Over the last 30 years our understanding of the effects of wildfire on tropical forest environments has expanded enormously. To introduce readers to this topic, we asked Christopher Uhl to recount some of his experiences studying fire in the humid tropics. His account sets the stage for four short contributions that compose this installment of Issues in International Conservation.

Joshua R. Ginsberg

Perspectives on Wildfire in the Humid Tropics

In the early 1970s, most ecologists regarded tropical rainforests as ancient, stable, and immune to fire. My first experience with fire in tropical forests occurred in 1974. I was studying slash-and-burn agriculture in the Upper Rio Negro region of Amazonia. When I set fire to our experimental slash-and-burn plot, flames raged across the small jungle clearing. I rushed to make a fire break but to my amazement the fire died out near the edge of the clearing. Later I walked into the forest and tried to start a fire. Although it hadn't rained in almost two weeks, the litter layer was too moist to burn.

A few years later Boone Kauffman, a fire ecologist from Oregon state, visited the Rio Negro forest. Kauffman referred to the litter on the forest floor as "fuel" and observed that there was more than enough "fuel" to carry a fire in these Rio Negro forests. But even when we artificially excluded rain from the forest floor for more than a month and tried repeatedly to coax a fire to life with a drip torch, we were unsuccessful. These forests seemed to be immune to fire; the moist air in the forest understory (relative humidity usually over 90%) had very limited drying power. It appeared that the only way to burn this forest was to cut it down and let it bake in the sun for many days, which is the approach taken by local farmers.

It is a common, albeit unfortunate, experience for researchers to fail to recognize something important right before their eyes. Digging soil pits in the Upper Rio Negro in the 1970s, our research team often encountered charcoal in the soil. But at that time we were intently focused on something else—estimating productivity and ecosystem nutrient stocks and fluxes. We regarded soil charcoal as an inconvenience: should we lump it into the soil compartment or should we consider it a separate compartment?

Later we began to see soil charcoal as intriguing in its own right. It had a story to tell. Using radiocarbon dating we determined that fires had occurred in this region roughly 250, 400, 650, 1500, 3000, and 6000 years ago (Sanford et al. 1985; Clark & Uhl 1987). Later, archeologist Betty Meggars found that the Rio Negro carbon-14 dates corresponded roughly to discontinuities in the ceramic patterns of Amerindian populations. She hypothesized that severe "Mega-Niño" events occurred roughly 400, 700, 1000, and 1500 years ago, and she proposed that the droughts caused by these events were severe enough to cause widespread fire and lead to the dispersal of Indian populations (Meggars 1994).

In the early 1980s, while we were examining soil charcoal and wondering about fire in Amazonian pre-history, a major ecological catastrophe was unfolding in the tropical forests of East Kalimantan, Indonesia, and fire was at center stage. A prolonged drought combined with light logging had rendered these forests flammable; tens of thousands of square kilometers burned.

Soon afterwards, we saw the potential for the same sort of eco-catastrophe in Amazonia (Uhl & Buschbacher 1985). Removing a half dozen trees per hectare (typical of Amazonian selective logging operations) created punctures in the forest canopy, allowing solar radiation to heat the ground and dry out the "fuels" on the forest floor. Amazonian ecosystems, especially in areas such as eastern Amazonia with a strong seasonal component to rainfall, were not as effectively buffered from fire as we had thought.

Before the 1990s the study of fire and its impact on plant and animal communities had been largely restricted to temperate and boreal communities. Now, ecologists in tropical moist environments are beginning to turn their attention to fire and its impacts. The four contributions that follow provide a sampling of what we are learning and its relevance to conservation biology.

The first selection, by David Hammond and Hans ter Steege, offers a long-term perspective on fire in tropical forests. These researchers present evidence of past wildfires in Guiana and for correlation of fires with severe El Niño events. The second article, by Mark Cochrane and Mark Schulze, considers the characteristics of mod-

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ern-day rainforest fires. These researchers observe that Amazonian wildfires are restricted to the ground layer and appear to cause only mild damage. Nevertheless, a first burning, by opening the canopy a bit, often creates conditions propitious for a second fire. Second fires, in turn, often lead to third fires. With each subsequent burn, the effects on the flora and fauna intensify until the forest ceases to exist.

The contribution by Daniel Nepstad places the research of Cochrane and Schulze into an Amazon-wide context. Combining information on climate, soil moisture, and land-use activities, Nepstad provides a map of fire risk for the entire basin. His map reveals that an immense area of Amazonia (perhaps as much as 1 million km^2) is capable of ignition during prolonged dry spells.

The final report, by Margaret Kinnaird and Timothy O'Brien, reveals that fire conditions and characteristics in Indonesia are strikingly similar to those in tropical South America. In 1997 a portion of the Indonesian national park (Bukit Barisan Selatan) where these researchers had established their study sites accidentally burned. Now they are transforming this misfortune into a research opportunity by carefully documenting changes in wildlife abundance and behavior following this large wildfire.

It has taken us almost 30 years to fully appreciate the significance of fire in tropical rainforest ecosystems. First came the realization that fire has been a part of the disturbance history of many tropical forests. Next came the observation that these forests can actually burn today. It only takes a strong El Niño event or a bit of open canopy, such as that caused by light logging, to tip the balance from a fire-resistant to fire-ready forest. Now we are faced with the most surprising revelation of all: these first fire events are capable of setting a positive feedback system in motion that could lead to the progressive impoverishment and degradation of vast expanses of tropical forest. Indeed, fire adds a whole new dimension to tropical disturbance ecology. No other disturbance has this self-reinforcing character with the potential to occur on such a grand scale.

Much research needs to be done to fully characterize the ecological impacts of fire. It is likely that the extensive fires in Brazil and Indonesia have already eliminated thousands of species (ground-dwelling organisms with limited ranges are especially vulnerable to extinction). Even for those species that survive, these grand fires might be among the largest biological selection events in modern history.

Christopher Uhl

Department of Biology, Pennsylvania State University, 208 Mueller Lab, University Park, PA 16802, U.S.A., email cful@psu.edu

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