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CARBON UPTAKE BY SECONDARY FORESTS IN BRAZILIAN AMAZONIA

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ABSTRACT

Fearnside, P.M. 1995. Carbon uptake by secondary forests in Brazilian Amazonia. For. Ecol. Manage.

Estimating the contribution of deforestation to greenhouse gas emissions requires calculations of the uptake of carbon by the vegetation that replaces the forest, as well as the emissions from burning and decay of forest biomass and from altered emissions and uptakes by the soil. The role of regeneration in offsetting emissions from deforestation in the Brazilian Legal Amazon has sometimes been exaggerated. Unlike many other tropical areas, cattle pasture (rather than shifting cultivation) usually replaces forest in Brazilian Amazonia. Degraded cattle pastures regenerate secondary forests more slowly than do fallows in shifting cultivation systems, leading to lower uptake of carbon. The calculations presented here indicate that in 1990 the 410 X 10^3 km^2 deforested landscape was taking up 29 X 10^6 t of carbon (C) annually (0.7 t C ha^{-1} $year^{-1}$). This does not include the emissions from clearing of secondary forests, which in 1990 released an estimated 27 X 10^6 t C, almost completely offsetting the uptake from the landscape. Were the present land-use change processes to continue, carbon uptake would rise to 365 X 10^6 t annually (0.9 t C ha^{-1} $year^{-1}$) in 2090 in the 3.9 X 10^6 km^2 area that would have been deforested by that year. The 1990 rate of emissions from deforestation in the region greatly exceeded the uptake from regrowth of replacement vegetation.

KEYWORDS: Global warming, Secondary succession, Greenhouse effect, Deforestation, Pasture, Shifting cultivation

INTRODUCTION

Carbon uptake by secondary forests is a key factor in net emissions calculations for greenhouse gases. "Carbon uptake" refers to the net annual per-hectare removal of carbon from the atmosphere while land is in a given land-use category, such as secondary forest. Uptake is carbon fixed minus carbon released through respiration and litter decay. This should not be confused with the net change in carbon that occurs in converting the original forest to the given land-use category, as by deforestation. As used here, "carbon uptake" also does not include the effects of transitions among land-use categories within the deforested landscape, such as the emissions from re-clearing secondary forests for agriculture or pasture. Carbon uptake is primarily determined by the rate of growth of secondary forests of different types. In addition to its importance for global warming, the rate of growth of secondary forest is also important for assessing the sustainability of agricultural systems that depend on a fallow period in woody vegetation in order to regenerate site quality for annual crops or pasture.

Secondary forests derived from agriculture (shifting cultivation) grow much faster than do secondary forests in abandoned cattle pastures. The rapid growth of shifting cultivation fallows has led Lugo and Brown (1981, 1982) to present them as greatly mitigating the global warming impact of deforestation. However, in Brazilian Amazonia (Figure 1), which is the largest single contributor to the deforestation component of global greenhouse gas emissions, land-use change is dominated by cattle pasture rather than by shifting cultivation. In the present paper, data from measurements of secondary forest growth in abandoned pastures are compared to rates that other studies have found in shifting cultivation fallows.

(Figure 1 here)

SECONDARY FORESTS FROM SHIFTING CULTIVATION FALLOWS

The literature on secondary forest in shifting cultivation fallows throughout the tropics has been reviewed by Brown and Lugo (1990). These authors plot the existing data for the dry weights of live biomass in wood, leaves and roots versus the age of the secondary forest, and trace a freehand curve to represent the growth of each component. In Table 1, values have been estimated from Brown and Lugo's (1990) graph for five ages ranging from 5 to 80 years.

(Table 1 here)

Table 1 also presents three measures that are calculated from the biomass values. The root/shoot ratio decreases from 0.42 in 5-year-old stands to values around 0.20 after the stands reach age 20 years. The growth rate of total live biomass, expressed as an average rate since abandonment (mean annual increment), decreases from about 10 t ha^{-1} $year^{-1}$ to 2 t ha^{-1} $year^{-1}$ at age 80 years. Expressed as a growth rate for each interval (periodic annual increment), the rate is steady at about 10 t ha^{-1} $year^{-1}$ until the tenth year, then falls by half by year 20, and continues to decline to very low levels after year 30.

