Growing in harsh conditions, limber pines may get help from nitrogen-fixing bacteria in their needles.

selves is still a distant dream.

Skeptics note that some of the leaf-dwelling bacteria Doty has isolated make plant hormones, which could increase growth. But because Doty did these experiments in artificial soil lacking nitrogen, she argues that nitrogen supplied by the bacteria must be driving the growth. At the meeting, Doty's former technician, Andrew Sher, reported what she considers the strongest evidence yet. Sher put cuttings from wild poplars into flasks and exposed them to a heavier form of nitrogen than exists in air. Afterward, the same isotope turned up in the plant tissues, evidence that the bacteria had captured it and converted it to a usable nutrient, Doty says.

Frank converged on the same conclusion from a different starting point: a 2012 discovery that 30% to 80% of the microbes in limber pine needles were related to known nitrogen-fixing species. It struck her that these bacteria might explain a puzzle. In forests, foliage and soil contain more nitrogen than they should, given the known sources. Nitrogen-rich bedrock can explain some of the extra, but about 25% remains unaccounted for, says Benjamin Houlton, a global ecologist at UC Davis who specializes in the nitrogen cycle. "When you add up the numbers you come up short," he says. If nitrogen fixers were at work in leaves and needles, they might balance the books, Frank thought.

Still, she was initially skeptical. "I'd had a lot of doubt, lying awake at night," she recalls. But at the meeting, she described putting a limber pine twig with needles into a jar and replacing some of the vessel's air with acetylene. As microbes fix nitrogen, their nitrogenase enzymes convert acetylene into ethylene. The presence of ethylene at the end of the experiment told Frank that nitrogen-fixing microbes were at work, far from any root nodule.

Others are now cautiously embracing the idea. "There's a change in attitude, not from skepticism to believing but from skepticism to cautious questioning," says Gerald Tuskan, a plant geneticist at Oak Ridge National Laboratory in Tennessee. Tuskan and his colleagues have isolated about 3000 microbes from poplar, many of which are equipped with nitrogenase. Some sequester themselves in biofilms with oxygen-limited compartments, where nitrogenase could function even in the leaf's oxygen-rich environment.

Bit by bit, the case for treetop nitrogen fixation is building, Frank says. "I think we are converting people slowly, including ourselves." ■

IMAGE: ESA

EARTH SCIENCE

Alarm over a sinking delta

Rise and Fall project seeks ways to slow land subsidence in Vietnam's populous Mekong delta

By **Charlie Schmidt**, *in Soc Trang, Vietnam*

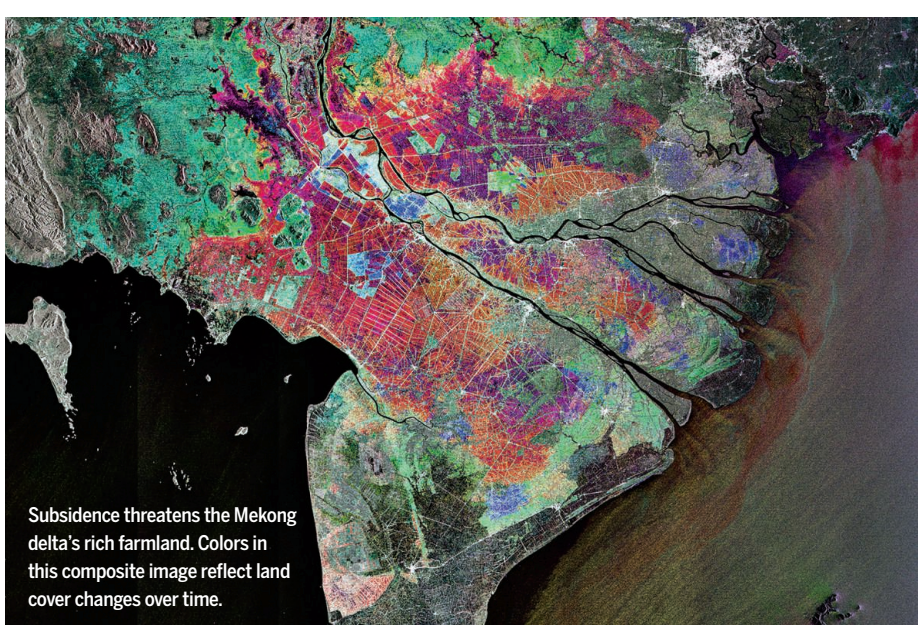
Leaning over a pond carved into the soft soils of the Mekong River delta, Ngwyen Khuong strains to lift a net of flapping shrimp. "We can harvest 4000 kilograms from a pond like this every 3 months," he says. But Khuong's booming shrimp business may be undermining the very land it occupies. Shrimp farmers in the delta are pumping prodigious amounts of ground water into their brackish ponds, causing water tables to drop, overlying sediments to compact, and the land to subside. The trends could expose the world's third largest river delta—home to some 20 million people—to flooding and other threats. "We face big problems if we have subsidence on one side and rising seas on the other," says environmental scientist Nguyen Hieu Trung of Vietnam's Can Tho University.

