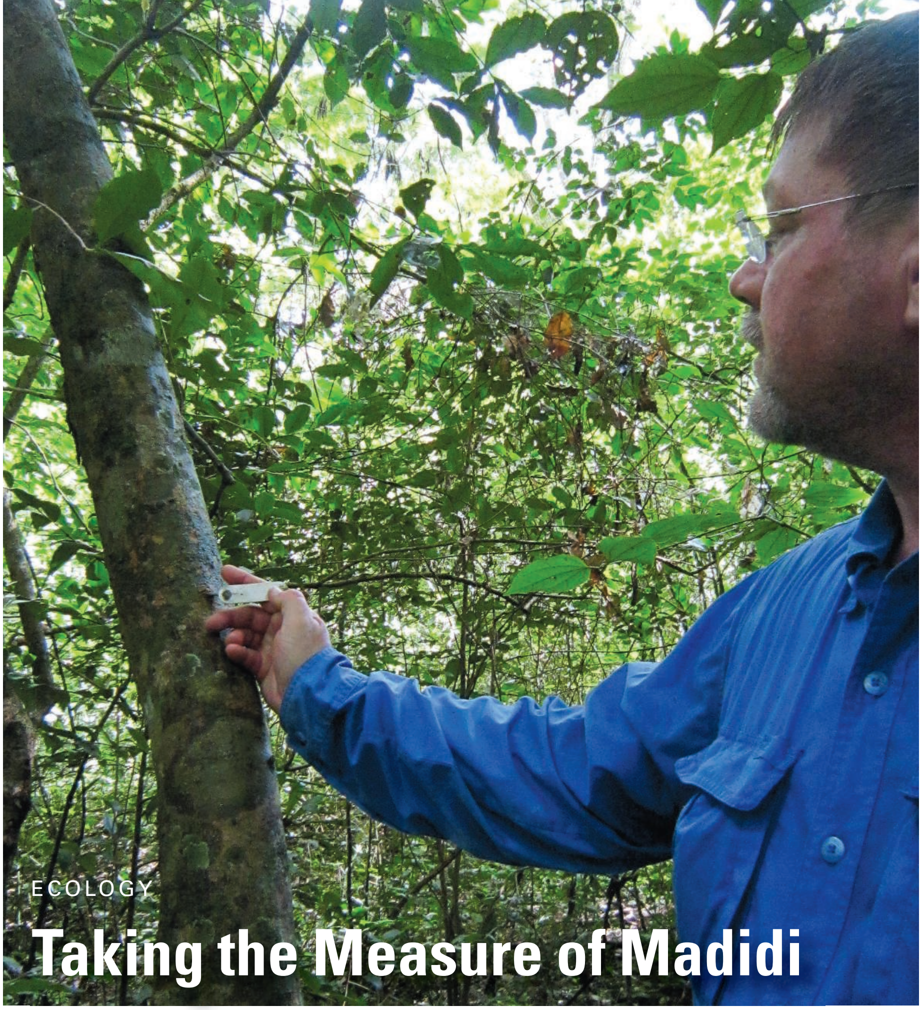

ECOLOGY

Taking the Measure of Madidi

Researchers journey into one of the world's most diverse areas to help predict the future of our planet's trees

Tracking trees. Peter Jørgensen started tagging trees in 2004 to understand forest diversity.

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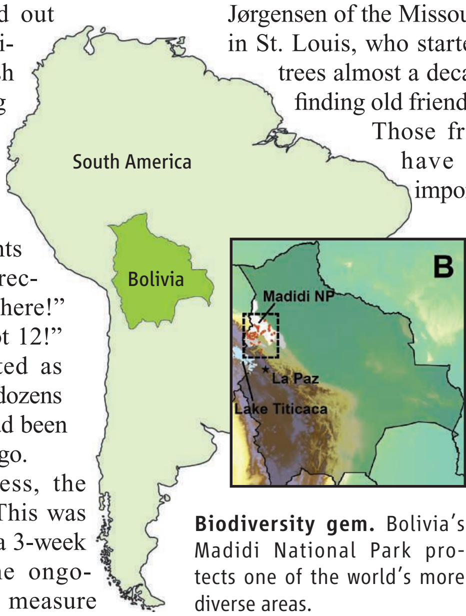
MADIDI NATIONAL PARK, BOLIVIA—It felt like an old-fashioned treasure hunt. For 5 days, two biologists, a botanist, and their students braved collapsing cliff-side roads, clambered across rushing rivers, and hacked their way through forest to reach this spot on their map. The researchers fanned out through the jungle, navigating thorny underbrush and armies of stinging ants, in search of small metal tags. A shout broke through over the rush of the nearby creek: "Number 191!" Moments later, calls from all directions: "Sixteen is over here!" "Seventy-two!" "I've got 12!" The excitement mounted as they located and read off dozens of numbered tags that had been nailed into trees 7 years ago.

