A rat trapped in Pau da Lima will help researchers understand how the rodents help spread *Leptospira*, a sometimes deadly bacterium.

A PLAGUE OF RATS

As more people crowd into urban slums,the risks posed by rodent-borne diseases are on the rise

By **Warren Cornwall**, *in Salvador, Brazil; Photography by* **Mauricio Susin**

Rats haunt the slums of Pau da Lima. Their paw prints surround drain pipes. Burrows pock dirt walls. Shriveled black feces speckle patio edges. The rodents even leave their mark in the blood of the people living here in a crowded favela on the edge of this sprawling coastal city, Brazil's third largest. Many residents carry antibodies for *Leptospira*, a bacterium found in rat urine that can be deadly to humans.

"There's so many rats. You can't believe it. Outside, inside," says Carlos Bautista as he sits on the step of his brick shack, looking out over a pile of sodden trash and a makeshift chicken coop.

The haunting is deeply personal for Bautista. Six years ago, his 22-year-old wife died, unexpectedly, from lung damage caused by leptospirosis. Soon after, Bautista sent his son to live in the countryside with his grandparents. "It's better to have him alive there than to have him here" exposed to rats and disease, he says in a voice barely above a whisper.

Rats have long been one of the world's

most ubiquitous—and infamous—forms of urban wildlife, synonymous with pestilence and squalor. They've attracted only sporadic attention from scientists, however. Much about the secretive city rat—chiefly the Norway rat, *Rattus norvegicus*—remains a mystery. But as the world's urban population surges and more people crowd into rat-plagued neighborhoods like Pau da Lima, the rodents are getting renewed attention from researchers and public health experts. Over the past decade, scientists in a number of cities have launched efforts to better understand rat behavior and evolution, and the role they play in spreading disease.

One of the most intensive and longest-running investigations into rat-human interactions is occurring here in Pau da Lima, a chaotic jumble of buildings astride a small, hilly swathe of this city of 2.9 million people. For the last 2 decades, researchers have scrutinized the bodies, homes, and habits of favela residents—rat and human alike—while dodging encounters with gun-toting gangs. The goal is to decipher the forces driving leptospirosis, which kills some 60,000 people annually worldwide, and find the best ways to curb a disease that experts warn is an underappreciated threat in the burgeoning slums of a more urban world.

"When we think about the slums in Jakarta or Manila or Cali, Colombia, what you see in Pau da Lima is exactly what you see in those areas, if not worse," says Albert Ko, a physician and infectious disease expert at Yale University, and a founder of the Salvador research project. "We need to find out what solutions can be done immediately that are also generalizable to many of the urban slums."

Researcher Arsinoê Pertile performs a necropsy, collecting tissue samples that might reveal whether rats of a certain age or sex serve as particularly important disease carriers.

KO'S INTEREST in Pau da Lima's rats dates back to 1996, when a surge of deathly ill people, many with failing kidneys, started appearing at the Salvador hospital where he worked. At the time, leptospirosis was considered a rural disease. The corkscrew-shaped spirochete that causes it dwells in the kidneys and urinary tracts of rats and farm animals, and it infects people when their skin or mucus membranes come in contact with water contaminated by the animals' urine. Many people show no sign of infection, or just fever and aches. But a small fraction develop severe kidney damage or massive bleeding in the lungs, although researchers aren't sure why.

Alarmed, Ko and Brazilian colleagues spent much of a year tracking the outbreak. The results, spelled out in a 1999 article in *The Lancet*, were among the first alerting the world that this infection had moved to cities. Over 8 months, they found 326 severe cases, with 50 people dead, and traced the cause to a strain of *Leptospira* found primarily in rats. They noticed that infections surged after intense rains, and that most of the sick came from favelas on the city's outskirts, nearly half of which had open sewers. One was Pau da Lima.

Beginning in 2001, that neighborhood became the focus of an ambitious attempt to merge infectious disease research, urban ecology, and community development. With backing from Brazilian and U.S. funding agencies, the scientists recruited local officials and favela residents to help understand and counter the disease.

The result has been pioneering work on a disease so neglected that it doesn't even make some lists of neglected diseases, says physician Joseph Vinetz of the University of California, San Diego, who studies leptospirosis. "As far as I know, there are no systematic urban studies like the one going on in Salvador."

ON AN APRIL MORNING, a dozen researchers wearing long white lab coats slip through gaps between buildings lining a traffic-clogged street, then descend steep paths into Pau da Lima for a day of data gathering. The coats are sweltering in the damp, tropical heat. But security trumps comfort. The uniforms serve as a white flag of neutrality to the drug-trafficking gangs that control these neighborhoods. Still, the scientists are constantly on guard, watching for police entering the favela, often the prelude to a gun battle.

