

Shifting Sands and Bacteria on the Beach

by Cherie Winner

Most coastal communities in the United States test the water at beaches for the presence of bacteria. But they don't routinely test the sand. Does sand also harbor bacteria?

Until recently, few people have worried about that possibility. We encounter potentially harmful microbes all the time, and they don't usually make us sick after casual exposure such as walking on contaminated sand, unless our immune system is suppressed or a break in our skin gives the organisms easy entry into our bodies.

"But how often do you go swimming or sit in the sand with some sort of nick on you?" said Britt Raubenheimer, a physical oceanographer at Woods Hole Oceanographic Institution (WHOI). "It doesn't take much. That's what happened with Steve."

She was referring to her colleague, Steve Elgar, who in the early 2000s suffered an infection from a particularly nasty strain of antibiotic-resistant bacteria that he was exposed to on a beach. It got into his system through a small cut on his leg, and he ended up spending three days in the hospital.

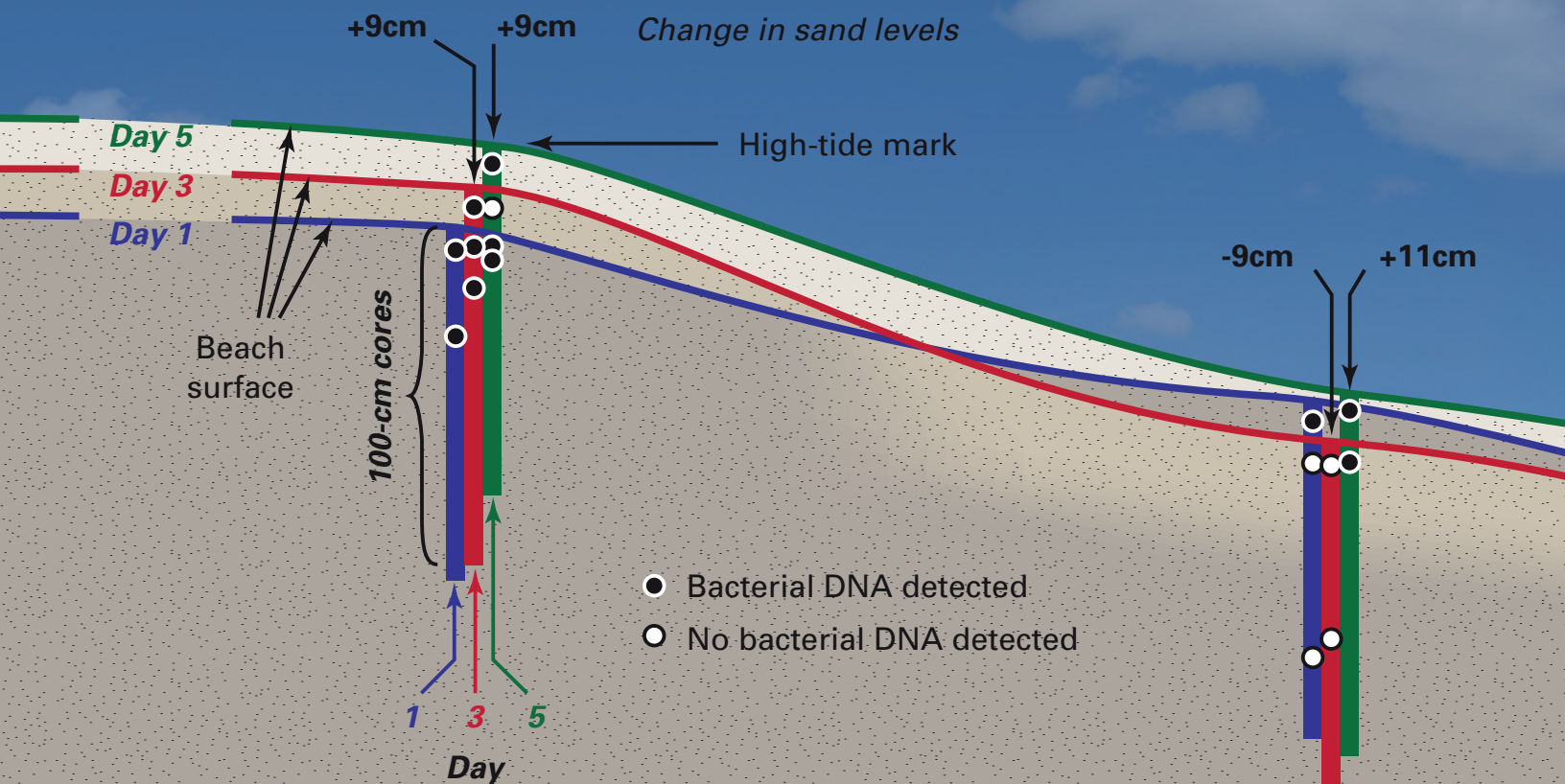
Then in 2003, Elgar and Raubenheimer witnessed a beach community's worst nightmare: A sewer pipe in a shoreline bluff ruptured, sending 300,000 gallons of raw sewage onto a popular beach below the Torrey Pines Municipal Golf Course in San Diego. The two scientists happened to be in the area studying how surf, winds, and tides move sand around and continually reshape



