TEXTO PARA DISCUSSÃO Nº 455

A Cost-Benefit Analysis of Deforestation in the Brazilian Amazon*

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Rio de Janeiro, janeiro de 1997

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* This research was carried out while the author was visiting the Institute for Applied Economics Research (IPEA) in Rio de Janeiro and the hospitality of the institute is gratefully acknowledged. Special gratitude is extended to Eustáquio J. Reis who has provided a continuous flow of inputs as well as constructive critical comments. I also need to thank Diana Weinhold and an anonymous referee for multiple comments and suggestions on earlier versions of the paper. Finally, since this paper collects information from many fields in which, I must admit, I have very little knowledge (e.g. biology, ecology, and farming), I invite specialists in these fields to try to make me wiser.

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ISSN 1415-4765

SERVIÇO EDITORIAL

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SUMÁRIO

ABSTRACT

This paper compares the Total Economic Value of standing Amazonian rain forest with the Net Present Value of alternative agricultural land uses. It is shown that, at the current level of deforestation, the potential benefits of deforestation are higher than the expected costs.

As the level of deforestation increases, however, the global costs of deforestation will rise, and eventually pass the value of agricultural land. At that point, the international community will have to provide incentives to induce Brazil to preserve the remainder of its rain forest.

1 - INTRODUCTION

The literature reflects a widespread belief that the current rate of deforestation exceeds the optimal rate. Even in the absence of several artificial incentives provided by government policy, there are economic arguments that support this point of view. For example, property rights to forests in frontier areas are often not enforced. This leads to the excessive use typical for an open access resource. Elementary public economics further teaches us that even when property rights are established and enforced, there are external benefits of forest preservation which are not taken into account by the owner (or decision maker). Intergenerational considerations are also important in this case, as future generations' preferences may not be taken into account in making current decisions on land use. Uncertainty about the true costs of deforestation to future generations makes this problem especially difficult.

However, there are also several characteristics of the Amazon that could theoretically lead to under-utilization of the forest from a social cost-benefit perspective. For example, imperfect capital markets and the resulting credit constraints may lead to under-investment in deforestation. Without a government presence in many remote regions, necessary public goods such as roads may never be constructed. Thus, there are both market imperfections and non-market forces that impact the process of deforestation in ways that cause it to deviate both positively and negatively from the socially optimal rate. In this paper we examine the data to try to ealculate the social costs and benefits of alternative land uses (including the option of leaving the forest undisturbed). From this analysis we can then attempt to determine how much the actual rate and level of deforestation has deviated from the (estimated) socially optimal figures.

The following section will provide a short introduction to the concept of Total Economic Value (TEV) which is used to calculate the value of different land uses (virgin forest, managed forest, crops land, and pasture) and Section 3 will discuss the problem of choosing an adequate social discount rate.

Section 4 estimares the Net Present Value (NPV) of different agricultural land uses. The NPV is first calculated for the typical extensive style land uses common in the Amazon. But since the productivity of land has been artificially low during the last decades due to highly distorting economic policies, we also calculate the NPV of the more intensive style agriculture that is expected to occur when policy distortions are reduced.

Section 5 collects estimares of the value of a standing forest. The total value of a standing forest includes a sustainable supply of timber and non-timber forest product, various ecological functions performed by the forest, as well as global services provided in the form of carbon storage and biodiversity preservation. It is quite difficult to obtain solid quantitative estimares for many of these values (especially the ecological services), so the estimares tend to be highly uncertain.

Other values (for example carbon sequestration) have been the subject of multiple quantitative studies. Nevertheless, significant controversy about the specific results still exists and care must be exercised when interpreting the figures.

In Section 6, despite a large amount of uncertainty in the estimares of the value of various land uses, we engage in a cost-benefit analysis of deforestation. The problem of making the (theoretically) globally optimal outcome feasible is also discussed. Section 7 provides some concluding remarks.

2 - ECONOMIC VALUATION

Many people may object to the very idea of putting a money value on such nonmarket quantities as the life of a squirrel monkey, general biodiversity in a rain forest, or the existence of an exquisitely beautiful yet hidden waterfall. However the sheer act of refusing to put a money value on such items does in fact imply a monetary valuation. By not sending 100% of their income to protect the rain forest, or by mailing $l5 to Save the Whales, people are acknowledging a less than infinite valuation of this region. Certainly, however, a zero valuation is equally inappropriate. Simply because it is difficult to apply a value to goods of this nature does not mean that we should not at least attempt to measure their value and make allocation decisions based on as much information as is economically reasonable to obtain.

In this chapter, we apply the concept of Total Economic Value [see, for example, Johanssen (1990) or Pearce (1993)] to asses the value people put on a standing rain forest and the value they put on alternative land uses.

The Total Economic Value concept is supposed to capture the full economic value that people attach to each type of land use. It can be expressed as:

TEV = Direct use value+Indirect use value+Option value+Existence value

For a standing rain forest the direct use value would, for example, stem from sustainable timber harvesting, non-timber products (nuts, fruits, latex, etc.), tourism, and genetic material.

Indirect use values refer to the 'ecological functions' performed by the forest. These include soil and watershed protection, fire prevention, water recycling, carbon storage, and biodiversity protection.

Option values represents the insurance premium we are willing to pay to secure that the forest, its biodiversity, and its ecological services are available in the future, in the case we find out that we need it.

Existence value is unrelated to both current and optional use. It arises because people are willing to pay for the existence of an environmental asset without ever taking part in the direct use of it (for example through recreation). The existence value includes the value we are willing to pay to secure the survival and well-being of other species.[1]

3 - CHOOSING A DISCOUNT RATE

Since a large part of the benefits of a standing rain forest will accrue to future generations of World citizens, it is important to consider their interests. It is customary, however, to attach less weight to costs and benefits materializing in the future than to those materializing today. The usual justification for this discounting procedure is that future generations will be better off anyway because of general economic growth, and they will therefore attach less value to an extra dollar of income than the current generation (because of diminishing marginal utility of income). They may also be better equipped to counteract any bad effects of the current generation activities that spill over to them [Pearce (1993, p.55)].

A standard formula for discounting future consumption is:

$$d = \sigma + \mu g$$

where d is the social discount rate, σ is the 'rate of pure time preference', μ is the elasticity of the marginal utility of consumption function, and g is the growth rate of per capita consumption [Pearce (1993, p.58)]. If the function linking utility to consumption is logarithmic, then $\mu = 1$. If, in addition, the pure time preference rate is set to zero on ethical grounds, then $d = g$. The discount rate becomes equal to the expected rate of growth of per capita consumption. Some empirical work suggests that li may be a little higher than unity [Fellner (1967) and Scott (1989)], and that the rate of pure time preference may be slightly above zero [Pearce (1993, p.59)]. Taking historical growth rates as a guide, this suggests reasonable discount rates in the range of 2 - 67%.

While these discount rates may be small compared to what is usually applied in cost-benefit analyses of investment projects, they do not particularly emphasize intergenerational equity. With a discount rate of 6%, a $1 benefit today would justify us to impose a $l00 cost on our grand children. In the following sections

[1] The existence value of other species are thus exclusively derived from human preferences and do not reflect any inherent right of existence of other species.

we will, for comparison, both adopt a 2% discount rate and a 6% discount rate.[2]

The 2% discount rate is believed to be closest to the rate a global social planner would choose.

4 - THE VALUE OF AGRICULTURAL LAND IN THE AMAZON

Approximately 14% of Brazil's Legal Amazonia has been converted to agricultural land[3] during the 1960/85 period. In 1985, about 63% of this area was used as pasture,[4] 7% used for annual crops, and 2% for perennial crops and planted forest. The rest (28%) became fallow land.

The average growth rate of agricultural output from Legal Amazonia was 8 percent per year during the period 1970/85. Much of the output growth can be contributed to an intensification in the use of agricultural land, rather than an expansion. Table 1 shows that the average real value of output per hectare of agricultural land has increased from $23/hectare in 1970 to $4l/hectare in 1985. With an annual growth rate of 4%, productivity increases accounted for about half of total output growth.

In 1985, animal output accounts for only 30% of agricultural output while taking up 63% of agricultural land. This reflects the relatively low per-hectare productivity of cattle ranching. In 1985 cattle raising generated an output of about $20/hectare.

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[2] The discount rate does not necessarily have to be constant over time. Weitzman (l994) develops a model which argue that the social discount rate should decline over time relative to the private discount rate (the discount rate used by a private investor who can disregard environmental considerations) because the environment is a time-varying externality. At relatively low levels of income, environmental concerns typically represent a relatively low priority. However, as levels of income rise, environmental effects become increasingly important.
To support this stylized fact he notes that total annualized costs of pollution control activities in the United States increased from 0.9% of GDP in 1972 to 2.l% in 1990, and is expected to increase to 2.7% in the year 2000 [Weitzman (1994, p. 208)].

[3] Agricultural land includes private natural pasture, planted pasture, crops land, planted forest, and fallow land. See Andersen *et alii* (l996).

[4] Of which 56% was natural pasture and 44% planted pasture.

Table 1
Value of Total Agricultural Production

State	Value of agricultural output in million l985 US$[a]				Agricult. output in 1985 US$ per hectare of cleared land			
	1970	1975	1980	1985	1970	1975	1980	1985
Acre	45	50	67	67	219	219	141	106
Amapá	9	16	17	22	22	34	49	29
Amazonas	173	214	253	295	174	219	187	188
Goiás	67	141	242	280	7	12	16	18
Maranhão	233	342	467	445	32	45	49	41
Mato Grosso	91	218	462	645	7	16	24	27
Pará	226	377	774	864	39	63	92	72
Rondônia	20	55	107	185	36	113	86	95
Roraima	10	14	19	26	8	9	11	18
Total	874	1,427	2,407	2,830	23	33	42	41

Source: The IPEA/Desmat data set, February 1996. Variables: VNAGPyy, LATOTyy, PASTOTyy, FALLOWyy.
[a]The exchange rate in 1985 was 6,200 CR$/US$.

