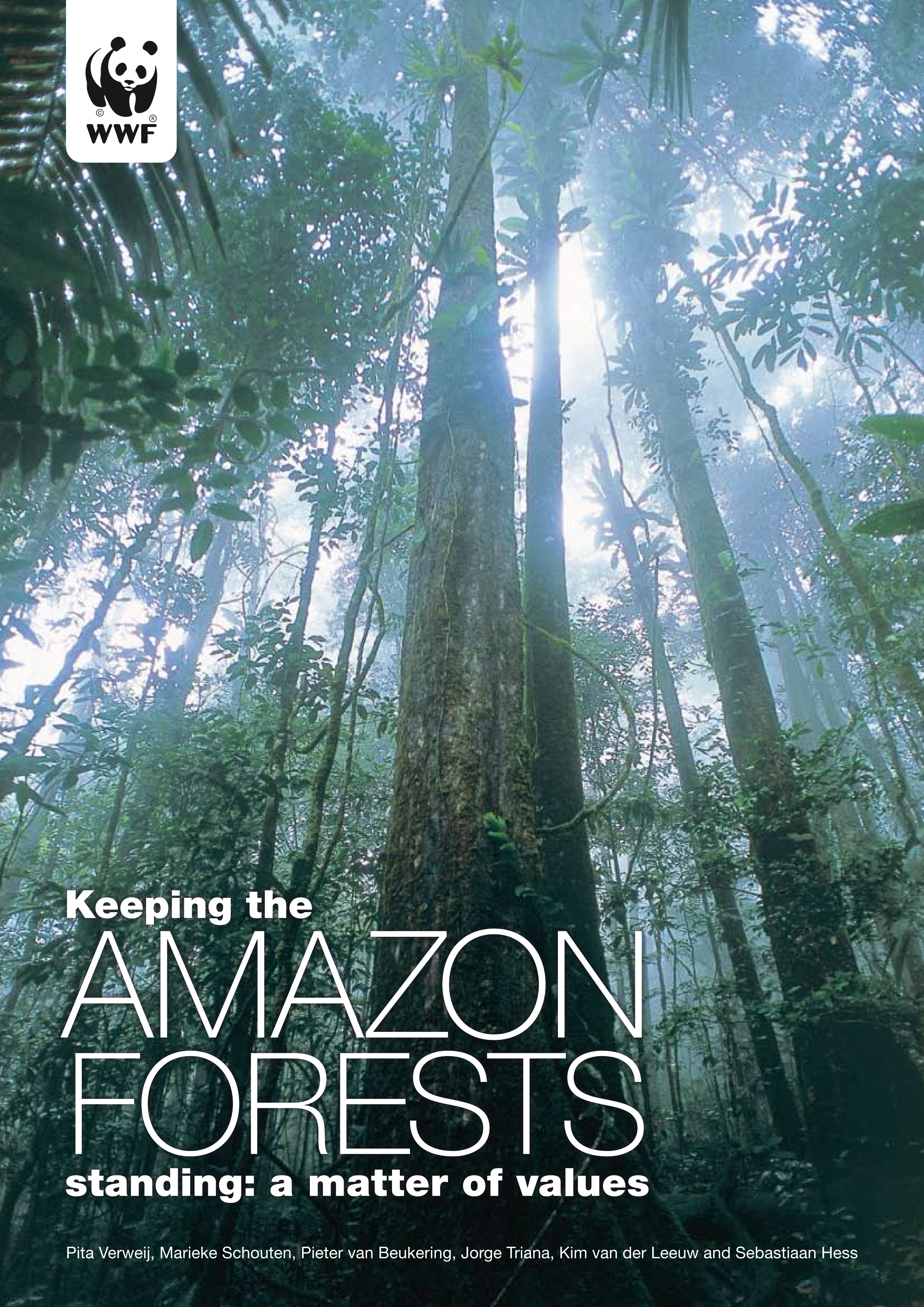

Keeping the AMAZON FORESTS standing: a matter of values

Pita Verweij, Marieke Schouten, Pieter van Beukering, Jorge Triana, Kim van der Leeuw and Sebastiaan Hess

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Summary

This report shows that investments in forest ecosystem services can form a powerful counter to the current disastrous developments in the Amazon. Ecosystem services are the benefits the ecosystem supplies to mankind – benefits on which our very existence in large measure depends. In view of this country's position and responsibility for the Amazon, this is a unique opportunity for the Netherlands to take the lead. But it must be done now!

Developments in the Amazon are alarming. Our image of the Amazon as an endless green carpet, pierced only by glistening rivers, is now only partly true. Historically, the most important cause of deforestation and forest degradation has been the expansion of cattle ranching, but additional threats have emerged recently. The expansion of soy cultivation in a number of Brazilian states is driving the ranchers deeper into the forest, making it a significant indirect cause of indirect deforestation. Immense infrastructure projects are planned (roads, dams, making rivers navigable) that will give access to large areas of the Amazon, leading to economically viable soy cultivation there, too. The western part of the Amazon, which is extremely humid, has not previously been very accessible. This region houses many different native communities and contains areas of the greatest biodiversity. It is precisely there that large areas of land have been allocated as oil and gas exploration concessions. The development of palm oil plantations also forms a significant potential threat for the future.

These developments mean that humankind has involved the Amazon in a huge experiment, with an unpredictable outcome. The widespread changes in land use are releasing vast quantities of carbon to the atmosphere. These emissions are contributing significantly to global climate change. In the near future we expect an increase of drought in the Amazon, as cattle ranching and soy cultivation disrupt the hydrological balance. New damage will be done by more forest fires, caused by forest degradation: a vicious circle, amplified by climate change. In the south of the continent, too, agriculture will be harmed as the Amazon generates less precipitation.

We need a new economic approach to maintaining the ecosystem services in this forest as best we can. This report shows the potential offered by marketing the ecosystem services supplied by the Amazon. Healthy forests offer a treasure trove of biodiversity, they supply clean water, mitigate erosion, allow crops to be pollinated and produce raw materials and foodstuffs such as timber, honey, rubber and fruits. Local communities depend significantly on these services and products. The Amazon forest plays an important part in the water circulation, both regionally and on the continental scale. The CO_2 stocks held in intact forest ecosystems also play a vital part in managing the climate problem. Deforestation of the Amazon leads to effects that can scarcely be expressed in monetary terms. Or can they?

The table on the next page presents a number of significant ecosystem services provided by the Amazon forest and the related economic values, as far as they are known. The studies and the assumptions on which these figures are based are explained in the report. These values cannot simply be added together. It is also important to note that the markets for these ecosystem services are either not available, or are still in their infancy. This does not imply that society does not benefit from these ecosystem services.

Ecosystem services	Economic value
Production of non-timber forest products	50-100 US$ per ha per yr
Production of timber, net present value of Reduced Impact Logging (not necessarily sustainable production)	419-615 US$ per ha
Erosion prevention	238 US$ per ha per yr
Fire protection	6 US$ per ha per yr
Pollination of coffee plantations from forest (Ecuador)	49 US$ per ha per yr
Disease protection	unknown
Carbon storage: 1) damage avoided due to CO_2 emissions avoided 2) value of total carbon stored in intact forest	70-100 US$ per ha per yr 750–10,000 US$ per ha
Maintenance of biodiversity	unknown
Cultural and spiritual aspects of the forest	unknown
Existence value	10-26 US$ per ha per yr
Recreational and ecotourism use	3-7 US$ per ha per yr

A new, sustainable approach offers great opportunities to improve the standard of living among the local communities, thus increasing support for forest conservation. Therefore timber should be produced as sustainably as possible by selective harvesting and long recovery periods, preferably under an FSC certification scheme. The sustainable exploitation of non-timber forest products and the development of ecotourism can also help generate income, while leaving the forest substantially intact. These strategies, though, are inadequate as a counter to the economic forces currently at work, so it is important to instantiate other values offered by the forest.

If one ascribes a value to the immense quantity of carbon stored in the Amazon forest, this could tip the balance from unsustainable to sustainable forest management. Under the post-2012 climate policy, industrialised nations will start to pay for forest conservation in tropical countries under the REDD mechanise (Reduced Emissions from Deforestation and forest Degradation). The carbon that remains stored in the forest by avoiding deforestation and forest degradation is allocated a cash value. Local communities would be able to profit from these payments if they demonstrably contribute to the preservation of the carbon stored in the forest ecosystem. Even now, in fact, a voluntary market is developing in which parties can partly compensate for their greenhouse gas emissions by investing in tropical forest conservation. On balance it is expected that REDD will generate new, substantial cash flows for forest conservation.

The Amazon forest supplies yet another, important global ecosystem service: preservation of biodiversity. That is why industrialized countries should contribute to the maintenance of biodiversity in the tropical forest, in analogy to the carbon market. There is as yet no global market for the maintenance of biodiversity.

The unsustainable exploitation of the Amazon's natural resources must also be cut dramatically. In this regard the Netherlands bears a great deal of responsibility as one of Brazil's largest trading partners and Europe's largest soy importer. The Dutch consumer, financial and business institutions, as well as the Dutch government all bear their share of the responsibility. The total area under soy cultivation Brazil needed to supply the Dutch market was 25.3 million ha in 2005: This corresponds to more than one-half of the Netherlands. It is larger than the area of the Netherlands under agriculture. The cattle industry in the Netherlands will have to drastically reduce its dependence on soy. Dutch consumers could also eat far less meat. Dutch financial institutions could invest far more in sustainable products and markets in the Amazon, with government facilitation and subsidy where needed. All major investments in industrial agriculture and infrastructure have hitherto had often adverse effects. They should be critically assessed.

Time is of the essence. The increasing demand for soy, meat, biofuels and other vegetable raw materials will amplify the call for more infrastructure, leading to deforestation at an ever increasing pace. If 30 to 40% of the forest cover were to disappear, it is expected that the major, large-scale disruptions that would ensue would become irreversible. We have already come half-way to this critical level. We need to take urgent action to avoid reaching the ecological tipover point. The values offered by the forest must be utilised as much as possible to maintain the Amazon ecosystem and the services it offers humanity.

1 Introduction

The Amazon forest biome represents an ecological region where the largest terrestrial stores of biodiversity and carbon are found. About 40% of the earth's remaining tropical rain forests lie in the Amazon region. Over the past 20 years, deforestation in the Amazon has consumed an area of at least half a million square kilometres. This threatens the livelihoods of the local population, including indigenous cultures dependent on the forest, and the provision of ecosystem services of vital importance to mankind. The processes of deforestation in the Amazon region have become increasingly complex as global market forces have been added to the local drivers of deforestation.

Effective strategies to contain the advancing deforestation require an understanding of both the processes driving deforestation and the nature of its impact. This trend can only be reversed if national and international policy makers and the public at large are made aware of the broad range of values at stake, the severity of the current and expected impacts, and the often indirect ways in which they are inflicted. The present study surveys the most important ecosystem services provided by the Amazon biome, the values they represent, and the current trends and drivers of forest degradation threatening the Amazon. Special emphasis is given to the role of the Netherlands, demonstrating the way in which the Dutch economy contributes to Amazon deforestation and identifying policies to minimize further loss and degradation of the Amazon's forests.

Various influential reviews of Amazon studies have appeared during the last two years, which this study aims to supplement. Published last year by WWF, "The Amazon's Vicious Cycles" seeks to determine how close we are to a point of no return leading to a major forest "dieback" in the Amazon, and to identify some steps that might be taken to counteract this process (Nepstad, 2007a). The WRI report "Human Pressure on the Brazilian Amazon Forests" compiles and integrates geospatial information on various indicators to present a picture of the human pressure on forests in the Brazilian Amazon (Barreto et al., 2006). Greenpeace International reviewed the contribution of the Netherlands to global deforestation and identified the Brazilian Amazon as the most affected forest region (Grieg-Gran et al., 2007). Our study supplements these major publications as it values the potential loss of the vital ecosystem services currently provided by the Amazon, thus providing an explicit picture of the costs and benefits of further deforestation and forest degradation in the Amazon.

Inevitably, the study focuses closely on the Brazilian Amazon, not just because only limited data are available for the other Amazon countries but also because the influence of the Dutch economy on the fate of the Amazon forest is strongest in this region.

2 Ecosystem services provided by Amazon forests

The Amazon biome provides a number of ecosystem services of vital importance to mankind. This chapter describes the main ecosystem services, following the classification provided by the Millennium Ecosystem Assessment (2005): i) support of human life; ii) provision of services that people rely on to make a living; iii) regulation of other natural systems; and iv) cultural services. In the context of valuing the Amazon biome, special care is needed to avoid double accounting when considering 'supporting' services. Life support functions of ecosystems are considered 'intermediate services', i.e. they enable humans to use the other three categories of services and are therefore not valued separately. This careful use of the ecosystem services approach is shown in Figure 1.

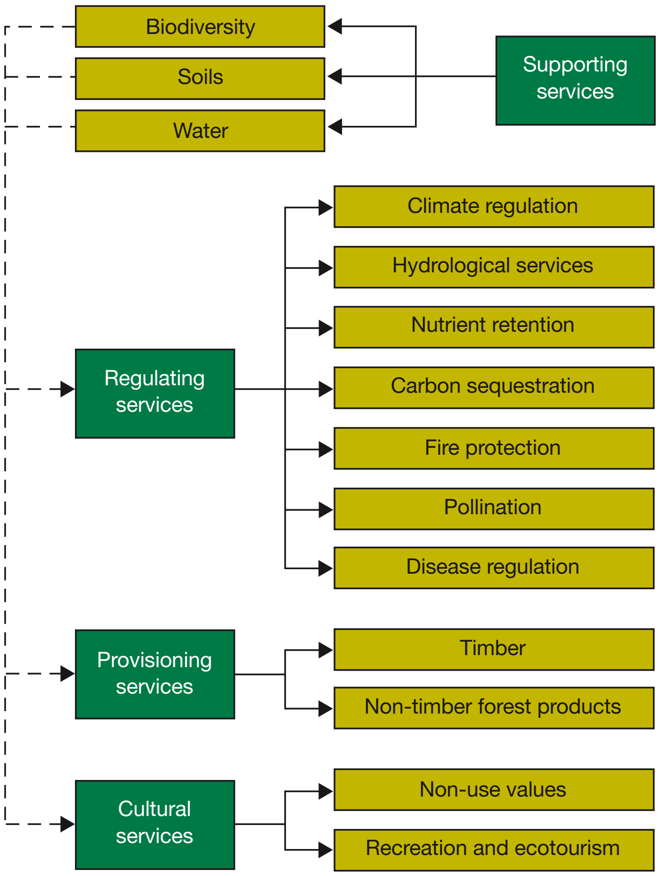


Figure 1 *Ecosystem services approach used to identify the main values of the Amazon.*

The following section surveys the different ecosystem services. The type of function is explained and scientific evidence is reported. Where possible, the ecosystem service is quantified in physical terms, and if information on economic values of the services in the Amazon is available, monetary values are reported as well. However, despite the significant efforts made to collect information this survey is by no means complete and all-encompassing.

2.1 Supporting services

Supporting services are services that are necessary to sustain all other ecosystem services. Their impact on people is either very indirect or occurs over a very long time (Millennium Ecosystem Assessment, 2005). Supporting services represent an insurance value, which is highly significant but very difficult to value (Turner et al., 2003). Primary production, habitat provision, soil formation and retention, and nutrient cycling are examples of supporting services. Here we describe supporting services linked to the three main building blocks of the Amazon system: Soil, Water and Biodiversity.

2.1.1. Soil formation

More than 75% of the Amazonian forest is underlain by oxisols, ultisols and alfisoils, old infertile loamy and clayey soils. Due to the geological history and effect of high temperatures and heavy rainfall, these soils are generally nutrient-poor compared to soils in other parts in the world. Millions of years of weathering and leaching have removed the nutrients from the minerals that form the parent material of the soil. Moreover, the presence of high concentrations of aluminium and hydrogen also means that soils in the Amazon are not very well equipped to retain the nutrients that leach down from decomposing organic matter (Jordan, 1985). The soils on floodplains are considerably richer in nutrients as they are fed by river sediments.

Besides the geological, temporal and climatic processes described above, biological processes also play an important role in soil formation. In natural systems, vegetation and soil fauna largely determine the composition of the upper part of the soil, the so called humus forms. These humus forms act both as sinks and sources of carbon and nutrients, determining for instance the habitat for decomposer organisms, controlling aeration, moisture, and nutrition for plant roots, and protecting the soil against erosion (Duivenvoorden & Lips, 1995). However, their position close to the surface means that humus forms are very sensitive to disturbance caused by deforestation, for example.

The nutrient balance of the soils is influenced by nutrient input from the weathering of parent material, throughfall and stemflow of rain and litter fall, and nutrient losses related to leaching. In the process of litter decomposition by micro-organisms, nutrients are released into the mineral soil and can be absorbed by plant roots. Since the parent material of the Amazonian soils is relatively nutrient poor there is a great urge to recycle nutrients as optimally as possible. The nutrient cycle in an undisturbed forest ecosystem is closed, preventing unnecessary loss of nutrients (e.g. Golley, 1983; Jordan, 1985, 1989).

2.1.2. Water cycling

Water is one of the main features of the Amazonian landscape. The Amazon and its affluents form the largest river system of the world, with catchment areas covering more than six million square kilometres (Junk & Furch, 1985; Neill et al., 2006). The total river system, located in seven countries, is 3300 km long. About 15% of all fresh water on earth transported by rivers to the oceans passes through the Amazon river (Salati & Vose, 1984, Neill et al., 2006, D'Almeida et al., 2007). This volume of water equals that of the earth's next six largest rivers together (Pekárova et al., 2003; Neill et al., 2006). Despite the massive appearance of the mainstream Amazon, most water enters the system via small watersheds (Neill et al., 2006).

A very important property of the water is its ability to dissolve many solid and gaseous substances, such as dissolved organic carbon and nitrogen, carbon dioxide and oxygen. Due to the huge quantity of water present in Amazonia, its solvent property is vital to the ecosystems' functioning. Moreover, this sheer magnitude means that the hydrological cycle of the Amazon river system constitutes a key component of global climate, which section 2.2 explains further.

2.1.3. Biodiversity conservation

Biodiversity conservation is an important ecosystem service that supports many of the functions of tropical rainforests (e.g. Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). Tropical rainforests form a major source of biological diversity (Figure 2). More than half of the world's species occur in tropical rain forests, even though rain forests occupy only 7% of the total land area worldwide (Whitmore, 1998).

