Amazon Dieback and the 21st Century

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The World Bank's Amazon dieback report appraises the risk that climate change poses to the world's great tropical rainforest, carbon sink, and biodiversity repository.

In the period of colonial conquest and later during the industrial age's boom-and-bust rubber trade, Amazonian peoples suffered huge declines. Yet the great tropical forest in which they lived—in Amazonia expert John Hemming's words, "the world's richest ecosystem," with its immensity as its best safeguard—survived. In the second half of the 20th century, however, expanding highways, dams, settlement programs, agriculture, and especially direct deforestation alarmingly altered vast areas of the Amazonian landscape. This, in turn, spurred diverse efforts to preserve the tropical forest and further advance indigenous peoples' rights in the Amazon.

Peru's Rio Alto Madre de Dios (pictured) is the headwaters of Brazil's Madeira River, one of the great tributaries entering the Amazon River from the southwest. The eastern slopes of the Andes are the source of most of the Amazon's sediments and where much of the forest diversity thrives. Migratory fish also spawn in these Andean headwaters after returning from long journeys downstream. Photograph: Michael Goulding.

Though this conservation effort has achieved some significant victories, recent studies of the impact of climate change on the Amazon add new urgency. The current trajectory of greenhouse gas emissions—especially when paired with land-use stresses—places vast stretches of Amazon tropical forest at risk of "Amazon dieback," or transmutation to savanna or other less biodiverse landscapes. Scientists have also begun talking about tipping points, which are reached when enough tropical biomass is lost to cause large areas of the Amazon to precipitously and irretrievably shift to biologically impoverished biomes.

The effect of Amazon dieback would not just be the tragic loss of the world's largest, most speciose tropical rainforest. The release of the Amazon's stored carbon could have a major cascading effect on the stability of Earth's biosphere, comparable to losing permafrost or the Antarctic and Greenland ice sheets. Climate scientist Carlos Nobre, who heads the Earth System Science Center at Brazil's National Institute for Space Research (INPE) and has conducted dieback-related research for more than 20 years,

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emphasizes the risk dieback poses to the Amazon's ability to regulate climate. He points out that the Amazon basin stores an estimated 90 billion to 120 billion metric tons of carbon, delivers 18 percent of the freshwater flowing into the oceans, and dissipates solar heat from Earth's surface to the atmosphere through evaporation and cloud condensation. "The Amazon is a key regional entity of the stability of the Earth system," Nobre says.

The World Bank's Amazon dieback report

In 2005 the World Bank decided to further scientific understanding of Amazon dieback and produce a paper that would also inform decisionmakers. On 7 December 2010, the World Bank officially presented its landmark report, *Assessment of the Risk of Amazon Dieback*, at its "Brazilian Knowledge Day" seminar, held at bank headquarters in Washington, DC. Just two days earlier, the study's World Bank lead, Walter Vergara, presented the report at a public "Forest Day" event in Cancun, during the United Nations Framework Convention on Climate Change (UNFCCC) negotiations.

The report describes Amazon dieback as "the process by which the Amazon basin loses biomass density as a consequence of changes in climate," and characterizes dieback as a reduction in biomass carbon of 25 percent or more. The World Bank report points to a high risk for dieback in southern and eastern parts of the Amazon and uncertainty for all regions, especially because the report used more conservative IPCC (Intergovernmental Panel on Climate Change) estimates for greenhouse gas emissions.

Biologist Tom Lovejoy, who has worked in the Amazon for almost 40 years and chaired the report's outside review panel, sketches a bleak forecast: "Were Amazon dieback to occur it would have huge consequences in biodiversity loss, much of which is distinct in that part of the Amazon. It would have dire consequences for people living there and of course particularly for indigenous people. An enormous pulse of carbon would go up in the atmosphere as the forest turned into savannah."

