Fearnside, P.M. 1996. Amazonia and global warming: Annual balance of greenhouse gas emissions from land-use change in Brazil's Amazon region. pp. 606-617 In: J. Levine (ed.) Biomass Burning and Global Change. Volume 2: Biomass Burning in South America, Southeast Asia and Temperate and Boreal Ecosystems and the Oil Fires of Kuwait. MIT Press, Cambridge, Massachusetts, U.S.A. 902 pp.

AMAZONIA AND GLOBAL WARMING: ANNUAL BALANCE OF GREENHOUSE GAS EMISSIONS FROM LAND USE CHANGE IN BRAZIL'S AMAZON REGION

Philip M. Fearnside
National Institute for Research
in the Amazon (INPA)
C.P. 478
69011-970 Manaus, Amazonas
BRAZIL

Fax: 55 - 92 - 642-3028

Paper presented at the American Geophysical Union Chapman Conference on Biomass Burning and Global Change. March 13-17, 1995, Williamsburg, Virginia.

2 July 1995
9 Aug. 1995

ABSTRACT

Land use changes in 1990 in Brazil's 5 X 10^{6} km^{2} Legal Amazon Region included 13.8 X 10^{3} km^{2} of deforestation, approximately 5 X 10^{3} km^{2} of clearing in *cerrado* (savanna), 7 X 10^{2} km^{2} in "old" (pre-1970) and 19 X 10^{3} km^{2} in "young" (1970+) secondary forests; burning of 40 X 10^{3} km^{2} of productive pasture (33% of area present), and regrowth in 121 X 10^{3} km^{2} of "young" secondary forests. No new hydroelectric flooding occurred in 1990, but decomposition continued in 4.8 X 10^{3} km^{2} of reservoirs already in place. Logging 24.6 X 10^{6} m^{3} was assumed, the 1988 official rate.

Unlogged original forest in Brazilian Amazonia are estimated to have an average total biomass of 464 metric tons per hectare (t ha^{-1}), including below-ground and dead components. Adjustment for the spatial distribution of clearing and for logging indicates an average total biomass cleared in 1990 of 407 t ha^{-1} in original forest areas, 308 t ha^{-1} of which is above-ground (exposed to the initial burn). In addition to emissions from the initial burn, remains from clearing in previous years emitted gases through decay and combustion in reburns. More rapid deforestation in the years preceding 1990 make these inherited emissions greater than they would have been had deforestation rates been constant at their 1990 levels.

Emissions are calculated in low- and high-trace gas scenarios, reflecting the range of emissions factors appearing in the literature for different burning and decomposition processes. These scenarios do not reflect the uncertainty of values for deforestation rate, forest biomass, logging intensity and other inputs to the calculation.

Sinks for carbon are calculated for conversion to charcoal and graphitic particulate carbon. Charcoal represented 5.6 X 10^{6} t of carbon, while graphitic particulate carbon represented 0.32-0.42 X 10^{6} t.

Estimated net emissions from deforestation (not including logging emissions) totaled 1245-1248 X 10^{6} t CO_2, 2.0-2.4 X 10^{6} t CH_4, 36-46 X 10^{6} t CO, and 0.15-0.27 X 10^{6} t N_2O. These emissions are equivalent to 358-367 X 10^{6} t of CO_2-equivalent carbon, using IPCC 1992 100-year GWPs (direct effects only). CO_2 emissions include 228 X 10^{6} t of gas from the initial burn, 876-878 X 10^{6} t from decay and 83 X 10^{6} t from subsequent burns of primary forest biomass; 44-45 X 10^{6} t from decay and 53-56 X 10^{6} t from burning of secondary forest biomass of all ages; 37 X 10^{6} t from hydroelectric reservoirs, 32 X 10^{6} t from soil to 20 cm, and 220 X 10^{6} t from logging. Pastures release through burning (and assimilate in growth) 17-18 X 10^{6} t, not counted in the above total. Secondary forest regrowth removes 108 X 10^{6} t (only 8% of the gross emission, excluding pasture). The total CO_2 emissions, excluding logging, are triple Brazil's official estimate, mainly because the latter omits decay and combustion after initial deforestation.

INTRODUCTION: TYPES OF EMISSION CALCULATIONS

Deforestation in Brazilian Amazonia releases quantities of greenhouse gases that are significant both in terms of their present impact and in terms of the implied potential for long-term contribution to global warming from continued clearing of Brazil's vast area of remaining forest. The way in which emissions are calculated can have a tremendous effect on the impact attributed to deforestation. One form of calculation is net committed emissions, which expresses the ultimate contribution of transforming the forested landscape into a new one, using as the basis of comparison the mosaic of land uses that would result from an equilibrium condition created by projection of current trends. This includes emissions from decay or reburning of logs that are left unburned when forest is initially felled (committed emissions), and uptake of carbon from growing secondary forests on sites abandoned after use in agriculture and ranching (committed uptake), to give net committed emissions (Fearnside, 1992).

Another form of calculation, which is the subject of the present paper, looks at the annual balance of release and uptake of greenhouse gases in a given year. Estimates of the annual balance of greenhouse gases for specific regions are needed in order to understand the fluxes of these gases at a global level.

The annual balance appears likely to form the basis for assigning responsibility for global warming among nations. The Framework Convention on Climate Change, which was signed in June 1992 by 155 countries plus the European Union at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, requires that each country make an inventory of the sources, sinks and reservoirs of greenhouse gases--indicating that the guiding principle for quantifying impact will be the net flux of gases entering and leaving the atmosphere.

The criterion of annual balance or flux has important implications for how different response strategies are viewed by individual countries. Global interests are not necessarily analogous with national interests. One consequence of the emphasis on annual flux is that the act of cutting trees is not the critical moment for counting greenhouse effect impact, but rather fluxes that occur after this event. In the case of wood exported from any given country, the greenhouse impact will be counted against the importing country where the wood products will eventually decay.

Wood exporting countries get credit for carbon removed from the atmosphere as the trees grow. The credit is further enhanced by an increase in growth rates in trees that remain after forests are logged. The emissions credits can be expected to accrue to wood exporting countries to the extent that carbon leaves these countries in the form of wood or wood products instead of as CO_2 or other gases; when the paper, buildings, furniture and other products eventually decay or burn, the emission is added to the account of the country where the carbon enters the atmosphere. This means that timber exports can contribute to greenhouse credit--but the net effect may be otherwise, as non-exported portions of harvested trees, and the many other trees killed or damaged during logging operations, lead to immediate emissions. More emissions come from deforestation done by immigrants and others whose entry is facilitated by logging roads. Assessment of current and potential contributions of each of these processes is a high priority. Annual balance calculations in the present paper offer a starting point for evaluating these implications.