SECONDARY FORESTS FROM CATTLE PASTURE

Two studies of secondary forest derived from abandoned cattle pasture in Brazilian Amazonia exist: one of the Transamazon Highway colonists in Altamira, Pará (Guimarães, 1993) and the other in ranches near Paragominas, Pará (Uhl et al., 1988). In Altamira, measurements were made in 10 stands of secondary forest with an average age of 4.0 years (range 2 to 7 years) and an average time of use in pasture prior to abandonment of 8.1 years (range 3 to 12 years). The Paragominas study measured secondary forests in three use-history types: light, moderate and heavy. Only the moderate category is considered here; this being the category into which the Altamira plots would fall and by far the most common pasture-use pattern in Brazilian Amazonia. The data set from Paragominas considered here consists of six stands with an average age of 4.6 years (range 1 to 8 years) and an average time under pasture of 8.2 years (range 6 to 12 years).

In the abandoned pastures in Paragominas studied by Uhl et al. (1988), the growth of above-ground live biomass of secondary forests in the "moderate" use category is given by:

$$Y = 4.28\ A \qquad (1)$$

where:

Y =above-ground live biomass (t ha^{-1})
A =time since abandonment (years)

The average stock of above-ground dead biomass excluding fine litter is 2.6 t ha^{-1} and the growth rate (mean annual increment) is 0.57 t ha^{-1} $year^{-1}$ (Table 2). The average fine litter stock is 4.9 t ha^{-1}.

(Table 2 here)

In the abandoned pastures in Altamira studied by Guimarães (1993), the above-ground biomass excluding fine litter is given by:

$$Y = 3.38\ A - 2.64\ B + 35.16 \qquad (2)$$
$$(P < 0.05,\ r^2=0.80,\ N=7)$$

where:

Y =the above-ground biomass (live + dead), excluding fine litter.
A =time since abandonment (years)
B =time used as pasture (years).

The Altamira equation excludes secondary forest stands aged two or less years. The young stands have been excluded for several reasons. Since the age of secondary forest derived from pasture is counted from the date of the last burn rather than the date the last head of cattle is removed, emissions from cutting in the first three years are counted as part of pasture maintenance rather than as secondary forest clearing (Fearnside, in prep.). In addition, because variability of biomass accumulation is greater in the early years, regressions that include very young stands explain less of the variance than do those that exclude them. The predicted biomass in the age range of greatest interest (for stands approximately six years old) is believed to be more reliably predicted by confining the data to stands nearer this age.

The form of regression chosen was linear, rather than the exponential form that one might expect to better represent the slowing of biomass accumulation with time that characterizes secondary forest growth. In the Altamira study, linear models explained more of the variance, regardless of whether young stands were excluded. Since the regression is not being used to extrapolate far beyond its range, the linear representation is not believed to result in significant distortion of the predictions.

The calculated growth rates of secondary forests derived from abandoned pastures are shown in Table 3 for Paragominas and in Table 4 for Altamira. In the case of Paragominas (Table 3), data are presented reflecting the mix of pasture use histories studied by Uhl et al. (1988). In the case of Altamira (Table 4), the values are derived from Equation 2. Biomass accumulates faster in shifting cultivation fallows than in the secondary forest derived from pasture at either site (Figure 2). In Table 5 the Paragominas data are recalculated to adjust for the difference in mean use times as pasture in the two data sets (using Equation 2). For the unadjusted data, the stands at Paragominas grew at a faster rate than those at Altamira at all ages (up to the maximum of 20 years for the pasture secondary forest data). When adjusted, the Paragominas stands still grew faster than those at Altamira, except a slightly higher growth rate at Paragominas during the first (4 to 5 year) interval.

(Tables 3, 4 and 5 here; Figure 2 here)

The calculated growth rates of the secondary forests in abandoned pastures are compared to those of shifting cultivation fallows in Table 6. The pattern of slower growth in pasture-derived secondary forests is maintained. The most important comparison is the biomass that will be accumulated at the average age at which the secondary forests are cut. On a regional scale, the average age at which secondary forest derived from pasture is cut estimated at 6.2 years, while the equivalent value for secondary forest derived from farmland is 5.2 years (Fearnside, 1995). The weighted average for secondary forests of both origins would be 6.1 years.