Not all the news is bad: On 1 December 2010, the INPE announced that the rate of Amazon deforestation for 2009–2010 was the lowest since 1988, when the INPE first conducted its deforestation survey. Moreover, the UNFCCC at Cancun advanced consensus on its REDD (reducing emissions from deforestation and forest degradation) agenda, initiated in Bali, Indonesia, in 2007. However, 2010 was also a year of drought in the Amazon, which, alongside 2005's worst drought on record, substantiates concerns that extreme weather threatens the Amazon region in this century. The World Bank report makes clear that Amazon dieback, with its regional and global ecological repercussions, must be avoided. "This is a threshold that should not be tested," Vergara says. "The results of the study add to the urgency to restrict global greenhouse gas emissions."

Brazilian climate scientist Carlos Nobre has played a leading role in understanding Amazon dieback. His seminal study, published in 1991, examined deforestation and its simulated impact on rainfall and temperature in the Amazon. His recent research includes a focus on tipping points for Amazon dieback. Photograph: INPE.

Extreme weather in the Amazon region includes droughts in 2005 and 2010, and the most rainfall ever in 2009. The Purus River (pictured), a low-lying tributary of the Amazon, suffered from the 2010 drought and ensuing low-water extreme. Low waters can lead to loss of lake connectivity, which diminishes water quality. More ups and downs in the Amazon's climate should be expected, Nobre says, with forests experiencing both floods and droughts that can lead to fire. Photograph: Eduardo Arraut/INPE.

Decades of science to build on

Vergara, who heads the Global Expert Team on Climate Change Adaptation at the World Bank and is lead engineer of its Environment Department, initiated the idea of a World Bank study on Amazon dieback while presenting his work on climate adaptation at a UNFCCC subsidiary meeting in 2005. Vergara explains that the World Bank's unique convening ability brought together scientific teams from different continents and different specializations, facilitating synergies and advancing models of the complex factors that converge to cause Amazon dieback. The World Bank also engaged important stakeholders in the work and presented the Amazon dieback team's findings to policymakers in Brazil and elsewhere during the study's ongoing process. "A key function of the bank is to facilitate the link between knowledge and science and decisionmaking," Vergara explains.

Anthropologist Maritta Koch-Weser, who heads the Earth3000 organization and contributed to the study with a background paper on the social aspects of Amazon dieback, points to the World Bank's long involvement in the Amazon as especially pertinent to this dieback work. The upshot of these decades of experience, Koch-Wesser notes, is that "the Amazon has shaped the evolution of thinking at the World Bank.… The Amazon has been a case that has taught us all."

The new report also builds on decades of biological and meteorological research on the ecological stability of the Amazon. Lovejoy, whose early advances in understanding biodiversity coincided with his work in the Amazon, believes that scientific thinking on dieback has roots in the 1970s in the paradigm-shifting work of Brazilian physicist Eneas Salati, whose research undermined the notion that vegetation was "just the consequence of climate." Salati analyzed the ratios of oxygen isotopes found in clouds and rainwater, from the Atlantic Ocean in the east to the Brazilian border in the west, and demonstrated that the "Amazon had a hydrological cycle that generated roughly half of its own rainfall." Salati, Lovejoy, and others subsequently wrote about the effects of deforestation on the hydrologic cycle.

Also among the significant scientific contributions to understanding dieback is Nobre's work on permanent

The forest at Paraná do Jarauá (pictured), Mamirauá Sustainable Development Reserve, flooded in the 2009 high-water season. Though Amazonian forests have inspired scientists and visitors with their unmatched biological diversity, the forest is also home for indigenous peoples who suffered greatly for centuries under foreign intrusions. The tropical forest thrives because it is generally contiguous, but climate change and a continuing legacy of land conversion raise serious concerns among scientists assessing the future of the Amazon. Photograph: Eduardo Arraut/INPE.

biome loss and weather impacts arising from Amazonian deforestation, published in 1991, and his later work postulating a two-state, "bistability" of forest and savannah biomes in previously forested Amazon regions. Ecologist Daniel Nepstad's diverse investigations on the Amazon and factors influencing dieback include such impacts as deforestation, fire, and the drying out of the forest and its soil. And geoscientist Peter Cox and climate modelers at Exeter University and the Hadley Centre for prediction and Research have improved estimates of the effects of global temperature rise on the tropical forest and the likelihood of dieback.