The annual balance represents an instantaneous measure of the fluxes of greenhouse gases, of which carbon dioxide is one. This is sometimes called the annual balance of net emissions. Even though the present calculations are made on a yearly basis, they are termed "instantaneous" here to emphasize the fact that they do not include future consequences of deforestation and other actions taking place during the year in question. It should be stressed that annual balance is not the best measure of the greenhouse impact of deforestation, which should include the future releases and uptakes. Net committed emissions and time-weighted net emissions are more meaningful for policy decisions, especially the latter. Time-weighted net emissions calculates the net flux for each year, allowing application of a time horizon and a time-preference weighting scheme (either discounting or an alternative procedure) to reflect the values placed by society on short-term versus long-term effects.

Using the annual fluxes of greenhouse gases to and from the atmosphere as the basis for assigning responsibility for global warming, while much better than nothing, contains various distortions as a basis for fixing the blame for the greenhouse effect. The industrialized countries escape all responsibility for having used up much of the capacity of the oceans and other sinks to absorb carbon, as these are now largely saturated with carbon that has come from historical burning of fossil fuels and from removal of temperate forests in these countries. On the other side, the Intergovernmental Panel on Climate Change (IPCC), which provides the technical basis for the climate convention negotiation process, currently calculates the effects of trace gases such as methane (CH_4), carbon monoxide (CO) and nitrous oxide (N_2O) such that their impact relative to CO_2 is understated: all indirect effects of these gases are ignored, and the time preference scheme adopted for standard calculations emphasizes long-lived gases (like CO_2) by considering a 100-year period without discounting (Isaksen et al., 1992). The relatively greater weight that these procedures give to CO_2 favors tropical countries, where other gases--such as methane from deforestation, rice paddies and livestock--make up a greater portion of emissions than in industrialized countries where fossil fuel burning dominates greenhouse gas contributions.

GREENHOUSE EMISSIONS

Initial burn

Greenhouse gas emissions and uptakes are tabulated for a "low trace gas scenario" (Table 1) and for a "high trace gas scenario" (Table 2). These two scenarios use high and low values appearing in the literature for the emissions factors for each gas in different types of burning (reviewed in Fearnside, 1991, 1992). They do not reflect the doubt concerning forest biomass, deforestation rates, burning efficiency and other important factors.

(Tables 1 and 2 here)

The initial burn represents 228 X 10^6 t of CO_2 gas, or 17% of the gross emission of 1353-1357 X 10^6 t. Gross emission of a gas refers to all releases of the gas, but not uptakes. The initial burn contribution of CH_4 is 0.74-0.88 of 1.98-2.39 X 10^6 t (37%), CO is 18-22 of 36-46 X 10^6 t (48-50%) and N_2O is 0.05 of 0.15-0.27 X 10^6 t (19-33%). For NO_x and NMHC, if considered apart from the loss of mature forest sources, represent, respectively, 0.56 of 1.38 X 10^6 t (41%) and 0.49-0.93 of 0.85-1.61 X 10^6 t (58%).

The average biomass of the primary forests present in the Brazilian Amazon has been estimated based on analysis of published wood volume data from 2954 ha of forest inventory surveys distributed throughout the region (Fearnside, nd-a). Average total biomass (including dead and below-ground components) is estimated to be 463 t ha^{-1} for all unlogged mature forests originally present in the Brazilian Legal Amazon. The average above-ground biomass is 354 t ha^{-1}, of which 28 t ha^{-1} is dead; below-ground biomass averages 109 t ha^{-1}. The total biomass estimates are disaggregated by state and forest type, allowing use of the data in conjunction with Brazil's LANDSAT-based deforestation estimates, which are reported on a state-by-state basis (Fearnside et al., nd-a; Fearnside, 1993a,b.

The areas of protected and unprotected vegetation of each type in each state have been estimated (Fearnside and Ferraz, 1995). By multiplying the per-hectare biomass of each forest type by the unprotected area present in each state, one can estimate the biomass cleared if one assumes that clearing within each state is distributed among the different vegetation types in proportion to the unprotected area present. By weighting the biomass by the deforestation rate in each state, the average total biomass cleared in 1990 has been estimated to be 434 t ha^{-1}, or 6.3% lower than the average for forests present in the Legal Amazon as a whole (see Fearnside, 1992). The difference is due to concentration of clearing activity along the southern and eastern edges of the forest, where per-hectare biomass is lower than in the areas of slower deforestation in the central and northern parts of the region.

The burning efficiency (percentage of pre-burn carbon presumed emitted as gases) averaged 32.6% in available studies: 27.6% in a 1984 burn and 28.3% in a 1990 burn studied near Manaus (Fearnside et al., 1993, nd-b); and 42.0% in three burns in 1986 studied in Altamira, Pará (Fearnside et al., nd-c). Adjustments for the effect of logging on the diameter distribution of the biomass gives an efficiency of 33.2%.

Charcoal formation averaged 2.7% and 1.8% of pre-burn above-ground carbon at Manaus (Fearnside et al., 1993) and 1.3% in Altamira (Fearnside et al., nd-c). The value used in the present calculation is the average value of 1.9%.

Graphitic particulate carbon is another sink for carbon that is burned. This is calculated by emission factors from the amount of wood combusted. The amount of carbon entering this sink is only 1/20 the amount entering the charcoal sink (Tables 1 and 2).

The pre-1970 secondary forest must be considered separately from the primary forest, as these areas are not included in the deforestation rate estimate (13.8 X 10^6 km^2 $year^{-1}$ in 1990). A rough estimate of clearing rate is derived in Table 3. The amounts of greenhouse gases contributed by clearing of pre-1970 forest are very small (Tables 1 and 2).

(Table 3 here)

Subsequent burns

Subsequent burns combust both remains of original forest and the secondary forest biomass. The original forest remains burned with an efficiency of 28.0% in a study in Roraima (Fearnside et al., nd-d). In pasture burning in Roraima studied by Barbosa (1994) 12.3% of the pre-burn carbon in the original forest remains was consumed. The mean of the results of the two studies (20.1%) is used in the present calculation.

