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Chapter 9: Climate Change as a Threat to the Tropical Forests of Amazonia

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I.) INTRODUCTION

Tropical forests are vulnerable to climate change and large areas of these forests will not survive under “business as usual” scenarios. Projected climate changes could threaten the biodiversity of these forests and the traditional peoples and others who depend upon the forests for their livelihoods. It also threatens global economic interests and the environmental services supplied by the forests to locations both near and far from the forests themselves. Greenhouse-gas emissions provoked by forest dieoff are part of a potential positive feedback relationship leading to more warming and more dieoff. The Amazon forest is a focus of concern both because of the particularly severe impacts of climate changes predicted for this area and because the vast extent of this forest gives it a significant role in either intensifying or mitigating future climate change. If all of Brazil’s Amazon forest were replaced with the landscape implied by land-use trends in the region’s deforested areas today, the net committed emission that would be released totals 68.7 Gt CO_2-equivalent C[1], or gigatons (billion metric tons) of carbon in the form of carbon dioxide, with non-CO_2 gases converted to CO_2 equivalents using the global warming potentials adopted under the Kyoto Protocol. The equivalent value for all vegetation types in the tropics as a whole would be 225 Gt CO_2-equivalent C—an astronomical amount were it to enter the atmosphere.

This chapter discusses modeled scenarios for climate change impacts in Amazonia and explains climate-forest interactions that magnify the threat to forest survival. These include synergisms with deforestation and loss of evapotranspiration and feedbacks with El Niño, forest fires and the release of soil carbon. The chapter concludes with an explanation of the role Amazonian rainforests in defining “dangerous” climate change. Unfortunately, the climate has already become dangerous for Amazonian forest.

II.) CLIMATE-FOREST INTERACTION IN AMAZONIA

A.) SCENARIOS

Modeled scenarios for future climate in tropical forest areas vary widely, which can easily be misleading from a policy perspective for three reasons. First, the ghost of resolved uncertainties can continue to haunt not only popular discourse, but also scientific discussion of the topic for years or decades (see.[2]). Second, there is a strong tendency to fall victim to the “Goldilocks fallacy”-- when presented with a range of projections, one naturally assumes that the one in the middle will be “just right,” even though the best result may well be at either the high or the low end of a range of available estimates (see [3]). Third, the existence of uncertainty commonly provokes the response of “let’s wait and see what the experts decide,” when this uncertainty should instead lead to even more vigorous action based on the precautionary principle (*e.g.*[4]).

The case of predicted climate changes and their impacts on Amazonian forest is a highly relevant example of the danger of applying a “Goldilocks” approach to interpreting modeled scenarios. In 2000, the Hadley Center model of the UK Meteorological office (UKMO) was the first model to forecast a catastrophic die off of Amazonian forest by the year 2080 under a business-as-usual scenario[4] (**Insert Figure 9.1 and Caption 9.1**) due to the inclusion of important feedback effects previously ignored. Other global climate models, which lacked these feedbacks, did not indicate any such catastrophe (see review by.C.A. Nobre [5]). By 2005, most of the global climate models had been revised to include feedbacks that had previously been restricted to the Hadley model, with the result that five out of seven models show permanent "El Niño-like conditions" in the Pacific, with reduced rainfall and increased temperature in Amazonia. The Hadley model indicates Amazonia experiencing temperature increases ranging from 8.7°C to 14°C by the end of the century depending on the climate sensitivity.[6] .

This calculation assumed the equilibrium concentration of CO_2 double the pre-industrial level, a mark that should be reached around 2070 if there is no mitigation of the greenhouse effect. Under a business-as-usual emissions scenario, projected increases by 2100 are approximately 40% higher than the corresponding value for climate sensitivity (i.e. 3.5°C as a "most likely" value in 2100 versus 2.5°C for climate sensitivity).

