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TROPICAL FOREST LOGGING AND MANAGEMENT: IMPLICATIONS FOR GLOBAL WARMING

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ABSTRACT

Logging releases greenhouse gases when logging slash and logging-killed trees decay and when sawmill waste and wood products either burn or decay. Carbon sequestration benefits accrue from long-term storage of carbon in wood products pools and from regrowth of trees in the harvested areas. The rates and magnitudes of these processes, and the discounting or other time-preference schemes applied to the costs and benefits determine the impact and/or gain attributed to logging. When no discounting is applied and time horizons are very long or infinite, carbon gains accrue in long-term wood product pools when equilibrium is approached. Equilibrium calculations make forestry management appear attractive as a global warming response option. However, management is unattractive (and current logging practice is even more damaging) when calculations are made with time horizons and time preference weights that are consistent with other parts of the policy debate concerning global warming. The calculations presented here indicate that, at the official 1988 rate of logging, emissions from this activity raise the total emission for the forest sector in Brazilian Amazonia in 1990 by about one-third over the amount from deforestation (approximately___ 100 X 10^6 t CO_2-equivalent C/year from logging versus ___ 320 X 10^6 t CO_2-equivalent C/year from deforestation). If logging were taking place at triple this rate, then emissions from logging would be almost equal to those from deforestation.

I.) INTRODUCTION

A.) SOURCES OF CONTROVERSY

The present and probable future levels of greenhouse gas (GHG) emissions and uptakes from the forest sector of tropical countries represents one of the most controversial and least-studied areas of research related to global warming. Deforestation is one source of emissions, but possibly of equal importance is the related problem of emissions from logging, and the potential benefits of sustainable forest management and of replacing logging with output from silvicultural plantations. Part of the controversy surrounding logging and forest management stems from lack of data, but perhaps an even larger part stems from lack of an adequate structure with which to interpret the data that we have. The present paper hopes to offer such a structure and to explore the implications of our current understanding of emissions and uptakes from these processes.

B.) BRAZILIAN AMAZONIA AND THE TROPICAL TIMBER TRADE

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The present paper focuses on the Brazilian Amazon (Figure 1), but much of it applies to forests throughout the humid tropics. In 1990, Brazil had approximately 30% of the world's remaining closed tropical forests and 16% of the annual rate of forest loss to deforestation (Fearnside, nd-a, based mainly on WRI, 1992: 286-287). However, Brazil accounted for only a tiny fraction of tropical hardwood exports: in terms of all hardwoods traded internationally (both temperate and tropical), all of Latin America represented only 2% in 1988, according to data compiled by the Food and Agriculture Organization of the United Nations (FAO). By contrast, Asia represented 57% and Africa, 8%. Importing nations prefer Asian timber over that from Amazonia because of the relative uniformity of wood properties in forests dominated by a single plant family (Dipterocarpaceae). Asia's forests are undergoing rapid depletion, making increased pressure on Amazonia likely once Asian sources are commercially exhausted. Such an event could radically transform logging in Amazonia, where operations are now dominated by small Brazilian entrepreneurs rather than by large multinational (primarily Japanese) export firms that dominate Asian logging.

(Figure 1 here)

C.) ~~LOGGING~~ IMPACTS OF MAHOGANY VERSUS NON-MAHOGANY SPECIES

Mahogany (Swietenia macrophylla) represents a special case in Brazilian Amazonian logging activity. Despite the relatively low volume of this very valuable species, logging for mahogany has a disproportionately greater environmental impact. Loggers build roads within the forest, sometimes extending for hundreds of kilometers, in order to remove this species. The result is that, even though actual bole removal is minimal, tremendous damage is wrought on the remaining forest. Part of this is through killing and damaging of other trees when access roads are built and mahogany is hauled out. Indirect damage is even greater; the logging roads built for mahogany subsequently lead to entry of loggers after less-valuable species, and then to entry of squatters and speculators who clear the land for agriculture and cattle ranching.

The average wholesale price for mahogany over the 1985-1990 period in Brazil (weighted by volume sold) was US$ 610.37 per ton, versus US$ 295.69 for non-mahogany and US$ 374.62 for all species. Mahogany represented 25% of the tonnage sold during this period, and represented 41% of the value--but undoubtedly represented a much higher percentage of the environmental damage caused by logging. The average yearly export of timber was 401,312 t, worth US$ 150 million. These values are calculated from data from CACEX export records in Hahn (nd [1990]). Wood prices (in constant dollars) in Brazil's domestic market declined

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as a result the country's worsening economic recession in the early 1990s.

Mahogany extraction has been further speeded by a series of subsidies granted through the Superintendency for Development of the Amazon (SUDAM). These have increased the concentration of effort in larger logging operations, and the focus on mahogany (Browder, 1986: 311).

Brazil's domestic market consumes roughly three times more forest products than the country exports: internal consumption in 1989 was 3.6 X 10^6 m^3, while exports totaled 1.3 X 10^6 m^3 (FAO, 1991; cited by Johnson and Cabarle, 1993: 13). Forest products are defined by here as non-coniferous industrial roundwood, non-coniferous sawnwood, and wood-based panels. Not all forest products are from native forest, but Brazil's extensive _Eucalyptus_ plantations in the central-south region supply mostly pulp, charcoal and other commodities not included in the FAO definition of "forest products." Considerable doubt exists over the true volumes of timber harvested and of products marketed. Brazil's export records are not even close to being in agreement with the records of importing countries, according to an investigation conducted by Greenpeace (J.A. Padua, personal communication, 1993). The 1988 official log harvest of 24.6 X 10^6 m^3 (NB: without correction for processing losses) is about six times higher than the 4.9 X 10^6 m^3 total for forest products reported by FAO for 1989.

The identity, as well as the volume, of species harvested is a source of doubt. Firms tend to under-report valuable species such as mahogany in order to minimize taxes. Most information, including government statistics, ultimately comes from the timber industry itself. Industry organizations have a motivation to understate exports and exaggerate domestic consumption, as this helps to defuse international criticism over the impacts of tropical logging (J.A. Padua, personal communication, 1993).

II.) RELATION OF LOGGING TO EMISSIONS

A.) EMISSIONS FROM CURRENT LOGGING ACTIVITY

1.) Relation of Logging to Emissions

The relationships between logging and emissions have been simplified in Figure 2. In causal loop diagrams (such as Figure 2), the sign at the head of each arrow indicates the direction of change in the quantity at the head of the arrow if the quantity at the tail of the arrow increases (following the conventions of Forrester, 1970). Logging produces emissions through decay of slash and forest products. Logging reduces forest biomass by removing selectively the larger tree boles. This reduction

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increases CO_2 uptake by releasing faster growth of the remaining trees, which had been limited by competition with their neighbors. The lower biomass acts to reduce deforestation emissions, as less stock is present to be exposed to burning and decay at the time of clearing. On the other hand, removal of large boles also increases combustion efficiency, as a greater percentage of the biomass in small-diameter classes burns than is the case for large trunks. The increased combustion efficiency increases the emissions from deforestation when logged areas are cleared. Logging also stimulates deforestation by providing access roads to forest areas (both private and public) and by providing a source of cash to landholders, enabling them to invest in clearing to expand their agriculture and ranching activities.