Below-ground biomass estimates are rare. One must rely on the root/shoot ratio encountered in studies elsewhere, available only for a few secondary forests in shifting cultivation fallows, rather than abandoned pastures (see Table 1). The root/shoot ratio (below-ground biomass/live above-ground biomass) used to derive approximate below-ground stocks of six-year-old stands is 0.35 (based on Brown and Lugo, 1990, p. 17).

The average total biomass expected at age 6.2 years for a pasture-derived secondary forest at Altamira would be 52.2 t ha^{-1} (interpolated from Table 4). For a pasture-derived secondary forest at Paragominas (from Table 5), it would be 51.4 t ha^{-1} (46.5 t ha^{-1} total biomass excluding fine litter + 4.9 t ha^{-1} fine litter), and for a shifting-cultivation fallow, it would be 66.5 t ha^{-1}: 59.0 t ha^{-1} total live biomass (interpolated from Table 1) plus values for dead components equal to those for pasture-derived secondary forests with moderate use at Paragominas (2.6 t ha^{-1} dead above-ground excluding fine litter and 4.9 t ha^{-1} fine litter). The total biomass of secondary forest derived from farmland at the average age this category is cut (5.2 years; root/shoot ratio=0.42) would be 49.6 t ha^{-1}, including the same amounts for fine litter and other dead above-ground biomass.

(Table 6 here)

CALCULATION OF UPTAKE OF THE REPLACEMENT LANDSCAPE

The carbon uptake rates (t C ha^{-1} $year^{-1}$) for land remaining in each of the land-use categories change over time as shown in Figure 3. If one were to follow the fate of the landscape that was deforested in a given year, for example 1990, its carbon stock and and uptake would increase and eventually level off (Figure 4). Note that this is for uptake by an average hectare in a landscape where secondary forest stands are continually being cut, thereby repeatedly cycling through the first (most virorously growing) age classes. The emissions from cutting of the secondary forest are not included in the uptake figures, such as those in Figure 4. The carbon uptake rate of 0.97 t ha^{-1} $year^{-1}$ after 100 years approximates the equilibrium condition.

(Figures 3 and 4 here)

The landscape that replaces forest following deforestation will evolve as the proportions in each land-use category approach the equilibrium conditions. The fraction of the landscape in each use at equilibrium can be calculated using a Markov matrix of annual probabilities of transition among different use categories, if one assumes that farmers and ranchers in the region do not change their behavior patterns. This has been done using a 98 X 98 matrix representing six land-use classes with their respective age classes (Fearnside, 1995). At equilibrium, the deforested landscape has <0.01% regenerated forest (i.e. secondary forest over 100 years old), 2.6% farmland, 22.8% productive pasture, 36.1% degraded pasture, 2.1% secondary forest from farmland, and 36.3% secondary forest from pasture.

Carbon uptake will approach an equilibrium after about 100 years (Figure 5). Carbon uptake can be expected to increase as the old secondary forests in Pará and Maranhão are cleared and replaced with younger, more rapidly growing vegetation. Again, it should be remembered that "carbon uptake" does not include the release of carbon from cutting the secondary forests.

(Figure 5 here)

The situation in 1990 is summarized in Table 7. The total (gross) carbon uptake of the landscape is calculated to be 29 X 10^6 t C $year^{-1}$ in 1990, or 0.7 t C $year^{-1}$ ha^{-1} of deforested landscape. The uptake for the landscape in 2090 is calculated to be 365 X 10^6 t C $year^{-1}$ (0.9 t C $year^{-1}$ ha^{-1} of deforested landscape). This assumes that deforestation continues at the 11.1 X 10^3 km^2 $year^{-1}$ 1991 rate (Fearnside, 1993) for the 1992-1994 period, after which it increases at the rates forecast by Reis and Margulis (1991) for the 1995-2030 period, and remains constant over the 2031-2090 period at the 2030 rate (36 X 10^3 km^2 $year^{-1}$). The cumulative deforested area (excluding hydroelectric dams) was 410 X 10^3 km^2 in 1990 (Fearnside, 1993), and would reach 3.9 X 10^6 km^2 in 2090, or virtually the entire forest.

