CONSERVATION BIOLOGY

Combined Insults Spell Trouble for Rainforests

Interactions among fire, El Niño–driven drought, and fragmentation are increasingly putting tropical forests at risk

For tropical ecologist William Laurance, the most striking thing about walking through a parched rainforest is the sound. He likens it to walking on cornflakes. Leaves and branches crackle underfoot. Rather than a thin layer of soggy leaves, ankle-deep dry debris covers the ground and provides fuel for fire that will further desiccate the forest, priming it for repeated burning.

The ferocity and frequency of fires in the rainforests of Brazil and Borneo reached new heights during the 1997–98 El Niño, and scientists are now saying that a combination of interacting factors—including forest fragmentation, logging, and El Niño–driven drought—has altered the forests' fire regimes and is changing regional climates and reconfiguring the landscape. These interactions are synergistic, they say—that is, the whole is greater than the sum of its parts. The concept provides a new paradigm for understanding the dynamics of fragmented rainforests and for approaching their conservation, says William Laurance of the Smithsonian Institution and Brazil's National Institute for Amazonian Research.*

The Amazon and Borneo support two of the world's largest remaining rainforests. About 14% of the Amazon's 5 million square kilometers is already deforested, says Laurance, and up to 40% of the forest suffers from the damaging effects of fragmentation. In Borneo, the situation is even more dire. About 80% of forest cover has been allocated to commercial logging and industrial plantations, says Lisa Curran, a tropical ecologist at the University of Michigan, Ann Arbor. In both regions, synergistic interactions are establishing "critical thresholds for deforestation above which the system may collapse," she says.

Laurance contends that this new awareness of synergistic interactions calls for rethinking conservation goals in the Amazon. Currently, about 3% to 4% of the Amazon is fully protected, with plans to protect 10%. But Laurance considers this goal inadequate, in part because it is based on an outmoded scientific view of fragmented landscapes.

* Synergisms in fragmented landscapes were discussed last month during the Society for Conservation Biology meeting in Missoula, Montana, and are the subject of a number of forthcoming publications.

Although scientists have studied forest fragments for 3 decades, Laurance contends that their theoretical models have been dangerously simplistic. Most use the prism of landscape ecology, emphasizing edge effects—ecological changes associated with the artificial boundaries of fragments—as well as the size, shape, and connectivity of fragments, and the quality of their surrounding habitats. "The notion of synergisms is one more step toward reality," Laurance contends. Curran concurs: "Synergisms look at complexity and ecological processes," she says. Unique ecology, land use, and climate may all work in concert to change forest dynamics—sometimes in unpredictable ways. The outcome depends on the net effects.

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Going fast. Extensive logging and more frequent fires are destroying the rainforests of Borneo—and their unique ecology.

In Borneo, the net effects appear devastating. At work are an intensified El Niño and extensive logging and clearing of the land for plantations, which together are undermining an exceptional ecosystem. The Borneo rainforest is unique: Most of the canopy trees are dipterocarps that arc high across the canopy, distinguished by their method of reproduction, which is limited to El Niño years. When El Niño hits, hundreds of species of dipterocarps across 150,000 km^2 of forest reproduce in synchrony. Triggered by the dry warmth, they flower, fruit, and within a 6-week period, disperse their seeds (*Science*, 10 December 1999, p. 2184). The bounty on the forest floor initiates a feeding frenzy by orangutans, wild boar, parakeets, and other animals. It also provides a valued resource for local people who gather the seed for use or sale. The seeds are so abundant that some remain to sprout.

But Curran has found that the ecosystem is breaking down. In her study area, deep within a protected national park on Indonesian Borneo, many dipterocarp species have failed to produce a single seedling since 1991, and Curran blames interactions between drought and deforestation: "El Niño, the creator, has turned into the destroyer." In the last 2 decades, El Niño droughts have become longer and more severe, a trend some scientists think is linked to global climate change. Although the protected national forest where Curran conducts her research is unlogged, many surrounding areas are denuded of trees or destroyed by fire. Therefore, wildlife in these areas stream into the more intact forest when seeds fall. They devour all the seed, leaving none to regenerate. In part because seed production can no longer keep up with wildlife, populations are plummeting, says Curran, citing the decline of Bornean orangutans from some 15,000 to 7000 in the last decade.

