ENVIRONMENTAL SERVICES AS A STRATEGY FOR SUSTAINABLE DEVELOPMENT IN RURAL AMAZONIA

Philip M. Fearnside
National Institute for Research
in the Amazon (INPA)
C.P. 478
69011-970 Manaus, Amazonas
BRAZIL
Fax: 55 - 92 - 236-3822
Tel: 55 (92) 643-1822
Email: PMFEARN@INPA.GOV.BR

12 March 1998
14 March 1998
22 Jan. 2000

Abstract

ENVIRONMENTAL SERVICES AS A STRATEGY FOR SUSTAINABLE DEVELOPMENT IN RURAL AMAZONIA

Rural Amazonians, especially Indians, extractivists and other forest dwellers, desperately need something that they can sell. Sale of material commodities taken from the rainforest is the focus of most attempts to encourage 'sustainable development' for these populations, but the mother lode waiting to be tapped is not a material commodity, but rather the forest's environmental services. Converting services like biodiversity maintenance, carbon storage and water cycling into monetary flows that can support a population of forest guardians requires crossing a series of hurdles. Reliable quantification of the magnitude of services being offered is a first necessity. How to convert forest environmental services into an income stream, and how to convert this stream into a foundation for sustainable development in rural Amazonia is a great challenge. Effort should be focused on tapping environmental services as a long-term strategy for maintaining both rainforest and its population. In addition to progressing toward long-term goals, immediate measures are needed to support the population and to avoid further loss of forest.

1. Introduction

1.1. Sustainable development

What is 'sustainable development?' 'Development' refers to a change, implying an improvement, in the way that people support themselves. Although the term is frequently misused as synonymous with 'growth,' it does not necessarily imply an increase in the throughput of matter and energy in an economy (Goodland and Ledec, 1987). Indeed, if continual increase in either flows or stocks were a requirement, then 'sustainable development' would be a contradiction in terms. Since 'limits to growth' constrain the use of both renewable and non-renewable resources, strategies for sustainable development must, in the long run, concentrate on reorganization of how resources are used and how benefits are shared.

Much discourse on sustainable development has implied that this can be achieved with unending growth, adding only the caveat that environmental quality standards will somehow be respected (see review by Willers, 1994). Sustainable development is seen as a means of not admitting to the existence of limits. Recognizing limits is resisted by the rich as a potential cap on their profit making, while the poor and those who work on their behalf often have an ideological aversion to recognizing limits for fear that doing so condemns the poor to poverty. Unfortunately, limits to what can be removed and sold from Amazonia or any other region exist, independent of what people may think about the matter. 'Continual' growth is not an option; the option that is often confused with this is merely a postponement of restraining the offtake of products to within the bounds that limit their sustainable production. What must be answered is the question of how and when 'growth' will cease, and what kind of society one wants to have when this transition has passed. Rather than condemning the poor to poverty, recognizing the existence of limits condemns the rich to facing up to dividing the pie (see Fearnside, 1993a).

'Development' implies creation of an economic basis for support of a population. It is essential to define clearly what population is to be benefited. I have long argued that, in the case of Brazilian Amazonia, this should be limited to the present population of the region and their descendants. From the perspective of the local population, a cattle ranch for an absentee landlord is not development. Neither, for example, are the aluminum smelters in Barcarena, Pará, and São Luís, Maranhão, that export (mostly to Japan) two-thirds of the power from Tucuruí Dam, in the form of aluminum ingots. Most of the output of the US$ 8 billion dam goes to support an industry that employs less than 2000 people (Fearnside, 1989a).

In order to be 'sustainable,' the basis of support must be maintained for a long time. Ideally this would be forever, but in practice it must be defined in terms of a finite time horizon, for example, a period on the order of hundreds of years. It must also be recognized that nothing is certain--the probability is always less than one that the activity will last for the specified time period. One must define the maximum acceptable probability of failing to last this period. The choice of a value for the probability criterion depends on the magnitude of impacts in the event of a failure and a social decision regarding the relationship between magnitude of impacts and acceptable risk (see Fearnside, 1997a).

1.2. Elements of a strategy

One must decide on a strategy for attaining sustainable development, that is, a broad indication of the direction of activities, rather than a specific recipe for sustainability. The approach to be taken must be based on what is most likely to yield the long-term result that defines sustainable development. Cattle pasture, the dominant system at present, is unlikely to prove sustainable over the long run (Fearnside, 1997a). Soybeans, the crop currently favored by government agencies for a future support base, also has a high probability of proving unsustainable, no matter how correctly specified the technical formula of fertilizers, pesticides, etc., may be. Some future change, such as a disease, pest, or change in price, is likely to intervene. Once the forest has been thrown away to plant such a crop, there is no return to the security offered by the original diversity. As a general rule it is better to make something sustainable into development than to try to make an unsustainable form of development sustainable. Rather than try to extend the life of cattle pastures by means of fertilizers and changes in pasture grass species, it is better to start with tropical forest, which has proved itself sustainable by thousands of years of existence, and find ways to market the services that rainforest provides.

Sustainable use is most likely if the country maintains control over what is sold. Brazil must sell what it wants to sell rather than what the world wants to buy. The world may want to buy jaguar skins, pig iron and mahogany, but, as with jaguar skins, Brazil can decide that these are not what the country wants to sell. The fact that a country has a given resource in no way implies that the country in question is under some sort of moral obligation to supply it to the world. The situation is analogous to prostitution: everyone, no matter how physically endowed, has at least some potential to supply the market's demand for prostitutes--but most people decide not to sell this particular service. In the same way, a country may have tropical hardwoods and decide, without any qualms, not to sell them. What Brazil would be wiser to sell are the environmental services of its forests.

1.3. Long-term versus short-term objectives

While it is all well and good to pursue a long-term strategy of tapping the value of environmental services as the foundation of sustainable development in rural Amazonia, under the best of assumptions this can only be expected to bring results years in the future. What are rural Amazonians to do in the meantime? One is reminded of the famous remark by Harry Hopkins to U.S. President Franklin D. Roosevelt: "People do not eat, in the long run, nor, on the average; they eat every day."

Attention must be paid to both short-term and long-term concerns. If concern is only with the long term, people will starve in the meantime. The temptation is therefore strong for all effort to be devoted to dealing with the day-to-day crises of survival. However, if thought is given only to these immediate demands, then long-term sustainability will never be achieved.

A variety of mechanisms for short- and medium-term support have been suggested, such as use of non-timber forest products (NTFPs), ecotourism, etc. Whatever short-term solutions are adopted, it is essential that the options chosen not destroy the resource base of the long-term strategy (the forest), nor the credibility of local groups. Amerindians have the best record of maintaining forest, and in certain regions the only forest left is that on indigenous lands. However, sale of timber by tribes is increasing as leaders succumb to the temptations that money offers (Fearnside, 1997b). The loss from selling resources such as logs is much more than the value the tribes can receive from the sales, even if they were not subject to unfavorable terms and outright cheating on the part of timber merchants. In addition to losing trees and damaging forest, they also lose part of their most valuable future resource: credibility for maintaining environmental services.

2. Criteria for sustainability

2.1. Biological sustainability

In order to be sustainable, any form of forest use or other land use must meet certain criteria. One class of such criteria relates to biological sustainability, or the long-term maintenance of biological processes that keep the ecosystem in a stable state that is unlikely to collapse in the face of foreseeable stresses. Population biology is one area in which a balance must be achieved: if trees or other ecosystem components are harvested at rates greater than regenerative processes of the population can replenish, then the forest will inevitably become depleted. Nutrient balance must also be maintained, as a drain of nutrients greater than what is input and captured by the system will lead to impoverishment and inability of living components of the ecosystem to survive. The system must have a stable biomass, as any tendency to decline will eventually degrade the forest and its environmental function as a carbon store. Genetic quality of the populations of trees or other taxa must be maintained, as degradation, for example, by repeated harvesting of individuals with the best form, will eventually worsen the quality of the remaining population even if the numbers of individuals and species represented remain the same. Keeping forest intact requires a low probability of fire, this being one way that forests can quickly be decimated, even if they are not deliberately felled. Finally, provision of an adequate number, diversity and area of fully protected reserves must be included as part of any strategy for making economic use of the forest.