Despite the giddiness, the endeavor was serious. This was day one of fieldwork in a 3-week expedition, part of the ongoing Madidi Project, to measure tree growth here in one of the planet's most unusual protected areas. For the students, locating silver strips obscured by moss or leaves in the middle of a forest the size of Vermont was like discovering buried treasure. For the Madidi Project's director, Peter Jørgensen of the Missouri Botanical Garden in St. Louis, who started tagging Madidi's trees almost a decade ago, it was "like finding old friends."



Biodiversity gem. Bolivia's Madidi National Park protects one of the world's more diverse areas.

Those friends, it turns out, have an increasingly important tale to tell. Botanists and biologists have long grounded their understanding of the natural world on long-term projects such as Madidi. Recurrent surveys of the same communities generate data that help researchers figure out how species interact in the face of environmental change or nearby human activity. As climate change descends upon us, it's becoming critical to identify factors influencing tree survival. "Local populations of trees have three options," says Nathan Kraft, a biologist at the University of Maryland, College Park. "They can move, adapt, or die off." By "move," he means that trees have the ability to shift their range when threatened in their current habitat, say by long-term drought or a more competitive species. Through seed dispersal and other regeneration mechanisms, trees can move to a better area. Otherwise, to survive, they must adapt, evolving traits better suited to the new conditions. The choices will determine the biodiversity of future forests. "Only once we know how species will behave can we figure out how to save them," not just in Madidi but elsewhere as well, Jørgensen says.

It's not easy being a botanist

Madidi National Park is home to 11% of the world's bird species and an estimated 12,000 plant species. Located in northwestern Bolivia, it is one of the largest, most diverse protected areas on the planet, on par with Madagascar's national parks and Colombia's Chocó jungle. It is also remarkably untouched. Aside from the handful of communities living inside the park and limited ecotourism on its eastern edge, human activity is scarce in the area. "Madidi is exceptional for scientific study," says Peter Raven, president emeritus of the Missouri Botanical Garden, the main sponsor of ongoing studies here, "because of this lack of disturbance."

For biodiversity researchers, it has another attribute: the longest continuous elevation gradient on the planet. The park ranges from Andean peaks of just over 6000 meters above sea level to the Amazon basin, approximately 180 meters above sea level. "Madidi is like a laboratory for climate change," says the Madidi Project's Bolivia coordinator, Alfredo Fuentes, a La Paz–based botanist at the Higher University of San Andrés in La Paz, Bolivia, Bolivia's largest university. Because temperatures drop as the elevation increases, species in Madidi can theoretically shift uphill instead of adapting to global warming in place. "Madidi offers an excellent opportunity to watch reactions to climatic change," Fuentes says.

Online
sciencemag.org
Podcast interview with Jean Friedman-Rudovsky (http://scim.ag/pod_6092).

The Madidi Project, launched by the Missouri Botanical Garden in 2001, has begun to capitalize on an opportunity not only to look at the effects of climate change but also to test existing theories about what controls biodiversity. Researchers are looking in particular at factors that influence the composition of plant communities, a concept known as beta diversity (see sidebar). The project's entire data set includes more than 206,000 trunks and about 2400 tree species. "Nothing along these lines has been done before," says Thomas Lovejoy, biodiversity chair at the Heinz Center in Washington, D.C.

From 2001 to 2010, the project established 442 small plots (0.1 hectare) and 50 large ones (1 hectare) throughout the park, each of which are now demarcated by small plastic tubes topped by a strand of orange fabric. Within each plot, researchers mapped, identified, tagged, and noted the characteristics of all trees with at least a 10-centimeter diameter, establishing a baseline.

