NEWS

A Second Chance for Rainforest Biodiversity

As ever more of the Amazon falls under the ax, a large-scale project is helping to clarify how well various tropical species survive in recovering forests

In 1967, an American billionaire named Daniel Ludwig purchased 16,000 square kilometers of rainforest in Brazil—an area half the size of Belgium. Ludwig, who had made his fortune building supertankers, was betting on a paper shortage and hoped to boost his wealth by growing *Eucalyptus* trees for pulp.

Thinking big, Ludwig shipped a preassembled paper mill from Japan and floated it up the Jari River. He built a new town, and his workers chopped down about 1300 square kilometers of rainforest to make way for the plantations. The rest remained untouched. After a little more than a decade, however, the scheme failed. Stymied by rising energy costs and business setbacks, Ludwig pulled out. Logging continues in the area, but many of the clearcuts have been returning to the wild.

Ludwig's losses have been science's gain. Given the rate at which rainforests are being cleared, some ecologists say there is a growing need to turn more attention to the woods that sprout up in their place. Whether the land is left to its own devices or managed by humans as tree farms, these second-generation ecosystems are coming to dominate the wooded landscape. Attracted by the Jari property's combination of intact rainforest, vast tree plantations, and regenerating forest, Carlos Peres recognized it was a perfect place to figure out which species persist where. "If you're trying to predict the future, this is what you need to do," says Peres. A wildlife biologist at the University of East Anglia in Norwich, U.K., he and his team have now published their follow-up of Ludwig's folly in a series of recent papers.

This research is by no means the first to look at the biodiversity of so-called secondary forests—those allowed to regrow on their own—and plantations, but it is one of the largest and most rigorous assessments in the tropics. "It's comprehensive enough that the results are convincing," says ecologist Robert Dunn of North Carolina State University in Raleigh. Whether those results are good news or bad news, however, is a matter of debate.

"The big take-home message is that there are a lot of species missing" from secondary forests and plantations, Dunn says. And for Peres's team, the findings reinforce the need to conserve the remaining old-growth tropical forests. "Primary forest is even harder to replace than many researchers expect," says Toby Gardner of the Federal University of Lavras in Brazil. "For many species, once these virgin forests have gone there is nowhere else to go."

Drawing on these and other findings, other ecologists

Different fates. The harlequin toad is one of many species that require old-growth forest, whereas the black-spotted barbet can survive in regenerating forest.

CREDIT (TOP): TOBY GARDNER; (BOTTOM LEFT TO RIGHT) JOS BARLOW; JOE HAWES

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Rich habitat. Uncut rainforest near the Jari River in northeastern Brazil.

accentuate the positive. They point to the species that can cope, even thrive, in secondary forests and plantations. "There is a huge opportunity for conserving forest ecosystem functions and biodiversity," says tropical ecologist Daniel Nepstad of the Woods Hole Research Center in Falmouth, Massachusetts. Ultimately, the amount of diversity that persists in the Amazon will be determined by how much land is set aside—and by how hard humans work the rest.

Return of the forests

The statistics are grim for old-growth forests. The United Nations Food and Agriculture Organization estimated in 2005 that just 36% of the world's forests remain relatively untouched by humans. That fraction is disappearing quickly in the tropics, by as much as 12% per year, much of it destroyed by slashing and burning for fields or pasture for cattle.

Yet tropical trees are making something of a comeback. Clear-cut areas and abandoned farms are being turned into timber plantations or being reforested as part of government programs (*Science*, 23 February 2007, p. 1070). In parts of Latin America and elsewhere, trees are planted for side benefits to agriculture, such as shade and the "live fencing" they can provide.

And when the land is left alone, new saplings take hold, blossoming into secondary forests. "The amounts of land involved are absolutely staggering," says S. Joseph Wright of the Smithsonian Tropical Research Institute in Balboa, Panama. According to one global analysis, for every six or seven hectares of tropical forest cut during the 1990s, one hectare regrew (*Science*, 9 August 2002, p. 999). Costa Rica and Puerto Rico now have more secondary forest than primary. Because these new landscapes will eventually dwarf the intact forests preserved in national parks and other reserves, ecologists say these reborn places will be critical for the future of tropical biodiversity.