2.2. Social sustainability

If a system implies a social injustice that represents the seeds of its own destruction, then it will be unsustainable on social grounds. For example, the charcoal industry for manufacture of pig iron in the Grande Carajás area of eastern Amazonia is based on a form of debt slavery that must sooner or later come to an end, even if the system were technically sound. Brazil's charcoal industry has provoked national and international scandal following charges brought before the International Labor Organization in 1994 (Pachauski, 1994; Ribeiro, 1994; Sutton, 1994; Pamplona and Rodrigues, 1995).

3. Environmental services as sustainable development

3.1. Types of environmental service

3.1.1. Biodiversity

Maintenance of biological diversity constitutes an environmental service for which beneficiaries around the world might be willing to pay. Biodiversity maintenance has some direct local benefits, such as providing non-timber forest products (Fearnside, 1989b; Grimes et al., 1994; Hecht, 1992; Peters et al., 1989; Pimentel et al., 1997a; Richards, 1993; Vásquez and Gentry, 1989; Whitehead and Godoy, 1991). Local benefits also accrue from the stock of genetic material of plants and animals needed to give a degree of adaptability to forest management and to agricultural systems that sacrifice biodiversity in nearby unprotected areas (Myers, 1989). However, many benefits of biodiversity are global rather than local. The stock of useful chemical compounds, and of genetic materials for other than local use, represents an investment in protecting future generations in distant places from the consequences of lacking that material when it is needed one day. This value is different from the commercial value of products that may be marketed in the future (which would represent a lost local opportunity should biodiversity be destroyed). A medicinal use, such as a cure for some dreaded disease, is worth more to humanity than money that can be earned from selling the drug. An estimate of the opportunity cost for medicinal uses for rainforests in Mexico arrived at a figure of US$ 6.4/ha/year, with a range from US$ 1 to US$ 90 (Adger et al., 1995). Substantial potential exists for identifying chemical models for pharmacological products based on Amazonian plants (Cordell, 1995; Elisabetsky and Shanley, 1994; Kaplan and Gottlieb, 1990). It is important to realize, however, that the financial value of pharmaceutical products, although clearly important, is not sufficiently large to support conservation on the scale sometimes envisioned. Existence value is also something that accrues mostly to populations who are either very close to the forest, such as indigenous peoples, or who are far removed from it, such as urban dwellers elsewhere. Whether or not one believes that biodiversity is worth spending money to protect, it is sufficient to know that many people in the world do believe it is important, and that it therefore can be converted into a source of income to support the population and protect the forest in Amazonia.

Negotiating for protection of biodiversity is especially complicated because it represents a balance between two opposing lines of argument, both of which are inadmissible. On the side of countries with biodiversity, there is the implied threat of blackmail: either 'developed' countries pay whatever is demanded or forests will be cut and the species they contain sacrificed. On the other side, there is the implication that countries with biodiversity should be protecting their natural heritage anyway, so any payments from outside are strictly optional.

One difficult point is the question of national sovereignty. It is often said that by agreeing to set aside reserves and abstain from 'development' in these areas, countries like Brazil are giving away their national sovereignty. However, there is no difference between the sovereignty effects of entering into an agreement on reserves and biodiversity and the effects of entering into any other sort of commercial contract. If a country contracts to sell anything, including both traditional commodities and environmental services, it is in effect exchanging the assurance of a monetary flow for the option to do whatever it wants with part of its land. For example, when Brazil agrees to sell a certain quantity of soybeans in a future year at a given price, it is giving up the option to plant some other crop in a given part of its territory. Nor is the permanence of protected areas a significant difference from most commercial contracts, which are usually temporary: the changes from a commercial contract may be just as permanent as those brought about by a contract for permanent maintenance of an area of natural habitat. For example, if forest is cut or inundated as part of a development project, it cannot be brought back should the country later change its mind.

The value of biodiversity is poorly quantified, and severe methodological constraints limit our ability to assign meaningful monetary values to it (Norton, 1988; Stirling, 1993). While one knows that its monetary value is very high (Costanza et al., 1997; Pimentel et al., 1997b), the willingness of the world at large to pay is the limiting factor on how much of this value can be translated into a monetary flow. That willingness to pay has, in general, been increasing, and it may be hoped that it increase substantially in the future.

One problem is that what individuals and governments are willing to spend on biodiversity is constrained by other priorities these money sources have. The total allotted to biodiversity, even though it may increase both proportionally and in absolute terms, is, in effect, a pie over which potential beneficiaries compete. It is a zero-sum game: what is spent on saving the rhinoceros is not spent on slowing Amazonian deforestation, and vice versa. It is rare when true 'new and additional funds' are provided, as demanded by Agenda 21--the 800-page internationally negotiated document that provides for implementation of conventions signed at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992.

Biodiversity assessment and monitoring, although plagued by difficulties, can be approached quantitatively in a hierarchical manner (Noss, 1990). Monitoring protocols must capture the three primary attributes of ecosystems: composition, structure and function. The monitoring must be done over a range of levels of organization and at different temporal and spatial scales.

Among the difficulties in assessing biodiversity protection value is the question of how time preference should be treated. Discounting may be applied, similar to the discounting of monetary values routinely done by bankers in financial calculations. However, biodiversity has a unique characteristic that makes it different from money and other environmental services, such as maintaining carbon stocks. Biodiversity is not substitutable or interchangeable. Once a species or an ecosystem becomes extinct, there is no going back. This fact provides an argument against discounting in the case of biodiversity.

The criterion for achievement in biodiversity protection, however, must include some kind of reward for long-term maintenance. Should weight be given for the number of species-years of survival achieved as compared to a 'business-as-usual' reference scenario, or should one make a count of the biodiversity present at some future time, say 100 years from now, and compare this to the biodiversity that would be present in the reference scenario? If any kind of discounting were applied, this would give advantage to places like Rondônia, where the threat of extinction is more imminent, as compared to relatively untouched areas in the interior of the state of Amazonas. Countries like Costa Rica, where the last remnants of rainforest are under threat of destruction, also have an advantage. It is true that, from the point of view of biodiversity, a hectare of forest loss in Costa Rica implies a much greater loss of species than does a hectare in many parts of Brazilian Amazonia, where extensive rainforest is still standing.

How much might the world be willing to pay for maintenance of biodiversity in Amazonia? Considerable research effort would be needed to answer such a question with reliable numbers, and this has yet to be done. As a starting point for discussion, however, one may take the value of US$ 20/ha/year suggested by Cartwright (1985, p. 185) as what would be needed to convince tropical countries to enter into agreements for biodiversity maintenance. Cartwright believes such a value is feasible. Table 1 presents data on deforestation and on the population of the Legal Amazon used in subsequent calculations for the values of biodiversity, carbon and water cycling. This makes it possible to explore the implications of these values for supporting the human population, considering the value of the standing stock of forest, the annual environmental damage at the 1990 deforestation rate, and the part of this damaged caused by the small farmer population. Small farmers are defined in Brazilian Amazonia by the Brazilian Institute of Geography and Statistics (IBGE) as those having less than 100 ha of land. The distribution of deforestation among states with varying degrees of land tenure concentration indicates that 30.5% of clearing is done by small farmers, with the remainder done by either medium or large ranchers (Fearnside, 1993b).

[Table 1 here]

Because most deforestation is done by the rich, distribution of benefits derived from a government decision to halt further clearing would lend itself well to a 'Robin Hood solution': a means of taking from the rich to give to the poor. No qualms need be felt about removing the profitability of land speculation for ranchland without compensating the large landholders (Fearnside 1989c,d). The value of halting damages caused by the rich provides a potential key for solving social and environmental problems of the poor. While the value of avoided environmental impact achieved by halting clearing by large landholders might also be pocketed as a windfall, it also provides a basis for negotiating a middle ground between the 'Robin Hood' and 'windfall' extremes.

