The impact of cattle ranching on biodiversity in the Brazilian rain forest

Management implications

Christa Blokhuis (3366448)

Bachelor thesis environmental sciences

Supervised by prof. dr. ir. Max ietkerk

June 29, 2011

Preface

In front of you lies the report of a literature research about management implications for the impact of cattle ranching on biodiversity in the Brazilian Amazon. This research was done within the framework of the bachelor's thesis of environmental sciences. In two months I have found my way into a subject that has always caught my attention as being an environmental problem caused by materialism. I could however not have completed this paper without the help of my supervisor prof. dr. ir. Max Rietkerk, my co-reporter Jules Kerckhoffs, and my fellow students. I would like to thank them for their comments, suggestions and tips, which certainly helped to improve the quality of my report.

Christa Blokhuis
Amersfoort, June 29, 2011.

Abstract

Despite the importance of the high species diversity in tropical rainforest in terms of ecosystem services and usefulness to humans, the Brazilian Amazon is severely threatened by international meat demand causing rapid spread of cattle ranching. In Brazil, cattle ranches form the largest cause of deforestation activities. The aim of this research paper was to analyse the effects of cattle ranching on biodiversity in the Brazilian Amazon and to bring forward management implications for conservation of interior species diversity. By using literature resources, forest fragmentation, edge-forest effects, changes in microclimate conditions and nutrients, and alternating species interactions were explored. For fragmentation it was shown that number of fragments, patch size, isolation and interior habitat percolation are very important aspects to consider in management of tropical forest and deforestation. Both conversion from forest to pasture and independent settlements were found to cause the greatest losses in interior forest diversity and should therefore be avoided as much as possible. Another problem related to deforestation is edge creation and the accompanying changes in microclimate conditions like humidity and temperature, which cause mortality of interior forest species. Forest clearing also directly removes nutrients and biomass from the ecosystem, which could hinder regeneration. As removal of suitable habitat and/or keystone species can affect other species as well, considering the complex interaction web in the tropical forest ecosystem is very crucial for management. To preserve or regain biodiversity, management should have a holistic approach, aiming at existing forest, pastures and abandoned lands. In original forest, forest size and connectivity between forest patches are the most essential measures for protecting biodiversity, though preferences differ per species. Pastures should be managed sustainably to prevent more deforestation. This could be done by using the so-called "slash-and-mulch" and agro forestry systems, or selective clearing of non-palatable secondary woody vegetation. To reduce impact of edge effects on original forest, edges could be buffered by using, for example, eucalypt plantations. When aiming at restoration of forest, rain forest conditions can be re-established by re-growth or planting of trees, which will enhance primary production, nutrient cycling, succession and eventually biodiversity. Also, intermediate disturbance could contribute to preserving or regaining tropical forest diversity. More research is needed to find out about the required magnitude of (human) disturbance to enhance biodiversity, the magnitude of different factors and processes affecting biodiversity and possible amplifications, edge effects of nutrient and biomass removal and cattle activities on adjacent forest, and to what extent plant community composition is a (better) determent for ecosystem functioning than biodiversity.

Table of contents

1. Introduction-- 5
2. Biodiversity in the Brazilian Amazon --- 7
3. Cattle ranching affecting biodiversity-- 9
3.1 Forest fragments --- 9
3.2 Edges and microclimate conditions ---11
3.3 Nutrients--13
3.4 Species interactions ---13
4. Management implications--14
4.1 Conserving the Brazilian Amazon --14
4.2 Sustainable management of pastures---15
4.3 Restoration of tropical forest---16
5. Discussion--19
5. Conclusion ---20
6. Bibliography--21

1. Introduction

The tropical rain forest in Brazil houses a huge diversity of plants, animals, micro-organisms and fungi. It is widely acceded that this diverse range of species is essentially irreplaceable and is regarded very valuable in many ways. Many plant species perform ecosystem services like oxygen provision and regulation of precipitation, while both animal and plant species are of great use to humans because of food, medicines and manufacturing. For that reason species diversity is a vital part of the natural capital. Besides, many people have the opinion that each species has intrinsic value based on its right to exist and fulfil its ecological role, regardless of its usefulness to humans (Miller & Spoolman 2009).

Despite the importance of the tropical rain forest, Brazil lost nearly 150.000 square kilometres of rain forest between May 2000 and August 2006. In the past, a large amount of deforestation could be attributed to a mix of clearing for pastures, poor government policies and commercial exploitation of forest resources. In many countries deforestation currently results from cultivators using slash-and-burn practises for agriculture, but in Brazil only about one-third of recent deforestation is caused by 'shifting' cultivators (Butler, 2010). Contrary to what is generally thought, most recent analyses suggest that it is not soybean cultivation that is driving deforestation, but cattle ranching. Soybean farms seem to be replacing previously deforested land and/or land previously under pasture (Barona et al. 2010).

