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GLOBAL WARMING RESPONSE OPTIONS IN BRAZIL'S FOREST SECTOR: COMPARISON OF PROJECT-LEVEL COSTS AND BENEFITS

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ABSTRACT

A project-level assessment of monetary and carbon costs and benefits for 5 classes of global warming response options in the forest sector is attempted for typical Brazilian conditions. Options considered are: silvicultural plantations (for pulp, charcoal and sawlogs), sustainable timber management and reduction of deforestation. Comparison of pulpwood and sawlog plantations with the vegetation characteristic of deforested areas indicates a modest carbon benefit. Plantations for charcoal can produce a substantial carbon benefit through fossil fuel substitution, but much of this calculated benefit disappears if discount rates greater than zero are applied to carbon. Sustainable timber management, when compared with existing forest, represents a net carbon loss, accumulation of carbon in wood products being insufficient to compensate for biomass reduction over a 100-year time scale. Reduction of deforestation has great potential as a global warming response option, its per-hectare carbon benefits being approximately four times that of silvicultural plantation establishment for pulp and sawlogs over a 100-year period. The costs of reducing deforestation are difficult to assess, however, due to the importance of government policy changes such as removal of land speculation and land tenure establishment as motives for clearing. Although these changes would not cost money and would have tremendous carbon and other benefits, they have not yet occurred.

KEY WORDS: Brazil, Amazon, silviculture, global warming, deforestation, carbon sequestration, tropical forest, Eucalyptus, plantations, greenhouse effect

1. TYPES OF COMPARISONS OF FOREST SECTOR RESPONSE OPTIONS

1.1. Project- versus program-level analysis

Costs and benefits of global warming response options can be examined at various levels, such as the project level and the program level. Costs and benefits should include not only the monetary and greenhouse gas (GHG) implications of a response option, but also consequences such as impacts on the local society and environment. A project-level analysis limits its scope to the immediate area of a project, and does not include changes outside these narrow boundaries, such as macro-economic effects of products produced by the project, carbon consequences of the output from the project (such as wood from plantations) substituting for products that would otherwise be coming from other sources, or impacts of deforestation carried out by people displaced by a plantation or other project. These concerns would be included in a program-level analysis, where scenarios for an entire region or country are constructed with and without the project, thereby allowing assessment of overall GHG emissions, economic well-being, etc.

The present paper limits itself to the project level. The methods follow those outlined by Sathaye et al.[1] and allow some comparisons among countries. The project-level results are essential inputs to program-level analyses, but cannot by themselves be expected to provide the information needed to choose among global warming response options.

1.2. Discounting carbon

Most analyses of carbon benefits of response options do not discount carbon (i.e., they adopt a discount rate of zero). This is currently the practice of the Global Environment Facility (GEF) in comparing options for financing with the funds this agency distributes under Agenda 21. However, a zero discount rate introduces distortions in the relative merit of different options. Giving some additional weight to the short-term, as opposed to the long-term, is warranted. Selfish or not, most people are more concerned with what will occur over the remainder of their own lives than they are with what will occur a century in the future. It is also true that an emission today sets in motion physical processes (such as warming of oceans) that have momentums of their own, and which can be expected to provoke impacts (including increased human mortality rates) from the time that they begin onwards. Postponing these increases in the level of impacts is similar to avoided fossil fuel emissions, representing a permanent gain if net emissions occur later rather than sooner. This makes a discount rate greater than zero reasonable for carbon. There is no reason, however, that it should be the same rate as that used for money. The decision as to what discount rate should be used for carbon, or whether an alternative method of time-preference weighting should be used, is an ethical and moral one that needs to be taken by society as a whole.

The length of the time horizon has a strong effect on the importance of discounting. As time horizons become longer, the distortions become greater if no discounting is applied. In the case of forest sector options that can transfer carbon to very long-term pools, these pools can dominate the results if very long horizons are considered without discounting. In the case of an infinite time horizon, equilibrium conditions will apply. Slow buildup of carbon in very-slow-turnover classes of wood products dominates the results at equilibrium, but occurs at such remote times that it has little bearing on present decisions when discounting is applied. These problems also apply to calculations made under the assumption that the shadow price of carbon increases at the same rate as the discount rate for money, thereby allowing analysis without discounting carbon.

In order to avoid these problems, carbon accounting is presented in the present paper using 3 discount rates for carbon: 0%, 1% and 5%. As the results to be presented show, the arguments for adopting a discount rate for carbon greater than zero add to those favoring maintenance of standing forest rather than, for example, fossil fuel substitution through plantations for charcoal.

1.3. Opportunity cost accounting

The inclusion of opportunity costs in carbon offset calculations raises difficult and unresolved issues, especially in comparisons of non-forest land uses with maintaining native forest. First is the need for balance, avoiding the usual tendency to include opportunity cost only for one side of the comparison, namely the foregone profits of possible non-forest land uses, but not the value of the environmental services that would be sacrificed by clearing the forest. The difficulty of quantifying these services should not be used as an excuse for including only one side of the comparison.

Even in the more straightforward case of determining opportunity cost for deforested land, wide margin for manipulating the results exists depending on the values chosen. The sale value of the land is often taken as an indicator of what the land could produce under an alternative use, and also represents a potential income source that could be obtained by those who have fee simple title to their land. What the sale value is is not always clear. In Brazil the "value of the naked land" is established for tax purposes, but is much lower than the price actually paid when land is sold. In the State of Sao Paulo, the "value of the naked land" for plantation land is only US$114 ha^{-1} (Ref. 2, p. 24), roughly an order of magnitude lower than sale prices. Sale price of forest land in Paragominas, in the eastern Amazonian state of Para, is around US$150 ha^{-1} (Ref. 3).

The appropriateness of opportunity costs as a basis for forest maintenance compensation is often questionable. To be valid as opportunity costs, the alternative land use against which a project is compared must be a real option if the project is not implemented. Opportunity costs are frequently judged by the market value of the land. However, if land on the scale of, for example, Amazonian forests, were offered for sale, the price of land could be expected to fall. Market limits would also constrain the expansion of virtually any crop that might be planted were an attempt made to put into practice the implied alternative of conversion to agriculture, including the green revolution high-input crops that groups claiming compensation for maintaining forest sometimes use as the indicator of opportunity cost. In addition, the soil, climate and other characteristics of tropical forest areas are often not appropriate for agriculture of this type. Also, the human population often does not have the skills and capital needed to implant the alternative land use assumed in claiming opportunity costs. For example, an indigenous tribe would almost never be able to transform its forest habitat into fields of green revolution crops. Compensating such a tribe for the "opportunity costs" of maintaining the forest on the basis of what the land could produce under high-input agriculture (as has sometimes been proposed) would be unjustifiable. At the same time, compensating a multinational firm for maintaining an equal area of forest using the same opportunity cost criterion would be unfair to the indigenous tribe that receives less for the same service. Fundamentally, the problem is that compensation should be based on the value of environmental services, not the "costs" of providing them.