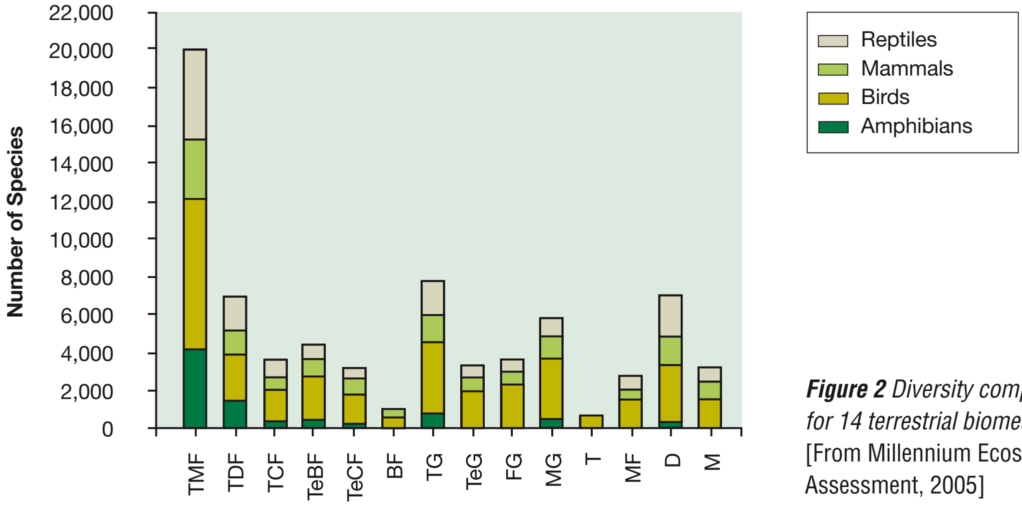


Figure 2 *Diversity comparisons for 14 terrestrial biomes.* [From Millennium Ecosystem Assessment, 2005]

TMF: Tropical and sub-tropical moist broadleaf forests
TDF: Tropical and sub-tropical dry broadleaf forests
TCF: Tropical and sub-tropical coniferous forests
TeBF: Temperate broadleaf and mixed forests
TeCF: Temperate coniferous forests
BF: Boreal forests/ taiga
TG: Tropical and sub-tropical grasslands, savannas and shrublands
TeG: Temperate grasslands, savannas and shrublands
FG: Flooded grasslands and savannas
MG: Montane grasslands and shrublands
T: Tundra
MF: Mediterranean forests, woodlands and shrub
D: Deserts and xeric shrublands
M: Mangroves

Darwin & Wallace (1858) already hypothesized that biodiversity might exert an impact on ecosystem processes by enhancing productivity. The vast majority of experiments done since then (reviewed by McCann, 2000 and Chapin III et al., 2000) confirm this positive relationship. The Amazon rainforest accounts for 10% of the world's terrestrial primary production (Melillo et al., 1993; Houghton et al., 2001).

About 40% of the world's remaining tropical rainforest is located in the Amazon. It is presumed that these Neotropical rainforests are the most species-rich in existence (Gentry, 1988a). A remarkable fact is that 200 to 300 tree species can frequently be found within one ha of Amazon forest – more than in the entire European Union. Rylands et al. (2002) estimated that at least 40,000 plant species, 427 mammals, 1294 birds, 378 reptiles, 427 amphibians and about 3,000 fish species are represented within the Amazon biome (Silva et al., 2005). Western Amazonia in particular, with its extraordinarily large numbers of tree, bird, butterfly, reptile, amphibian and mammal species (see references in Gentry, 1988a), has a species diversity unrivalled by any other place on earth. Forests in eastern Amazonia, especially the Guianas, are, for example, generally less rich in plant species (ter Steege, 1998; ter Steege at al, 2000) and mammal species (Kay et al., 1997; Voss & Emmons, 1996). Besides large numbers of species, the Amazon biome also contains many, large areas of endemism, housing species that do not occur elsewhere.

Presenting an overall picture of the biodiversity of the Amazon biome is greatly hampered by a lack of data. Our knowledge of the diversity and distribution of species in the Amazon biome is still at an early stage of development (Silva et al., 2005; Peres, 2005). Although Amazonia has welcomed a steady stream of scientists since the beginning of the 18th century (e.g. von Humboldt, Bates, Spruce, Wallace) and a huge number of books and articles on its diversity are available (Pitman et al., 2007), few basic field data are available on the species diversity of Amazonia, while such as do exist give a very fragmented impression of the region. Large parts of the region are still unexplored by scientists and many of the specimens that have been collected to date have not yet been studied (Silva et al., 2005). Peres (2005) illustrates our limited knowledge of species diversity and distributions in the Brazilian Amazon with figures on recently discovered species. For example, new bird species are being found at an annual rate of 2.3 species a year, while, since 1990, 10 new primate species have been described. Moreover, he estimates that over 50,000 higher plant species still remain to be discovered within the Brazilian Amazon. Understanding the extent of insect diversity in the humid tropics is one of the major challenges in modern ecology (Godfray et al., 1999). The fact that only a fraction of tropical insects (certainly less than 20%) has been properly described is certainly not the least of the problems in this respect.

Bio-geographical patterns in terrestrial species composition

In relation to biodiversity conservation, it is important to note that species are not homogeneously distributed over Amazonia. After the first scientific expeditions to the region, the idea emerged that Amazonia comprised several different bio-geographical regions. By studying the distribution ranges of primates, Wallace (1852) recognized four different districts: Guyana, Ecuador, Peru and Brazil. Later studies of the biogeography of lowland bird species subdivided Wallace's four districts into seven distinct districts. The Ecuador district was split into two (Imeri and Napo), the Peru district was renamed Inambari, and the Brazil district was divided into three (Rondônia, Pára and Belém). This division has since been corroborated by studies of different taxonomic groups (Hall & Harvey, 2002, see also Figure 3).

Many hypotheses have been proposed to explain the large number of (endemic) species and the patterns found in the distribution of species diversity (Haffer, 1997). One of the oldest, the river or riverine barrier hypothesis, originates from the work of Alfred Russel Wallace. The bio-geographical districts Wallace defined are delineated by the major Amazonian rivers. The river hypothesis states that broad rivers form a barrier; the distribution ranges of animal species are restricted by rivers. In this way, once widespread, uniform populations became divided into isolated sub-populations when the Amazonian rivers developed, allowing speciation to occur in regions physically isolated by river barriers (e.g. Ayers & Clutton-Brock, 1992).

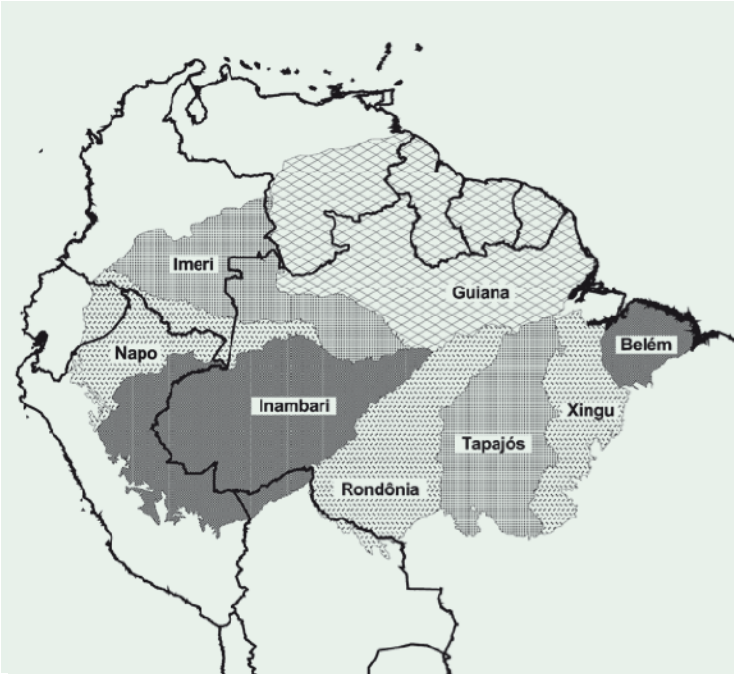


Figure 3 *Amazonian lowland areas of endemism based on the distribution ranges of terrestrial vertebrates.* [From Silva et al., 2005]

For a long time Amazonia was thought to be a stable, safe environment throughout most of the Cenozoic Era. Due to this environmental constancy, combined with high productivity due to high temperatures and humidity, levels of extinction were low and speciation high, so species were able to accumulate over time (e.g. Darlington, 1957; Ashton, 1969). However, pollen records, for example, revealed that Amazonia was subject to considerable environmental changes in the Quaternary (e.g. van der Hammen & Gonzales, 1960; Hooghiemstra, 1989). Haffer's refugia hypothesis (Haffer, 1969) provides an explanation for the occurrence of a number of high-diversity areas in the Amazon. According to this hypothesis the forest became fragmented several times due to the hostile climatic conditions during the arid periods of the Quaternary. The remaining forest formed stable, isolated patches in a matrix of savannah-like vegetation that served as 'refugia' for the flora and fauna. Over time these species started to evolve divergently, resulting in areas of high species richness and endemism. There has been much debate on Haffer's theory; Mayle et al. (2004) for example argued that the landscape matrix largely consisted of dry forest instead of savannah vegetation.

Patterns in terrestrial species diversity

Clear regional and local differences in species diversity can be observed within the Amazon biome. Existing studies of present-day biodiversity tend to cover limited areas. Ter Steege's work represents a significant exception, presenting the larger picture for the entire Amazon basin. Using data from 268 forest inventory plots, ter Steege et al. (2000) found that plots in the Guiana Shield area and eastern Amazonia usually have a lower tree diversity than those in central or western Amazonia. Using data of large forest inventories from seven countries, ter Steege et al. (2006) show two dominant gradients in tree species diversity across the Amazon. The first stretches from the Guiana Shield to south-western Amazonia, paralleling a major gradient in soil fertility. The other reaches from Colombia to south-eastern Amazonia, paralleling a gradient in dry season length.

Climate (Gentry, 1988b), soil fertility (Huston, 1980), geomorphology and other environmental gradients (Duivenvoorden & Lips, 1995; ter Steege, 1998), are thought to have a major influence on local diversity patterns in the Amazon rainforests. Variation in local diversity patterns can have especially significant implications for nature conservation. If the rate of species turnover across landscapes (or beta diversity) is high, it means that large areas are needed in each bio-geographical region to protect representative

samples of biodiversity. Indeed, there is considerable variation in species composition over short distances (Tuomisto et al., 1995; Condit et al., 2002). In terra firma forest in Peru, neighbouring 1 ha plots share only 55% of their species (Condit et al., 2002). Similarity declines rapidly with distances up to 5 km, with plots at distances of 5 to 100 km sharing only 30-40% of their species.

Aquatic diversity

Compared to terrestrial species, little attention has so far been paid to the distribution patterns of freshwater species in the Amazon and its tributaries. The study by Fernandes et al. (2004) forms one of the few exceptions. They surveyed electric fish species across a 2000 km transect of the Amazon basin and found that tributaries have a large, but local, positive effect on the mainstream species richness at confluences. The downstream species accumulation hypothesis (Matthews, 1998) was not confirmed by these results. Diversity was highest in the tributaries, while it also became clear that the Amazon River encounters distinct bio-geographical units as it cuts across the basin.

2.2 Regulating services

Regulating services refer to the benefits obtained from the regulation of ecosystem processes, and therefore to indirect use values of ecosystems.

2.2.1. Climate regulation

The sheer size of the system means that the energy and moisture cycles in the Amazon region play an important role in the regulation of climate at different scales. About 1350 to 1570 mm of rainfall per year, corresponding to 63–73% of the annual rainfall, evaporates or transpires in the Amazon (Costa & Foley, 1999; Marengo & Nobre, 2001; Malhi et al., 2008).

Because vegetation cover partly determines the albedo (the fraction of incoming radiation that is reflected), water cycle and CO2 storage, vegetation exerts a powerful influence on the climate. It is estimated that more than 70% of the forest cover of the Amazon landscape may be necessary to maintain the forest-dependent rainfall regime (Silva Dias et al., 2002 in Soares Filho 2006). Deforestation can therefore lead to substantial changes in local and regional climate.

Many published studies have used atmospheric general circulation models (AGCMs) to assess the possible effects that deforestation of (parts of) the Amazon biome may have on the global and regional climate (e.g. Nobre et al., 1991; Marengo & Nobre, 2001; Werth & Avissar, 2002). Costa & Foley (2000) compared nine such studies and came to the conclusion that several generalizations can be made regarding the outcomes of these simulations.

- All nine AGCM deforestation simulations reviewed showed a significant increase in temperature and a significant decrease in evapotranspiration over the Amazon basin after deforestation.
- Most of the AGCM simulations pointed towards a significant decrease in precipitation over the Amazon basin after deforestation. This effect is questioned by other authors, though (e.g. Negri et al., 2004). For example, Chagnon & Bras (2005) found that significantly more rainfall occurred over deforested areas in the Amazon. This may be due to the fact that rainfall's natural variability is very large in both space and time (Bruijnzeel, 2004).

The effect of atmospheric warming and a decrease in evapotranspiration may be to weaken moisture recycling and deep convection in the atmosphere over the Amazon. This has major implications for the climate of South America (e.g. Nobre et al., 1991; Costa & Foley, 2000). The influence of deforestation on climate may also extend far beyond the region. As it is one of the three major convection centres in the tropics, the Amazon helps to fuel the Hadley and Walker circulations. The Amazonian rainforests therefore play a crucial role in regulating the general circulation of the atmosphere. The atmospheric circulation modulates surface temperatures over land and sea, and determines rainfall patterns. Disturbance of the rainforests may therefore also have major implications for the global climate. Werth & Avissar (2002) illustrate this potential for "teleconnections" from Amazonian climate change, causing changes in the climate of other regions outside the tropics.

There is a clear hydro-climatological connection between the Amazon and the adjacent La Plata River basin extending far into Argentina. The Amazon forests play an important role in the "leap-frogging" transport of moisture across the continent (Sudradjat et al., 2002). Moisture from the tropical Atlantic Ocean contributes 32% to precipitation in the Amazon. After evaporation, moisture is transported to the La Plata river basin where it contributes about 19% to precipitation. Fearnside (1997) estimated the value of water cycling at US$ 19 per ha per year by estimating the economic damage to Brazilian agriculture outside the Amazon per ha of forest loss. The assumption was that 10% of agricultural harvest depends on water from the Amazon. Andersen (1997) estimated the Net Present Value of water cycling at US$ 1000-3000 according to productivity loss.

2.2.2. Hydrological services

Globally, about 16 million has of arable land are lost as a result of soil degradation and erosion each year. Soil erosion is one of the most serious threats to the sustainability of agriculture, silviculture and forestry in the Amazon (Smith et al., 1991). Various studies have shown that natural ecosystems are more efficient in controlling erosion than systems that remove the understorey or litter layer, as in forest plantations or overgrazed pastures (e.g. Wiersum, 1984; Bruijnzeel, 2004).

More specifically, natural forest ecosystems provide the following hydrological services that contribute to erosion control (Bonnel & Bruijnzeel, 2005; Bruijnzeel, 2004; Wiersum, 1984):

- ***Regulation of runoff.*** Runoff is the surface water flow after precipitation, which occurs because not all precipitation infiltrates into the soil. Runoff is a major cause of erosion on hill slopes. The water flow transports the fertile topsoil particles downstream. A dense vegetation cover can mitigate runoff, as 1) it increases the permeability of the topsoil for water and 2) it slows the velocity with which raindrops hit the soil surface. Severe erosion can have serious environmental impacts, since vegetation recovery is inhibited once the topsoil layer is removed.
- ***Sediment control.*** Vegetation can trap sediment from rivers because it slows the speed of flowing water.
- ***Regulation of flooding.*** Flooding is a crucial process in Amazon as Várzea forests are inundated regularly, which results in nutrient rich mineral soils. The absence of flooding implies a loss of nutrients.

The estimated cost of on-site soil erosion in the Amazon is US$ 68 per ha per year. Downstream or off-site costs are difficult to estimate but a ratio of 2:5 gives US$170 per ha per year (Torras, 2000), resulting in a total value of soil erosion prevention of US$ 238 per ha per year.

2.2.3. Nutrient retention

The relatively poor soil of the Amazon has a closed nutrient cycle. Nutrients added to the soil by litter decomposition and rainfall are directly taken up gain by shallow rooted tree species. Disturbance of the natural vegetation can imply a significant loss of nutrients from the system, as a result of soil erosion, for example. The replacement method can be used to assess the value of e.g. nutrient losses resulting from soil erosion. Uhl et al. (1993) estimated the value of nutrients removed by forest clearance at US$ 3480 per ha according to the market prices of NPK fertilizers.

2.2.4. Carbon sequestration

Tropical forests play an important role in the world's carbon balance. The Amazon basin plays an important role in the global carbon exchange because it stores large amounts of carbon in biomass, both above ground and in the soil (see Tables 1 & 2). The Amazon forest vegetation in Brazil alone contains 70 Pg of carbon (C), which is between 10% and 15% of all terrestrial carbon (Keller et al, 1997; Houghton et al. 2001).

Table 1 **Carbon pools (Mg C ha^{-1}) for a range of natural tropical forest sites in the Brazilian Amazon.**

Carbon in biomass	Carbon in coarse woody debris	Carbon in ecosystem	Reference
281	41.1	447	Malhi et al., 1999
143.7 ± 5.4	48.0 +/- 5.2		Rice et al, 2004
105.8 ± 23.7			Fearnside et al., 2007
140.81 - 174.49			Saatchi et al., 2007
177 ± 17			Houghton et al., 2001
156-164			Chambers et al., 2001
		291-495	Alves et al., 1997
284.7-327.6	35.6-48.1	332.8-363.2	Uhl et al., 1988
177.8	39.1	216.5	Fearnside, 2000

All soils in the Brazilian Amazon may contain up to 136 Pg of carbon, of which is located in the uppermost meter (Fearnside & Barbosa, 1998). Soils covered by natural forest have the highest carbon density (Lal, 2005).

Table 2 Soil Organic Carbon (SOC) stocks (Pg C) of natural tropical forest in the Brazilian Amazon.