Many other scientists have studied dieback-related facets of the Amazon region for many years. However, the World Bank effort is unprecedented for its coordination of diverse science centers with unique capabilities.

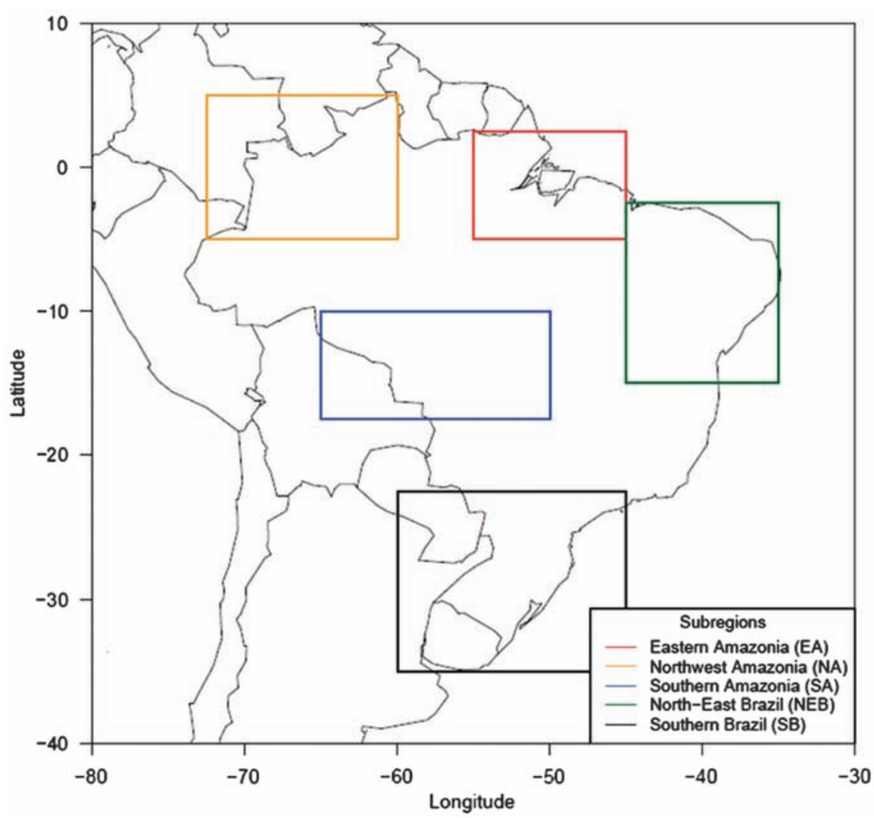
Report findings and open questions

The World Bank steered scientific centers around the world to look at climate change's impact on the Amazon rainforest and to estimate future changes in rainfall and vegetation, as well as how deforestation and fire compound these impacts. The Meteorological Research Institute of Japan and Exeter University of Great Britain provided advanced model predictions for climate and precipitation in the Amazon. The German Potsdam Institute for Climate Impact Research used its advanced Lund-Potsdam-Jena managed land (LPJmL) dynamic global vegetation and water balance model to look at expected vegetation responses to climate impacts. The Center for Weather Forecasting and Climate Studies (CPTEC) in Brazil collaborated with the INPE to integrate climate and biomass findings with land-use conversions resulting from deforestation and fire.