(Table 7 here)

DISCUSSION

It should be emphasized that substantial uncertainty exists regarding secondary forest growth rates, especially for the below-ground component. The root/shoot ratio of 0.42 at age four years used here (based on Brown and Lugo, 1990) is higher than that found in some studies. Williams-Linera (1983, p. 277) found a root/shoot ratio of 0.21 for a seven-year-old stand in Mexico, considering roots > 1 mm diameter (regardless of depth) excavated for individual trees. Szott et al. (1994, p. 185), working in Amazonian Peru, found ratios of 0.15 and 0.09, respectively, for stands 3.4 and 4.4 years old, implying a ratio of 0.12 at age four years (considering only roots to 45-cm depth, extracted from soil monoliths by washing on a 1-mm sieve). Were a lower root/shoot ratio used in the calculation, carbon uptake would be less than the amounts estimated in the present paper.

Carbon uptake by the replacement vegetation is an important part of the carbon balance in areas undergoing tropical deforestation. Uptake has often been omitted from global warming calculations for lack of data. On the other hand, exaggerated expectations have sometimes been expressed with respect to this uptake in Brazil, some even suggesting that the sink in secondary forest growth could be completely counteracting the emissions from deforestation in the region. Unfortunately, the landscape could not possibly be taking up the amount of carbon that this notion implies, even if a variety of optimistic assumptions are made.

Suggestions that all carbon emissions from Brazilian deforestation might be being offset by uptake from the replacement vegetation are based on one or more of the following erroneous assumptions: 1) that young (post-1970) secondary forests cover either all or a much larger fraction of the replacement landscape than is the case, 2) that no emissions occur from clearing of secondary forests, and/or 3) that no emissions occur from reburning and decay of original forest biomass not consumed in the initial burn. Two additional factors have often contributed to exaggeration of uptake related to deforestation emissions: 1) assumption that secondary forests are shifting cultivation fallows rather than abandoned cattle pastures, and 2) use of deforestation emission estimates based on forest biomass that significantly underestimates the carbon stock, and hence emissions (see review of biomass estimates in Fearnside et al., 1993).

A major reason that the deforested terrestrial landscape takes up so much less carbon than might be imagined is that only 31% of the deforested area is in young (post-1970) secondary forest, and, of this, 90% is abandoned pasture rather than agricultural fallows (Table 7). The uptake by the replacement vegetation is almost completely offset by emissions from secondary forest clearing within the replacement landscape. In addition, in order to negate the effects of deforestation, net uptake of the replacement landscape would have to be greater than the total emission including oxidation of unburned forest remains, either through decay or through combustion when pastures and fallows are reburned in succeeding years. Carbon release from original forest biomass not consumed in the initial burn roughly triples the gross emissions from deforestation as compared to the initial combustion releases alone.

Considering carbon dioxide carbon only, the annual balance of emissions in 1990 (excluding hydroelectric dams and logging) included gross emissions of 62.2 X 10^6 t C year^{-1} from the initial burn, 261.5 X 10^6 t C year^{-1} from decay and reburnings of original forest biomass; 27.4 X 10^6 t C from burning and decay of secondary forest biomass (including pre-1970 secondary forests); 31.5 X 10^6 t C from the top 20 cm of soil, and zero net emission from pasture biomass (which re-absorbs emitted carbon through annual regrowth), or a total of 382.6 X 10^6 t C year^{-1} in the form of CO_2. The uptake of 29.4 X 10^6 t C year^{-1} calculated here corresponds to only about 8% of these emissions, (considered here on a carbon-only basis: the percentage would be less if considered in terms of CO_2-equivalent carbon) (Fearnside, in prep.). The 1990 uptake of 29.4 X 10^6 t C year^{-1} is only 2.0 X 10^6 t C greater than the 27.4 t C year^{-1} estimated emission in that year from clearing secondary forest (including 5 X 10^6 t C from "old", or pre-1970, secondary forests), indicating that the net flux from the replacement landscape offset a minuscule 0.5% of the deforestation emissions.