An alliance of Vietnamese and Dutch scientists is now trying to get ahead of the problem. They met here recently to launch the Rise and Fall project, a $1 million, 5-year effort to better understand what's driving Mekong delta subsidence and develop strategies to reverse it. "We know virtually nothing about what's beneath our feet," said geographer Philip Minderhoud, a co-leader of the project and doctoral candidate at Utrecht University in the Netherlands, during the 11 March gathering. "In many places the rates, causes, and future implications of subsidence remain an open question."

Although researchers have documented subsidence in other large river deltas, they only recently published the first hard evidence that the Mekong delta, which covers some 55,000 square kilometers and sits about 2 meters above sea level, is sinking. Ground- and satellite-based instruments have clocked average subsidence rates of 1 to 4.7 centimeters per year, a group led by hydrogeologist Laura Erban of Stanford University in Palo Alto, California, reported last year in *Environmental Research Letters*. In Ca Mau, a province on the delta's southern tip, the sinking reaches nearly 5 cm annually.

Among the culprits: levees that prevent sediment from spilling out of rivers and into the delta, and some 1 million wells drilled since the 1980s for drinking and agriculture. If groundwater depletion continues at present rates, researchers estimate, the delta could sink by nearly a meter by midcentury. Ca Mau alone has more than 100,000 wells, which have caused water tables to fall some 5 meters and allowed seawater to creep inland, making the well water increasingly salty.

At the meeting, the researchers began sharing what they know. The next step in the project, which is primarily funded by the Dutch Science Foundation, will be extensive



Subsidence threatens the Mekong delta's rich farmland. Colors in this composite image reflect land cover changes over time.

Published by AAAS

fieldwork, say project leaders Minderhoud and Pham Van Hung, director of the Center for Water Resources Technology for the South of Vietnam in Ho Chi Minh City. Geologists, for example, will map layers of sand, clay, and peat, which compact in different ways. Such data will be fed into modeling tools that will help researchers and policymakers understand how water use, development, and sea level rise could affect the fate of the delta.

One sensitive question is exactly how much of the subsidence is due to groundwater extraction—a main driver of delta economic growth. "People just say, 'Ground water is causing this,' but we have no data to prove it," says Bui Tran Vuong, the deputy director of the Division of Water Resources, Planning, and Investigation for South Vietnam in Ho Chi Minh City. Other factors are likely at play, says geologist Esther Stouthamer of Utrecht University. Urban infrastructure can squash poorly drained soils, and intruding salt water can weaken the chemical bonds between soil grains, making soils more likely to compress. Still, Stouthamer says, "ground water is probably the main driver" of subsidence.

In other nations, government efforts to limit groundwater use or switch to surface supplies have slowed or halted subsidence, but can require intrusive regulation and expensive infrastructure. Another option is to pump water back into the ground to raise the surface, a process called recharge. But the pumping tends to require a lot of energy, the water can escape through unseen cracks, and roads and buildings can "buckle as the land rises," says James Syvitski, an oceanographer at the University of Colorado, Boulder.