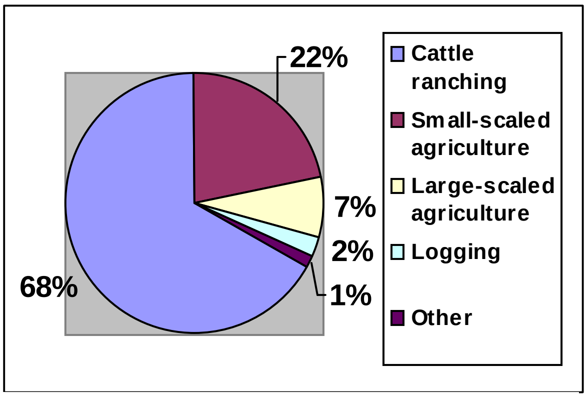

Figure 1: Causes of deforestation in the Brazilian rain forest. Small-scaled refers to subsistence agriculture; large-scaled to commercial agriculture. Other causes include fires, mining, urbanization, road construction and dams (Butler, 2010).

Cattle ranching is the main cause of the clearing of tropical forest in Brazil (figure 1) and is largely driving deforestation because of booming meat exports (Tollefson 2008). According to the Centre for International Forestry Research (CIFOR), between 1990 and 2003 Europe's meat import from Brazil increased from 40 to 80 percent. This raising demand induces deforestation even more (Kaimowitz et al. 2004). Laurance (2002) observed deforestation is accelerating and the patterns of forest loss and fragmentation are rapidly changing: large-scaled deforestation is shifting from southern and eastern areas more to northern and western areas. If this trends continues, settlers and loggers could bisect the Amazon forest.

Fragmentation, altering of microclimate conditions, an increase in edge-forest area ratio and disturbed species interactions are consequences of deforestation and pose several threats to species living in the rain forest. In accordance with processes associated with population dynamics and shrinking of suitable habitat, the diagram in figure 2 has been drawn up to plainly represent the expected relationships between cattle ranching and loss of biodiversity. Therefore, the objective of this research paper is to analyse how deforestation because of cattle ranching affects biodiversity in the Brazilian rain forest and to bring forward management implications to preserve tropical forest and reduce the impact of cattle ranching on deforestation. The research question that will be answered is the following: *What are the impacts of cattle ranching on biodiversity in the Brazilian rain forest?* Hence, as cattle ranching is driving deforestation, there are two sub questions: *What are the impacts of deforestation on biodiversity?* And: *What are the management implications for prevention of further forest clearing and for compensation of lost forest?*

To answer these questions, first will be looked more closely at characteristics of tropical forests that contribute to high biodiversity. Next, fragmentation, an increasing edge-forest ratio, changing microclimate conditions and disturbed species interactions will be analysed for their influence on biodiversity. Then management implications for the impact of cattle ranching on biodiversity will be considered for existing forest, pastures and re-growth of tropical forest. Last, in the discussion section some remarks on the analysis and the suggested management will be considered.

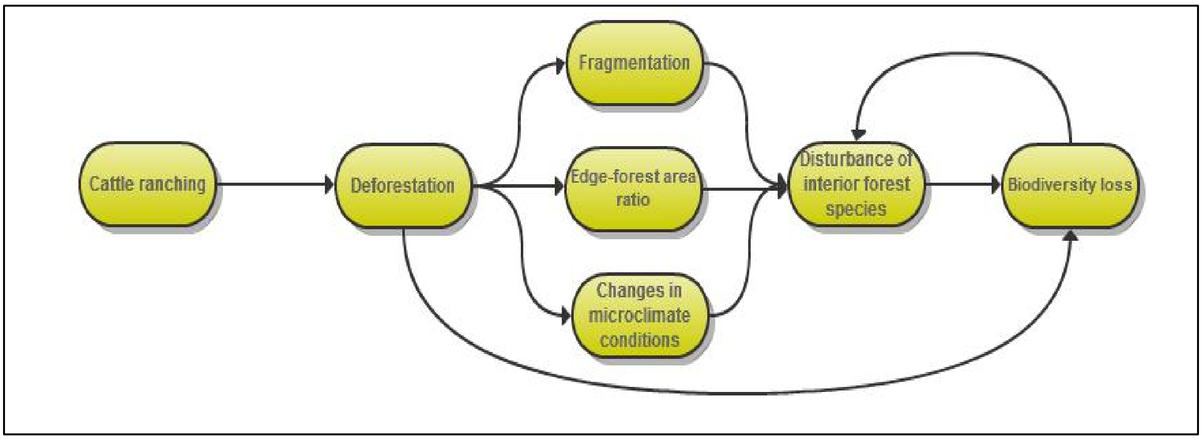

Figure 2: Diagram of cattle ranching affecting biodiversity. The arrows represent an increasing effect.

2. Biodiversity in the Brazilian Amazon

The Amazon River Basin was formed somewhere between 500 and 200 million years ago, in the Palaeozoic Era (Taylor 2004). The rain forest currently stretches out between 15° - 20° north and south of the equator and is located at the north side of the South American continent. The largest portion of the Amazon forest and river basin lies within the borders of Brazil.

Although tropical forests only cover about 5-6 percent of the earth's surface, they house about one-third of all living animal and plant species on the planet (Tollefson 2008). In terms of biodiversity, tropical forests are the most important compared to other biomes (May 1990). Of all tropical forests, the Amazon River Basin contains the largest biodiversity. It is assessed that at some places one acre of this rain forest houses 200 tree species, while, for example, in all of North America only 60 species occur (Morell 1997). Plus, one in five of all bird species lives in the Amazon (Taylor 2004).