Decay of unburned remains

Above-ground decay of unburned remains is calculated the available studies listed in Table 4. Decay makes a significant contribution to greenhouse gas emissions, and it is apparent that the focus of interest on biomass burning leads many to overlook the contributions of decay. The greenhouse gas emissions from deforestation that have been put forward by official Brazilian government sources (Borges, 1992; Silveira, 1992) are lower than those calculated in the present paper by a factor of three, mainly because they ignore the inherited emissions, in which decay plays a large role.

(Table 4 here)

Termite emissions of methane from decay of unburned biomass (Martius et al., nd) are substantially lower than previous estimates (Fearnside, 1991, 1992). This is mainly because estimates of the number of termites in deforested areas indicate that the populations are insufficient to consume the quantity of wood that had previously been assumed. Nasutitermes macrocephalus, the only species of Amazonian termite for which measurements are available, consumes 49 mg of dry wood per g termites per day (Martius, 1989). Lower emissions of methane (0.002 g CH_4 per g of dry wood consumed) also contributes to lower emissions from this source, estimated to total only 0.02 X 10^6 t of CH_4 gas from original forest in cleared area in 1990 (Tables 1-2).

Soils

In order to estimate CO_2 emissions from soils, one must consider the layer of soil in the replacement land-use, such as pasture, that is compacted from a given depth of forest soil (see Fearnside, 1980). The emission calculated here (30-32 X 10^6 t CO_2) considers only the top 20 cm of forest soil; considering soil to 1-m depth would approximately double these emissions. Converting forest to pasture releases 3.96 t C ha^{-1} from the top 20 cm of forest soil (see Fearnside, 1991, 1992). Pasture soil also emits N_2O (Luizão et al., 1989).

Removal of sources and sinks in pre-clearing landscape

1.) Soil sink for CH_4

The tropical forest soil provides a natural sink for methane, removing 0.0004 tons of carbon per hectare per year (Keller et al., 1986). Clearing the forest eliminates this sink, thereby having an effect equal to a source of the same magnitude. In 1990 the forests that had been cleared accounted for 0.02 X 10^6 t of CH_4 gas (Tables 1 and 2).

2.) Forest source of NO_x and NMHC

The leaves of the forest release 0.0131 t ha^{-1} $year^{-1}$ of NO_x (Kaplan et al., 1988; see Keller et al., 1991) and 0.12 t ha^{-1} $year^{-1}$ of NMHC (Rasmussen and Khalil, 1988, p. 1420). No information is available on the releases of these gases from the replacement vegetation. Assuming no releases from farmland, productive and degraded cattle pasture, and releases from secondary forests the same as those from primary forests, the landscape in 1990 implied a negative flux of 2.73 X 10^6 t $year^{-1}$ of NO_x and a positive flux of 1.02 X 10^6 t of NMHC (Tables 1 and 2).

3.) CH_4 release by termites

Termites in the mature forest release methane produced by bacteria that digest cellulose under anaerobic conditions in the insects' abdomens. These emissions will be lost when forest is cleared, but for a long time thereafter these emissions will be more than compensated for by termites that ingest the unburned biomass after clearing. In calculating emissions from termites in the forest, the item of interest is the absolute amount of biomass decaying annually (in t ha^{-1} $year^{-1}$), rather than the rate (fraction) of decomposition per year. For fine litter the amount can be known directly from data on litter fall rates, since all that falls decomposes and the level of the stock can be assumed to be in equilibrium. For coarse litter such data are unavailable, and the amount decomposing must be calculated from information on the stock and the rate of decomposition. Dead trees in a tropical forest can decay remarkably quickly. The decay constant (k) for decomposition of boles in Panama has been calculated to be 0.461 year^{-1} for trees >10 cm DBH, based on observation after a 10-year interval (Lang and Knight, 1979). Here, however, the lower decay rates measured in slash-and-burn fields (Table 4) are used for all coarse biomass. The amounts of fine and coarse litter are calculated from available studies in Tables 5 and 6.

(Tables 5 and 6 here)

Hydroelectric dams

One of the impacts of hydroelectric dams in Amazonia is emission of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Hydropower is often promoted by government authorities as a "clean" source of energy, in contrast to fossil fuels. While fossil fuel contributions to global warming are well-known, hydroelectric dams are not free of impact. The ratio of impact to benefit varies tremendously among dams depending on their power output. Balbina has the worst balance of impact to benefit due to the large area of the reservoir (2360 km^2) compared to the power generated, which averages only 109 megawatts delivered to Manaus (Fearnside, 1989).

Existing hydroelectric dams in Brazilian Amazonia emitted about 0.27 X 10^6 t of methane and 37 X 10^6 t of carbon dioxide in 1990. The CO_2 flux in 1990 included part of the large peak of release from above-water decay of trees left standing in the Balbina reservoir (closed in 1987) and the Samuel reservoir (closed in 1988). Most CO_2 release occurs in the first decade after closing. The methane emissions represent an essentially permanent addition to gas fluxes from the region, rather than a one-time release. The total area of reservoirs planned in the region is about 20 times the area existing in 1990, implying a potential annual methane release of about 5.2 X 10^6 t. About 40% of this estimated release is from underwater decay of forest biomass, which is the most uncertain of the components in the calculation. Methane is also released from open water, macrophyte beds, and above-water decay of forest biomass (Fearnside, 1995a).

Logging

In a typical situation, forests accessible by land or river transportation are logged, reducing their biomass both by the removal of timber and by killing or damaging many unharvested trees. This logged-over forest is later cleared for agriculture or cattle ranching. False color LANDSAT-TM images show small red dots appearing in a band around some deforested areas; in the next year the areas with the red dots have been cleared in the normal way (L. Gylvan Meira Filho, personal communication, 1993). The red dots probably indicate disturbance from heavy levels of selective logging in the year prior to felling.

The effect of logging is not as straightforward as it might appear. By removing the trunks of large trees, the burning efficiency will increase, as will the average decay rate of the unburned biomass. This is because small-diameter branches burn better and decay more quickly than do large trunks. These changes will partially compensate for the reduction in emissions from lower biomass. Where discounting or time preference weighting gives emphasis to short-term releases, the effect of logging will be further reduced, since the large logs removed would have been slow to decay had they been left in the forest.