Annual crops account for 37% of total agricultural output while taking up only 7% of the land. However, if fallow lands are included in the area used for annual crops production this percentage increases to 35%, and thus matches the share of output value produeed. Annual crops generated an annual output of $210 per hectare of actively cultivated crop area. However, most of the Amazonian soils cannot support annual crops for more than a few years. Then the nutrients are used up and a long fallow period is needed. If fallow lands are included in the area used for crops production, annual crops generate only $43/hectare/year.

Perennial crops (black pepper, oranges, coffee, cocoa, banana, passion fruit, cotton, etc.) accounted for more than 12% of total agricultural output while taking up less than 2% of the area. No fallow period is required for perennial crops land, so the output of perennial crops land was $377/hectare in 1985. Table 2 reports average gross output per hectare for different types of agricultural activity in the Amazon. The IPEA/Desmat data set does not contain information to calculate net outputs, but they will of course be lower than the figures in Table 2.

Table 2
Productivity of Agricultural Activities

Type	Value of agricultural output in million 1985-US$				Output value in 1985-US$ per hectare of area[a]			
	1970	1975	1980	1985	1970	1975	1980	1985
Animal products	162	362	716	856	7	12	18	20
Annual crops	304	636	928	1,055	202	244	213	210
Perennial crops	58	78	178	352	296	225	228	377
Silviculture	0	0	8	26	0	0	32	127
Horti & fioriculture	55	5	12	18	-	-	-	-
Wood extraction	120	166	334	256	5	5	7	5
Other	230	160	231	267	-	-	-	-
Total	874	1,427	2,407	2,830	23	33	42	41

Source: The IPEA/DesmAT data set, February 1996. Variables: VNAGPyy, VNANIyy, VNTyy, VNPyy, VNXyy, VNFyy, VNHFyy, FLONATyy, FLOPLAyy, PASTOTyy, LATEMYY, LAPERyy.
[a]The value from silviculture is assumed to be generated from planted forest, and the value of wood extraction are assumed to be generated from private natural forest. Animal products are assumed to be generated from private natural and planted pasture.

The land use structure and productivities in the past did not reflect the true value of agricultural land, however. The aggressive development policies implemented during the 1960/85 period greatly distorted economic incentives and led to economic activities with low productivity and artificially high profits. Titles to land were basically granted in proportion to the amount of land converted. Since cattle ranching had relatively low start up costs and, in addition, ensured very attractive government subsidies and tax breaks, ranching was an attractive way of acquiring land.

Several economic analyses show that ranching in the Amazon had a very low or even negative productivity if land speculation was not taken into account [e.g. Hecht (1986), Hecht, Norgard and Possio (1988), and Almeida and Uhl (1995)].

As land becomes more scarce and the government abandons its distorting policies there will be a tendency towards more intensive agricultural methods. Researchers at Imazon[5] have performed detailed analyses of agricultural methods in Pará during the early 1990s. Pará is one of the earliest settled states and has therefore had more time to develop and refine its agricultural methods. The Imazon studies provide information about start up costs and annual profits for different types of land uses as well as information on employment generation [see Almeida and Uhl (1995), Veríssimo *et alii* (1992), Mattos and Uhl (1994), Toniolo and Uhl (1995)].

[5] Instituto do Homem e Meio Ambiente da Amazônia (Amazon Institute of People and the Environment), Pará, Brazil.

Table 3 reports the net present value[6] of three different styles of land uses: **a**) the typical, unsustainable, extensive style that is currently predominant in the Amazon; **b**) the extensive style adjusted to be sustainable through sufficiently long fallow periods; and **c**) a sustainable, intensive style which is beginning to appear in areas with higher land prices. For each of the three styles, the table reports results for crops, pasture, and logging.

The typical farming method in the Amazon involves extensive-style shifting cultivation of annual crops like rice, corn, and cassava. A piece of forest is burned and the land is used for annual crops for a couple of years until the nutrients from the ashes are used up or washed away. The burning provides a nutrient rich and relatively pest-free environment, which implies high yields for the first couple of years, but rapidly declining yields thereafter. A much more intensiveand sustainable-farming approach is to grow perennials, such as black pepper, oranges, and passion fruit. Inputs of fertilizers and pesticides are then required, however.

The average stocking density on cattle pastures was 0.4 animais per hectare in 1985. Even with this low density pastures tend to degrade. Mattos and Uhl (l994) report that 25 - 50% of pastures in the Eastern Amazon are badly degraded and/or abandonei. Degraded pastures can be rejuvenated, though, by tilling, fertilizing, and implanting better adapted forages. Rejuvenated pastures can support more animais and the weight gain of the animais is higher [Mattos and Uhl (1994)]. Ranching on rejuvenated pastures is referred to as intensive-style ranching.

Logging is still not very widespread in the Amazon, but its importance is increasing. In its typical extensive-style form it involves a rather brutal and unplanned extraction of a few of the most valuable species with great damage being done to the remaining species. A typical mill in the eastern Amazon has one band-saw and requires about 21,000 ha of forest to operate on a sustainable basis. If simple forest management techniques are implemented, the logging cycle could be reduced to a third and profits doubled or tripled. The forest area needed for sustainable logging would then be reduced to about 7,000 ha/mill [Almeida and Uhl (1995)].

[6] The net present values in Table 3 does not include the price of the land — only the capital costs and labour costs.

Table 3
NPV and Employment for Different Land Uses

	NPV/hectare (l990-US$/hectare)		Employment[j] (persons/l00 ha)
Discount rate	2%	6%	
Typical unsustainable methods			
Annual crops (4 years)[a]	1,510	1,402	
Pasture[b]	- 289	- 292	
Logging[c]	600	600	
Sustainable extensive methods			
Annual crops[d]	3,366	1,531	6.3
Pasture[e]	- 57	- 208	1.1
Logging[f]	431	156	0.2
Sustainable intensive methods			
Perennial crops[g]	18,305	4,960	71.4
Pasture[h]	1,748	373	2.1
Logging[i]	1,081	381	0.6

[a] Start-up costs: $291, Proflts: $l,O79 the first year, falling by 30 % annually the next four years. Then left as fallow forever. Source: Almeida and Uhl (l995, Table 3) and Schneider (l9g5, Table 2.1).
[b] Start-up costs: 8307, Profits: $2/year for 10 years, zero thereafter. Source: Almeida and Uhl (l995, Table 2).
[c] First year profit of $2OO/m 3 . Average extraction rate: 3 M3 /ha. Source: Motta and May (l992) and the IPEA/Desmat data set. See also Section 5.1.1.
[d] Start-up costs: $291, Profits: $l,079 the first year, 80 the next 10 years (fallow period). Source:Almeida and Uhl (l995, Table 3).
[e] Start-up costs: $307, Profits: $6/year. Source: Almeida & Uhl (l995, Uble 2).
[f] Start-up costs: $27, Profits: $ll/year. It is assumed that the mill has access to enough land to operate at full capacity for the full 90 felling cycle (21,780 ha for a typical mill with one band saw). Source: Almeida and Uhl (l995, Table l and 4).
[g] Start-up costs: $2,695, Profits: $802/year. Source: Almcida k Uhl (l995, Table 3).
[h] Start-up costs: $539, Profits: $55/year. Source. Almeida & Uhl (l995, Table 2).
[i] Start-up costs: $83, Profits: $28/year. lt is assumed that the mill has access to enough land to operate at full capacity during the whole 30 year felling cycle (7,260 ha/mill). Source: Almeida and Uhl (l995, Table l and 4).
[j] Source: Almeida and Uhl (l995, Table 5).

4.1 - Typical NPV and Optimal NPV of Agricultural Land

The agricultural profits from the Paragominas studies may be used to approximate the future benefits of agricultural land in Amazonas. Assuming that the consumer surplus derived from consumption of Amazonian agricultural outputs is negligible because the products could be bought at the world market at the same prices, we equate the Total Economic Value of agricultural land uses to the Net Present Value of agricultural profits (the producer surplus).

The NPV is highest if the land is used for intensive agriculture (perennial crops). If it is used for extensive style cattle ranching, as is predominantly the case at the moment, the NPV is negative.

Using the land use structure of 1985, we can calculate a NPV of Amazonian agricultural land as it was used in a regime with highly distorting economic policies (such as subsidies to large scale cattle ranching).

About 8 million cubic meters were logged in 1985, corresponding to roughly three cubic meters per hectare of cleared land.[7] Each cubic meter yields a profit of approximately $200,[8] implying an average first year logging profit of $600 hectare. Then 63% is converted to pasture, 7% is used for annual crops and 2% is used for perennial crops. With a 2% discount rate this implies a typical NPV of $890/hectare [$600 + 0.63 - (-$289) + 0.07 - $l,510 + 0.02 - 18,305]. The corresponding NPV for the 67% discount rate is $613.

However, if the policy incentives that has promoted large scale cattle ranching and artificially low land prices are removed, the potential NPV increases dramatically.

If land is efficiently logged before clearing, it can yield a first year profit of about $6400/hectare.[9] This profit can be shared between the logging company and the small farmer that owns the land. Annual crops can then provide quick profits for a couple of years ($1079/ha the first year, $788/ha the second year and $464/ha the third year[10]), and when sufficient funds have been generated and the area has developed a better infrastructure, the land can be planted with perennial crops which are sustainable and yield a net present value of $l8,305/ha at the 2% discount rate".[11] The total net present value of this sequence of land uses is thus $24,380/ha. With a 6% discount rate it becomes $l2,05l/ha.

The typical and potential NPVs of agricultural land in the Amazon are summarized in Table 4.

[7] In Pará, where the logging industry is more developed, the average is now 32 M3/ha [Uhl *et alii* (1996, p.9)], and the logging potential is significantly higher.

[8] See Section 5.1.1.

[9] Assuming that 32 m^3/hectare (the average for Pará in 1995) can be profitably logged with a profit of $200/$m^3$.

[10] When assuming a land degration of 30% per year. See also footnotes in Table 3.

[11] See Table 3.

Table 4
The Typical and Potential NPV of Agricultural Land

	Net Present Value per hectare (l990-US$/hectare)	
Discount rate	2%	6%
Typical unsustainable sequence	890	613
Potential sustainable sequence	245,380	12,051

Source: Author's estimates.

