TECHNICAL COMMENTS

Comment on "Determination of Deforestation Rates of the World's Humid Tropical Forests"

Achard *et al.* (*1*) estimated tropical deforestation and atmospheric carbon emissions from 1990 to 1997 and concluded that both were substantially lower than had been found in previous studies. However, we believe that the evidence favors higher estimates, particularly for carbon emissions. We would cite seven specific items that suggest a cautious approach toward the Achard *et al*. results.

1) Achard *et al*. (*1*) confined their study to "humid tropical forests," and thereby excluded extensive drier forest types that were incorporated into earlier studies of tropical forests worldwide (*2*) and in Brazilian Amazonia (*3*). Excluding dry forest types reduced deforestation estimates by 16.6% in Brazilian Amazonia (*3*) and by even greater amounts in tropical regions that include large expanses of seasonal forest.

2) The Achard *et al*. estimates of forest biomass are clearly too low. The estimates were derived by averaging two sets of published numbers. The first dataset they used (*4*), however, was not intended as an estimate of forest biomass for each country, but rather as a methodological primer for assessing biomass from forestry surveys. Indeed, for the vast Brazilian Amazon—which contains nearly half of the world's tropical forest—biomass was extrapolated from a preliminary survey of a single site (*5*). Far more representative studies of biomass are available for Brazilian Amazonia, based on nearly three thousand 1-ha plots that were weighted both by individual vegetation types and by deforestation activity (*6*, *7*) and that yielded considerably higher estimates of carbon emissions.

The second set of published numbers used by Achard *et al*. (*1*) was actually a mean of three estimates (*8*). The "low" case (*9*, *10*) substantially underestimated biomass because it omitted palms, vines, stranglers, and other understory vegetation, and because it used an unduly low form factor to calculate wood volume from tree diameter and height measurements (*11*, *12*). The "medium" case (*8*) was extrapolated from just 56 plots, some as small as 0.2 ha—obviously very crude resolution compared with studies of nearly three thousand 1-ha plots (*6*, *7*). The "high" case (*8*) is most realistic because it was based on a detailed allometric study of Amazonian trees (*13*) and included adjustments for biomass components (*6*) omitted from other estimates. Thus, the second set of values, generated by averaging a realistic value with two others that underestimate biomass, is biased downward.

3) The principal forest biomass estimates used by Achard *et al.* for Brazilian Amazonia (*4*, *9*, *10*) failed to include dead material (necromass), which increases forest carbon stocks by 8 to 10% (*8*, *14*, *15*). Their method of calculation should produce an underestimate of carbon emissions of 5.3 to 6.7% (*16*). Reductions in soil carbon (including fine roots <2 mm in diameter) following deforestation were also not included; for Brazilian Amazonia, including carbon loss from the top meter of soil (*7*, *17*) would add 9.6% to the emissions estimate of Achard *et al*. (*1*).

4) Achard *et al*. assumed that secondary forests would regenerate rapidly on abandoned lands, recovering about 70% of their biomass in just 25 years. Such rapid recovery may occur during shifting cultivation but is far less likely on degraded pastures (*18*), which predominate in Amazonia. Moreover, Achard *et al*. implicitly assumed that regenerating forests will remain undisturbed over the next 75 years; in reality, such forests are often recleared (*18*, *19*).

5) Achard *et al*. assumed that only 72% of carbon stocks in cleared primary forests would be released to the atmosphere. That estimate was for committed flux during the first decade after forest clearing, but did not include the remaining carbon stock (28%), which will also eventually be emitted (*6*, *7*, *20*). The impact of deforestation is underestimated because the timeline for carbon emissions is truncated at year 10, and the area under consideration is restricted to a single year's clearing. If the full landscape were considered—including areas cleared in previous years—then decay of previously felled biomass in those areas would contribute the missing 28% of carbon emissions, if deforestation rates were assumed to be constant. Hence, important fluxes are omitted when the time horizon for emissions and the area of cleared land under consideration are both truncated. A valid index of the impact of deforestation on global warming requires either an estimate of net committed emissions for each year's clearing (*6*) or the annual balance of emissions from the full landscape (*7*).

6) The effects of trace gases, such as methane and nitrous oxide, were not considered in the Achard *et al*. study—yet these gases add 6 to 25% to the impact of deforestation emissions compared with estimates that count only changes in carbon stocks, based on published emission factors and land-clearing and -burning practices in Brazilian Amazonia (*20*). For example, methane is produced by burning and by termites on recently deforested lands. Each Mg of carbon released as methane has 7.6 times more impact on global warming than does the same amount of carbon released as CO_2 (*20*). By restricting their analysis to simple carbon emissions, Achard *et al*. understated the contribution of tropical deforestation to global warming—an understatement that becomes especially problematic when policy-makers use their results for comparisons with fossil-fuel emissions.

7) Finally, Achard *et al.* did not include emissions from selective logging (*19*), forest fragmentation (*21*), and other forms of degradation that reduce forest carbon stocks but do not cause deforestation per se. Tropical logging and other thinning caused annual emissions of over 400 teragrams of carbon (TgC) during the 1980s (*20*).

The cumulative effect of these omissions and other choices is a large underestimate of greenhouse gas emissions. By excluding various components of land-use change and carbon stocks in affected landscapes, Achard *et al*. have not "reduce[d] the amount of uncertainty," as they claimed, but have merely produced a less complete estimate.

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References and Notes

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