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Viewpoint

Are climate change impacts already affecting tropical forest biomass?

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Abstract

Tropical forests contain large stocks of carbon and any change in the balance of inflows and outflows of carbon to the biomass of standing forest has potentially important consequences for the global carbon cycle and related greenhouse warming, as well as for tropical biodiversity. Despite unresolved controversies over observed changes in biomass and gas fluxes, current observations indicate the likelihood that additional climate change would have substantial impacts on tropical forests and would reinforce their contributions to global climate change. Climate change impacts are already affecting tropical forest biomass.

Keywords: Climate change, Amazonia, Tropical forest, Rainforest, Biomass, Carbon, Carbon dioxide

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Running headline: Climate-change impacts in tropical forests

1. Introduction

The impact of the current level of climate change on tropical forests is a matter of considerable controversy, with estimates ranging from massive uptakes to massive emissions of carbon by standing tropical forest. The amount of monitoring data, although much greater than what was available only a few years ago, is still inadequate to resolve some of the controversies. Other parts are a matter of interpretation of the data at hand.

The problem of measuring how much a forest is growing is sometimes likened to a farmer measuring the growth of a pig. There are two ways to go about this. One is to measure all of the carbon that goes into the pig in its food and all that comes out in its excrement and exhaled CO_2, and calculate the growth by difference. The other is to simply weigh the pig, wait for a time, and then weigh it again. In the case of a forest, neither the measurement of carbon flows in and out (with eddy-flux towers) nor direct estimates of carbon stock changes (from forest plot measurements) is so simple – but in the end the results of both methods must match.

2. Eddy-flux towers

In Brazilian Amazonia, the Large-Scale Biosphere-Atmosphere (LBA) project has built a series of towers that project above the forest canopy, with instruments to measure gas exchanges between the atmosphere and the forest. Early eddy flux correlation studies from towers indicated uptakes of carbon of up to almost six tonnes per hectare per year (Malhi et al., 1998). However, additional towers and subsequent refinements of the method indicate much lower rates of uptake: one to two tonnes per hectare per year, according to ongoing research by LBA (Pesquisa FAPESP, 2003). Even the low end of this range, when extrapolated to all of Amazonia, represents an annual uptake of about 0.6 billion tonnes of carbon, or approximately triple the annual emission from fossil-fuel burning in the U.K.

An important reason for high estimates of uptake from measurements using towers is believed to be lateral movement of CO_2 at night: carbon flux into the forest as photosynthesis proceeds during the day is fully captured by the sensors at the top of towers, but at night much of the CO_2 released by respiration concentrates near the forest floor and flows downhill in a sort of "river" of gas, thus escaping measurement, making net flux calculated by difference of inflow and outflow at the top of the tower misleading. Towers in different locations show substantial differences, some of which can be explained by topography and drainage and other factors, and some of which remain unexplained. Uptake has been presumed to be the result of response to CO_2 enrichment.

3. Forest plot measurements

Information on biomass changes as measured in monitored plots is inconsistent, as is the interpretation of the information. An analysis of existing data sets by Phillips et al. (1998) indicated uptake over recent decades, especially in Amazonia. However, the largest and longest-running series of monitored plots, with 36 ha of plots located at least 100 m from a forest edge, showed no change in biomass at all over the 1980-1997 period (Laurance et al., 1997). A 50-ha plot in Panama monitored for 15 years also showed no net change in above-ground biomass when data were corrected for tree breakage (Chave et al., 2003); correction for breakage was not included in the estimates calculated by Phillips et al. (1998).

The conclusion by Phillips et al. (1998) that plots were showing net gains in biomass was largely based on significantly higher frequency of plots showing gains rather than losses; however, this is the pattern that would also be expected in small plots were the forest in complete equilibrium, since large trees occasionally fall and die, causing large declines in a few plots, while most plots will show gradual growth by the remaining trees instead (Fearnside, 2000). The same logic applies to sporadic losses of multiple trees, as from blowdowns or fires, as an explanation of why most tower and plot measurements would be expected to show carbon uptake (Körner, 2003). Although the Phillips et al. (1998) study was questioned on the basis of possible bias from using tree girth measurements that include buttress growth (Clark, 2002; see reply by Phillips et al., 2002), the original conclusion of a net C uptake by the forest has been confirmed by re-analyses of the plot data with correction for buttresses and with elimination of plots where girth measurements included or might have included buttresses (Lewis et al., 2004). The highest uptakes were for plots in Peru and Ecuador—areas without tower data.