Insert Figure 9.2 and Caption 9.2

An analysis of indicators of past climatic changes has recently reduced the estimates for the probability of the true value of climate sensitivity being at the extreme high end of the range of possible values, the point that corresponds to a 95% margin of safety decreasing from 9.7 to 6.2°C (Fig. 9.3).[8] Proportionally, the 14°C increase in Amazonia in approximately 2070 under high climate sensitivity would fall to an increase of 8.7°C, which would still be a catastrophe that threatens both the forest and the human population in the area.

Insert Figure 9.3 and Caption 9.3

El Niño, the phenomenon where a warming of surface water in the tropical Pacific Ocean triggers changes in air currents that alter rainfall at many places around the world, causes droughts in some locations such as Amazonia and floods in others, such as southern Brazil. A causal connection between climate change and El Niño phenomenon has major policy implications because El Niño weather patterns have unambiguous and devastating global consequences that are known already. Of 21 models, Hadley Center's Had3CM model provides the best representation of the link between sea-surface temperature in the Pacific and Amazonian droughts [9] The connection between water temperatures in the Pacific and Amazonian droughts is known from direct observations and does not rely on model results. Even the more modest climate changes in Amazonia indicated by models with no El Niño connection would be sufficient to cause a large part of the Amazon forest to be replaced by savanna within the current century.[7] [11]

Sea-surface temperatures in the Atlantic Ocean, which are also affected by global warming[12], have a significant effect on droughts in the southern and western parts of Amazonia, as occurred in 2005. [13] The Hadley model indicates a dramatic increase in this kind of drought beginning almost immediately assuming business-as-usual emissions, with the annual probability of such droughts increasing from 5% in 2005 to 50% in 2025 and 90% in 2060.[14]

B.) SYNERGISMS AND FEEDBACKS

Flammability of Amazonian forest is expected to increase under numerous climatic scenarios,[15] which will have significant feedback effects on climate change as carbon is released into the atmosphere and carbon sinks are removed. The logical result of reducing rainfall and increasing temperature is to dry out the litter on the forest floor that serves as fuel for forest fires. Tree mortality increases the amount of litter available to burn, forming a positive feedback loop with fire occurrence. [16] [17] Forest flammability is further increased through logging, which greatly increases the risk of fire by opening canopy and by the logging operations that kill many trees in addition to those that are harvested. [18] [19] [20] In addition, loss of forest both through deforestation and through dieback from climate change would lead to reduced evapotranspiration in the region, thereby cutting off part of the supply of water vapor needed to maintain large amounts of rainfall in the region—forming another positive feedback relationship leading to forest degradation and loss.[21]

Current El Niño conditions already result in wide areas of the region becoming susceptible to fire. [22] [23] [24] Forest fires have become a major threat to forests both in Amazonia and in Southeast Asia. These forests are not adapted to fire, and the thin bark of the trees makes them more susceptible to mortality when fires do occur than is the case for trees such as those in savannas or coniferous forests. In Amazonia, fire entering surrounding forest from burning in agricultural clearings or in cattle pastures was practically unknown to most Amazonian residents prior to the 1982/1983 El Niño event. Nevertheless, droughts caused by severe El Niños in the past resulted in forest burning as in the "big smoke" of 1926 [25] and in four "mega-El Niño" events over the last 2000 years when forest fires left charcoal in the soil.[26] But the 1982/1983 El Niño was a change, with substantial areas burning both in Amazonia and in Indonesia.[27] Fires are favored both by the greater frequency of El Niño and by the greatly increased presence of ignition sources from the spread of human agriculture and ranching in these areas.