Opportunity costs, when based on realistic alternatives, represent the minimum price at which one could be expected to find a seller for the services. The costs of carbon offsets such as carbon sequestration and avoided emissions (including fossil fuel substitution) provide important information for formulating policies on global warming responses, but should not be confused with the question of justice in designing a new economy that provides proper compensation for maintenance of environmental services. The costs of carbon offsets (including opportunity costs from the perspective of real options available to the actors who would be involved) are necessary but not sufficient information. In the context of international negotiations over global warming responses, the value of the environmental services represents the information needed by the seller of the services (the tropical countries) in negotiating the best obtainable deal, while knowledge of the costs represents information needed by the buyer of the services (the developed countries) in assessing how low they can force competing potential providers to reduce their offers. Both kinds of information are needed for informed negotiation to take place.

2. BRAZIL'S FOREST SECTOR IN COMBATING GLOBAL WARMING

2.1. Silvicultural plantations

The choice of a silvicultural plantation project, and associated technical parameters, is not an easy one. There is no single project that represents Brazilian plantations as a global warming response option, as the marginal yield and other characteristics of new plantations can be expected to change through time. Here examples will be given with values typical of current yields in existing plantations.

Plantations can be classified into short-rotation and long-rotation plantations. Short-rotation plantations in Brazil are usually of *Eucalyptus* grown for pulpwood or charcoal, both with a time between cuttings of about six years, while long-rotation plantations can be either *Eucalyptus* or *Pinus*. Here *Eucalyptus* is assumed on a 12-year cycle for use as sawlogs. Parameters for carbon and economic calculations for these and other options are given in the Appendix. Changes in the stocks are calculated explicitly for live components, while dead biomass components (coarse litter, fine litter and below-ground dead) and soil stocks are assumed to be in equilibrium, thereby exaggerating somewhat the dead biomass components in the project calculations over the time horizon considered. The time horizon is taken to be the largest multiple of the time between harvests up to 100 years. Using an even multiple of this time (which includes both replantings and coppices) makes the results consistent with the procedures outlined in this volume by Sathaye and coworkers[1].

Carbon stocks in plantations for pulpwood, charcoal and sawlogs are simulated over 100 years in Figures 1, 2 and 3, respectively. Total carbon and above-ground live biomass stocks are shown for all plantation types, together with wood products (for pulpwood and sawlog plantations) and fossil fuel substitution (for charcoal plantations). The components for above- and below-ground dead biomass, below-ground dead and soil (to 20-cm depth) are included in the total stocks shown, but are not indicated separately.

(Figures 1, 2 and 3 here)

All charcoal is assumed (optimistically) to be a fossil fuel substitute (substituting for mineral coal as a heat source and reducing agent in Brazil's iron and steel industries). No adjustments are made for differences in energy content per t of C between coal and charcoal and for proportions used for energy and iron reduction. Pulpwood is all assumed to go into the short-term wood products pool (average residence time 0.5 yrs). Sawlog wood is assumed to be allocated with 40% entering the short-term pool, 50% the medium-term pool (average residence 5 yrs), 8% the long-term pool (average residence 50 yrs) and 2% the very-long-term pool (average residence 500 yrs). These proportions imply an average product life of about 13 yrs for sawlogs. Wood product pools decay exponentially (different from the assumption in Ref. 1).

Calculation of carbon benefits requires knowing not only the biomass and product flows of the plantations themselves, but also those that would have existed in the absence of the plantation project. This would require an analysis at a national or larger scale, since the output of the plantation affects the economy as a whole. The standing biomass of the vegetation present on the site where the plantation is installed is much more easily determined, but this does not capture the plantation's effects on wood product flows, logging, or deforestation.

Carbon stocks, flows, and other parameters of plantations for pulpwood, charcoal and sawlogs, and the current mix of these plantation types, are compared to prior vegetation in Table 1. Prior vegetation is assumed to be the equilibrium landscape in deforested areas of the Brazilian Legal Amazon (Ref. 4; modified from Ref. 5). These areas, which totaled 41 X 10^6 ha in 1990[14] (excluding areas flooded by hydroelectric dams) are a mosaic dominated by productive pasture, degraded pasture, and secondary vegetation. Brazil's Legal Amazon is an administrative region covering 500 X 10^6 ha (about 60% of the country); most of the present plantations are in the southern part of Brazil, outside of the Legal Amazon.

(Table 1 here)

The carbon stocks in biomass and wood products for a given area of plantation are relatively easy to calculate, despite uncertainty. The carbon consequences of a program of plantations as a response option are much more difficult to assess. A program-level analysis must not only consider the plantation itself, but also the surrounding landscape to which people may have moved when the plantation was installed. A credible scenario with and without the plantation program has to be constructed to allow a comparison.

2.2. Sustainable timber management

A response option such as sustainable management of native forest for timber may seem reasonable, theoretically stocking away carbon in long-lasting wood products from tropical timber. However, even under the unrealistically optimistic assumption adopted here or perfect compliance with management plans, sustainable management does not constitute a global warming "response option" when compared to native forest.

In addition, proposals for sustainable management as a response option invariably presume that the timber management system is not only sustainable in silvicultural terms but is also sustainable in practice--rather than serving as the first step in the process of deforestation. Were analysis of timber management to include realistic probabilities of the system being perverted to deforestation (probabilities that most likely have values closer to one than to zero), the result would be very large net releases of carbon. The problem lies in fundamental contradictions between maximizing financial return to the primary actors in implanting forestry management for timber, and the criteria applied by those interested in promoting sustainable systems for other reasons, including carbon benefits[6].

In the sustainable timber management scenario considered here, production, management and forest recovery are assumed to follow the results of Verissimo, Barreto and coworkers[3, 7], who have calculated that the 38 m^3 ha^{-1} harvest rate predominating in the area of Paragominas, Para, could be maintained on a 30-yr rotation if appropriate management were applied. The damage to the remainder of the forest is assumed in the management scenario adopted here to be half that prevailing in the region under normal practices at this harvest intensity (see Appendix). Wood products are assumed to enter the different pools in the same proportions as for sawlog plantations.

One of the choices with which sustainable timber management can be compared is unsustainable logging: the norm in Amazonia today. Logging is assumed to occur at the 38 m^3 ha^{-1} intensity prevailing in Paragominas. Verissimo, Barreto and coworkers[3, 7] calculated that recovery in Paragominas could occur in 90 yrs without management. The calculations include an increment of 0.52 t C ha^{-1} yr^{-1} to the above-ground live biomass pool (and proportional increments to the other pools), as implied by this finding. A second harvest after 90 yrs is not included in the calculations as, in practice, potential returns that far in the future do not affect decisions of landowners in Amazonia.

Carbon stocks under timber management and unsustainable (one-time) logging are shown in Figures 4 and 5. Only biomass carbon (live + dead, above- and below-ground), wood products, and total stocks are shown. Soil carbon to 20-cm depth is included in the total but not shown separately.