CONCLUSIONS

Land-use change in Brazilian Amazonia is dominated by transformation of forest to cattle pasture. Degraded cattle pastures regenerate secondary forests more slowly than do fallows in shifting cultivation, leading to lower uptake of carbon than is sometimes believed. The 1990 rate of emissions from deforestation and secondary forest clearing in the region greatly exceeds the uptake from regrowth of replacement vegetation. The calculations presented here indicate that in 1990 the landscape was taking up 29 X 10^6 t of carbon and emitting 27 X 10^6 t C annually, or a net removal of only about 0.5% of the gross emissions in that year. Were the present land-use change processes to continue with the deforestation rate increasing in accord with a forecast, uptake by 2090 would increase to 365 X 10^6 t C $year^{-1}$, or about one-third of annual gross emissions, at which time the deforested area would be about 10 times the 1990 one, and the annual deforestation rate, under the assumptions of the forecast, about triple the 1990 rate (note that the cumulative area cleared by 2090 corresponds approximately to the whole of the forest, after which there could be no further deforestation). Land-use change in Brazilian Amazonia would continue to result in net releases of large quantities of carbon even with the large areas of secondary vegetation expected to replace primary forest over the next century.

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Figure legends

Figure 1:Brazil's Legal Amazon region. Of this 5 X 10^6 km^2 administrative region (60% of Brazil), 4 X 10^6 km^2 was originally forested.

Figure 2:Biomass accumulation per hectare in shifting cultivation and pasture.

Figure 3:Carbon uptake per different by different land uses.

Figure 4:Projected annual carbon uptake per hectare for land deforested in 1990. Note that stands in this landscape are continually being cut and returned to the younger (more vigorously growing) categories, and that the emissions from the cutting of secondary forests are not included in the uptake rates of the landscape.

Figure 5:Projected annual carbon uptake per hectare for the landscape in deforested areas (410 X 10^3 km^2 in 1990, increasing to 3.9 X 10^6 km^2 in 2090).

TABLE 1: SHIFTING CULTIVATION FALLOW GROWTH[a]

Age (years)	Live biomass (t ha^{-1}) Wood	Leaves	Roots	Total live	Root/ shoot ratio	Average growth rate of total live biomass since abandonment (t ha^{-1} $year^{-1}$)[b]	Growth rate of total live biomass in interval (t ha^{-1} $year^{-1}$)[c]
5	29.2	4.0	13.8	47.0	0.42	9.4	9.4
10	70.8	6.0	23.1	99.9	0.30	10.0	10.6
20	110.8	10.0	24.2	145.0	0.20	7.3	4.5
30	113.8	9.5	27.7	151.0	0.22	5.0	0.6
80	135.4	8.0	28.5	171.9	0.20	2.1	0.4

(a) Biomass values estimated from graph drawn by Brown and Lugo (1990, p. 17) based on data from on Bartholomew et al. (1953), Ewel (1971, 1975), Saldarriaga et al. (1986) and Williams-Linera (1983).

(b) Mean annual increment.

(c) Periodic annual increment.

TABLE 2: SECONDARY FOREST GROWTH RATES IN ABANDONED PASTURES

LOCATION	Pasture type	Frequency (% of pastures)	Growth rate (t ha^{-1} $year^{-1}$)	
			Above-ground live biomass	Above-ground total excluding fine litter
Paragominas	Light use	20	10.72	11.84
	Moderate use	70	4.28	4.84
	Heavy use	10	2.13	2.27
	Weighted average		5.35	5.99
Altamira	Moderate use	100		6.5

		Stand ages (years since abandonment)		Use periods (years as pasture)	
Above-ground total	Approximate total (above- + below-ground)	Mean	Range	Mean	Range
21.23	21.23	6.0	3.5-8	1.0	0-4
5.92	5.92	4.6	1-8	8.2	6-12
3.85	3.85	3.9	2.588	8.7	8-11
8.77	8.77	4.8		6.8	
		4	2-7	8.1	3-12

Sample size	Description of pasture type	Source
4	Seeded to pasture but never weeded. Abandoned shortly after pasture formation. Grazing intensity <0.5 adult animals ha^{-1}.	Uhl et al., 1988
6	Weedings and burnings every 1-3 years. Abandoned after 6-12 years. Grazing intensity 0.5-1.5 adult animals ha^{-1}.	Uhl et al., 1988
3	After several weedings and burnings, vegetation bulldozed into windrows and burned; pasture replanted and abandoned 6-13 years later. Grazing intensity 0.5=1.5 adult animals ha^{-1}.	Uhl et al., 1988
10		Guimarães, 1993

TABLE 3: CALCULATED BIOMASS AND GROWTH RATES IN ABANDONED PASTURES (Paragominas)

Time since abandonment (years)	Expected above-ground live biomass (t ha^{-1})	Expected above-ground biomass excluding fine litter (t ha^{-1})	Expected above-ground biomass including fine litter (t ha^{-1})	Root/shoot ratio
4.8	25.7	28.7	42.1	0.42
5.0	26.8	29.9	43.9	0.42
8.0	42.8	47.9	70.2	0.35
10.0	53.5	59.9	87.7	0.30
15.0	80.3	89.8	131.6	0.25
20.0	107.0	119.7	175.5	0.20

(a) Mean annual increment.