4.2 - Spill-Over Effects to the Urban Sector

So far, the analysis has only included the value of agricultural production derived from converted rain forest land. Urban activities were assumed to be independent of deforestation-neither causing deforestation, nor depending on deforestation. This may not be a reasonable assumption. During the 1970/85 period urban output in Legal Amazonia increased at an impressive rate of 14% per year. Rural output grew only by 8.7% per year during the same period. By 1985, urban CDP accounted for 83% of total GDP, and this share is predicted to increase further [see Andersen and Reis (1996)]. While annual rural output increased by $l.6 billion (in real terms) during the 1970/85 period, urban output increased by $9.7 billion. This implies that the total benefits associated with deforestation may be up to seven times higher than the rural benefits alone.

The urban benefits include value added in the service sector, in agro-processing industries, in timber-processing industries, and in mining industries. A large part of this value could probably not be generated without accompanying land clearing. Some components of urban output, for example mining output, is closely related to the amount of cleared land, while others are related to amount of rural output (productivity of land x land area cleared). Thus, as rural productivity increases, we would expect the spill-over factor to decrease slightly. More research on the links between the rural and urban sectors in the Amazon is needed to find out how important these spill-over effects are.

For the optimal land use sequence, we assume that total benefits are five times larger than rural benefits alone (compared to the observed seven times in the 1970/85 period). This implies that the total potential net present value of one hectare of cleared land is 5 x $24,380 = $l2l,900 for a discount value of 2% and S60,255 for a discount rate of 6%.

5 - THE VALUE OF INTACT AMAZONIAN FORESTS

Table 5 summarizes the economic values of a standing rain forest. The subsequent subsections explain how the individual components are estimated.
The classification of values into local private, local public, and global benefits is made to provide some indication of what transfers should take place to obtain the optimal amount of forest preservation.

Table 5
The Total Economic Value of a Standing Rain Forest

	Total Economic Value per hectare (l990-US$/hectare)	
Discount rate	2%	6%
Local private benefits		
Sustainable timber supply	5,200	1,733
Non-timber products	500	167
Tourism	80	26
Local public benefits		
Water recycling	3,000	1,000
Nutrient recycling	0	0
Protection against fire	300	83
Watershed protection	150	50
Global benefits		
Carbon storage	6,750	750
Biodiversity protection	1,540	513
Recreational value	80	26
Existence value	400	133
Total Economic Value	18,000	4,481

Source: Author's estimates. See derivations in the following sections.

5.1 - Local Private Benefits

The private benefits derived from a standing forest consist of the profits derived from the timber and non-timber forest products that can be sustainably harvested from the forest, plus the profits that can be generated through tourism.

5.1.1 - Sustainable Timber Production

This section derives a rough estimate of the value of sustainable timber production per hectare of forest and per hectare of savanna. The calculations are based on Motta and May (l992).

First, we have to determine the amount of timber that can be harvested in a sustainable fashion. For that purpose we assume that average annual sustainable timber harvest is equivalent to the average annual natural increment in merchantable timber volume.[12]

For typical Amazonian dense forest (*ombrofila densa*) the natural increment is about 0.60 m^3/hectare. For the more open forests (*ombrofila aberta*) found in Maranhão, Rondônia, and Mato Grosso, the average natural increment is about O.48 m^3/hectare. For cerrado type vegetation it is only 0.20 m^3 /hectare [Motta (May 1992, Table 3)].

Legal Amazonia consists of roughly 15% savanna, and 85% more or less dense forest. A natural savanna is assumed to yield no sustainable benefits over and above the benefits from cultivated savanna. We therefore concentrate on the forested part of Legal Amazonia. The forested part consists of 74% dense forest, 10% open forest, and 16% cerrado.[13] The weighted average annual increment is therefore approximately 0.52 m^3 /hectare of forest.

To find the stumpage value of annual sustainable wood production, we follow Motta and May (l992). We approximate the stumpage value by deducting the average costs of extraction and transport from international market prices per unit of output. The average FOB price during the period 1971/80 was roughly 300 US$/ton in 1980 prices [Motta and May (1992, Table 4)]. This price has stayed relatively stable during the eighties, and is not expected to rise dramatically in the future.[14] Extraction and transportation costs accounted for approximately 25% of the FOB price [Motta and May (1992, p.12)]. This implies an average rent to wood product resource owners of $225/ton or $l9l/$m^3$ since one cubic meter of logs weighs appromately 0.85 ton. Rounding up, we assume that a rent value of $200/$m^3$ is a reasonable approximation to future rent values.

Multiplying the 0.52 m^3 that can be sustainably harvested every year from one hectare of forest with the rent value of $200/$m^3$, we get a value of sustainable timber of $l04/hectare/year. Using a discount rate of 2%, this implies a net present value of $5,200/hectare. If the discount rate is 6% the net present value drops to $l,733/hectare.

5.1.2 - Non-Timber Forest Products

[12] This is a conservative assumption, since managed forests can be assumed to produce volumes well in excess of the natural increment [Motta and May (1992, p.12)].

[13] Source. The IPEA/DesmAT data set. Variables: FODAR2, FESAR2, SAVAR2, TECAR2, FOPAR2, and CAMAR2.
Note: Dense *forest* is counted as dense forest; *seasonal open* and *closed forest* and varzea *forest* is counted as open forest; while *cerradão* and *campina* is counted as cerrado.

[14] Declining tropical hardwood inventories are expected to lead to rising log prices, but most of the increase is expected to occur in Southeast Asia. An increase in the supply of temperate hardwoods is expected to keep prices in the rest of the world relatively stable [see Barbier *et alii* (l994)].

Besides timber, it is possible to extract a wide range of non-timber products from a standing forest. Currently, the commercially most important extractive products are açai (fruit), babassu oil, palmito (heart of palm), rubber, and Brazilnuts [IBGE (1994)].

Besides the commercial products, forests also provide an astonishing array of subsistence products including shelter, clothing, food, beverages, oils, charcoal, kitchen utensils, tools, weapons, bait, hammocks, baskets, flshing nets, brooms, ornaments, cosmetics, toys, medicine, and magic [Anderson, May and Baliek (1991, p.5)].

Anderson, May and Balick (l991) provide a detailed analysis of the value of wild babassu products in the state of Maranhão. Babassu is a tree-sized palm which thrives in areas that has been disturbed by human activity. It is thus present at high densities in large areas of the Amazon, and forras more than 150,000 km^2 of secondary forest areas with virtually pure stands in Maranhão, Goiás, Mato Grosso, and Pará.

All parts of the palm can be used[15] but the kernels from the fruits are commercially most important.[16] Anderson, May and Balick (l99l) conservatively estimate that babassu fruit products utilized both in the market and in the subsistence economy contributed $85 million annually in direct benefits to the Maranhão economy. This is approximately twice the value of the comercially exploited babassu oil. Dividing this value by the forested area of Maranhão,[17] we get an average value of about $7/ha/year just for one product.

Similar analyses can be made for the other states. The commercially most important extractive products in the state of Pará is açai with a reported market value of $55 million in 1992.[18] Assume that the value to the non-market economy is of roughly the same magnitude. Then the value of açai amounts to approximately $l/hectare of forest.

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[15] For an impressive list of product that can be derived from the babassu palm [see Andersen, May and Balick (l99l, Table 4.2)].

[16] About 300,000 households in Maranhão are engaged in babassu-related production. Throughout the 197Os, babassu oil production — crushed from from kernels obtained entirely from wild stands by peasant farmers — generated over half the tax revenue in Maranhão. Extraction of babassu kernels continues to comprise the largest oilseed industry in the world based on a wild plant [Anderson et alii (1991, p.138-139)].

[17] Forest covered originally about 20 million hectares. 30% of the area was cleared by 1985 [Andersen *et alii* (1996, Table 4.3)]. If the trend from the 1970/85 period has continued, then about 35% would have been cleared by 1991. This implies an estimated forested area in 1991 of approximately 13 million hectares.

[18] Anuário Estatístico do Brasil (1994, Table 3.21).

For the state of Amapá, palmito was the most important product with a commercial value of about $6 million in 1992.[19] Again assuming an equivalent non-market value, we get a value of $l/hectare for the most valuable extractive product.

Rubber is mainly extracted from the state of Acre where it generated a commercial value of $4.5 million according to official numbers.[20] The non-market benefits are likely to be small for rubber, and the commercial value may be overstated since Brazil used to subsidize its rubber industry. So when taking the commercial value and dividing by the forested area of Acre, we get a value of rubber extraction of $0.3/hectare.

In contrast to these broad averages of extractive values over states, site studies provide much higher estimares of the value of extractive products. Peters *et alii* (l989) have estimated the net value of non-timber forest products from a plot in the Peruvian Amazon (Mishana). After deducting costs of collection, transportation, and regeneration, they found a net value of $317/ha/year. Using a similar methodology for another plot in the Peruvian Amazon (the San Rafael Reserve), Pinedo-Vasquez *et alii* (l992) found a net value of $20/ha/year.

The babassu study is judged to be more representative for Legal Amazonia than the Peruvian site-studies. Thus, in the absence of any other reliable estimate, we extend the babassu results from Eastern Amazonia to the rest of the Legal Amazonia. Allowing for benefits from other extractive products, we choose a central value of extractive products of $l0/ha/year. This implies a net present value of $500/ha with a 2% discount rate, and of $l67/ha at the 6% rate.

5.2 - Local Public Benefits

The natural forest provides a range of ecological services at the local and regional level. These include water recycling, fire prevention, erosion control, and watershed protection. No quantitative studies could be found to provide estimares of the value of these services. The following sub-sections will attempt to provide some order-of-magnitude guesses, but more serious research is certainly needed in these areas.

[19] Anuário Estatístico do Brasil (1994, Table 3.21).
[20] Anuário Estatístico do Brasil (1994, Table 3.22).

5.2.1 - Water Recycling

Compared to other parts of the world, a relatively large part of rainfall in the Amazon is derived from water recycled into the atmosphere through evapotranspiration rather than being blown into the region in the form of clouds from the ocean.[21] Since evapotranspiration is roughly proportional to leaf area, the water recycled through forest is much higher than that recycled through pasture and savanna.

Deforestation and the implied reduction in evaporation and precipitation could seriously reduce the source of water vapor for neighboring agricultural land. This effect is aggravated by the rain running of compacted pasture soils much more quickly, becoming unavailable for later release to the atmosphere through transpiration [Fearnside (1995, p.53)]. Thus, deforestation is likely to cause the dry season to become longer and more severe.

