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Amazonia in three dimensions

Three-dimensional maps show details of forest structure and aid monitoring of the impacts of fragmentation on native vegetation

Carlos Fioravanti, in Manaus

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The forest as seen from the International Space Station: 150 kilometers of the Amazon River, its tributaries and the many lakes and floodplains along its course

The trees appear as red, yellow and other vibrant colors, as if each had been hand-painted on the maps posted alongside scientific articles and invitations to seminars in the hallway of the building that is home to the Biological Dynamics of Forest Fragments Project (BDFFP) at the National Institute for Amazonian Research (Inpa) in the Brazilian city of Manaus. The technique that made it possible to assemble the maps—LiDAR, or Light Detection and Ranging, which records variations in light reflected by the trees—is greatly facilitating the work of the researchers in the oldest tropical-forest monitoring program in Brazil, one of the world's longest-running programs of its type. Launched in 1979 to gauge the impact of road construction and expanded farming on the Amazon forest, the BDFFP monitors changes over time in 11 forest fragments, as well as in adjacent continuous forest areas that serve as controls for comparison purposes. The total area under study encompasses a thousand square kilometers (km^2) of forest and includes trees up to 55 meters in height.

Until a few years ago, the only way to obtain detailed data on forest composition and changes was to travel for many hours on unpaved roads in rain, heat, mosquitoes and fungi to reach the areas under study, some of which are 80 kilometers from Manaus. "This new technique will

Landscape mosaic

Program studies dynamics of plant and animal populations in 23 forest areas near Manaus

of course not solve all of our problems, nor will it spare us from making field trips, but it's a great help," says José Luís Camargo, an ecologist from São Paulo State and scientific coordinator of the BDFFP, which is presently funded by the Smithsonian Institution and Inpa, in conjunction with research-supporting foundations and agencies in both Brazil and the United States. Satellite images are two-dimensional, but LiDAR images are three-dimensional. They are created from light reflected off the tops of trees and captured by planes flying over the areas under study. "We can map clearings, which are important to the functioning of the forest, and get a good idea of the relief that sustains the vegetation," Camargo says.

LiDAR, alone or in combination with other remote sensing techniques, can provide detailed data on the height, concentration and distribution of trees and can indicate which animal groups are likely to be living there. A more matted—or, as Camargo says, structurally complex—forest is less likely to be a habitat for certain groups of birds and bats, for example. In a recently completed study in one of the project areas, Brazilian biologist Karl Mokross of Louisiana State University in the U.S. confirmed that birds living in the understory—the area below the tree canopy—prefer to feed on insects in the primary forest, and rarely feed in the secondary forest, also known as the capoeira.

In addition to using three-dimensional images, the Inpa team borrowed from the field of chemistry a technique for identifying chemical compounds, known as near-infrared spectroscopy, to classify plants. This technique is based on the fact that the chemical bonds of certain molecules have specific vibration frequencies. These frequencies can be recorded by an instrument and expressed in graphical form. Using this method, biologist Flávia Machado Durgante and other researchers at Inpa examined 159 leaves from 10 tree species collected from a preserved forest area near Manaus and from the BDFFP study areas and retained in the program's collection, which currently has 54,000 samples of leaves and reproductive structures (flowers and fruits) from the monitored trees. They then obtained the so-called spectral signature of each species and concluded that the technique is a simple, low-cost method for identifying plant species and differentiating very closely related species, even when they lack reproductive structures such as flowers and fruits that would facilitate recognition by botanists and ecologists. In their paper, published in March in the journal Forest Ecology and Management, they reported an average accuracy of 96.6%. Biologist Carla Lang has begun to analyze the spectral signatures of leaves from trees and seedlings of the same species to determine whether they are consistent with one another. If so, this will facilitate the rather difficult work of identifying seedlings and predicting the distribution of species in the forest.