A wide collection of theories has been formulated to explain the enormous biodiversity in tropical rain forests. The first theory is based on an idea by Wallace (1878): the older a biome, the more time their inhabitants have to diversify. As the tropical forest areas on earth are considered the oldest biomes on earth, the vast species richness has much to do with the high age of the forest area (Taylor 2004).

The second theory draws from the area-species curve, generally given by the equation $S = CA^z$, where S is the number of species of a given taxon on an island and A is the area surface. Here 'island' refers to any area of suitable habitat surrounded by an expanse of unsuitable habitat, such as forest surrounded by non-forest. C and z are both parameters, depending on population density and proximity of an island to the mainland, respectively (MacArthur & Wilson 1967: 8-9). As the whole Amazon River Basin coats around 6.915.000 km^2 and the Brazilian Amazon covers 4.100.000 km^2, this could be considered one of the largest biomes in the world.

A third explanation for the rich diversity in tropical rain forests can be attributed to the climate: a combination of large amounts of daily solar input, frequent rainfall and steady high temperature. High levels of solar energy enable high plant productivity, resulting in high plant diversity (Nee 2002). A warm, humid, relatively stable environment is furthermore beneficial for the existence of lots of plant species (Wallace 1878). Besides that, when a lot of plants are present, this facilitates many consumers with food resources (Burslem et al. 2001).

Fourth, next to high plant productivity, soils in the tropics have low nutrient availability. Apart from solar input and water availability, biomass (carbon) and nutrients are essential for plant growth. Because high temperature and rainfall and near-optimal abiotic conditions lead to rapid decomposition in tropical forests, most nutrients and biomass in these biomes are stored in aboveground vegetation (Wieder et al. 2009). Low nutrient availability stimulates inter-specific competition, which prevents dominance of a few competitively strong species because nutrients are not abundant (Grime 1979). Aerts (1998), though, highlights that also traits which reduce nutrient losses or enhance nutrient efficiency in plants contribute to high diversity. This means that low growth rate of plants on nutrient poor soils could also be a consequence of nutrient retention rather than a cause of selection.

A fifth theory explaining rich diversity in tropical rain forests is the unique canopy structure consisting of several distinctive habitats. By means of vertical layers, the canopy structure offers many different food sources and shelters for both plants and animals and leads to an incredibly interrelated ecosystem (Butler 2010).

On last factor that can contribute to a large species diversity is disturbance. On a short timescale, there is natural disturbance of rain forest habitat by heavy weather such as hail and tornados, but also by wildfires. This results in gaps in forests. Large gaps are usually filled with pioneer species, but when these species do not sufficiently occupy the gap or conditions also allow non-pioneer species, this will result in high biodiversity. As the species composition of ecosystem communities fluctuates over time, both low and high disturbance will diminish species diversity, as one (group of) species could dominate and many species will not survive, respectively. For natural habitats with intermediate disturbances, with high species richness comes a large amount of ecosystem functions performed (Odum 1989). See figure 3 for the relationship between disturbance and biodiversity. Nevertheless, recent studies have shown that on a large timescale, geological events, like earthquakes, ridges being pushed up and basins being filled with sediment, are most likely responsible for disturbance by splitting forest habitats, because these events cause populations of the same species to drift genetically, resulting in large biodiversity (Morell 1997).

In short, a combination of characteristics – age; vastness; a warm, humid climate; nutrient poor soils; a unique canopy structure; and intermediate disturbance – contribute to the enormous biodiversity in the Brazilian Amazon.

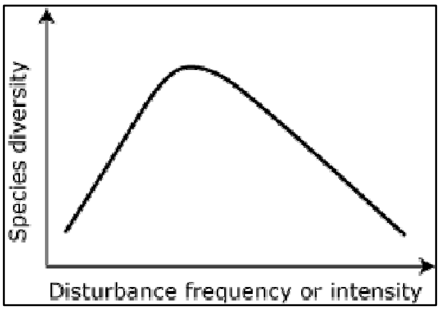

Figure 3: Graph showing the relationship between disturbance and species diversity (Odum 1989).

3. Cattle ranching affecting biodiversity

In a time span of seven years (1997-2004), Brazil's cattle herd expanded from 153 to 205 million, an annual growth rate of 3.7 percent. 60 percent of land converted to cattle pastures is located in the wet-dry and humid tropical areas of the Cerrado and the Amazon (FAO 2007). Large forest areas are cleared to give place to meadows for meat production, negatively affecting forest habitat and species.

Habitat destruction is considered the major cause of species extinction (Lawton & May 1995), while the rate of forest destruction in the Brazilian Amazon is not promising: deforestation increased from 1.1 million ha yr^{-1} in the early 1990s to more than 1.9 million ha yr^{-1} from 1995-1998, and is still accelerating (Laurance 2002). As stated earlier in this paper, cattle ranching is by far the largest cause of deforestation in this region. The resulting reduction and fragmentation of forest habitat – defined as both the increase in forest edge-to-area ratio and number of fragments (Broadbent et al. 2008) – severely interfere with fundamental processes of biogeography. For example, less suitable habitat and higher rates of fragmentation hamper dispersal of a species and (seasonal) migration but increase invasion by non-native species, which could be negative for native forest species (MacArthur & Wilson 1967). In this section, the consequences of deforestation for species diversity in the Brazilian Amazon will be explored.