(Figure 2 here)

The relationships in Figure 2 (with the exception of the link between logging and deforestation rates) are shown in more detail in Figure 3. Logging produces wood products, which decay over various time scales, producing emissions through decay. The logs also generate sawmill waste, which usually is burned, releasing gases through combustion. The logging takes place in two types of areas, with distinct emissions effects: areas that will be deforested within a short time (say, up to three years), and the remainder of the forest (designated as "not to be cleared"). In both types of areas, logging removes wood, but at different intensities. The fraction of the harvest that is done in areas to be cleared depends on the deforestation rate, the intensity of harvesting in these "preparatory" operations, and the total volume of wood harvested annually in the region. Wood removal in areas to be cleared lowers the above-ground biomass in these areas. Deforestation emissions both from decay and from combustion are positively related to above-ground biomass.

(Figure 3 here)

The effect of above-ground biomass (as altered by logging) on combustion efficiency can be calculated from the results of three studies of mature forest burns in Brazilian Amazonia (Table 1 and Figure 4). All of the wood removed by logging is in the > 10 cm diameter class, and the resulting proportion of the biomass in this category (and the corresponding combustion efficiency) can be calculated for any logging intensity. The biomass that does not burn is left on the site, where it is eventually oxidized either through decay or through combustion when cattle pastures or secondary forests are subsequently burned.

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(Table 1 and Figure 4 here)

In areas to be cleared, the pre-logging biomass is reduced by the non-preparatory harvesting--the relatively low level of harvest that prevails in areas not scheduled for deforestation. The root biomass corresponding to this above-ground biomass level will be the quantity subject to below-ground decay in the deforestation sector (the roots of the trees harvested or killed during the non-preparatory harvested are accounted for in the calculations for logging in areas not to be cleared).

In areas not to be cleared, the wood removed leaves both above-ground slash and roots from the harvested trees in proportion to the amount harvested. These stocks will be subject to above-ground and below-ground decay, respectively. The amount of wood removal divided by the pre-logging total biomass determines the percentage of above-ground biomass removed. The percent damage to forest can be calculated from this. The conservative assumption is made that logging damage and harvest intensity are linearly related (Figure 5, solid curve). In reality, light levels of harvest, as for mahogany, produce disproportionately greater damage to the forest (for example, as in Figure 5, dotted curve). As logging intensity increases, logging damage continues to increase in the range of likely logging intensities, but the increase tapers off progressively. Were logging intensity to increase still further, the damage would eventually decline, and, in the hypothetical extreme case where all trees are harvested, the logging damage would fall to zero.

(Figure 5 here)

The available data for establishing a relationship between logging intensity and logging damage (Figure 5) is clearly much less than might be desired. The study by Uhl and Kauffman (1990), for an area with logging intensity of 50 m^3/ha and a damage estimate that includes the building of access roads is the most appropriate available. Experimental harvesting at INPA's Model Basin site caused less damage (the open squares in Figure 5), but the damage estimates omits losses to access roads (Coic et al., 1990)

The absolute amount of damage to forest in areas not to be cleared can be calculated by multiplying the percent damage to the forest by the pre-logging total biomass in areas not to be cleared. The damage to the forest not to be cleared (in t/ha) is added to the above-ground decay pool, and the roots of the trees killed by logging damage (which is directly proportional to the damage to the forest) is subtracted from the pre-logging total biomass in areas not to be cleared to yield the forest above-ground biomass in areas not to be cleared. Forest growth stimulation by the reduction of above-ground biomass will act over a fixed period of years to increase biomass. The forest above-ground biomass is negatively related to the percent reduction in biomass from non-preparatory harvesting.

2.) Unlogged Forest Parameters

Biomass estimates are based on data from forest inventories carried out by Projeto RADAMBRASIL (1973-1982) and by the Food and Agriculture Organization of the United Nations (FAO) (Glerum, 1960; Heinsdijk, 1957, 1958a,b,c) at 2954 points distributed throughout Brazilian Amazon region. The calculations are presented in detail elsewhere (Fearnside et al., 1993; Fearnside, nd-b).

One is naturally tempted to use all available data for every parameter independent of what values may be selected for each parameter and the others to which it is linked. However, by doing so, one sometimes can create unrealistic behavior in the model calculations as the inconsistencies among the specified parameters adjust themselves to an equilibrium. This occurs for the parameters relative to above-ground live and dead biomass stocks, rates of decay, background tree mortality rate in the mature unlogged forest, and the natural growth rate of the mature forest trees. These parameters all have a logical relationship to one another for a forest that is in equilibrium. The natural growth rate of the trees must be equal to the background mortality rate (both expressed as fractions of above-ground live biomass per year). The coarse litter production (in t/ha/year) must be equal to either of these two rates multiplied by the above-ground live biomass of the forest. This may have to be adjusted for any effect of fine litter to the extent that leaves have been included in the growth and mortality rate estimates. The stock of above-ground dead biomass used for this equilibrium calculation should include only wood parts.

The assumption of equilibrium is prudent. It is a basic principle of modeling that one should begin with relationships in equilibrium and then proceed to perturb the system--otherwise one would be unable to understand how the system functions and spot anomalous behavior. In this case, it is better to have an internally consistent set of parameters than to use best estimates determined independently for each such parameter. Given that the data supporting some parameters is stronger than those for others, it is logical to use the best-documented parameters as the basis for the others that are logically linked to them.

The assumption of equilibrium in the mature unlogged forest is necessary, although one must recognize that it is an

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assumption. Available data are insufficient to justify an alternative such as that unlogged forest would continue to accumulate carbon at an appreciable rate. Such a possibility would have significant implications for the global carbon balance, but must await more refined measurements of the various components of the balance in such forests.

Just as equilibrium conditions are assumed for above-ground biomass, a similar equilibrium must be assumed for below-ground dead stock, underground decay rate and root growth rate. The equilibrium parameters are given in Table 2.

(Table 2 here)

3.) Logging Parameters

The parameters used in calculating logging effects on forest biomass and the emissions and uptakes in logged forests are given in Table 3. The sources of the parameters are also given. These calculations do not include acceleration of deforestation as a result of access from logging roads. Also not included are emissions from burning in standing forest; relatively high-flammability logging slash allows fires from neighboring pastures to enter logged-over forests (Uhl and Buschbacher, 1985; Uhl and Kauffman, 1990).

(Table 3 here)

The biomass of unlogged forest, discussed earlier, can be modified in accord with the relationships in Figure 3 and the parameters in Table 3 to calculate biomass levels for forest after non-preparatory and preparatory logging in areas to be cleared and after non-preparatory logging in areas not to be cleared (Table 4). These include above-ground and below-ground components, needed for calculation of emissions from subsequent combustion and decay.