Value derived from the environmental damage avoided could be sufficient to offer sustainable livelihoods to a large number of people. As Table 2 makes evident, capturing the value of the stock of remaining forest has much greater potential than the value of avoided damage calculated based on the present rates of forest loss. This much larger value is currently not recognized in international conventions on climatic change and biodiversity, but it is important to keep this value in view. Whether the standing stock of forest has a value of zero or of hundreds of billions of dollars is obviously a tremendous point of uncertainty. As of now, only 'mutually agreed negotiated incremental costs' are recognized in the Framework Convention on Climate Change (FCCC), meaning that the value of standing forest is considered zero.

[Table 2 here]

The value of avoided damages (changes in the flux) can also reach very high values when one considers not just the damage of one year of deforestation, but also the damage of continuing deforestation in future years. Here the damages in future years are calculated assuming that the annual rate of clearing remains fixed for 100 years at the level observed in 1990. This implies that population growth of the rural population in the region is stopped, which would be an improbable event in reality but which serves as an illustration of the magnitude of the values. Considering future years raises the value attributed to avoided damages approximately 20 fold (using a discount rate of 5%/year). That is, stopping deforestation forever has 20 times more value than suspending deforestation for one year (i.e., postponing all future deforestation by one year). Values based on stock maintenance are approximately 12 times higher than those based on avoided damages from stopping deforestation in 1990 (considering a discount rate of 5%/year).

3.1.2. Carbon

Maintaining carbon stocks also represents a valuable environmental service. Unlike biodiversity, carbon is completely interchangeable, an atom of carbon stocked in Amazonian forest has the same atmospheric effect as an atom of carbon stocked in a eucalyptus plantation or an atom of carbon stocked in the ground as fossil fuel that was not burned due to an energy conservation response option. What may vary is the time that the carbon may be held under different circumstances; but when comparisons are made on a carbon ton-year basis, they are completely equivalent (Fearnside, 1995).

Discounting is a matter of controversy regarding how the benefits should be calculated in programs designed to combat global warming. Currently, the Global Environment Facility (GEF), which at present administers funds for combating global warming under the FCCC, does not apply discounting to physical quantities such as tons of carbon. However, there are strong reasons why discounting or some alternative form of time preference should be applied to carbon. The selfish interests of the current generation are not the only argument. Many people will die as impacts begin to appear from global warming. If those impacts begin sooner rather than later, the number of lives that would be lost between the 'sooner' and the 'later' represents a net gain to be had from postponing global warming. This is the same as postponing the emission of a ton of carbon by a given time. It therefore should be treated in a manner analogous to fossil fuel substitution, where a ton of carbon emission avoided this year is considered to have been avoided forever, even though that same carbon atom in the next year's stock of coal and oil will be released into the atmosphere just one year later.

The criterion that is used by the GEF in evaluating global warming projects is 'mutually agreed incremental costs.' This means that only the difference will be paid between what would happen under the 'project' scenario and what would happen under the 'no-project' scenario. If something is going to happen anyway then there is no need for the GEF to contribute funds, even though the event in question stores carbon. There is no 'benefit' from changing the course of events. Projects to avoid deforestation would therefore only be funded if the forest in question would have been cleared in the absence of the GEF project. Forests that are under immediate threat of clearing, such as those in Rondônia, would represent a gain if saved, whereas forests in remote areas of the state of Amazonas would represent no carbon benefit if protected as reserves. This sets up the potential for conflict between those whose primary interest is defending biodiversity and those interested mainly in global warming. To gain credit for carbon, only reserves near the deforestation front are rewarded, whereas for biodiversity, it may be (in the absence of discounting) much cheaper to set up large reserves in relatively unthreatened areas. The most threatened areas are also the areas with the greatest problems of conflicting land claims, population requiring resettlement or other measures, high land prices, and probable high costs of guards and other defensive measures to keep the threat of invasion at bay.

The question of how value is to be assigned to the damages of global warming is an extremely controversial one. This is in large part because not just financial losses are involved. The impacts of global warming are not restricted to damaging the economies of a few rich countries, even if this constitutes a major motivation behind the willingness of industrialized nations to invest in response options around the world, including maintaining tropical forests. The effects of global warming will also be felt each time a tropical storm hits the mudflats of Bangladesh or a drought hits already famine-prone areas of Africa. Millions of people are liable to die horrible deaths over the next century as a result of global warming (Daily and Ehrlich, 1990).

Considering the estimates of Fankhauser (1995) for doubling the pre-industrial concentration of CO_2, assuming that the world, including its population size, are fixed as they were in 1990, the result would be loss of 138,000 lives per year (115,000 of which would be in the poor countries). Since the world's population can be expected to increase substantially before pre-industrial CO_2 doubles, which would be in approximately 2070 under the IPCC reference scenario, the real cost in lost lives would be much greater than this (see Fankhauser and Tol, 1997). The annual monetary losses, without counting the value of human lives, would be US$ 221 billion, at 1990 prices (Pearce et al., 1996). It should be emphasized that these are annual losses (rather than one-time events), both in terms of human lives and money.

One common response to dealing with impacts on human life is to consider the value of human life as infinite, which ironically results in its being ignored in any form of cost/benefit calculation--in effect, loss of life being given a weight of zero. Formulations that are ultimately based on ability to pay to avoid risk impute greater monetary worth to lives lost in rich countries than in poor ones (e.g., Fankhauser, 1992, p. 14). These are morally unacceptable to many, including this author (Fearnside, 1998).

Nevertheless, what the rich are willing to pay to avoid the impacts of global warming is perhaps a good measure of the volume of funds that could be tapped to maintain the carbon storage services of Amazonian forest. Since this reflects only impacts on the rich, it is grossly unfair as a measure of real damage that would be done by global warming, which would also fall on people who cannot afford to pay anything to avoid impacts. Nordhaus (1991) derived values based on willingness to pay, which, along with other indicators of this willingness, have been used by Schneider (1994) to estimate per-hectare values for carbon storage in Amazonian forests. Additional values per ton of carbon stored considered by Schneider (1994) are from enacted carbon taxes: US$ 6.10/t in Finland and US$ 45.00/t in the Netherlands and Sweden (Shah and Larson, 1992), and from a proposed penny-a-gallon (US$ 0.0027/l) gasoline tax in the United States equivalent to US$ 3.50/t of carbon. Recent calculations of how the United States might comply with the 1997 Kyoto Protocol indicate that carbon emission permit prices between US$ 25 and US$ 50/t of carbon would have to be paid (Romm et al., 1998). An illustration of the carbon storage value of forest, using low, medium and high values of US$ 1.80, US$ 7.30 and US$ 66.00/t from Nordhaus (1991), is given in Table 3. The table extends Schneider's (1994) analysis based on updated values for greenhouse gas emissions from deforestation (Fearnside, 1997c), and also includes interpretation of per-hectare values in terms of the total stock of forest, 1990 deforestation rate, and the portion of the rate attributable to small farmers.

[Table 3 here]

It is important to distinguish between the true value of an environmental service like carbon storage versus the value as represented by willingness to pay. Willingness to pay is limited by the amount of money that individuals or countries have at their disposal, and, of course, by the other priorities that they may have for spending it. There is also a problem of scale: the world might be willing to pay, say, US$ 1 billion or US$ 10 billion on combating global warming, but not US$ 100 billion, even if the cost to the rich of global warming damages exceeded this value. The true value of the damages, of course, would always be much higher than the damages to the rich. The tremendous amount of environmental service that Brazil effectively has to offer means that the price obtained could decline, just as in any other kind of market. As Brazil well knows, if a country offers for sale a few sacks of a commodity like coffee or cacao the price may be 'X', but if the quantity offered is millions of sacks the price may no longer be 'X'. Considering prices without the effects of scale, however, provides a starting point for thinking about the problem of marketing environmental services. Willingness to pay may increase significantly in the future when the magnitude of potential damage from global warming becomes more apparent to decision-makers and the general public.