3.1 Forest fragments

In Brazil, deforestation takes places in three common patterns: fishbone (small properties regularly distributed along roads), independent settlements (irregularly distributed small properties), and large properties (large deforested areas of more than 1000 ha). See figure 4. Forest fragmentation can hence be considered by looking at the number of fragments, mean patch size, forest isolation and interior habitat percolation (Oliveira & Metzger 2006).

Interior habitat percolation as a characteristic of landscape fragmentation is based on percolation theory. This theory predicts that for an infinite lattice (e.g. a large forest area) there is a critical percolation value for which a certain cluster size (e.g. a suitable habitat) becomes finite. A species population cannot move freely between clusters anymore when its phase transition value has been reached. This means that below a certain forest cover ratio, species are unable to disperse or migrate to a nearby suitable habitat. When their current habitat is too small or does not provide for essential resources, a species will become extinct in that area.

Boswell et al. (1998) simulated percolation theory for the ant species *Eciton burchelli,* which lives in the Brazilian Amazon. One would expect that the ant species would become extinct when the phase transition value is reached. Results showed, conversely, that the *Ecition burchelli* population goes extinct much earlier. For fragmentation processes affecting biodiversity it is important to consider that migrating from one piece of suitable habitat in the cluster to any other may not be impossible, but still can be difficult. Furthermore, continuous forest area is not necessarily able to provide a suitable habitat for a population of any species. It is possible other (threshold) values and specific habitat characteristics determine the boundary between survival and extinction.

Both simulations and LANDSAT images were used by Oliveira & Metzger (2006) to examine thresholds values (i.e. abrupt changes) for the conversion from forest to non-forest (areas prone to human interference, including secondary forest) compared between fishbone, independent settlements and large settlements. Independent settlements and fishbone patterns showed greatest landscape fragmentation compared with large properties. It was concluded that the independent settlements pattern is least favourable when it comes to conserving interior forest species, as with this clearing method most remaining forest is near an edge. Large properties seemed best to preserve interior forest species because with this clearing method large forest patches remain. However, in later stages of deforestation, isolation of patches and lack of corridors restricts movement of species that cannot cross large expanses, which will contribute to biodiversity loss.

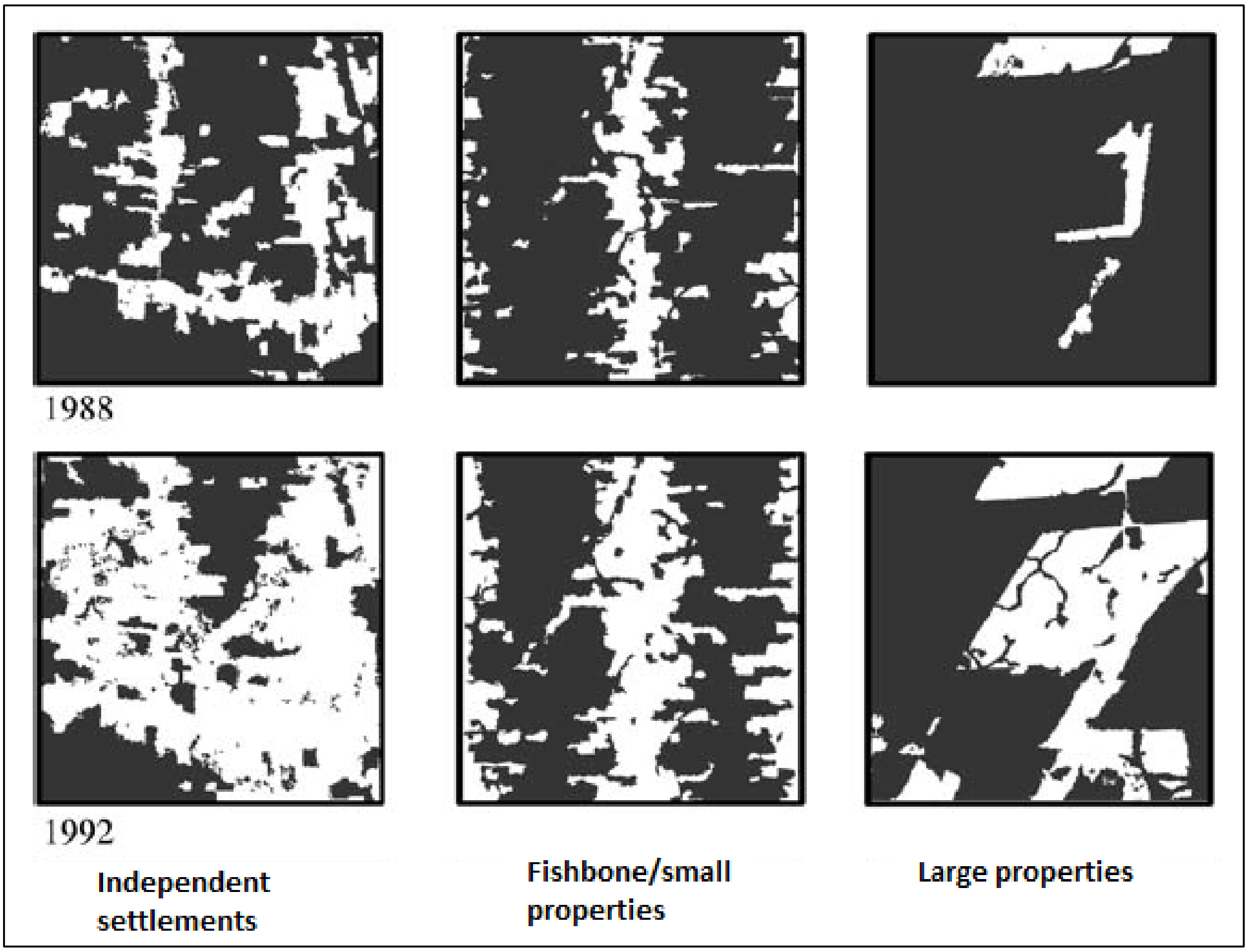

Figure 4: Satellite images showing three common deforestation patterns in Brazil, independent settlements, fishbone and large properties, and their development in four years (Oliveira & Metzger 2006).