(b) Periodic annual increment.

TABLE 4: CALCULATED BIOMASS AND GROWTH RATES IN ABANDONED PASTURES (Altamira)

Time since abandonment (years)	Expected above-ground live biomass (t ha^{-1})[(a)]	Expected above-ground biomass excluding fine litter (t ha^{-1})	Expected above-ground biomass including fine litter (t ha^{-1})[(a)]	Root/shoot ratio
4.0	25.0	27.3	32.2	0.42
5.0	27.8	30.7	35.6	0.42
8.0	36.3	40.8	45.7	0.35
10.0	41.9	47.5	52.5	0.30
15.0	55.9	64.4	69.4	0.25
20.0	70.0	81.3	86.2	0.20

(a) Assumes same dead biomass accumulation rate and fine litter stock as found by Uhl et al. (1988) in moderate use pasture in Paragominas.

(b) Mean annual increment.

(c) Periodic annual increment.

Approximate total biomass (t ha^{-1})	Total biomass growth rate since abandonment (t ha^{-1} $year^{-1}$)	Total biomass growth rate in interval (t ha^{-1} $year^{-1}$)	Above-ground biomass growth rate since abandonment (t ha^{-1} $year^{-1}$)[b]	Above-ground biomass growth rate in interval (t ha^{-1} $year^{-1}$)[c]
38.6	9.7	9.7	6.8	6.8
43.4	8.7	4.8	6.1	3.4
54.9	6.9	3.8	5.1	3.4
61.8	6.2	3.5	4.8	3.4
80.6	5.4	3.7	4.3	3.4
97.6	4.9	3.4	4.1	3.4

TABLE 5: CALCULATED BIOMASS AND GROWTH RATES IN ABANDONED PASTURES IN PARAGOMINAS COMPARABLE TO ALTAMIRA PASTURES

Time since abandonment (years)	Expected above-ground live biomass (t ha^{-1})	Expected above-ground biomass excluding fine litter (t ha^{-1})	Expected above-ground biomass including fine litter (t ha^{-1})	Root/ shoot ratio
4.0	17.1	19.4	24.3	0.42
5.0	21.4	24.2	29.2	0.42
8.0	34.2	38.7	43.7	0.35
10.0	42.8	48.4	53.4	0.30
15.0	64.2	72.7	77.6	0.25
20.0	85.6	96.9	101.8	0.20

Note: Moderate-use pasture only, average age since abandonment 4.0 years (considering all Altamira plots). Altamira pastures average use as pasture = 8.1 years.

Approximate total biomass excluding fine litter (t ha^{-1})	Total biomass growth rate since abandonment (t ha^{-1} year^{-1})	Total biomass growth rate in interval excluding fine litter (t ha^{-1} year^{-1})
26.5	6.6	6.6
33.1	6.6	6.6
50.6	6.3	5.8
61.3	6.1	5.3
88.7	5.9	5.5
114.0	5.7	5.1

TABLE 6: COMPARISON OF CALCULATED GROWTH OF SECONDARY FOREST IN ABANDONED PASTURE AND IN SHIFTING CULTIVATION FALLOWS

Age (years)	Total live biomass ($t\ ha^{-1}$)		
	Shifting cultivation[a]	Abandoned pasture (Altamira)	Abandoned pasture (Paragominas)
5	47.0	38.6	55.0
10	99.9	61.8	72.3
20	145.0	97.6	111.2
30	151.0		
80	171.9		

(a) Shifting cultivation values calculated from Brown and Lugo (1990); abandoned pasture values from Altamira from Guimarães (1993) and from Paragominas from Uhl et al. (1988). See Tables 3 and 5.

(b) Mean annual increment.

(c) Periodic annual increment.