Now, several expeditions a year here measure these trees, ideally returning to each plot every 5 years to take stock of the changes. During this visit in April, the group will remeasure more than 1600 trees from three plots in a semideciduous tract of Madidi ranging between 900 and 1100 meters above sea level. (One plot is on the banks of a river, one on a slope, and another on a crest.) Every tagged tree's location is double-checked against a map from the plot's establishment, and if a tagged tree has died, the team tries to establish the cause of death by examining the stump or remaining limbs for evidence of infection or other impacts such as a lightning strike.

Before their first trip, "everyone thinks it's like being on vacation," says Denmark-born Jørgensen as he swats away swarming mariwees, gnatlike insects that sting. It's the first day working the plots, and his neck is already swollen from bee stings and ant bites in the campground the night before.

Around him, the number calls continue, but they are no longer random. Rather, at each tagged tree, the researchers methodically sound off with codes that correspond to every possible characteristic: width, height, smell, bark texture, closeness to canopy, leaf patterns, and more. "I've got to be very careful to enter everything right," says Esther Mosqueria of the Higher University of San Andrés. Her undergraduate biology thesis will be on Madidi's tree population. She scribbles furiously to keep up with her colleagues' shouts.

One of the local guides accompanying the group is 3 meters off the ground, balancing on a thick branch leaned against a tree. He wraps a tape measure around the midsec-

Test bed. Extensive, long-term studies of Madidi National Park are testing biodiversity theories.

Probing Diversity's Complexity

Rainforests may be the conservationist's poster child, but they fall short as models of the true complexity of our planet's biodiversity. So says Peter Jørgensen, a botanist at the Missouri Botanical Garden in St. Louis, whose long-term project in Bolivia promises to shake up our understanding of the distribution of tree species in tropical South America. The Madidi Project (see main text) charts the changes in tree communities growing along an elevation gradient that plunges from above 6000 meters in the mountains to 180 meters above sea level. By identifying all trees at least 10 centimeters in diameter within hundreds of research plots along this gradient, Jørgensen and his colleagues have built a database that allows them to examine spatial patterns of diversity in ways not possible from studies limited to rainforests, which tend to be comparatively homogeneous because they are confined to the lowlands.

The Madidi Project focuses on comparing the rate of turnover of species in a sample of plots—a concept known as beta diversity. "It's about trying to understand why a certain species lives in one area and not in another nearby," says Brad Boyle, a biologist at the University of Arizona in Tucson. To gauge beta diversity, researchers count the number of species in various plots. Then they ask: How many species are common to the plots? How many are different? The higher the number of species found in only one plot, the greater an area's beta diversity.

Researchers want to know why beta diversity is higher in some areas than others. Why do some species thrive in two different areas while some drop out? "There are many different factors," says Nathan Kraft, a biologist at the University of Maryland, College Park, including climatic tolerance, soil quality, rainfall, and the differences in the dispersal abilities of species. "The really important next step is determining the relative importance of these factors and how they interact."

His work shows that the high beta diversity along elevation gradients arises because so many species are capable of living in these areas that by chance each plot has numerous species not found in another nearby (*Science*, 23 September 2011, p. 1755). But Jørgensen and his colleagues suspect that chance is not the most important factor. They think that high beta diversity in tropical mountain forests like those of Madidi is driven by a special mix of environmental factors. They hope an analysis under way will prove them right. "The value of [the Madidi Project] is in testing diversity theories of a landscape with real actual data, which is very rare," says Thomas Lovejoy, biodiversity chair at the Heinz Center in Washington, D.C. "It speaks to the importance of matching theories and what happens in nature."

Kraft is eager to see the results: "The strength of the Madidi data set is that it's intensively sampled and spans a broad elevation gradient. It will be a great step forward." **–J.F.-R.**

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tion of a large trunk. Many trees in this area have aboveground root structures, so team members must climb to measure the trunk diameter accurately. Tree height is estimated (with roughly 90% accuracy) because taking an exact measurement through triangulation would triple the fieldwork time.