Carbon in the biomass of standing Amazonian forests is released to the atmosphere during El Niño events. [28] [29] These forests can subsequently reabsorb the carbon during La Niña and "normal" years, but the observed shift towards more frequent El Niños, together with the prediction of a permanent El Niño after the middle of the current century, suggest that carbon stocks will be steadily drawn down in the remaining forest. Forest degradation takes place under experimentally induced dry conditions in the Amazonian forest that mimic conditions predicted by models.[30] In these experimental plots, where plastic sheeting intercepts 60% of the moisture, large trees are the first to die, thus greatly increasing the release of carbon.[31] The same occurs at forest edges, where microclimatic conditions are hotter and drier than in the interior of a continuous forest. [32] [33]

Unfortunately, fire risk is virtually never included in forest management plans. Logging is rapidly spreading to formerly inaccessible areas of the forest. Outside of fully protected parks and reserves, management for timber is expected to be the use to which large areas of forest will be put. Fire risk will increase in the large areas subject to illegal logging, in legally managed areas on private land and in new areas of public land to be opened for forest management in accord with a law enacted in January 2006 allowing 40-year concessions in up to 13 million hectares of "public forests."

The future role of soil carbon under climate change is a worldwide concern.[34] An early model indicating the possibility of substantial loss of soil carbon in Amazonia was developed by Townsend. [35] The Hadley Center model [36] [37] predictions are much more severe -- by 2080, approximately two-thirds of the soil carbon is lost.

These soil carbon stocks represent a veritable time bomb. As the soil releases its carbon store, global temperatures will rise even more and trigger a "runaway greenhouse effect" that could escape from human control. The magnitude of this feedback effect is staggering since the total of soil carbon emissions potentially exceeds the combined fossil fuel and deforestation emissions from human activity. Unlike emissions from fossil fuels and deforestation, we humans do not have the option of solving the problem by altering our actions. The need for intensified research to quantify soil emissions under different climatic scenarios is urgent.

Insert Figure 9.4
Insert Caption 9.4

IV.) CONCLUSIONS

The consequences of climate change for the Amazon are globally significant due to the important feedback effects of the Amazon forest. Loss of forest in Amazonia, through deforestation and increased fire risk exacerbates the trends driving climate change, especially changes in El Niño effects, while the greenhouse gases released from loss of forest biomass and soil carbon augments carbon forcings. In addition to its substantial contribution to the impacts of climate-change around the world, loss of Amazonian forest destroys other environmental services such as maintenance of biodiversity and water cycling and deprives the region's traditional inhabitants of their livelihoods. Restricting emissions to keep atmospheric CO_2 concentrations from rising much above their current levels would avert this disaster. [38] Stabilizing atmospheric CO_2 concentration at 750 parts per million by volume (ppmv) would stave off the demise of Amazonian forest approximately 100 years, while limiting the concentration to 550 ppmv would postpone the disaster by over 200 years (Fig. 9.4). Limiting the rise in average global temperature to 2°C would be necessary to avoid substantial forest degradation in Amazonia and consequent carbon releases.[39] A global average temperature rise of 2°C is close to the amount of temperature increase that has been set in motion by emissions that have already occurred.[40]

V.) ACKNOWLEDGMENTS

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[1] This estimate is updated from: Fearnside, P.M. 2000. Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. *Climatic Change* 46(1-2): 115-158 based on wood-density adjustments of: Nogueira, E.M., B.W. Nelson and P.M. Fearnside. 2005. Wood density in dense forest in central Amazonia, Brazil. *Forest Ecology and Management* 208(1-3): 261-286, Nogueira, E.M., P.M. Fearnside, B.W. Nelson and M.B. França. 2007. Wood density in forests of Brazil's 'arc of deforestation': Implications for biomass and flux of carbon from land-use change in Amazonia. *Forest Ecology and Management* 248(3): 119-135 and and adjustments for hollow trees and form factor based on Nogueira, E.M., B.W. Nelson and P.M. Fearnside. 2006. Volume and biomass of trees in central Amazonia: Influence of irregularly shaped and hollow trunks. *Forest Ecology and Management* 227(1-2): 14-21 and Nogueira, E.M., P.M. Fearnside, B.W. Nelson, R.I. Barbosa and E.W.H. Keizer. 2008. Estimates of forest biomass in the Brazilian Amazon: New allometric equations and adjustments to biomass from wood-volume inventories. *Forest Ecology and Management* 256(11): 1853-1857; this includes unchanged values for uptake by the replacement landscape (4.9 GtC) and for soil carbon loss to 1 m depth (4.9 GtC); proportionate adjustment applied to the all-tropics value derived in Fearnside, 2000 *op. cit.*

