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Commentary: Tropical deforestation and greenhouse-gas emissions

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Abstract. A recent (2002) analysis concluded that rates of tropical deforestation and atmospheric carbon emissions during the 1990-1997 interval were lower than previously suggested. We challenged this assertion with respect to tropical carbon emissions, but our conclusions were disputed by the authors of the original study. Here we provide further evidence to support our conclusion that the effect of tropical deforestation on greenhouse-gas emissions and global warming is substantial. At least for Brazilian Amazonia, the net impact of tropical deforestation on global warming may be more than double that estimated in the recent study.

Key words: Amazon, carbon emission, deforestation, global warming, tropical forest.

INTRODUCTION

The rapid destruction and degradation of tropical forests is considered a major source of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, and could play an important role in exacerbating global warming (Fearnside 2000*a*; Houghton et al. 2000). However, the magnitude of tropical emissions is the subject of considerable uncertainty and debate, with estimates of annual carbon emissions varying from 0.8 to 2.4 gigatons (Gt=10^9 metric tonnes=Pg; Houghton et al. 2000, Schimel et al. 2001, Achard et al. 2002). Hence, tropical-forest conversion could account for as much as one-third, or as little as one-tenth, of all anthropogenic emissions (roughly 7-8 Gt yr^{-1} at present). Correctly quantifying such emissions is essential for understanding the earth's carbon balance, for assessing the impacts of tropical deforestation on the global climate, and for developing viable mechanisms to conserve forests via carbon-offset funds and related international agreements (Fearnside 1997, 2000*a*, 2000*b*).

In a recent paper, Achard et al. (2002) assessed deforestation of humid tropical forests worldwide for the 1990-1997 period, using chronosequences of remote-sensing data and a stratified sampling strategy that focused on "hotspots" of rapid forest conversion that comprised a relatively small fraction (6.5%) of total forest cover. A key conclusion of their study was that both annual deforestation rates and atmospheric carbon emissions were substantially lower than was previously estimated for this same interval by earlier investigators. Achard et al. (2002) estimated emissions of 0.64±0.21 (95% C.I.) Gt for humid tropical forests and 0.96 Gt for all tropical forests. They emphasized that this is much lower than the value of 1.6 Gt C for annual emissions from land use, land-use change an d forestry in the tropics used by the Intergovernmental Panel on Climate Change (IPCC) (Bolin et al. 2000).

We challenged key tenets of the Achard et al. (2002) study, citing seven specific ways by which their methodology and assumptions should yield underestimates of greenhouse gas emissions (Fearnside and Laurance 2003). In their response, these same authors argued that their methods were sound, and they attempted to discount or dispute most of our criticisms (Eva et al. 2003). Because we disagree with key elements of their response, we provide here a more detailed explanation for our continued belief that Achard et al. (2002) underestimate the impact of tropical deforestation on global warming.

FOREST BIOMASS AND GREENHOUSE GAS EMISSIONS

At the outset, Eva et al. (2003) suggested that we produced “no evidence at all contesting our [Achard et al.’s] global biomass estimates or global deforestation rates”. The key word here is “global”. Because of our long-term experience in Amazonia—which contains about half of the world’s remaining tropical forests and nearly 60% of all humid tropical forests—we focused on errors and questionable assumptions relating to this critical region. The fact that so many points of concern were raised about Amazonia poses broader questions regarding the general methods and assumptions of the Achard et al. study.

To be fair, Achard et al. (2002) make some valuable contributions to improving remote-sensing estimates of deforestation rates in humid forests, and Eva et al. (2003) emphasize that we did not dispute their global deforestation estimate. We purposely restricted our comments to their estimates of greenhouse-gas emissions, for which we believe we have both better data and a better interpretation than that provided by Achard et al.

One of the greatest sources of uncertainty is that estimates of forest biomass (50% of which is carbon) vary considerably among studies and forest types. The reliability of a biomass estimate for a given region depends on three factors: quality of the data, quantity (and representativeness) of the data, and consistency of the interpretation. For all three criteria, we have concerns about the biomass data for Amazonia used by Achard et al. (2002).

A key point of contention is that Achard et al. derived their forest-biomass values for Amazonia by averaging two sets of numbers, one of which is from Brown’s (1997) methodological primer on estimating biomass. In the case of Brazil, the dataset employed by Brown (1997, p. 24) was for the Tapajós National Forest in Pará (FAO 1978), and made no claim to represent the whole of Amazonia or of Brazil. With only a tiny fraction of the total area for which forest surveys have been conducted, use of this value as an estimate for Brazilian Amazonia errs grossly on the side of inadequate representation. The best approach to producing biomass estimates for use in conjunction with satellite data on Amazonian deforestation is to use the thousands of tree-volume estimates from 1-ha samples produced by RADAMBRASIL (1973-1983). Such an analysis, weighted by varying deforestation intensity among different forest types, yields a higher estimate of carbon emissions for Amazonia (Fearnside 1997) than do most of the values used by Achard et al. (2002).