In a few days, Lovejoy obtained approval from the directors of Inpa and from Suframa to begin the work

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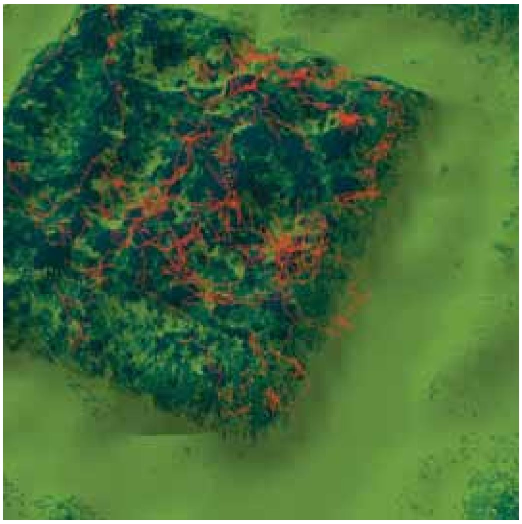
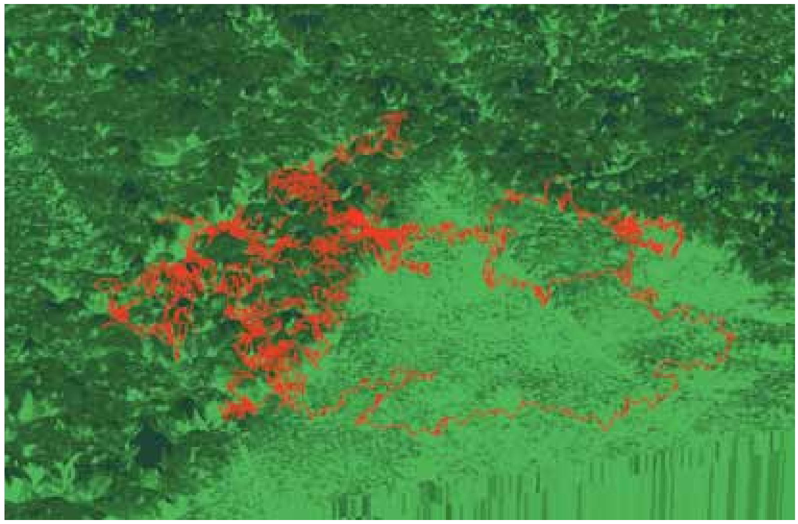




Flocks of birds (*in red*) prefer the primary forest in a 10-hectare fragment (*above*) and seldom traverse the capoeira (*in light green, magnified at right*). Darker greens indicate taller vegetation.

EARLY ALLIANCES

The working methods now available provide a modicum of well-deserved comfort for the researchers in the Amazon studies program that two biologists from the U.S., Thomas Lovejoy and David Conway Oren, started designing in the mid-1970s. Both had already had several years of experience conducting field research in the region. At that time, the government was promoting occupation of the forests north of Manaus by cattle ranchers. "I was the one who alerted Lovejoy about this unique opportunity to talk with the land owners, go into the forest prior to deforestation and do biological inventories—something that had not been done in Panama," recalls Oren, an ornithologist who has worked at Inpa, the Goeldi Museum and the Federal University of Pará (UFPA) at Belém and who is currently the biodiversity coordinator for the Ministry of Science, Technology and Innovation (MCTI). The biologists did not forget the fact that construction of the Panama Canal, completed in 1914, had isolated areas of a tropical forest about which they knew very little. Lovejoy liked the idea and said he would seek funding.

Lovejoy became the program's spokesman and became an international authority on biodiversity. He is presently a professor of environmental science and policy at George Mason University in the United States (see Pesquisa FAPESP No. 171). A clipping of a page from the journal A Província do Pará from January 7, 1979, which hangs in the hallway of the building that houses the BDFFP, announces the Minimum Critical Size of Ecosystems Project, as it was then called, with expected annual costs of $500,000 and support from Inpa, the Brazilian Institute for Forestry Development (IBDF), which gave rise to the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), and the Manaus Free Trade Zone Authority (Suframa). Determining the minimum area needed to effectively preserve a forest was a concern of the Brazilian government, as well as "a global problem," argued Lovejoy, who at the time was with the World Wildlife Fund (WWF), the first international institution to fund this work.