3.1.3. Water cycle

One consequence of massive conversion of forest to pasture would be a decrease in rainfall in Amazonia and in neighboring regions. Half of Amazonia's rainfall is derived from water that recycles through forest as evapotranspiration, rather than from water vapor in clouds originating over the Atlantic Ocean. Four independent lines of evidence lead to this conclusion. First, water and energy balances derived from average charts of temperature and humidity indicate 56% of the precipitation as derived from evapotranspiration (Molion, 1975). Second, calculations of precipitable water and water vapor flux for a transect from Belém to Manaus indicate a contribution from evapotranspiration of 48% (Marques et al., 1977). Third, isotope ratioing of water vapor samples in the same area indicates up to 50% as recycled through the forest, depending on the month (Salati et al., 1978, 1979). Fourth, the volume of water flowing out of the Amazon River can be compared with the volume of water falling as rain in the catchment basin. River flow is 5.5 X 10^{12} m^3/year measured at the Amazon's narrow point at Óbidos, and rainfall is 12.0 X 10^{12} m^3/year estimated from pluviometers around the region (Villa Nova et al., 1976). The volume of water in the rain is slightly more than double the amount leaving through the river, meaning that the approximately half (54%) that does not drain out through the river has been returned to the atmosphere as evapotranspiration.

Only by seeing the Amazon River at flood season can one fully appreciate the immense volume of water involved: what one sees in the river is the same volume that is returning unseen to the atmosphere through the leaves of the forest. That the leaves of the forest are constantly giving off water is evident to anyone who has tied a plastic bag over a handful of leaves: in only a few minutes the inside of the bag is covered with water droplets condensed from evapotranspiration. Summed over the several hundred billion trees in Amazonia a vast amount of water is returned to the atmosphere. Since evapotranspiration is proportional to leaf area, the water recycled through the forest is much more than that recycled through the pasture, especially in the dry season when the pasture is dry while the forest remains evergreen. This is aggravated by the much higher runoff under pasture. Increases in runoff by one order of magnitude have been measured near Manaus (Amazonas), Altamira (Pará) and Ouro Preto do Oeste (Rondônia) (see Fearnside, 1989e). Soil under pasture quickly becomes highly compacted, inhibiting infiltration of rainwater into the soil (Dantas, 1979; Schubart et al., 1976). Rain falling on the compacted soil runs off quickly, becoming unavailable for later release to the atmosphere through transpiration.

An appreciable amount of the rain in Brazil s principal agricultural areas in the center-south part of the country also derives from the Amazon forest (Salati and Vose, 1984). The rotation of the earth causes the predominant (trade) winds south of the equator to curve from an east-west to a north-south and then to a northwest-southeast direction. The movement of clouds in this direction is evident from images of the GOES meteorological satellite. A simulation using the global circulation model (GCM) of the Goddard Institute of Space Studies (GISS) in New York indicates that water that begins in Amazonia falls as rain in all Brazil, although it does not affect the climate of other continents (Eagleson, 1986).

No one knows how much the input of Amazonian rainfall is to agriculture in southern Brazil, nor how much the harvest would be affected by loss of this input. Brazil's harvest has a gross value of around US$ 65 billion annually, meaning that even a relatively small fraction of this lost to decreased water vapor supply would translate into a substantial financial impact. Merely as an illustration, if 10% were dependent on Amazonian water, the annual value is equivalent to US$ 19/ha of remaining forest in the Legal Amazon. An illustration of the water cycling value of forest is given in Table 4. Assuming 10% dependency (the "medium" value) and that the effect continues indefinitely after deforestation, the net present value (NPV) of the forest loss calculated at a 5%/year discount is US$ 127/small farmer family if only clearing done by small farmers in 1990 is considered, or US$ 417/family if all of the 1990 annual deforestation rate is considered. Corresponding values, including future deforestation, are US$ 2600/family and US$ 8400/family, respectively. A much larger value lies in the stock of forest that remains uncleared: this stock has an NPV of US$ 130 billion if a 5% annual discount rate is considered, or over US$ 100,000/family. If considered at 5%/year interest, the value of the stock is equivalent to a total annuity of US$ 7 billion/year, or over US$ 5000/family/year.

[Table 4 here]

The "medium" estimates of value for the three categories of environmental services (biodiversity, carbon storage and water cycling) are summarized and totaled in Table 5. The great variety of values is evident depending on the measure adopted. Again, it should be remembered that the much higher values related to the value of the stock of remaining forest represent a form of value not recognized in current international conventions, which give no value to stocks or even to flows per se, but only to deliberately caused changes in flows.

[Table 5 here]

3.2. How to sustain the forest

3.2.1. Involvement of local peoples

The involvement of local people represents the key to any plan to maintain areas of natural vegetation. Only grassroots organizations can exert social pressure on those who would invade and cut an area that has been agreed to remain as a reserve. The alternative approach, with functionaries of government agencies trying to enforce boundaries and regulations against the will of the surrounding population, has failed countless times.

Empowerment of local groups must be linked to the establishment and enforcement of limits--groups cannot be free to cut forest at will. The balance of responsibility and freedom in such relationships is a difficult area in which no set answers exist. Perhaps the best known example of the problem of local peoples (including Indians) not always acting in an environmentally benign way is the Navajo and Apache tribes in the United States, whose leaders have been negotiating for establishment of nuclear waste dumps on tribal land. The question remains unresolved of what means are necessary for protecting the environment when local peoples fail.

The question must be considered as to whether local peoples receiving funds derived from environmental services should have complete independence in deciding how the funds should be used, whether all or part of it should be used for maintaining the natural habitats that provide the services, or whether the funds should at least be restricted to uses that do not harm these habitats. For example, would it be acceptable if a community receiving funds for environmental services were to decide to use the money to buy chain saws to cut down the rest of its forest? This example is not entirely hypothetical. In 1988 and 1989, the current governor of the state of Amazonas actually distributed free chain saws to voters in the interior of the state (during a previous term in office).

3.2.2. Independent monitoring

One of the problems in achieving internationally negotiated agreements for forest protection is the question of how compliance would be monitored. Remote sensing technology can greatly facilitate monitoring processes and increase the confidence that parties can place in agreements being carried out. Remote sensing can produce data by property, not just by state, as has been done so far. With proper priority, remote-sensing information can be obtained with a fast turnaround, but so far the motivation for such speed has been restricted to the 1989-1992 period when international attention was focused on Amazonian deforestation. Although LANDSAT thematic mapper (TM) data have primarily been used for measurements of deforestation, logging scars too are visible on TM but disappear quickly (D. Nepstad, 1995, personal communication).

Monitoring the status of forest maintenance agreed to in any international negotiations would have to be done by a politically independent body (Fearnside, 1997d). Remote sensing alone is not sufficient, making free ground access essential. As in the case of nuclear disarmament negotiations, these questions are likely to be diplomatic stumbling blocks.

3.2.3. Economic viability for local peoples

Evaluating the economic viability of a proposal to maintain forest requires, among other things, defining the discount rates both of money and of environmental services such as biodiversity and carbon stock maintenance. In addition, mechanisms are needed by which the economic value of information can be captured, including genetic material and intellectual property rights (IPRs) (see Posey, this volume).

The value of a local community's role in conserving a resource cannot be calculated based on what the area of land involved would produce had it been instead a green revolution rice field. Local peoples rarely have land with soil or climate like that in green revolution areas, and their lack of capital means that even if they had such land no green revolution profits would have materialized (i.e., it is not really an 'opportunity cost').

Establishing values for environmental services requires several steps. First, research to quantify the amount of the services, such as tons of carbon, numbers of species or cubic meters of water. These quantities then must be translated into prices, or to subsidies. The values in question would be negotiated values, which are distinct from (and inevitably lower than) the true values of environmental services. The definition of ground rules is essential if biodiversity and carbon are to attain values. A key question is whether this kind of valuation is restricted to 'incremental costs,' implying that resources are valuable only if they are doomed.

"Economic viability for whom?" is a recurrent question regarding evaluation of this and other development possibilities. Whether payments for environmental services would accrue to local people or only to the government and intermediaries is essential to whether this option constitutes a form of sustainable development.