(Table 4 here)

The logged forest will partially compensate for the emissions from logging by increased growth resulting both from increased light availability and from the flush of nutrients available from decomposing slash. Although there is great variation at the level of individual trees, canopy exposure is one of the most important determinants of growth (Ayphassorho and Feuillet, 1984: 24). Growth stimulation can be substantial, but

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slows down after a few years: 8-10 years after refinements reduce standing stem volume by half to two-thirds in the CELOS management system in Suriname (De Graaf and Poels, 1990: 120) or 3-4 years after logging in the Tapajós National Forest in Brazil (Silva and Whitmore, 1990). In French Guiana an exploitation of 70 m^3/ha plus poisoning of an additional 45 m^3/ha was estimated to have stimulated growth by 1.25 $\pm$ 0.25 m^3/ha over the background (presumably equilibrium) growth rate of 2 m^3/ha, based on previous work in the Ivory Coast (Maitre et al., 1984: 18). Mortality also increases, estimated in Suriname at 1.5% per year in undisturbed forest versus 2% per year in forest treated under the CELOS system, with poison-girdling of all non-commercial species over 20 cm diameter at breast height (Boxman et al., 1985: 8). In forest logged at 75 m^3/ha at the Tapajós National Forest in Brazil, mortality was 2.8% per year over a 6-year observation period (2-8 years after logging) (Silva and Whitmore, 1990). Undisturbed tropical forests generally have mortality in the 1-2% per year range (Swaine et al., 1987).

4.) Logging Emissions

Emissions from logging at the level officially reported for 1988 correspond to approximately 100___ X 10^6 t of CO_2-equivalent carbon (Figure 6). Together with 320 ____ X 10^6 t of CO_2-equivalent carbon emissions from 13.8 X 10^3 km^2 of deforestation in 1990 and from inherited emissions from the larger areas deforested in the years prior to 1990, the logging emissions raise the total to 420 X 10^6 t (Fearnside, nd-c). Were logging triple the official value, logging emissions of 288 X 10^6 t would be nearly equal to the 312 X 10^6 t from outright deforestation, raising the total to 599 X 10^6 t/year.

(Figure 6 here)

B.) EFFECT OF LOGGING REMOVALS ON DEFORESTATION EMISSIONS

For the areas deforested in 1990, it is clear that logging effects could be important. It is the values for above-ground biomass (both live and dead) that are relevant to calculating emissions from burning while it is the total biomass (both above- and below-ground) for emissions from decay. It should be noted that the above-ground live biomass has been erroneously used for both burning and decay in some studies, including the study of R.A. Houghton (1991) that the IPCC classified as a high estimate of deforestation emissions (Watson et al., 1992: 33). Biomass estimates for Amazonian forests (Fearnside, nd-b, Fearnside and Bliss, nd), derived from the forest volume information, indicate that the IPCC and R.A. Houghton (1991) estimates of emissions

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per hectare of deforestation both have a low bias from the estimates of forest biomass they used. The total emissions from deforestation, however, is the result of multiplying the emissions per hectare deforested by the deforestation rate. In the case of the estimates on which the IPCC based it's midpoint, the deforestation rate for Brazil was calculated for 1980 by R.A. Houghton et al. (1987: 126) using clearing data by state from Fearnside (1984) adjusted for the proportion of cerrado in each state (Brazil, IBGE, 1979: 44), giving a deforestation rate in the forested area the Legal Amazon region of about 8000 ____ km^2/year. In the case of R.A. Houghton (1991), the effect of low biomass value from Brown and Lugo (1984) is compensated by a high bias in the deforestation rate estimate used (from Myers, 1989, 1991), which for Brazilian Amazonia overestimates clearing rates by more than a factor of two (see Fearnside, 1990).

Lugo and Brown (1992) have condemned use of biomass estimates for unlogged forests when GHG emissions calculations are made for deforestation. Adjustment of the biomass value for the effect of logging is indeed needed. However the adjusted values can only be expected to yield better estimates of emissions if the emissions from logging and wood products are also included in the calculations. The practice of using biomass estimates adjusted for logging but not including the logging emissions (e.g. R.A. Houghton, 1991) produces greater distortion than use of the unadjusted pre-logging biomass for the forest. What is needed is a procedure for calculating emissions from logging, thereby allowing deforestation and logging emissions to be calculated and reported separately. The estimates in the present paper are intended to help fill this need.

C.) EMISSIONS FROM FOREST MANAGEMENT

Forestry management is often suggested as a form of global warming response. The benefits of management are: 1) avoiding deforestation with its consequent large emissions, 2) avoiding non-sustainable logging, and 3) producing forest products which will maintain carbon out of the atmosphere for long periods of time, while the forest continues to grow and to shunt carbon into the long-term forest product pools.

The key assumption in achieving the hoped-for benefits in averting global warming is that the management systems are really sustainable. The record so far has been extremely poor, and basic contradictions between the discounting used in financial calculations and the biological limitations of forest growth rates mean that sustainable management is unlikely to take hold without fundamental changes in the current system of economic rewards (Fearnside, 1989).

The way in which accounting is done for greenhouse gas benefits can have a strong effect on the value attributed to forest management, and the level of subsidy or support it merits, if any, on the grounds of environmental services. Of critical importance is whether national or global accounts are being considered. The United Nations Framework Convention on Climate (UNFCC) calls for compiling an inventory of the annual fluxes of carbon entering and leaving each country. Although protocols regarding national responsibilities are yet to be negotiated, the national inventory system reflects the understanding that

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assigning responsibility will be based on the point at which the carbon enters or leaves the atmosphere. This has significant implications for the role of forest management--making the carbon credit to the country under the convention something entirely different from the global benefit. The benefit of the plantation for abating global warming is much less than the benefit for the country's carbon balance. For the country's annual carbon balance, the carbon sequestration classification of the harvested biomass only requires that it remain out of the atmosphere long enough to be put on a ship and exported. A country exporting wood from logging natural forests will gain a carbon credit as trees grow back in the harvested areas.

From the point of view of international financing of natural forest management for greenhouse effect abatement, the benefit of interest is that to the global (not the national) account. The most relevant index is the contribution to the total global warming potential of the various gases in the atmosphere, calculated over an appropriate time span.

Discounting, or an alternative time-preference weighting scheme, has a dramatic effect on global warming costs and benefits from logging and forest management. When calculations are made with no discounting or equivalent and with an infinite time horizon, one arrives at the equilibrium stocks in product pools of different life times. Table 5 presents plausible equilibrium values from present logging activity, and Table 6 presents comparable values for forestry management. Such equilibrium calculations are dominated by the long and very long-term pools, even though these pools may take hundreds of years to approach their equilibrium levels and would have only a minimal role over the time horizons used for most human planning.

(Tables 5 and 6 here)

D.) RELATION OF PLANTATIONS TO LOGGING

The relation of plantations to carbon flows takes various forms in addition to the uptake by the planted trees. Plantations lead directly to uptake (in biomass growth) and emissions (as through decay of wood products and slash and through methane release from litter decomposition). Plantations also have a link to logging, avoided logging sometimes representing a large part of the credit claimed for plantations--often with little objective rationale. The assumptions regarding logging substitutions are some of the most important determinants of whether plantation schemes are attractive response options to global warming (Fearnside, nd-d).