Species identification is a key component of the project; the team double-checks trees identified in the past, taking samples back for confirmation if there's any doubt. "You can have a ton of data, but it doesn't mean anything if you can't consistently identify and standardize the species," says Brian Enquist, an ecologist and evolutionary biologist at the University of Arizona in Tucson. While identifying tree species might seem the task of a third-grader, "in tropical areas, the extreme number of species means identification is exceptionally difficult," says Iván Jiménez, a botanist at the Missouri Botanical Garden who analyzes the Madidi Project's data.

More than 6 hours later, everyone has worked up a sweat—better to be covered from head to toe than ravaged by insects and spiky trunks and bushes. Just before sundown, they head back to the small campsite, which is roughly one-quarter the size of a football field and took a day of machete-slashing to clear. Shared tents ring a common area with a large table and benches built out of branches and 8-meter-tall river grass stalks, held together with string. The wife of one of the guides prepares meals and boils stream water for drinking. But not even the burning fire can mask an omnipresent odor of nearby "wild-garlic" trees.

At night, wearing headlamps, team members press leaf samples into old newspapers to store them intact for the trip back. They listen to Bolivian rock on a battery-operated MP3 player and tell bad jokes until they collapse onto their foam sleeping pads, anticipating a dawn wake-up call to repeat the day's activity.

How big? Researchers go to great lengths to measure trunk diameters of surveyed trees.

"It's not easy being a botanist," says biology student Eber Renjito of the Higher University of San Andrés.

How forests work

The scale of the Madidi Project makes the hardships worthwhile. Already a decade old, the project is slated to go on for at least one more year or longer if continued funding can be found. Other similar biodiversity studies are smaller and have a shorter life span. Relatively few are based in the tropics, even though tropical plant species are among the most susceptible to climate change. And very little is known about tree patterns in tropical mountainous zones such as the Andes.

What is known points to a move-rather-than-adapt strategy for coping with climate change. Miles Silman, a biologist at Wake Forest University in Winston-Salem, North Carolina, has studied an area of Peru with a similar elevation gradient to Madidi. His work has shown that many trees are in fact shifting their ranges to higher, cooler ground rather than trying to adapt in place to increasing temperatures.

CREDITS: JEAN FRIEDMAN-RUDOVSKY

For the record. The location of each tagged tree is mapped and recorded for future visits.

That's what Sebastian Tello, a biologist with the Madidi Project based at the Missouri Botanical Garden, thinks is going on in Madidi. Adaptation requires genetic change that occurs over the course of generations. Woody plants have long lives, so the shifts in genetic composition are extremely slow. "In general, we hypothesize that it's easier for tree species to move than adapt," Tello says.

Yet other environmental factors may impede geographical shifts by certain species, causing them to be left behind even as community compositions change. For example, the project's research has found a species-rich belt within Madidi, between 1000 and 1500 meters above sea level, that mixes trees from the lowlands and the mountains. "What will happen to this belt is uncertain," Jørgensen says, "since species adapted to lowlands and flat areas are not particularly well adapted to growing on sloping terrain." Trees with large buttresses, for instance, might be in danger because they may not be able to survive on a hill. "The high-diversity belt may shrink or disappear completely," he says.

Having even a vague idea of whether a community or species is at exceptional risk of disappearing is a main goal. "This kind of research is fundamental if you want to have representative ecosystems going into the future," Lovejoy says. Ideally, research like the Madidi Project gives policymakers an idea of which areas are most in jeopardy and in need of protection. "Since there is limited money for conservation," Jørgensen says, "we want to make sure the areas with greatest range of species, as well as the species that may have less chance for survival, are protected."

He warns, though, against drawing firm conclusions about climate change's effect on forests even after accumulating a mass of data over 10 years. A decade is not long enough. Sustaining the work over many decades may be the most important element to advancing this research. But Jørgensen admits that his own days of fieldwork might be nearing their end. "I'm getting a little too old for this," says the 54-year-old, red in the face and tired already. He hopes his Bolivian colleagues will take over the expeditions while he focuses on taxonomy and data analysis back at his desk in St. Louis. "It may be decades before we can really understand how our forests will change," he says. "But Madidi is a start."

–JEAN FRIEDMAN-RUDOVSKY

Jean Friedman-Rudovsky is a journalist based in La Paz, Bolivia.