The Caribbean Gets Dusted

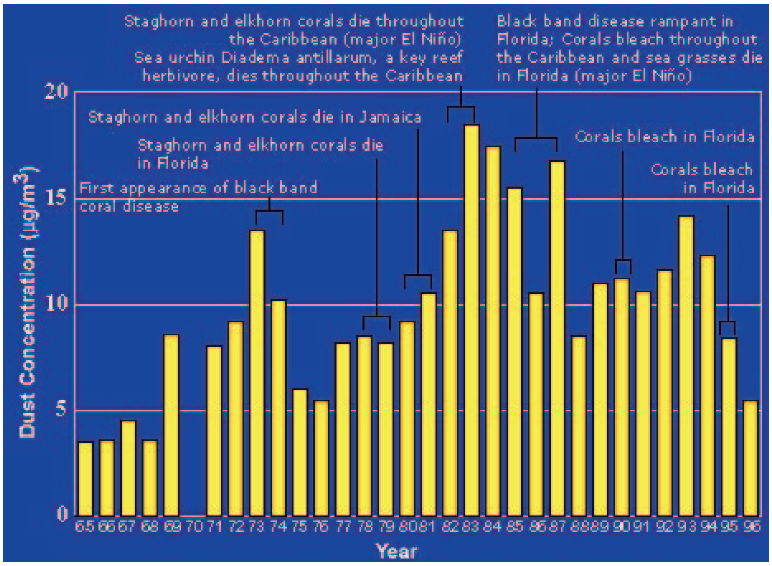
Spores and Nutrients from Africa's Sahel May Be Killing Coral Reefs an Ocean Away

JOHN C. RYAN

African dust is nothing new to the Caribbean. Residents have long suffered through the occasional sinus-clogging haze or risen some mornings to find their islands coated in a thin layer of fine red powder. Dust carried by trade winds across the Atlantic from Africa's Sahel occasionally reduces visibility and reddens skies from Miami to Caracas, sometimes even forcing airports to close. Pre-Columbian natives in the eastern Bahamas crafted pottery from windborne deposits of African clay; agriculture in the Bahamas today depends largely on the red soils known as pineapple loam, composed of African dust deposited millennia ago.

Though mariners and researchers ever since Darwin (see the box on page 335) have observed African particulates carried aloft hundreds of miles into the Atlantic, studies of atmospheric dust have focused mostly on its impacts on global heat budgets and carbon cycles. Only recently have researchers begun exploring the possibility that the hundreds of millions of tons of African aerosols landing annually in the Caribbean might have major, direct impacts on the region's marine ecosystems—and even on public health.

With all the other forces working to unravel the Caribbean's ecosystems—from global climate change to local water quality—some reef scientists and reef managers have seen the red dust as a red herring. But an increasing body of evidence, along with increasing loads of airborne pathogens and nutrients, is making it harder to ignore these transatlantic inputs to the troubled marine ecosystems of the Caribbean.



Joe Prospero of the University of Miami has tracked the increase in African dust reaching the east coast of Barbados since 1965. Years of peak dust deposition also saw widespread environmental change on Caribbean coral reefs. Graph: Courtesy of Joseph Prospero.

On the dusty trail

No one disputes that Caribbean coral reefs are dying. An extensive literature, including the comprehensive *Status of Coral Reefs of the World 2000* (edited by Clive Wilkinson and published by the Australian Institute of Marine Science in 2000), documents how anthropogenic threats—overfishing, sedimentation, and direct damage from boats and divers, among others—have combined with elevated sea surface temperatures, pathogens, and hurricanes to severely degrade reef ecosystems around the region. As Ernest Williams and Lucy Bunkley-Williams of the University of Puerto Rico summarize in the September 2000 issue of *The Infectious Disease Review,* the Caribbean has had, by far, the world's most numerous and severe coral reef–associated ecological disturbances. Around the region, diseases and bleaching have decimated once-dominant species like staghorn and elkhorn corals (*Acropora cervicornis* and *A. palmata*), longspine sea urchins (*Diadema antillarum*), and sea fans (*Gorgonia spp.*). Few species or sites have recovered, and carpets of algae—released from grazing by overfishing and mass mortalities of urchins and other algae-eaters—now dominate many Caribbean reef ecosystems.