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III.) CONCLUSIONS

Logging already makes a substantial contribution to greenhouse gas emissions from Amazonia. These emissions can be expected to increase in the future. In other parts of the humid tropics where logging activity is currently concentrated, emissions from logging are undoubtedly large.

Assuming that the 1988 official rate of logging harvest in forests of Brazilian Amazonia prevailed in 1990, about one-third of the forest sector emissions came from logging and two-thirds from deforestation. If the logging harvest were triple the 1988 official figure, then logging and deforestation would each contribute 50%, and the total emissions would be double that implied by considering only deforestation. The lowering of biomass by logging has only a relatively minor effect in attenuating the emissions impact of deforestation.

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TABLE : EFFECT OF LOGGING ON COMBUSTION EFFICIENCY

Site	year of burn	% of above-ground biomass >=10 cm diameter	% of above-ground carbon >=10 cm diameter	Pre-burn above-ground carbon (t/ha)			Post-burn above-ground carbon (t/ha)		
				< 10 cm diameter	>=10 cm diameter	Total in wood	< 10 cm diameter	>=10 cm diameter	Total in wood
Manaus	1984	76.08	76.19	31.0	99.2	130.2	11.4	79.4	90.8
Altamira	1986	60.25	60.12	54.9	82.7	137.5	11.7	67.8	79.5
Manaus	1990	73.61	73.56	48.8	135.8	184.6	14.8	108.4	123.2

Site	year of burn	Transformation efficiency (% released or charcoal)			Total carbon presumed released (t/ha)	Total carbon left as charcoal (t/ha)	Combustion efficiency (% released)		
		< 10 cm diameter	>=10 cm diameter	Total			< 10 cm diameter	>=10 cm diameter	Total
Manaus	1984	63.27	19.93	30.26	35.9	3.5	57.11	17.99	27.6
Altamira	1986	78.65	18.01	42.19	56.2	1.8	76.10	17.43	40.9
Manaus	1990	69.63	20.16	33.23	58.1	3.2	65.77	19.04	31.5
	Mean:	70.51	19.37	35.23			66.33	18.15	33.3

Site	year of burn	Source
Manaus	1984	Fearnside et al., 1993
Altamira	1986	Fearnside et al., nd-__
Manaus	1990	Fearnside et al., nd-__

TABLE 2: ESTIMATED AND IMPLIED VALUES FOR PARAMETERS FOR EQUILIBRIUM
MATURE UNLOGGED FOREST

Parameter	Units	Value used in this analysis	Justification of value used
Coarse litter stock	t biomass/ ha	14.74	Average for studies for which biomass partioning complete enough for inputs to Table 4 (biom-log), adjusted for total biomass difference between sampled and average for all unlogged forests in the Legal Amazon.
Coarse litter decay rate	fraction/ year	0.17	The decay rate up to the time when 50% of the initial above-ground biomass has disappeared. Subsequent rates decline.
Coarse litter production	t/ha/ year	2.49	Value implied by coarse litter stock and decay rate
Background mortality	fraction of biomass/ year	0.0085	Value implied by coarse litter production and above-ground live biomass in all unlogged forests.
Natural growth rate	fraction/ year	0.0085	Assumed equal to background mortality rate.
Fine litter stock	t biomass/ ha	10.31	Table __ F7-tab9 [illegible]
Fine litter decay rate	fraction/ year	0.8050	Implied equilibrium rate: fine litter production/ fine litter stock
Fine litter production	t/ha/ year	8.3	~~Table __ Fine-lit~~ [illegible]
Below-ground dead stock	t biomass/ ha	4.45	Table 4 Biom-log
Under-ground decay rate	fraction/ year	0.1691	Assumed equal to above-ground decay rate
Root natural death rate	fraction of biomass/ year	0.0085	Assumed equal to above-ground background mortality rate

TABLE 3 : LOGGING PARAMETERS

Parameter	Value	units	Source
Sawmill waste	0.53	fraction of processed wood	Verissimo et al., ~~nd.~~ 199-
Above-ground slash from harvested trees	0.34	fraction with respect to logging removals	da Cruz and Machado, 1986: 9
Roots of harvested trees	0.26	fraction with respect to logging removals	See Fearnside, nd-_ plantations.
Damage to forest above-ground biomass	2.66	fraction with respect to logging removals	Calculated from Uhl and Kauffman, 1990; See Fearnside, nd-d plantations. Assumes linear relation of damage to logging intensity.
Roots killed in logged forest	0.52	fraction with respect to logging removals	Calculated from Uhl and Kauffman, 1990; See Fearnside, nd-d plantations. Assumes linear relation of damage to logging intensity.
Logging intensity in areas to be cleared	12.5	m3/ha	Assumed to be one-fourth the intensity in Paragominas, Para in study area of Uhl and Kauffman (1990).
Logging intensity in logged areas that are not to be cleared	5	m3/ha	Guess.
Logging removals in forest subjected to pre-preparatory and to preparatory harvesting	11.4	t/ha	Calculated from logging intensities and basic density of wood.
Fraction of remaining forest that has been logged in areas not to be cleared	0.041	fraction	Calculated as twice the average years since logging time the area logged annually in forest that is not to be cleare divided by the area of forest not to be logged existing in 1 The area (ha) logged by 1990= 7,327,500 = 73,275
Basic wood density	0.65	dry weight/ green volume	Fearnside, nd-e
Background mortality	0.0085	fraction	Equilibrium implied by coarse litter stock

rate of trees in undisturbed forest		of trees per year	and coarse litter decay rate (see Table 2 equilib.)
Increase over background mortality, Years 2-8 in logged forest	0.013	fraction of trees per year	Silva and Whitmore, ~~nd.~~ 1990
Years of increased mortality effect	8	years	End of observation period at Tapajos (Silva and Whitmore, ~~nd~~ 1990).
Fraction of harvesting that is done in areas to be cleared	0.702	fraction	Calculated from total wood harvest, logging intensity in cleared areas and 1990 deforestation rate.
Above-ground growth stimulation by logging in logged areas that are not to be cleared	0.058	t/ha/year	Assumed proportional to stimulation in French Guiana at 70 m3 logging + 45 m3 poisoning/ha
Years of growth stimulation effect	6.25	years	Mean of effect in Suriname (9 yrs: De Graaf and Poels, 1990: 120) and Tapajos (3.5 +- 0.5 years: Silva and Whitmore, ~~nd~~. 1990
Fraction of undisturbed forest above-ground biomass >=10 cm diameter	0.6988	fraction	Mean of two studies in Manaus and one in Altamira (Fearnside et al., nd-a,b,c 1993
Undisturbed forest above-ground biomass >=10 cm diameter	210.5	t/ha	Calculated from Table 4 and fraction of undisturbed forest above-ground biomass >=10 cm diameter.
Fraction of above-ground biomass >=10 cm diameter in forest subjected to pre-preparatory harvesting and preparatory harvesting logging	0.6869	fraction	calculated from Table 4 Biom-log.
Combustion efficiency for biomass >=10 cm diameter	0.1710	fraction released	Mean of two studies in Manaus and one in Altamira (Table 1)
Combustion efficiency for biomass <10 cm diameter	0.6635	fraction released	Mean of two studies in Manaus and one in Altamira (Table 1)
Combustion efficiency for above-ground biomass in areas cleared after pre-preparatory harvesting and preparatory harvesting	0.3252	fraction released	Calculated from combustion efficiencies for diameter classes present after logging; does not include enhancement of burning efficiency because of greater proportion of biomass being dead.