All groups focused their work on five regional domains: Eastern Amazonia, Northwest Amazonia, Southern Amazonia, Northeast Brazil, and Southern Brazil. Ecologist Michael Goulding, who coauthored *The Smithsonian Atlas of the Amazon* (Smithsonian Books, 2003) and did not participate in the World Bank study, says that the five domains are "not natural units but rather windows that represent the logical need for constraints for mathematical models." Northwest Amazonia, for example, does not include areas of the Amazon basin located in Ecuador and Columbia, where there is "already considerable deforestation and probably hydrologic changes."

The most significantly at-risk domains are Southern and Eastern Amazonia. Northwest Amazonia shows signs of resiliency (if conserved), but "growing anthropogenic impacts" are already affecting northeastern Brazil. In its assessment of the different regions, the report concludes that "for Southern Amazonia, two scenarios indicate a relative increase in the area of savanna," ranging from 30 to 87 percent. "The deforestation contributes…with a drier and hotter climate, favoring savanna expansion in place of tropical forests. In this region, fire has an important effect." It bears noting that the report also highlights uncertainties that warrant more study.

Nobre, who led the CPTEC/INPE contribution, points out that his team's input helped bring to the public "for the first time…knowledge of the synergies of global warming, deforestation, and fire in the Amazon." He highlights that his team gained a great deal from the international collaboration, but he emphasizes how the World Bank effort underscores the genuine scientific contributions coming from the South, or developing world. "In general, there is an ignoring of good science in the 'South,'" he says. "You have to realize that there is very good



The World Bank's 2010 report,* Assessment of the Risk of Amazon Dieback, *is the product of five years of collaboration. The report investigated the likelihood of Amazon dieback in the five regions highlighted in this map. Two areas, in southern and eastern Brazil, are not considered to be part of the Amazon region proper. Graphic: Courtesy of INPE.

science in the 'South' and look at the rapid emergence of world-class developing-nation science centers."

In terms of the report's overall conclusions, Nobre says, finding that the southern and southeastern regions of the Amazon area are much more vulnerable compared with the northwest conveys two messages: "First, you have to prevent deforestation in the west and northwest and maintain it as protected lands as much as possible. That is where the forest is resilient. Second, considering the south and southeast, reduce deforestation, and special effort is needed to save as many species as possible."

Climate scientist Akio Kitoh, who directs the Meteorological Research Institute (MRI) Climate Research Department, led his unit's contribution to identifying "how climate will change in terms of extreme weather events." The MRI global circulation model, Kitoh explains, was generated by MRI's Earth Simulator supercomputer and is considered "the highest resolution climate model in the world" with a 20-kilometer (km) and 60-km mesh. This high refinement is extremely helpful in simulating extreme weather events, such as hurricanes, storms, cyclones, and drought, as other climate models can focus only at a coarser scale on large biomes.

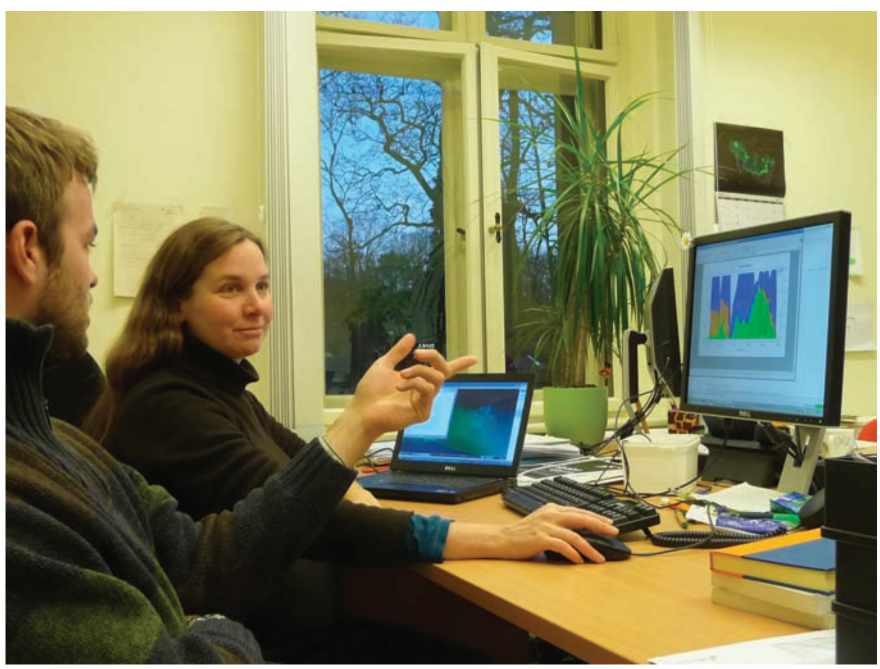
"The biggest surprise," Kitoh says, "is that we have detailed analyses where we found present-day intermittent rainfall even today in the Amazon dry periods. In the future we see almost nothing." As recent droughts demonstrate, extreme dry periods allow openings for fires, which are not natural to the Amazon.