(Figures 4 and 5 here)

Table 2 summarizes carbon stocks and other parameters for sustainable timber management, unsustainable (one-time) logging, and forest in 1990 (virtually all of which was outside of managed areas). The carbon benefits or losses attributable to sustainable timber management will obviously be very different depending on whether one assumes that the alternative is the uncut forest or whether it is unsustainable logging or deforestation. As compared to forest, sustainable timber management represents a net carbon loss, the accumulations in forest products being insufficient to compensate for losses of forest biomass over the 90-yr time horizon used for timber management and logging (three 30-yr management cycles).

(Table 2 here)

2.3. Deforestation reduction

2.3.1. Carbon benefit of reducing deforestation. Reducing Brazil's rate of deforestation in Amazonia represents an obvious response option to global warming. In 1990, deforestation resulted in a net emission of approximately 307 X 10^6 t of C, or 6 times more carbon than all fossil fuel use in Brazil[10]. Carbon stocks in intact forest and deforested land are summarized in Table 3.

(Table 3 here)

Since the biomass of a hectare of Amazonian forest is much greater than that of a hectare of silvicultural plantation, several hectares of plantation would have to be established for the vegetation carbon stock to equal the loss from a hectare of clearing. In addition, reduction of deforestation rate produces immediate benefits in avoided emissions, whereas plantations will take years to fix carbon, adding to the comparative advantage of deforestation reduction if any form of discounting is applied.

The principal impediments that discourage investment in deforestation reduction as a response option are: 1) the difficulty of assessing the costs of avoiding a hectare of clearing, 2) the need for changes in government policies to remove motivations for deforestation (often these changes could be made at no financial cost, and would have greater impact than monetary investments), and 3) lack of definition of criteria for assigning credit for avoided emissions.

2.3.2. Costs of avoiding deforestation. It is important to realize that reserve protection is not the same as avoided deforestation. For example, consider a hypothetical project to "put a fence around" a piece of forest (this is not the way forest protection works in a literal sense, but is useful as an illustration). If the forest is far from the deforestation frontier the cost per hectare will be very low, but the "avoided emission" will be zero, at least for a number of years, since the area was not at risk anyway. If the area chosen is at the deforestation frontier, the cost per hectare will be extremely high, but the carbon in the biomass stock can be more easily claimed as an "avoided emission." On the other hand, those who would have been clearing forest in the now-fenced area will probably simply go elsewhere in Amazonia and continue to clear--thereby reducing to zero the net avoided emissions from the region.

Investment in both research and organizational activities related to the broader policy context of deforestation undoubtedly represents a cost-effective use of funds motivated by concern over global warming. It is difficult, however, to build a case for this that is both easily understood and free of obvious uncertainties. While an agency that has financed a silvicultural plantation can point to the trees and proclaim convincingly "We fixed that carbon," no such visual confirmation can be had from calculations of reduced deforestation. Above all, investment in reducing deforestation produces very little that is apparent at a project level. Despite these drawbacks, indications are many that deforestation reduction is the general area that should have the highest priority.

It is important to realize that allocation of resources among classes of possible forest sector response options represents a zero-sum game from the standpoint of funding for combating global warming. At the Global Environmental Facility (GEF), which administers funds under Agenda 21 (the action plan adopted at the United Nations Conference on Environment and Development-UNCED, held in Rio de Janeiro in June 1992), forest sector options are grouped in a single category (separate from energy options), such that every dollar spent, for example, on promoting plantations means one less dollar spent on reducing deforestation.

2.3.3. <u>Policy changes versus project investments</u>.

Deforestation in Brazilian Amazonia is done by different actors for different reasons. Unlike many other tropical countries, cattle ranching is by far the predominant form of land use in areas being cleared in Brazil[11]. Much (but by no means all) of the pasture is in large ranches. Particularly in the 1970s and early 1980s these ranches received generous government incentives in the form of various tax advantages and concessionary financing programs. Ranchers were also especially benefited by speculative profits, the value of land increasing more quickly than the rate of inflation for many years. Part of this increase owes to the function of land as a "reserve of value," part to the expectation of future speculative gains, and part to highways and other infrastructure built in Amazonia with funds from taxpayers in Brazil and in the other countries contributing to the multilateral banks that financed many of these projects. Deforestation is also done as a means of establishing land tenure[12, 13]. This applies both to small farmers and to large "land grabbers" (grileiros), who obtain tracts by fraudulent and/or violent means.

The notion that deforestation is the result of poor people clearing to feed themselves is promoted by politicians in Brazilian Amazonia to justify their claims that anyone suggesting that deforestation is harmful or should be reduced is against the people. Central government officials have also begun to blame the poor for clearing, using the (erroneous) argument that clearing by large ranchers has been controlled by suspending incentives, so that the remaining clearing is the work of small farmers. A strong association between the size distribution of properties and deforestation rate, sufficient to explain 74% of the variance in deforestation rates among the Amazonian states, indicates that neither of these claims is true[14]. Relatively little deforestation in Brazil is due to subsistence agriculture; established cattle ranching projects continue to receive government subsidies, and ranches (many of which never had incentives) continue to account for most deforestation. In both 1990 and 1991 small farmers (defined in Brazilian Amazonia as those with <100 ha of land) accounted for about 30% of the deforestation activity, with 70% being done by ranchers. The social costs of greatly reducing the rate would therefore be much less than is implied by those who blame poverty for deforestation.

Immediate steps needed to reduce deforestation in Brazil include: applying heavy taxes to take the profit out of land speculation, changing land titling procedures to cease recognizing deforestation for cattle pasture as an "improvement" (benfeitoria), removing the remaining subsidies, reinforcing procedures for the Environmental Impact Report (RIMA), carrying out agrarian reform both in Amazonia and the source areas of migrants, and offering alternative employment in both rural and urban areas. A more detailed description of needed steps to slow deforestation is presented elsewhere[15].

2.3.4. Criteria for crediting avoided emissions. "Incremental Costs" have been adopted by the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) as the guiding criterion for awarding carbon credits in the evaluation of projects competing for funding as global warming response options. While the logic of this approach is clear in setting priorities for scarce financial resources, it also has disturbing implications as a means of rewarding bad behavior, especially with regard to tropical deforestation. Is it fair that a country only gets credit if it is behaving badly and then repents, while countries that behave well all along get no credit? If a country is rapidly clearing its forests and then stops as a result of policy changes, then the difference between continuation of the old behavior and the new scenario represents forest "saved," and represents a credit for avoided emissions. In addition, because forest was being rapidly cleared, any discounting or other time-preference weighting will increase the benefits attributed to these avoided emissions, as compared, for example, to emissions that might be avoided in a country where deforestation is progressing slowly and would, in the no-project scenario, not occur anyway until a more remote future date.