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logging

Total annual wood harvest	24,600,000	m3/yr	Assumed official 1988 value of 24.6 million m3.
Area logged annually outside of area to be cleared (adjusted for average logging intensity in logged areas) (no plantation scenario)	1,465,500	ha	Calculated after logging in area to be cleared, assuming specified average logging intensities in the areas to be cleared and not to be cleared. Clearing is at 1990 rate.
Area logged annually outside of area to be cleared (adjusted for average logging intensity in logged areas) (plantation scenario)	1,465,500	ha	Calculated after logging in area to be cleared, assuming specified average logging intensities in the areas to be cleared and not to be cleared. Clearing is at 1990 rate.
1990 area of forest not to be cleared	****.******	ha	Assumes originally forested area of 4.3 million km2 from Fearnside and Ferraz, nd.
Average annual logging intensity over 1990 area of forest not to be cleared	0.020	m3/ha	Calculated from intensity in logged areas not to be cleared and area of remaining forest.
Annual wood harvest in area not to be cleared	7,327,500	m3	Calculated from proportion of total.
Average time since logging in not-to-be-cleared forest that was standing in 1990	5	years	guess
Average time since logging at preparatory harvesting intensity in to-be-cleared areas when cleared in 1990	1	year	guess

TABLE 4 : FOREST BIOMASS BY LOGGING STATUS

Biomass type	Total biomass (t/ha)	Above-ground biomass (t/ha)			Below-ground biomass (t/ha)			Source
		Live	Dead	Above-ground total	Live	Dead	Below-ground total	
Pre-logging biomass in areas not to be cleared	412.4	293.6	25.2	318.9	88.6	4.4	93.0	Assumed same as average for all mature forests present in the Legal Amazon (Fearnside, nd)
Pre-logging biomass in areas to be cleared	389.6	277.4	23.8	301.2	83.7	4.2	87.9	Table [illegible]
1990 biomass in logged areas not to be cleared	393.2	271.2	33.0	304.3	81.8	7.2	88.9	Assumes volume removed in pre-preparatory harvest= (See Table 3).
1990 biomass prior to preparatory harvest in areas to be cleared	371.2	256.0	31.2	287.2	77.2	6.8	84.0	Assumes volume removed in pre-preparatory harvest= (See Table 3).
1990 biomass at time of clearing in areas to be cleared (a)	363.7	214.1	65.6	279.7	64.5	19.4	84.0	Assumes volume removed in preparatory harvest = (See Table 3).
1990 average biomass of remaining forest	411.6	292.7	25.6	318.3	88.3	4.6	92.9	Fraction of the not-to-be-cleared forest that is logged is (Table 3)

(a) Slash from decay from the preparatory harvest is not included so as not to double count decay over the period between logging and burning; a full year of decay is counted in the deforestation portion of the annual balance for the portion of the biomass that is not consumed by the burn or transformed into charcoal. The above-ground biomass decaying from preparatory logging in the areas to be cleared over a period of one year is 28.5 t/ha, and the below-ground biomass decaying is 15.9 t/ha.

TABLE 5: CARBON SEQUESTRATION IN WOOD PRODUCTS FROM CURRENT LOGGING ACTIVITY

Pool	Average residence time (years)	Decay rate (proportion/year)	Percent of production entering pool	Equilibrium percent	Annual addition to pool (t C X 103/yr)(a)	Equilibrium stock (t C X 106)
Short term	0.5	0.750	40	1.7	2,573	3
Medium term	5	0.129	40	9.9	2,573	20
Long term	50	0.014	18	42.0	1,158	84
Very long term	500	0.001	2	46.4	129	93
Total					6,431	200

(a) Considering total annual production of 6,431 X 10^3 t carbon in wood products, for harvest of 0.0615 m3/ha/year, with density of 0.65 and carbon content of 0.50 and 0.8 of the production incorporated into wood products. This considers a total forest area of 400.000.000 *********** ha and a total timber harvest of 24.600.000 ********** m3 (1988 official value).

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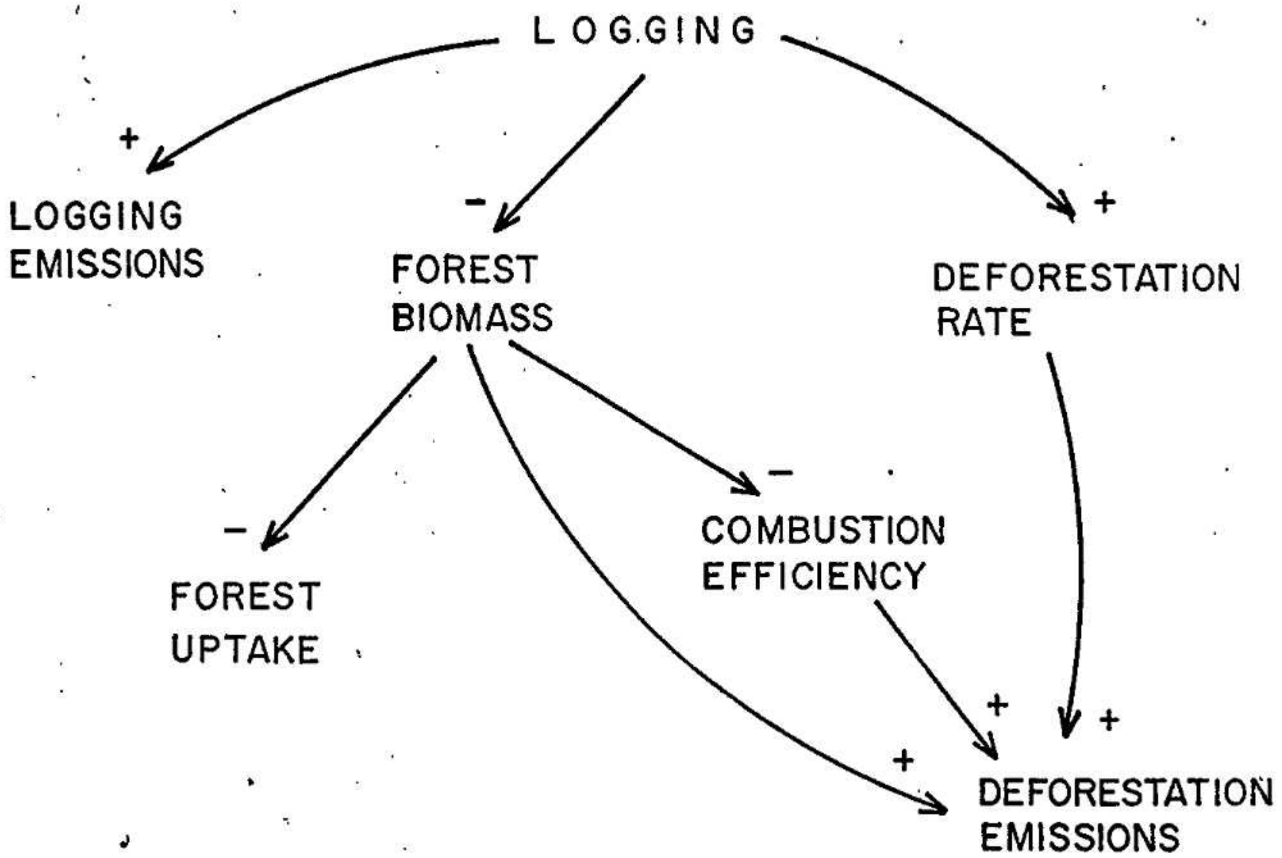
TABLE 6: CARBON SEQUESTRATION IN WOOD PRODUCTS FROM FORESTRY MANAGEMENT