Ecologist Arsinoê Pertile, a graduate student at Salvador's Federal University of Bahia (UFBA) here, walks past shacks clinging to a hillside of red clay. Brassy rhythms pump from stereo speakers, melding with the whine of saws and the bang of hammers, a testament to the constant construction of improvised dwellings in a place the scientists have dubbed Valley 4. This and several neighboring ravines are home to more than 3000 people squeezed into less than a fifth of a square kilometer—a population density twice that of New York City. Nearly 90% of the residents are squatters. The average person survives on the equivalent of $2.60 a day.

At the valley floor, Pertile enters a cramped, walled courtyard that serves as a tiny open-air market, selling beer and other drinks. There, a cage trap tucked between a washing machine and a stack of empty bottles has captured a new addition to her research: a fist-sized ball of dull brown fur with a pair of shining black eyes.

That afternoon, Pertile will kill and dissect the rat, recording its size and sex and taking tissue samples. Among other things, its urine will be checked for *Leptospira*. "Close to 80% (of the rats) had *Leptospira*" during one recent research

sweep, she says, examining the caged animal as the shop owner calmly sweeps the floor nearby. Researchers hope to help pin down the chief reservoirs of the bacteria by correlating rats' age, sex, and capture site with *Leptospira* levels in the urine. Some rats may be more important carriers than others.

The traps are part of a much broader effort to construct a detailed picture of the favela's rats. To identify hot spots of rat activity, for instance, scientists have scattered throughout the valley hundreds of plastic squares the size of dinner plates, coated with a sticky film of soot mixed with methyl alcohol. They record a visual impression of every paw and tail that passes over them.

On this day, Pertile and her research partner, Luciano Lima, a rat exterminator for the city, are particularly interested in how quickly rats are repopulating Valley 4 after a recent extermination effort—and where they are coming from. Genetic studies have found that rat populations in each of the favela's valleys are relatively distinct, suggesting the rodents don't stray too far. Now, with traps at 60 spots in three valleys, they hope to learn whether rat numbers are rebounding because the animals are moving in from neighboring slums, or simply because Valley 4 survivors are reproducing. The answer could help shape future rat control programs.

The market is emblematic of how intimately people and rats coexist here. The building is perched at the edge of a stream of gray, fetid water, fed by trickles from white plastic pipes jutting from nearby buildings. It's the valley's improvised sewer system. Empty plastic bottles and food bags litter the streamside, tossed there rather than carried on the long hike to the top of the valley.

Lima, a 7-year veteran of the rat wars, points out the water, food, and thick vegetation that make this a rat haven. He traces the route the rats can take from the streambank, up through a drain pipe and into the back of the bar. Within 4 months of the last extermination attempt, the valley "was again full of rodents," he says.

DECLARING WAR ON RATS might seem the obvious way to address a rat-borne disease. But the Pau da Lima study has also shown that killing rats isn't always the answer. That's because researchers have realized another major culprit is water, specifically untreated sewage and runoff. It connects everything in the favela—the rats, the bacteria, and the people.

Even in wealthy cities, rats can be rife with *Leptospira* infections, but the number of human cases is low. That's probably because modern infrastructure steers most sewage and rainwater—and *Leptospira*—into pipes and away from people, says Federico Costa, an ecologist at UFBA who now directs the Pau da Lima work. Not so in Valley 4. Open sewers are the norm. The months-long rainy season turns paths to muddy streams and floods homes in the valley bottom.

A few hundred yards downstream from the courtyard market, researchers crowd into the small living room of one of those homes. Jamile da Cruz Nascimento, her husband, and their three children live in the disease's bullseye—in a low spot, near the confluence of two sewage-filled streams.

For nearly 2 decades, the favela of Pau da Lima has a been a focus of urban rat research.

Flood waters can reach almost to her doorstep. Her sons often go barefoot or wear flip-flops rather than closed shoes; their skin is constantly exposed to polluted water.

Asked how serious she thinks leptospirosis is, Nascimento gives it a 10 out of 10. She pegs her risk of getting it as a five out of five. A friend who lived nearby died from the disease several years ago. "We have many cases here," she says. "It's very serious."

A small electric fan wags hypnotically back and forth as a researcher slides a needle into the arm of Eric, Nascimento's lanky, 12-year-old son. Dark blood courses into a vial, to be tested for signs of recent *Leptospira* infections. Another worker questions the boy: Has he had a fever or joint pain in the last year? No. How often has he recently walked in floodwater? Frequently. Did he wear rubber boots? Sometimes.