Establishing a park in an area of forest that would not be cleared receives no credit, whereas one in an area experiencing rapid clearing is heavily rewarded. The park in the area with little clearing is likely to be cheaper to establish. How carbon credits are allotted can therefore influence where parks are created. The same considerations also apply to biodiversity, not necessarily with the same results. Depending on how benefits are counted, the conservationist dogma can unravel that those interested in carbon offsets and biodiversity preservation speak with one voice on tropical forest protection. In Brazil, the least well-protected and most threatened types of forest are along the southern boundary of Amazonia where reserve establishment is very expensive per unit of area[16]. Because carbon atoms are interchangeable, a discounting approach to avoided emissions may be appropriate. In contrast, biodiversity is not interchangeable, and indices of success in maintaining biodiversity should focus on the diversity expected to be present at some chosen time in the longer-term future (without discounting).

2.3.5. Avoided deforestation as a permanent offset. Avoided deforestation can be treated in a manner similar to fossil fuel substitution. Even though the clearing of a given patch of forest may be postponed for only one year, just as the burning of a given ton of coal may be postponed for only one year, the benefit can be considered to be permanent. One is assuming that the avoided deforestation does not create a repressed demand for clearing that will be compensated for in succeeding years with a more rapid rate of felling. This assumption appears reasonable under Brazilian conditions.

3. COMPARISON OF OPTIONS

3.1. Silvicultural plantations

Table 4 compares the carbon and monetary costs and benefits of forest sector response options at the project-level in Brazil. Carbon stocks are calculated at 3 discount rates for carbon: 0%, 1% and 5%. The average stock at these discount rates refers to the net present carbon value of the stock (discounted at the specified rate) divided by the net present carbon value of one ton of carbon held for the same period of time. Discount rates for carbon therefore have no effect on options that maintain carbon stocks at a constant level, such as maintaining forest without alteration (assumed to be in equilibrium) or that have many short oscillations over the time horizon, such as pulpwood plantations. Discount rates greater than zero reduce the attractiveness of options that accumulate carbon slowly over the period, such as accumulation as fossil fuel substitution from charcoal plantations or, to a lesser extent, in wood product pools in sawlog plantations. Charcoal plantations can displace so much fossil carbon over the course of the 96-yr time horizon for these plantations that their average stocks approach that of maintaining the forest, but only if the discount rate is zero. At a 5% discount rate the average carbon stock for charcoal plantations falls to almost half this value, while the benefit of forest maintenance remains unchanged.

(Table 4 here)

Inclusion of industries can have a great influence on the calculated profitability of different options, as well as on the practicality of obtaining capital for significant expansion of these land uses. Where to draw the line between the response option and the rest of the economy is not always clear. In the present analysis, charcoal manufacture costs are included for charcoal plantations (but not pig-iron industry investments). For pulp, only the plantations (not the pulp mills) are included. Given that the investment needed for a pulp mill is very large compared to that for the silvicultural plantations that supply it, lack of capital poses a significant restraint on large-scale expansion (i.e., the "establishment cost per ha" given in Table 4 greatly understates the cost of the full array of investments needed to expand this land use). For sawlog plantations, the present analysis only includes the plantations themselves, while for timber management and logging the sawmills are included.

Table 4 indicates that the net present value (NPV) of plantations for pulp is lower than those for sawlogs, yet most plantations in Brazil are for pulp rather than sawlogs. Assuming that the price and cost information used (based on figures from forest industry associations in Sao Paulo: see Appendix) accurately reflects these factors, one would expect greater planting of long-rotation plantations. The explanation for this not occurring is probably that it is even more profitable to obtain wood for the same markets through unsustainable logging of natural forests in Amazonia. However, at the seed distribution facility maintained in Piracicaba, Sao Paulo by the University of Sao Paulo, demand for seeds of species appropriate for long-rotation plantations has increased sharply relative to demand for short-rotation species (Mario Ferreira, personal communication, 1994).

3.1. Timber management and unsustainable logging

It is easy to see from Table 4 why sustainable timber management is not being practiced on a significant scale: considering a 12% discount rate, its net present value (NPV) is highly negative, while unsustainable one-time logging yields substantial profits. In financial terms (as distinguished from economic or social terms), sustainable management has an internal rate of return (IRR) of 3.8%, meaning that the discount rate would have to be less than this value in order for the management scheme to have a positive NPV. Since alternative investments that yield more than this in real terms are readily available, including unsustainable logging and land speculation, sustainable management for timber is unattractive as an investment (as distinguished from government certification of "forestry management plans" as part of the paperwork required for legalizing logging operations).

The tremendous per-hectare carbon benefit of avoiding deforestation is apparent. The rapid pace of clearing makes the total potential for reduction in emissions far greater than for other options, and the vast areas of still uncleared forest in Brazil mean that the ultimate total benefit is much greater than the current annual emissions imply. Brazil's 1990 emissions of 307 X 10^6 t of carbon from deforestation[10] contrasts with the 7 X 10^6 t of avoided carbon emissions from the country's use of alcohol fuel and cogeneration from bagasse (the fiber by-product of sugarcane crushing)[18].

3.2. Deforestation for ranching and speculation

Deforestation for extensive cattle ranching is far the worst option from the point of view of carbon storage. The information in Table 4 indicates that it is also financially unattractive, yet this is by far the most common fate of the rapidly expanding areas of deforested land in the Brazilian Amazon today. Something is clearly missing from the monetary costs and benefits included in Table 4 that renders it unreliable as a predictor of behavior. One essential factor is the effect of land speculation, which can make extensive cattle ranching profitable despite cash expenses that exceed the revenue from beef sales[17]. Speculation, along with use of deforestation as a means of establishing land tenure, could be greatly reduced by government action. Removing the profits from speculation by levying and collecting heavy taxes on the resale of land would remove the motive for clearing to protect investments in future land sales. Ceasing to recognize clearing, especially for cattle pasture, as an "improvement" would remove an additional motive for clearing for unproductive purposes. These changes could be made at a minimum of expense in monetary terms, but would require the political will to displease those who benefit from the present system.

4. CONCLUSION AND WARNING

The results of a project-level analysis such as those in Table 4 can serve only as inputs to a program-level analysis. They cannot be used for assessing the global warming benefit of investing a given amount in any of these options, and therefore cannot provide answers to policy questions without a program-level analysis. All or part of a benefit may be canceled by secondary effects elsewhere, or may even yield net global warming costs. For example, plantations that have been subsidized as global warming response options may have carbon benefits stolen by the "invisible hand" when wood products derived from them simply replace products that would otherwise have come from elsewhere, or when output from subsidized plantations causes the price of plantation-produced wood to fall and unsubsidized plantations elsewhere are consequently cut and replaced with pasture or other low-biomass land uses.