But relatively little is known about the potential of this habitat to serve as a refuge for the same species that depend on old-growth forest. Scientists have tended to focus on tropical forests that show no obvious sign of direct interference, in part because they are storehouses of diversity and are disappearing quickly. "Most secondary forests have been seen as trammeled and uninteresting," says geographer Susanna Hecht of the University of California, Los Angeles (UCLA). In fact, "they're much more diverse than people think."

Most of the research on secondary forests has been done in Costa Rica and other Mesoamerican countries, where original forests were mostly converted to agriculture decades ago. Patches of that land have slowly reverted to forests, whereas the remainder remains in cultivation. Such studies have tended to be small-scale, so the results don't readily apply to the Amazon's immense swaths of deforestation. "From the perspective of conserving rare species, the whole literature missed the effect of scale and disturbance," says Dunn, who published a meta-analysis in *Conservation Biology* in 2004.

New growth. When cleared land is left alone, secondary forests like this one in Mato Grosso, Brazil, can take hold.

Testing for biodiversity

The Jari landholdings have no shortage of large-scale disturbance. Peres, who grew up in the Brazilian Amazon, had visited the plantations as a teenager. Looking for a new research project in 2002, he recalled their vast size and set up shop there to assess the local biodiversity. Working primarily with his Ph.D. students Gardner and Jos Barlow, Peres initially surveyed a half-dozen major kinds of animals. But as collaborations flourished with Brazilian taxonomists from the Goeldi Natural History Museum in Belém, Brazil, that number swelled to 16 groups of vertebrates, invertebrates, and plants.

Half the battle was logistical: It was a struggle to keep the team's cars running given the daily 200 kilometers of off-road driving between field sites. Another strain was cutting transects through dense thickets of regrowth—hot, humid forests dominated by 10-meter-tall palms. "It was a crazy few years in the field," recalls Barlow, now at Lancaster University in the U.K.

Unlike many other tropical researchers, the team was able to set up multiple field sites, five each of primary forest, secondary forest, and *Eucalyptus* plantations. The sites were also extremely large—averaging 26 square kilometers for the secondary forest plots, up to 1000 times larger than field plots in previous studies.

Large plots allowed the team to minimize so-called edge effects. If animals spotted by observers are simply visiting the secondary forest from nearby primary forest, they will inflate the estimate of biodiversity that would exist, say, in a forest tract that is isolated in "a sea of soy," Gardner explains. "We maximized our ability to understand what lives in the landscape." And because the primary forest study sites are both large and surrounded by many more hectares of intact forest, they could get an accurate baseline of prelogging biodiversity.

The study's good news was that the secondary forests restored some of the ecosystem functions of the primary forests. The rate of decomposition of fallen leaves, which replenishes the soil, was about the same in primary and secondary forests (it was much lower in the plantations), the team reported with Leandro Ferreira of the Goeldi Museum in the August 2007 issue of *Forest Ecology and Management*.

But for many creatures, the news was bad (see chart, p. 1438). Secondary forests had

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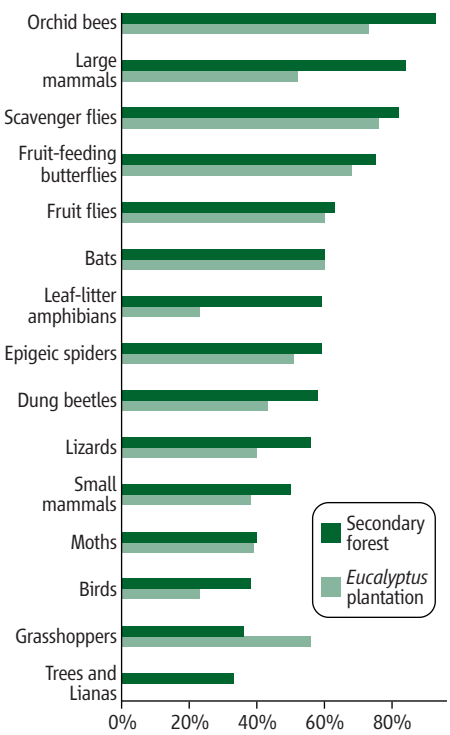
less than 40% of the bird species found in the Jari primary forest, and those present were those that prefer disturbed areas. The 14- to 19-year-old secondary forests "clearly failed to compensate for the loss of primary habitats and the habitat specialists they contain," the team concluded in the April 2007 issue of *Biological Conservation*. Amphibians, trees, and woody vines called liana that are common in tropical rainforests were also particularly depauperate.