Despite extensive research, the demise of Caribbean reefs has left many scientists frustrated. "We really don't understand why this is happening on a regional level, and it's happening not only in areas where there are a lot of people, it's also happening on remote reefs. Why?" asks Ginger Garrison, a marine ecologist with the US Geological Survey (USGS) field station at Virgin Islands National Park.

In the 1 October 2000 issue of *Geophysical Research Letters* ("African Dust and the Demise of Caribbean Coral Reefs," pp. 3029–3032), Gene Shinn, a marine geologist with USGS in St. Petersburg, Florida, and colleagues note the tremendous increase in African dust arriving in the Caribbean beginning in the 1970s. They see more than coincidence in the occurrence of benchmark events in the prolonged, Caribbean-wide decline of coral reefs—such as the arrival of coral black band disease in 1973, mass dieoffs of *Acropora* corals and *Diadema* urchins in 1983, along with coral bleaching beginning in 1987—during peak dust years.

"There are just so many things that have happened during this same period of time that the dust levels have been rising. I'm just amazed that people haven't looked at it," says Shinn, who has been studying the effects of oil drilling, sewage spills, and other threats to reefs in the Florida Keys, and watching their continued decline, for decades.

Joseph Prospero, one of the coauthors of "African Dust and the Demise of Caribbean Coral Reefs" and an atmospheric and marine chemist at the University of Miami, has monitored dust deposition in Barbados, at the far eastern edge of the Caribbean, since 1965. His work shows dustfall increasing there in the 1970s following an abrupt shift in the decadal climate cycle known as the North Atlantic Oscillation (NAO). A strengthened NAO led to prolonged drought conditions in the arid Sahel region, on the southern edge of the Sahara desert, as well as easterly trade winds blowing harder across the Atlantic. The changed climate, combined with widespread overgrazing and destructive farming practices in the Sahel, sent vastly greater quantities of exposed soil into the global atmosphere. In peak years, notably during El Niño conditions, winds deposit four times more dust on Barbados than they did before 1970. During the largest dust event ever recorded, in February 2000, satellite photos revealed dust forming a continuous bridge from Africa to the Americas. The dust is made up mostly of iron-bearing clays, but it also carries a wide array of living hitchhikers. "The dust is loaded with spores and bacteria," Shinn says. From the first dust sample taken in 1997 by Ginger Garrison, a marine ecologist with the USGS field station at Virgin Islands National Park, researchers at the University of South Carolina now have in culture more than 110 types of bacteria remaining to be identified, as well as a variety of fungal spores. "Conventional wisdom among most microbiologists was that bacteria would be killed by ultraviolet radiation making this five-day trip. But we now know that that's not true, and there are other organisms that can make it," Shinn says. "Swarms of live locusts made it all the way across in 1988 and landed in the Windward Islands. Ships at sea were pelted with locusts. If one-inch grasshoppers can make it, I imagine almost anything can make it."

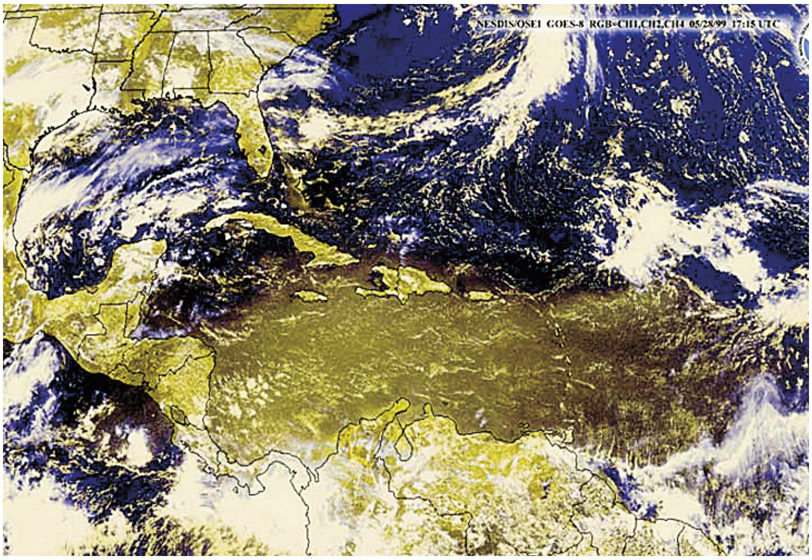
Linking components of the dust to specific diseases is a difficult task—not least because scientists have yet to identify the causative agents for the vast majority of coral reef diseases. In 1996 Garriet Smith of the University of South Carolina and colleagues were able to identify the pathogen behind the mass dieoffs

Darwin on Dust

While off the African coast en route to South America, Charles Darwin noted the abundance of organisms transported far from Africa by dust-laden winds. Below is an excerpt from chapter 1, "St. Jago–Cape de Verde Islands," of Darwin's The Voyage of the Beagle *(available from the Gutenberg Project at the Web site* promo.net/pg/*).*

On the 16th of January, 1832, we anchored at Porto Praya, in St. Jago, the chief island of the Cape de Verd archipelago....