Despite independent settlements being the least favourable pattern, it seems this deforestation pattern is applied most. Infrastructural developments in Brazil provide new highways that are cutting through tropical forest and give small settlers using slash-and-burn methods easy access to virgin forest (Laurance 2002). One example is how in 1973 the Brazilian government improved an important highway to connect the south-central region with a newly-established colony in Rondônia:

Theobroma. In the next twenty years, 43% of the forest in the 2165 km^2 area was cleared. Fujisaka et al. (1998) subsequently analysed the impacts of deforestation in Theobroma on plant diversity. They discovered that from the 326 plant species encountered in the forest, only 20 remained on pastures, along with 66 non-forest species.

When looking at plant community diversity over time, Fujisaka et al. (1997) stated it is not slash-and-burn agriculture per se, but conversion from forest to pasture that leads to the highest biodiversity loss. In an agricultural settlement, land use usually shifts from forest, to cropped after forest, to fallows, to cropped after fallows, and to pastures. Original forest plants decrease with land conversion, although biodiversity values on fallow lands are comparable to forest due to both re-establishment and emergence of non-forest species. Since pastures are at the final land use stage, the greatest losses of forest flora were encountered in pastures.

Future deforestation practises will likely result in the situation that characterizes eastern Amazonia at the moment. These rain forest lands are the most populated area of the Brazilian Amazon and are extremely fragmented by roads, agriculture, slash-and-burn agriculture, secondary forests, and pastures (Stone et al. 2009).

To gain some insights in the future expansion of agricultural and cattle raising activities in Brazil, Maeda et al. (2011) used simulations to figure out forest conversion trends in 2015. In all simulated scenarios, pasturelands remained nearly stable, while croplands underwent major expansion. Soares Filho et al. (2006) add that 40% of the Amazon forest will be removed by 2050 if current trends continue. The cleared forest will cause one quarter of 382 mammal species to lose their habitat. Therefore it is likely, if people keep clearing forest at current pace, that regardless of the deforestation pattern only small, secondary, highly isolated and disturbed forest fragments will remain (Metzger 2002).

3.2 Edges and microclimate conditions

Besides actual loss of habitat because of deforestation, microclimate conditions like amount of wind and air moisture affecting the edges of (original) forest also play a role in threatening tropical forest biodiversity. The amount of edge forest is usually underestimated, but already in the late 1980s, forest fragments (<100 km^2) or forest area subject to edge effects (<1 km from forest edge) were more than 150% larger than actual deforested area (Skole & Tucker 1993). In the period 1999-2002 Broadbent et al. (2008) used GIS and remote sensing to quantify the effects of both deforestation (and selective logging) on forest fragmentation and edge effects. They found that 90% of all individual forest fragments were smaller than 4 km^2. What is more, at that time 53% of all forests was located within two kilometres of an edge. Both logging and deforestation contribute to an edge-forest increase of 2.6% annually. Some other findings are summarized in table 1.

The transformation from forest to pastures also alters environmental conditions at forest edges, which affect interior species diversity. In an elaborate literature review, Broadbent et al. (2008) identified 146 impacts of deforestation on microclimate conditions, forest structure and composition of edge forest. They found that in 2002, 6.4% of all remaining forest was subject to edge effects impacting biodiversity.

Table 1: Quantitative data for forest fragmentation in the Brazilian Amazon, 1999-2002. Selective logging generates more edge forest because these logging activities extend deeper into original forest than deforestation (for pastures) (Broadbent et al. 2008).

	Deforestation	Selective logging
New forest fragments (1999-2002)	5539	3383
Forest edge generated (km yr^{-1})	32.000	38.000
Edge-forest generated (km^2 in 1999-2002)	3000	20.000

Deforestation directly causes more canopy openness, creates edges, removes native vegetation and changes original forest vegetation structure. Both more canopy openness and edge creation contribute to more sunlight and wind penetration. Hence, air and soil moisture decrease, temperature rises, susceptibility to wildfire increases (also caused by fires in adjacent pastures) and this leads to tree mortality, decline in forest species abundance and eventually to a loss in biodiversity. An increase in sunlight and wind penetration also causes direct mortality of trees up to 300 meters into the intact forest. Moreover, increased sunlight penetration also enhances photosynthetic-active radiation, which increases plant growth and litter fall and causes a higher susceptibility to wildfire as well. By changing original vegetation, interactions between organisms become disrupted and could lead to extinction of one or more species involved in the ecosystem. Combined with edge creation, it also opens up opportunities for invasive/pioneer species to cover the cleared area, which reduces original biomass and diminishes re-growth of forest plant species (Broadbent et al. 2008, and references therein). These effects are shown in figure 5.

