted. The dried sediments that continue to blanket much of the low-lying, flooded areas of the city are more problematic; when suspended in the air, they could be inhaled or ingested, exposing citizens to particle-associated microbes. Sinigalliano *et al.* recommend epidemiological studies in this regard. Perhaps the most difficult issue to resolve will be the city's faulty sanitary sewage system, which, if we accept the interpretation of Sinigalliano *et al.*, is the root cause of the hurricane-related microbiological pollution.

In closing, it is appropriate to extend kudos to these and other researchers who mobilized their field teams and laboratories to collect, in a scientifically defensible manner, water and sediment samples from a flood-ravaged city, and by extension, from points all along the Gulf Coast. Their quick response, no doubt in some cases performed under distressing conditions, has generated the posthurricane data necessary for public health (and other) decisions to be made by government officials, clean-up and repair crews, and of course, those Crescent City citizens who simply want to return to their homes.


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