The values for biomass from "unlogged" forest (Fearnside, nd-a) represent the best estimates for each forest type at the time it was surveyed (in the 1950s in the case of the FAO forest inventories that comprise 10% of the data and in the early 1970s in the case of the RADAMBRASIL data covering the remaining 90%). FAO data are from Heinsdijk (1957, 1958a,b,c) and Glerum (1960); RADAMBRASIL data are from Brazil, Projeto RADAMBRASIL (1973-1983). There is some reason to believe that the survey teams avoided logged-over locations (Sombroek, 1992). In addition, logging damage was much less widespread at the time of the surveys than it is at present. Logging is progressing rapidly, with the fraction of areas cleared that are logged prior to felling increasing noticeably since the mid-1970s as road access has improved. The number of sawmills purchasing wood has exploded, and wood prices have increased (cf. Veríssimo et al. 1992). In addition, logs and wood for charcoal and firewood are sometimes sold after the burn.

The biomass reduction due to logging in areas being felled is much higher than the average biomass reduction over the forest as a whole, as the areas being felled generally have the best road access. Much of the biomass reduction from logging will result in gas releases similar to those that would occur through felling: decay of the slash and the substantial number of non-commercial trees that are killed or damaged during the logging process; decay and/or burning of the scrap generated in the sawmilling process, plus a slower decay of wood products made from the harvested timber (see Fearnside, 1995b). With adjustment for logging, areas cleared in 1990 had an average total biomass of 407 t ha^{-1}, of which 250 t ha^{-1} was above-ground live biomass, 58 t ha^{-1} was above-ground dead and 98 t ha^{-1} was below-ground.

Interpretation of historical emissions

The annual balance should not be confused with the change in the annual balance. Many components of the balance, such as the fluxes from soils, termites and native forest vegetation that are lost when conversion occurs, will not change much as time progresses. The question of how much historical emissions will weigh, if anything, in international negotiations is still an open one. The industrialized countries have been the principal emitters of gases, especially CO_2, in the past, and any weighting for historical emissions by country would undoubtedly reflect this.

The area considered for calculating the loss of intact forest sources and sinks is taken here to be all of the 4.15 X 10^6 ha deforested through 1990, regardless of how long ago the original forest was cleared. About 75% of the clearing in Brazilian Amazonia has occurred within the past two decades, and the remaining 25% is almost all from within the present century. In other parts of the world the issue of a cutoff time for inherited effects is more complicated, and remains unresolved--such as the question of whether accounting should include removal of natural methane sources from Asiatic wetlands that were converted to irrigated rice several thousand years ago.

The treatment of historical emissions is important for establishing the way that responsibility for global warming is shared among countries. Knowing the magnitude of historical emissions is not necessary, however, for the annual balance (and its separate components) to be useful in understanding the global biogeochemical balances of the gases concerned, the magnitude of changes in the annual balance over the coming years as national inventory data are compiled, and the potential effectiveness of different response options in altering the annual balance of greenhouse gases.

UPTAKE BY REPLACEMENT VEGETATION

The replacement landscape

A Markov matrix of annual transition probabilities was constructed to estimate landscape composition in 1990 and to project future changes, assuming behavior of farmers and ranchers remains unchanged. Transition probabilities for small farmers are derived from satellite studies of government settlement areas (Moran et al. 1994; Skole et al., 1994). Probabilities for ranchers are derived from typical behavior elicited in interview surveys by Uhl et al., 1988). Six land uses are considered, which, when divided to reflect age structure, results in a matrix of 98 rows and columns.

The estimated 1990 landscape was 5.4% farmland, 44.8% productive pasture, 2.2% degraded pasture, 2.1% 'young' (1970 or later) secondary forest derived from agriculture, and 28.1% 'young' secondary forest derived from pasture, and 17.4% 'old' (pre-1970) secondary forest. The landscape would eventually approach an equilibrium of 4.0% farmland, 43.8% productive pasture, 5.2% degraded pasture, 2.0% secondary forest derived from agriculture, and 44.9% secondary forest derived from pasture. An insignificant amount is regenerated 'forest' (defined as secondary forest over 100 years old). Average total biomass (dry matter, including below-ground and dead components) was 43.5 t ha^{-1} in 1990 in the 410 X 10^3 km^2 deforested by that year for uses other than hydroelectric dams. At equilibrium, average biomass would be 28.5 t ha^{-1} over all deforested areas (excluding dams) (Fearnside, nd-b)

Secondary forest growth rates

The growth rate of secondary forests is critical in determining the uptake over the replacement landscape. Most discussions of uptake by secondary forests have assumed that these will grow at the rapid rates that characterize shifting cultivation fallows (e.g. Lugo and Brown, 1981, 1982). In Brazilian Amazonia, however, most deforestation is for cattle pasture, shifting cultivation playing a relative minor role (Fearnside, 1993a). Secondary forests on degraded pastures grow much more slowly than on sites where only annual crops have been planted following the initial forest felling.

Brown and Lugo (1990) have reviewed the available data on growth of tropical secondary forests. The available information is virtually all from shifting cultivation fallows. Brown and Lugo (1990, p. 17) trace a freehand graph from available data for secondary forest stands ranging in age from 1 to 80 years, including biomass for wood (twigs, branches and stems: 13 data points), leaves (10 data points), and roots (12 data points). This has been used to estimate growth rate and the root/shoot ratio for shifting cultivation fallows of different ages. Secondary forests on abandoned pastures grow more slowly (Guimarães, 1993; Uhl et al., 1988). This information on growth rate of secondary vegetation of different origins has been used to calculate uptakes in the landscape in 1990 (Fearnside and Guimarães, nd).

NET ANNUAL EMISSIONS

Considering only CO_2, 1353-1357 X 10^6 t of gas were emitted (gross emission) by deforestation (not including logging emissions). Deducting the uptake of 108 X 10^6 t yields a net emission of 1245-1249 X 10^6 t of CO_2, or 340-341 X 10^6 t of carbon. Adding effects of trace gases using the IPCC's 1992 global warming potentials for a 100-year time horizon (direct effects only), the impacts increase to 358-367 X 10^6 t of CO_2-equivalent carbon. Consideration of indirect effects of trace gases would raise these values substantially. Logging added 220 X 10^6 t of CO_2 gas, plus trace gases that raised the impact to 222-224 X 10^6 t of CO_2 equivalent, considering direct effects only.