One problem has been aptly summed up by Michael Dove (1993) by analogy to John Steinbeck's (1945) short story 'The Pearl' (and its Indonesian analog: "little man and the big stone"). In Steinbeck's story a poor Indian named Kino in an unnamed Latin American country lives by the ocean and makes a meager living diving for pearls. One day he finds a huge pearl and imagines that his son will be able to gain an education and leave the cycle of poverty. Instead, the wealthy of the village try every possible artifice to trick Kino into giving up the pearl. Finally, he throws the pearl back into the ocean, ending the story. In the case of tropical forests, the same might be expected to happen were any marvelous new source of money discovered. Were a poor forest dweller to find a tree with a cure for AIDS, for example, it is highly unlikely that any of the great value of the discovery would return to the poor person or community that found it. In the same way, if large sums of money were to materialize for environmental services of standing forest, the rich would enter into action to capture the benefits for themselves. As in the story, the surrounding society can be expected employ all imaginable means to take the pearl away, almost as if it were a moral duty not to allow a poor person to keep the benefits of such a find. A major challenge in defining strategies for sustainable development, then, is to find ways to assure that forest dwellers get to keep the pearl of environmental services.

The government's percentage of returns from biodiversity use is less fundamental than the mechanism by which returns will be transferred to local peoples. Governments (for example, Brazil) are anxious to avoid allowing funds to pass directly from abroad to local peoples. However, if funds are given to government for redistribution to local peoples, the practical consequence is likely to be that local peoples will never receive anything. Aside from funds siphoned off in illicit ways, the normal delays of months (or sometimes years), with inflation at its usual rate, means that the value of any funds evaporates before the money ever reaches its intended beneficiaries.

Identification of what local partners within a community should receive benefits or enter into agreements is more difficult than it appears, and can have divisive effects. An example is provided by the destructive results in distribution of proceeds from rights for a film on Chico Mendes, which led to ugly infighting between factions of rubbertappers, an aspect that did not exist before the possibility of significant monetary flows became apparent. This would be a natural human reaction if a large amount of money were dropped on any community in interior Amazonia. The problem of factions within local communities can impede return of funds from biodiversity or other sources.

Responsibility of local people to maintain natural habitats that provide environmental services needs to be made clear. Linkage of this responsibility to revenue from forest, for example, from the economic use of biodiversity, would be a useful way of making this operational.

3.3. How to make services into development

What needs to be done to transform environmental services into sustainable development? One obvious need is to quantify basic costs. This is especially true for avoidance of deforestation. How much does it really cost to avoid a hectare of deforestation in Rondônia? No one has an adequate answer to such a question today. Costs of silvicultural plantations, in contrast, are relatively well known, due to years of experience in planting them and due to the relatively few uncertainties in foreseeing their future if specified investments are made. Deforestation, on the other hand, is strongly influenced by government policy decisions that have little direct connection with financial costs. For example, tax policies that allow land speculation to continue as a highly profitable activity, and policies that to this day allow deforestation to justify land titling as an 'improvement,' could be changed at no financial cost, although there would clearly be political costs for making the change.

Significant difficulties exist in financing the conservation of tropical forests (e.g., Dobson and Absher, 1991; Goodland, 1992). In addition to international agencies such as the GEF, private and public deals for carbon offset already exist on a limited scale, and these may potentially be applied to other environmental services. Carbon offsets do not imply conservation in perpetuity, although similar projects for biodiversity might well make this a requirement. In the case of carbon, benefits need to be viewed in terms of ton-years of carbon storage with appropriate adjustments for time preference (Fearnside, 1995, 1997e). Political feasibility, especially perceived infringement of sovereignty, has been a major barrier to carbon offsets (e.g., Brown and Adger, 1994). Under the 1997 Kyoto Protocol of the Framework Convention on Climate Change, for example, actions implemented jointly are currently limited to projects in industrialized countries (i.e., mainly related to reduced energy emissions in eastern Europe). Future protocols may someday include the potential of tropical forests in global warming mitigation. Such projects have substantial potential (Sathaye and Makundi, 1995; Sathaye et al., 1995).

Another area of great doubt in translating environmental services into a means of support is the mechanism by which funds received on the basis of services would be distributed. Would this be done, for example, by a successor to the recently disbanded Brazilian Legion for Assistance (LBA), which became a symbol of corruption in Brazil after a long series of scandals involving the wife of former President Collor? What is the Brazilian proposal for using funds received? If the nations of the world miraculously agreed to pay handsomely for the environmental services of Amazon rainforest and sent the government a check, how much of this money would actually go to the two principal objectives: maintaining the forest and supporting the region's population?

The channel that would be used for transferring funds to Brazil and to the individual activities needing support is another area of doubt. The Pilot Program to Conserve the Brazilian Rainforest, administered by the World Bank and funded by G-7 countries as a result of a commitment made in Houston in 1990, encountered frustrating impediments to getting its program underway. While a number of these problems have been solved, and several parts of the program are finally underway, the four year delay made clear that transferring much larger sums would not be an easy task. It is hoped that the experience of the pilot program will serve to unplug some of the pipelines through which such larger inflows might one day pass. Although some progress has been made, much more needs to be done.

Employment is often raised as a key question in discussions of forest preservation in protected areas. What will Brazil or the Amazonian states gain from reserves in terms of employment? Would it not be better to hand out land as agricultural lots to support part of the unemployed population? The answer to employment depends very much on what is to be done with money that is brought in by environmental services of the forest. If the sums involved are large, as the true importance of the services implies they should be, then there is substantial scope for creating employment. One form of employment is guarding the reserves themselves. It is important to realize that this form of employment can only occupy a limited number of people, and that these are not the same people who would receive lots if the land were to be handed out for agricultural settlement instead of being made into reserves. However, this is an important option for the true 'local' inhabitants (rubbertappers, etc.), already in the interior. Often these people would not have other opportunities for employment. Rural employment could also be generated in scientific research in the reserves, for example, in botanically collecting, mapping, and measuring trees in large areas of reserves, and monitoring tree mortality, regeneration and phenology. Unfortunately, these options are severely limited in their potential scale by the number of taxonomists and other scientists available to process material and information gathered by field personnel employed in such projects.

It must be recognized that Amazonia's population is rapidly becoming urban. Employment in urban centers is, in some ways, easier to create than rural employment. Activities somehow linked to forest maintenance would be preferable. For example, laboratories could be set up in Amazonian cities to analyze plant secondary compounds obtained from the reserves.

A certain danger exists of pernicious effects arising from any form of welfare or giveaway of money coming from payments for environmental services. For example, cash payments made to individual members of a tribe in the southwestern United States as compensation for damages caused by a copper mine on tribal lands led to disintegration of much of the tribe's culture, severe problems with alcoholism and high mortality from automobile accidents (G. Nabhan, 1994, personal communication). In addition, most 'made-work' has a tendency to be relatively unproductive. A good example is the case of Trinidad and Tobago, a small Caribbean country (population 1.2 million) that has the good fortune to have oil. Public works, such as endless repair of roads with mostly idle crews, are the means of transferring government wealth to the people. It must be remembered that potential for political abuse is very high. If Amazonian state governments are given the opportunity of handing out a significant number of make-work jobs using money received from payments for environmental services, it is likely that this would be used primarily to assure electoral benefits to whoever is in power. Safeguards are therefore needed in any way that the employment question is addressed.

One of the dilemmas of sustainable development proposals is that success can attract the destruction of the very features that made a given activity sustainable. For example, if an agroforestry system proves to be sustainable and a financial success, it can attract a migration of population eager to share in the success, leading to increased deforestation to expand the system. This has occurred on the island of Sumatra, Indonesia, where areas with financially successful tree crops have experienced an increase rather than a decrease of deforestation (Alternatives to Slash and Burn, 1995, p. 131). One is placed in a situation of being 'damned if you do and damned if you don't': if a settlement project is an agronomic failure, then people will invade surrounding forest and cut for slash-and-burn agriculture, whereas if it is a success, then others will be drawn to the area and will cut the forest just the same.