The German Potsdam Institute and its LPJmL model is another example of the World Bank's convening reach. Biologist Anja Rammig, who ran the model for the study, says the LPJmL model combines terrestrial vegetation dynamics and land–atmosphere carbon and water cycles. With data from the Exeter group's global circulation models, the LPJmL model then "explicitly simulates photosynthesis and respiration, the water balance, and the allocation of assimilated carbon to the plant's compartments," she says, "based on climate drivers: temperature, precipitation, solar radiation, and atmospheric CO_2 [carbon dioxide] concentration." The dynamic physiological data assimilated into the LPJmL model give superior estimates of biomass in its living state. "It is the dean of vegetation models," Vergara says. "It is a well-tested model...capable of providing a detailed projection of biomass dynamics."

The report's findings indicate "that the best ranking [global climate] models predict a reduction in density of vegetation carbon in all geographic domains." However, the report and Rammig stress, the different inputs yielded findings that were varied. Moreover, the work with the LPJmL model excluded data on CO_2 fertilization from its biomass calculation, but not from all possibilities. "More CO_2 leads to an increased productivity," Rammig explains, "because of increased carbon assimilation through photosynthesis. Additionally, with a higher atmospheric CO_2 concentration, plants have to open their stomata less in order to get the same amount of CO_2. This decreases transpiration rates and causes plants to lose less water and be more resistant to drought."

If it's a factor, CO_2 fertilization could significantly reduce the loss of biomass from climate stresses. However, CO_2 fertilization is a matter of uncertainty for the Amazon, and there is little consensus about its impacts. A central point of skepticism is that CO_2 fertilization depends on rich nutrient availability. Amazonian soils are known to be short on nutrients, in part because the tall-canopied, rich biomass of the rainforest pulls up whatever nutrients are available. This nutrient-poor soil is also the reason the Amazon is most often unproductive for farming.

"These effects can be observed in plant physiological experiments," Rammig says. "But we currently do not know how big the combined effects are on the ecosystem level.… Much more research is needed for tropical forests."



Biologist Anja Rummig works with a colleague on the Potsdam Institute's LPJmL model, which simulates vegetation responses to climate change. A major reason for bringing the LPJmL model into the World Bank study, she says, was its detailed analysis, using a wide range of climate scenarios, of the potential changes in precipitation and vegetation for the Amazon region in the 21st century. Photograph: Benjamin Bodirsky.

*The dourado catfish (***Brachyplatystoma flavicans***) migrates from the Amazon's Atlantic estuary to the Andean foothills, a distance of 3500 to 5000 kilometers. Here fishers haul dourado, an important food source, at the Teotonio cataracts on the Madeira River in western Brazil. A new dam at Santo Antonio will completely inundate these rapids. Photograph: Michael Goulding.*

Charting first actions

The World Bank's report is explicit about uncertainty and areas for further research, especially about CO_2 fertilization. In addition to ongoing scientific questions, Vergara says, more needs to be done to assess the possible economic impacts of dieback, such as consequences for downstream concerns such as the Latin American agricultural beltway, which depends on Amazonian rainfall.