Generally the atmosphere is hazy; and this is caused by the falling of impalpably fine dust, which was found to have slightly injured the astronomical instruments. The morning before we anchored at Porto Praya, I collected a little packet of this brown-coloured fine dust, which appeared to have been filtered from the wind by the gauze of the vane at the masthead. Mr. Lyell has also given me four packets of dust which fell on a vessel a few hundred miles northward of these islands. Professor Ehrenberg finds that this dust consists in great part of infusoria [protozoans] with siliceous shields, and of the siliceous tissue of plants. In five little packets which I sent him, he has ascertained no less than sixty-seven different organic forms! The infusoria, with the exception of two marine species, are all inhabitants of fresh-water. I have found no less than fifteen different accounts of dust having fallen on vessels when far out in the Atlantic. From the direction of the wind whenever it has fallen, and from its having always fallen during those months when the harmattan is known to raise clouds of dust high into the atmosphere, we may feel sure that it all comes from Africa.... The dust falls in such quantities as to dirty everything on board, and to hurt people's eyes; vessels even have run on shore owing to the obscurity of the atmosphere.... In some dust which was collected on a vessel three hundred miles from the land, I was much surprised to find particles of stone above the thousandth of an inch square, mixed with finer matter. After this fact one need not be surprised at the diffusion of the far lighter and smaller sporules of cryptogamic plants.



Satellite image (5 May 1999) showing dust covering the southern Caribbean, Windward Islands, and the Amazon rain forest. Phtoto: Courtesy of NASA/Goddard Space Flight Center and Orbital Imaging Corporation.

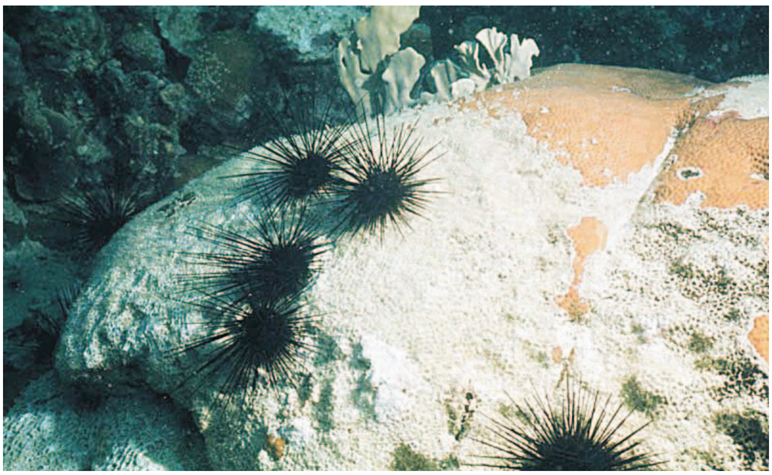
of the venus and common sea fans (*G. ventalina* and *G. flabellum*) as the soil fungus *Aspergillus sydowii*. He speculated that widespread deforestation and the ensuing increase in runoff in the Caribbean basin had spread the soil fungus. Not long thereafter, Ginger Garrison sent Smith a sample to see whether the fungus, which does not reproduce in seawater, might be arriving in the air. "We were all absolutely blown away to find out that the very first sample of African dust that I sent him, using all the proper sterile techniques, had *Aspergillus sydowii* in its pathogenic form," Garrison says.