Biodiversity index. The percentage of old-growth forest species that survive in *Eucalyptus* plantations (*above*) and secondary forests varies from group to group, habitat to habitat.

Plantations were even less suitable refuges for most old-growth taxa. The rows of 4- to 6-year-old *Eucalytpus* trees had just 20% of bird species in primary forest. Yet bats and fruit flies did just as well in plantations as in secondary forests, and grasshoppers did better. A summary paper published in the 20 November 2007 *Proceedings of the National Academy of Sciences* charted all the trends.

Decreased animal diversity is cause for concern about the health of secondary forests, the team says. In a paper published in the May *Journal of Applied Ecology*, Malva Hernández of the Universidade Federal da Paraíba, Brazil, and others reported that the "exceptionally impoverished" dung beetle communities in secondary forests could have ecological repercussions, as the beetles bury many kinds of seeds, helping to repopulate the flora. Studies of dung beetles elsewhere have not seen such a stark difference in their diversity among habitats, but the team says the larger study plots make the new findings more reliable.

For some groups, total diversity—not just old-growth species—didn't change much. Species richness of scavenger flies and mammals, for example, was not measurably different between the three habitats studied by Peres and his colleagues. However, the species were not the same from one forest type to another. In the November issue of the *Journal of Tropical Ecology*, undergraduate Luke Parry of the University of East Anglia and the Jari team reported that secondary forests had more ungulate browsers but fewer fruit-eating monkeys and particularly lacked vertebrates that disperse large seeds.

The fieldwork has wrapped up, and now the team is refining its estimates of how much diversity is lost when forests are cut down and then regrow. Overall, Barlow says, the latest work is showing that widespread conversion of primary habitats to secondary forests results in species losses worse than they reported in November: Tree diversity dropped by as much as 86%, for example. "These results highlight the overwhelming importance of primary forest," he notes.

A bright side

In some ways, the results from the Jari landholdings foretell a dire future for forest biodiversity in the rest of the Amazon. Clear-cutting and burning of primary forests, such as what this area endured in the 1970s, are particularly damaging to any next generation of forest because those practices compact soil and alter its chemistry. The loss of tree canopy also makes the land reflect less sunlight; over large areas this change influences weather, reducing rainfall and drying the soil. The altered environs drive away animals. Once they vanish, plants that rely on those species to disperse their seeds have trouble reproducing and may not get reestablished. These severe impacts continue across the Amazon today.

Moreover, secondary forests throughout the Amazon aren't given enough time to recover the biodiversity of primary forests. "For some [taxonomic] groups, it may take 200 to 300 years to get a pale shadow of what a primary forest contains," Peres says. In Jari and elsewhere, regrowing forests are logged within 2 decades, and the plantations are cut even more frequently.

But that hardly makes them worthless. Secondary forests can have their own conservation benefits, says David Lindenmayer of Australian National University in Canberra. In some places, they provide a buffer around protected forests, dampening the impact of development and other human activities. And secondary forests usually benefit species that do best in disturbed areas, Lindenmayer notes.

Furthermore, other species can often do just fine with just a semblance of old-growth forest structure—an understory and a canopy with trees and gaps of various sizes, for example. "It's not actually the whole forest that needs to be [old-growth]," he says.

As has been shown in temperate and tropical forests, foresters can salvage biodiversity by retaining some of the largest trees. A few giants can have "a big effect on plantations," Lindenmayer points out. Within secondary forests, an approach called selective logging—where most of the forest is left in place—can make a huge difference, says UCLA ecologist Stephen Hubbell. If this practice is widely adopted, secondary forest "biodiversity will be okay," he says.

Peres's team hopes to continue working in the Jari area, identifying other ways that the biodiversity can be enhanced in the plantations. And even though the loss of biodiversity in the plantations is sobering, Barlow says the overall situation in Jari may be positive. The Brazilian company that owns the land behind Ludwig's grand scheme is now making a profit selling pulp from the plantations and is only selectively logging the primary forest.

–ERIK STOKSTAD