Achard et al. (2002) averaged the biomass estimate of Brown (1997) with a second value (Houghton et al. 2000), which itself was the mean of three estimates. Of the three, two had important methodological problems. One of the estimates (Brown et al. 1989, Brown and Lugo 1992) underestimated forest biomass due to omissions of palms, vines, strangler figs, and understory vegetation (Fearnside 1992, Fearnside et al. 1993). Palms are a particularly important omission in the “arc of deforestation” along the eastern and southern edge of Brazil’s Amazon forest—especially in southern Pará and in Maranhão. Vine biomass can also be substantial in this area, especially in Maranhão. Using available information for these omissions (Fearnside 1994) would increase the above-ground carbon stock by 4.3% from vines, 3.5% from palms and 0.2% from other non-tree components, increasing the estimates by a total of 8% (Table 1). Two other effects, hollow trees (which would lower the result by 9.2%) and use of a form factor that was 15.6% too low (Fearnside 1992) for calculating wood volume from tree diameter and height measurements, would not affect the result, contrary to our previous statement (Fearnside and Laurance 2003), because the biomass expansion factors derived by Brown et al. (1989) were based on data that included the same deficiencies. Another of the estimates used by Achard et al. (2002) was extrapolated from just 56 plots, some as small as 0.2 ha (Houghton et al. 2000), and also yields a value that appears unrealistically low.

An additional likely bias inherent in Achard et al. (2002) is that several studies that comprised their estimate of Amazon biomass (Brown et al. 1989, Brown and Lugo 1992, Brown 1997) did not include dead material (necromass), which is typically 8-10% of aboveground forest biomass; adjustments for the surveys that omitted necromass translate into an upward correction to the Achard et al. estimate of biomass C stocks by 6.0%, with the range of published necromass estimates corresponding to a minimum adjustment of 5.3% and a maximum of 6.7% (Fearnside and Laurance 2003) (Table 1). This is an important clarification because Eva et al. (2003) asserted erroneously that only one of the studies they used (Brown 1977) failed to include necromass. Soil carbon release from the top meter of soil (9.6% of the impact: Fearnside 2000b, Fearnside and Barbosa 1998) is an additional omission, and should not be confused with below-ground biomass (e.g., Eva et al. 2003).

REGROWTH, FOREST DEGRADATIONAND TRACE GASES

Regrowth in deforested areas is a key part of the carbon balance. Eva et al (2003) clearly erred when they asserted that the original analysis of regrowth-related carbon flux by Achard et al. was concerned only with the 1990s. The problem here is that the “actual carbon flux” they seek would require information on the areas of regrowth of different ages and histories, and the ages (and state of decay) of parcels cleared in the years prior to the time period of interest (Fearnside 1996a). Achard et al. (2002) circumvent this by assuming constant deforestation rates and behavior with respect to regrowth. Fundamental to this simplification is the equivalence, assuming constant deforestation, of the inherited emissions and the committed emissions (e.g., Makundi et al. 1992).

Estimates of inherited emissions (emissions from decay and burning of remaining original-forest biomass in clearings that were made before the start of the period of interest—i.e., the “1990s”) have been made for Brazilian Amazonia based on past deforestation rates (Fearnside 1996*a*). These estimates are larger than those calculated by Achard et al. (2002) on the basis of their improbable assumptions regarding deforestation rates and farmers refraining from re-clearing secondary forests. In order for Achard et al.’s comparison of their estimate for emissions (0.96 Gt C for all tropical foresrts) with IPCC value (1.6 Gt C) to be valid, they would have to include either the carbon that is released after the first 10 years (the committed emissions), or the identical amount (assuming constant deforestation) released during the 1990s from clearings made in previous years (the inherited emissions). The Achard et al. (2002, p. 1002) estimate, that 28% of the carbon remains unreleased at the end of 10 years, combined with their estimate of 190 Mg ha^{-1} for the average biomass carbon stock in "Brazilian Amazon forests" (Achard et al., 2002, p. 1001), with corrections to biomass as in Table 1, implies that the inherited emission is 57.5 Mg C ha^{-1} (a 47.1% increase over the Achard et al. net emission of 122.1 Mg C ha^{-1}).