Pool	Average residence time (years)	Decay rate (proportion/year)	Percent of production entering pool	Equilibrium percent	Annual addition to pool (a) (MT C/yr)	Equilibrium stock (MT C)
Short term	0.5	0.750	40	1.7	0.2	0.3
Medium term	5	0.129	40	9.9	0.2	1.9
Long term	50	0.014	18	42.0	0.1	7.8
Very long term	500	0.001	2	46.4	0.0	8.7
Total						18.7

(a) Considering total annual production of 0.6 MT carbon in wood produ

For system producing 3 m3/ha/year, with density of 0.5 and carbon content of 0.5 and 0.8 of the production incorporated into w[illegible]d products.


LOGGING
+
LOGGING EMISSIONS
−
FOREST BIOMASS
+
DEFORESTATION RATE
−
FOREST UPTAKE
−
COMBUSTION EFFICIENCY
+
+
+
DEFORESTATION EMISSIONS

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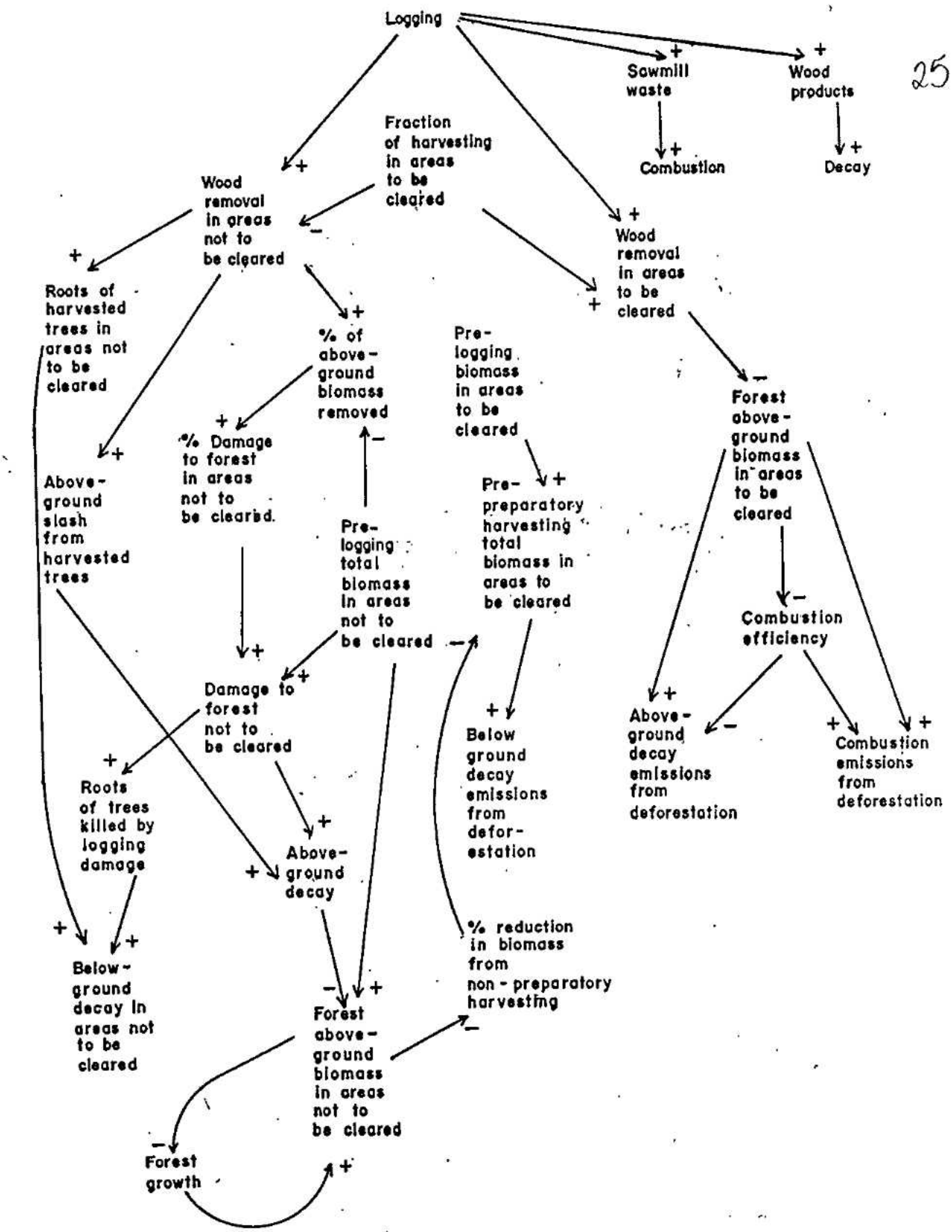

Logging
Sawmill waste
Wood products
Combustion
Decay
Fraction of harvesting in areas to be cleared
Wood removal in areas not to be cleared
Wood removal in areas to be cleared
Roots of harvested trees in areas not to be cleared
% of above-ground biomass removed
Pre-logging biomass in areas to be cleared
Forest above-ground biomass in areas to be cleared
% Damage to forest in areas not to be clearэd.
Above-ground slash from harvested trees
Pre-logging total biomass in areas not to be cleared
Pre-preparatory harvesting total biomass in areas to be cleared
Combustion efficiency
Damage to forest not to be cleared
Roots of trees killed by logging damage
Above-ground decay
Below ground decay emissions from defor-estation
Above-ground decay emissions from deforestation
Combustion emissions from deforestation
% reduction in biomass from non-preparatory harvesting
Below-ground decay in areas not to be cleared
Forest above-ground biomass in areas not to be cleared
Forest growth

COMBUSTION EFFICIENCY
AND BIOMASS DIAMETER (Unlogged forest)