Steve Elgar, WHOI

MIT/WHOI Joint Program student Elizabeth Halliday (left) and microbial ecologist Rebecca Gast watch and wait as the tide recedes past their sample sites, marked by pennants. The scientists analyzed core samples from each site for the presence of bacterial DNA.

beaches. The spill soon became a can't-look-away-from-the-wreck kind of scene. San Diego authorities decided the best way to deal with the mess was to bring in bulldozers to pile up berms of sand around it, in an attempt to isolate it from the rest of the beach.



“Their idea was to make this sort of a cesspool, and the sewage would slowly filter through the sand before it got to the ocean,” said Raubenheimer.

But she and Elgar knew the berms were not likely to last long. Their research has shown that when tides come in, a hole 6 feet deep and 30 feet across can refill with sand in about two hours, as the hole's walls collapse inward and new sand is deposited.

“So then you wonder: What happens when the waves come up and bury this stuff under the sand?” Raubenheimer said. “And maybe it's buried by clean sand, but then that erodes? That got us thinking about all sorts of questions.”

Questions such as: What kinds of disease-causing organisms live in sand? How long can they survive there and still infect people? And, closer to their own area of expertise, can movement of the sand bring buried microbes back to the surface and carry them to other parts of the beach or into the water?



Courtesy of Steve Elgar, WHOI

Steve Elgar

Between the cracks

After the San Diego spill, the questions became too urgent to put off any longer. Elgar and Raubenheimer invited WHOI biologist Rebecca Gast to join them in a project to find out whether beach sand might act as a reservoir of microbes that waves, tides, or storm surges might later carry into the water.

Gast studies microbial ecology in a variety of settings, including beaches, and has done public-information programs about

beach closures. She welcomed the chance to combine her expertise in microbiology with physical oceanography techniques exploring the dynamics of water and sand. At the time, there had been no studies of how many microbes are in the sand, how long they live, or how far they could move from their initial location.

“A couple of studies have shown that you do have an increased risk of disease when you play in the sand, but that's all,” she said.

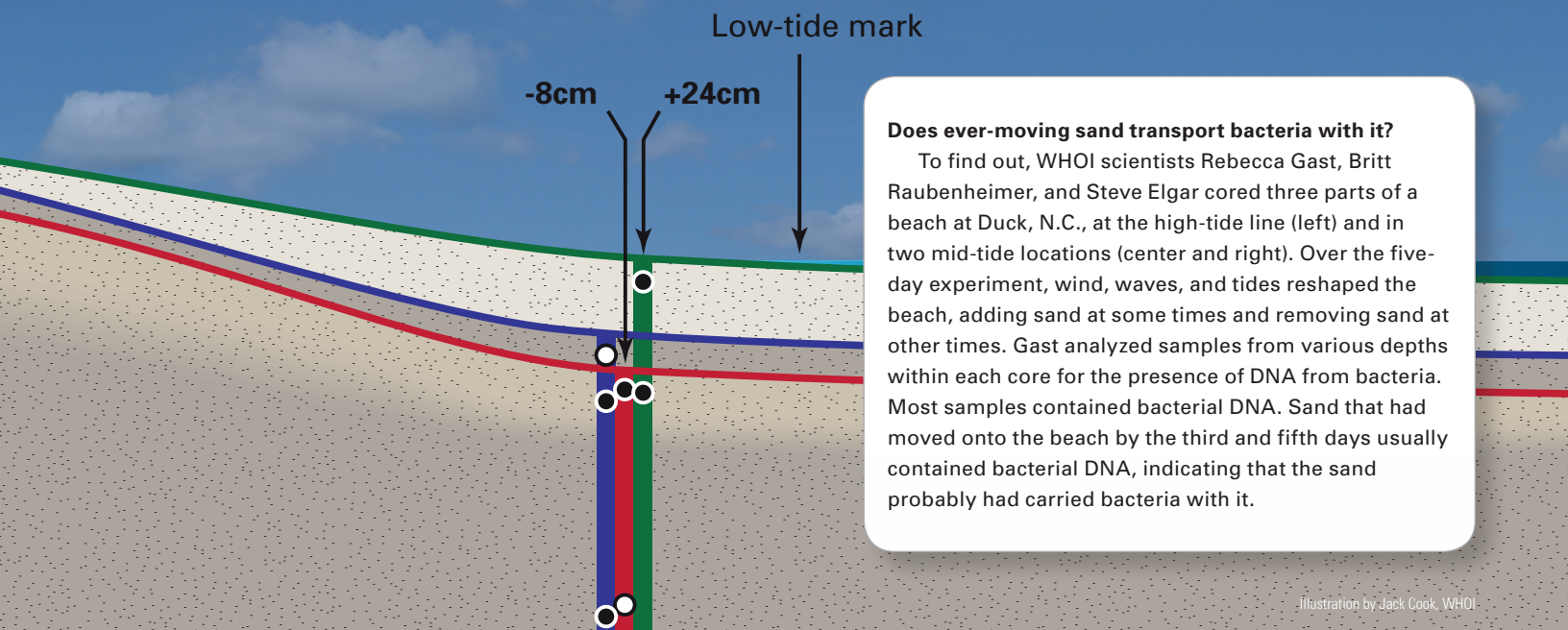
Before they could launch the project, the researchers first had to get funding for it—and that turned out to be a struggle. Elgar said the U.S. Environmental Protection Agency is dealing with hefty budget cuts and is hard-pressed to maintain its current water-quality programs, let alone expand into new areas. The National Science Foundation (NSF), which has funded physical oceanography research by Elgar and Raubenheimer and microbial research by Gast, was not interested in funding a project that combined the two.