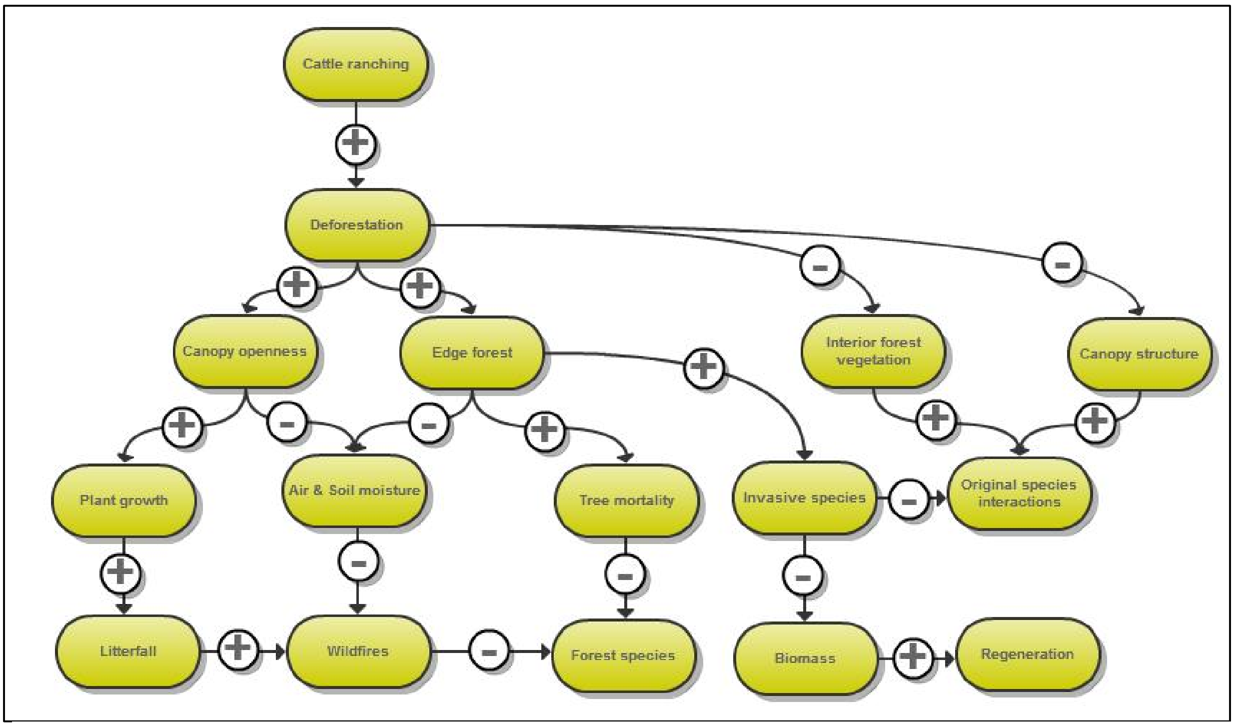

Figure 5: Diagram of the impacts of deforestation because of cattle ranching on forest species and opportunities for forest regeneration. After Broadbent et al. (2008).

In a recent study, Souza et al. (2010) evaluated the effects of adjacent land uses on plant populations flourishing in forest remnants in South Brazil by assessing the conservation of four woody species comparing fragments surrounded by eucalypts plantations or pastures on both a local and regional level. Results showed that in local fragments surrounded by eucalypts plantations, small individual plants prevailed, indicating regeneration, whereas in areas surrounded by cattle ranching, small individuals consistently lacked for all species. Based on the fact that the forest remnants now occupied by eucalypts plantations were formerly surrounded by pastures, two conclusions were made. First, the observed increase in regeneration was due to a decrease in harmful microclimate factors, as eucalypts plantations generally buffer microclimate conditions by forming soft forest edges (Denyer et al. 2006). Second, regeneration enhanced due to a decrease in disturbing foraging activities by cattle (Souza et al. 2010).

3.3 Nutrients

As the bulk of nutrients and biomass in tropical forest systems is stored in aboveground vegetation, clearing and burning of trees removes essential nutrient pools and biomass by wind, leaching and evaporation. In a study by Ward et al. (1998) the impact of pasture formation on biomass, C and nutrient pools was investigated. Factors needed for plant production (see section 2. Biodiversity in the Brazilian Amazon) are all subject to slash-and-burn fires and subsequent fires occurring every two years in pastures. Ward et al. (1998) found that after six years just 3% of aboveground C pools that primary forests contain was still present on pastures. Fires removed furthermore 21-84% of aboveground biomass. Additionally, an equivalent of 94% of the N pool in intact forest was lost in that period. Last, total losses of S, P, Ca and K were <33 kg ha^{-1}.

3.4 Species interactions

Cattle ranching poses a threat to biodiversity by driving deforestation. As ecosystems are a complex web of interactions between living organisms and abiotic factors, removal of one or more parts of the web could lead to changes in interactions, extinction of one or more species or, in the worst scenario, to a collapse of the system.