C in soil	Depth (in cm)	Reference
136	0-800	Fearnside & Barbosa, 1998
47	0-100	Fearnside & Barbosa, 1998
47	0-100	Moraes et al., 1995
41	0-100	Cerri et al., 2000
23.4	0-30	Cerri et al., 2000
25	0-30	Batjes & Dijkshoorn, 1999
22.7 ± 2.3	0-30	Bernoux et al., 2002
23.9 - 24.2	0-30	Batjes, 2005
21	0-20	Moraes et al., 1995
32.6	0-20	Cerri et al., 2007a (Century)
27.0	0-20	Cerri et al., 2007a (RothC)
26.9	0-30	Cerri et al., 2007a (IPCC)

There are two main forms of carbon: organic (such as biomass of plants) and inorganic (e.g. CO_2 in the atmosphere). Photosynthesis in plants turns organic carbon into inorganic carbon, which is either stored in biomass or turned back to its inorganic form (CO_2) by decomposition or soil respiration. This CO_2 can either return to the atmosphere or enter the rivers: alternatively, it can react with soil minerals to form inorganic dissolved carbonates, which remain stored in the soils or wash out into the rivers. In rivers, organic and inorganic forms of carbon exist in approximately equal proportions (Raymond, 2005). It was shown only recently (Mayorga et al., 2005) that a significant amount of terrestrial carbon in the Amazon basin decomposes to CO_2 and is cycled back in to the atmosphere through the basin's network of rivers, which 'breathe' CO_2 out in a process also known as degassing. However, the CO_2 added back to the atmosphere by degassing originates from the decomposition of organic carbon from recent plant growth and does not represent extra inputs of greenhouse gases.

Since the start of the last century there has been a steady rise in atmospheric CO_2 concentration. However, the sum of emissions of greenhouse gases due to fossil fuel consumption and land use change is currently higher than the net volume of CO_2 absorbed by the oceans and terrestrial biomes (Houghton et al., 1998). It became also clear that there was an unaccounted terrestrial carbon sink in the global carbon cycle. This budget mismatch, initially called the 'missing carbon sink', which led to years of discussion on where this so far unaccounted-for carbon sink could be located (Ometto et al., 2005). Some authors claim that the Amazon is a carbon sink (see Table 3), potentially absorbing 0.44–0.56 Pg (10^{15} g) C per year (Grace et al., 1995; Phillips et al., 1998; Malhi et al., 1998) based on a carbon uptake of 1 to 6 Mg C ha^{-1} $year^{-1}$. This would be the result of the fertilization effect of the increased CO_2 concentrations in the atmosphere. Others argue that the Amazon is neutral with respect to carbon because emissions from deforestation, decomposition and fire, are balanced by uptake by forests and vegetative re-growth (Houghton et al., 2000; Schimel et al., 2001). Yet others hold that the Amazon even acts as a carbon source (Saleska et al., 2003; Rice et al., 2004; Wright, 2005).

Table 3 Carbon flux in Mg C ha^{-1} $year^{-1}$ from above ground biomass.

C flux	Method	Source or sink?	Reference
-1.9 +/- 1.0	2 year, eddy covariance	source	Rice et al., 2004
+1.0	<1 year 1993, eddy covariance	sink	Grace et al., 1995
+5.9	1 year 1995-1996, eddy covariance	sink	Mahli et al., 1998
+ 0.71 +/- 0.34	< 2 ha sites, 1975-1996	sink	Phillips et al., 1998
-1,3	3 year, eddy covariance	source	Saleska et al., 2003
-3.0 to +0.75	LBA	source/ sink	Ometto et al., 2005
-4.03 to 2.22	2 year, Bayesian model approach	~	Sierra et al., 2007
+0.38	tree measurements, site in Ecuador	sink	Chave et al., 2008
+1.27	tree measurements, site in Colombia	sink	Chave et al., 2008
-0.2 to +0.7 Pg C year	15 year, Terrestrial ecosystem model	sink of 0.2 Pg C per year	Tian et al., 1998

Uncertainty about the Amazon's role as a net carbon source or sink reflects the limited availability of data on forest biomass stock and uptake rates across this ecologically heterogeneous region (Phillips et al., 1998; Watson et al., 2000). Measuring carbon fluxes is complex and the various methods applied each have limitations (Houghton, 2003b). In addition, interannual variation in climate and atmospheric CO_2 concentrations alter carbon uptake rates and forest flammability (Tian, 1998; Nepstad et al., 2001; Watson et al., 2000; Wright, 2005; Chave, 2008). Studies cover a short period of time, of several years or a few decades only.

Despite the uncertainties mentioned above, and given the considerable regional and interannual variation in carbon fluxes, more recent studies reflect a growing consensus among scientists that old-growth tropical forest ecosystems may currently be acting as a strong CO_2 sink (e.g. the review of Stephens et al., 2007). Recent investigations by Phillips et al. (2008) show that the carbon taken up by old-growth forest and the carbon emissions from deforestation in the Amazon are currently in balance. Further deforestation and forest degradation would initiate a switch from sink to source.

The potential value of sequestering or emitting carbon in the Amazon can be determined in different ways. One the one hand, the value can de derived from currently emerging international markets for trade in avoided carbon emissions. Tropical deforestation is responsible for about 20% of global greenhouse gas emissions. Moreover, because investing in the conservation of carbon sinks in developing countries is economically more efficient than avoiding greenhouse gas emissions in developed countries, the international community is willing to pay to prevent such releases resulting from the conversion of rainforest. Market values are shown in the first rows of Table 4. On the other hand, carbon sequestration can be valued on the basis of the avoided damage caused by climate change. The remaining rows of Table 4 illustrate the wide range of available estimates of the marginal costs of climate change. The main parameters determining these variations are the level of the benchmark estimates of climate change, the time horizon and discount rate selected, and the vulnerability to climate change over time.

Table 4 Value estimates for carbon sequestration.

Value	Reference	Comment
6.1 US$ per tonne CO_2	www.ecosystemmarketplace.com	OTC (Voluntary over-the-counter market) 2007
3.2 US$ per tonne CO_2	www.ecosystemmarketplace.com	CCX (Chicago Climate Exchange) 2007
24.3 US$ per tonne CO_2	www.ecosystemmarketplace.com	EU ETS (European Union Emissions Trading Scheme) 2007
9.0 US$ per tonne CO_2	www.ecosystemmarketplace.com	NSW (New South Wales Greenhouse Gas Abatement Scheme) 2007
100 US$ per ha per year	Brown & Pearce (1994)	Based on avoided damage due to deforestation, at US$ 10 per tonne CO_2
70 US$ per ha per year	Fearnside (1997)/ Torras (2000)	US$ 1.80 - 66 damage per tonne released CO_2 based on willingness to pay to avoid damage and carbon/gasoline taxes.
US$ 0.52-1.96 billion per year	Laurance et al. (2001)	Value of reduced carbon emissions from deforestation
US$ 1,500-$10,000 per ha	Chomitz (2007)	Based on storage of 500 tonnes of CO_2 per ha
US$ 750 – 6750 per ha	Andersen (1997)	Both direct and indirect methods

2.2.5. Fire protection

Humid tropical forests provide natural protection against wild fires. Various factors make disturbed forest more prone to fires than primary forest. The danger that a forest will burn depends on the level of fire hazard and fire risk: *fire hazard* is a measure of the amount, type, and dryness of potential fuel in the forest. Logged forest contains a relatively large amount of dry logging waste; *fire risk* is a measure of the probability that the fuel will ignite. In the presence of abandoned logging roads, which provide easy access to otherwise remote forests, the fire risk is significantly increased when settlers use fire for land clearance.

Andersen (1997) calculated a value of about US$ 6 per ha per year for the fire protecting service of Brazilian Amazon forest ecosystems, based on loss of timber.

2.2.6. Pollination

Pollination is a basic ecosystem service with an estimated global economic value between € 90 billion (Constanza et al., 1997) and € 160 billion (Kearns et al., 1998). Recently Gallai et al. (2008) calculated that the global economic value of pollination services provided by insects (mainly bees) in 2005 for the main crops (fruits, vegetables, and stimulants) was € 153 billion (~US$ 200 billion).

As individual trees of each species are often widely spaced, pollination in the Amazonian primary rainforest tends to depend on large, strong, flying pollinators, able to travel long distances, such as euglossine and carpenter bees, birds and bats (Prance, 1985). The following examples illustrate this for Amazonia:

- Species belonging to the Brazil nut family (Lecythidaceae) depend on euglossine and carpenter bees to produce their valuable harvest (Prance, 1985).
- The important Amazonian crop of Guaraná (*Paullinia cupana* HBK *var. sorbilis*) depends on the smaller Trigona and Melipona bees (Prance, 1985).
- Cowpea, *Vigna unguiculata* (L.) Walp., is a very important legume in the diet of the Amazon population. Over several years, the mean productivity of cowpea has declined. Vaz et al. (1998)

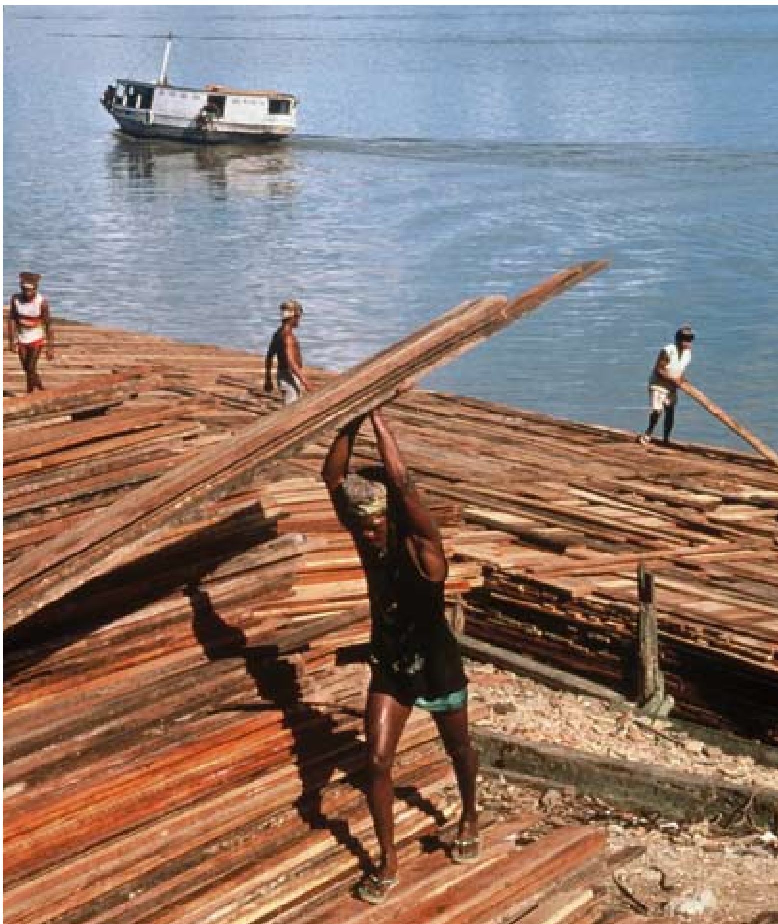
suggested that this is linked to a decrease in or an absence of pollinating insects in the fields.

- Cacao, *Theobroma cacao* L., is strictly dependent on pollination by midges (Klein et al., 2008).
- Species of the genus *Coffea* (coffee) are capable of autonomous self-pollination. This means that, in practice, they do not need pollinators for their reproduction. However, the benefits of cross-pollination have recently been investigated. Klein et al. (2003) showed that self-pollination lead to 45% initial fruit set, whereas cross pollination lead to 75%. Moreover, fruit weight proved to be 25% higher when pollinators had access to flowers.

The value of pollination services has not been quantified for the Amazon. Coffee, for example, is grown in the Amazon region, albeit not on a large-scale. According to data from the Ecuador Association of Coffee Growers (CORECAF), the Ecuadorian Amazon region contains approximately 130,000 has of coffee plantation. The following figures on production of Indonesian (Sulawesi) coffee (Priess et al., 2007) and coffee in Costa Rica (Ricketts et al., 2004) and Ecuador (Olschewski et al., 2006) give an impression of the value pollination services may represent in this sector. Deforestation can cause a direct reduction of coffee yields up to 18-20% and a decline of net revenues per ha up to 14% over a period of two decades. Forests in the studied provide pollination services with an estimated annual value of 46 per ha in Indonesia and US$ 60,000 per coffee plantation in Costa Rica. Olscheweski et al (2006) calculated that for a plantation in southern Manabí in Ecuador average pollination value represents 49 US$ per ha. These values are obviously valid for relatively small forest areas in the vicinity of such plantations. However, it can be an important motivation to maintain landscape mosaics of agriculture or plantations intertwined with patches of forest.

2.2.7. Disease regulation

Rainforests moderate the risk of infectious diseases by regulating the populations of disease organisms (viruses, bacteria and parasites), their hosts, or the intermediate disease vectors (e.g. rodents and insects). Changes in the environment (natural or human-induced) also affect the ecological balance and context in which disease hosts or vectors and parasites breed, develop, and transmit diseases (Patz et al., 2000). There is growing evidence that deforestation (or more general environmental changes and ecological disturbances) results in an increased spread and/or incidence of human infectious diseases (e.g. Vittor et al., 2006).



2.3 Provisioning services

2.3.1. Timber

An important provisioning service of the Amazon forest is the production of timber.
Based on a survey of sawmills, in 2004 the Brazilian timber sector harvested 24.5 million m^3 of roundwood, the equivalent of about 6.2 million trees, compared to 28.3 million m^3 in 1998. This reduction is ascribed to increased controls on illegal logging, the cancellation of hundreds of forest management permits due to a worsening of the land tenure crisis, and improved efficiency in wood processing (Lentini et al., 2005).

Brazilian data on timber production for the period 2002-2007 show the same trend (see Table 5). Production figures for logging are dropping, while the volume of timber products such as sawn wood is actually increasing.

Table 5 **Production of tropical timber in Brazil, in 1000 m^3.** ***[Source: ITTO, 2008]***

	2002	2003	2004	2005	2006	2007
Logs	28835	29700	28000	25000	22867	20517
Sawnwood	14168	14430	14500	15423	15777	16274
Veneer	300	300	300	300	300	300
Plywood	1100	1220	1380	1125	1147	1099

A number of studies have compared the costs and profits of conventional logging and Reduced Impact Logging (RIL: application of improved harvest techniques to minimize damage to the forest ecosystem). Barreto et al. (1998) found that RIL in primary forest in Pará, eastern Amazonia, is more profitable over the short and medium term than conventional logging. Short-term profits were US$ 1.81 higher per m^3 (i.e. US$ 3.68 extra profits minus US$ 1.87 management costs). Over the medium term, managed logging generally leads to higher NPVs as well, ranging from US$ 419 to US$ 615 per ha, depending on the discount rate and cutting cycle. For conventional logging the range is US$ 304 to US$ 562 per ha. The higher values for managed logging are mainly due from increased productivity and reduced timber wastage. Holmes et al. (2002) also reported higher profits for RIL: 45.7% compared to 38.6% under conventional logging.

An important question that remains to be answered however is whether sustainable forest management is possible, by applying multiple long rotation cycles of 20-40 years (Fredericksen & Putz, 2003). Typically, at the second harvest only 20-30% of the volume harvested at first harvest is available. This implies that there are important limitations to ecological and economic sustainability of poly-cyclic harvesting, even when applying relatively long rotation cycles.

2.3.2. Non-timber forest products

Another important service provided by the Amazon is the supply of non-timber forest products (NTFP). These products provide the people inhabiting the forest with both a means for living as well as a cash income. Moreover, some of these products, such as palm heart and natural rubber, have been marketed successfully.

Because of their commercial and private use, the value of this service cannot easily be calculated. The data collected on NTFPs by the Brazilian Institute for Statistics and Geography (IBGE) are considered sound (FAO, 1999; Viana et al., 2002), but at the least they ignore the subsistence use of the products. The most important forest products commercially traded in Brazil are food, oil products, fibres, rubber, aromatics and medicines, gums, and tannins. In 2005 the commercial value of NTFP products from the Brazilian Amazon was almost US$ 100 million.

Since statistics on commercial forest products only represent one dimension of NTFPs, attempts have been made to estimate the value of NTFP in other ways. For example, tracts of the Amazon have been studied in detail and inventories of all marketable goods have been made, using local market prices to determine their value. Other studies have focused on the contribution of NTFPs to the incomes of various groups of forest users.

Studies at the plot level, which assign economic value to large forest areas or to large numbers of species within a plot, are important in that they remind us of the potential wealth of NTFP resources compared to other forest uses (Neumann and Hirsch, 2000). However, they can give only a broad indication. For several reasons, generalisations of NTFP values over large tracts of forests, or even forests in other continents, are deemed inappropriate (Chomitz and Kumari, 1998):

- Transport costs are substantial and depend strongly on the distance to roads, for instance. Large portions of forests are far from roads and are therefore not suitable for the extraction of many forest products.
- Forests differ in the density of exploitable species, while some products may only fulfil a specific, relatively small demand.
- If forest products are successfully domesticated they may out-compete the original product. Production of Brazilian rubber, for example, was severely affected by expansion of rubber plantations in Malaysia.
- Reported potential values often do not account for costs and other factors that would impinge on the actual profitability of NTFP enterprises. Major costs include transportation, the need for marketing and advertising, storage, processing and training for collection, storage, processing and marketing.

Few studies reporting on the values of NTFPs exceed the plot level. The following studies, which do cover larger areas, provide further insights into the variation in NTFP values.

Intensification of NTFP production. The regional study by MunizMiret et al. (1996) reported on management of Açaí palm for fruit and palm heart in secondary forests and homegardens in the north-eastern Amazonian flood plains. The tree products are collected in both natural forests and cultivated plots. The annual domestic and export value of açaí heart was estimated at US$ 300 million. They found that 1 ha of managed secondary forest gave net production valued between US$ 481 and US$ 934 per year, depending on the distance to the main market in the area. They reported that managed homegardens produced higher values of US$ 931 and US$ 1,501, which shows that more intensive management has a significant effect on the value of the harvested products. The higher values found closer to the market were mainly due to more intensive management of the açaí. Extension of the supply would have limited advantages, as they found that a 50% increase in supply would lead to a 40% drop in price.