Average total live biomass growth since abandonment (t ha^{-1} year^{-1})[(b)]		
Shifting culti-vation	Abandoned pasture (Alta-mira)	Abandoned pasture (Parago-minas)
9.4	8.7	6.6
10.0	6.2	6.1
7.3	4.9	5.7
5.0		
2.1		

Average total live biomass growth in interval (t ha^{-1} $year^{-1}$)[(c)]

Shifting cultivation	Abandoned pasture (Alta=-mira)	Abandoned pasture (Parago-minas)
9.4	8.7	6.6
10.6	3.7	3.5
4.5	3.6	3.9
0.86		
0.4		

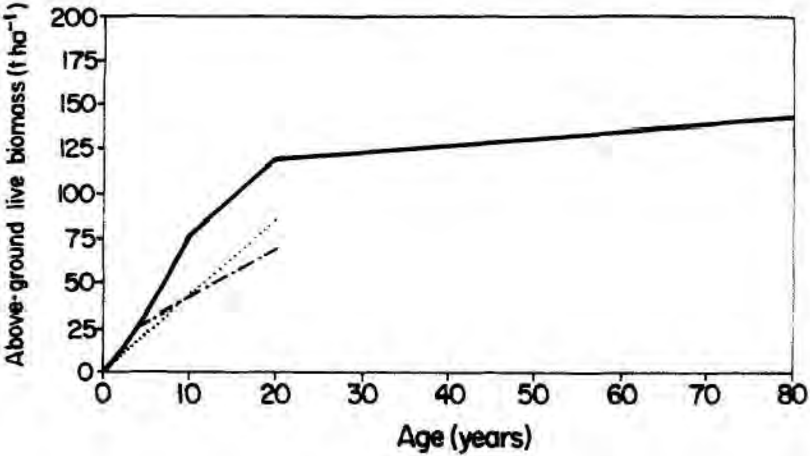
TABLE 7: CARBON UPTAKE SUMMARY FOR 1990

Vegetation type	Area present (10^3 ha)	Percent of defor-ested area	Average age of land use (years)
Farmland	2,221	5	1
Productive pasture	18,400	45	4
Degraded pasture	904	2.2	4
Secondary forest from farmland	854	2	3
Secondary forest from pasture	11,536	28	3
Pre-1970 secondary forest	7,127	17	30
Total:	41,042	100.0	8

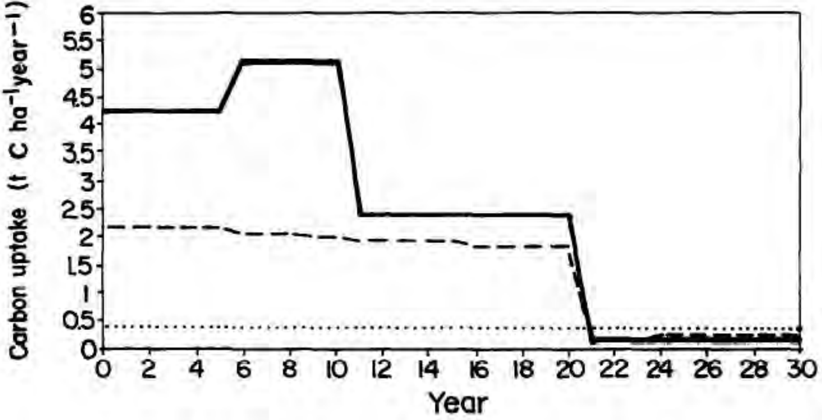
Total biomass (10^6 t)	Average total biomass (t ha^{-1})	Average carbon content (%)	Total carbon stock (10^6 t)	Average carbon stock (t ha^{-1})
1	1	45	1	0
196	11	45	88	5
3	3.4	45	1	1.5
25	29	45	11	13
508	44	45	229	20
1,053	148	45	474	67
1,787	43.5	45	804	19.6

Average growth rate (t ha^{-1} $year^{-1}$)	Total growth (10^6 t $year^{-1}$)	Average carbon uptake (t C ha^{-1} $year^{-1}$)	Total carbon uptake (10^6 t)
0	0	0	0
0	0	0	0
0.8	1	0.4	0
10	8	4	4
5	54	2	24
0	2	0	1
1.6	65	0.7	29