The tremendous pool of people in non-Amazonian parts of Brazil who would be drawn to any source of easy money is a problem that must be faced effectively. The great value of the forest means that, in theory, one could even contemplate pensioning off the current residents in luxurious circumstances--the 'Copacabana solution'. Many Brazilians regard living in an apartment near Copacabana Beach in Rio de Janeiro as the pinnacle of material achievement. But for the limitations of space (the rural population of the Legal Amazon is about the same as the city of Rio de Janeiro), the annuities from forest standing stock are of an order of magnitude sufficient to support such an expense. If they could be collected (note that the limits of available funds make "willingness to pay" figures based on linear extrapolation to large scales unrealistic, as noted earlier), annuities at 5%/year would yield US$ 7 billion/year from biodiversity, US$ 24 billion/year from carbon storage and US$ 7 billion/year from water cycling, or US$ 37 billion/year total, equivalent to almost US$ 29,000/family of small farmers (Table 5). The gravest problem with such a hypothetical scenario, of course, is that if one ever tried to transport Amazonia's rural population to Copacabana or any equivalent place, others would soon occupy the deforestation frontier and clearing would continue.

In order for any form of development to be sustainable, population growth in the area, both from reproduction and from migration effects, must remain within the limits of carrying capacity, which, while not fixed, is also not free to increase at will (e.g., Fearnside, 1986, 1997f; Cohen, 1995). There is no such thing as 'sustainable development' for an infinite number of people.

4. Conclusions

A strategy for achieving sustainable development in rural Amazonia requires both short-term and long-term measures. While immediate steps to maintain the population and to prevent further loss of forest are needed, progress also must be made on long-term goals that will provide a stable basis for maintaining both the forest and the population. This should focus on the environmental services of standing forest. The biodiversity maintenance, carbon storage and water cycling functions of rainforest are worth more to rich countries than the value of land in Amazonia, which reflects the potential profitability of selling timber and replacing forest with agriculture or ranching. How to convert environmental services of forest into an income stream, and how to convert this stream into a foundation for sustainable development in rural Amazonia is a great challenge.

Acknowledgments

Earlier versions of this paper were presented at the conference on "The Development Enterprise: Economic, Environmental and Sociological Perspectives on Sustainability," Chicago, IL, 26-29 October 1995, and at the Workshop "Meio Ambiente, Desenvolvimento e Política do Governo", Fundação Joaquim Nabuco, Recife, Pernambuco, 22-25 April 1996. The calculations presented here have been updated from previous versions of this proposal (Fearnside, 1997g,h). I thank Elsevier Science-NL, Sara Burgerhartstraat 25, 1055 KV Amsterdam, The Netherlands, for kind permission to publish parts of my article appearing in Ecological Economics 20(1): 53-70 (1997). The Conselho Nacional de Desenvolvimento Científico e Tecnológico--CNPq (BPP 350230/97-98), the Instituto Nacional de Pesquisas da Amazônia--INPA (PPI 5-3150), and the Pew Scholars Program in Conservation and the Environment provided financial support. R.I. Barbosa, C. Cavalcanti, P.M.L.A. Graça, S.V. Wilson and two anonymous reviewers commented on the manuscript.

References

Adger, W.N., Brown, K., Cervigni, R. & Moran, D. 1995. Total economic value of forests in Mexico. Ambio 24(5): 286-296.

Alternatives to Slash and Burn (ASB). 1995. Alternatives to Slash-and-Burn in Indonesia. Phase I Report. ASB/International Centre for Agroforestry-Southeast Asia, Bogor, Indonesia, 150 pp.

Brazil, Instituto Brasileiro de Geografia e Estatística (IBGE). 1989. Anuário Estatístico do Brasil 1989, Vol. 49. IBGE, Rio de Janeiro, Brazil. 715 pp.

Brazil, Instituto Brasileiro de Geografia e Estatística (IBGE). 1992. Anuário Estatístico do Brasil 1992, Vol. 52. IBGE, Rio de Janeiro, Brazil, electronic version.

Brown, K. and Adger, W.N. 1994. Economic and political feasibility of international carbon offsets. Forest Ecology and Management 68: 217-229.

Cartwright, J. 1985. The politics of preserving natural areas in Third World states. The Environmentalist 5(3): 179-186.

Cohen, J. 1995. Population growth and earth's human carrying capacity. Science 269: 341-346.

Cordell, G.A. 1995. Natural products as medicinal and biological agents: Potentiating the resources of the rain forest. pp. 8-18 In: P.R. Seidl, O.R. Gottlieb and M.A.C. Kaplan (eds.) Chemistry of the Amazon: Biodiversity, Natural Products and Environmental Issues. American Chemical Society, Washington, DC, U.S.A. 315 pp.

*Costanza, R. et al. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Daily, G.C. and Ehrlich, P.R. 1990. An exploratory model of the impact of rapid climate change on the world food situation. Proceedings of the Royal Society of London B 241: 232-244.

Dantas, M. 1979. Pastagens da Amazônia Central: Ecologia e fauna do solo. Acta Amazonica 9(2) suplemento: 1-54.

Dobson, A. and Absher, R. 1991. How to pay for tropical rain forests. Trends in Ecology and Evolution 6(11): 348-351.

Dove, M. 1993. A revisionist view of tropical deforestation and development. Environmental Conservation 20(1): 17-24, 56.

Eagleson, P.S. 1986. The emergence of global-scale hydrology. Water Resources Research 22(9): 6s-14s.

Elisabetsky, E. and Shanley, P. 1994. Ethnopharmacology in the Brazilian Amazon. Pharmacology and Therapeutics 64: 201-214.

Fankhauser, S. 1992. Global warming damage costs: Some monetary estimates. Centre for Social and Economic Research on the Global Environment (CSERG) Working Paper GEC 92-29. University College, London and University of East Anglia, Norwich, UK. 45 pp.

Fankhauser, S. 1995. Valuing Climate Change--The Economics of the Greenhouse. Earthscan, London, UK.

Fankhauser, S. and Tol, R.S.J. 1997. The social costs of climate change: The IPCC Second Assessment Report and beyond. Mitigation and Adaptation Strategies for Global Change 1(4): 385-403.

Fearnside, P.M. 1986. Human Carrying Capacity of the Brazilian Rainforest. Columbia University Press, New York, USA. 293 pp.

Fearnside, P.M. 1989a. Brazil's Balbina Dam: Environment versus the legacy of the pharaohs in Amazonia. Environmental Management 13(4): 401-423.

Fearnside, P.M. 1989b. Extractive reserves in Brazilian Amazonia: An opportunity to maintain tropical rain forest under sustainable use. BioScience 39(6): 387-393.

Fearnside, P.M. 1989c. A prescription for slowing deforestation in Brazilian Amazonia. Environment 31(4): 16-20, 39-40.

Fearnside, P.M. 1989d. Deforestation in the Amazon. Environment 31(7): 4-5.

Fearnside, P.M. 1989e. A ocupação humana de Rondônia: Impactos, limites e planejamento. CNPq Relatórios de Pesquisa No. 5. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brasilia, Brazil. 76 pp.

Fearnside, P.M. 1993a. Forests or fields: A response to the theory that tropical forest conservation poses a threat to the poor. Land Use Policy 10(2): 108-121.

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

Fearnside, P.M. 1995. Global warming response options in Brazil's forest sector: Comparison of project-level costs and benefits. Biomass and Bioenergy 8(5): 309-322.

Fearnside, P.M. 1997a. Limiting factors for development of agriculture and ranching in Brazilian Amazonia. Revista Brasileira de Biologia 57(4): 531-549.

Fearnside, P.M. 1997b. Protection of mahogany: a catalytic species in the destruction of rain forests in the American tropics. Environmental Conservation 24(4): 303-306.

Fearnside, P.M. 1997c. Greenhouse gases from deforestation in Brazilian Amazonia: Net committed emissions. Climatic Change 35(3): 285-302.

