Microbial Life Forced into the Fast Lane: the Sudden "Awakening" of Hypersaline Microbial Communities by Hurricane Frances

2004's active hurricane season has grabbed headlines nationwide and provided a rare scientific opportunity to a group of researchers at the University of North Carolina at Chapel Hill's Institute of Marine Sciences. The research team, led by Dr. Hans Paerl, has been funded by the National Science Foundation's Microbial Observatories program to study microbial "mat" communities in the shallow, hypersaline lakes common throughout the tropics. By chance, their field site on San Salvador Island, Bahamas was directly in the path of Hurricane Frances, the Category 4 storm that lashed the island with 140 mph+ winds and torrential rains for nearly 24 hours on September 2, 2004. Paerl's group is hoping to use this event as a natural experiment to learn about how these storm events affect ecosystems and to help them forecast the ecological changes that might occur if the predicted elevated period of Atlantic hurricane activity (Goldenberg et al. 2001, Science 293: 474-79) persists over the next few decades.

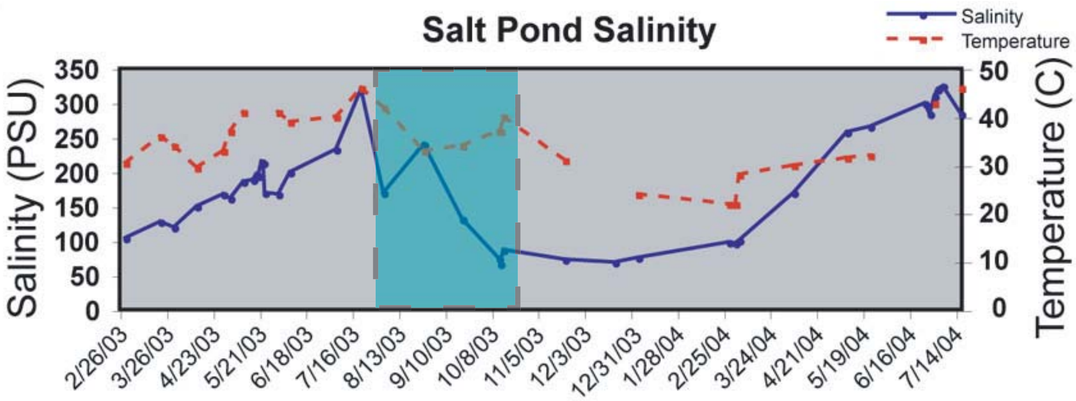
SeaWiFS image of Hurricane Frances on September 2, 2004, as the storm moves over the Bahamas. San Salvador Island is underneath the eye in this view.

Seasonal rains provide most of San Salvador's annual rainfall, and so they are an important part of the water budget for the lakes the researchers study. The microbes in one such lake, Salt Pond, rely on these rain events to bring the salinity of their environment down from a dry-season high of around 320 ppt—roughly ten times that of seawater—to a less extreme 60 ppt, and it is during the low-salinity periods that these microbial communities are most active. Because these microbes form the base of the food web and control nutrient cycling in Salt Pond, this seasonal freshwater pulse is crucial for the functioning of the whole lake ecosystem. Normally this "freshening" occurs over a 6 month period in the summer and fall, but Frances provided almost a year's worth of fresh water to Salt Pond in only a few days. In addition, hurricane-force winds can disrupt mat structure and transport foreign material, such as sand and debris, into the environment. Paerl's group sent two researchers, Drs. Tim Steppe and Anthony Yannarell, to San Salvador in October to investigate how Salt Pond's microbes responded to this extreme disturbance.

The changes they found were dramatic. Much of the mat had been covered by a deposit of white sand blown over from a nearby beach, and the thickness of this deposit varied from location to location. In search of light, photosynthetic organisms had migrated up through the sand to recolonize the new surface of the lake bottom in a green layer up to 4 mm thick. These colonists produced a prodigious amount of slimy extracellular polymers, substances which may help produce a more favorable light and nutrient environment, contribute to enhanced survivorship during the dry season, and play a crucial role in the annual cycling of carbon and nitrogen in the mats.