An estimate of net emissions must also include either the inherited uptake (carbon absorption by regrowtth in areas that were cleared before the period under consideration) or the identical amount (assuming constant deforestation rate) of committed uptake after the end of the period. The inherited uptake can be estimated, assuming a constant deforestation rate, as the difference between the C stock over the landscape at year ten (7.3 Mg ha^{-1}) and that at the long-term equilibrium (12.8 Mg ha^{-1}) (Fearnside 1996*b*); this would reduce the net emission by 5.5 Mg C ha^{-1}, or 4.5% with respect to the Achard et al. net emission. Thus, the omission of inherited fluxes by Achard et al. underestimates relevant carbon emissions by 57.5 – 5.5 = 52.0 Mg ha^{-1} (Table 1).

Achard et al. (2002) also underestimate net emissions by assuming an unrealistically high rate of regrowth. Although Achard et al. (2002, p. 1002) incorrectly refer to "regrowth rates that we [Achard et al.] have measured", Eva et al. (2003) clarify that they "used regrowth data from Houghton et al. (2000)". However, Houghton et al. (2000, p. 303) also lacked data on regrowth, and instead used an unsupported assumption that 70% of the original forest biomass is recovered in 25 years (for Brazilian Amazonia, 190 Mg C ha^{-1} × 0.7 / 25 = 5.32 Mg C ha^{-1} yr^{-1}, which Achard et al. rounded to the 5.5 Mg C ha^{-1} yr^{-1} value they used). Maintained over the 10-year time horizon, regrowth at 5.5 Mg C ha^{-1} yr^{-1} results in a carbon stock of 55 Mg C ha^{-1} in these lands at the end of the period. A growth rate this high is unlikely, given that most of the land being abandoned is degraded cattle pasture where secondary vegetation grows slowly (Fearnside and Guimarães 1996). Poor soils in Amazonia also contribute to slow growth in secondary forests. At age 10 years, secondary forests derived from cattle pastures with use histories typical of deforested areas in Brazilian Amazonia reach a total (above- and below-ground) carbon stock in biomass of approximately 26 Mg C ha^{-1} (Fearnside 1996*b*, p. 30), or about half the amount assumed by Achard et al. (2002).

For the landscape as a whole, Achard et al. (2002) assumed that 30% of the area deforested in Brazilian Amazonia would become secondary forest (the region-wide average proportion used by Houghton et al. 2000). If the biomass carbon stock in this 30% is 55 Mg C ha^{-1}, and the remaining 70% of the area is conservatively assumed to hold no carbon, then the average regrowth stock over the deforested landscape at age 10 years would be 16.5 Mg C ha^{-1}, or over twice the 7.3 Mg C ha^{-1} calculated for the landscape at this age on the basis of data on area transformations and biomasses of deforested landscapes in Brazilian Amazonia, divided into six land-use categories (Fearnside 1996*b*). The exaggeration of the stock by 16.5 – 7.3 = 9.2 Mg C ha^{-1} translates into an understatement by 7.5% of the net emission by year 10 (Table 1), given Achard et al.'s other assumptions regarding biomass (190 Mg C ha^{-1}) and the proportion of original carbon stocks emitted over 10 years (72%).

Although Eva et al. (2003) downplayed its importance, forest degradation from selective logging, surface fires, habitat fragmentation, edge effects, and other anthropogenic impacts is a large source of atmospheric emissions. Even light surface fires can kill up to half of all forest biomass (Barlow et al. 2003) and the occurrence of such fires is increasing rapidly (Cochrane 2003). Likewise, in fragmented forests, substantial live biomass is killed within several hundred meters of forest edges as a result of sharply elevated tree mortality (Laurance et al. 1997, 1998*a*, *b*; only net increases in the length of edges affect emissions estimates; Fearnside 2000a). Although regrowth can partially replace live biomass losses over time if edges are protected from ground fires and biomass removal by humans (Nascimento and Laurance 2004), edges emit carbon under normal circumstances.

Yet another concern is that Eva et al. (2003) attempted to simply define away the issue of forest degradation (by claiming that the Achard et al. study was concerned solely with emissions from deforestation). This is inconsistent with the contrast the group emphasizes between their emissions estimate and the value produced by the International Panel on Climate Change (1.6 Gt C yr^{-1}) for all emissions from land use and land-use change in tropical forests over the same interval (Bolin et al. 2000).

Finally, the decision by Achard et al. not to consider deforestation-produced trace gases—some of which, like methane, have a major impact on global warming—plays into the hands of those who would prefer to avoid policy measures to reduce tropical deforestation. Trace gases add 15.3% to the impact, with a range of ± 9.7% depending on which of the published values for trace-gas emission factors are used in the calculation (Fearnside 2000a, pp. 143-145). Because emissions from land-use change are inevitably compared to those from fossil fuels (for example, in identifying where policy changes and international negotiations can reduce global warming), trace gases are highly relevant, and leaving them out understates the impact of tropical deforestation and the global benefits of avoiding it (Table 1).