Most imperatively, say Vergara and others, precautionary measures against Amazon dieback need to be taken. "This is an exercise in looking at the future," Vergara explains. "We have done this study using very conservative baselines for emissions paths. The current emissions path is at a much higher level than what was assumed in the report. The severity of the problem of dieback will increase with higher temperatures and higher rates of emissions…. Even if the probability of dieback is small, which in some regions it is, the massive nature of this event should force actions to prevent it from taking place."

Koch-Weser agrees. She quotes former head of the United Nations Environment Program Klaus Töpfer, who said, "the best forecasts may indeed be those that never happen. It is a key function of forecasts to trigger timely, precautionary, and preventative action." In addition to calling for strategic programs to avert or minimize dieback, Koch-Weser says, "we need to get away from the national perspective on this issue. We need to have much more structural collaboration among the watershed countries. I urge an Amazon-wide vision on this."

Lovejoy says that the World Bank study, "the first to model what the forest itself experiences, namely climate change, deforestation and fire all together," sends "a huge warning signal that the Amazon needs to be managed as a system. The good news is that the margin of safety can be built back by aggressive reforestation in the arc of deforestation. This would seem to be one of the most logical policy responses. Others include taking fresh looks at ways to achieve integration and infrastructure—as well as generation of energy—without undercutting the system."

For more information, visit these sites:

http://go.worldbank.org/9YJI8A2MA0
www.inpe.br/ingles
www.pik-potsdam.de
www.mri-jma.go.jp/Dep/cl/cl.html
www.yesart.co.uk/JH/002b.htm
www.amazonconservation.org

Warning and wonder in the Amazon

Saving the Amazon region, Goulding says, means going back to its central allure, both for indigenous

Walter Vergara, lead engineer of the World Bank's Environment Department, initiated, coordinated, and led the World Bank's dieback study. Here he presents the final version of the report during a "Forest Day" event at the United Nations Framework Convention on Climate Change in December. Photograph: Alexander Buck, courtesy of the World Bank.

cultures and for so many scientists, writers, and explorers. He points to more study on possible dieback impacts on the floodable rainforest, "because the greatest vertebrate biodiversity in all the Amazon is found in flooded forests.… [This is where] fishes, birds, mammals, amphibians, and reptiles all come together in a rainforest in the water." Goulding also emphasizes that REDD and dieback advocates alone will not energize "the wide array of players that have been interested in Amazon conservation.... We need to celebrate the Amazon as an exciting place—nature's most diverse theater of life—by continuing to explore its ecology and biology within the framework of its amazing rivers."

Nobre is also looking ahead and is concerned about what will happen to the Amazon's biodiversity should dieback occur. He sees the need to intensively focus on an early warning system for Amazon dieback, "like the early warning systems we have for natural or health disasters." This system is linked in importance with "more research on what threats to species diversity are we talking about; on assessing what are the risks to biodiversity, in terms of losing species, what kind of species are most vulnerable."

Goulding offers one example that might serve as an early warning signal. "Nothing illustrates the Amazon better as an ecosystem than its fantastic long-distance migratory fish," he says. "The life cycle of some of the species span not only the dieback windows but an area from the Atlantic to the Andes. Fishes such as the dourado catfish use the estuary as their nursery but migrate upstream to spawn in Andean foothills. Adults remain in the western Amazon, but the newborn young migrate 3500 to 5000 kilometers downstream to find the estuary that becomes their nursery. Most anthropogenic changes have been in headwaters, and the most drastic climate changes will be in those areas as well; thus migratory species will be at high risk because of drastically altered hydrologic regimes."

From the great, biodiverse Amazon we can learn to value species threatened by climate change and take steps to avoid compounding its perils, of which we are sufficiently warned.

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