The extent of recolonization and the types of recolonizing organisms changed with different levels of sand deposition. In particular, a layer of purple photosynthetic bacteria appeared at different depths in the sand layer, apparently orienting themselves in response to light conditions that changed with the thickness of the sand. Thus, Frances did not affect the mat's structure uniformly across Salt Pond. In some places the photosynthetic community was separated by sand from the underlying mat layers, which are hypothesized to be important recyclers of essential nutrients, while in other places the sand did not impact the vertical layering of the mat. The hurricane's pattern of disturbance, there-

Flipping the seasonal switch:



Salinity and temperature change over the course of the year in Salt Pond (upper graph), as the water evaporates in the dry season and is replenished with rain from storms in the fall (blue box). This creates the typical seasonal signal in this environment. The two photographs, taken from the same approximate location, show Salt Pond before (left) and after (right) Hurricane Frances. The quick pulse of fresh rainwater activitated the microbial mat community, which had previously been dormant due to high salinity.

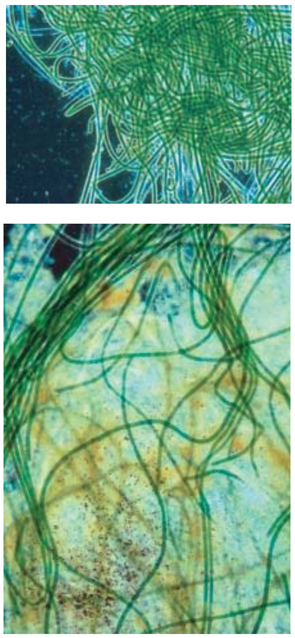
fore, provided the researchers with a natural experiment allowing them to examine whether vertically contiguous (undisturbed) mat communities behaved differently from noncontiguous (disturbed) ones.

Being able to observe, characterize and quantify these differences has broad ramifications, including understanding microbial survival and colonization strategies in response to catastrophic events such as large storms, floods, and landslides. Just as tree rings record the living history of forests, the alternating patterns of disturbance and recolonization due to these events are written into the layered structure commonly seen in modern microbial communities as well as those from fossil sediments and rock formations. These include the enigmatic stromatolites, which, dating back several billions of years, represent the earliest signs of organized life on Earth.

Another change noted by the researchers was the unusual abundance of potential mat-consuming organisms in Salt Pond. These life forms are frequently excluded by the high salinity of the Salt Pond water, and so the microbial mat communities are usually unaffected by herbivory. The sudden freshening of the water by Frances provided these animals with an environment in which they could thrive. Numerous brine shrimp could be seen in the water, and both nematode and isopod grazers were found in the mat. It is unclear whether the activities of these organisms will have important impacts on microbial community structure and function or whether such impacts will be short-lived. If climatic changes keep Salt Pond's salinity down more consistently throughout the year, these herbivores will be able to maintain pressure on the microbial mat communities, potentially ushering in major food web and nutrient cycling changes (Paerl et al. 2003, Ambio 32: 87-90).

The ability of Dr. Paerl and his San Salvador research team to document the effects of Hurricane Frances—a major disturbance "caught in the act"—demonstrates the potential of long-term research programs such as those enabled by the National Science Foundation's Microbial Observatories Program. Long-term observation of a single system not only increases the likelihood of encountering a rare disturbance event, but it also allows scientists to collect the background data necessary to make pre- and post-disturbance comparisons. Paerl's group is excited by the prospect of documenting the recovery of this interesting microbial system, and their research promises to provide a wealth of data about the development, structure, and evolution of ecologically important microbial mats. In addition, knowledge of hurricane-induced changes to the Salt Pond mat community may allow the researchers to use this system as an indicator of short and longer-term climate change.

For more information about this project, please visit the San Salvador Microbial Observatory website at: http://www.sansalmo.net.



Photomicrographs of photosynthetic mat organisms. A dense fabric of *Lyngbia spp.*, a cyanobacterium common in the upper layers of mats (upper). The deeper layers (lower) show a transition from green phototrophs, like this *Microcoleus spp.* to purple sulfur bacteria. The orange strings are streams of extracellular polymers.

Laminated structure of Salt Pond mat communities. The upper panel shows the mat prior to Hurricane Frances, when the mat structure was vertically contiguous. A layer of sand deposited in 1999 by Hurricane Floyd is visible. The bottom panel shows the separation of mat layers by sand from Frances (upper layer), with Floyd's sand layer visible at the bottom.

Disturbance and response:

These mat cores, taken after Hurricane Frances, show the uneven distribution of wind-blown sand deposits across the Salt Pond mat. The sand depth ranges from over 10 cm (left) to less than 2 mm (right), and the patchy nature of this disturbance will influence the ecology of the new photosynthetic communities (above the sand) and the older mat layers buried underneath. The vertical "fingers" on the top are slimy secretions of extracellular polymers, which create tower-like structures that can harbor photosynthetic organisms and associated bacteria. The white shapes that can be seen in the water (second panel from the left) are brine shrimp, potential herbivores of mat microbes.