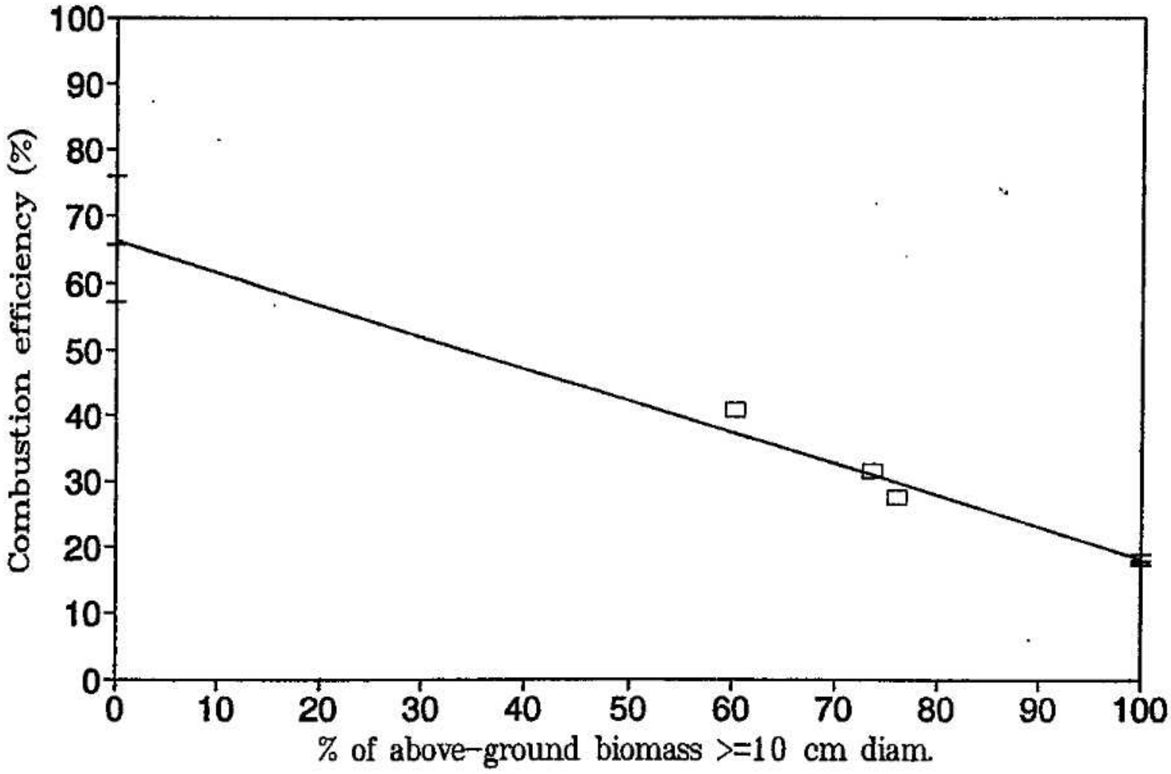

FIG 4

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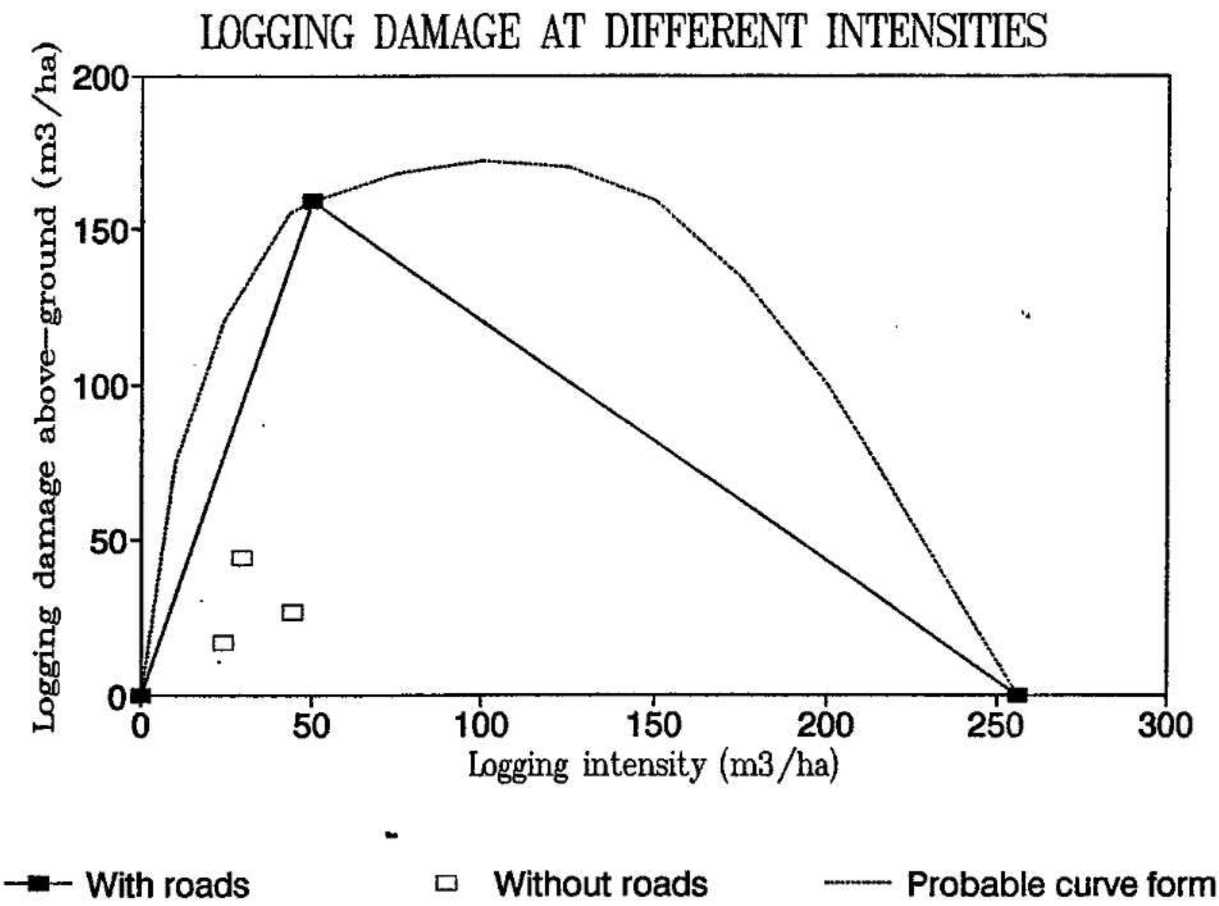
LOGGING DAMAGE AT DIFFERENT INTENSITIES
Logging damage above-ground (m3/ha)
200
150
100
50
0
0
50
100
150
200
250
300
Logging intensity (m3/ha)
With roads
Without roads
Probable curve form

FIG. 5

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NET GREENHOUSE GAS EMISSIONS FROM BRAZILIAN AMAZONIA:
CONTRIBUTIONS OF DEFORESTATION AND LOGGING
(LOW TRACE GAS SCENARIO)