Marketability of NTFPs. Shanley et al. (2002) studied the marketability of forest products in the North-Eastern Brazilian Amazon region. They found that the demand for forest fruits has increased but the supply is coming increasingly from semi-domestic plots, due in part to forest clearing for timber and cattle. Communities located further from the market and closer to natural forests enjoy worse opportunities due to the perishable nature of the products and the distances over difficult terrain that have to be overcome to reach the market. Shanley et al. found sales revenues of over US$ 4 million (1994) in three important fruit markets in Belem, representing only a small part of the total fruit market. They also looked at medicinal products and fibres, and concluded that prices are low, barely compensating the costs of collection and transport. Despite increases in the use of some forest-based products, the volume of most Amazonian NTFPs in international trade has declined due to resource degradation, the emergence of substitute products and competitive displacement of the production and marketing systems.

Extractors of NTFPs. Belcher et al. (2005) and Kusters et al. (2006) argue that a distinction should be made between different groups of NTFP extractors. Forests products have very different roles, from providing some cash income mostly to households with minimal income who gather in de facto open access land, to making up more than half of the income from specialized extraction and cultivation on private land. Belcher and Schreckenberg (2007) see little chance that the poorest would benefit much from NTFP marketing due to the limited skills and capital available to make NTFP extraction profitable. Intensified production of NTFPs can even lead to reduced safety-net functions for this group.

Impacts of NTFP extraction. Arnold and Perez (2001) conclude that NTFPs can be important in some cases for some people but there is no straightforward link between development and conservation. Belcher et al. (2005) and Kusters et al. (2006) also conclude that commercial success of NTFP extraction is not generally likely to be reconciled with conservation. Extraction of NTFPs can cause forest degradation, especially if repeated harvesting occurs at close intervals. Demand for NTFP products is selective, which could lead to domestication and loss of diversity. NTFPs are mostly used to supplement diets in particular seasons, but generally do not represent a road to prosperity for poor communities, due among other things to the high transaction costs of marketing them.

Export of NTFPs. Belcher and Schreckenberg (2007) look specifically at the difficulties of marketing NTFPs as an export product, and see problems due to unstable markets, long development paths and the introduction of domesticated or synthetic products once a product becomes successful. Other problems they see are the generally low volume of NTFP markets and the barriers to export to developed countries, such as strict quality controls. Conservation problems loom exactly when these difficulties are overcome. Increased production can lead to over-exploitation, especially in open access situations, or product management can become more intensive, so that the natural vegetation finally becomes replaced by NTFP production systems.

In conclusion, determining a generic economic value for NTFPs in the Amazon is a difficult exercise. Various broadly-based studies may at least give some indication of the NTFP value.

- One of the earliest studies by Peters et al. (1989) arrived at a high Net Present Value of $6330 per ha. They show that this type of use generates much greater benefits than if the land were to be logged or converted to agriculture. This suggests that the commercialization of these products could be a way to conserve the rainforest. Later on, these high values were criticized, for instance, for taking the value of the standing inventory of products at current market prices rather than the extracted quantities (Godoy, 1992; Pinedo-Vasquez et al., 1992), and much lower values were derived (Gavin, 2004).
- Kvist et al. (2001) studied the socio-economic importance of forest product collection in seven lowland Amazonian communities in Peru, and found that collection of these products surpassed agriculture in terms of importance to income. The average value extracted lay in the range of US$ 911 to US$ 2,018 (1995), with about half used for subsistence and half sold. They looked at all products and subtracted direct costs, except labour costs. Fish made up the largest share of the value of products collected (44% on average).
- A literature review presented by the Secretariat of the CBD (2001) suggests a clustering of NTFP net values up to around US$ 100 per ha per year. Pearce (1998) also analyzed a number of studies and suggested a rule of thumb of US$ 50 per ha per year.

2.4 Cultural services

Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences (Millennium Ecosystem Assessment, 2005). These include non-use values, such as the awareness of the value of ecosystems for future generations and the ecosystems' intrinsic value. As many different indigenous societies and communities live in the Amazon region, many different types of values are attached to the forest and its components.

Plant and animal species are used for ceremonial dances, to communicate with the Gods, or for so-called 'mambeaderos': nightly conversations, councils or learning sessions, while preparing and using concentrates of coca and ambil (Sánchez, 2005). In Napo Runa culture, for example, all species are managed by a dueño or owner, who is the spirit master (Uzendoski, 2004). Different cultures have different value systems. Spiritual and religious values attached to the Amazon rainforest are not usually translated into economic terms.

2.4.1. Non-use values

Muriithi and Kenyon (2002) showed that if non-use values are not included, the cost-benefit balance of nature conservation will almost certainly be negative on the conservation side. Non-use values include existence values derived from the simple knowledge that a good or service exists, while bequest values relate to ensuring that goods or services will be preserved for future generations.

A method frequently used by environmental economists to estimate non-consumptive use values and existence values is to estimate people's willingness to pay to protect the service. A survey among US citizens revealed that they are willing to pay about US$ 21 to US$ 31 per household as a one-time payment to permanently protect 10% of the world's tropical forests (Kramer & Mercer, 1997). This implies a total of about US$ 3 billion, or US$ 110 to US$ 230 per ha of forest.

Few studies venture to assign a price to the existence value of the Amazonian rainforest in particular. Pearce (1991) estimated a range of existence values of US$ 10-26 per ha per year. Horton et al. (2003) evaluated willingness to pay of Italian and UK citizens for the implementation of a proposed programme of protected areas in the Brazilian Amazon. Households of both countries were willing to pay on average US$ 45.60 per year to protect 5% of the Brazilian Amazon, and US$ 59.28 for a 20% programme. Aggregation across households showed that this amount of payments would correspond to a fund of US$ 912 million per year in the UK (for protection of 5%) and a similar amount in Italy. Obviously the respondents had difficulties in valuing distant and non-familiar goods and services, which affected the reliability of the outcomes of the study, but it shows nevertheless that international transfer payments for Amazon conservation do have potential.

2.4.2. Recreation and ecotourism

Tourism is one of the largest industries and employers in the world. It currently accounts for 10.7% of the world's Gross Domestic Product (GDP), and employs 260 million people. In some places, rainforest visits have become a major tourist attraction. Based on the principle that biodiversity must pay for itself by generating economic benefits, community-based ecotourism has become a popular tool for biodiversity conservation (Kiss, 2004).

Several valuation studies have focused on the tourism value of the Amazon. One such study focused on ecotourism in Amazonian Ecuador. This industry is probably the best developed ecotourism sector in the region and therefore serves as a model for other parts of Amazonia. For Reserva Cuyabeno in Ecuador, the admission fees result in revenues of US$ 0.15 per ha per year (Gössling, 1999). Wunder (2000) reported revenues of US$ 148,235 per year for five sites at Cuyabeno. Dividing by an area of 603,380 ha yields a similarly low figure of US$ 0.25 per ha per year.

An alternative method of calculating the tourism value is to take the gross revenues from visitors to the Amazon and translate these into per ha values. Drumm (1991) reported total tourist expenditure in the entire Ecuadorian Amazon at a level of US$ 5.32 million per year. Dividing by the area of Oriente (80,000 km2) yields an annual expenditure of US$ 6.65 per ha. Andersen (1997) estimated that if the Amazon were to receive 1 million visitors a year and each person were to spend US$ 1,699 during the trip, this would correspond to a willingness to pay for the rainforest experience of US$ 3.2 per ha per year. The net present recreational value would then lie between US$ 53 per ha (discount rate of 6%) and US$ 160 per ha (discount rate 2%).

3 Trends in forest loss and forest protection

In this chapter we describe the patterns of deforestation and the forces driving it, and the reverse trend of forest conservation.

3.1 Patterns in Amazonian deforestation

Since 1970, over 600,000 km^2 of Amazon rainforest has been subject to deforestation. Figure 4 shows that over the last two decades, deforestation in the Brazilian Amazon has been a linear process, with rates of around 1.8 million ha per year since 1988 (INPE, 2008). Between May 2000 and August 2006, Brazil lost almost 150,000 km^2 of forest - an area larger than Greece. Deforestation rates of 2002 and 2003 moved up to almost 2.4 million ha per year, a number equal to 11 football fields every minute (Laurance et al., 2004). While deforestation decreased temporarily in the period 2005-2007, preliminary figures from INPE for 2007-2008 show a sharp increase in deforestation, probably due to high market prices for beef and soy. Eighty per cent of total deforestation is concentrated in the south and southeast, forming the so-called arc of deforestation (Nepstad et al., 2001). However, besides deforestation large parts of primary forests are also severely degraded due to habitat fragmentation, edge effects, selective logging, surface fires, excessive hunting, illegal gold mining, and other activities (Laurance & Peres, 2005).

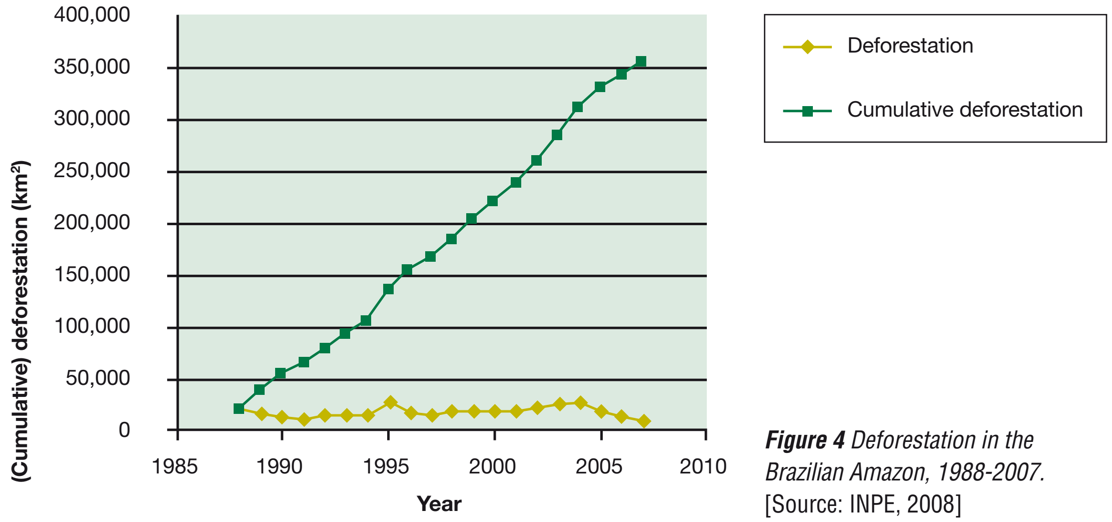


Figure 4 *Deforestation in the Brazilian Amazon, 1988-2007.* [Source: INPE, 2008]

Deforestation figures for all Amazon countries are presented in Table 6. Patterns in countries other than Brazil are generally less well documented. Armenteras et al. (2006) studied patterns and causes of deforestation in the Colombian Amazon; they found an annual deforestation rate between 0.97 and 3.73% in areas with high population density, and a rate between 0.01 and 0.31% in sparsely populated areas. The spatial patterns of deforestation are entirely different from those in Brazil, though. Pasture-led deforestation occurs, but is not promoted by state policy, while spontaneous colonisation has also occurred since the early 1970s. Both activities follow rivers as these are the only existing transport network in most areas.

Table 6 **Deforestation in the Amazon (defined here as the Legal Amazon in Brazil, the Amazon River watershed and the Guianas), in km^2.** ***[Source: Soares Filho et al., 2006]***

Country	Amazon area	Forest area in 2001	Deforested area in 2001	Non-forest area	Net deforestation rate in 2001
Brazil	5,189,032	3,343,757	667,766	1,177,508	0.70%
Suriname	147,479	133,119	2,086	12,274	0.18%
Venezuela	184,265	160,13	12,776	11,359	0.35%
Ecuador	116,947	94,745	8,540	13,663	0.41%
Guyana	215,409	182,233	7,390	25,786	0.12%
Peru	973,523	677,048	69,713	226,762	0.18%
Bolivia	688,450	330,623	39,322	318,505	0.57%
Colombia	445,085	390,506	29,302	25,276	0.24%
French Guiana	85,301	78,760	285	6,257	0.18%
Total Amazon	8,045,491	5,390,921	837,180	1,817,389	0.54%

If we extrapolate the deforestation figures of 2001 of Soares Filho et al. (2006), we see that the total area of forest loss is approaching 1 million km^2 by the time of publication of this report: with an estimated deforested area of about 995,000 km^2 by December 2008, or 16% of the original forest cover in the Amazon.

3.2 Causes of deforestation and forest degradation

The Amazon forest is put under pressure from a variety of sources. The deforestation rate is influenced by agricultural expansion related to increasing market demand for agricultural commodities such as beef and soy, infrastructure development, timber extraction, land speculation and fiscal policies. Forest degradation is caused by selective logging, the occurrence of fires and climate change.

3.2.1 Agricultural expansion

Due to the availability of cheap land, agriculture is expanding rapidly in Amazonia. Cattle ranching and soy cultivation are two important factors driving Amazonian deforestation, which is described in the next chapter. Pastures for cattle ranching are the predominant land use replacing forest; in the Brazilian Amazon there are 6 ha of pasture for each ha of cultivated land. The cultivation of coca and the fight against this illicit crop form an important factor driving deforestation in Peru, Bolivia and Colombia. The United States Department of State (1999) claimed that, over a period of two decades, illicit cropping had led to the destruction of at least 2.4 million ha of tropical rainforest. According to Álvarez (2000) the growth of illicit crops was responsible for half of the total deforested area in Colombia in 1998. In Peru, coca cultivation is held responsible for 24% of the deforestation occurring in the Peruvian Amazon. More recently, cropping of illicit cultivars such as coca and poppy is posing a significant threat, especially to the eastern slopes of the Andes (including in Peru and Bolivia).

3.2.2 Expansion of infrastructure

The most important supranational infrastructure plan that affects the Amazon is the Initiative for the Integration of Regional Infrastructure in South America (IIRSA), which aims to promote the development of regional transportation, energy and telecommunications infrastructure, by improving the physical connections between the twelve South American countries. In December 2004, for example, the governments of Brazil and Peru agreed to construct the Transoceanic Highway, stretching from the Atlantic coast of Brazil across the Amazon and Andes to the Peruvian Pacific coast. This highway will carve a route through some of Peru's most diverse primary rainforests and will affect the territories of currently isolated indigenous cultures.

The three main seaports of Brazil are located on the south-eastern coastline and handle nearly 80% of Brazil's agricultural exports. However, as soy production moves into the interior, the cost of moving the product to the markets decreases the profitability and competitiveness of soy in these regions. Since 1996, the government has therefore launched several massive multiannual programs to construct infrastructure in the interior of the country. The programmes aim to improve transportation facilities and decrease the costs of moving the agricultural output from the interior to the port facilities, mainly by means of the Amazon River and its largest tributaries. The most recently development plan is known as PAC (growth acceleration plan 2007-2010).

Examples of major projects are the *Madeira-Amazon waterway*, in operation since 1997, facilitating the transportation of agricultural products, of which soy is the most important, from the state of Mato Grosso upstream to the Amazon port of Itacoatiara; the *BR163 Highway* from the southern city of Cuiaba in the state of Mato Grosso to the Amazon port of Santarem; the *BR319 Highway* in western Amazonia linking Porto Velho to Manaus; and the *BR158 Highway* running parallel at the east of the BR163. The planned paving of the 1,500 kilometre *BR163 Highway* by itself will open up 10 million ha of Amazon forest to exploitation (Van Gelder, 2006). In combination, the two roads cut through 1,800 km of forests, which currently have a low population density (Cattaneo, 2002). Of all deforestation occurring in the Brazilian Amazon, 85% occurs within a radius of 30 km from official roads.
Bolivia is currently implementing its National Transport Development Plan. For Colombia, a transportation plan was developed by the National Social and Economic Policy Council (CONPES), which in the Amazon includes road construction and paving, and improvement of ports and waterways.

Many of these projects will create corridors between densely populated areas and the remote Amazonian frontier (Laurence 2001), facilitating the process of colonization, which subsequently leads to deforestation and other irreversible environmental effects. According to Cattaneo (2002) a 20% reduction in transportation costs for agricultural products from the Amazon increases deforestation by approximately 15% in the short term and 40% over the long term, which equates to an annual increase of 8,000 km^2 of deforested area. The reduction in transportation costs would imply a considerable increase in the return on arable lands, thereby increasing the incentive to deforest.

Hydroelectric projects are known to have caused the disappearance of large tracts of rainforest and are responsible for the emission of large volumes of greenhouse gasses. The emission of methane from hydroelectric reservoirs is particularly important since it is caused by the decomposition of plant material. The Balbina dam, for example, was responsible for the loss of 2,400 km^2 of forest. The total area flooded is more than 3,000 km^2, while the annual emissions initially were about 30.2 million tonnes of CO_2 equivalent. The Tucurui reservoir caused the flooding of 2,430 km^2 forest in 1984 and emitted 51.5 million tonnes of CO_2 equivalent per year. Only a few large hydropower plants have been completed or are near completion in the Amazon basin. Plans exist for more than 70 new plants, flooding a total area of 100,000 km^2.

A major project is the construction of two large hydroelectric power plants including dams on the Madeira River in the State of Rondônia in the Brazilian Amazon: Santo Antonio (installed capacity of 3,150 MW) and Jirau (3,300 MW). The project would have to satisfy 8% of the national demand for electricity, while the total cost currently exceeds US$ 9 billion, excluding the transmission lines. This would open a 4,200 km industrial waterway, allowing transport of soy and timber to Atlantic ports. Soy is expected to expand in the region by about 7 million ha, and another large area in Bolivia. Dams with a low installed capacity and large, shallow reservoirs tend to have a powerful impact on climate warming.

3.2.3 Timber extraction

Timber extraction from natural forests plays a relatively minor but increasing economic role in most of the Amazon region. Bolivia, Peru and some other countries have introduced forest concession systems that are expanding access to Amazonian timber resources; others (such as Brazil and Colombia) are considering or are in the process of doing so (ITTO, 2006). Exports of tropical wood have risen sharply. In Brazil, most wood is still used domestically, but 36% was exported in 2004 compared to only 14% in 1998.

Even though logging usually does not lead directly to deforestation, it does lead to forest degradation and is part of the forest clearing cycle. Both Asner et al. (2005) and Nepstad et al. (1999) show that large areas are affected by selective logging. Nepstad et al. estimated that 10,000 to 15,000 km^2 are damaged by logging each year. Asner et al. used satellite mapping and found that an even larger area, between 12,000 and 20,000 km^2, was affected by logging between 1999 and 2002. Some of these forests are converted to agricultural and pasture land soon after timber is harvested, while other areas remain as logged forest.
Selective logging is widespread in large areas and can cause light to severe damage. Unplanned logging generates greater quantities of slash and opens larger gaps in the forest canopy than planned harvesting operations, making forests more susceptible to fires that start in areas used for shifting cultivation or pasture (Barreto et al., 2006).

