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

Fearnside and Laurance (*1*) assert that "the evidence favors higher estimates" for tropical deforestation and carbon emissions than those of our study (*2*). That assertion is based on deforestation and forest biomass data for the Brazilian Amazon, which they compare with our deforestation results and our use of published data of forest biomass for the same region. We find their comments less than convincing for the Brazilian Amazon, however, and they produce no evidence at all contesting our global biomass estimates or global deforestation rates.

For net carbon emissions, we validated our estimate of 75-year committed flux over Brazilian Amazonia (*2*) using Fearnside's own estimate of the 100-year committed flux (*3*); the close rapport between the two estimates highlights an inconsistency in the present claim that we underestimated carbon emissions. Furthermore, independent estimates of net annual CO_2 emissions in Southeast Asia during the 1990s, using inverse modeling of observed atmospheric CO_2 (*4*), generally support our figure for this major region (*5*).

Below, we address, in as much detail as this exchange permits, each of the seven points raised by Fearnside and Laurance (*1*)—all of which, except point 2, seem to arise from a misunderstanding of our study.

1) We did not, as Fearnside and Laurance suggest, omit dry forests from our carbon estimate. We specifically stated that we measured only the change in the humid forests (*2*); then, to provide an estimate of global net emissions from land-use change in the tropics, we added to our humid-forest deforestation figure an estimate to account for the dry forests. We considered the net forest area change in the dry tropics to be of the same magnitude as in the humid tropics—that is, we added 100% of deforested area in the dry tropics. The assertion therefore that our approach "reduced deforestation estimates by 16.6% in Brazilian Amazonia" is incorrect. Our estimate for humid forests is exceptionally close to the data from the comprehensive annual national monitoring program conducted by INPE (The Brazilian National Space Agency) (*6*).

2) In the absence of an undisputed reference figure for forest biomass, our study (*2*) opted for the latest published estimates, specifically the average of the estimates by Brown (*7*) and Houghton *et al.* (*8*). Contrary to the statement of Fearnside and Laurance (*1*), the purpose of the Brown study was not solely to "present methods that are available for estimating biomass density," but also to "present biomass density estimates for many tropical countries using the methodologies given" (*7*). The biomass estimate in the Houghton *et al.* study (*8*), one of the more recent publications on the Amazon, was indeed the average of three estimates, as Fearnside and Laurance (*1*) note. The highest of those three was the estimate of Fearnside (*3*), which is not as yet accepted as the reference value. Fearnside and Laurance also do not cite a more recent article by Houghton *et al*. (*9*) that reviewed the estimates of biomass for the Brazilian Amazon. In that study, Fearnside's estimate (*3*) was the highest of seven surveys, at 232 tons of carbon (tC) ha^{-1}; the mean of the seven was 177 tC ha^{-1}, and our study used 190 tC ha^{-1}. Finally, deforestation is not spatially distributed in a homogeneous fashion across Amazonia: more than half of the clearing in the last 10 years has taken place in areas with lower biomass results (Mato Grosso and Rondônia).

All these points suggest that our net carbon emission result may actually be overestimated, not underestimated as suggested by Fearnside and Laurance (*1*). Still, the point they raise demonstrates the difficulties implicit in extrapolating from sets of point surveys to global estimates.

3) Only the estimate of Brown (*7*) did not include dead material—and, as already mentioned, the Houghton *et al*. (*9*) average estimate of all biomass (including dead material) from seven surveys is lower than the average that our study used (*2*). The comment by Fearnside and Laurance (*1*) about the soil component may also be incorrect, because we added 20% for below-ground biomass (*7*), which should include part of the soil biomass.

4) We used regrowth data from Houghton *et al*. (*8*), who admitted that "the assumption that forests are fully regrown after as little as 75 years is probably not valid," but also noted that their analysis largely dealt with "human-induced changes over the past 10-40 years." Our study (*2*) was concerned only with human-induced changes during the 1990s. Also, Fearnside and Laurance (*1*) err in asserting that we "implicitly assumed that regenerating forests will remain undisturbed over the next 75 years." Our aim was to compute the actual carbon flux for the mid-1990s, which involves assumptions about events in previous years, not future ones. We specifically stated that to use the 75-year committed flux would imply "that the deforestation and regrowth rates we have measured have been constant for the past 75 years," and that "[t]he 10-year committed flux has therefore been assumed to be more representative than the 75-year committed flux." Thus, our final estimate only assumed regrowth and deforestation rates at the same level for the previous decade—over a period of 10 years, not 75 years.

Irrespective of all this, we stress that this is a minor point. For the Brazilian Amazon, for example, our estimate of the regrowth sink was 2.3 % of our estimate of deforestation emissions; thus, even a 50% reduction in the regeneration rate would affect the overall result by only on the order of 1%.

5) The comments by Fearnside and Laurance (*1*) on the fluxes we studied suggests that they did not understand our method. We looked at the estimate of the "annual net flux" as produced by Houghton *et al*. (*8*), not at the total committed flux, as Fearnside and Laurance suggest.

6) Our paper consistently referred to total carbon fluxes. Whether that carbon was emitted as CO_2 or CH_4 makes no difference in terms of carbon volume. We did not study nitrogen components at all.

7) The last objection raised by Fearnside and Laurance (*1*)—that we did not include loss of carbon from forest degradation—was also clearly mentioned in our study (*2*). The reason these factors were not included is that selective logging and a part of forest fragmentation are below the minimum mapping unit of our study and, therefore, could not accounted for in our change estimates. That said, the impact of selective logging on carbon emissions may not be very significant, because there is no burning, the damage to soils may be smaller than in the case of forest conversion, and there will be regrowth in the openings. Further, in most of the tropics, selective logging is an initial phase in the transformation of "pristine" forest to nonforest. When logged forests were transformed to pasture or degraded forests to mosaics, we counted 100% of the forest area as deforested, with a 100% biomass content.

We thus reject the assertion by Fearnside and Laurance (*1*) that we have produced a less than complete estimate. We do recognize, however, that lack of local data on forests biomass remains a major problem in making global estimates of emissions from deforestation.

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References and Notes

1. P. M. Fearnside, W. F. Laurance, *Science* **299**, 1015; www.sciencemag.org/cgi/content/full/299/5609/1015a.
2. F. Achard *et al.*, *Science* **297**, 999 (2002).
3. P. M. Fearnside, *Clim. Change* **35**, 321 (1997).
4. D. Schimel, D. Baker, *Nature* **420**, 29 (2002).
5. The estimates in (*4*) of net annual emissions for Southeast Asia (without the South China Sea region) are very close to our estimate of 0.25 GtC year^{-1} for the period from 1991 to 1997, with the exception of 2 years, 1994 and 1995, for which the estimates in (*4*) are higher than our estimates (by around 0.4 GtC year^{-1}). These estimates, however, integrate all sources of CO_2, in particular fossil fuel emissions.
6. *Deforestation 1995-1997 Amazonia* (INPE & IBAMA, Brazil, 1997).
7. S. Brown, *Estimating Biomass and Biomass Change of Tropical Forests* (FAO, Rome, 1997).
8. R. A. Houghton *et al.*, *Nature* **403**, 301 (2000).
9. R. A. Houghton, K. T. Lawrence, J. L. Hackler, S. Brown, *Global Change Biol.* **7**, 731 (2001).

28 October 2002; accepted 20 December 2002