"It was the golden age of Inpa, under the direction of Warwick Kerr. In just a day or two, I received approval from the director and the head of Inpa's Department of Ecology, Herbert Schubart, and from Suframa, which was also very open to the idea. The cattle ranchers cooperated as well," Lovejoy said, recalling the creation of the research program in Amazonia. "I basically accompanied Rob (Richard Bierregaard, a biologist and first scientific coordinator of the BDFFP, now with the University of North Carolina at Charlotte in the U.S.), introduced him to the people in Manaus and left him to work. Rob made friends with the ranchers, who were pleased to participate in work that was receiving media attention."

The program provided for isolation of forest areas of varying sizes and for surveying and monitoring of trees, insects, amphibians, reptiles, birds and mammals. The objective was to determine which species die off and which survive as the forest decreases in size. This program was a way to examine the impact of fragmentation on the forest and the organisms that live there. Even today, the reduced size of the native vegetation that has resulted from the expansion of roads, agriculture and cattle ranching is a principal cause of the loss of biodiversity in Amazonia, the world's largest tropical forest.

AMAZON DATABASE

The field work, conducted over a 33-year period and completed in 2012, resulted in an immense database of trees and birds. The researchers are now observing the growth of 45,376 trees and 178,295 saplings (less than 10 centimeters in diameter at chest height) on 55 hectares of continuous forest and 39 hectares of fragmented forest. "We are monitoring a forest with one of the most diverse tree communities in the world," Camargo says. In addition to monitoring trees, they recently began to include records for lianas. In a recently completed survey on 69 hectares, they counted 33,154 lianas. "Lianas are generally not a subject of forest surveys, but they represent an important component of a forest's biomass and biodiversity."

The database contains information on 60,000 birds from 400 species that live in the understory, the intermediate level between the canopy and the forest floor. Each bird was banded with a number that will enable biologists to learn where they have been when they are captured in what are called "mist nets." "This database enables us to ask more complex questions that arise only after decades of monitoring and that build a basis for public policies and help solve new problems such as the impact of climate change on Amazonia," Camargo says. "Many researchers come to work here because we have a long track record, so they don't need to start at square one. This knowledge is a national asset."

Many conclusions of the BDFFP would have been impracticable in a shorter-term study, according to a January 2011 article in the journal Biological Conservation that synthesizes 32 years of field work. The article is signed by 16 biologists from institutions in Brazil, the United States, Australia and Mexico connected with the BDFFP. The first author is U.S. biologist William Laurance, who lived in Manaus for five years and is currently working in Australia. The vulnerability of large trees to fragmentation and the effects of ephemeral events such as El Niño and storms, they argue, became evident only after decades of monitoring. They noted that when trees fall, they may create clearings that draw moisture away from nearby trees and alter the light and temperature (see illustration). Fragmentation can reduce water circulation; limit the territory of many species of birds that are unable to traverse large deforested areas; reduce the populations of bees, wasps, beetles and ants; and increase the populations of frogs and spiders. These changes result in a cumulative loss of biodiversity and a reduction in water reserves.