One example of a group of species affected by deforestation and pasture formation is the leaf-litter frog community in Rondônia, Brazil. Bernarde et al. (2008) examined abundance and diversity of this frog species in both forest and pastures. It was concluded that forest converted to pasture negatively affects different quality features of the frog's habitat, among which: less places for reproduction, loss of leaf-litter, soil compaction and reduction in food supply. Furthermore, the arrival of other species more common in open areas could form a threat to the frog species.

Some species have more tight interactions in the ecosystem web than others. If removal of one such species would lead to large changes in abundance of several other species, or even extinction, this species is referred to as a *keystone species* (Townsend et al. 2000). Therefore, another risk of forest habitat destruction is the removal of key stone species.

Two examples of key stone species in the Brazilian Amazon are agouti, ground-dwelling rodent species *Dasyproct,* and orchid bees *Euglossa*, that are both essential for the regeneration of the Brazil nut tree *Bertholletia excelsa*. The agouti is the only animal that has teeth strong enough to open the grapefruit-sized seed pods of the nut tree. It also spreads seeds around the forest by burying caches away from the parent tree. For pollination, Brazil nut trees depend on the large-bodied orchid bees. This is why cultivation of *Bertholletia excelsa* in plantations so far has had little success, as the tree species only seems to grow in primary forest where agouti and orchid bees are present (Butler 2010).

More generally, the shrinking of tropical forest area causes large predators and other mega fauna to vanish. Examples are tapirs, jaguars, pumas and harpy eagles. In the smaller forest fragments these animals have basically disappeared, while these species fulfil essential functions in the ecosystem, like hunting prey species. Large rainforest predators help to regulate the density of prey species, and their absence can provoke ecological disturbances that resound throughout the entire tropical forest ecosystem (Terborgh et al. 2010).

4. Management implications

In the previous section forest fragmentation, edge effects, changes in microclimate and nutrient stocks, and alternating species interactions were explored. Vastness, a warm, humid climate, nutrients stored in aboveground biomass and the unique canopy structure are all negatively affected by deforestation activities. Furthermore, human interference is causing large disturbances throughout the tropical forest. In figure 5 all effects of cattle ranching on biodiversity in the Brazilian Amazon that were presented in the previous section are summarized. To conserve interior species diversity, conditions and resources of the tropical forest should be protected or regained. Therefore, in the next paragraphs measures to conserve and restore tropical forest habitat and to reduce deforestation for pastures will be explored.

4.1 Conserving the Brazilian Amazon

For decades Brazil has been struggling with the preservation of its vast tropical forest resources and the need for economic development, a prime example of the conservation versus development dichotomy (Veríssimo et al. 2002). Countless programmes, organizations and national parks contribute to the protection of tropical forest habitat and its inhabitants, mainly by setting up restricted areas and/or research projects. Unfortunately, a lot of conservation areas are insufficient in protecting the tropical forest.

One well-known preservation measure that is about to fail is the Central Amazonian Conservation Corridor (CACC). This very important network of protected and indigenous lands forms the inner core of the Brazilian Amazon, but is, unfortunately, threatened by the Manaus-Venezuela highway. Forest colonization alongside the highway is even promoted by SUFRAMA, a Brazilian federal agency, that has started settling families in farming plots a couple of years ago. The Manaus-Venezuela highway is about to bisect the CACC (Ayres et al. 1997) and will, moreover, attract illegal independent settlements (Laurance & Luizão 2007).

Independent settlers are responsible for a lot of illegal deforestation, because 35 percent of Brazilian territory – 38.5 million hectares, an area larger than Germany – is ‘open access’, meaning it is not assigned to a governmental zoning plan. Many have come to the conclusion that programmes, organizations and national parks protecting rain forest area should be expanded with private lands, (Soares Filho et al. 2006; Negrôes et al. 2011), because it is recognized people are more likely to care for private properties than for common ones (Miller & Spoolman 2009). One solution is the Amazon Protected Areas Programme (ARPA), designed to expand legal protection of land and registration of public lands in the Amazon. In the past, a simple registration process has proven to be sufficient in preventing deforestation, as settlers want to avoid confiscation of their land by the government. Other ways to avoid deforestation is by offering market activities so communities can make money without clearing trees, such as extracting rubber and collecting seeds and oils. Unfortunately, as people gained some wealth, they began investing in cattle, as this is more profitable (Tollefson 2008).

It is clear that current preservation measures are inadequate in protecting forest habitat against fragmentation, changing microclimate conditions and disturbed species interactions. There is a considerable call to preserve as much forest as possible, but it is particularly important to avoid the loss of interior forest connectivity. This will reduce the number of fragments, maintain large mean patch size, prevent forest isolation and increases interior habitat percolation (Oliveira Filho & Metzger 2006). Metzger & Décamps (1997) observed clear threshold values for the percolation of interior habitat when forest proportion ranges between 0.40 and 0.60 (in one cluster of a lattice), indicating that landscapes with a lower forest cover index severely hamper persistence of interior forest species that need high forest cover and that have not dispersed through the lattice. Therefore, Oliveira Filho & Metzger (2006) plead for maintaining forest portion above 0.60.

Besides, it is widely recognized that, once separated from the bulk of forest habitat, fragments smaller than a specific size are unable to maintain the structure of intact tropical forest, and therefore incapable of sustaining the original species diversity (Williams 1997). Therefore, to preserve biodiversity, management should be aimed at conserving a certain minimum forest patch size, though one should not forget each (group of) species has its own preference. Souza et al. (2010) found, for example, that tree populations in very small fragments are influenced very strongly by cattle pressure and vice versa. To preserve tree populations in fragments, these patches should be at least one hectare.