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Figure Legends

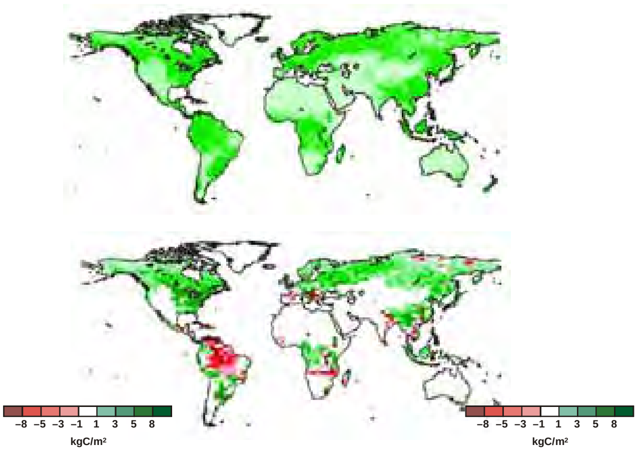
Figure 1. Change in vegetation biomass by 2080 projected with the Hadley center model under median climate sensitivity (61). Subsequent improvements of the model also show collapse of the Amazon forest on the same time scale (19).

Figure 2. Temperature increases over pre-industrial levels under high climate sensitivity (21). These calculations, made using the Hadley Center model at double the pre-industrial CO_2 concentration (*i.e.*, in approximately 2070 in the absence of mitigation), are now out of date due to recent revision of climate sensitivity probabilities (Fig. 3), but the map now represents a close representation of the high climate sensitivity scenario for 2116.

Figure 3. Revision of climate sensitivity, leaving the most probabile value unchanged but reducing the probability of very low or very high sensitivities (Adapted from 22 by 62). Climate sensitivity is the increase in equilibrium global mean temperature above pre-industrial levels when the pre-industrial concentration of atmospheric CO_2 is doubled (*i.e.*, in approximately 2070).

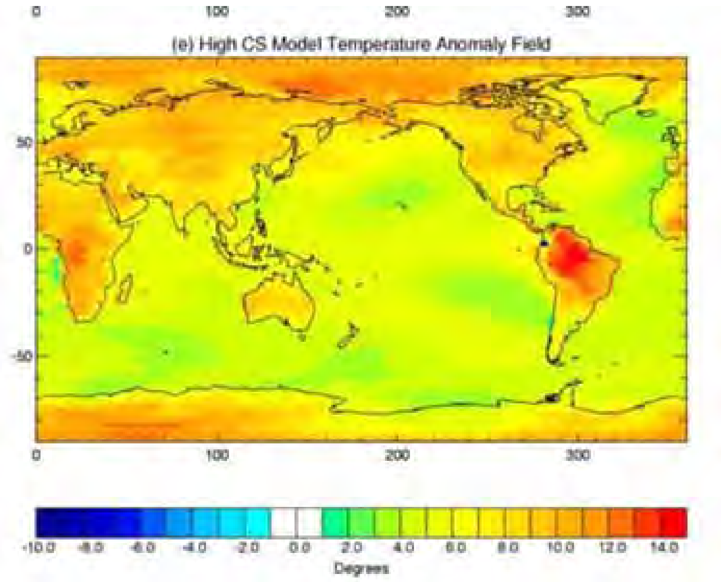
Figure 4. Dieoff of global vegetation at different equilibrium concentrations of atmospheric CO_2 using the Hadley Center model (24). The global vegetation dieoff is dominated by mortality in Amazonia (Fig. 1). The atmospheric CO_2 concentration passed the 380 ppmv mark in 2006 and is increasing at 2.6 ppmv/year.