So far, Nascimento and her children have gotten good news: They've never shown signs of a *Leptospira* infection. But she says her husband, who works as a garbage collector, always has a positive blood test.

Given the abundance of rats and *Leptospira* in the slum, why doesn't everyone here get sick? Ko's team would like to know. Understanding why Nascimento and her kids dodged the bacteria, while her husband didn't, for example, could offer clues to strategies for coping with the dangers.

Overall, researchers have found that approximately 3.2% of the favela's residents are infected every year. One in 30 of those infections leads to mild sickness, and one in roughly 200 causes severe illness, based on the number of cases admitted to the city's hospitals.

A string of studies published in the last 3 years lays out key risk factors. Houses with signs of rat infestation are nearly twice as likely to have a *Leptospira* infection, for instance. Other factors are barometers of poverty. The danger increases the farther downhill someone lives, tracing the slum's economic pecking order, which has pushed the poorest residents into the lowest, wettest areas. One study found the chance of infection fell by half with every additional dollar a day a person earned.

THE LINK between infection and water suggests that killing rats alone won't be enough to protect Pau da Lima's residents. "People are very close to the sewage and very close to the rats," Costa says. "I think if it could be done, a system that collects most of the water … would avoid most of the infections."

But in the favela, that's a big "if." In the early years of the project, scientists and community leaders successfully lobbied the federal government for $36 million to build a road and sewer lines through some of the most flood-prone parts of Valley 4 and a neighboring valley, as well as new housing for 271 households, or about 7% of the population. But today just a fraction of the project is built. A tidy row of apartment buildings sits empty along a freshly paved street at the lowest end of Valley 4. But sewage still flows down an open stream. In the adjoining valley, the only sign of work is a dirt road running down a hillside.

Delays ate into the funding, the researchers say. And in 2015, gangs controlling the other valley shut down the construction there, fearing it would give police easier access. "That project should have been done 10 years ago," Ko laments.

Researchers question Pau da Lima residents Jamile da Cruz Nascimento and her 12-year-old son Eric as part of their effort to understand disease risks.

GIVEN SUCH DIFFICULTIES, the scientists are looking for cheaper, quicker ways to make inroads against leptospirosis. They want to know how to fine-tune extermination campaigns, and whether things as simple as fencing off certain areas, or giving everyone rubber boots, could help.

The researchers hope to first test such interventions using a computer model that simulates how people, rats, and the bacteria commingle in the favela. Right now, the model—being developed by Costa and scientists at Yale and the University of Liverpool in the United Kingdom—is relatively coarse; researchers can run scenarios only at the level of a whole valley. Eventually, they hope to be able to see patterns at a much finer scale, just tens of meters.

Still, insights from Pau da Lima are influencing city government practices. Fifteen years ago, for instance, Salvador's rat control efforts were haphazard, often centering on affluent neighborhoods where residents and the politically connected complained, Ko says. Today, in contrast, the city focuses on 11 neighborhoods with the highest leptospirosis rates. In 2015, exterminators went house to house in five of the worst areas, leaving poison where they found signs of rats. When a case of leptospirosis is reported anywhere in the city, a team applies the same treatment within 200 meters of the patient's home.

Ko admits that they don't yet have data confirming that such strategies reduce infections. But "my gut feeling," he says, "is that we have to figure out ways to reduce the rat population."

A MORNING spent with the city's rat patrol, however, offers a glimpse into the difficulties of brute-force extermination. An aging Volkswagon van parks on a ridge above Valley 4, and eight people spill out, wearing white and blue polo shirts emblazoned with a logo reading "Centro de Controle de Zoonoses." They are responding to a report that a 12-year-old boy had come down with a fever—perhaps leptospirosis.

The agents fan out into the valley to hunt for signs of rats and distribute poison. Last year, the city had five of these vans and a staff of 120 conducting extensive, neighborhood-wide campaigns, says Maria Gorete Magalhães Rodrigues, who oversees the city's rat program. But with the arrival of the Zika virus, four vans and 80 workers were reassigned to fight mosquitoes. Now, her rat team responds only to reports of infections.

"Leptospirosis is not taken as seriously as it should be," she says through a translator. Then she switches briefly to English: "But I fight for leptospirosis."

After less than 20 minutes of rat hunting, the agents in Valley 4 suddenly retreat up the hill and back to the van. It turns out one had seen a policeman and feared bullets might start flying. Valley 4's rats, it seemed, would be safe for the moment. ■

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Editor's Summary