The changes in the water cycle will also have an impact on the energy cycle. As there will be less water available for evapotranspiration there will be a decrease in air-humidity, which will alter the energy balance. Instead of being used for water evaporation, the incident solar energy will be used for heating the air, thus further increasing the possibility of drought problems.

The most dangerous effects are likely to occur durlng oecasional "extreme" events rather than gradually from year to year [Fearnside (1995, p.54)]. Reduced evapotranspiration is likely to increase the probability of severe droughts which would kill many plants and trees of susceptible species. The result would be replacement of the tropical moist forest with more drought-tolerant forms of scrubby, open vegetation resembling the scrub savanna of central Brazil [Fearnside (1995, p 54)].[22]

No estimares of the value of the water recycling service could be found in the literature. The estimate developed below should therefore be interpretei as little more than a wild guess, and it should be easy for more qualified researchers to improve on this guess.

Consider a representative 100 hectare plot in the Amazon forest composed of 90% primary forest and l0% agricultural land. When optimally used, the agricultural land will be covered with perennial crops with a value of about $2,695/hectare. The yields are approximately $800/ha/year, but sensitive to changes in rainfall.

[21] Studies by Villa Nova *et alii* (l976), Lettau *et alii* (l979), Marques *et alii* (l980), Jordan and Heuneldop (l98l), and Leopoldo *et alii* (l982) show that, on average, about 50% (and in some places up to 75%) of precipitation returns to the atmosphere in the form of water vapour through evapotranspiration, while the rest is discharged through the Amazon River system.

[22] The value of biodiversity is counted under global benefits.

Allowing for some substitution towards less water demanding crops, we assume that a 10% reduction in average rainfall will lead to a 5% reduction in output.

Now assume that an additional 20% of the area is cleared and converted to agricultural land, so that forest only takes up 70% of the area. This will reduce leaf area by about 20%. Evapotranspiration is roughly proportional to leaf area and contributes about 50% percent of total rainfall. Assume therefore that there will be a l0% reduction in average rainfall.

This implies that the extra 20 hectares deforested implied a productivity loss of $l200 (5% of $800 multiplied by the 30 hectares of agricultural land). Thus the value of water recycling can be estimated at 60$/hectare/year for this level of deforestation.[23] This implies a net present value of the water recycling service of $3,000/hectare if we employ a 2% discount rate and $l,000/hectare if the discount rate is 6%.

5.2.2 - Nutrient Recycling

The main share of nutrients in a rain forest is located in the biomass above ground rather than in the soil. When the forest is burned these nutrients are temporarily transferred to the soils, where some of them are captured by planted crops and pasture grasses, while the rest are washed away. The value of nutrients removed by forest clearing is calculated at $3480/ha given market prices of NPK fertilizers in Brazil [Uhl, Bezerra and Martini (1993, p.224)]. However, this value cannot just be added to the other values of a standing rain forest, sinee the appropriation of this value would imply the elimination of the other values.

A mature forest is in nutrient balance and thus does not provide any nutrient recycling value to surrounding areas.

5.2.3 - Fire Control

With its humid micro climate the rain forest provides at natural protection against wildfires. The value of the fire control service performed by intact forests has not yet been calculated, but fire damage could be catastrophic during one of the droughts aggravated by deforestation. The remainder of this sub-section attempts to provide a first guess of the value of fire-protection.

Consider again a typical 100 hectare plot in the Amazonian forest where l0% have been cleared for agricultural land.

[23] At higher levels of deforestation, the productivity fall will be higher for two reasons: **a**) the percentage reduction in leaf area will be bigger and therefore imply a bigger reduction in rainfall, and **b**) the agricultural area adversely affected is bigger.

Intact forest has a very low fire risk. Wild fires happen maybe once every 500 years on a given hectare, i.e. the probability of fire is 0.2% per year. For cleared land wild fire risk is much larger, lets say 2% per year (once every 50 years).

Additional deforestation will increase total fire risk both because the fireresistant area is reduced and because of the drier climate resulting from deforestation. Let us assume that fire risk in both categories of land increases by l0% if an extra 20 hectares are deforested.[24] The increase in the probability of wild fire in forests is therefore 0.02 percentage point and the increase in the probability of uncontrolled fire on agricultural land 0.2 percentage points.

If wild fire consumes agricultural land, an average of about $2,695 worth of crops are lost per hectare. If fire consumes virgin forest, the loss will amount to the services lost during the period of regeneration . Carbon will be released during burning, but an equivalent amount of carbon will be absorbed by growing trees during the period of regeneration.[25] Since forests regenerate relatively quickly on burned land from which the nutrients have not been removed, the ecological functions will soon be restored. The biggest loss will come from the loss of sustainable timber supplies, since it will take many decades before the new trees are ready for harvest. Assume that a sustainable timber supply worth $l04/ha/year is lost for 50 years. This amounts to a cost of $3,268/ha at the 2% discount rate, and $l,639/ha at the 6% discount rate.

Now we are ready to calculate the value of the fire protection service. At the 2% discount rate a 20 hectare increase in deforestation will imply an expected loss of $l27 (0.02%.70 hectares.$3,268/hectare + 0.l9%.30 hectares.$2,695/hectare).

This implies an expected annual fire protection service of about $6/hectare, or a net present value of $300/hectare. At the 6% discount rate the corresponding number will be $83.

5.2.4 - Erosion Control and Watershed Protection

Deforestation and placer mining along rivers cause an increase in siltation and sedimentation which can have serious consequences for downstream fisheries and for the capacity of downstream dams and reservoirs. Brazil already has a law which seeks to protect watersheds by requiring the permanent preservation of forest and other natural vegetation at the origin of rivers. Within these areas a *Paralelograma de Cobertura Florestal* is to be established, within which deforestation and other forms of land alteration are to be forbidden [Schneider (1992, p. 21)].

[24] The 10% increase is chosen to correspond to the 10% reduction in rainfall that was assumed to follow from the same amount of deforestation.

[25] Regeneration of naturally burned forests is much easier than regeneration on abandoned agricultural land because all the nutrients are maintained at the site.

No estimares of the value watershed protection in the Amazon could be found either. A rough idea about the magnitude of the value can be found by looking at the amounts of money being spent on watershed rehabilitation in the Columbia River Basin in the Pacific Northwest.

The Columbia River Basin covers some 259,000 square miles [McGinnis (1995, p.67)] or some 67 million hectares. Extensive hydropower development during the last six decades has transformei the river and surrounding habitats dramatically driving many species toward extinction.

One of the world's largest ecosystem restoration programs have recently been initiated to rehabilitate and protect the watersheds, which include a billion dollar fishing industry. The federal government currently spends about $l70 million annually on watershed and wildlife enhancement projects in the Columbia River area. Special projects, such as the $77 million stream rehabilitation project in 1994 and projects initiated by other interest groups, add to this figure [McGinnis (1995, p.64)]. lf we assume an annual willingness to pay for watershed protection in the Columbia River Basin of about $200 million/year, this implies a value of about $3/hectare/year.

Assuming that the value of watershed protection is approximately the same in the Amazon Basin as in the Columbia River Basin, we get a net present value of watershed protection of $l50/hectare if we apply a 2% discount rate and a net present value of $50/hectare if we use a 6% discount rate.

5.3 - Global Benefits

The global benefits derived from an intact rain forest include direct use values from recreation (eco-tourism) and from the provision of genetic material for scientific research; indirect use value in the form of a carbon storage service mitigating global warming; option values in the form of unknown genetic material which may be used for medical purposes in the future; and an existence value derived from the mere satisfaction of knowing that a place exists where hundreds of thousands of to us unknown species live in their natural environment protected from the massive human interference that has altered the places we now live to unrecognition.

5.3.1 - Carbon Dioxide Storage

The concentration of carbon dioxide in the atmosphere has increased steadily during the last century, because carbon is released from two of the Earth's major storage depots; fossil fuels and forests.[26] The Intergovernmental Panel on Climate Change (IPCC) estimares that deforestation accounted for 1.6 ± 1.0 billion tonnes of carbon emissions during the 1980s while fossil fuel burning accounted for 5.4 ± 0.5 billion tonnes [IPCC (1990**b**, p. 14)]. With 10-35% of total carbon emissions, deforestation may be a major cause of future climate change.

Since dense tropical forests have a much higher biomass than alternative land uses, carbon will be released when forests are converted to crops land or pasture. Brown and Pearce (l994, p.5) estimate that the conversion of one hectare average rain forest will imply a carbon release of 100-200 tonnes. If we assume that pasture or farmland contains about 60 tons of carbon per hectare, then this range is supported by estimares by Sombroek (l992), Feamside (l992), Houghton *et alii* (1987), and the German Bundestag (l990).[27]

Indications of the costs of an additional ton of carbon released to the atmosphere can be obtained both indirectly and directly. Indirect methods include looking at the value societies are willing to tax themselves in order to stabilize greenhouse emissions or looking at abatement costs implied by various methods of reducing greenhouse emissions. The direct approach sums up all the estimated costs and benefits of climate changes over sectors and regions. The direct approach requires much more information than the indirect approaches. The indirect approach has been adopted by Schneider (l991), McKinsey and Company (l989), Nordhaus (l990, 1991), and ERL (l990). The direct approach has been employed in Nordhaus (l993**a**, l993**b**), in Fankhauser (l994), in Cline (l992), and in Titus (l992).

Indirect approach. The indirect approach is a convenient short cut, since it requires very little information. Schneider (l991) provides an overview of enacted and proposed carbon taxes. Enacted taxes in Finland, the Netherlands, and Sweden are in the range $6.1-45/ton of carbon [Shah and Larson (1992)]. Proposed carbon taxes in the US and the EC are in the range $5-70/tC [Shah and Larson (1992)]. The US Congressional Budget Office concluded in a 1990 study that the tax required to reduce US greenhouse emission to 1988 levels by the year 2000 should be $l0/tC in 1991 increasing gradually to 100 in the year 2000 [CBO (1990) and Schneider (1993)].