Brazil's 1990 contribution from Amazonian deforestation alone, considering only CO_2 (1353-1357 X 10^6 t), represented approximately 5% of the total global emissions from fossil fuels and deforestation. The value 1991 was approximately 4%. This is three times higher than the value of 1.4% that has been frequently put forward by INPE (Borges, 1992; Silveira, 1992). The principal reason for the discrepancy is omission of inherited emissions in the INPE figure.

CONCLUSIONS

The annual balance of greenhouse gas emissions from land use change in Brazilian Amazonia in 1990 was dominated by deforestation. In terms of carbon dioxide only, approximately 26% was from prompt emissions from deforestation in that year, and 74% was inherited emissions principally from decay and reburning of unburned biomass left from clearing in previous years. Because deforestation rates declined in the three years immediately preceding 1990, the annual balance from deforestation (i.e. excluding logging) is higher than the net committed emissions, or the net amounts of greenhouse gases that will ultimately be emitted as a result of the clearing done in 1990. The annual balance is higher by 35% if only CO_2 is considered and by 29% if the CO_2 equivalents of other gases are also included. Net committed emissions would be equal to the annual balance that would prevail were deforestation to proceed at a constant rate over a long period.

The amounts of net emissions (excluding logging) are calculated for low and high trace gas scenarios, expressing the range of available estimates of emission factors, but not the range of doubt for estimates of biomass and deforestation rates. The net emissions, expressed in millions of tons of gas were: CO_2: 1245-1249; CH_4: 2.0-2.4; CO: 36-46; N_2O: 0.15-0.27; NO_x: -2.7 - -2.9; NMHC: 0.4-1.2. Logging releases an additional 220 X 10^6 t of CO_2 gas, plus trace gases equivalent to 2-4 X 10^6 t of CO_2.

Acknowledgments. The Pew Scholars Program in Conservation and the Environment provided financial support. S.V. Wilson made helpful comments on the manuscript.

REFERENCES

Barbosa, R.I. 1994. Efeito Estufa na Amazônia: Estimativa da Biomassa e a Quantificação do Estoque e Liberação de Carbono na Queima de Pastagens Convertidas de Florestas Tropicais em Roraima, Brasil. Masters thesis in ecology, Instituto Nacional de Pesquisas da Amazônia (INPA) and Universidade Federal do Amazonas (UFAM).

Barbosa, R.I. and P.M. Fearnside. nd. Carbon and nutrient flows in an amazonian forest: fine litter production and composition Colônia do Apiaú, Roraima, Brazil. Journal of Geophysical Research (Atmospheres) (in press).

Bartholomew, W.V., J. Meyer and H. Laudelout. 1953. Mineral nutrient immobilization under forest and grass fallow in the Yangambi (Belgian Congo) region. Publication de l'Institut Nacional pour l'étude Agronomique du Congo Belge. Série Scientifique No. 57. 27 pp.

Borges, L. 1992. "Desmatamento emite só 1,4% de carbono, diz Inpe" O Estado de São Paulo 10 April 1992, p. 13.

Brazil, Projeto RADAMBRASIL. 1973-1983. Levantamento de Recursos Naturais, Vols. 1-23. Ministério das Minas e Energia, Departamento Nacional de Produção Mineral (DNPM), Rio de Janeiro, Brazil.

Brown, S. and A.E. Lugo. 1990. Tropical secondary forests. Journal of Tropical Ecology 6: 1-32.

Brown, S. and A.E. Lugo. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia 17(1): 8-18.

Buschbacher, R.J. 1984. Changes in Productivity and Nutrient Cycling following Conversion of Amazon Rainforest to Pasture. Ph.D. dissertation in ecology, University of Georgia, Athens, Georgia, U.S.A.

Cuevas, E. and E. Medina. 1988. Nutrient dynamics within Amazonian forests II. Fine root growth, nutrient availability and leaf litter decomposition. Oecologia 76: 222-235.

Dantas, M. and J. Phillipson. 1989. Litterfall and litter nutrient content in primary and secondary Amazonian 'terra firme' rain forest. Journal of Tropical Ecology 5: 27-36.

Ewel, J.J. 1971. Biomass changes in early tropical succession. Turrialba 21: 110-112.

Ewel, J.J. 1975. Biomass of second growth tropical moist forest. pp. 143-150 In: F.B. Golley, J.T. McGinnis, R.G. Clements, G.I. Child and M.J. Duever (eds.) Mineral Cycling in a Tropical Moist Forest Ecosystem. University of Georgia Press, Athens, Georgia. 248 pp.

Fearnside, P.M. 1980. The effects of cattle pastures on soil fertility in the Brazilian Amazon: consequences for beef production sustainability. Tropical Ecology 21(1): 125-137.

Fearnside, P.M. 1990. The rate and extent of deforestation in Brazilian Amazonia. Environmental Conservation 17(3): 213-226.

Fearnside, P.M. 1991. Greenhouse gas contributions from deforestation in Brazilian Amazonia. pp. 92-105 In: J.S. Levine (ed.) Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications. MIT Press, Boston, Massachusetts. 640 pp.

Fearnside, P.M. 1992. Greenhouse Gas Emissions from Deforestation in the Brazilian Amazon. Carbon Emissions and Sequestration in Forests: Case Studies from Developing Countries. Volume 2. LBL-32758, UC-402. Climate Change Division, Environmental Protection Agency, Washington, DC and Energy and Environment Division, Lawrence Berkeley Laboratory (LBL), University of California (UC), Berkeley, California, U.S.A. 73 pp.

Fearnside, P.M. 1993a. Deforestation in Brazilian Amazonia: The effect of population and land tenure. Ambio 22(8): 537-545.

Fearnside, P.M. 1993b. Desmatamento na Amazônia: Quem tem razão -- o INPE ou a NASA? Ciência Hoje 16(96): 6-8.

Fearnside, P.M. 1995a. Hydroelectric dams in the Brazilian Amazon as sources of 'greenhouse' gases. Environmental Conservation 22(1): 7-19.

Fearnside, P.M. 1995b. Global warming response options in Brazil's forest sector: Comparison of project-level costs and benefits. Biomass and Bioenergy (in press).

Fearnside, P.M. nd-a. Biomass of Brazil's Amazonian forests (in preparation).

Fearnside, P.M. 1996 [nd-b]. Amazonian deforestation and global warming: Carbon stocks in vegetation replacing Brazil's Amazon forest. For. Ecol. Manage. 80: 21-34.

Fearnside, P.M. and W.M. Guimarães. 1996. Carbon uptake by secondary forests in Brazilian Amazonia. For. Ecol. Manage. 80: 35-46.