Fearnside, P.M. 1997d. Monitoring needs to transform Amazonian forest maintenance into a global warming mitigation option. Mitigation and Adaptation Strategies for Global Change 2(2-3): 285-302.

Fearnside, P.M. 1997e. Greenhouse-gas emissions from Amazonian hydroelectric reservoirs: The example of Brazil's Tucuruí Dam as compared to fossil fuel alternatives. Environmental Conservation 24(1): 64-75.

Fearnside, P.M. 1997f. Human carrying capacity estimation in Brazilian Amazonia as a basis for sustainable development. Environmental Conservation 24(3): 271-282.

Fearnside, P.M. 1997g. Environmental services as a strategy for sustainable development in rural Amazonia. Ecological Economics 20(1): 53-70.

Fearnside, P.M. 1997h. Serviços ambientais como estratégia para o desenvolvimento sustentável na Amazônia rural. pp. 314-344 In: C. Cavalcanti (ed.) Meio Ambiente, Desenvolvimento Sustentável e Políticas Públicas. Cortez Editora, Sao Paulo, Brazil. 436 pp.

Fearnside, P.M. 1998. The value of human life in global warming impacts. Mitigation and Adaptation Strategies for Global Change 3(1): 83-85.

Goodland, R. 1992. Neotropical moist forests: Priorities for the next two decades. pp. 416-433 In: K.H. Redford and C. Padoch (eds.) Conservation of Neotropical Forests: Working from Traditional Resource Use. Columbia University Press, New York, U.S.A. 475 pp.

Goodland, R. and Ledec, G. 1987. Neoclassical economics and principles of sustainable development. Ecological Modelling 38: 19-46.

Grimes, A., Loomis, S., Jahnige, P., Burnham, M., Onthank, K., Alcarón, R., Cuenca, W.P., Martinez, C.C., Neill, D., Balick, M., Bennett, B. and Mendelsohn, R. 1994. Valuing the rain forest: The economic value of nontimber forest products in Ecuador. Ambio 23(7): 405-410.

Hecht, S.B. 1992. Valuing land uses in Amazonia: Colonist agriculture, cattle, and petty extraction in comparative perspective. pp. 379-399 In: K.H. Redford and C. Padoch (eds.) Conservation of Neotropical Forests: Working from Traditional Resource Use. Columbia University Press, New York, U.S.A. 475 pp.

Kaplan, M.A.C. and Gottlieb, O.R. 1990. Busca racional de princípios ativos em plantas. Interciencia 15(1): 26-29.

Marques, J., dos Santos, J.M., Villa Nova, N.A. and Salati. E. 1977. Precipitable water and water vapor flux between Belém and Manaus. Acta Amazonica 7(3): 355-362.

Molion, L.C.B. 1975. A climatonomic study of the energy and moisture fluxes of the Amazonas Basin with considerations of deforestation effects. Ph.D. dissertation in meteorology, University of Wisconsin, Madison. University Microfilms International, Ann Arbor, MI, U.S.A.

Myers, N. 1989. Loss of biological diversity and its potential impact on agriculture and food production. pp. 49-68 In: D. Pimentel and C.W. Hall (eds.) Food and Natural Resources. Academic Press, San Diego, CA, U.S.A.

Nordhaus, W. 1991. A sketch of the economics of the greenhouse effect. American Economic Review 81(2): 146-150.

Norton, B. 1988. Commodity, amenity and morality: The limits of quantification in valuing biodiversity. pp. 200-205 In: E.O. Wilson (ed.) Biodiversity. National Academy Press, Washington, DC, U.S.A. 521 pp.

Noss, R. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4: 355-364.

Pachauski, F. 1994. "Trabalha, escravo." Isto É (Brasília) 4 May 1994, pp. 32-35.

Pamplona, G. and Rodrigues, A. 1995. "História sem fim: Um ano depois da denúncia de ISTOÉ, carvoeiros ainda trabalham como escravos no norte de Minas." Isto É (Brasilia) 21 June 1995, pp. 46-47.

Pearce, D.W., Cline, W.R., Achanta, A.N., Fankhauser, S., Pachauri, R.K., Tol, R.S.J. and Velinga, P. 1996. The social costs of climate change: Greenhouse damage and the benefits of control. pp. 179-224 In: J.P. Bruce, H. Lee and E.F. Haites (eds.) Climate Change 1995: Economic and Social Dimensions--Contributions of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 448 pp.

Peters, C.M., Gentry, A.H. and Mendelsohn, R.O. 1989. Valuation of an Amazonian rainforest. Nature 339: 655-656.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. 1997a. Economic and environmental benefits of biodiversity. BioScience 47(11): 747-757.

Pimentel, D., McNair, M., Buck, L., Pimentel, M. and Kamil, J. 1997b. The value of forests to world food security. Human Ecology 25(1): 91-120.

Ribeiro Jr., A. 1994. "Carvoeiros são 'escravos' em MG." A Folha de São Paulo 31 July 1994, pp. 1-1 and 1-12.

Richards, M. 1993. The potential of non-timber forest products in sustainable forest management in Amazonia. Commonwealth Forestry Review 72(1): 21-27.

Romm, J., Levine, M., Brown, M. and Peterson, E. 1998. A road map for U.S. carbon reductions. Science 279: 669-670.

Salati, E., Marques, J. and Molion, L.C.B. 1978. Origem e distribuição das chuvas na Amazônia. Interciencia 3(4): 200-206.

Salati, E., Dall'Olio, A., Matusi, E. and Gat, J.R. 1979.

Recycling of water in the Brazilian Amazon Basin: An isotopic study. Water Resources Research 15: 1250-1258.

Salati, E. and Vose, P.B. 1984. Amazon Basin: A system in equilibrium. Science 225: 129-138.

Sathaye, J. and Makundi, W.R. (eds.) 1995. Forestry and Climate Change. Special issue of Biomass and Bioenergy 8(5): 279-393.

Sathaye, J., Myers, S., Allen-Diaz, B., Cirillo, R., Gibbs, M., Hillsman, E., Ohi, J., Conzelmann, G., Corbus, D., Gadgil, A., Heaps, C., Koomey, J., Lazarus, M., Mark, J., Ojima, D., Ross, M., Sanstad, A., Unander, F. and Weyant, J. 1995. Greenhouse Gas Mitigation Assessment: A Guidebook. Kluwer Academic Publishers, Dordrecht, The Netherlands. Irregular pagination.

Schneider, R.R. 1994. Government and the economy on the Amazon frontier. Latin America and the Caribbean Technical Department Regional Studies Program Report No. 34, The World Bank, Washington, DC, U.S.A. 86 pp.

Schubart, H.O.R., Junk, W.J. and Petrere Jr., M., 1976. Sumário de ecologia Amazônica. Ciência e Cultura 28(5): 507-509.

Shah, A. and Larson, B. 1992. Carbon taxes, the greenhouse effect and developing countries. In: World Development Report 1992. The World Bank, Washington, DC and Oxford University Press, New York, U.S.A.

Stirling, A. 1993. Environmental valuation: How much is the emperor wearing? The Ecologist 23(3): 97-103.

Steinbeck, J., 1945 [1974]. The Pearl. Bantam Books, New York, U.S.A. 118 pp.

Sutton, A. 1994. Slavery in Brazil--A link in the chain of modernization. Oxford University Press, Oxford, UK.

Vásquez, R. and Gentry, A.H. 1989. Use and misuse of forest-harvested fruits in the Iquitos area. Conservation Biology 3(4): 350-361.

Villa Nova, N.A., Salati, E. and Matusi, E. 1976. Estimativa da evapotranspiração na Bacia Amazônia. Acta Amazonica 6(2): 215-228.

Whitehead, B.W. and Godoy, R. 1991. The extraction of rattan-like lianas in the new world tropics: A possible prototype for sustainable forest management. Agroforestry Systems 16: 247-255.

Willers, B. 1994. Sustainable development: A new world deception. Conservation Biology 8(4): 1146-1148.