The carbon tax approach has two potential biases, which work in opposite directions. A positive bias arises from the fact that a carbon tax will have positive

[26] The total carbon pool, estimated at about 49,000 metric gigatons (l metric gigaton equals 109 metric tons), is distributed among organic and inorganic forms. Fossil carbon accounts for 22 percent of the total pool. The oceans contain 71 percent of the world's carbon, mostly in the form of bicarbonate and carbonate ions. An additional 3 percent is in dead organic matter and phytoplankton. Terrestrial ecosystems, in which forests are the main reservoir, hold about 3 percent of the total carbon. The remaining I percent is held in the atmosphere, circulated, and used in photosynthesis ("Carbon Cycle", Microsoft Encarta 1994).

[27] Estimates reported in Schneider (l993).

effects other than nútigating global warming. Considerable secondary benefits can be expected in the form of local and regional air quality improvements, reduced traffic externalities (accidents and congestion), and tax revenues which can be used to lower other distortionary taxes. A large part of the supposed willingness to pay for carbon reduction is probably due to such immediate local benefits rather than the more uncertain future effects through global warming.[28] Ekins (l996) reviews estimares of secondary benefits Of CO_2 abatement achieved through reductions in fossil fuel consumption. The estimares reviewed are in the range $l25-795/tC. These estimares of secondary benefits are all higher than the highest carbon tax implemented ($45/tC in Sweden), so enacted carbon taxes attached to fossil fuel consumption tells us little about the true cost of carbon emissions.

A negative bias arises from the free-rider problem. In absence of strong international cooperation, individual countries will be reluctant to impose signiflcant costs on the national economy, since only a negligible part of the benefits of reduced emissions accrue to themselves, while the costs in terms of loss in international competitiveness may be large.

Nordhaus (l99l) surveys a lot of studies on various methods of reducing CO_2 emissions.[29] By applying the most cost effective methods first he arrives at an estimate of the marginal cost of emissions reduction of $S.3/tC for a 10% reduction from baseline. As we use up the most cost effective methods (CFC reductions) these costs increase rapidly. A 15% reduction from baseline will cost $l6.3/tC, a 20% reduction $27.9/tC, and a 25% reduction $40.2/tC [Nordhaus (1991, Table 9)]. To stabilize emissions at the 1990 level, a 14% reduction from the no controls scenario is needed by 1995, increasing to a 28% reduction by 2005, 38% by 2015 and about 45% by 1925 [Nordhaus (1994, Figure 5.2)]. Combining the cost estimates from Nordhaus (l991, Table 9), with the estimated reductions required to stabilize emissions at 1995 levels [derived from Nordhaus (l994, Figure 5.2)], we get a time path for the costs of carbon emissions. It increases from $l5/tC in 1995 to $l05/tC in 2025. The results are given in Table 6.

A study by Energy Modeling Forum 12 (EMF 12)[30] also uses thé results from a big collection of models to arrive at "Phased-In-Tax" scenario which includes a carbon tax imposed by all countries that increases from $l5/tC in 1990 at 5 percent per year. This is approximately the tax trajectory that would be needed to limit the

[28] The existing taxes on fuel and other oil products already imply implicit carbon taxes of $65/tC in United States and $200 - 350/tC in Europe [Hoeller and Coppel (1992), quoted in Poterba (1993)].

[29] The methods of carbon-equivalent reductions investigated include: **a**) reduction of CFG emissions, **b**) slowing tropical deforestation, **c**) reforesting open land, **d**) a lumber storage program, and **e**) geoengineering. The last method includes creating a global sunscreen by sending tiny particles into the atmosphere and chemically change the carbon absorbing ability of the oceans. Too little was known about these options, however, to include them in the estimations.

[30] Results reported in Gaskins and Weyant 1993*a* and 1993*b*.

cumulative world emissions over the next 50 years to 50 times 1990 levels [Weyant (1993, p. 35)].

Another indirect approach is to estimate the costs of carbon sequestration by reforestation. This approach produces highly varying estimares depending on the assumed opportunity cost of land used for forest. Mckinsey and Company (l989) estimate the cost of forest management, afforestation and reduction of deforestation to range from $5 per ton of carbon conserved in the tropics to $28 in OECD countries. Nordhaus (l990) estimares that total cost of carbon sequestration lie between $41 per ton in tropical countries and $ll4 in the United States. These numbers are broadly confirmed by a study undertaken by ERL (l990).

The direct cost approach. Most estimares arising from the direct cost approach has focused on a benchmark scenario defined as the level of global warming associated with a doubling of pre-industrial carbon dioxide equivalents of all greenhouse gases. Without a drastic change in the use of fossil fuels, the doubling of the CO_2 level from 330 ppm to 660 ppm is expected to occur within 50-75 years. It is expected to cause an increase in world mean temperature of 3±1.5ºC. The increase will be unevenly distributed and will have positive effects in some regions and for some sectors. In general, however, the negative effects are believed to exceed the positive by several hundred billion dollars [e.g. Fankhauser (1994), Nordhaus (1994), and Cline (1992)].

Agricultural losses are expected to be largest in developing countries, where erops are currently grown near their limits of temperature tolerance and the capacity for adjustment is low. Even small climate changes can cause large water resource problems in many areas, and the change in drought risk represents potentially the most serious impact of climate change on agriculture and human life [IPCC (l990a)]. In large parts of the developed world, however, the effect on agriculture is likely to be negligible, or even positive, due to adaptation and the off-setting effects of longer growing seasons, increased precipitation, and increased CO_2 fertilization.

A doubling of the CO2 concentrations is expected to cause the sea level to rise 50-60 em during the next 100 years. It will continue to rise for several hundred years thereafter, however, because of the very slow adjustment to equilibrium [Titus (1992)]. A one meter rise will inundate approximately 37% of the world's land area [Rosenberg *et alii* (1989)], displace tens of m-illions of people, seriously threaten low-lying urban areas, flood productive land, and contaminate fresh water supplies. The costs of a rising sea level thus include capital costs associated with protective constructions, annual costs of foregone land services, and migration costs including the utility sacrificed by the migrants and the costs imposed on the host countries.

Global warming is also expected to cause an increased intensity of tropical storms, since these are very sensitive to changes in the sea surface temperature. Emanuel (l987) estimated that a doubling of the CO_2 level would increase the destructive potential of hurricanes by 40-50%. Hurricanes can cause both great material damage and large human losses.

Other costs of global warming include a net increase in energy consumption (because cooling is more expensive than heating), an increased mortality rate (because summer deaths are expected to increase more than winter deaths will decrease), and a possibly increased morbidity rate because of a spread of vector borne diseases such as malaria. Furthermore, global warming is expected to aggravate the problems of urban pollution. For more thorough discussions of the costs of global warming, see, for example, Cline (l992), Nordhaus (l994), and Fankhauser (l994).

While estimates vary widely for the different damage categories, the central total damage estimares concentrate around l-27% of gross world product. The confidence bounds tend to be asymmetric indicating that the costs could be much higher than that if climate changes turned out to be in the upper end of the predicted range.

Due to the rising atmospheric carbon concentration over time, the annual damages will be lower before the doubling date and higher in subsequent decades. But since virtually all research has focused on the 2. CO_2 point estimate very little is known about the slope of the damage curve. The few studies attempting to estimate the damage curve has had to rely on several ad hoc assumptions. Pearce *et alii* (l994) provides a survey of these and the estimares are given in Table 6.

Summarizing the results. Table 6 summarizes the estimated social costs of carbon emitted to the atmosphere over time. The table includes estimares based on direct marginal cost studies (MC), studies that find the shadow price of carbon when balancing the costs and benefits of abatement (CBA), and studies based on the carbon tax needed to stabilize emissions (CT).

The variation in the estimates is to a large degree a consequence of different assumptions about the discount rate. In his base case using DICE**,** Nordhaus (l993*a,b*) finds that the shadow price of carbon begins at only $5 per ton in 1995, rises to $10 by 2025, and reaches $21 by 2095. Cline (l992) uses a lower discount rate of about 2% and finds that the DICE model generates a path of shadow prices beginning at $45 per ton in 1995, rising to $84 by 2025, and reaching $243 by 2105 [Pearce *et alii* (1994)].

The direct approach and the indirect approaches yield estimares approximately in the same ranges. The range is still wide, though. $5-10 for lower bound estimares and $6-145 for upper bound estimares in 1995. Central values of the current marginal cost of carbon emissions can be set at $5 for high discount rates (about 6%) and at $45 for low discount rates (about 2%).

Table 6
The social costs of CO2 emmissions

		Social costs in US4/ton carbon			
Study	Type[a]	1991 - 2000	2001 - 2010	2001 - 2020	2021 - 2030
CBO	CT	10 — 100	100	100	100
Cline (1992, 1993)	CBA	5 — 145	7 — 150	9 — 165	10 — 215
Fankhauser (1994a,b)	MC	6 — 45	7 — 53	8 — 58	9 — 64
Maddison (1994)	CBA/MC	6	8	11	15
Nordhaus (1991)	CT	15	50	80	105
Nordhaus (1993a,b)	CBA	5.3	6.8	8.6	10.0
Peck and Teisberg(1992)	CBA	10 — 12	12 — 14	14 — 18	18 — 22
Weyant (1993)	CT	19	31	51	82

[a]Note: MG = Marginal Social Cost study, CBA = shadow value in a cost-benefit study. CT = Carbon Tax needed to stabilize emissions.

Multiplying Brown and Pearce's median value of 150 tons of carbon/hectare with the low cost of $5/tC we get a "high discount rate" estimate of the value of carbon sequestration in tropical forests of $75O/hectare. The corresponding "low discount rate" estimate is $675O/hectare.

5.3.2 - Biodiversity

Biodiversity has both an aesthetic and a scientific benefit. The aesthetic benefit can be expressei in the marketplace in the form of "eco-tourism" and market forces will allocate land to accommodate this kind of demand for biodiversity [Schneider (l99l, p.5)]. The potential for "eco-tourism” in the Amazon is discussed in Section 5.3.3 below.

The scientific benefit of biodiversity arises from the provision of genetic material to be used for medical purposes or for genetic engineering of, for example, more pest resistant crops. The scientific benefit of biodiversity is allocated poorly in the market place. This is primarily because the owner of the land which provides the habitat within which genetic information will flourish will usually not benefit from its discovery and eventual application[31] [Schneider (1991, p.5)].