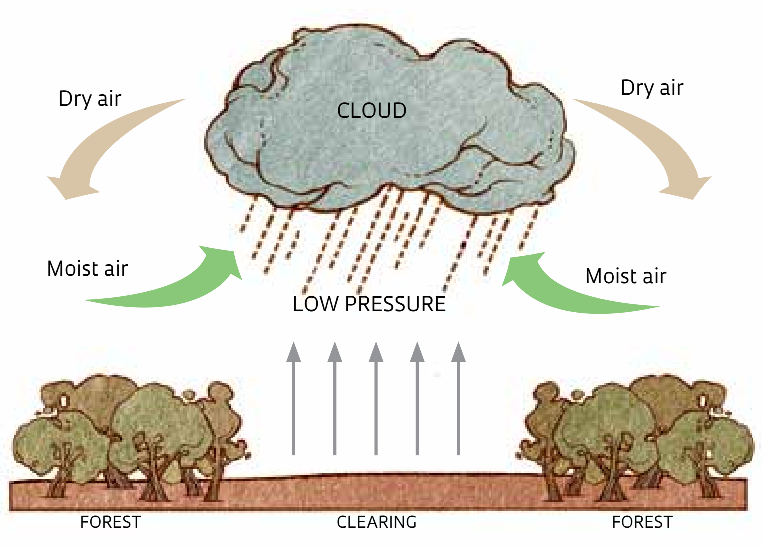
FRAGILE FOREST

Simulations of forest behavior using data from the BDFFP suggested that even 10-hectare fragments need at least a century to recover their earlier biological diversity and biomass. Once established, these fragments undergo a profound reorganization of their communities of trees, palms, climbing plants, and animals. "As a general rule, the smaller the area, the more severe the effects of fragmentation," says Camargo. Anyone passing through the study areas will notice the difference: the smaller fragments of a hectare or less in size have now lost part of their original forest structure and look like a capoeira struggling to survive, while the larger fragments, particularly those 100 hectares in size, still harbor tree species that grow in the low light and high moisture conditions that are typical of an Amazon forest. Small areas are more fragile "and suffer more from more intense droughts, such as those that occurred in 2005 and 2010," Camargo observes.

One consequence of fragmentation is the so-called edge effect: changes that occur at the edges of a forest due to solar radiation, light and wind from outside the periphery of the forest. Because they are exposed to more changes in the microclimate, the trees closest to the edge may fall more easily or dry up and die standing. As a result of the edge effect and forest fragmentation, "half the understory birds and mammals may become locally extinct, sometimes irreversibly so," Camargo warns. According to the 2011 article, deforestation to open up pastureland creates 32,000 kilometers of new forest edge each year and produces landscapes dominated by irregularly shaped small fragments of less than 400 hectares, which increases the effect of solar radiation and wind on the na-

The clearing effect

Open areas alter air circulation in the lower atmosphere and promote cloud formation and rainfall



SOURCE ADAPTED FROM WALLACE ET AL. 2012

PHOTO SERGIO JORGE BRAZIL / PHOTONONSTOP **ILLUSTRATION** SANDRO CASTELLI

Roads such as this one destroy forest unity and create fragments that limit the movements of animals, reduce biodiversity and affect the climate.

tive vegetation. "If it's this way here, it may be even worse in other areas, such as the Arc of Fire, the region in the states of Pará, Mato Grosso and Rondônia that is the most subject to deforestation."

"Two days ago, you couldn't get through the hallway because of all the luggage," Camargo said on the morning of November 9, 2012. "Our twenty-first training course ended yesterday. We've trained 420 ecologists." Every year, the course in Amazonian Landscape Ecology—usually held in July or August and occasionally in October, as it was last year—brings together 20 graduate students and 15 professors from universities throughout Brazil. "Most of the participants have never set foot in Amazonia," Camargo says. The professors introduce the different environments in the region, from the várzea, or floodplain, to archipelagos such as Anavilhanas, to train professionals to understand and help solve the problems in the region.

Another way to share the researchers' findings and increase understanding of the region is through three-week courses for undergraduate students. "Recently, I was one of the people responsible for that course at the Universidade Estadual Paulista (Unesp) in Rio Claro, the State University of Minas Gerais and the Federal University of Amazonas," Camargo says. "Today the BDFFP trains more researchers from Brazil than from the United States."

According to Camargo, at the present time, the Smithsonian and Inpa cover only 20% of the annual costs, and most of the annual budget of R$1.2 million comes from grants or from funding agencies or foundations in the United States and Brazil. "In the past decade, it was difficult to obtain funding because the focus of the grants changed. The money migrated from forest fragmentation studies to climate change studies," Camargo notes. "Another major problem we face is the devaluation of the dollar. Some years we lose a third of the anticipated budget because of the exchange rate." There are other concerns, such as a possible redistribution of land near the study areas, which could change the land use and amplify the negative impacts on the fragments. ■

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