The recent discovery of large emissions of CO_2 from water in the Amazon River (Richey et al., 2002) has been suggested as an explanation of the inconsistency between the tower measurements indicating carbon uptake by the forest while plot measurements near the same sites indicate little or none. Carbon could be taken up by the forest but, instead of being stored as wood in the trees, the carbon would be released into the soil where it would travel through groundwater as dissolved organic carbon, later to be oxidized to CO_2 after reaching the streams and rivers. A problem with this explanation is that the CO_2 flux from the water only accounts for one side of the carbon balance for the aquatic ecosystem; estimates of the input of carbon to the water from fixation by macrophytes (water weeds) and phytoplankton need to be included before conclusions can be drawn. Recent measurements of net primary production of flooded canarana meadows in the *várzea* (Amazonian floodplain) indicate massive fixation of carbon in these ecosystems (M.T. Piedade et al., unpublished).

4. Modeling studies

Modeling studies suggest that climate-change impacts on standing tropical forests could result in both substantial uptake of carbon and substantial losses. Increasing temperature is expected to lead to carbon loss; when extrapolated to future climate scenarios, these losses become catastrophic: the HadCM3 model, developed by the Hadley Center of the U.K. Meteorological Office, indicates climate change decimating Amazonian forests by 2080 (Cox et al., 2000), while slightly less is dieback shown by a subsequent version of the model: HadCM3LC (Cox et al., 2003). It should be emphasized that the same climate changes, on a more modest scale, are already occurring. Of particular importance is the increased frequency of El Niño events observed since 1976 that the Intergovernmental Panel on Climate Change has recognized since its second assessment report. El Niño would be especially important as an anthropogenic climate change impact if a causal relationship with global warming is accepted (e.g., Timmermann et al., 1999). Modeling results in Amazonia indicate droughts during El Niño events lead to net releases of carbon during these periods, while forests absorb carbon in non-El Niño years (Tian et al., 1998); releases continuing years after the El Niño events of the 1990s have been documented by LBA tower measurements near Santarém (Pesquisa FAPESP, 2003).

The importance of temperature is indicated by results from the La Selva research station in Costa Rica, an area without significant limitation from moisture stress. Clark et al. (2003) found that night-time temperatures are critical at La Selva: in hot years, trees grow less at La Selva, and, on a global scale, tropical terrestrial ecosystems emit CO_2 in hot years. The La Selva growth data correlate with atmospheric measurements of CO_2 concentrations. The inferred amounts emitted are substantial: if extrapolated to all tropical forests, annual emissions are as high as 6.7 billion tonnes of carbon in El Niño years—an amount on a par with the worldwide carbon emissions from fossil-fuel combustion.

The observations at La Selva cast doubt on modeling results by Nemani et al. (2003) indicating large uptakes of carbon in most tropical forest areas (including Costa Rica) during the same time period that Clark et al. (2003) found a large release. These models consider the critical factor to be irradiation: warming results in greater cloud cover, producing diffuse light that increases photosynthesis. However, Clark et al. (2003) found no response of the forest to changes in irradiation in Costa Rica, with fluctuations of up to 35% between years during the period of observation. The study (Clark et al., 2003) is based on a meticulous long-term data set (the only one with annual measurements) and an "intimate knowledge of trees" (Kaiser, 2003).

The Hadley Center results contain assumptions that both exaggerate and understate the impacts of climate change on tropical forests, whether present or future. On the side of exaggeration, trees in Amazonian forests have very deep roots, giving them more resistance to drought than the simulated trees (P. Cox, personal communication, 2002). On the side of understatement, the predictions of substantial dieback of Amazonian forest (Cox et al., 2000, 2003) are based on the effects of climate change alone, without the interactions with direct human-induced changes such as logging, forest fragmentation and edge formation through the expansion of deforestation, and the increasing number of ignition sources and prevalence of ground fires in the forest.

Logging greatly increases the flammability of forest, and the consequent probability of ground fires, by opening the canopy and leaving large amounts of dead wood to serve as fuel. Ground fires, especially in El Niño years, have affected large areas of forest, which then become more susceptible to subsequent fires that are hotter and more destructive than the first fire. Fragmentation and edge formation cause similar increases in large-tree mortality, increasing the flammability of the forest. Road building over the past decades, and expected increases in roads and other infrastructure for which plans have been announced, imply great increases in all of these risk factors. Climate changes included in the Hadley model, such as increased temperature and increased frequency of droughts, would have much greater impact on the forest under these altered conditions. It should be emphasized that these changes apply not only to future projections, but also to the present and to the last two decades.

5. Unresolved controversies

In summary, controversies concerning the impact of present climate change on tropical forests remain unfinished. The possibility of substantial impacts that damage the forest and introduce positive feedback effects into the climate system are sufficiently large that these impacts should be an important consideration in defining policies that affect both land-use change and global greenhouse gas emissions. The need for more research is obvious, but policy changes should not be held hostage to the results of further research.

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