[31] At the 1992 UNCED conference in Rio, a treaty on bio-diversity was proposed, which addressed the issue of patent rights to medicine derived from tropical plants. The economic importance of such rights are highlighted by the fact that George Bush refused to sign the contract because "it would undermine the patent rights acquired at great cost by US companies" [Earth Summit (1992, p. 43)].

The scientific value of biodiversity contains both a direct use value component and an option value component. The direct use value includes the use of plant and animal species in the production of medicine. More than 5000 plant and animal species are used in traditional and modern medicine in China, 2000 in the Amazon Basin, 2500 in the former Soviet Union. In the United States, a quarter of all prescription drugs contain ingredients from plants, and over 3000 antibiotics are derived from n-úcroorganisms [Reid, Barber and Miller (1992)].

Direct use value of biodiversity. Pearce (l993, p. 87) notes that in the United States about 40 plant species accounted for plant-based prescription sales of some $l0-15 billion/year during the l980s (at 1990 prices). For the whole world he gives an estimated prescription value of about $50 billion. However, market prices understate the true willingness to pay for drugs. Since the demand for drugs tend to be very price inelastic, there could be a considerable consumer surplus element included in the total value of a drug. If we multiply the number of lives saved by these drugs by the value of a statistical life, we will get another estimate of the value of the 40 plant species. Pearce (l993, p. 86) uses an average of 126,000 lives saved per year and uses a value of a statistical life of $4 million.[32] This value is high compared to the value other researchers use [e.g. Cline (1992a)], so we will adopt a compromise value of $l million for a statistical life. This implies a value of those 40 plants of $l26 billion per year.

Assuming that these 40 species are among the most valuable of the several thousand species used for medical purposes, we set the total gross direct use value of medicinal plants that come exclusively from the Amazon to just ten times that value-$1260 billion/year. Costs of producing the medicine is assumed to be 50% of prescription values, *i.e.* about $250 billion. Subtracting these costs from the gross benefits we get a net direct use value of about $l,0l0 billion/year.

Island biograph — the branch of biology concerned with the relationship between species and land area, has found that when a habitat area is reduced by 90%, the number of species is roughly halved [Schneider (1992, p.16)]. This implies that the biodiversity value of the last 10% of the Amazonian rain forest is the same as the value of the first 90%. Halving the total direct use value of Amazonian species 21 times, we find that, at the 10% level of deforestation, additional clearing of 1.09% would imply a lost value of $4.2 million/year. This amounts to only $0.77/hectare/year, and implies a net present direct use value of biodiversity of about $40/hectare at the 2% discount rate, and $l3/hectare at the 6% rate. Notice that this value will increase dramatically with deforested area. Around 25% deforestation, the net present direct use values of biodiversity will have

[32] Life-valuation estimares differ widely. Estimates based on the statistical relationship between wages and risk place the value of a statistical life in the $2-6 million range. Contingent valuation studies that ask workers what wage differentials would be required for more dangerous work generate results in the $2-3 million range. Studies measuring actual hazard avoidance behaviour, on the other hand, place the value of a statistical life in a much lower range of $500,000-600,000 [Cline (l992*a*, p.117)].

increased to $4,800/hectare (with a 2% discount rate), and around 50% deforestation it will be approximately $265,000/ha.

Option value of biodiversity. Less than one percent of all tropical plant species have been screened for potentially useful medical properties [Repetto (1990)], so there is also a big option value component in biodiversity.

Again, we use the data on the 40 plant species from Pearce (l993). Using the same assumptions as in the previous section, the net value these 40 species amount to about $l00 billion/year, or $2.5 billion/year per successful species.

Some 60,000 species are expected to become extinct in the next 50 years[33] [Pearce (1993, p.85)]. If half of them come from the Amazon, which account for about half of the worlds remaining tropical rain forest area, then about 30,000 Amazonian species will be unavailable for medical research.

The probability that any given plant will produce a marketable prescription drug is estimated to be in the range 10^{-3} to 10^{-4} [Pearce (1993, p. 87)].[34] Taking the mean of 5. 10^{-4} implies that 6 successful drugs will be lost. This amounts to a value of $l5 billion/year, or $30/hectare/year given the 500 million hectares of Amazonian rain forest. The net present option value of biodiversity then becomes $l,500/ha for a discount rate of 2% and $500/ha for a discount rate of 6%.

5.3.3 - Recreational Value

World tourism is growing rapidly, now representing about l2% of the World Product and mobilizing close to 6.3% of total employment. Within this sector there is a shift towards ecological tourism, where the Amazon has great potential [Sudam (1992, p.36)].

Because of its characteristics, tourism is a very clean and environmentally friendly economic activity, provided that the intensity does not exceed the carrying capacity of the ecosystem. At present, Amazonia has an extremely modest tourist industry, with only half a million tourists visiting between 1984 and 1989 [Sudam (1992, p.37)]. Properly managed, this number could be multiplied many times without hurting the environment. It would at the same time be one of the most effective ways of earning foreign currency.

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[33] This value seenis conservative compared to UNEP (l996) who estimares that, at current rates of deforestation, 0.4-8 million species will disappear. They do not mention in which time period, however.

[34] This estimate is based on an assumption of independence between the value of different species. This is probably too simplistic. Polasky and Solow (l995, p. 303) notes that "if a species is discovered to be beneficial, then attention would tend to focus on close relatives, reflecting their greater conditional probability of succes." They develop a model for valuing a collection of species that allows for imperfect substitution and dependence between species.

Suppose the number of tourists visiting the Amazon would inerease to l million per year and each person would be willing to spend $l699 on the trip (plus foregone earnings),[35] then the total willingness to pay for experiencing the rain forest would amount to $l.6 billion/year or $3.2 per hectare per year. The net present recreational value would then be $53/ha with a discount rate of 6% and $l60/ha with a discount rate of 2%. Brazil would probably be able to appropriate about half of this value, so we will divide this value evenly between local direct use value in the form of revenues from tourism and global benefit in form of recreational value.

5.3.4 - Existence Value

People reveal a willingness to pay for the mere existence of environmental assets by contributing to wildlife and other environmental charities without taking direct use of the wildlife through recreation. Existence value is likely to be an important part of TEV in contexts where **a**) the asset is unique and **b**) many people are familiar with the attributes of the asset to be valued [Pearce (1993, p.21)].

The Amazon rain forest is certainly unique and many people know that it hosts an abundance of unique plant and animal species in its intricate and delicate ecosystems. They may therefore place quite a big existence value on the Amazon rain forest as a whole.

No contingent valuation study has yet been carried out for the Amazon rain forest. Based on studies for other endangered species and natural assets, Pearce (l99l) proposes a conservative figure of $8 per person per year for the 400 million richest people in the world. This would amount to $3.2 billion/year or on average $6.4 per hectare per year, given the approximately 500 million hectares of Amazon rain forest.

The existence value may not be as big for the first many hectares to be removed, though, since people are not familiar with the uniqueness of each single hectare of rain forest. 300 million hectares of undisturbed Amazon rain forest may yield almost the same existence value as 500 million hectares. We would therefore expect the existence value per hectare to be close to zero at relatively low levels of deforestation but be exponentially increasing with the level of deforestation. Pearce's estimate seem very modest, so we will adopt it as the marginal existence value at the current level of deforestation. This will imply a net present existence value of $l33/ha if the discount rate is 6% and $400/ha if the discount rate is 2%.

[35] For comparison: Kenya is currently visited by 250,000 adult safari-turists per year, and they leave about $800 per person in Kenya and spends about twice that amount on the whole trip [Pearce (1993, p. 82)].

6 - COST-BENEFIT ANALYSIS

Having collected estimates of the values of different land uses, it is now possible to do a cost-benefit analysis of deforestation. The cost-benefit analysis can be made at three levels: **a**) At the level of the world social planner, who seeks to maximize global utility of the land uses in the Amazon; **b**) At the level of the federal government of Brazil, which is expeeted to seek to maximize the discounted value of the benefits that Brazil can derive from the Amazon forest; and **c**) At the level of the Amazonian farmer, who decides how to use his land.

The difference in outcomes between the three analyses is very big, both because of externalities, because of credit rationing, and because of differences in time-horizon.

6.1 - The Farmer

Let's first consider a typical first generation settler, who has ventured to the Amazonian frontier in hope of finding better economic opportunities than was available at his place of origin. First generation settlers will typically be relatively disadvantaged in terms of human and physical capital and have very restricted access to credit.[36] To overcome the barrier to migration, the government has offered the settler a 100 hectare plot of land for free and a small start-up package to tide the family over the first difficult months.

The settler faces two restrictions when deciding how to use his plot of land. He and his family can only provide a limited amount of labor, and credit is only available at exorbitant rates from local money lenders. If he chooses to rely on extractivism, he can exploit l00% of his area, but earn only $3/hectare/year.[37] No initial investment is required. If he chooses slash-and-burn agriculture, he can only exploit 50% of his plot with the family labor available, and the start-up costs are $29l/hectare.[38] After one year he gets a profit of $l079/hectare. If he chooses intensive perennial cropping, he can only exploit 5% of his plot,[39] and the start up costs are $2,695/hectare. Yields do not start showing up before the third year, then at a rate of about $802/hectare/year. Ranching and logging options are ruled out by the limited credit access.

[36] As Schneider (l995, p. vii) points out: "People with low physical and human capital, and little opportunity to do well elsewhere, are most likely to endure the deprivation and health risks associated with opening new lands at the frontier. People with somewhat higher opportunity costs are likely to wait until the frontier is better established before they take the risk."

[37] See Section 5.1.2.

[38] Slash-and-burn agriculture employs about 6.3 persons per 100 hectare plot. Assuming a family size of about 3 full time workers, the family can therefore only cultivate half of the 100 hectare plot each year. See Table 3.

[39] Perennial cropping is about 10 times more labour intensive than annual cropping. See Table 3.