Changes in vegetation biomass
between the present day and the 2080s



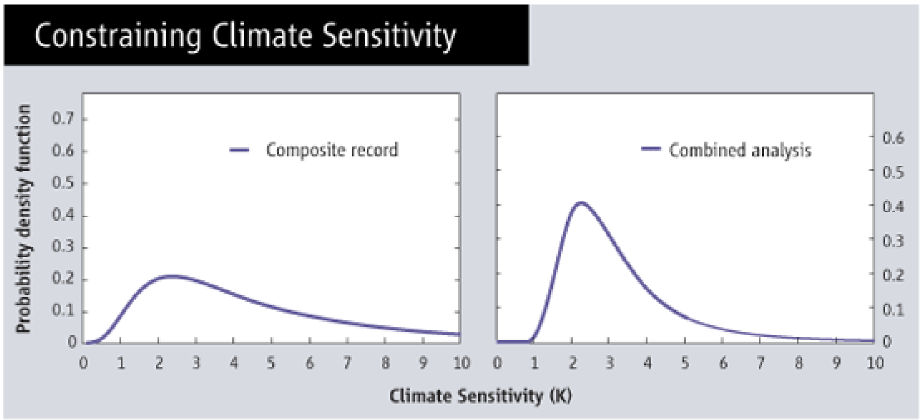
[Hadley Centre, 2000]

Figure 1



Stainforth,2005

Figure 2



ADAPTED FROM HEGERL *ET AL., NATURE* (2006)

Figure 3

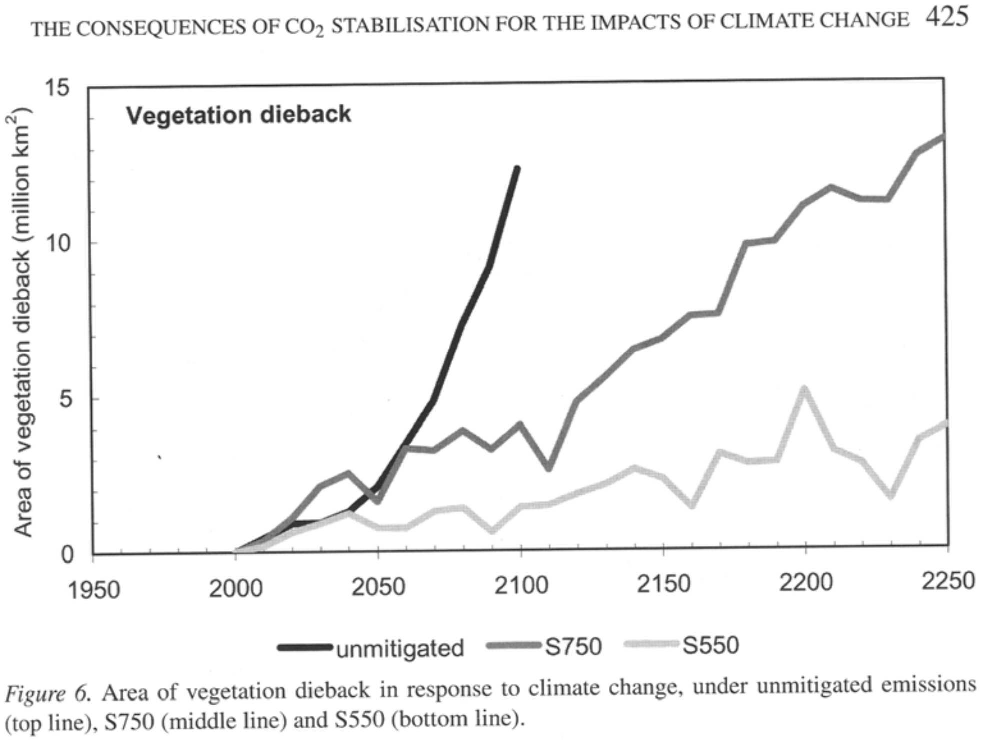


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Figure 6. Area of vegetation dieback in response to climate change, under unmitigated emissions (top line), S750 (middle line) and S550 (bottom line).

Figure 4