Production data for the Brazilian timber sector over 2002-2007 are presented in Table 5. Of the timber harvest, more than 40% is thought to be illegal, and this probably still represents an underestimate of illegal logging, since numerous licensed loggers fail to implement forest management plans or harvest illegally on unclaimed lands (Barreto et al., 2006).

There is an important connection between the presence of roads, selective logging practices and deforestation (Asner et al., 2006). Within a radius of 25 km from main roads the probability that a logged forest will become completely deforested is up to four times greater than that for unlogged forests. Harvesting is mainly done along the main transportation routes in the Amazon, the BR-163 and BR-364 highways and the Amazon River. Logging near these three routes together supplies 58% of all processed wood originating from the Amazon (Lentini et al., 2005).

3.2.4 Mining

The old soils of the Brazilian Amazon are rich in precious minerals, such as gold, bauxite, iron ore, diamonds and oil. The exploitation of these materials involves several threats to the rainforest. First of all there is the deforestation itself. Compared to the amount of forest cleared for, for example, agriculture, logging and hydroelectric dams, mining only affects relatively small areas of forest. However, mining is almost always associated with a far-reaching degradation of the ecosystem caused by erosion, runoff, infrastructure development, settlement of labourers, and environmental pollution.

The Brazilian Amazon has a long history of gold mining with large numbers of people involved, working in hazardous conditions. For example, between 1550 and 1880 gold mining released about 200,000 metric tonnes of mercury to the environment (Malm, 1998). During the peak of the gold rush in the 1980s at least 1.6 million people were active in gold mining in Brazil (Pfeiffer and Lacerda, 1988). Mercury is a heavy metal that degrades only slowly, remaining in the environment for a long time. Environmental impact and human exposure studies have been conducted in the affected areas in the Amazon since the 1980s, revealing a considerable impact on the environment and health effects due to human exposure (e.g. Malm, 1998 and references therein). However, mercury can also be released as a side effect of deforestation (Mainville et al., 2006). Soil erosion subsequent to deforestation exposes the mineral horizon of the soil, thus accelerating mercury leaching.

Oil is mainly exploited in Venezuela, Peru, Bolivia and Ecuador. A well-documented effect of the roads constructed for oil exploitation is the ability to colonize the area (e.g. Marquette, 1998; Sierra, 2000). The agricultural practices along the roadsides of pipeline construction areas are estimated to cause at least 85% of the deforestation in the Napa river valley (Sierra, 2000).
Finer et al. (2008) review the status of oil and gas development for the entire western Amazon (see Figure 5). According to the inventory of Finer et al. (2008), 180 geographical areas oil and gas blocks cover about 688,000 km^2 of the western Amazon. In Ecuador and Peru, this concerns more than two-thirds of the Amazon. In Bolivia and western Brazil, major exploration activities will be undertaken in the near future. Many of the oil and gas blocks coincide with indigenous territories, including those of un-contacted indigenous groups. The oil and gas blocks are concentrated in the most intact regions of the Amazon, where the highest diversity levels of birds, reptiles and mammals are found.

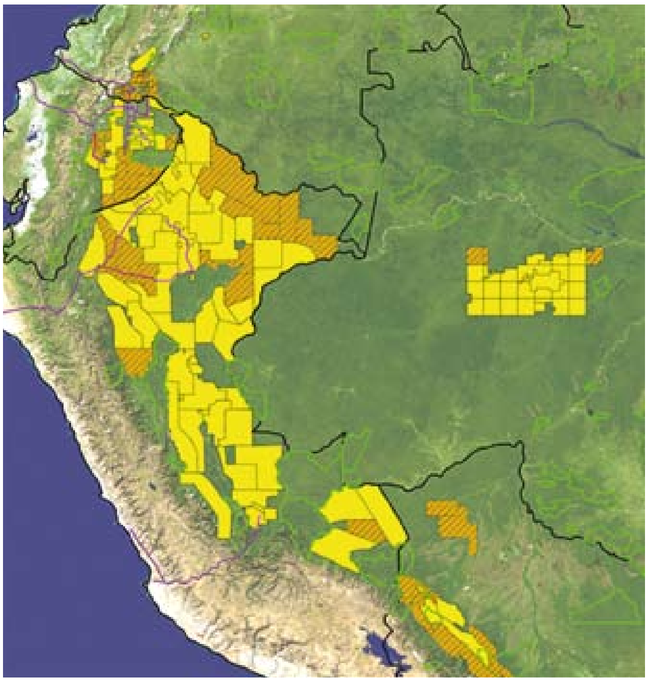


***Figure 5** Oil and gas blocks in the western Amazon, including blocks already leased out to companies and proposed blocks or blocks still in the negotiation phase. Protected areas are strictly protected according to IUCN categories I to III.* [Source: PLoS ONE, Finer et al., 2008]

3.2.5 Biofuels

The growing market demand for biodiesel and bioethanol is expected to increase production, mainly of oil palm and sugarcane, while soy oil could in principle also be used for biodiesel production. The growing demand for bioenergy is driven by the increasing oil prices over the past years, coupled with the need to mitigate greenhouse gas emissions from fossil fuel use. The effectiveness of biofuel use in the reduction of CO_2 emissions is currently the subject of fierce debate (e.g. Righelato & Spracklen, 2007; Fargione et al., 2008; Scharlemann & Laurance, 2008). Especially if land use changes from tropical rainforest to biofuel crops, biofuels are not an effective option for mitigating greenhouse gas emissions, as the case of palm oil diesel production in Malaysia illustrates. Reijnders and Huijbregts (2008) found that carbon emission due to the losses of, inter alia, biogenic carbon from soils and forests that preceded the oil palm plantations was between 2.8 and 19.7 kg CO_2 per kg palm oil.

Although biofuel crops are not currently being grown on a large scale in the Amazon area, there is a so-called economic teleconnection effect (Nepstad et al., 2008). An indirect effect of the rising demand for biofuel on Amazonian rainforests is what can be called the “corn connection”. In order to promote the production of biofuels, the US government is currently subsidizing the production of maize for the production of bioethanol. As a result, farmers in the USA, the world leader in soy production, are increasingly shifting their cropping from soy to maize (Laurance, 2007a). With this rise in production of maize at the cost of soy, soy prices have risen globally. Brazil, the second largest producer of soy, benefits from this development. It is observed that deforestation rates and fire incidences have increased sharply with the increasing demand for soy.

Expansion of oil palm production can be expected in e.g. the Guianas and parts of the Brazilian Amazon, in the proximity of harbours. Malaysia’s Land Development Authority FELDA announced plans to establish 100,000 ha of oil palm plantations in the Brazilian Amazon. If this model proves to be successful, it could be replicated in the future. In the Brazilian Amazon, the area suitable for oil palm production is much larger than for soy cultivation. Problems of diseases still pose a barrier to oil palm expansion, but this might be overcome by technological improvements. The humid western Amazon is biophysically suitable for oil palm but currently lacks infrastructure.

Sugarcane expansion is mainly occurring in the savannah-like Cerrado biome and might push cattle ranching further into the Amazon, which could make it an indirect cause of deforestation. Biodiesel derived from soy is not a very energy efficient option compared to palm oil biodiesel and sugarcane ethanol; however increasing demand for soy oil next to other products derived from soy is still expected to contribute significantly to sending soy prices up. Since January 2008, Brazilian law requires a 2% mixture of biofuels in diesel. Most of the 850 million litres of biodiesel should be produced from soy oil.

Nevertheless, despite the expected increase of deforestation driven directly and indirectly by biofuel production, there may be some potential for sustainable biofuel crop production within the Amazon. Cunha da Costa (2004), for example, studied the possibility of producing biofuels on degraded lands. He found that palm oil offers the best results in terms of income, job creation and CO_2 emissions avoided.

3.2.6 Climate change

According to several modelling studies, by the end of the 20th century large parts of the Amazon rainforest will be replaced by savannah and semi-arid vegetation as an effect of climate change (e.g. Nobre et al., 1991). If 30 to 40% of the forest cover were to be removed, the Amazon would be pushed into a permanently drier climate (Oyama & Nobre, 2003). This critical level of forest loss is referred to as a “tipping point”, beyond which return is unlikely (Nepstad, 2007a).

There are also important feedback mechanisms that make intact Amazon forests resilient to drought – more resilient, probably, than current climate models represent: (1) the mechanism of hydraulic lift, extraction of deep soil water by tree roots and redistribution to superficial soil layers; (2) improved plant water use efficiency, making up for increased transpiration due to higher temperatures; and (3) shifts in vegetation composition towards an increased number of dry forest species (Malhi et al., 2008). Evidence for the resilience of intact Amazon forests is provided by the fact that the largest part of the Southern Amazon remained under forest, even when the climate was much drier than it is today (Mayle et al., 2004).

Nepstad et al. (2008), however, argue that this climate-driven change is probably even more extensive than most climate models predict, as they identify several important feedback effects. Forest fires, drought and logging make forests more susceptible to future burning. The risk of fire is further enhanced by reduction of rainfall as a result of smoke and deforestation. Moreover, the degradation of the Amazon forest is accompanied by the emission of large quantities of CO_2 into the atmosphere, which again contributes to further global warming. Therefore, Nepstad et al. (2008) estimate that more than half of the Amazon forest will be degraded by 2030. It does seem plausible that, in contrast to the past, there may be a limit to the natural resilience of Amazon forest ecosystems, which can be reached within a time span of several decades, due to the additional, powerful impacts of human-induced fragmentation and degradation. Drier conditions will also expand the proportion of Amazon land suitable for soy production.

3.3. Trends in forest conservation

It is only 30 years since nature and biodiversity conservation in Brazil started to attract serious attention (Mittermeier et al., 2005). The adverse impact on nature of the development of a network of highways in the 70s can be seen as the situation that triggered conservation interest. From 1976 to the 1990s Brazil made an enormous commitment to parks and other protected areas at the federal, state, municipal and private levels. A brief illustration is provided by the following facts:

- In 1970 there was only one national park in Brazilian Amazonia (Araguaia National Park, then 20,000 km^2, now 5,000 km^2)
- In 1974 the Amazônia National Park (10,000 km^2 along Rio Tapajós) was created.
- In 1979-1989 the identification of priority areas led to the establishment of five national parks and four reserves (80,871 km^2).
- In 2002 the Amazon Region Protected Areas Project (ARPA) started in Brazil, which will finally result in the protection of 500,000 km^2 of the Amazon rainforest in Brazil by 2010. The initiative is funded by GEF, WWF, World Bank, FUNBIO, the Brazilian government and KFW (German Development Bank) and was ahead of schedule in 2006.

Nowadays, about 37% (Baretto et al., 2006; Azevedo-Ramos et al., 2006) of the total Brazilian Amazon is protected in some way, while 6% is strictly protected (Schulman et al., 2007). The coverage of protected areas will rise to 46% if ARPA is fully implemented. That nature conservation works is, for example, clearly pointed out by Nepstad et al. (2006), who showed that nature reserves, parks and indigenous lands greatly reduced the probability of logging and fire.

Of great significance for conservation are the 29 Amerindian territories in the Brazilian Amazon (demarcated indigenous lands) which in total cover about 20% of the legally defined Amazon in Brazil (Mittermeier et al., 2005; Schwartzman & Zimmerman, 2005). In Colombia, too, coverage of indigenous territories is substantial. There is an increasing awareness that these indigenous territories, due to their size and protected status, will play a key role in the ultimate fate of the Amazonian ecosystems (e.g. Schwartzman & Zimmerman, 2005; Fearnside, 2003). For example, these territories (and other conservational areas) act as a barrier to deforestation along the arc of deforestation. The Kayapó indigenous territories of Pará and Matta Grosso and the Xingu Indigenous Park have halted intensive waves of deforestation for nearly two decades. However, currently there is an increasing pressure on these lands from infrastructure development and agricultural expansion (Nepstad et al., 2001; Laurance et al., 2004).

4 Soy and beef production in Brazil

Agricultural and livestock expansion are currently two of the most representative examples of economic growth at the expense of the Amazon forest. Soy is the most important indirect driver of deforestation, and cattle farming the major direct cause. This chapter specifically describes these two direct use values of the Amazon in terms of economic and environmental impacts. The scope of this part of the study is restricted to the Brazilian region known as “Legal Amazonia”, which includes the seven states of the northern region (Acre, Amazonas, Rondônia, Roraima, Pará, Amapá and Tocantins), Mato Grosso in the central-west region and the western part of Maranhão. This area represents 60% of Brazil’s national territory, of which 82% corresponds to forest biome and the other 18% to biomes known as Cerrado and Catinga.

4.1 Soy production

Production methods

Soy can be planted according to three different methods: traditional soy planting using tillage, no-till planting of conventional soy and no-till planting of genetically modified soy. Over the last 30 years, Brazil has shifted from conventional tilling to no-tilling practices, the latter accounting for approximately 22 million ha planted by this method.

- ***Traditional method:*** soy is planted as the main crop, followed by a second crop of grains. Tilling has severe impacts on the soil (erosion and removal of the organic layer) and requires large investments in machinery.
- ***No-till planting of conventional soy:*** this is also called farming zero or direct sowing. Essentially, direct sowing consists of sowing in uncultivated soil, crop rotation and constantly covering the soil with agricultural residues remaining from previous crops. Avoiding bare soil has several advantages; it reduces the runoff caused by rain and thereby reduces erosion as much as 90% and increases the infiltration of rain by between 30 and 60%, so less water is needed for irrigation. Generally, costs of seeds and herbicides are higher (Lence, 2000)
- ***No-till planting of genetically modified soy:*** this is similar to the method described above, but instead of rotational crops, two crops of soy are cultivated annually. Lower machinery costs and easier weed control are advantages of this method but indiscriminate herbicide application is a major drawback, resulting in severe environmental impacts (Dros, 2004).

Production over time

Soybean production in Brazil has grown rapidly since the 1960s; it was initially stimulated by government subsidies and encouraged by an increase in the world demand. During the 1980s soy became one of the dominant crops and since the 1990s it expanded from the southern states in Brazil to regions in the central-western region of the country. This was achieved through the development of high yielding varieties of soy, adapted to the tropical conditions, which drastically increased the country’s production. Figure 6 shows this rapid increase from 1990 to 2008. Current soy production at a national level is estimated at 60 million tonnes. The area harvested has increased up to 22 million ha (five and a half times the size of the Netherlands).

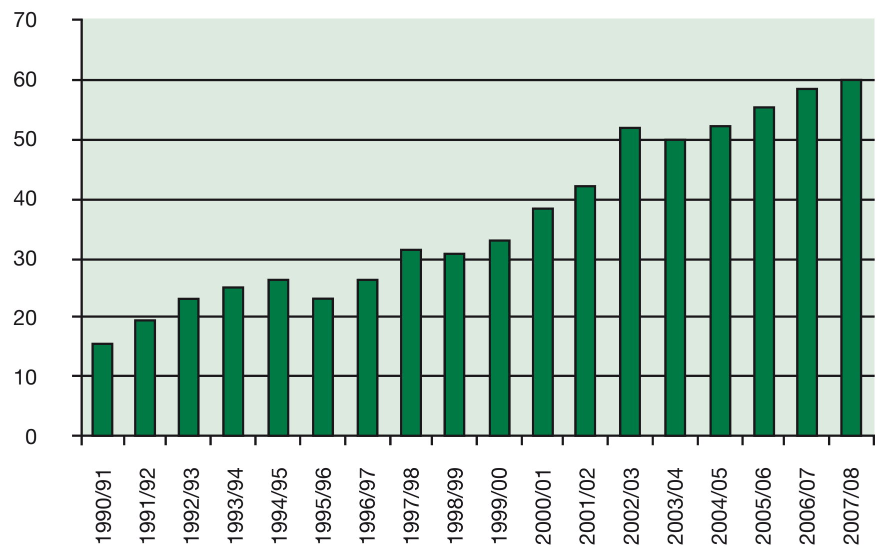


***Figure 6** Production of soybeans in Brazil 1990-2008 (million tonnes); figures for 2006-2008 are preliminary.* [Source: CONAB, 2008]

Table 7 lists the quantity of soy produced and the area harvested. However, the average yields have also increased considerably, from less than 2 tonnes per ha in the 1990s up to an average of 3.0 – 3.3 tonnes per ha in recent years.

Table 7 Soybean acreage and production in Brazil. ***[Source: CONAB, 2008; figures for 2007-2008 are preliminary]***

Indicator	1990/1991	1995/96	1999/00	2002/03	2005/06	2007/08
Production quantity (million tonnes)	15.4	23.2	32.9	52.0	55.0	60.2
Area harvested (million ha)	9.7	10.7	13.6	18.5	22.7	21.3

Agriculture and agribusiness have played a key role in Brazil's recent economic performance, accounting for 28% of total exports. The three main products exported, in order of importance, are soybeans, soy meal and chicken meat, all three combined representing 48% of total agriculture exports (FAO, 2005b). The soy chain accounted for 11.1% of the Brazilian exports, with annual receipts of US$ 8.1 billion. Soy represents 6% of Brazilian GDP and employs close to 5.5 million people (Jaccoud, 2003).

Soy production in the Brazilian Amazon

Legal Amazonia produced more than one third of the country's soy, Mato Grosso being the single largest producer, accounting for more than 20% of the national area under soy cultivation (IBGE, 2006). Soybean expansion in the Amazonian states totals 14.1% a year from 1990 to 2005, but with a sharp increase over the last 5 years (see Figure 7).

According to data from IBGE, based on figures from the Municipal Agriculture Production (Producão Agrícola Municipal-PAM), soy only occupies 0.3% of the Amazon biome (see Table 8); thereby, to date it has been a negligible vector of direct deforestation of the Amazon. However, as explained later in the report, soy can be an important, indirect driver of deforestation and is expected to become a very important, direct driver of deforestation.