Syvitski is similarly skeptical of scenarios that envision the delta becoming an Asian version of Holland: a lowland protected from the sea by tall dikes. "Doing that for the Mekong coastline is cost-prohibitive," he believes. Others disagree. "Life on the future delta will be lived below sea level," predicts historian David Biggs, a Vietnam specialist at the University of California, Riverside. "But to make it work on the scale that we see in Holland will require a lot of education and democratic participation."

In the meantime, the delta confronts existential threats from abroad. Nations upstream along the Mekong are building dams expected to reduce the flow of sediments that build the delta, and sea level is rising. Still, many researchers are optimistic that such change can be managed. Projects like Rise and Fall are coming none too soon, Syvitski believes. "The Mekong delta," he says, "is at a tipping point." ■

Charlie Schmidt is a freelance writer in Portland, Maine.

BIOMEDICAL RESEARCH

Canadian registry to track thousands of pot smokers

Data could answer questions about safety, efficacy, and dosage

By **Lizzie Wade**, *in Montreal, Canada*

When a healthy looking man in his 70s walked into a sickle cell clinic in Kingston, Mark Ware sat up and took notice. A newly minted doctor, Ware saw many patients in chronic pain who often died young. The elderly Rastafarian seemed unscathed by the disease. "I asked him, 'What's your secret?' " says Ware, recalling an encounter that took place 15 years ago. "He leaned over, fixed me with his eyes, and said, 'Study the herb.' "

Ware is now doing so on a grand scale. A pain management researcher at McGill University Health Centre here, the native Jamaican directs the Quebec Cannabis Registry, a new, one-of-a-kind database that aims to gather information on every patient prescribed marijuana in the province over the next 10 years—thousands in all. By collecting data on symptoms, dosage, improvement, and side effects, the registry, launched on 11 May and funded by a grant from the nonprofit Canadian Consortium for the Investigation of Cannabinoids, aims to fill gaps in knowledge about the efficacy and safety of medical marijuana. It's a "wonderful step in the right direction" for "legitimizing some of the medical uses of cannabis," says Raul Gonzalez, a psychologist at Florida International University in Miami who studies the cognitive effects of cannabis use in HIV/AIDS patients.

Scientists anticipate a trove of data on Canada's medical marijuana use.

PHOTO: © BLAIR GABLE/REUTERS/CORBIS

Most drugs go through years of rigorous clinical trials before they are prescribed. That's not the case for marijuana. Even as more and more states and countries legalize pot for medical purposes, clinical trials of smoked cannabis remain rare. "Decisions [about medical marijuana] are being made at the ballot box instead of in the laboratories," Gonzalez says.

Few doubt that the drug can relieve certain symptoms. It eases neuropathic pain, reduces spasticity in people with multiple sclerosis, and improves appetite and weight gain in chemotherapy patients and those with wasting conditions, according to psychiatrist Igor Grant, director of the Center for Medicinal Cannabis Research at the University of California, San Diego. However, doctors have almost no guidance on recommended dosages or possible side effects. "If we knew what we were prescribing more accurately, we'd be a lot more willing to work with it," says Barbara Koppel, a neurologist at the Metropolitan Hospital Center in New York City.

Amassing and analyzing a large volume of patient data could answer long-standing questions, Ware says. Canada could have done this sooner: In the first 15 years of its medical marijuana program, 40,000 people were authorized to smoke the plant. But "we didn't learn anything from that process—about who they were, why they used it, how they used it, how much—nothing," Ware says. "We don't want to be in the same position 10 years from now." Through 2025, the Quebec registry aims to collect anonymous data from 3000 patients, each of whom will be tracked for 4 years to probe for rare side effects.

Large clinical trials would help bring medical marijuana out of the shadows. "Without well-controlled empirical studies, we're still going to be left scratching our heads about whether [medical marijuana] really works," Gonzalez says. Funding them is a challenge. Drug companies show scant interest in dried, smoked cannabis, Ware says, because it "may not have long-term payback." In the meantime, collecting vital data from users can't wait, he says. Marijuana "is part of our society now," Ware says, "and we need to have a means of talking to our patients about it." ■