Fearnside, P.M. and J. Ferraz. 1995. A conservation gap analysis of Brazil's Amazonian vegetation. Conservation Biology 9(5): 1134-1147.

Fearnside, P.M., L.G. Meira Filho, and A.T. Tardin. nd-a. Deforestation rate in Brazilian Amazonia. (in preparation).

Fearnside, P.M., N. Leal Filho and P.M. Fernandes. 1993. Rainforest burning and the global carbon budget: Biomass, combustion efficiency and charcoal formation in the Brazilian Amazon. Journal of Geophysical Research (Atmospheres) 98(D9): 16,733-16,743.

Fearnside, P.M., P.M.L.A. Graça, N. Leal Filho, F.J.A. Rodrigues, and J.M. Robinson. nd-c. Tropical forest burning in Brazilian Amazonia: Measurements of biomass, combustion efficiency and charcoal formation at Altamira, Pará (in preparation).

Fearnside, P.M., R.I. Barbosa and P.M.L.A. Graça. nd-d. Burning of secondary forest in Amazonia: Biomass, combustion efficiency and charcoal formation during land preparation for agriculture in Roraima, Brazil (in preparation).

Fearnside, P.M., P.M.L.A. Graça and F.J.A. Rodrigues. nd-b. Burning of Amazonian rainforests: Burning efficiency and charcoal formation in forest cleared for cattle pasture near Manaus, Brazil. (in preparation).

Franken, M., U. Irmler and H. Klinge. 1979. Litterfall in inundation, riverine and terra firme forests of Central Amazonia. Tropical Ecology 20(2): 225-235.

Glerum, B.B. 1960. Report to the Government of Brazil on a Forestry Inventory in the Amazon Valley (Part Five) (Region between Rio Caete and Rio Maracassume), FAO Report No. 1250, Project No. BRA/FO, 6en Sociale Geografie 68(5): 297-311. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Guimarães, W.M. 1993. Liberação de carbono e mudanças nos estoques dos nutrientes contidos na biomassa aérea e no solo resultante de queimadas de florestas secundárias em áreas de pastagens abandonadas, em Altamira, Pará. Masters thesis in Ecology, Instituto Nacional de Pesquisas da Amazônia/Fundação Universidade do Amazonas (INPA/FUA), Manaus. 69 pp.

Heinsdijk, D. 1957. Report to the Government of Brazil on a Forest Inventory in the Amazon Valley (Region between Rio Tapajós and Rio Xingú). FAO Report No. 601, Project No. BRA/FO, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 135 pp.

Heinsdijk, D. 1958a. Report to the Government of Brazil on a Forest Inventory in the Amazon Valley (Part Three) (Region between Rio Tapajós and Rio Madeira), FAO Report No. 969, Project No. BRA/FO, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 83 pp.

Heinsdijk, D. 1958b. Report to the Government of Brazil on a Forest Inventory in the Amazon Valley (Part Four) (Region between Rio Tocantins and Rios Guamá and Capim), FAO Report No. 992, Project No. BRA/FO, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 72 pp.

Heinsdijk, D. 1958c. Report to the Government of Brazil on a Forestry Inventory in the Amazon Valley (Part Two) (Region between Rio Xingú and Rio Tocantins), FAO Report No. 949, Project No. BRA/FO, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 94 pp.

Isaksen, I.S.A., V. Ramaswamy, H. Rodhe and T.M.L. Wigley. 1992. Radiative forcing of climate. pp. 47-67 In: J.T. Houghton, B.A. Callander and S.K. Varney (eds.) Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment. Cambridge University Press, Cambridge, U.K. 200 pp.

Kaplan, W.A., S.C. Wofsy, M. Keller and J.M. da Costa. 1988. Emission of NO and deposition of O_3 in a tropical forest system. Journal of Geophysical Research 93: 1389-1395.

Keller, M., D.J. Jacob, S.C. Wofsy and R.C. Harriss. 1991. Effects of tropical deforestation on global and regional atmospheric chemistry. Climatic Change 19(1-2): 139-158.

Keller, M., W.A. Kaplan and S.C. Wofsy. 1986. Emissions of N_2O,

CH_4 and CO_2 from tropical forest soils. Journal of Geophysical Research 91: 11,791-11,802.

Klinge, H. 1973. Biomassa y materia orgánica del suelo en el ecosistema de la pluviselva centro-amazónica. Acta Científica Venezolana 24(5): 174-181.

Klinge, H. 1977. Fine litter production and nutrient return to the soil in three natural forest stands of Eastern Amazonia. Geo-Eco-Trop 1(2): 159-167.

Klinge, H. and W.A. Rodrigues. 1968. Litter production in an area of Amazonian terra firme forest. Part I. Litter-fall, organic carbon and total nitrogen contents of litter. Amazoniana 1(4): 287-302.

Lang, G.E. and D.H. Knight. 1979. Decay rates of boles for tropical trees in Panama. Biotropica 11(4): 316-317.

Lugo, A.E. and S. Brown. 1981. Tropical lands: popular misconceptions. Mazingira 5(2): 10-19.

Lugo, A.E. and S. Brown. 1982. Conversion of tropical moist forests: a critique. Interciencia 7(2): 89-93.

Lugo, A.E. and S. Brown. 1992. Tropical forests as sinks of atmospheric carbon. Forest Ecology and Management 54: 239-255.

Luizão, F.J. 1989. Litter production and mineral element input to the forest floor in a Central Amazonian forest. Geo-Journal 19(4): 407-417.

Luizão, F., P. Matson, G. Livingston, R. Luizão and P. Vitousek. 1989. Nitrous oxide flux following tropical land clearing. Global Biogeochemical Cycles 3: 281-285.

Martius, C. 1989. Untersuchungen zur Ökologie des Holzabbaus durch Termiten (Isoptera) in zentralamazonischen Überschwemmungswäldern (Várzea). AFRA-Verlag, Frankfurt am Main, Germany. 285 pp.

Martius, C., P.M. Fearnside, A.G. Bandeira, and R. Wassmann nd. Deforestation and methane release from termites in Amazonia. (in preparation).

Moran, E.F., E. Brondizio, P. Mausel and Y. Wo. 1994. Integrating Amazonian vegetation, land-use, and satellite data. BioScience 44(5): 329-338.