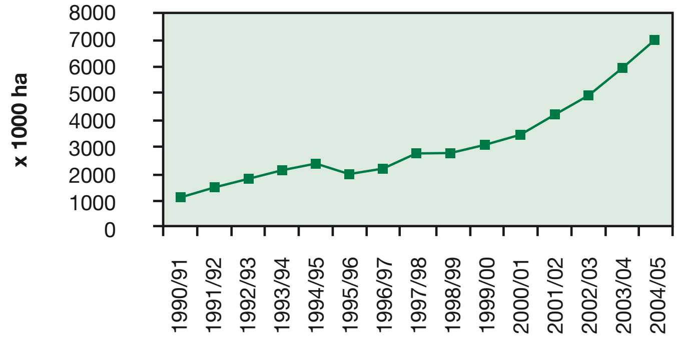


Figure 7 *Soybean expansion in the Amazon states of Brazil.* [From Costa et al., 2007]

Table 8 Soybean acreage and share in Brazil, Legal Amazon and Amazon biome. ***[Source: IBGE, 2005]***

	Total area (millions of ha)	Soybean area (millions of ha)	Soybean share
Brazil	851	23.4	2.7%
Legal Amazon	510	7.0	1.4%
Amazon biome	419	1.1	0.3%

Production costs and the world market

Brazil is currently the world's second largest producer of soy after the United States (US), and was the second largest exporter until 2005, when it overtook the US as the world's biggest soybean exporter. This may be due to several reasons:

- The outbreaks of *Bovine Spongiform Encephalopathy* (BSE) in the United Kingdom (UK) and Europe increased the demand for substitute protein sources. Soy was targeted as the best alternative.
- The *EU regulations* which restricted the import of genetically modified organisms (GMOs) gave Brazil a comparative advantage over the US and Argentina. Over 80% of US and 99% of Argentinean soy is genetically modified. GMOs are severely restricted in the Brazilian Amazon.
- The emergence of *China as the dominant country* in the global import of soy. China's rise can be attributed to the rapid expansion of the livestock sector, mainly poultry and aquaculture, derived from a speedily growing middle class population, which increased the demand for these products.
- An important element in the rapid spread of soybean production in Brazil was the development of *soybean-bacteria combinations* that allowed soybean plants to be planted without the need for nitrogenous fertilizers (Donald, 2004).

Despite its strong international market position, Brazil has a number of comparative disadvantages. The Brazilian Association of Vegetable Oil manufacturers ABIOVE (2000) concluded that Brazilian producers suffer a significant competitive disadvantage due to deficiencies in transportation. It is estimated that 67% of Brazilian soy is transported by trucks, 28% by train and only 5% by ship and similar means. The average transportation distance of the grains to the nearest port is about 1,000 km. On average, the cost of transportation of a tonne of soy in Brazil is about twice the cost in Argentina and in the US. These differences in the costs of transportation and loading also lead to variations in revenues received by producers within Brazil.

Prognosis

Brazil's main international comparative advantage in agriculture is the widespread availability of cheap land. The abundant availability of land, combined with high international prices and a constantly increasing demand from China, suggests that this sector is likely to continue to expand in Brazil. Land in the Amazon states of Brazil is cheaper than in the south, which leads to lower production costs: for the harvest season 2006-2007 in Mato Grosso the breakeven price was US$ 8.50 – 9.00 per 60 kg bag (at a yield of about 3.3 tonnes per ha), compared to US$ 12.00 for the same unit in Parana. Bolivia could form a blueprint. Unlike many other Amazonian countries, Bolivia's current economy is not thriving on the extraction of minerals and timber (like Ecuador and parts of Brazil) or rentier rangelands and speculative fronts (Brazil) but on a productive, high value, agro-industrial frontier with an enormous capacity for converting large areas of forest (Hecht, 2005). Soy accounts for one third of the total area taken up by food production.

Vera-Diaz et al. (2008) used a soybean crop simulation model to estimate soybean yields for the Amazon. In 20% of the Amazon (excluding protected areas), soybean cultivation can produce roughly 2 tonnes per ha or more. Soybean production may be possible over a more extensive area but this would require improvements in e.g. transportation infrastructure. Several major improvements in transportation infrastructure will be implemented in the near future, however. Considering restrictions in climatic factors (excessive rainfall) and soil conditions (rocky soils and poor drainage), soybean cultivation could expand to a maximum of 30% of the Amazon area, with higher concentrations in Mato Grosso, Rondônia, southern Pará and alongside ports and roads (Soares-Filho et al., 2006).

Cerri et al. (2007) expect that by 2030, 70% of the newly cleared areas will be dedicated to soy cultivation. Moreover, 80% of the existing pastures will be in a degraded condition by that time. Three options exist for these pastures: remaining degraded, becoming well managed after rehabilitation, or being converted to row crops such as soy. Siqueira et al. (2001) simulated production of several crops under climate change scenarios. They found that a rise of 3 to 5 °C and an increase in precipitation of 11% for the Centre-South region through the year 2050 would result in a decrease of wheat and corn production (30% and 16% respectively) but an increase of 21% (or 3.5 million tonnes) in soybean production.

The approval of transgenic soybeans opens up the way for genetically modified soybeans that are resistant to the Roundup® herbicide glyphosate. Some authors expect that introduction of genetically modified soybeans will make soybean production more profitable and accelerate its expansion into the Amazon (Fearnside, 2001).

4.2 Cattle production

Production methods

The predominant beef production system is based on grazing and relies on native and cultivated pastures, which are grazed under continuous stocking all year round. Beef production in tropical pasture-based systems is notorious for its poor productivity (Caravalho, 2002), which is explained by the overexploitation of grasslands, poor management and the low fertility of the Amazon soils, which are characterized by extremely low levels of phosphorus and high acidity. Brazil has recently shown that productivity improvements are possible if modern management practices are implemented, but the extensive production pattern still predominates, characterized by extensive grazing, a prolonged time to slaughter, and low production costs. This production method means that Brazilian beef can still compete worldwide.

Production over time

With more than 200 million head of cattle (Table 9), Brazil possesses the world second biggest herd, surpassed only by India, where bovine livestock farming is not done for commercial ends. More than one-third of the herd is located in the Central-West Region. More specifically, the state of Mato Grosso makes up 13% of the total Brazilian herd.

Table 9 Herd size from 2000 to 2005 in Brazil (in millions of cattle). *[Source: IBGE, Pesquisa Pecuária Municipal (PPM)]*

	2000	2001	2002	2003	2004	2005
Cattle	170	176	185	196	205	207
Swine	32	33	32	32	33	34
Sheep	15	15	14	42	15	16

Cattle production in the Brazilian Amazon

Besides the continuous increase in the herd size, significant geographic shifts have taken place over the last 15 years. Production areas have gradually shifted from the south-east part of Brazil towards the northern region. Figure 8 shows the evolution of the herd size over the same 15-year period in the states constituting the Legal Amazon. The state of Rondônia displayed the highest growth in the region, with an annual increase of 38%. Mato Grosso and Pará expanded their herds by 13% annually. One of the causes of this expansion was the Foot and Mouth Disease (FMD) free status conferred on a large part of the southern Amazon (Nepstad et al, 2006). Another reason was the displacement and consequent migration of ranchers from areas of Cerrado - principally due to soy expansion - to forested areas in the Legal Amazon. North and North East Mato Grosso, West Maranhão and West Tocantins are located within the Amazon biome. In these subregions, the cattle herd grew by 37% over the period from 2001 to 2005.

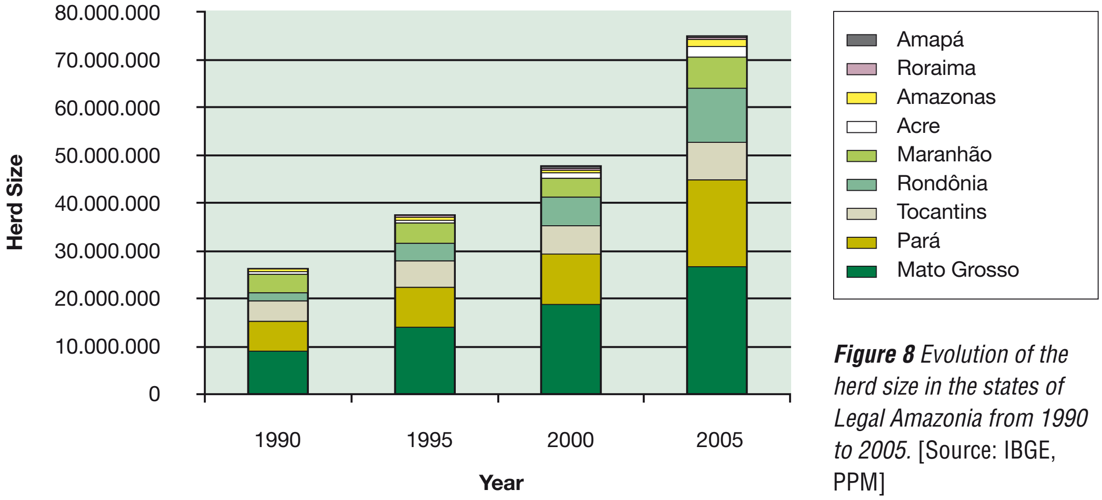


***Figure 8** Evolution of the herd size in the states of Legal Amazonia from 1990 to 2005.* [Source: IBGE, PPM]

Production costs and the world market

Brazil has one of the world's lowest beef production costs. The average production cost in Brazil is approximately US$ 1.5 per kg, compared to US$ 3.5-5.3 per kg in the US (ABIEC, 2007). With the world's biggest commercial herd and its low production costs, Brazil is the largest exporter of meat in metric tonnes, while Australia is the largest exporter in value. The main reasons why Brazil has reached its current levels of productivity are advantages in terms of horizontal expansion, such as growth into unexplored lands, and vertical expansion, such as productivity improvements. Brazil has consolidated its position as the world's food supplier (Barbosa et al, 2007). It is the world leader in beef (i.e. 26% of the total) and in chicken meat exports (40% of the total), and it occupies fourth position in pork exports (14% of the total). The main importer of Brazilian beef, in quantity and value, is Russia followed by the UK and Egypt. The Netherlands is the fourth biggest importer in value, with around US$ 304 million imported in 2006 (ABIEC, 2007).

According to data from EMBRAPA, the average national weight of the carcasses is around 210 kg. Taking into account the intensity of 1.1 AU/ha for the North region of Brazil, each ha produces approximately 231 kg in a period of four years. Combining the above data, it is calculated that each ha produces roughly 57.8 kg per year.

Beef prices have fluctuated sharply over the years. Prices in January to May 2007 lay around R$ 55 per arroba (15 kg), which, multiplied by the productivity, amounts to a total of R$ 212 or US$112 per ha per year. Land prices are difficult to attribute, since this land is sometimes acquired illegally through illegitimately obtained titles and occupancy rights, a process referred to as 'grilagem' (i.e. the Portuguese term for cricket). However, the rental fee in Pará and Goias ranges from 60 to 85 US$/ha. Adding the productivity figures to the rental fee of the land, a production price range of 170 to 195 US$/ha is estimated.

Prognosis

Total beef consumption in Brazil is 40 kg per person per year and it exports 8% of its production, indicating a huge internal market. This means that, to the extent that the acquisitive potential of the Brazilians is increasing, it could lead to a national beef shortage, meaning a total lack of beef for exports. On the contrary, the country could shift to become a net importer of beef.

4.3 Soy and beef complex

The soy and beef industry are closely connected. As soy production in Brazil grows and the pressure on suitable lands increases, soy producers, who generally have easy access to relatively cheap international credit, buy land from livestock farmers, creating the soy-beef-deforestation cycle (Figure 9). Through this mechanism, ranchers are given the opportunity to capitalise and expand their businesses without relying on expensive domestic loans (Landers 2004). These ranchers move toward forested areas, facilitated by the presence of soy-related infrastructure (e.g. BR163 Highway) and, driven by the low land prices, clear much larger areas of forested land along these roads than the area originally occupied (Dros, 2004).

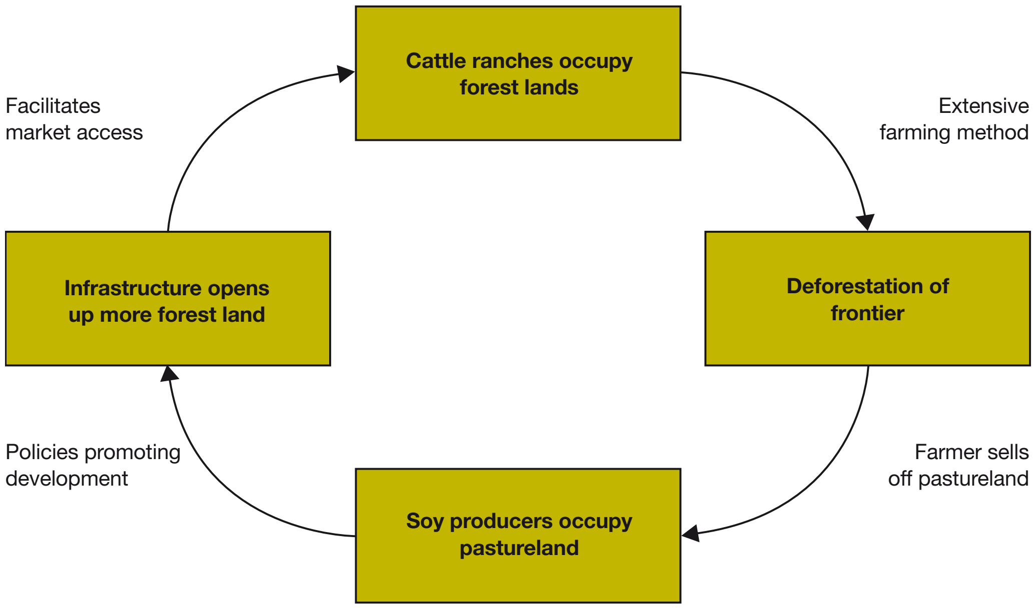


Figure 9 *The soy-beef-deforestation interaction cycle.*

Expansion of livestock farming into the Amazon is mainly induced by soybean expansion. Livestock producers are displaced by soy farmers, who overtake and convert existing cattle ranches to soy fields. The majority of the expansion takes place in Cerrado areas. The soil in the Cerrado offers suitable conditions and high productivity for soybean crops. These conditions make soy crops easier to establish, less labour intensive and more profitable in terms of land preparation, given that most of the farms acquired are already converted to pastures.

The accessibility to transportation infrastructure is also a reason to prefer this area, because it represents an important reduction in costs of freight to export ports and crushing facilities.
The “push-effect”, which soy farmers have on cattle ranchers, induces a shift which usually goes beyond the agricultural frontier extending into the Amazon biome. Once migration has occurred, the forest is cleared to re-establish the cattle enterprises. This cycle is repeated as the agricultural frontier moves north-east, threatening the Amazon rain forest. Figure 10 shows the movements of the frontiers. Two of the three frontier stretches converge in the south-east of the state of Pará: northern Mato Grosso and west Tocantins. The south east of Pará contains about 70% of the state’s herd.

Figure 10 *Agricultural expansion frontier and congregation of the largest cattle herd.*
[Source: Adapted from Cattaneo (2002)]

The Brazilian government calculated that the agricultural sector is responsible for deforesting nearly two million ha per year, mostly to establish new pastures for cattle ranching (USDA, 2004). The estimated area of pastures in the Amazon exceeds 24 million ha (IBGE, 1996) supporting 41.5 million head. The largest area of cultivated pasture is found in the state of Pará (5.8 million ha) and Tocantins (5.2 million ha).

Due to low soil fertility and unfavourable climate conditions, the Amazon land has a low carrying capacity, and should therefore be characterised as low productivity pasture. Calculations based on data obtained from the IBGE show that the overall cattle density in the northern region is of the order of 1.3 Animal Units (AU) per ha, which is similar to the average in Mato Grosso, but slightly higher than the density seen in the state of Pará (1.1 AU per ha). Taking into consideration the data on pasture extension from the last three agricultural censuses (1980, 1985 and 1995), cultivated pastures grew at a rate of 2.8% per year, whereas native pastures declined at a rate of 1.37%.

The soy-cattle nexus and deforestation

The soy-cattle complex is driven by federal government policies, designed to integrate the region within the Brazilian national economy (Hecht & Cockburn 1982). In 1990 Pará was the Brazilian state with the highest annual deforestation rate (4,890 km^2), closely followed by Mato Grosso. As a result of an intense, state-led campaign to promote agriculture development, Mato Grosso took the lead in 1992. Total deforestation peaked in 1995 with approximately 29,000 km^2, which coincided with a peak in beef prices. With a forest loss of 11,814 km^2, Mato Grosso contributed most to this overall number.

Agriculture expansion and cattle ranching have been identified as the main drivers of deforestation and forest degradation. Agriculture can be categorized as having a dual impact on of deforestation: direct and indirect. Direct deforestation occurs when forested areas are directly converted into commercial crops such as sugar cane, oil palm, rubber, coffee, and tropical fruits, as well as cattle or other livestock. In contrast to popular belief, the main driver of direct deforestation in the Amazon is cattle ranching rather than soy cropping. Concentrations of deforestation coincide with areas of cattle herd expansion in agricultural frontier regions adjacent to or belonging to the Amazon biome. Indirect deforestation occurs when the expansion of soy cultivation results in displacement of cattle ranching into the Amazon biome. On the basis of an analysis of municipal data, we conclude that for each ha of newly planted soy, on average 1.15 ha of cattle ranching is opened up beyond the agricultural frontiers in the states of Mato Grosso, Pará, Maranhao and Tocantins. The figures for each state are presented in Table 10. This results in conversion of (semi-)natural ecosystems in both the Cerrado and Amazon

biomes. Not every hectare of soy planted will automatically translate into an additional hectare of cultivated pasture for cattle ranching as the expansion of cattle ranching is partly an independent process. However, Grieg-Gran et al. (2007) reported a multiplier effect for several regions, where the sale of land for soy production resulted in the purchase of a larger area of land for cattle ranching in the agricultural frontier.

Table 10 Relation between expansion of soy and establishment of cattle pastures beyond the agricultural frontier. ***[Source: municipal data of IBGE; Agricultural census 1980, 1985, 1996; Pesquisa Agropecuaria Municipal 2005]***

State	Planted soy (ha)	Cultivated pasture (ha)
Pará	1	1.23
Maranhao	1	1.18
Mato Grosso	1	1.10
Tocantins	1	1.10

Expansion of sugar cane in the Cerrado is also expected to result in increased displacement of cattle ranching into the agricultural frontier zones, and therefore increased pressure on Amazon forests (WWF, 2008).