“The three of us sent a proposal to NSF and the program manager asked us to withdraw it,” said Elgar. “He said, ‘No, I'm not interested.’”

The scientists think their proposal fell between the cracks in a system in which funds are granted by programs in traditional scientific disciplines. Their proposed research didn't have enough physics to satisfy physical oceanographers who reviewed it, and for basic research biologists, it was too directed toward human health issues.

“The public is interested in beach closures and public health, but the scientific community that reviews these things still has difficulty with the interdisciplinary aspect,” said Raubenheimer.

To make the project more appealing, the team trimmed costs by piggybacking this project onto research Elgar and



Does ever-moving sand transport bacteria with it?
To find out, WHOI scientists Rebecca Gast, Britt Raubenheimer, and Steve Elgar cored three parts of a beach at Duck, N.C., at the high-tide line (left) and in two mid-tide locations (center and right). Over the five-day experiment, wind, waves, and tides reshaped the beach, adding sand at some times and removing sand at other times. Gast analyzed samples from various depths within each core for the presence of DNA from bacteria. Most samples contained bacterial DNA. Sand that had moved onto the beach by the third and fifth days usually contained bacterial DNA, indicating that the sand probably had carried bacteria with it.

Illustration by Jack Cook, WHOI



Raubenheimer were already doing on the beach at the U.S. Army Corps of Engineers' Field Research Facility in Duck, N.C., under a National Security Science and Engineering Faculty Fellowship that Elgar had been awarded. Since they and their equipment would already be on site, additional grants wouldn't have to pay those travel and shipping expenses.

In the end, three local sources stepped up to help support the research: the WHOI Coastal Ocean Institute, a Mellon Joint Initiatives Award at WHOI, and the Woods Hole Center for Oceans and Human Health, a joint venture of WHOI and the Marine Biological Laboratory that is funded by NSF and the National Institute of Environmental Health Sciences.

The core of the matter

The team came up with a simple but elegant experiment to find out whether moving sand carries bacteria with it. They planned to sample during one of the early fall storms that affect the Outer Banks, when the beach would show measurable rearrangements of sand. They marked three spots on the beach at Duck: one at the high-tide mark, one several yards downshore in the mid-tide zone, and a third several yards farther out, but still in the mid-tide zone. The high-tide spot was covered by water briefly during each tidal cycle; the mid-tide areas were submerged for part of each day and exposed to the air for part of each day.

At each spot, the scientists drove coring tubes into the sand. They pulled out the tubes with cores of sand about 100 centimeters (just over 3 feet) long and 7.5 centimeters (about 3 inches) across and froze them for transport home.

Soon after the cores were removed from the ground, the narrow holes refilled with sand. Two days later, the team took another set of cores from near the same spots. Two days after that, they took a third set of cores. During the experiment, they also measured the height of the beach surface each day, using a highly sensitive GPS device, so they could determine how much sand was removed from or added to the beach between sampling days.