"We've identified *Aspergillus* in air samples from both dust and nondust events—not surprising, since *Aspergillus* is very common," says Julianna Weir, one of Smith's graduate students. (Though the genus is hardly a household name, *Aspergillus* species include the major killer of people with AIDS, the producer of the carcinogen aflatoxin, and the main ingredient of the digestive aid Beano.) "But we only identified *Aspergillus* once in a nondust event," she says. Weir, who successfully inoculated healthy venus sea fans with *Aspergillus* spores cultured from Virgin Island dust samples, emphasizes that "African dust is not the only source of coral pathogens." But her results demonstrate, as she concluded in her talk at the Ninth International Coral Reef Symposium (ICRS) in Bali last October, that "African dust storms are one way in which pathogens may be introduced into the marine environment." The storms may be the most plausible source of *Aspergillus* on isolated reefs and near small islands with no forests and little runoff.

Dying Diademas

With other diseases, proponents of the dust hypothesis have had to rely on more circumstantial evidence. Shinn and coauthors speculate that African dust may have caused the largest mass mortality ever recorded of a marine invertebrate, the dieoff of longspine sea urchins. These algae-grazing urchins started dying along the Caribbean coast of Panama in January 1983, a year that brought both a strong El Niño and a major pulse of African dust. Within a year and a half, the mortality front had spread around the Caribbean and western Atlantic. Populations of the urchin, formerly one of the most abundant large invertebrates in the Caribbean, were reduced by 90 percent or more and have made little recovery since.

The prevailing hypothesis is that urchin-killers were somehow transported through the Panama Canal from the Pacific and spread by the main Caribbean current to the east and north. But Shinn and coauthors argue that currents cannot explain the rapid spread of the unknown pathogen to the south—against known currents—through the Windward Islands. They also point to the seasonal pattern of dust events: In the Northern Hemisphere winter, African dust tends to travel to South America and the southern Caribbean; in summer, it heads more for the northern Caribbean and the southeastern United States. "The pattern of seasonal change suggests that a dust-



Photograph of the urchin Diadema antillarum *on a coral head taken before 1983, when 90 percent of these urchins died throughout the Caribbean. Today, without the browsing of these algae-eating urchins, dead coral surfaces like this are coated with fleshy algal mats, which retard the establishment of coral larvae. Photo: US Geological Survey.*

borne pathogen could impact...Panama during January and a few months later the entire Caribbean," Shina and colleagues write.

The proposed link between urchin deaths and dust is one of the more controversial parts of the African dust hypothesis. "I have no rival hypothesis for how the *Diadema* dieoff got started," says Harilaos Lessios, a marine ecologist and leading *Diadema* researcher with the Smithsonian Tropical Research Institute in Panama. "I kind of like the hypothesis. But the timing is problematic." He observes that if one or two huge dust clouds spread the *Diadema* pathogen, one would expect to see simultaneous dieoffs over large areas and not, as he and colleagues first documented in the 19 October 1984 issue of *Science*, a mortality front making rapid but distinct advances. Lessios notes too that the Canary and Cape Verde Islands off Africa's Atlantic coast also support populations of *Diadema antillarum*. Despite the heavy dustings these islands receive, the urchins there have not suffered mass mortality.

A brain coral infected with black band disease, one of dozens of diseases that have afflicted Caribbean coral reefs in the past 25 years. The white area in the center is dead tissue–free coral skeleton. Black band disease on brain corals was first reported in Bermuda in the early 1970s but became rampant in other species in the Florida Keys, and elsewhere, beginning in 1985. Photo: US Geological Survey.

Fortified with iron?

Of course, dust need not carry live organisms to spur outbreaks of pathogens or other opportunistic organisms. It might instead transport nutrients that favor the growth of opportunistic species or help trigger microbes' switch from nonpathogenic to pathogenic forms. African dust is certainly rich in nutrients: Ginger Garrison has found that it is the main source of atmospheric nitrates on the Virgin Island shelf, and it is well known that the dust, by carrying phosphates and other nutrients, supports much of the growth of epiphytes in the Amazon rain forest canopy. Microbiologist Hans Paerl, of the University of North Carolina's Institute of Marine Sciences in Morehead City, says the dust's composition—aluminum, silicon, iron, phosphates, nitrates, and sulfates—makes it like "Geritol for bugs."

Most work on the fertilizing effects of dust in the sea has focused on iron, that essential micronutrient whose chemistry removes it rapidly from seawater. Based in part on experiments in iron-limited areas of the open ocean, proponents suggest that the intense pulses of iron brought by clouds of African dust (which is about 3–6 percent iron) in the Caribbean may be stimulating harmful algal blooms and the rapid growth of both coral-smothering macroalgae and pathogenic microbes. Marshall Hayes, a doctoral candidate in geology at the Duke University Marine Laboratory in Beaufort, North Carolina, has also shown in the lab that doses both of dust and of iron in its more soluble Fe(II) form trigger exponential growth in two types of bacteria that are confirmed coral pathogens.