There's another negative synergy involving seed dispersal. The trees' synchronized reproduction requires vast spatial areas. With reduced forest cover, the trees produce less seed—and less viable seed. Furthermore, as El Niño droughts have intensified, fires in the rainforest have worsened. During the 1997–98 El Niño in Indonesia, about 10 million hectares, an area the size of Costa Rica, went up in flames.

Smoke from those fires kills vulnerable seedlings and causes health problems for people and wildlife. And it creates another kind of feedback. Last year, in an article in *Geophysical Research Letters*, Daniel Rosenfeld of the Hebrew University of Jerusalem showed that heavy smoke from forest fires can nearly shut down rainfall in tropical areas. Using cloud observations gathered by the Tropical Rainfall Measuring Mission satellite over Borneo, he determined that the particulate matter of smoke forms so many tiny condensation nuclei that no single water droplet gets big enough to fall. As a result, the moisture is spirited away in the smoke. Thus drought, fire, and smoke are affecting the regional climate, causing yet more drought, fire, and smoke.

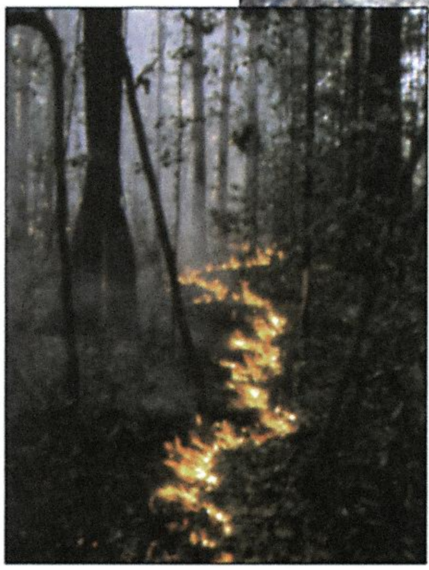
Very similar forces are also drying the Amazon. There, to probe the synergism between forest fragmentation and fire, ecologist Mark Cochrane at Michigan State University in East Lansing analyzed satellite images of two fragmented areas in the eastern Amazon over 12 to 14 years. Biologists already knew that trees near the edges of fragments have high rates of mortality. Wind shear from surrounding cleared areas can snap off tree crowns, and the woody vines that rope trees together ensure that when one tree falls it drags others along. But Cochrane suspected that fire amplified these effects.

His two study areas had been rapidly settled and partly deforested following the paving of major roads. In both areas, more than half the forest is now within 300 meters of an edge. And in both regions, Cochrane found, more than 90% of the fires were associated with these edges, demonstrating a clear synergism between fragmentation and fire. "Once fire gets into these forests, it's usually the end of them," says Cochrane, who has submitted this work for publication. "Even light ground fires kill lots of trees, creating fuel for much bigger fires in the future."

Also working in the Amazon, Laurance has found a similar synergism between fragmentation and drought. On 23 1-ha plots containing a total of 16,000 trees, he compared tree mortality data from up to 17 years before the 1997–98 drought with 1 year of data during the drought. "During the drought, mortality increased throughout the forest, but jumped up most within 70 to 100 meters of the edge," he says. In an upcoming paper he reports that average annual mortality increased from 2.44% to 2.93% near edges and from 1.13% to 1.91% in interiors.

Although indigenous people have long used fire to clear space for farming, catastrophic wildfires are recent in the Amazon. Charcoal dating and archaeological evidence suggest that they have occurred only when mega–El Niños caused prolonged droughts, about once every 400 to 700 years. Most of the time, the forest was too wet to burn, even when struck by lightning. But all that has changed. Today, more than half the fires in the Amazon are accidental, caused when blazes set to prepare pasture or agricultural lands burn out of control. Some parts of the Amazon now burn several times a decade.

Today, as in the past, there are great variations in climate across the Amazon. Nearly one-half of the rainforest is at its physiological minimum for water, receiving just enough rainfall to survive. Trees in these southern, eastern, and north-central regions send roots down through 8 or 10 meters of soil to soak up moisture during rainless months. These regions of the Amazon are the most susceptible to drought, for should the soil moisture run out, trees will perish. These are also the regions where El Niño droughts pack their biggest punch.