Puig, H. and J.-P. Delobelle. 1988. Production de litière, nécromasse, apports minéreaux au sol par la litière en forêt Guyanaise. Revue Ecologie (Terre Vie) 43: 3-22.

Rasmussen, R.A. and M.A.K. Khalil. 1988. Isoprene over the Amazon Basin. Journal of Geophysical Research 93: 1417-1421.

Saldarriaga, J.G., D.C. West and M.L. Tharp. 1986. Forest Succession in the Upper Rio Negro of Colombia and Venezuela. Oak Ridge National Laboratory, Environmental Sciences Publication No. 2694, ORNL/TM-9712. National Technical Information Service, Springfield, Virginia, U.S.A. 164 pp.

Scott, D.A., J. Proctor and J. Thompson. nd. Ecological studies on a lowland evergreen rain forest on Maracá Island, Roraima, Brazil II. Litter and nutrient cycling. (manuscript, 41 pp.).

Silva, M.F.F. 1984. Produção anual de serrapilheira e seu conteudo minerológico em mata tropical de terra firme, Tucuruí-PA. Boletim do Museu Paraense Emílio Goeldi, Botânica. 1(1/2): 111-158.

Silva, M.F.F. and M.G.A. Lobo. 1982. Nota sobre deposição da matéria orgânica em floresta de terra firme, várzea e igapó. Boletim do Museu Paraense Emílio Goeldi No. 56: 1-13.

Silveira, V. 1992. "Amazônia polui com apenas 1,4%" Gazeta Mercantil [São Paulo] 29 May 1992, pp. 2 and 6.

Skole, D.L., W.H. Chomentowski, W.A. Salas and A.D. Nobre. 1994. Physical and human dimensions of deforestation in Amazonia. BioScience 44(5): 314-322.

Sombroek, W.G. 1992. Biomass and carbon storage in the Amazon ecosystems. Interciencia 17(5): 269-272.

Uhl, C., R. Buschbacher and E.A.S. Serrão. 1988. Abandoned pastures in Eastern Amazonia. I. Patterns of plant succession. Journal of Ecology 76: 663-681.

Veríssimo, A., P. Barreto, M. Mattos, R. Tarifa and C. Uhl. 1992. Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: The case of Paragominas. Forest Ecology and Management 55: 169-199.

TABLE 1: 1990 ANNUAL BALANCE OF NET EMISSIONS BY SOURCE
IN THE ORIGINALLY FORESTED AREA OF THE BRAZILIAN LEGAL AMAZON[(a)]:
LOW TRACE GAS SCENARIO

Source	Emissions (million t of gas)						Sinks (Million t carbon)	
	CO2	CH4	CO	N2O	NOx	NMHC	Charcoal carbon	Graphitic particulate carbon
ORIGINAL FOREST BIOMASS								
Initial burn	228.15	0.74	17.66	0.05	0.56	0.49	4.13	0.17
Reburns	82.50	0.41	12.96	0.02	0.65	0.21	1.39	0.10
Termites above-ground decay	15.27	0.02						
Other above-ground decay	540.79							
Below-ground decay	320.18							
SECONDARY FOREST BIOMASS								
Burning[(b)]	49.93	0.16	3.87	0.010	0.06	0.11	0.01	0.04
Termites above-ground decay	0.39	0.000						
Other above-ground decay	12.96							
Below-ground decay	20.53							
Termites in secondary forest		0.00						
PRE-1970 SECONDARY FOREST BIOMASS								
Initial burning	4.50	0.015	0.349	0.001	0.011	0.010	0.082	0.00
Reburnings	1.08	0.005	0.169	0.000	0.009	0.003	0.018	0.00
Termites above-ground decay	0.23	0.0002						
Other above-ground decay	8.05							
Below-ground decay	3.00							
Termites in pre-1970 stands		0.00						
PASTURE BURNING	(c)	0.06	1.39	0.004	0.10	0.04	0.00	0.01

HYDROELECTRIC DAMS											
	Forest biomass			37.45	0.12						
	Water				0.11						
	Macrophytes			0.04							
OTHER SOURCES											
	Cattle			0.32							
	Pasture soil					0.08					
	Loss of intact forest sources and sinks			0.02				-4.24	-0.46		
	Loss of natural forest termites			-0.02							
	Soil carbon (top 20 cm)			31.50							
TOTAL EMISSIONS				1,356.52	1.98	36.40	0.15	-2.86	0.39	5.63	0.32
UPTAKE				-107.89							
NET EMISSIONS				1,248.63	1.98	36.40	0.15	-2.86	0.39	5.63	0.32
---------	---------	---------	---------	-----------	---------	---------	------------	---------	---------	---------	---------

(a) Deforestation in originally forested area in 1990 was 1,381,800 ha.

(b) Secondary forest burning includes both initial and subsequent burns for secondary forest from both agriculture and pasture, and for degraded pasture that is cut and recuperated.

(c) CO_2 from maintenance burning of pasture is not counted, as this is re-assimilated annually as the pastures regrow, making the net flux equal to zero. The gross flux in 1990 from this source is estimated at 18 X 10^6 t of CO_2 gas.

TABLE 2: 1990 ANNUAL BALANCE OF NET EMISSIONS BY SOURCE
IN THE ORIGINALLY FORESTED AREA OF THE BRAZILIAN LEGAL AMAZON[(a)]:
HIGH TRACE GAS SCENARIO

Source	Emissions (million t of gas)						Sinks (million t carbon)	
							Charcoal carbon	Grap part te carb
	CO_2	CH_4	CO	N_2O	NO_x	NMHC		
ORIGINAL FOREST BIOMASS								
Initial burn	228.15	0.88	22.08	0.05	0.56	0.93	4.13	0.21
Reburns	82.50	0.65	16.50	0.14	0.65	0.40	1.39	0.15
Termites above-ground decay	16.80	0.02						
Other above-ground decay	540.79							
ow-ground decay	320.18							
SECONDARY FOREST BIOMASS								

	Burning(b)	47.65	0.18	4.61	0.010	0.05	0.19	0.01	0.04
	Termites above-ground decay	0.37	0.0003						
	Other above-ground decay	12.31							
	Below-ground decay	19.54							
	Termites in secondary forest		0.002						
PRE-1970 SECONDARY FOREST BIOMASS									
	Initial burning	4.50	0.017	0.436	0.001	0.011	0.018	0.082	0.00
	Reburnings	1.08	0.008	0.216	0.002	0.009	0.005	0.018	0.00
	Termites above-ground decay	0.25	0.0002						
	Other above-ground decay	8.05							
	Below-ground decay	3.00							
	Termites in pre-1970 stands		0.00						
PASTURE BURNING		(c)	0.07	1.67	0.003	0.09	0.07	0.00	0.02