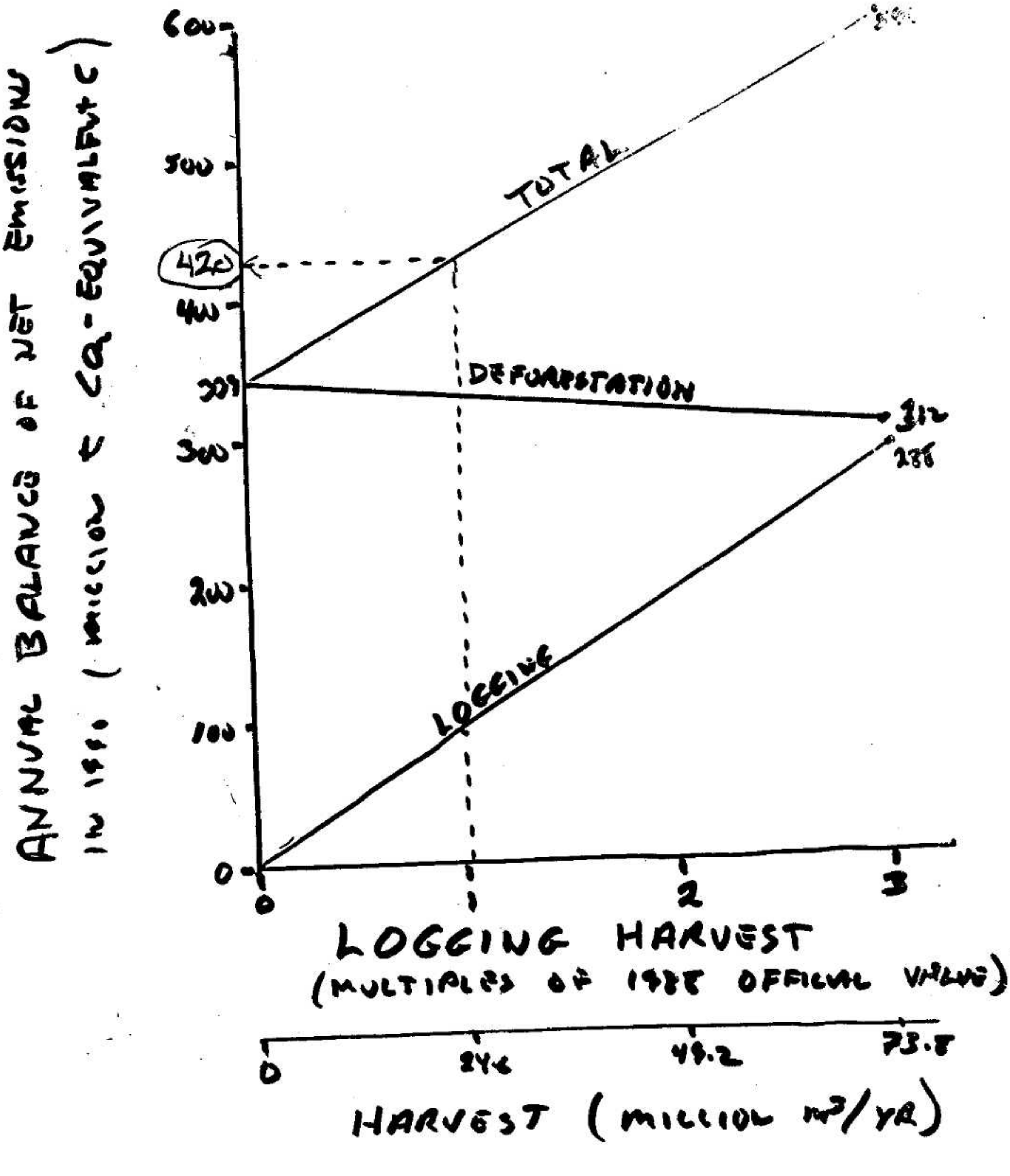

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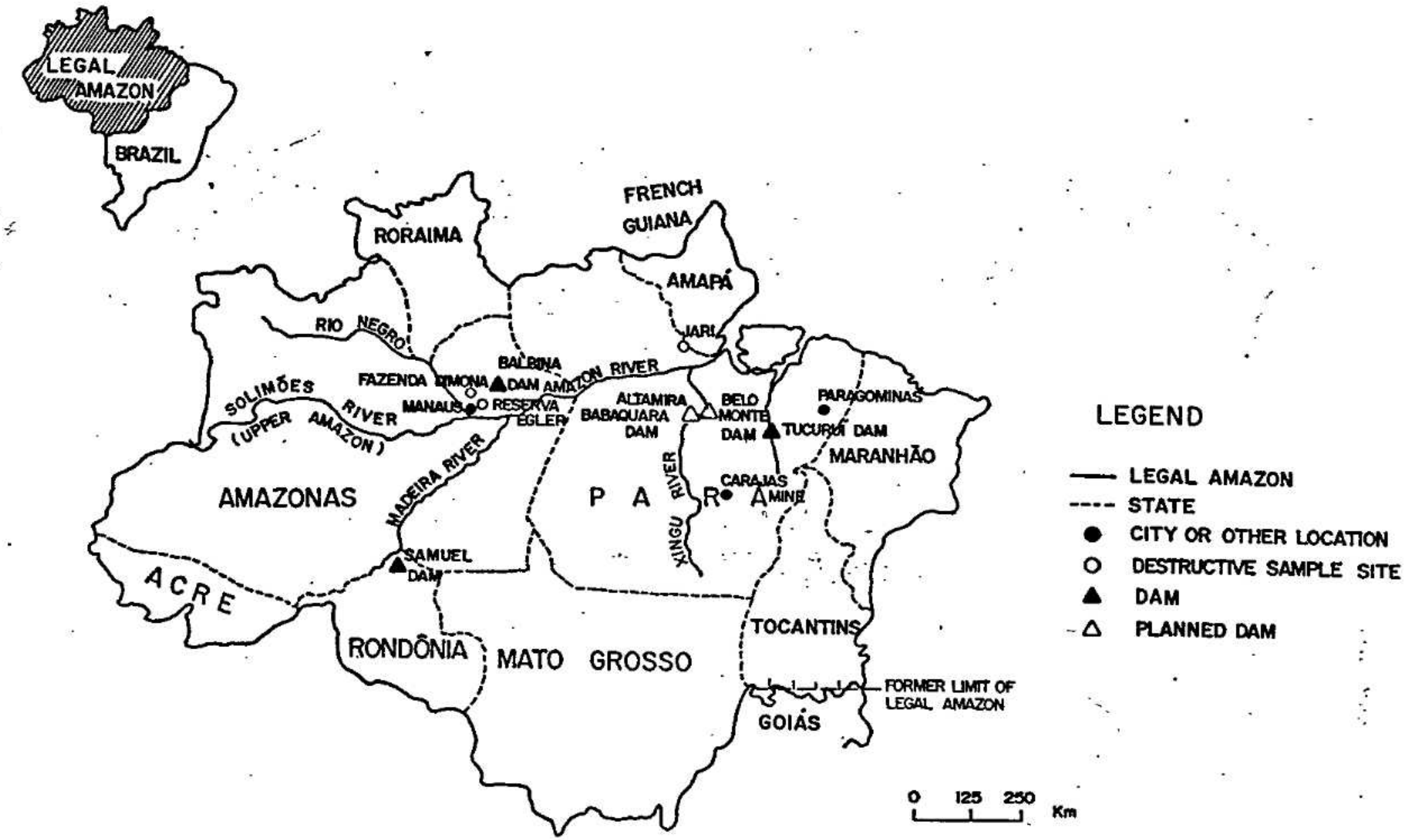
Fig 1



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