TABLE 1: CONSTANTS USED IN CALCULATIONS OF FOREST VALUE

Area deforested in 1990	Millions of ha	1.38 (a)
Forest remaining in 1990	Millions of ha	337.72
Percent deforestation in 1990 caused by small farmers	%	30.5 (a)
Rural population	Millions of individuals	7.65 (b)
Percent of properties (= families) of small farmers	%	83.2 (c)
Population of small farmers	Millions of individuals	6.4 (d)
Average family size	Individuals	5
Discount rate	%/year	5

(a) Fearnside, 1993b.

(b) Brazil, IBGE, 1994.

(c) Brazil, IBGE, 1989.

(d) Calculated from rural population and percent of small farmers.

Erro! Indicador não definido.TABLE 2: VALUE OF BIODIVERSITY MAINTENANCE

Type	Environmental value basis	Description	Units	Value			Obs.
				Low	Medium	High	
ASSUMPTION		Value of biodiversity maintenance	US$/ha/yr	10	20	30	(a)
CALCULATED VALUES							
	Damage in 1990 caused by the total population	NPV	US$ million	276	552	828	(b)
		NPV per small farmer family	US$/family	217	434	650	(b)
		Total annuity	US$ million/ yr	14	28	41	(c)
		Annuity per small farmer family	US$/family/yr	11	22	33	(c)
	1990 damage caused by small farmer population	NPV	US$ million	84	168	253	(b)
		NPV per small farmer family	US$/family	66	132	198	(b)
	1990 and all future damage caused by the total population	NPV	US$ billion	5.5	11.1	16.6	(b)
		NPV per small farmer family	US$ thousand/ family	4.4	8.7	13.1	(b)
		Total annuity	US$ million/ yr	277	554	831	(c)
		Annuity per small farmer family	US$/family/yr	218	435	653	(c)

1990 and all future damage caused by small farmer population	NPV	US$ billion	1.7	3.4	5.1	(b)
	NPV per small farmer family	US$ thousand/ family	1.3	2.7	4.0	(b)
Value of forest stock in 1990	NPV	US$ billion	68	135	203	(b)
	NPV per small farmer family	US$ thousand/ family	53	106	159	(b)
	Annuity on value of forest stock	US$ billion/ yr	3	7	10	(c)
	Annuity per small farmer family	US$ thousand/ family/yr	2.7	5.3	8.0	(c)

(a) Cartwright, 1985, for "medium" value. Value presumed equal to cost.
(b) At 5%/yr discount.
(c) At 5%/yr interest.

TABLE 3: CARBON STORAGE VALUE

Type	Environmental value basis	Description	Units	Value			Obs.
				Low	Medium	High	
ASSUMPTION		Value per ton of carbon permanently sequestered	US$/t C	1.8	7.3	66.0	(a)
CONSTANTS							
		Net committed emission in 1990	Million t CO_2 equivalent C		267		(b)
		Net committed emission/ha of deforestation in 1990	t C/ha		194		(b)
CALCULATED VALUES							
	Damage per ha of forest loss	Annual value	US$/ha/yr	17.4	70.7	638.9	(c)
		Damage	US$/ha	349	1413	12,778	(d)
	Total damage in 1990	Damage	US$ million	481	1950	17,634	(d)
		Damage per small farmer family	US$/family	378	1532	13,853	(d)
		Total annuity	US$ million/yr	24	98	882	(e)
		Annuity per small farmer family	US$/family/yr	19	77	693	(e)
	Damages in 1990	Total damage in	US$ million	147	595	5378	(d)

caused by small farmer population	1990					
	Damage in 1990 per small farmer family	US$/family	115	467	4225	(d)
1990 and all future damage caused by total population	NPV	US$ billion	9.6	39.0	352.7	(f)
	NPV per small farmer family	US$ thousand/ family	7.6	30.6	277.1	(f)
	Total annuity	US$ million/yr	481	1950	17,634	(e)
	Annuity per small farmer family	US$/family/yr	378	1532	13,853	(e)
1990 and all future damage of the 1990 small farmer population	NPV	US$ billion	2.9	11.9	107.6	(f)
	NPV per small farmer family	US$ thousand/ family	2.3	9.3	84.5	(f)
Value of forest stock in 1990	NPV	US$ billion	118	477	4316	(f)
	NPV per small farmer family	US$ thousand/ family	92.5	375.0	3,390.2	(f)
	Annuity from value of forest stock	US$ billion/yr	6	24	216	(e)
	Annuity per small	US$ thousand/	4.6	18.7	169.5	(e)

	farmer family	family/yr

(a) Nordhaus, 1991 (values used by Schneider, 1994).
(b) Updated from Fearnside (1997c) considering the impact of trace gases in the low trace gas scenario.
(c) Annualized at 5%/yr from value for permanent sequestration.
(d) Value of permanent sequestration (i.e., equivalent to NPV).
(e) At 5%/yr interest.
(f) At 5%/yr discount.

TABLE 4: WATER CYCLING VALUE

Type	Environmental value base	Description	Units	Value			Obs.
				Low	Medium	High	
ASSUMPTION		Percent of harvest that depends on water from Amazonia	%	5	10	20	
CONSTANT		Gross value of Brazilian harvest	US$ billion		65		
CALCULATED VALUES							
	Damage per ha of forest loss	Annual value	US$/ha/yr	10	19	38	
	Damage in 1990 caused by total population	NPV	US$ million	266	531	1062	(a)
		NPV per small farmer family	US$/family	209	417	835	(a)
		Total annuity	US$ million/yr	13	27	53	(b)
		Annuity per small farmer family	US$/family/yr	10	21	42	(b)
	1990 damage caused by small farmer population	NPV	US$ million	81	161	323	(a)
		NPV per small	US$/family	63	127	254	(a)

	farmer family					
1990 and all future damage caused by total population	NPV	US$ billion	5.3	10.7	21.3	(a)
	NPV per small farmer family	US$ thousand/ family	4.2	8.4	16.8	(a)
	Total annuity	US$ million/yr	267	533	1067	(b)
	Annuity per small farmer family	US$/family/yr	209	419	838	(b)
1990 and all future damage caused by small farmer population	NPV	US$ billion	1.6	3.3	6.5	(a)
	NPV per small farmer family	US$ thousand/ family	1.3	2.6	5.1	(a)
Value of forest stock in 1990	NPV	US$ billion	65	130	260	(a)
	NPV per small farmer family	US$ thousand/ family	51.1	102.1	204.2	(a)
	Annuity from value of forest stock	US$ billion/yr	3	7	13	(b)
	Annuity per small farmer family	US$ thousand/ family/yr	2.6	5.1	10.2	(b)

(a) At 5%/yr interest.
(b) At 5%/yr discount.

TABLE 5: SUMMARY OF "MEDIUM" ESTIMATES OF FOREST VALUE

Environmental value basis	Description	Units	Biodiversity	Carbon	Water	Total	Obs.
Damage per ha of forest loss	Annual value	US$/ha/yr	20	71	19	110	(a)
	NPV	US$/ha	400	1413	385	2198	(b)
Damage in 1990 caused by total population	NPV	US$ million	552	1950	531	3034	(b)
	NPV/small farmer family	US$/family	434	1532	417	2383	(c)
1990 and all future damage caused by total population	NPV	US$ billion	11.1	39	10.7	60.8	(b,d)
	NPV/small farmer family	US$ thousand/ family	9	31	8	48	(b,d)
	Annual value	US$ million/ yr	554	1950	533	3098	(e)
	Value/yr/ small farmer family	US$/family/ yr	435	1532	419	2387	(e)
Value of forest stock	Total NPV	US$ billion	135	477	130	742	(b)
	Annual value	US$ billion/ yr	7	24	7	37	(e)
	Value/yr/ small farmer family	US$ thousand/ family/yr	5	19	5	29	(e)

(a) Value of carbon and permanent sequestration annualized at 5%/yr.

(b) Biodiversity and water values are net present value (NPV).
(c) Carbon value same as NPV.
(d) Assuming no population growth either in total or in small farmer population, with deforestation remaining at 1990 rate for 100 years.
(e) At 5%/yr interest.