HYDROELECTRIC DAMS									
	Forest biomass	37.45	0.12						
	Water		0.11						
	Macrophytes		0.04						
OTHER SOURCES									
	Cattle		0.30						
	Pasture soil				0.07				
	Loss of intact forest sources and sinks		0.02			-4.06	-0.44		
	Loss of natural forest termites		-0.02						
	Soil carbon (top 20 cm)	30.25							
TOTAL EMISSIONS		1352.89	2.39	45.51	0.27	-2.68	1.17	5.62	0.42
UPTAKE		-107.89							
NET EMISSIONS		1244.99	2.39	45.51	0.27	-2.68	1.17	5.62	0.42

(a) Deforestation in originally forested area in 1990 was 1,381,800 hectares.

(b) Secondary forest burning includes both initial and subsequent burns for secondary forest from both agriculture and pasture, and for degraded pasture that is cut and recuperated.

(c) CO_2 from maintenance burning of pasture is not counted, as this is re-assimilated annually as the pastures regrow, making the net flux equal to zero. The gross flux in 1990 from this source is estimated at 17 million t of CO_2 gas.

TABLE 3: PRE-1970 SECONDARY FOREST: AREA AND RATE OF CLEARING 1970-1988

State	Area of pre-1970 secondary forest (km^2)			Area of pre-1970 secondary forest cleared per year (km^2)	Percent of pre-1970 secondary forest area cleared per year	
	Present in 1988(a)	Cleared by 1988(b)	Present in 1970(c)			
Pará	39,819	10,369	50,188	576	1.15	
Maranhão	57,824	2,459	60,283	137	0.23	
Total	97,643	12,828	110,471	713	0.65	

(a) Fearnside et al., nd-a

(b) Fearnside, 1990: 219.

(c) The year before which secondary forests are considered "old deforestation" is reported variously by the INPE team working with the images as 1960 and 1970. In truth, both are guesses. Here 1970 is assumed to be the date, as the clearing prior to this would have been much slower than that after this date.

TABLE 4: ABOVE-GROUND DECAY IN SLASH-AND-BURN FIELDS

Source	Biomass type	Age range of decaying biomass	Age midpoint	Above-ground biomass dry wt. (t ha^{-1})	Interval	Interval Length (years)	Decay rate ("k")	Note
Uhl and Saldarriaga, nd.	Mature forest	0	0	188				(a)
		3-4	3.5	97.3	0-3.5	3.5	-0.188	
		6-7	6.5	56	3.5-6.5	3	-0.184	
		8-10	9	45.3	6.5-9	2.5	-0.085	
		12-20	16	22.7	9-16	7	-0.099	
Buschbacher, 1984: 72	Mature forest	0.5	0.5	279				
		2.5	2.5	208	0.5-2.5	2	-0.147	
	Secondary forest	0.5	0.5	17.7				
		2.5	2.5	14.2	0.5-2.5	2	-0.110	

AVERAGE DECAY RATES FOR MATURE AND SECONDARY FOREST REMAINS IN INTERBURN INTERVALS

Interval	Interval length (years)	Mature forest			Secondary forest	
		Annual rate	Fraction surviving decay in interval		Annual rate	Fraction surviving decay in interval
0-4 yrs	5	-0.168	0.400		-0.110	0.558
5-7 yrs	3	-0.184	0.543		-0.110	0.705
8-10 yrs	3	-0.085	0.767		-0.110	0.705
After 10 yrs	infinite	-0.099	0.000		-0.110	0.000

a) Uses initial biomass of 290 t ha^{-1} from Stark and Spratt, 1977, less loss to combustion with efficency of 0.332 and charcoal formation fraction of 0.019 (mean of measurements by Fearnside et al., 1993, nd-b,c).

TABLE 5: FINE LITTER PRODUCTION IN AMAZONIAN FORESTS

COUNTRY	Location	State	Forest type	Annual production (t dry weight/ha)							
				Leaf litter	Wood <20 mm diameter	Wood <25 mm diameter	Wood of unstated diameter	Flowers and fruits	Other fine litter	Total fine litter reported	Total fine litt <20 mm or <25 mm
Brazil	Manaus (Reserva Egler)	Amazonas	Terra firme	5.60			1.35	0.35		7.30	
	Manaus (Bacia Modelo)	Amazonas	Terra firme Plateau site	5.42		1.56		0.42	0.79	8.19	8.19
	Manaus (Bacia Modelo)	Amazonas	Terra firme Valley site	4.69		1.17		0.43	1.12	7.41	7.41
	Manaus (Reserva Ducke)	Amazonas	Terra firme	6.34			1.03	0.47		7.90	
	Capitão Poco	Pará	Terra firme							8.04	
	Belém	Pará	Terra firme	8.0						9.9	
	Belém (Mocambo)	Pará	Terra firme	6.1			0.88	0.31		7.3	
	Tucuruí	Para	Terra firme	4.76						6.65	
	Apiaú	Roraima	Terra firme	5.73						9.15	
	Maracá	Roraima	Terra firme	6.30	1.34			1.21	0.42	9.3	9.3

French	Piste de		Terra firme	5.67			1.44	0.72		7.83	
Guiana	Saint-Elie										
Venezuela	San Carlos		Terra firme	7.56						10.25	
	de Rio Negro										
-------	--------	-------	---------	-------	-------	-----	-------	-------	------	---------	---------
MEAN				6.02	1.34	1.37	1.18	0.56	0.78	8.27	8.30
-------	--------	-------	---------	-------	-------	-----	-------	-------	------	---------	---------

TABLE 6: STOCKS OF LARGE DEAD BIOMASS IN UNDISTURBED TERRA FIRME FORESTS

Country	Location	Downed wood (t dry wt/ha)			Standing dead wood	Total large dead	Reference
		Small	trunks	total			
Brazil	Manaus, Amazonas			18.02	7.60	25.62	Klinge, 1973
	Maracá, Roraima	1.72	2.38	4.10	0.98	5.08	Scott et al., nd.
French Guiana	Piste de Sainte-Elie	3.60	11.42	15.02	3.49	18.51	Puig and Delobelle, 1988: 12.
Mean				12.38	4.02	16.40	