Given these options, the settler barely needs to be able to count to be able to figure out that slash-and-burn agriculture is the only viable option. Not only is annual cropping the safest, since it at least provides basic food for the family. It is also the most profitable when land is very cheap and the time horizon limited. The settler reaps a first year return of 270%, and he can do the same with the second half of his plot the following year. Returns will be lower the third year because the nutrient level in the soil will be substantially lower. But he can probably make a positive profit for another four to six years.[40] By that time the frontier area is more developed and second generation settlers with better capital access will probably be interested in buying his land for cattle ranching purposes or for perennial crops cultivation. Perennial crops become increasingly attractive as land becomes scarcer relative to labor. It is particularly attractive if you are not restricted to your own family's labor, but can hire additional labor at cheap rates.

6.2 - The Federal Government

From the point of view of the Brazilian government, the best development option seems to be to continue the conversion of forest and to stimulate perennial crops cultivation. Table 7 shows that the net present value of agricultural land (when used optimally) is higher than all the sustainable benefits it could derive from an intact forest.

To reach the desired outcome of intensively cultivated agricultural land in large parts of the Amazon, the government has had to accept less than optimal land uses in a transitional period. Slash-and-burn agriculture, although unsustainable, has been sufficiently profitable to attract people with low opportunity costs to the frontier. These people have cleared the way and helped construct the necessary infrastructure for more sustainable land use practises such as perennial cropping. Logging and mining companies have provided a similar service. The big revenues that can be derived from unsustainable logging and mining allowed extra investment in infrastructure, which in turn helped speed up agricultural settlement. Only large scale cattle ranching seems to have been an un-necessary and expensive stage.

6.3 - The Global Social Planner

At the current level of deforestation, the potential value of agricultural land exceeds the estimated value of a standing forest. However, as the agricultural land in the Amazon is currently used, a very large part of this potential value is wasted. Enormous forest areas have been bumed without extracting any timber and turned into pasture of virtually no value just for tax and land speculation purposes. Deforestation can be justified, but only if the land is being used sensibly.

[40] Schneider (l995, Table 2.l) report yield decay rates for unsustainable agricultural activities in the range of 22-50% for various studies in Latin America.

Table 7
Cost-benefit analysis from Brazil's viewpoint

	NPV/hectare (1990-US4/hectare)	
Discount rate	2%	6%
Costs of deforestation	9,230	3,059
Foregone sustainable timber	5,200	1,733
Foregone forest products	500	167
Foregone tourism	80	26
Reduced water recycling	3,000	1,000
Reduced fire protection	300	83
Reduced watershed protection	150	50
Benefits of deforestation	121,900	60,255
NPV of optimal land use sequence	24,380	12,051
Spill-over effects to urban sector	97,520	48,204

Source: Author's estimates.

This will not continue for long, however. The costs of deforestation are likely to rise as the forested area shrinks, and the per hectare value of a standing rain forest will therefore increase. This is true for almost all accounts on the balance sheet. The value of timber will increase as the worlds supply of tropical hardwood becomes more and more scarce. The same holds for the unique non-timber forest products that can be extracted from these forests. Tourists will be willing to pay increasing amounts of money to visit the worlds last piece of virgin rain forest, and the recreational value per hectare will increase even more as the total area shrinks. The local and regional ecological consequences of deforestation are also likely to be more severe at high levels of deforestation. Droughts and fires will be more expensive as the forest becomes more valuable.

The biggest item on the balance sheet is the value of carbon sequestration. The cost of releasing carbon to the atmosphere is driven up mostly by the use of fossil fuel, and this use is likely to continue upwards as developing countries industrialize and motorize.

The direct use value of biodiversity was shown to increase dramatically with deforested area, because the genetic information becomes more and more concentrated in the remaining forest. Biodiversity is also likely to become more valuable as we get better at exploiting the genetic information. Since the existence value of the Amazonian rain forest as a whole is roughly constant or maybe increasing, the existence value per hectare will increase with the level of deforestation.

Finally, the value put on environmental quality tends to increase as economies develop and people become richer. This will further increase the costs of deforestation over time.

Thus, at some not very distant point, the total economic value of a standing rain forest will come to exceed the total economic value of agricultural land. At that time it will be necessary for the global planner to step in and provide incentives for Brazil to preserve the remainder of the forest. If the global planner does not step in, Brazil will continue the development of the Amazon until it is privately profitable to preserve the forest. And at that time the Brazilian rain forest will be a good deal smaller (see Figure 1).

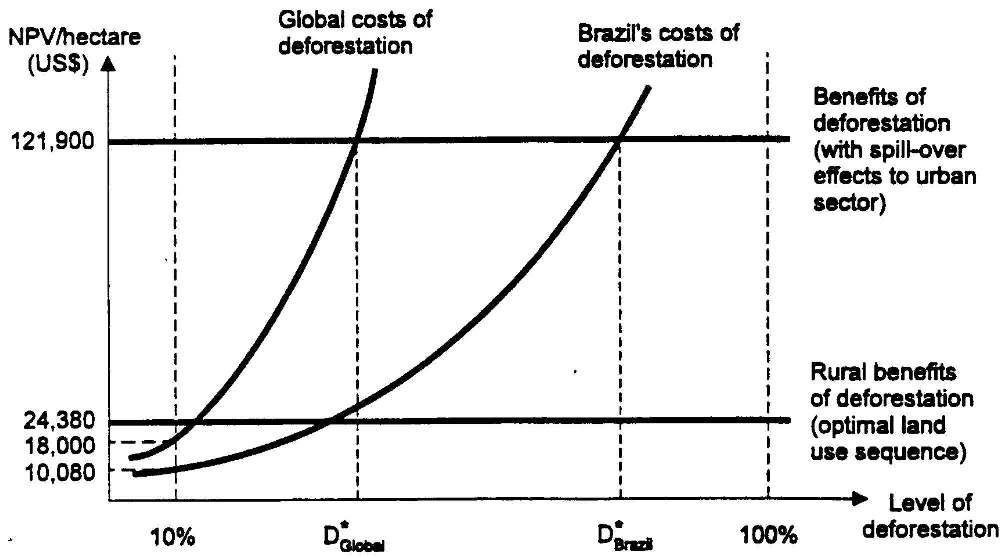

Figure 1: Costs and benefits of deforestation (2% discount rate)

6.4 - Reaching the Optimum

Government policies have been successful in the first stage of attracting farmers and entrepreneurs to the Amazon region. But the current land use pattern is far from the optimal. The question now is how to promote the intensification of land use?

The factor most directly affecting the intensity of land use is the price of land. The higher the land price (relative to labor) the more intensive the land use.

The government has several policy measures available that affect land prices. Road building is one of them. Improvement of the road network in already settled areas will reduce transportation costs and thus increase farm profitability. This will put an upward pressure on land prices. New road building through virgin areas, on the other hand, will increase the supply of cheap land and therefore put a downward pressure on currently accessible land.[41]

Land ownership policies and enforcement of property rights are other important instruments. Until recently, land titles were granted in proportion to the amount of land cleared. This policy of course promoted artificially extensive land uses. This could be corrected, and is being corrected. A lack of enforcement of property rights further promotes extensive land use, since land being kept as virgin forest is subject to encroachment by squatters who perceive the land as unoecupied.

One of the big barriers to intensification, is the start-up capital needed and the three or more years it takes before returns start to arrive. Access to credit on reasonable terms would therefore promote intensification. Lower interest rates will make perennial cropping relatively more attractive because it is sustainable over a longer period.

The provision of health, educational, cultural, and recreational services in settlement areas will further increase the attractiveness of settlement and push up land prices.

Another important policy question is how to secure maximum spill-over effects to the urban sector with minimum deforestation costs.

[41] Andersen and Reis (l996) estimate the effect of new road building on land prices in a multiple equation spatial model. About 34,250 kilometers of new roads were planned for construction in Legal Amazonia during the period 1985/2010. Land prices is predicted to be 45% higher in 2010 if the road building program is abandonei, compared to the scenario where roads are completei on schedule.

7 - CONCLUSIONS

This paper has attempted to collect the best available evidence on the total economic value of standing Amazonian rain forest. Estimates were calculated for both a low discount rate of 2% and a higher discount rate of 6%. The low discount rate is most compatible with the rate a global social planner would adopt. At this rate the total economic value of a standing rain forest is estimated at roughly $l8,000/hectare (in 1990 US$).

The value of a standing forest was compared with estimares of the net present value of different agricultural land uses. It was shown that a sequence of land uses provides the optimal development strategy. Loggers should first be allowed to extract the commercially valuable timber from the virgin forest. Then smallscale farmers should be granted property rights and be allowed to use the land as they find optimal. This is likely to be unsustainable slash-and-burn cultivation of annual crops initially, but as the area develops and population densities and land prices increase, there will be a natural intensification in the use of land and the area will eventually be covered with sustainable perennial crops. This sequence of land uses yields an estimated net present agricultural value of roughly $24,000/hectare. With spill-over effects to the urban sector the total net present value of agricultural land increases to about $l20,000/hectare.

The potential benefits of deforestation thus seem to exceed the costs at the current level of deforestation. However, these two estimares of the costs and the benefits of deforestation only represent one point on the cost curve and one point on the benefit curve, namely the points associated with approximately 10% deforestation. As the level of deforestation increases, the global costs of deforestation will rise, and it will eventually pass the value of agricultural land. At that point, the international comunity has to provide incentives to induce Brazil to preserve the remainder of the forest. The external benefits of a standing rain forest amounts to roughly $9,000/hectare at the current level of deforestation. At the optimal level it will be much higher. Thus, international transfers in excess of $9,000/hectare will be needed to secure that deforestation in the world largest remaining rain forest will not exceed the globally optimal level.

BIBLIOGRAPHY

ALMEIDA, 0. T. de, UHL, C. Developing a quantitative framework for sustainable resource-use planning in the Brazilian Amazon. **World Development**, v.23**,** p.1.745-1.764, 1995.

ANDERSEN, L. E., REIS, E. J. **Prediction and evaluation of Amazon deforestation**. Rio de Janeiro, IPEA/DIPES, 1996 (Texto para Discussão).

ANDERSEN, L. E. **et alii**. **Report on Amazon deforestation**. San Diego, Department of Economics/University of California, 1996 (Discussion Paper).

ANDERSON, A. B., MAY, P. H., BALICK, M. J. **The subsidy from nature: palm forests, peasantry, and development on an Amazonian frontier**. New York, Columbia University Press, 1991.