Back in her lab at WHOI, Gast analyzed sand from specific depths in each core for the presence of bacterial DNA. She looked for DNA from *Enterococcus faecalis*, a species that comes from feces



WHOI microbial ecologist Rebecca Gast checks the distances between coring sites on the beach at Duck, N.C., as WHOI physical oceanographer Britt Raubenheimer (red jacket) confers with other colleagues.

and can cause illness in people. Because the study area had not suffered a contamination event recently, the chances of finding *E. faecalis* DNA were low. So Gast also looked for DNA from free-living, naturally occurring enterococci bacteria. They are not known to be harmful to humans, but they are fairly abundant in the environment, and they could indicate whether sand movements can redistribute microbes of that size.

Analyzing the sand

The scientists' findings underscored how dynamic the beach was. As a result of an offshore hurricane, there were some high waves and rain at the start of their sampling week, but those diminished rapidly after the storm passed. During the five-day study, a lot of sand moved. Nine centimeters (3.5 inches) of sand piled atop the high-tide site between the first and third days; another 9 centimeters arrived between the third and fifth. Both mid-tide sites lost 9 to 11 centimeters (3.5 to 4.3 inches) of sand during the first interval and gained even more sand during the second.

And that's just measuring how high the surface of the beach was. In one case, the sand 60 centimeters below the surface changed from fine-grain to coarse-grain. In other words, tides and waves had replaced the sand at that spot with new sand to a depth of at least 2 feet.

Gast didn't find DNA from *E. faecalis* in any of the samples, but about two-thirds of them—even those many centimeters deep in the cores—had enterococcal DNA. Most significantly, areas that did not have bacterial DNA on an earlier day did have it on a later day. The additional sand that raised the level of the beach also tested positive for bacterial DNA. Clearly, enterococcal DNA was being moved with the sand and was not washed away in the surf. The research team concluded that sand that can move harmless enterococci could also probably move *E. faecalis* and other disease-causing species.

When it came time to publish their results, the scientists once again faced reviewers unable or unwilling to consider interdisciplinary projects.

"We sent it out to a microbiology journal, and they just flung it right back at us," said Gast. "They didn't want to see it. There

wasn't enough microbiology in it."

The paper got a more enthusiastic reception from the editor and reviewers at the journal *Continental Shelf Research*, which published it in June 2011.

Dry ≠ Clean

One of the study's intriguing findings is that even sand below the surface at the high-water mark wasn't free of bacterial DNA, which might surprise those of us who tend to think of dry sand as somehow "cleaner" than wet sand, clay, or mud.

"It's 'dry,' but this is not the great Libyan Desert," said Elgar. "There's dew. You're on the beach, so there's spray. It feels dry to us, but there are still water molecules in there. Bacteria don't need much water to live."

"The dry sand is worse than wet sand, in some ways," said Raubenheimer. If the area hasn't been contaminated recently and the water is clean, "you're better off being at the low-tide area where the sand has been washed by the waves quite a bit."

That's consistent with work Elizabeth Halliday, a graduate

WHOI biologist Rebecca Gast steadies a coring tube as Bill Boyd, a senior engineer at Scripps Institution of Oceanography, drives it into the sand. WHOI research associate Levi Gorrell looks on. Each tube collected a core of sand about 100 centimeters long. Gast analyzed samples from different depths in each tube for the presence of bacterial DNA.

student in the MIT/WHOI Joint Program who is advised by Gast, did on beaches at Provincetown, Mass., in 2010.

"Elizabeth found that the dry sand tended to get higher numbers of bacteria," said Gast. "The wet sand, where it was always wetted throughout the tidal cycles, tended to have much lower numbers."

The researchers stressed that the mere presence of bacterial DNA does not mean that playing in the sand can be dangerous.

"The jury's still out," said Elgar. Additional research might conclude that bacterial contamination of sand is not a big health issue, he said.

Gast added that their findings might turn out to be most useful for beach managers wanting to predict which beaches should be closed after a major contamination event like the big spill in San Diego. "We might conclude that sand contamination isn't a big deal that we need to test for all the time on all beaches, but if you know there's been 300,000 gallons of raw sewage, here are some tests that you can use to check the sand, not just the water."

In the meantime, the researchers urge beachgoers to use common sense, which in this case is pretty much what your mother told you when you were a kid.

"We don't tell people not to go to the beach or not to dig in the sand," said Gast. "But clean your hands off before you eat. Don't just dust the sand off. Wash your hands. And if you were buried in sand, rinse off afterward."



Steve Elgar, WHOI