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6.) APPENDIX: PARAMETERS FOR ECONOMIC AND CARBON CALCULATIONS

6.1. Plantations

For all plantations: wood density=0.43 t m^{-3} (mean of 0.47 for Northeast Brazil from Ref. 19 and 0.39 for Sao Paulo from Ref. 2, p. 11; above-ground waste fraction=0.2; root death rate (proportion yr^{-1})=0.070 (assumed equal to background mortality rate in forest trees); underground fraction=0.183 (calculated from Ref. 20 as mean of values for 6.1-yr-old *Eucalyptus grandis* at Bom Despacho, Minas Gerais and 5.6-yr-old *E. grandis* at Carbonita, Minas Gerais); coarse litter decay rate (proportion yr^{-1})=0.11 (assumed equal to secondary forest coarse litter, calculated from Ref. 21, p. 72); fine litter decay rate (proportion yr^{-1})=0.36 (mean of *E. saligna* in Piracicaba, Sao Paulo from Ref. 22, p. 98 and of *E. grandis* at Bom Despacho and Carbonita, Minas Gerais from Ref. 20); wood carbon content=0.45; below-ground decay rate (fraction yr^{-1})=0.167 (assumed equal to above-ground decay of primary forest remains in fields studied by Ref. 20, p. 72 and Ref. 37); larger stocks would accumulate decay rates lower than the plantation biomass growth rate (fraction yr^{-1}) of 0.254 at mid-cycle implied by the yield of short-rotation *Eucalyptus*; slash and waste decay rate (fraction yr^{-1})=0.11 (assumed equal to secondary forest remains studied by Ref. 21, p. 72); logging substitution fraction=0.00; soil (0-20 cm) carbon=6.7 t ha^{-1} (10.2 t ha^{-1} average 0-20 cm C content of Amazonian soil multiplied by ratio of 3.8% plantation to 5.8% forest soil (0-10 cm) C in Minas Gerais measured by Ref. 23, p. 19); coppicing is assumed not to kill roots.

For pulpwood plantations: percent of plantation area=65.9[24]; yield=30.2 m^3 ha^{-1} yr^{-1} [19]; number of coppices per rotation=3; yrs between cutting=6; wood price=US$6 m^{-3} (Ref. 2, p. 46); fraction of output to short-term pools=1.0; fossil fuel substitution fraction=0.00.

For charcoal plantations: charcoal conversion efficiency =0.371 t charcoal per t firewood (Ref. 2, p. 11); charcoal price=US$27 m^{-3} (price in Carajas area; also price in Sao Paulo: Ref. 2, p. 48); charcoal density=0.25 t m^{-3} (Ref. 2, p. 11); firewood usable fraction=0.952[25, 26]; charcoal making cost=US$22 (assumed to be 35% of the value US$62 t^{-1} published by Ref. 2, p. 50); charcoal transport cost=US$8.57 t^{-1} (assumed same as firewood transport in Sorocaba, Sao Paulo calculated from Ref. 2, pp. 11, 50); percent of landscape=29.1[24]; number of coppices per rotation=3; time between cutting=6 yrs; yield=30.2 m^3 ha^{-1} yr^{-1} [19]; calculated wood price=US$19.49 m^{-3}; charcoal carbon content= 0.74[27]; fossil fuel substitution fraction=1.00.

Plantations for sawlogs: percent of landscape=5.0[24]; number of coppices=0; rotation length=12 yrs; yield=20 m^3 ha^{-1} yr^{-1} [24];

wood price=US$15 m^{-3} Ref. 2, p. 46); fraction of output to short-term pools=1.0; fraction of output to medium-term pools=0.03; fraction of output to long-term pools=0.00; fossil fuel substitution fraction=0.00.

6.2. Logging

6.2.1. Parameters applicable both to sustainable timber management and unsustainable logging: sawmill waste fraction= 0.53[3]; sawmill costs exclusive of taxes=US$34.03 m^{-3} [3]; transport cost to sawmill=US$25.30 t^{-1} (assumed 1/3 of US$75.90 t^{-1} for mahogany from Ref. 28); logging damage/harvest ratio without management=1.64 for above-ground and 0.41 for below-ground damage, not counting direct and indirect damage from roads built to reach logging areas, calculated assuming mean logging intensity of 38 m^3 ha^{-1} [3] and regression of above-ground damage on logging intensity based on 11 measurements available in studies (Refs. 3; 28; 29, p. 69; 30; 31, p. 260); below-ground ratio from harvested trees=0.26; wood basic density=0.69 g cm^{-3} [32]; wood carbon content=0.50[33]; logged forest tree mortality rate increase over background mortality rate (fraction of trees yr^{-1})=0.013[34]; duration of increased mortality effect=8 yrs (assumed equal to end of observation period at Tapajos National Forest experiment studied by Ref. 34; above-ground growth stimulation by logging=0.75 t ha^{-1} yr^{-1} (assumed proportional to 1.25 m^3 ha^{-1} yr^{-1} stimulation in French Guiana provoked by 70 m^3 ha^{-1} of logging + 45 m^3 ha^{-1} poisoning: Ref. 35, p. 18, considering logging intensity of 38 m^3 ha^{-1} yr^{-1} and logging damage ratio of 1.64); duration of growth stimulation effect=6.25 yrs (mean of effect in Suriname of 9 yrs: Ref. 36, p. 120, and Tapajos of 3.5 yrs: Ref. 34); decay rates (fraction yr^{-1}) for below-ground dead biomass, coarse litter and slash and waste=0.167 (assumed equal to above-ground decay of primary forest remains in fields studied by Ref. 20, p. 72 and Ref. 37). The following parameters, based on Refs. 3 and 7 refer to quantities per hectare harvested (not per hectare managed): logging intensity=38 m^3; extraction costs=US$2051.24; industrial (sawmill) costs=US$339.67; depreciation=US$69.12; gross return=US$2772.00; taxes at 12% of gross return=US$332.64.

6.2.2. Parameters for sustainable timber management only (from Refs. 3 and 7): cutting cycle=30 yrs; management costs=US$113.00 ha^{-1} harvested. Recovery of above-ground live biomass to the original level for the above-ground live component is assumed to occur over the 30-yr cycle in a linear fashion, which implies increments of 0.90 t C ha^{-1} yr^{-1} to this component (and proportional increments to other components) in order to conform to the general finding of Verissimo, Barreto and coworkers[3, 7] of sustainability.

6.2.3. Parameters for unsustainable logging only: An increment of 0.52 t C ha^{-1} yr^{-1} is added to the above-ground live biomass pool (and proportional increments to the other pools), over the recovery period (implied by the finding of Verissimo, Barreto and coworkers[3, 7] that recovery occurs over 90 yrs).