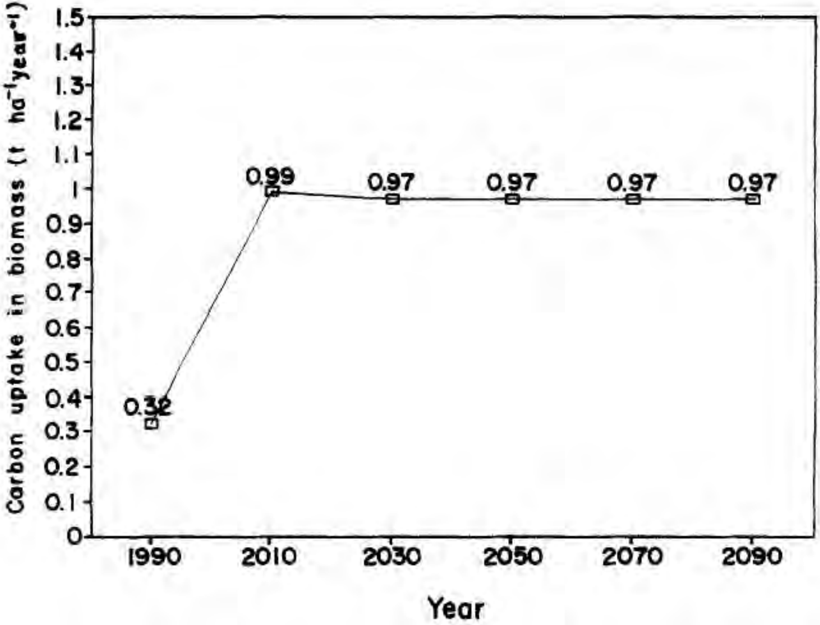

75°
70°
65°
60°
55°
50°
45°
5°
0°
5°
10°
15°
20°
RORAIMA
AMAPA
BELEM
MANAUS
AMAZON
RIVER
ALTAMIRA
PARAGOMINAS
TRANSAMAZON HIGHWAY
MARANHÃO
AMAZONAS
PARA
ACRE
RONDONIA
TOCANTINS
MATO GROSSO
BRAZIL
0 150 300 450 600



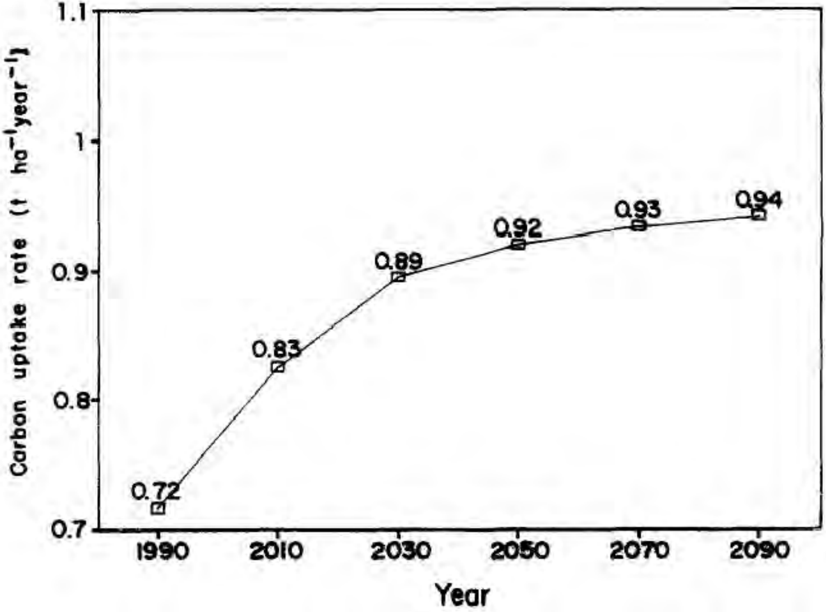
Above-ground live biomass (t ha⁻¹)
200
175
150
125
100
75
50
25
0
0
10
20
30
40
50
60
70
80
Age (years)



Carbon uptake (t C ha-1 year-1)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Year



Carbon uptake in biomass (t ha⁻¹year⁻¹)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.32
0.99
0.97
0.97
0.97
0.97
1990
2010
2030
2050
2070
2090
Year



Carbon uptake rate (t ha^{-1}year^{-1})
1.1
1
0.9
0.8
0.7
0.72
0.83
0.89
0.92
0.93
0.94
1990
2010
2030
2050
2070
2090
Year