Up in flames. Initial fires (*left*) in the Amazon may look tame, but repeated burnings destroy the forest.

Daniel Nepstad, an ecologist at the Woods Hole Research Center in Massachusetts, modeled areas of the Amazon forest dry enough to catch fire. In normal years, he estimates that few of the closed-canopy forests are vulnerable. But, by the end of the 1997–98 drought, 1.5 million km^2 were primed to go up in flames—that is, they had less than 250 mm of water moisture in the top 10 meters of soil.

Such findings call for a change in thinking, says Paulo Moutinho, an ecologist with IPAM, a scientific nongovernmental organization based in Belém, Brazil. "Fire in the Amazon may be more important than deforestation, because it is changing the original climate," he says. "In an El Niño–dominated world, we need to expand our vision," agrees Nepstad. "We've been fixated on deforestation and logging as the best measures of human effects on forests. But drought washes over those threats."

As scientists identify ways in which simultaneous ecological changes and land use practices are undermining rainforests, the debate continues over how much forest must be protected to prevent ecosystem collapse—and how best to protect it. Laurance estimates that perhaps half of the Brazilian Amazon must be fully conserved to maintain ecosystem function. "We need to think very big in terms of reserves, surrounded by a multiple-use forest," he says. Tom Lovejoy, a Smithsonian biologist and consultant with the World Bank, thinks that although 50% may not need to be fully protected, more than that needs to be maintained in some kind of tree cover, while allowing for multiple land uses, such as agriculture and forestry. "The magic number no one yet knows is how much forest you need to sustain the hydrologic cycle" through which the Amazon generates nearly one-half of its rainfall, he says.

Ana Cristina Barros, executive director of IPAM, argues as well that a large part of the Amazon should be used by people—for everything from small-scale agriculture to the extraction of forest products to logging. But it is essential at the same time to maintain the forest's hydrological, nutrient, and carbon cycles. "The key question is what is the best distribution of farmland, logged and exploited forest, and pristine forest [needed to preserve biodiversity]," she says.

The Brazilian government and international donors have earmarked several hundred thousand dollars for Amazon conservation over the next 10 years. Yet, as part of a \$40 billion nationwide infrastructure development program, Avança Brazil, the government also plans to pave some 4600 km of road in Amazonia, says Barros. If the past is any guide, she says, this will lead to more deforestation. Indeed, about three-fourths of deforestation in the region occurs within 50 km of major paved highways. Nepstad, too, argues that much of this fresh asphalt is unnecessary. Rather than opening up remote forest to development, he advocates intensifying development in the Amazon's 550,000 km^2 that have already been deforested yet are largely underutilized.

Lovejoy proposes using the Kyoto climate accord's Clean Development Mechanism to help conserve rainforest. It is, he says, "the single most important thing that can be done to slow tropical deforestation."

CREDITS: M. A. COCHRANE/BASIC SCIENCE AND REMOTE SENSING INITIATIVE, DEPARTMENT OF GEOGRAPHY

This mechanism enables companies and countries to offset their own carbon emissions by paying another for an ecosystem service. In this case, Brazil might receive payments for agreeing to preserve trees that would otherwise be burned and release carbon dioxide, a potent greenhouse gas, into the air. At the next meeting of the Conference of the Parties on the Climate Convention in November, delegates will decide whether this mechanism can be applied to protecting standing forests.

Nepstad estimates that the Amazon stores 70 billion tons of carbon. The World Bank has estimated that Indonesia's fires in 1997 alone contributed more carbon to the atmosphere than did all humanmade sources in North America—about 30% of all anthropogenic global carbon emissions. Curran is in the process of calculating the amount of carbon stored in the dipterocarp forests in Borneo, which she suspects is substantial. In addition to the carbon contained in their wood, dipterocarps form unique symbiosis between their roots and fungi, and as a result potentially store tons of carbon in roots below ground. Says Curran: "The challenge is to show local and regional governments that these forests are worth something standing, that they're worth more alive than dead."