6.3. Extensive ranching

Pasture biomass (above- + below-ground mean over annual cycle in Ouro Preto do Oeste, Rondonia)=10.67 t ha^{-1} (Ref. 38, p. 44); below-ground share of total biomass=41% (Ref. 38, pp. 46-47); equilibrium landscape total biomass calculation based on Markov matrix of transition probabilities between land-use states[4]; parameters for soil carbon in layer compacted from top 20 cm of forest soil at Paragominas, Para (calculated by Ref. 39): forest soil C content=0.91% (Ref. 40, pp. 31, 42), forest soil density=0.56 g cm^{-3} (Ref. 41, p. 95); pasture soil mean C content=0.56% (Ref. 40, pp. 31 and 42); pasture soil density =1.15 g cm^{-3} (Ref. 41, p. 95). Calculated values: forest soil C =10.19 t ha^{-1}, pasture soil C=6.27 t ha^{-1}, decrease from conversion of forest to pasture=3.92 t ha^{-1}; economic parameters from Ref. 42 for Paragominas extensive ranching (per hectare): pasture and livestock initial costs=US$307; annual gross return=US$31; taxes (@17% of gross return)=US$5; other expenses=US$20 (N.B.: includes no fertilizers, which are assumed not to be used--the normal course of events); duration of pasture production=15 yrs.

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FIGURE LEGENDS

Figure 1 -- Carbon stocks in pulpwood plantations.

Figure 2 -- Carbon stocks in charcoal plantations.

Figure 3 -- Carbon stocks in plantations for sawlogs.

Figure 4 -- Carbon stocks in timber management.

Figure 5 -- Carbon stocks in unsustainable one-time logging.

TABLE 1: COMPARISON OF PLANTATIONS WITH PRIOR VEGETATION

	Plantations		
	Pulpwood	Charcoal	Sawlogs
Average carbon stocks (t ha^{-1}):			
Live biomass C (above- + below ground)	23.7	23.5	31.1
Dead biomass C (above- + below ground)	13.2	13.2	19.0
Soil carbon (top 20 cm)	6.7	6.7	6.7
Wood products C	1.9	1.9	7.9
Fossil fuel substitution C	0.0	156.2	0.0
Total carbon stock	45.5	201.5	64.6
Other parameters:			
Average wood product life (yrs)	0.5	0.0	12.6
Rotation length (yrs)	24	24	12
Coppices (number per rotation)	3	3	0
Time between harvests (yrs)	6	6	12
Yield (m^3 ha^{-1} yr^{-1})	30.2	30.2	20.0

[Table 1, part 2]:

	Deforested landscape	Carbon benefit			
Current mix		Pulpwood	Charcoal	Sawlogs	Current mix
24.0	14.0	9.7	9.5	17.1	10.0
13.5	1.1	12.1	12.1	17.9	12.4
6.7	6.3	0.4	0.4	0.4	0.4
2.2	0.0	1.9	1.9	7.9	2.2
45.5	0.0	0.0	156.2	0.0	45.5
91.8	21.4	24.1	180.1	43.3	70.5
1.0					
23.4					
2.9					
6.3					
29.7					

TABLE 2: COMPARISON OF SUSTAINABLE TIMBER MANAGEMENT WITH UNSUSTAINABLE LOGGING AND DEFORESTATION

Carbon stocks (t ha^{-1}):
Live biomass C (above- + below-ground)
Dead biomass C (above- + below-ground)
Soil C (top 20 cm)
Wood products C (100-yr average)
Total C stock
Other parameters:
Annual yield (100-yr average) (m^3 ha^{-1})
Logging intensity in first cycle (m^3 ha^{-1})
Logging intensity in subsequent cycles (m^3 ha^{-1})
Harvest cycle (yrs)
Duration of yield (yrs)
Average wood product life (yrs)

a Comparing sustainable timber management with remaining primary forest.

b Comparing sustainable timber management with unsustainable logging.

c 30% reduction: assumed half the 60% in the top 30 cm used by Ref. 8 cited by Ref. 9, p. 756.

[Table 2, part 2]:

Sustainable timber management	Remaining forest in 1990	Carbon benefit[a]	Unsustain-able logging	Carbon benefit[b]
181.5	198.1	-16.6	167.9	13.7
17.1	15.6	1.5	14.9	2.1
6.8	10.2	-3.4	6.4[c]	0.4
3.5		3.5	1.8	1.7
209.0	223.9	-15.0	191.0	18.0
1.52				
38			38	
38				
30				
>100			1	
12.6			12.6	

TABLE 3: COMPARISON OF INTACT FOREST AND DEFORESTED AREAS

	Remaining forest in 1990	Deforested areas	Change in carbon stock
Carbon stocks (t ha^{-1}):			
Live biomass C (above- + below-ground)	198.1	14.0	-184.1
Dead biomass C (above- + below-ground)	15.6	1.1	-14.5
Soil C (top 20 cm of forest soil)	10.2	6.3	-3.9
Total carbon stock	223.9	21.4	-202.5
Other parameters:			
Other environmental benefits	high	low	
Monetary returns	0	low	

TABLE 4: COMPARISON OF PROJECT-LEVEL COSTS AND BENEFITS OF FOREST SECTOR RESPONSE OPTIONS IN BRAZIL

	Discount rate for carbon (% yr^{-1})	Units	Plantations		
			Pulp	Charcoal	Sawlogs
Average carbon stock	0	t ha^{-1}	46	202	65
Average carbon stock	1	t ha^{-1}	46	176	63
Average carbon stock	5	t ha^{-1}	45	104	58
Establishment cost ha^{-1}	--	US$	625.00	625.00	625.00
Establishment cost per t C	0	US$	13.60	3.47	14.45
Establishment cost per t C	1	US$	13.68	3.55	9.90
Establishment cost per t C	5	US$	13.98	5.99	10.76
Net present value ha^{-1} b,c	--	US$	165.93	81.34	612.56
Net present value per t C b	0	US$	6.88	0.45	14.16
Net present value per t C b	1	US$	3.63	0.46	9.70
Net present value per t C b	5	US$	3.71	0.78	10.54
Internal rate of return		% yr^{-1}	14.6	13.3	17.6

a No carbon sequestration occurs (a net loss of C).
b Uses discount rate for money of 12% (World Bank discount rate for Brazil). All monetary values are in 1992 US$.
c NPV of deforested landscape does not include speculative returns from land sales, which can make seemingly unprofitable ranching schemes lucrative (see Ref. 17).

[Table 4, part 2]:

Sustainable timber management	Remaining forest in 1990	Unsus-tainable logging	Extensive ranching
209	222	191	21
209	222	187	21
209	222	179	21
1814.77	0	1811.00	307.00
--a	--	--a	--a
--a	--	--a	--a
--a	--	--a	--a
-479.19	--	961.00	-261.23
--a	--	--a	--a
--a	--	--a	--a
--a	--	--a	--a
3.8	- --	infinite	-13.7

Fig. 1.