Pollution

The use of agrochemicals in large-scale soy production, mostly applied by aircraft spraying, leads to significant soil, air and water pollution. As chemicals are sometimes blown away by strong winds, the pollution effects are also felt by neighbouring farmlands, natural reserves, residential areas and water reservoirs (De Souza, 2004). Fish stocks are also affected by the indiscriminate use of herbicides, pesticides and fertilizers, as well as erosion, which influences the streams and rivers in which they live and breed. Soil erosion leads to increased sediment loads in the water, increasing its turbidity, which is also harmful to the fish.

Social impacts

Deforestation of the Amazon leads to socio-economic impacts at local and national levels. At the local level, deforestation forces many small producers to migrate to other areas. If they choose to migrate to urban areas, they often remain unemployed. If the farmers choose to settle in new, remote areas, another deforestation cycle is initiated. At the national level, agricultural expansion generates only limited welfare effects. In terms of rural income gain, increased production in the Amazon region replaces that from other regions. Thereby, any positive gain in a new agricultural area is offset by a negative impact on the other existing agricultural areas (Cattaneo, 2002). The trend whereby large-scale agriculture displaces smallholders is also leading to loss of employment at a national level: smallholder agriculture in Brazil generates one job per 8 ha of land (FAO/INCRA 2000), while industrial soy farming only generates one job per 200 ha (Carvalho, 1999).

Genetically Modified Soy

One of the major threats is the introduction of Genetically Modified Organisms (GMOs) in the Legal Amazon, specifically soy varieties resistant to the glyphosate herbicide (Roundup® Ready (RR) soy). Roundup® Ready soy can be considered in some ways advantageous to producers, since it represents a reduction in the production costs, higher yields, and improved management (Jaccoud, 2003). It also can be seen as beneficial to the soil, given that tillage is not necessary, thus reducing soil erosion and fragmentation of the organic layer. However, uncertainty about the potential risks between the release of GMOs into nature and damage related to the application of the herbicide glyphosate do still pose a serious threat. RR soy entered the South of Brazil illegally, but is now permitted by the Brazilian government. To date, the policy has been to cultivate non-GMO soy exclusively in the Amazon. It is not clear whether this position will nor can be maintained.

The impacts of allowing the introduction of RR soy in the Amazon could entail huge social, economic and environmental problems. Experience in Argentina shows that the introduction of RR soy substantially increased the rate of deforestation. The question is whether the same scenario would apply to Brazil. The combination of low-labour intensity, high profit margins and ease of crop establishment could encourage the use of RR soy, thereby leading to higher rates of deforestation. On the other hand, it is already standard practice in the North and Northeast of Brazil to harvest two crops per year, thus reducing the competitive advantage of GMO soy. Wide application of genetically modified soy may also represent important economic losses to the country. Brazil exports approximately 70% of the soy it produces (Jaccoud, 2007) and introducing this technology into the Amazon region could imply closure of the European market to Brazilian soy for human consumption. In 2007, the acreage of genetically modified soybean already reached 65% of the total soybean acreage in Brazil.

Moratorium on soy and certification

There is a two-year-old moratorium on the purchase of soybeans produced on rainforest lands deforested after 2006. Members of the Brazilian Vegetable Oils Industry Association ABIOVE, a soy industry group that accounts for 94 percent of Brazil's soy crush, recently extended the ban through July 23, 2009. The indirect effects of soy production on deforestation have not been addressed through this moratorium, however. Another important question is what will happen after July 2009. Important certification efforts include the Basel Criteria for Responsible Soy Production, and the Roundtable on Sustainable Soy involving multiple stakeholders as a longer-term process. These initiatives have resulted in the formulation of sustainability criteria but have not addressed the indirect effects of soy production on deforestation.

5 Impacts of deforestation and forest degradation

The Amazon forests play a critical role in regulating the climate, both regional and global. The release of massive quantities of carbon locked up in forest biomass would add significantly to global warming. The rainforests pump heat into the atmosphere, thereby cooling the tropics and distributing heat to temperate zones. Locally, deforestation increases temperatures, decreases rainfall, and disrupts hydrological cycles. Most ecosystem services provided by Amazon forests, as described in Chapter 2, will decline significantly. In this chapter we focus on the losses related to carbon, biodiversity, hydrology and cultural services.

5.1 Impacts on carbon services

The release of carbon by land-use change clearly is a huge source of carbon, although the magnitude is difficult to estimate. Slash and burn agriculture causes deforestation and releases the carbon stored in biomass. Deforestation currently causes 20-29% of the total greenhouse gas emissions world wide, making it the second largest source after fossil fuel use (Naughton-Treves, 2004). Three major assessments suggest that tropical deforestation accounted for at least a quarter of all anthropogenic carbon emissions in the 1980s and 1990s (with estimates ranging from 1.9 to 3.0 billion metric tonnes/yr; Fearnside 2000, Malhi & Grace, 2000, Houghton 2003a). In the 1990s the emissions of CO_2 from the Amazon due to land use changes were estimated at 1.4–3.0 Pg C year^{-1} (House et al., 2003).

Carbon stocks vary considerably among different vegetation and land-use types. The subsequent land use types after deforestation contain less carbon per ha than primary forests (compare Table 11 with Table 1). Long et al. (1989) calculated that grasslands contain about 0.062-0.844 Mg C ha^{-1} (excluding soil carbon: correcting for soil carbon would give about 2.62 Mg). Estimates published by Fearnside & Guimaraes (1996) are somewhat higher but do not exceed 5 Mg C ha^{-1}. For forest plantations Silver et al. (2000) found an average accumulation of carbon of 7.9 Mg C ha 1 year^{-1}. The carbon density of the soil varies between 81 and 99 Mg C ha^{-1} (Silver et al., 2000). Total carbon (excluding CWD) then varies between 117.8 and 153.4 Mg C ha^{-1}, with 135.6 Mg C ha^{-1} on average. Fearnside (2000) halves the value for the carbon density of a forest plantation (81.3 Mg C ha^{-1}) of the FAO (1995) to correct for age differences within the plantations, ending with 40.7 Mg C ha^{-1}. Fearnside & Guimarães (1996) estimated that secondary forests stock between 23.5 and 86.0 Mg C ha^{-1} depending on the age (5 to 80 years). Uhl et al. (1988) found a

Table 11 Carbon balance of deforested land in 1990. *[From Fearnside & Guimaraes, 1996]*

Vegetation type	Area (10^3 ha)	Area (%)	Average age of land use (years)	Average carbon stock (Mg C ha^{-1})	Carbon uptake (Mg C ha^{-1} yr^{-1})
Farmland	2,221	5	1	0	0
Productive pasture	18,400	45	4	5	0
Degraded pasture	904	2.2	4	1.5	0.4
Secondary forest (from farmland)	854	2	3	13	4
Secondary forest (from pasture)	11,536	28	3	20	2
Pre-1970 secondary forest	7,127	17	30	67	0
Total	41,042	100	8	19.6	0.7

maximum of 138.8 Mg C ha^{-1}, depending on age and historic use. Only the study of Alves et al. (1997) indicated a chance that secondary forest does not mean a loss of carbon storage capacity.

While land use change clearly has a negative impact on the amount of carbon stored in biomass, the Soil Organic Carbon (SOC) stock provides a somewhat different story. Soil carbon stocks after forest clearance for pastures show a broad range of responses (Table 12). SOC stock can increase when forest is cleared and turned into pasture. Especially well-managed pastures have been shown to accumulate more soil carbon than the original forest vegetation.

Table 12 **Soil Organic Carbon (SOC) flux after land use change.**

SOC stock	Age, soil type, depth	Reference
<7%	2 years, oxisoil, 0-30 cm	Bonde et al., 1992
<24%	8 years, oxisoil, 0-20 cm	Chone et al, 1991
Rise	2-4 years, utisoil, 0-10 cm	Eden et al., 1990
Rise	6-25 years, utisoil, 0-10 cm	Eden et al., 1990
Rise	Immediately after clearance	Neill et al., 1997
From <76% to >74%	Diverse (on average <0.5%)	Homes et al., 2006
Initial fall --> slow rise	Diverse, well managed pastures	Cerri et al., 2007a

The maintenance of carbon stocks is an important ecosystem service. Fearnside (1996) made up a balance of biomass in a deforested landscape in the Brazilian Amazon of 410 × 103 km^2. The average carbon stock (including below-ground and dead components) in the deforested landscape was estimated at 19.6 Mg ha^{-1} in 1990, the year of deforestation (see Table 11). These replacement carbon figures at landscape and regional level imply large net releases, when compared to the carbon pool present in the biomass of natural Brazilian Amazon forest, which lies in the range of 140-180 Mg C ha^{-1} according to recent estimates (see Table 1).

How severe is the economic damage of carbon emissions related to deforestation? This is difficult to assess, as the consequences of release are unknown and therefore incalculable (Fearnside, 1997). For example, as a consequence of climate change provoked by rising CO_2 concentrations, more hurricanes are expected to occur. Hurricanes can cause enormous damage: hurricane Katrina in 2005 resulted in insurance claims totalling US$ 81.2 billion. Economic damage through global warming from tropical deforestation alone is estimated at US$ 1.4-10.3 billion per year (Pearce and Brown, 1994). Fearnside (1996) calculated the economic damage from global warming in the Amazon region at approximately US$ 1200-8600 ha^{-1}. Fearnside (1997) estimated avoided damage in the range of US$ 1.80 to 66 per tonne carbon stored in the Brazilian Amazon.

Andersen (1997) summarized values estimated by direct and indirect approaches. She concludes that the value of carbon emissions in tropical forests ranges from US$ 750 to 6750 per ha. The calculations of Chomitz (2007) showed that carbon stocks represent a value of US$ 1,500-10,000 per ha (based on 500 tonnes of CO_2 per ha in dense Neotropical forests).

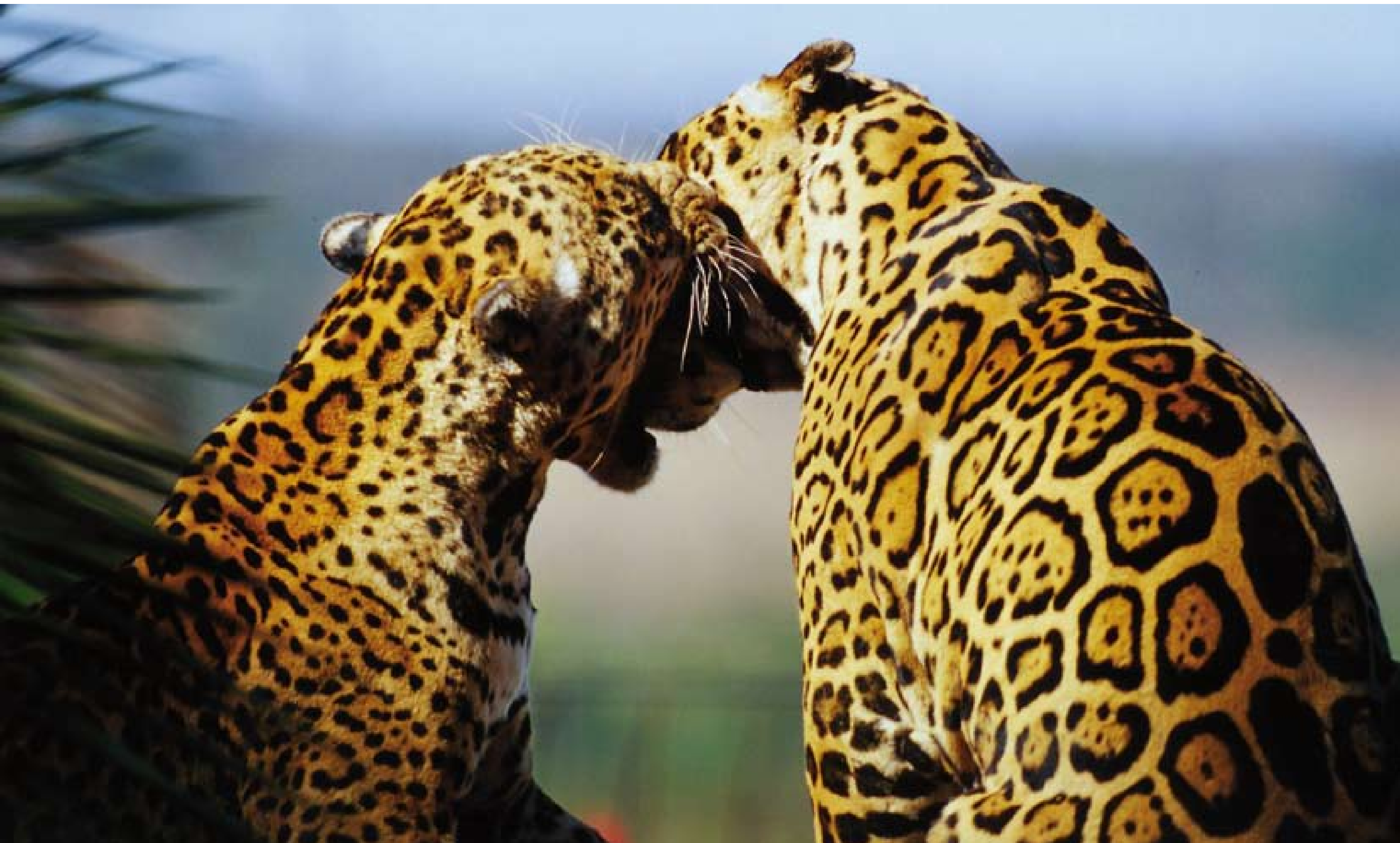
Nepstad (2007b) indicated that carbon emissions caused by deforestation and forest degradation in the Brazilian Amazon could be minimized over a 10 year period at a cost of US$ 100 – 600 million per year. Brazilian Amazon forests contain 47 ± 9 billion tonnes of forest carbon (excluding soil carbon) (Saatchi et al. 2007, Soares-Filho et al. 2006). The opportunity cost of forest conservation for this area would be US$ 257 billion and US$ 5.5 per tonne of carbon. The low opportunity costs are related to the low profitability of cattle ranching for large parts the Amazon, for which an estimate of US$ 50 per ha per year was applied. Opportunity costs exceeding $10 per tonne carbon apply to only 6% of the area, suitable for soy production.

5.2 Impacts on biodiversity

Deforestation obviously has a direct, local effect on diversity. Fujisaka et al. (1998), for example, examined numbers of plant species and individuals relative to land use in an agricultural settlement in the Brazilian Amazon and showed that plant species diversity is lowest on pastures. Deforestation, however, also has a regional impact on the remaining forest through, for example, edge fragmentation effects. Increasing fragmentation leads to an increasing length of forest edge and area of edge habitat. Nascimento and Laurance (2004) quantified the biomass and necromass in forest edges and forest interiors. They found that high tree mortality was accelerated in edge habitats compared to forest interiors.

The impact of deforestation is highest in areas with little remaining forest and high levels of endemism (Fearnside, 2005). Endemic species with small distribution ranges run a greater risk of extinction if their habitat is reduced. A recent study by Hubbell et al. (2008) estimates the number of tree species that are expected to become extinct due to habitat loss, across the entire Brazilian Amazon. Almost half the species are assumed to have small overall population sizes, less than 10,000 individuals, usually associated with small distribution ranges. Such species are therefore highly vulnerable to habitat loss. According to different future scenarios for the Amazon forest, model simulations show that between 20% and 33% of tree species would go extinct in several decades.

Besides range area, the biodiversity impact of deforestation and resulting fragmentation depends on several other species characteristics (Dale et al., 1994): (1) gap-crossing ability, (2) area requirement, and (3) specialized habitat requirements. Laurance et al. (2002) found that many Amazonian species avoid even small (<100 m wide) clearings. Other factors being equal, species with a limited gap crossing ability should be more affected by forest fragmentation than species with a better ability to cross gaps (Dale et al., 1994). Top predators, for example, have large area requirements, and the remaining forest can become too small. Even large Amazonian national parks such as Manu (Peru, 1.5 Mha) and Jaú (Brazil, 2.3 Mha) are probably too small to maintain viable populations of some top predators as giant river otters (Pteronura brasiliensis) (Peres, 2005). Ferraz et al. (2003) show a 50% decline in bird species in Amazonian forest fragments of 100 ha within 15 years after fragmentation.



Selective logging is a scattered but omnipresent disturbance of the forest. Selective logging rates from 1999-2002 were 12,075 to 19,823 km^2 (1.2 - 1.98 Mha) per year (Asner et al., 2005), which is close to the area affected by deforestation. The collateral damage of selective logging is usually pronounced: for every two trees extracted per ha, an additional 58 trees are damaged (Uhl et al., 1991). Asner et al. (2006) found that at least 76% of all harvest practices resulted in high levels of canopy damage, sufficient to leave forests susceptible to drought and fire. The impacts of selective logging on biodiversity, however, are still poorly known (Silva et al., 2005). Arets (2005) studied the impacts of selective logging on tree populations and forest composition in Guyana. The study found that the abundance of pioneer saplings increased at the expense of relative abundance of climax species.

Forest gaps can exert a variety of effects on other organisms. For example, while forest gaps may increase the number of bird and butterfly species by creating habitat heterogeneity, they may have an adverse effect on beetle species richness as their habitat becomes excessively fragmented (Tews et al., 2004). Castro-Arellano et al. (2007) studied the effects of low harvest (18 m^3 per ha), reduced impact logging (RIL) on bat diversity and found that 2-4 years post harvest, RIL had had only minor effects on the biodiversity of bats.

5.3 Impacts on hydrological cycles

If Amazonia were to be widely deforested, a pronounced decrease in evapotranspiration would be expected, leading to a significant decline in rainfall. This would in turn result in irreversible ecological changes in the basin, including damage to agriculture.

Costa et al. (2007) observed that as a result of the very high albedo (portion of light reflected by a surface) of the soybean, the decrease in precipitation due to forest conversion into soybean is significantly higher than that attributed to a change to pastureland. The albedo of rainforest is about 12.5%, that of pastures 18%, and soybeans 20.5% (with peaks up to 24-28%).

Damage from erosion and fire.

Gentry & Lopez-Parodi (1980) linked the increased height of the annual flood crest of the Amazon at Iquitos to increased deforestation in the upper parts of the Amazon watershed in Peru and Ecuador. However, a statistical study conducted by Richey et al. (1989) of flood peak levels between 1903 and 1985 did not reveal any such trend. They suggest that deforestation is probably affecting water quality and flow in certain areas, but that the enormous volume of the Amazon River appears to be masking such signals.