But the outcome of the November debate is far from certain. Nepstad points out that the Brazilian governmental delegation itself opposes including standing forests as part of the Clean Development equation. One thing is for certain: While the debate smolders, so do fires in the rainforest.

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BIOMEDICINE

New Insights Into Type 2 Diabetes

After discarding the old dogma, researchers are converging on a new hypothesis to explain this prevalent metabolic disorder

After 30 years of chasing leads down one blind alley after another, researchers studying type 2 diabetes are optimistic that they are closing in on the elusive causes of the world's most prevalent metabolic disorder—although no one is willing to bet the bank on it. Using both biochemical and genetic approaches, diabetes researchers have identified multiple intracellular signaling pathways that appear to lie at the heart of this condition, which affects some 250 million people worldwide and is the leading cause of blindness, kidney failure, and amputation among adults.

And in the process, they have thrown out much of the dogma of the past 10 years. The hallmark of type 2 diabetes is insulin resistance, a defect in the body's ability to remove glucose from the bloodstream despite the presence of normal or even elevated levels of insulin. For years, researchers thought a simple explanation, such as a malfunction in the insulin receptor, might lie behind this puzzling defect. But a decade of research has failed to turn up a direct link between insulin receptor malfunction and the disease, except for the rare mutation that accounts for less than 5% of cases. Indeed, "nearly every major feature of this disease that we thought was true 10 years ago turned out to be wrong," says Morris White, a molecular biologist at the Joslin Diabetes Center in Boston. "We used to think type 2 diabetes was an insulin receptor problem, and it's not. We used to think it was solely a problem of insulin resistance, and it's not. We used to think that muscle and fat were the primary tissues involved, and they are not."

Now researchers are converging on a more complex explanation. Work from several groups, published over the past few months, suggests that the disease is triggered when the delicate balance between insulin production and insulin responsiveness goes awry. First, cells in muscle, fat, and liver lose some of their ability to respond fully to insulin, a hormone released by the pancreas after a meal. At the heart of this insulin resistance lie at least two related pathways that normally respond to insulin by signaling cells in these tissues to remove glucose from circulation and convert it into chemical energy stores. In response to growing insulin resistance, pancreatic cells temporarily ratchet up their production of the hormone. But in some people, that's when the second malfunction occurs: The insulin-producing cells give out, and insulin production falls. Researchers are only now gaining insight into the molecular mechanisms involved in this failure, says White. "It's only then, when the body loses the fine-tuned balance between insulin action and insulin secretion, that type 2 diabetes results."

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>
> —Morris White

If this picture proves correct, the results could be significant for the growing number of people with this disorder. "If we're right about the pathways that we think are involved, then the treatment of type 2 diabetes should be completely different in 5 years," says Domenico Accili, a geneticist and head of the diabetes research unit at Columbia University.

But not everyone is convinced. The most intriguing support for this new view has come largely from studies in knockout mice. Unfortunately, research into the human genetics of type 2 diabetes doesn't necessarily mesh with those animal data. Graeme Bell, for one, a University of Chicago geneticist who has spent over a decade searching for human genes related to type 2 diabetes, is skeptical. Bell believes that there will prove to be just a few biochemical pathways involved, but he's not sure that the ones now under scrutiny are the true culprits: "We still have work to do to pin down the causes of this disorder."

Even supporters of the new view caution that it's premature to declare victory. "I do think we've identified many of the major biochemical pathways involved in this disorder, but we still don't know why these pathways are not working properly, and that's a critical piece of the puzzle we're missing," concedes Steven Shoelson, a senior researcher at Joslin.

The shift in thinking began in the mid-1990s, when, after the insulin receptor proved to be a dead end, investigators turned to probing the intracellular signaling apparatus that responds when insulin binds to and activates its receptor. Some of the first leads came from White and members of his lab, who were studying mice with inherited defects in glucose metabolism. In the process they discovered two related proteins that are activated inside a cell when insulin binds to the insulin receptor. Named IRS-1 and IRS-2, these two proteins serve as docking stations for numerous other intracellular proteins. When assembled, the resulting molecular complex turns on a multistep signaling pathway that activates the glu-