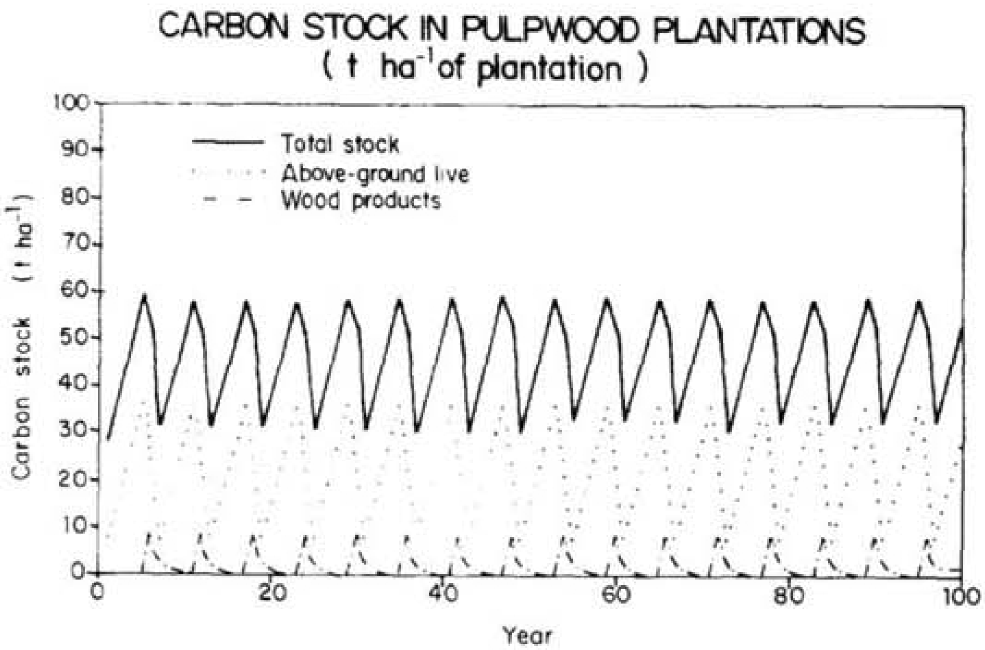


Fig. 1. Carbon stocks in pulpwood plantations.

Fig. 2.

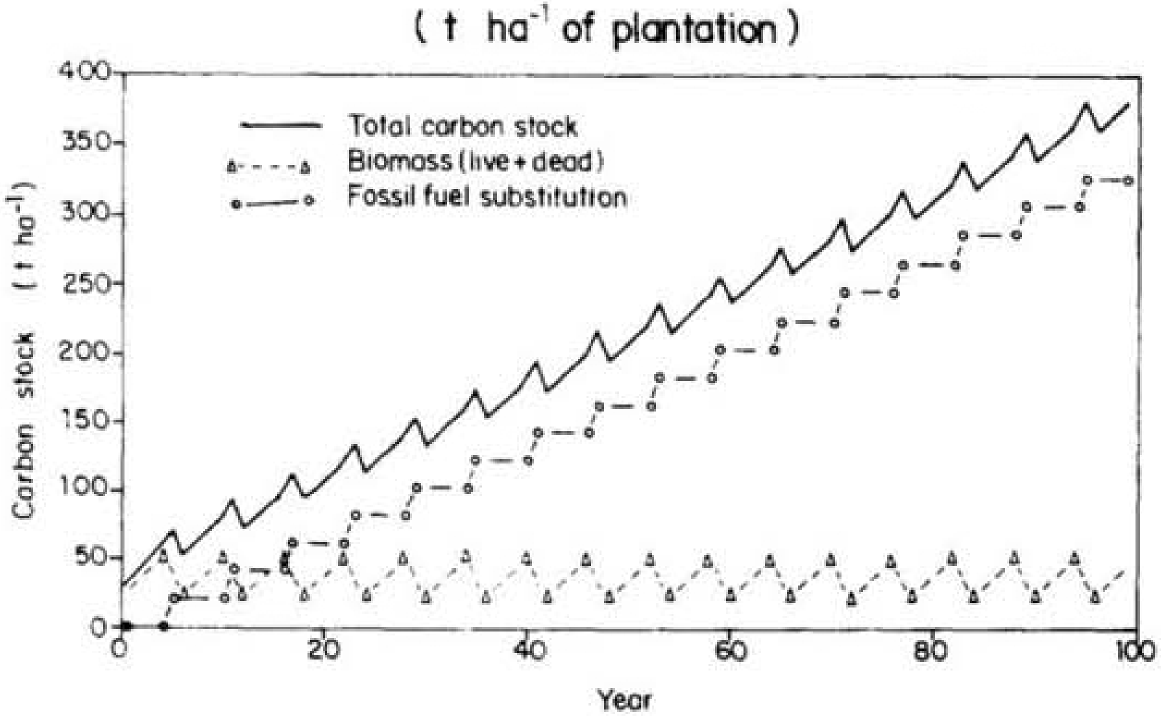

(t ha-1 of plantation)
Total carbon stock
Biomass (live + dead)
Fossil fuel substitution
Carbon stock (t ha-1)
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
Year

Fig 3.

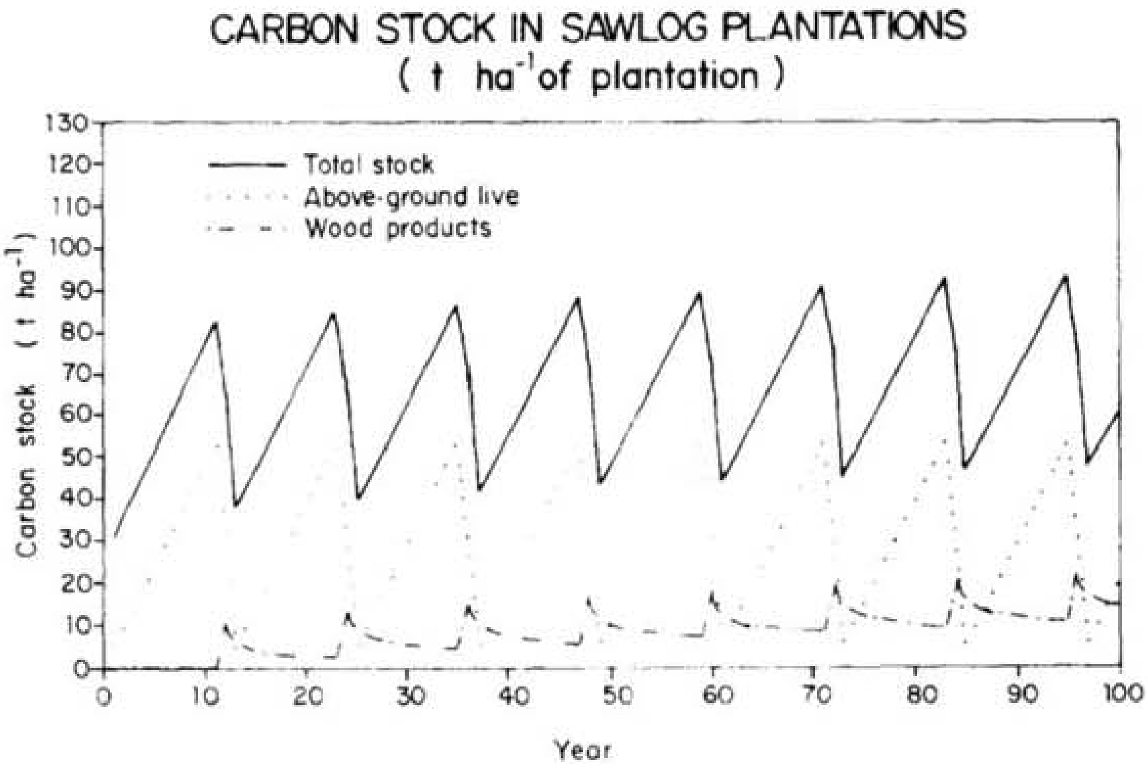

CARBON STOCK IN SAWLOG PLANTATIONS
(t ha-1 of plantation)
Total stock
Above-ground live
Wood products
Carbon stock (t ha-1)
Year
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100

Fig. 4.