5.4 Impacts on indigenous cultures and cultural services

Forest destruction has resulted in the death of indigenous peoples and loss of cultural identity. Five hundred years ago the Brazilian Amazon supported 230 native groups, with an estimated minimum of 6 million people. In 1990 only half of these groups remained in Brazil, with a total of 100,000 persons, according to estimates presented by Pearce and Meyers (1990). Redford and Streaman (1993) reported that the COICA (Coordinadora de las Organizaciones Indígenas de la Cuenca Amazónica) then (i.e. 1993) represented 229 native Amazonian groups comprising 1.2 million people in Peru, Bolivia, Ecuador, Brazil and Colombia.

In Brazil, large, government-promoted settlement schemes in the 1970s resulted in the death of large numbers of local indigenous people. Survivors were driven deeper into the forest until they encountered colonists moving in from another direction; they faced lethal epidemics, common colds, and measles. For some groups this ultimately meant the end of their culture.

In Peru and Ecuador, oil exploration is a serious threat to indigenous cultures. Forest communities living near the major oil producing regions are facing contamination, which is causing increased incidence of cancer and other illnesses as the local people have no option but to bathe, fish and drink from polluted rivers. Road and pipeline networks have been opened into previously roadless rainforest blocks, resulting in extensive deforestation. Throughout the northern Ecuadorian Amazon, oil projects have resulted in the large-scale displacement of indigenous peoples and occupation of their land by migrants from other regions. Another example is the Camisea Gas Project located in the south-eastern Peruvian Amazon. This US$ 1.6 billion project includes two pipelines to the Peruvian coast, cutting through high diversity rainforest. About 75% of gas extraction operations on the concession are located inside a state reserve for indigenous peoples living in isolation.

Besides the human tragedy related to the loss of numerous lives since colonial times, the disappearance of indigenous cultures destroys vital sources of information on how people can use and manage forest resources sustainably.

6 The role of the Netherlands

With only 0.25% of the world population and 1% of world production, the Netherlands accounts for 3.2% of world trade (WRR, 2002). International trade is a principal component of the Dutch economy and a major source of the country's wealth, given its strategic location and facilities (e.g. the Port of Rotterdam and Schiphol airport). The country imports goods from the rest of the world and re-exports them after they have passed through a number of added-value processes. The contribution of agricultural added-value products from the processing, supply and distribution of imported agricultural raw materials, reached 38% in 2003, employing around 211,000 people (Minaf, 2004).

Over the past decade the Netherlands has become one of most important destinations for Brazilian products; 4.5% of its external sales end up in the Netherlands, with soybeans and soybean derivatives being the most important item. Other products such as meat, coffee, cocoa, orange juice and various minerals like iron and manganese follow in importance. The Netherlands is Brazil's largest trading partner in Europe, accounting for a total of $US 5,283 million of Brazilian exports in 2005 (IBGE), while the country ranks fourth in importance worldwide as regards exports.

6.1 Soy imports

The Netherlands' most important soy suppliers are Brazil, the US and Argentina. In volume terms, over half these imports come from Brazil, mainly in the form of soybeans. The Netherlands imported around 4.8 million tonnes of soybeans in 2005; of this grand total, 3.3 million tonnes came from Brazil, accounting for 60% of the imports. Approximately one quarter of the soybean tonnage imported into the Netherlands is exported, to Germany and Belgium in particular.

Soy meal imports also represented a significant share, totalling 4.9 million tonnes; of this, 2.46 million tonnes originated in Brazil, representing a 50% share of the total imported in 2005. Even though the EU has strict regulations on GMOs, Argentina still plays a major role in soy meal supplies. This is because, as was stated above, livestock feed industries are major consumers of soy meal and according to EU regulations, meat, milk or eggs obtained from animals fed with GM feed or treated with GM medicinal products do not require GM labelling (Bendz, 2006.). In general, labelling regulations apply to bulk agricultural commodities such as whole grains and oilseeds. Finally, soy oil is less important in terms of the tonnage imported from Brazil, which exported only 14 tonnes of the total 74 tonnes imported by the Netherlands in 2005 (Eurostat).

Animal feed industry

The Netherlands has Europe's highest livestock density index (3.26 livestock units per ha of utilised agricultural area), followed by Belgium and Denmark. The demand for soybeans is essentially a derivative of the demand for meat. The average yield per ha in Brazil for the 2005 harvesting season was 2.6 tonne/ha; the demand for this period reached 3.34 million tonnes, which means that an extension of about 1.3 million has was harvested to supply the Dutch soybean demand.

Additional calculations need to be done for soy meal and soy oil. Each tonne of crushed soy produces approximately 0.78 tonnes of soy meal and 0.19 tonnes of soy oil (Zylbersztajn et al, 1999). Therefore, a total of 3.2 million tonnes was needed to satisfy the total demand for soy meal and soy oil, representing an area of approximately 1.2 million has harvested to meet the Dutch demand for these two products.

Embarkment station for soybeans.

Aggregating the data, the total area harvested in Brazil to supply the Dutch market for soybeans, soy meal and soy oil, for the year 2005 alone, adds up to 2.53 million ha (25,300 km^2, over half the area of the Netherlands). However, if the 0.3% of soy planted within the Amazon biome is considered, this resulted in limited direct impacts: an estimate of about 7,600 ha of direct deforestation. However, indirect deforestation caused by the soy-beef nexus is considered a much more important effect.

Financial institutions

Financial institutions contribute in large part to the expansion of soy in the form of credits, loans and investments. Some of these institutions are Dutch, such as ABN-AMRO and Rabobank. The latter, along with the German Bank for Investment and Development (DEG), granted credit in 2001 totalling US$ 12 million to “Grupo Maggi”, which provoked massive reactions from environmental NGOs. Regardless of the critique, in October 2002 the International Financial corporation (IFC), linked to the World Bank, granted another credit of US$ 30 million to the same group.

6.2 Timber imports

There is a ban on the export of unprocessed logs, so all Brazil’s timber is processed in the country itself to sawnwood at least. Part of this is exported, but most of it is re-used in Brazil itself. According to Brazilian export data for 2005, the Netherlands was the fourth largest importer of sawnwood from Brazil with an import volume of 113,000 m^3, after China, France and the US. Dutch data on imports indicate a smaller import volume, totalling 97,000 m^3 (ITTO, 2008).

Although the volumes are much smaller, the Netherlands were also the sixth largest importer of Brazilian plywood in 2005, at 5,000-6,000 m^3. Table 13 shows the importance of Brazil for Dutch imports of tropical timber. Only the two main categories of wood imported into the Netherlands are listed here. There are great fluctuations between the years, but the data do show the importance of Brazilian supply to the Netherlands.

Table 13 Dutch imports of tropical timber from Brazil.

	Sawnwood		Plywood	
	m³	% of total	m³	% of total
2000	58,912	13%	6,026	7%
2001	65,900	17%	55,000	24%
2002	66,898	15%	932	0%
2003	35,442	9%	2,997	1%
2004	125,466	28%	6,553	3%
2005	96,783	22%	6,550	3%

Grieg-Gran et al. (2007) calculated that this Dutch share of tropical timber imports from Brazil was responsible for forest degradation in the Amazon of around 62,000 ha between 1996 and 2005.

7 Responses and policy measures

As illustrated in the previous chapters, the rate of deforestation and forest degradation in Amazonia is expected to increase further over the coming decades. A number of developments underlie this trend:

- The expansion of infrastructure, including river transportation and roads, will open up large parts of the Amazon where agriculture is currently not profitable.
- Rising world population and rising commodity prices will promote agricultural expansion and non-sustainable timber production at an accelerated pace.
- Increasing demand for biofuels, added to the demand for timber and traditional agricultural commodities, promotes the agro-industrial production of oil palm and sugarcane, thus driving deforestation both directly and indirectly.
- Global climate change is expected to result in forest degradation over a large scale, which is accompanied by an increasing fire frequency.
- Widespread expansion of soy cultivation and pastures will significantly reduce rainfall, which exerts an adverse impact on the rainfall regime, promoting further degradation of the remaining forest.
- Massive emissions from deforestation and forest degradation in Amazonia will further fuel the problem of global climate change, partly because the region is expected to turn from a net sink into a net source of carbon emissions in the near future.

With continuing conversion of the Amazon, mankind is involved in a gigantic experiment, with the largest life support system on Earth at stake. The outcome of this experiment is largely unknown. Little is known about the exact synergies and feedbacks among these processes. It is obvious, however, that the value of the multiple ecosystem services provided by Amazon forests will decline sharply over the coming decades if current policies do not change. It is also becoming increasingly clear that the Amazon biome is reaching the limit of its ability to function with resilience. When we draw up the balance of all current threats and their mutual interactions, we are ineluctably forced to consider the notion that the destructive processes going on in the Amazon are approaching a point of no return.

Figure 11 shows different deforestation scenarios due to land use change in the Brazilian Amazon, for the period until 2050. This graph does not incorporate the effects of forest degradation due to climate change. The various deforestation scenarios result in widely ranging estimates of forest loss, which implies that there is currently still ample room for intervention. Soares-Filho et al. (2006) indicate that improved protected area management and governance, and limitation of the expansion of infrastructure, are effective ways to mitigate deforestation. Improved governance includes improving land use planning and implementing existing ecological-economical zoning, taking measures against land speculation, improving the regulatory framework for environmental impact assessment, and exerting control on existing regulation (e.g. the Brazilian legal requirement to maintain 80% forest on private land).

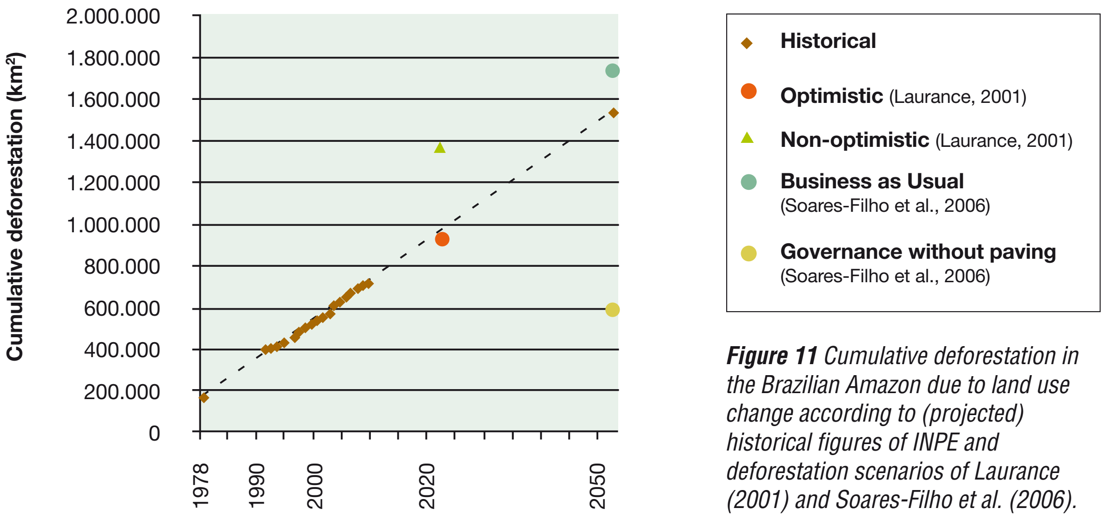


Figure 11 *Cumulative deforestation in the Brazilian Amazon due to land use change according to (projected) historical figures of INPE and deforestation scenarios of Laurance (2001) and Soares-Filho et al. (2006).*

The fact that the sum of all economic values represented by the ecosystem services provided by sustainably managed Amazon forests is far larger than the economic value of non-sustainable uses, also provides opportunities for change. An important challenge will be to further develop markets for sustainably produced goods, and to create new markets for ecosystem services which are currently not captured in financing mechanisms.

7.1 Protected area management

Parks and indigenous territories are effective in halting deforestation and forest fires according to a study by Nepstad et al. (2006). Using maps of land cover and fire occurrence based on satellite images obtained between 1997 and 2000, the authors conclude that deforestation was 1.7 to 20 times greater outside versus inside the perimeter of reserves, while fires occurred 4 to 9 times more frequently outside versus inside. In frontier areas where deforestation rates are high, in 33 out of 38 cases indigenous lands had deforestation rates of 0.75% or less versus more than 1.5% outside their borders. Parks and indigenous territories provide a similar picture of deforestation inhibition.

Indigenous territories form the most important barrier to Amazon deforestation. Indigenous land occupies a much larger area than the parks in the entire Amazon. Conservationists may argue that indigenous peoples will cease to protect forests as their contacts with a market society increase, but Nepstad et al. (2006) found that virtually all indigenous lands substantially inhibit deforestation up to 400 years after contact with the national society. There was no correlation between population density in indigenous areas and the inhibition of deforestation. In a large part of the Amazon, forest protection can be reconciled with human habitation and sustainable management – it would not happen without the people.
We therefore recommend strengthening protected area management and the creation of new protected areas ahead of the agricultural frontier. Furthermore, the rights of indigenous peoples over their land should be recognized and the capacity of indigenous organizations to manage their own territories should be strengthened.

7.2 REDD

An important opportunity for counteracting forest loss and forest degradation lies in establishing mechanisms of payments for ecosystem services, e.g. in relation to REDD (Reduced Emissions from Deforestation and forest Degradation: ‘avoided deforestation’). It is being proposed that governments and/or companies can compensate developing countries for reducing emissions related to forest loss and forest degradation, in post-2012 climate regimes. During the 2007 climate conference in Bali, countries agreed to start REDD pilot projects.

Including REDD the carbon market could become saturated, which could drive the price down. On the other hand, if industrial nations cannot comply with their emission reduction targets, demand for carbon credits related to REDD activities could be very high, stimulating the conservation of forests and lowering prices (Laurance, 2007b; Nordhaus, 2001). Emission reductions may not be permanent if climate change causes forest decline. Leakage may occur, when non-sustainable use simply shifts to other areas. Developing countries argue that future development options may be restricted. Furthermore, the ability to control deforestation might be overestimated (Skutsch et al., 2007).

Despite these risks and shortcomings, Nepstad (2007b) states that REDD-related financing has the potential to become the largest financial flow into tropical forest conservation. According to this author, carbon finance at US$ 5 per tonne or less could tip the balance from non-sustainable use towards sustainable forest management over 96% of the Brazilian Amazon. However, these calculations do not include compensation to governments at different levels, nor to private companies for foregone profits. They are also based on a limited expansion of the infrastructural network. As soon as infrastructure expands further, the opportunity costs of forest conservation would increase sharply for the newly accessible areas, notably if soy or oil palm were to be cultivated.

7.3 Payments for other ecosystem services

Despite the high economic value represented by the manifold ecosystem services provided by the Amazon forest, markets to capture these values are often non-existent or only incipient. The potential economic benefits of ecosystem services should not be overestimated. We illustrate in this report that expectations regarding the potential benefits of ecotourism or non-timber forest products are often too optimistic. The potential economic benefits of some other services, such as biodiversity conservation, maintenance of hydrological services, and provision of pollination services, seem more promising but these values are not yet captured in effective payment mechanisms.

In particular, valuable biodiversity is lost in the agricultural frontier zones. Few figures are available on biodiversity loss, but we can assume that many species will go extinct before they are even discovered. Biodiversity represents an important global service. Parallel to financial compensation for reduced carbon emissions related to avoided deforestation, international mechanisms should be developed aimed at paying for this global service of biodiversity conservation. Compensation for biodiversity loss elsewhere, for example due to agricultural development in less valuable areas, could provide substantial financial resources for biodiversity conservation in the Amazon.

We also recommend the development of markets for hydrological services. Stakeholders in the agricultural industry, for example, could contribute financially to the maintenance of forest cover in the same region as their operations, as they would benefit from the maintenance of a favourable rainfall regime. This holds also true for large grain production areas in southern Brazil, Paraguay, Uruguay and Argentina, where rainfall from the Amazon represents an important contribution to the regional hydrological cycle.

Mechanisms for payments of pollination services could be established locally, for coffee production systems in the Amazon and other agricultural crops which depend on pollination services provided by forest ecosystems.

7.4 Sustainable production and consumption

Grieg-Gran et al. (2007) estimated that, over the period 1996-2005, the Netherlands can be held responsible for the deforestation and degradation of 1.56 million ha of forest worldwide. 54% of this impact took place in Brazil and is related to the production of soy, beef and timber and an expanding agricultural area. In the same period, 7.18 million ha of forest area was converted in the legal Amazon, as a direct or indirect result of the expansion of soy production.
However, the existing agricultural land can be used more efficiently. According to Brazil's the Ministry of the Environment, agricultural production on existing agricultural land could in principle be tripled without cutting down a single tree. According to researchers from the IBGE and USDA, Brazil has an immense potential for agricultural expansion. They estimate that the total cultivated area could increase between 145 and 170 million has without any additional deforestation of the Amazon (Shean, 2003). This can only be accomplished if a number of legal, technical and financial constraints are eliminated. These improvements involve a shift of the tax burden to encourage processed products over raw material, law enforcement entailing illegal acquisition of land, and the enforcement of environmental laws.

The Netherlands should develop policies and mechanisms to reduce its footprint in the Amazon, including the following examples:

- Markets should be developed for sustainably produced goods. Not only should timber be certified, but also other key products such as beef and soy. Certification systems should include the requirement to maintain 80% forest cover on private land, according to Brazilian regulations. A system should be promoted for tracing the origin of products in appropriate certification schemes.
- Dutch consumers could decrease their meat consumption. The Netherlands ranks seventh among the nations consuming the largest quantities of meat, with an average meat consumption of 86 kg per year. An average European citizen consumes 87 kg of meat and 250 eggs a year. The soy cultivation coupled to this consumption is about 400 m^2, which is the size of a basketball court.
- Dutch livestock production systems should be developed to reduce dependence on soy feedstock. The production of certified organic meat using locally produced feedstock should be promoted. The development of more sustainable livestock production should in general lead to a smaller ecological footprint of the entire production chain.
- Subsidies that favour the expansion of soy, cattle ranching, oil palm and sugarcane into the Amazon should be eliminated, notably subsidies and loans for the expansion of related infrastructure. Export credit subsidies provided by the Dutch government to promote investments in agriculture in Brazil and other Amazon countries should also be critically evaluated in terms of their potential impacts on Amazon forests.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