CONCLUSIONS

Eva et al. (2003) summarize their response by stating that "[w]e do recognize, however, that lack of local data on forest biomass remains a major problem in making global estimates of emissions from deforestation". This is, of course, the whole point. It is a basic principle of science that when a grand theory does not match actual observations in nature, it is the theory and not nature that is wrong. When "local data" do not agree, something is wrong with the theory. Dismissing on-the-ground data as "point surveys"—as they do for the vast Amazon—is not the solution. In this case, the disagreement is not only with detailed studies of forest biomass at individual locations (e.g., Chambers et al. 2001, Cummings et al. 2002, Gerwing 2002, Laurance et al. 1999, Nascimento and Laurance 2002), which provide an anchor in reality that diverges from the Achard et al. estimates, but also with regional studies for Brazilian Amazonia that include weighting of thousands of individual data points (Fearnside 1997). Amazonia is too big to be dismissed if it is significantly different from what Achard et al. predict. By itself, Amazonia is a substantial part of the global total for tropical deforestation, and if the global theory has it wrong for Amazonia, then the global results must also be seriously questioned.

The various adjustments needed to the Achard et al. calculation of carbon emissions from tropical deforestation are summarized in Table 1. According to our calculations, their estimate understates by a factor of two the net impact on global warming from tropical deforestation, at least for the immense Brazilian Amazon. Moreover, this value conservatively excludes the effects of forest degradation via selective logging, surface fires, and edge effects on carbon emissions (Table 1), which are difficult to quantify. When the choices of which factors to include and which to omit lead to an underestimate of this magnitude, it carries an implicit policy message that mitigation efforts for slowing tropical deforestation should be a relatively low priority. We strongly disagree with this implication.

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Table 1. Summary of adjustments to the calculation of atmospheric carbon emissions proposed by Achard et al. (2002). Data are based on studies in Brazilian Amazonia.

Achard et al. estimate of net emissions by end of 10-yr time horizon:			
Biomass emission (190 Mg C ha^{-1} stock[a] × 0.72 emitted[b])	138.6	Mg C ha^{-1}	
Uptake (5.5 Mg C ha^{-1} regenerated yr^{-1} × 0.3 [prop. regen.] × 10 yrs	-16.5	Mg C ha^{-1}	
Net emission[c] =	122.1	Mg C ha^{-1}	
Adjustments needed to Achard et al. calculation:			
Live biomass (8% × 190 Mg C ha^{-1})	15.2	Mg C ha^{-1}	(=+12.4%)[e]
Necromass (6% × 205 Mg C ha^{-1} [d])	12.3	Mg C ha^{-1}	(=+10.1%)[e]
Soil carbon (9.6% × 205 Mg C ha^{-1} [d] long-term gross emission)	19.7	Mg C ha^{-1}	(=+16.1%)[e]
Regrowth over 10 years (16.5 – 7.3 Mg C ha^{-1})	9.2	Mg C ha^{-1}	(=+7.5%)[e]
Inherited uptake	-5.5	Mg C ha^{-1}	(=-4.5%)[e]
Inherited emissions (205 Mg C ha^{-1} [d] × 0.28[b])	57.5	Mg C ha^{-1}	(=+47.1%)[e]
Trace gases (15.3% × 130.5 Mg C ha^{-1} net emission[f])	35.3	Mg C equivalent ha^{-1}	(=+28.9%)[e]
Logging	unknown[g]		
Surface fires	unknown[g]		
Edge effects on net increase in edge length	unknown[g]		
TOTAL	143.6	Mg C ha^{-1}	(=117.6%)[e]

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a. Live biomass (above + belowground) C stock for "Brazilian Amazon forest" (Achard et al. 2002, p. 1001).

b. After ten years 28% of biomass C remains unreleased (Achard et al. 2002, p. 1002).

c. Note: there is a discrepancy between these per-hectare results from Achard et al. (2002) and the regional results presented in the same paper. The net emission from the regional result (0.19 Gt C/1.32 × 10^6 ha) is 143.9 Mg C ha^{-1}, or 21.8 Mg C ha^{-1} (17.9%) higher.

d. Achard et al. (2002, p. 1001) live biomass C (190 Mg C ha^{-1}) adjusted by 8% (4.3% for vines + 3.5% for palms + 0.2% for other non-tree components).

e. Percentage with respect to Achard et al. net emission (122.1 Mg C ha^{-1}).

f. Achard et al. (2002) net emission (122.1 Mg C ha^{-1}) corrected for all effects except trace gases (+15.2 + 12.3 + 19.7 + 9.2 - 5.5 + 57.5 Mg C ha^{-1}).

g. Estimates for these adjustments are not available, although work is in progress. Substantial quantities of emissions are produced by logging (Fearnside 2000a), surface fires (Cochrane 2003) and edge effects (Laurance et al. 1998a).