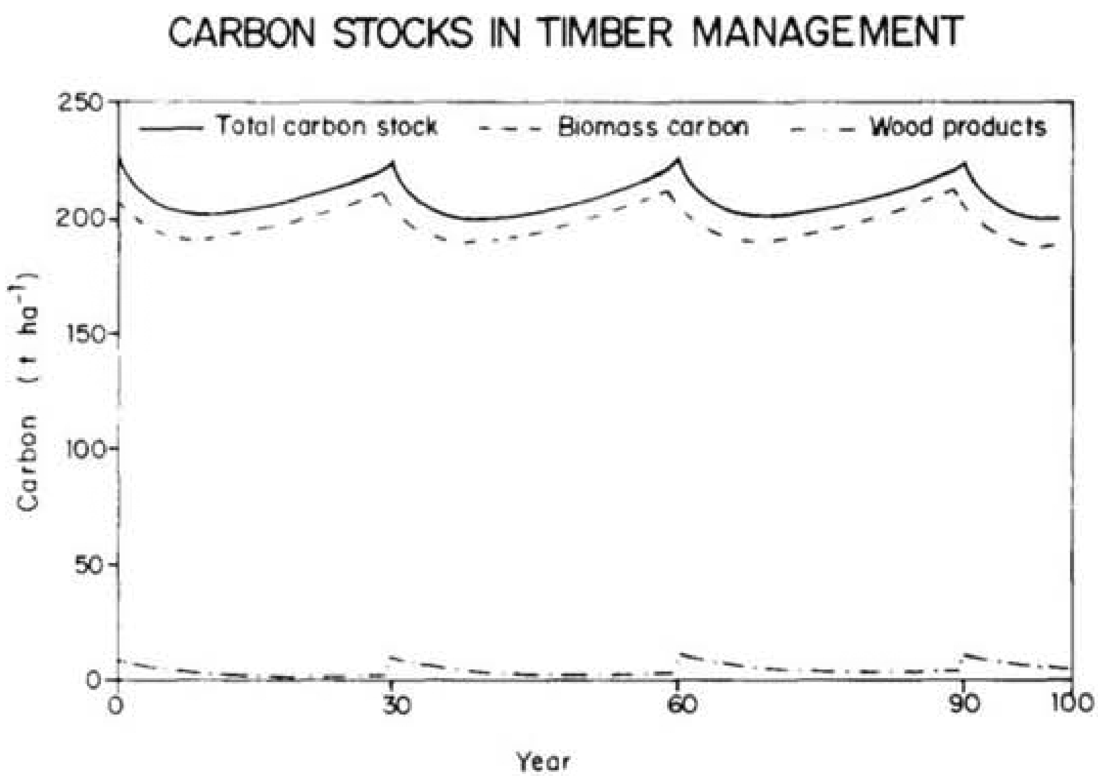
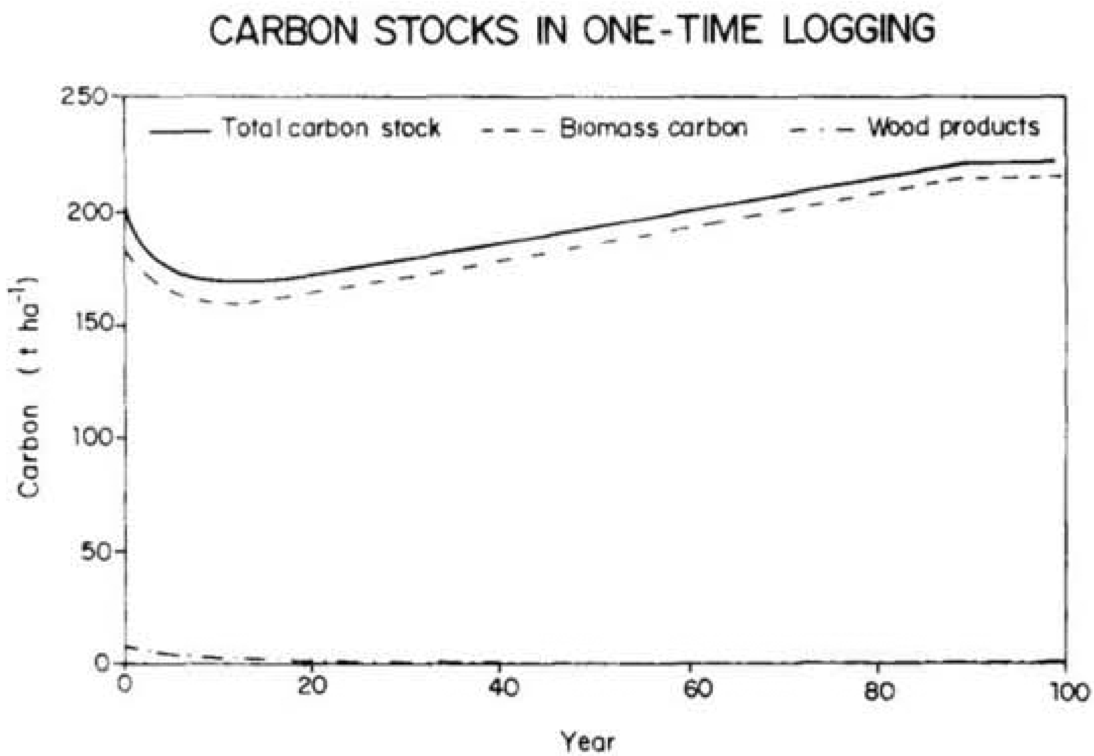

CARBON STOCKS IN TIMBER MANAGEMENT
Total carbon stock
Biomass carbon
Wood products
Carbon (t ha-1)
250
200
150
100
50
0
0
30
60
90
100
Year

Fig. 5.


CARBON STOCKS IN ONE-TIME LOGGING
Total carbon stock
Biomass carbon
Wood products
Carbon (t ha-1)
Year
0
50
100
150
200
250
0
20
40
60
80
100