BARBIER, E. B., MARKANDYA, A. The economics of tropical deforestation. **Ambio**, v.21**,** p.122, 1991.

BROWN, K., PEARCE, D.W. The economic value of carbon storage in tropical forests. In: WEISS (ed.). **The economics of project appraisal and the environment,** 1994.

BUNDESTAG, G. (ed.). **Protecting the tropical forests: a high priority international task**. Bonn, Bonner Universitats-Buchdruckerei, 1990.

CBO. **Carbon charges as a response to global warming: the effects of taxing fossil fuels.** Congressional Budget Office, Congress of the United States, 1990.

CLINE, W. R. **The economics of global warming**. Washington, D. C., Institute for International Economics, 1992**a**.

----------. **Optimal carbon emissions over time: experiments with the Nordhaus Dice model**. Washington, D. C., Institute for International Economics, 1992**b**, mimeo.

----------. **Modelling economically efficient abatement of greenhouse gases, technical report**. Tokyo, Sept. 1993. Paper presented at the United Nations University Conference on "Global Environment, Energy and Economic Development".

EKINS, P. The secondary benefits of CO_2 abatement: how much emissions reduction do they justify? **Ecological Economics**, v.16, p.13-24, 1996.

EMANUEL, K. A. The dependence of hurricane intensity on climate. **Nature**, v. 326**,** p.483-485, 1987.

ERL. **Assessing the cost effectiveness of selected options to reduce CO_2 emissions in developing countries**. Report prepared for the overseas development administration, Environmental Resources Limited, 1990.

FANKHAUSER, S. The social costs of greenhouse gas emissions: an expected value approach. **Energy Journal**, 1994**a**.

----------. **Valuing climate change: the economics of the greenhouse effect**. London, Earthscan, 1994**b**.

FEARNSIDE, P. M. Forest biomass in Brazilian Amazonia: comments on the estimate by Brown and Lugo. **Interciencia**, 1992.

----------. Potential impacts of climatic change on natural forests and forestry in Brazilian Amazonia. **Forest Ecology and Management,** v.78**,** p.51-70, 1995.

FELLNER, W. Operational utility: the theoretical background and a measurement. In: FELLNER, W. (ed.). **Ten economic studies in the tradition of irving fisher**. New York, John Wiley & Sons, 1967.

GASKINS, D., WEYANT, J. P. Model comparisons of the costs of reducing CO_2 emissions. **American Economic Review, Papers and Proceedings,** v. 83, p. 318-330, 1993**a**.

----------. **Reducing global carbon emissions: costs and policy options**. Stanford, California, 1993**b**. A report on the work of Energy Modeling Forum study number 12.

HECHT, S. B. Environment, development and politics: capital accumulation and the livestock sector in Eastern Amazônia. **World Development**, v.13. p. 663-684, 1986.

HECHT, S. B.**,** NORGARD, R., POSSIO, G. The economics of cattle ranching in Eastern Amazonia. **Interciencia**, v. 13**,** p. 233-240, 1988.

HOELLER, P., COPPEL, J. Energy taxation and price distortions in fossil fuel markets: some implications for climate change policy. In: OECD (ed.). **Climate change: designing a practical tax system**. Paris, OECD**,** p. 185-212, 1992.

HOUGHTON, R. **et alii**. **The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flux tellus 39b**. 1987 (Technical report, 122-139).

IBGE. **Anuário estatístico do Brasil**. Rio de Janeiro, 1994.

IPCC-Intergovernmental Panel on Climate Change. **First Assessment Report, v.I: Overview and Summaries**. New York: World Meterological Organization and United Nations Environmental Programme, Aug. 1990**a**.

----------. **Scientific assessment of climate change: report prepared for IPCC by Working Group I**. New York, World Meterological Organization and United Nations Environmental Programme, June, 1990**b**.

JOHANSSEN, P. Valuing environmental damage. **Oxford Review on Economic Policy**, 1990.

JORDAN, C., HEUNELDOP, J. The water budget of an Amazonian rain forest. **Acta Amazonica**, v.11, p.87-92, 1981.

LEOPOLDO, P. **et alii.** Estimativa da evapotranspiração de floresta Amazônica de terra firme. **Acta Amazonica**, v.12**,** p.23-28, 1982.

LETTAU, H., LETTAU, K., MOLION, L. Amazonia's hydrological cycle and the role of atmosphere recycling in assessing deforestation effects. **Monthly Weather Review**, v.107, p.227-238, 1979.

MADDISON, D. **The shadow price of greenhouse gases and aerosols**. Norwich, Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University of East Anglia, 1994, mimeo.

MARQUES, J., SALATI, E., SANTOS, J. Cálculo de evapotranspiração real na bacia Amazônica através do metodo aerológico. **Acta Amazonica**, v. 10, p.357-361, 1980.

MATTOS, M., UHL, C. Economic and ecological perspectives on ranching in Eastern Amazon. **World Development**, v.22, p.145-158, 1994.

McGINNIS, M. V. On the verge of collapse: the Columbia river system, wild salmon and the Northwest power planning council. **Natural Resources Journal**, v.35**,** p.63-92, 1995.

McKINSEY & COMPANY. **Protecting the global environment: funding mechanisms**. Noordwijk, Ministerial Conference on Atmospheric Pollution and Climate Change, 1989 (Technical report).

MOTTA, R.D., MAY, P. **Loss in forest resource values due to agricultural land cover conversion in Brazil**. Rio de Janeiro, IPEA, 1992 (Texto para Discussão, 248).

NORDHAUS, W. D. **A survey of estimates of the cost of reduction of greenhouse gases**. 1990, mimeo, draft.

----------. A survey of estimates of the costs of controlling greenhouse gases. **The Energy Journal**, v.12, p.37-66, 1991.

----------. Optimal greenhouse gas reductions and tax policy in the "DICE" model. **American Economic Review, Papers and Proceedings**, v.83, p.313-317, 1993**a**.

----------. Rolling the "DICE": an optimal transition path for controlling greenhouse gases. **Resource and Energy Economics**, v.15, p.27-50, 1993**b**.

----------. **Managing the global commons: the economics of climate change**. Cambridge, MA, MIT Press, 1994.

PEARCE, D. Deforesting the Amazon: toward an economic solution. **Ecodecision**, v.1, p.40-49, 1991.

PEARCE, D. **et alii**. **Greenhouse damage and the benefits of control.** 1994, preliminary draft.

PEARCE, D. W. **Economic values and the natural world**. Cambridge, Massachusetts, The MIT Press, 1993.

PECK, S., TEISBERG, T. J. CETA: a model for carbon emmissions trajectory assessment. **Energy Journal**, v.13, p.55-77, 1992.

PETERS, C., GENTRY, A., MENDELSOHN, R. Valuation of an Amazonian rainforest. **Nature**, v.339, p.655-656, 1989.

PINEDO-VASQUEZ, M., ZARIN, D., JIPP, P. Economic returns from forest conversion in the Peruvian Amazon. **Ecological Economics**, v.6, p.163-173, 1992.

POLASKY, S., SOLOW, A. R. On the value of a collection of species. **Journal of Environmental Economics and Management**, v.29**,** p.298-303, 1995.

POTERBA, J. M. Global warming policy: a public finance perspective. **Journal of Economic Perspectives**, v.7, p.47-63, 1993.

REID, W., BARBER, C., MILLER, K. **Global biodiversity strategy: a policy-maker's guide**. Washington, World Resources Institute, 1992.

REPETTO, R. Deforestation in the tropics. **Scientific American**, v. 262, p.36-42, 1990.

ROSENBERG, N. J. **et alii**. **Policy options for adaptation to climate change**. Washington, Resources for the Future, 1989 (Discussion Paper, 89-05).

SCHNEIDER, R. R. **An analysis of environmental problems and policies in the Amazon.** The World Bank, 1991. Paper presented at a ACT seminar in Caracas.

----------. **An economic analysis of environmental problems in the Amazon.** The World Bank, 1992, draft.

---------. **The potential for trade with the Amazon in greenhouse gas reduction.** Laten Dissemination Note II from The World Bank, 1993.

----------. **Government and the economy on the Amazon frontier**. The World Bank, 1995 (World Bank Environment Paper, ll).

SCOTT, M. **A new view of economic growth.** Oxford, Clarendon Press, 1989.

SHAH, A., LARSON, B. **Carbon taxes, the greenhouse effect and developing countries**. United Nations, 1992 (World Development Report 1992).

SOMBROEK, W. Biomass and carbon storage in the Amazon ecosystems. **Interciencia**, 1992.

SUDAM. **Sustainable development of the Amazon: development strategy and investment alternatives**. Rio de Janeiro, June 1992.

TITUS, J. The cost of climate change to the United States. In: MUJAMDAR, L. **et alii** (eds.). **Global climate change: implications, challenges and mitigation measures**. Pennsylvania: Pennsylvania Academy of Sciences, 1992.

TONIOLO, A., UHL, C. Economic and ecological perspectives on agriculture in Eastern Amazon. **World Development**, v. 23, p.959, 1995.

UHL, C., BEZERRA, 0., MARTINI, A. An ecosystem perspective on threats to biodiversity in Eastern Amazonia. In: POTTER, C. S., COHEN, J. I., JANCZEWSKI, D. (eds.). **Perspectives on biodiversity: case studies of genetic resource conservation and development**. AAAS Press, 1993.

UHL, C. **et alii**. The role of research in natural resource management: the case of logging in the Brazilian Amazon. **Bioscience**, 1996.

UNCED. **Earth summit 1992**. London, The Regency Press, 1992.

UNEP. **An explanatory leaflet about the Convention on Biological Diversity**. United Nations Environment Program, 1996.

VERÍSSIMO, A. **et alii**. Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: the case of Paragominas. **Forest Ecology and Management**, v.55, p.169-199, 1992.

VILLA NOVA, N., SALATI, E., MATSUI, E. Estimativa da evapotranspiração na bacia Amazônica. **Acta Amazonica**, v.6, p.215-228, 1976.

WEITZMAN, M. L. On the "environmental" discount rate. **Journal of Environmental Economics and Management**, v.26, p.200-209, 1994.

WEYANT, J. P. Costs of reducing global carbon emissions. **Journal of Economic Perspectives**, v.7, p.27-46, 1993.