Though iron-laden runoff from lateritic soils of the Caribbean basin reaches many nearshore reefs, Ginger Garrison suggests that the pulses of airborne iron may be of more concern for reef health. Dust events, unlike sedimentation, reach far from shore, and their iron may be more easily taken up by marine organisms. "Just because you have iron locked up in a mineral in a really large particle that hits the water doesn't mean it's available biologically. If you have tiny dust particles where the iron has been first oxidized in the atmosphere, then reduced back to Fe(II), it's hitting the water in a much more available form—chemically and physically—than a big chunk locked up in a clay," Garrison explains.

Yet Alina Szmant of the University of North Carolina at Wilmingon and other critics have questioned the applicability of iron experiments in upwelling zones of the open ocean to coral reefs, with their quite different nutrient availabilities. "There has been very little work on iron in coral reefs," Szmant says. She has observed iron-rich substrates, such as I-beams driven into reefs on the Florida Keys and shipwrecks in the Bahamas, where coral recruitment has been enhanced, compared with the surrounding iron-poor substrates. "When you have fresh volcanic surfaces made up of rocks with higher iron content, you tend to get them coated with corals, within just a few years. The algae could get in there too, and can grow faster, but it's the corals that do it," Szmant says.

Szmant acknowledges that her observations show only correlation, not a causal connection, between iron content and coral recruitment: "That's the same problem with the dust hypothesis," Szmant argues. "You can say this happened at the same time as that, so this may have caused that, but there could be ten other things that happened as well."

Broader implications

The various organisms and substances found in African dust may have effects on human as well as marine life in the Caribbean. Researchers have only begun to turn their attention to the potential health effects of long-distance aerosols, but they already have some surprising findings. Joseph Prospero says that there is "nothing unusual" about radiation levels of any dust he has sampled, but studies by the USGS's Chuck Holmes suggest that the dust has relatively high concentrations of beryllium-7, a radioactive isotope naturally present in the atmosphere but apparently concentrated on the dust particles in midair. A sample taken from the Azores during the giant dust events of February 2000 emitted gamma radiation at up to 45,000 dpm/g (disintegrations per minute per gram)—roughly three times the radiation allowed in the US workplace, according to Gene Shinn.

Dust researchers have also found pesticides banned for use in the United States mixed in with dust particles too small for human lungs to expel. "When they have locust plagues in Africa, we get chlordane and DDT that we can't use here anymore, but it comes back to us on the wind," Shinn says. "One has to wonder what one-micron-sized particles emitting gamma radiation do when embedded in lung tissue? One could even wonder what it could do to coral tissue once ingested."

While the researchers involved in exploring the potential impacts of African dust are careful to present their work as the basis for a working hypothesis in need of testing, some polluters have already tried to use the hypothesis to sway coral reef management decisions.

"As soon as the African dust theory hit the newspapers in the Florida Keys, the realtors and the developers and everyone who wanted to build up the Keys said, 'See there? We told you. It's not our wastewater. It's not the stormwater runoff. It's African dust.' Well, that comes back to me as a manager, and I have to work on the public relations and sort out what's fact from fiction," says Billy Causey, superintendent of the Florida Keys National Marine Sanctuary.

"When a scientist comes up with a theory, normally the scientific process should take over, and you either prove or disprove the theory," Causey says. "In this instance, people are grasping it as truth and moving forward with making excuses for all the other sins humans have done to coral reefs."

Shinn, who introduced his talk at the ninth ICRS by joking, "I do have my bulletproof vest on in case I need it," has had both scientists and nonscientists misunderstand or outright dismiss his work. "Some people thought we were trying to say that there are no real anthropogenic causes, that it's really this dust, and that's not what I was trying to say," Shinn says. "The dust is added on top of all these other problems."

Like many Caribbean reef researchers, Alina Szmant sees the impacts of African dust as an important area of inquiry but is withholding judgment until more results come in. "I think the value of a hypothesis like this is it gets a lot of people thinking and a lot of people doing work. It may be right, it may not be right, but that's part of the process of science. You don't always have to be right when you come up with a really great new idea." ❑

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