4.2 Sustainable management of pastures

Besides preserving forest by protecting tropical forest areas, sustainable management of pastures is also needed to decrease deforestation. Usually, pastures are abandoned after six years, which is understandable as soils by then have become largely depleted of original nutrients and biomass (Ward et al. 1998). Pasture degradation in Brazil is mainly caused by inadequate nutrient use and overstocking (Vilela et al. 2004). In general, the intensive use of pasture land results in reduction of carrying capacity, in Brazil starting with N and P deficiencies and ending with sever soil degradation through compaction and erosion. Overgrazing still is the most regular cause of poor pasture management (FAO 2007).

One way to maintain productivity and ecosystem functioning is by using “slash-and-mulch” in stead of “slash-and-burn” (Sommer et al. 2004). Natural mulch is a cover of not-burnt biomass residue placed over soil that conserves moisture, keeps soil well aerated by reducing soil compaction that occurs when raindrops hit the soil surface, reduces (water) runoff and erosion, prevents soil and fungi from splashing on the foliage (reducing the probability of soil-borne diseases), maintains a uniform soil temperature and stimulates the growth of soil micro-organisms (Evans 2000).

In a study comparing nutrient balances of slash-and-burn and slash-and-mulch lands, Sommer et al. (2004) tested the effect of mulch on aforementioned soil conditions by applying both clearing methods on old woody fallow vegetation. They concluded that slash-and-mulch noticeably avoids losses in C, N, P, Ca, Mg and K. Despite high amounts of rapidly decomposing surface mulch, mulching did not increase nutrient losses by leaching. It was also found that that nutrient fluxes for both methods declined with soil depth, which indicates retention of nutrients in upper soil layers. As this nutrient retention could be just temporary, re-establishment of naturally deep rooting (secondary) vegetation is needed to enable the uptake of nutrients after abandonment of sites and to facilitate regeneration of forest.

One way to recover nutrient pools on old pastures is by enhancing nutrient cycling using agro forestry systems. Tapia-Coral et al. (2005) compared the recovering of abandoned pastures between agro forestry systems and secondary forest controls. They found that litter in agro forestry systems had lower C:[nutrients] ratios than litter in secondary forest controls, which indicates faster decomposition and nutrient recycling in the first recovery method. Therefore, farmers could occupy abandoned pastures and use agro forestry systems to recover nutrient stocks.

Next to fertility decline and overstocking, brush invasion also limits pasture productivity in the Amazon. A permanent problem for cattle ranchers is the so-called “capoeira” on pastures: encroachment of re-sprouting secondary woody vegetation. This problem was investigated by Hohnwald et al. (2010). They found that some capoeira species and several domesticated tree species have the same palatability for cattle as common woody forage legumes. Besides, woody species are more suitable for a humid tropical climate than the grasses and small shrubs usually present in pasture lands, because these species restore nutrients in aboveground biomass in stead of in the depleted pasture soil. Therefore, Hohnwald et al. (2010) conclude that it is possible to enhance grazing production by selective slashing of non-palatable capoeira species, which will generate an ecologically sustainable pasture system and decreases the need to clear more forest area.

According to the Food and Agriculture Organization (2007), pastures should permanently have full ground cover and always stay in a productive phase to prevent degradation. This can be realized by decreasing stocking rates, using rest periods to avoid over-grazing, and adding lime and fertilizer when necessary.

4.3 Restoration of tropical forest

When aiming for reforestation or natural re-growth of tropical forest, nutrient and water availability and uptake are usually limiting factors. In a review comparing forest recovery data from different studies, Lugo et al. (2004) described processes and factors that could eventually redevelop tropical forest habitat and species diversity. They concluded that restoring tropical forests is an important activity to regain biodiversity and to help mitigate for deforestation and land degradation. Therefore, it is utterly essential to re-establish rain forest conditions. Re-growth of trees (canopy closure) will stimulate primary production, which will lead to more biomass accumulation, more litterfall, better nutrient cycling, and eventually to re-establishment of interior forest conditions. Once forest conditions are regained, succession and accompanied increase in biodiversity will take place over time. Plus, more biodiversity also contributes to succession, primary production and biomass accumulation. These processes and factors are presented in the diagram in figure 6.

Although it is recognized that nutrient-poor soils can sustain highly diverse vegetation, another theory states that below certain nutrient levels forests fail to (re)develop because the soil cannot provide for both the foliage and the wood. Bond (2010) estimated forests need (in kg ha^{-1}) 20-30 P, 200-350 K, 300-600 Ca and 55-65 Mg to construct woody biomass and leaf tissue. He concluded that, when including deeper soil layers, nearly all soils have sufficient nutrient stocks. Besides, soils usually have enough nutrients to support forest growth, except for very shallow or highly leached soils. This implicates that forest development seldom is constrained by low nutrient availability when the system is at steady state, but that other factors, such as physical soil properties and fires, influence vegetation structure. On highly degraded soils it can nevertheless be essential to have tree species with roots reaching very deep into soil for restoring original functioning of nutrient cycling and water uptake in the ecosystem (Nepstad et al. 2001).

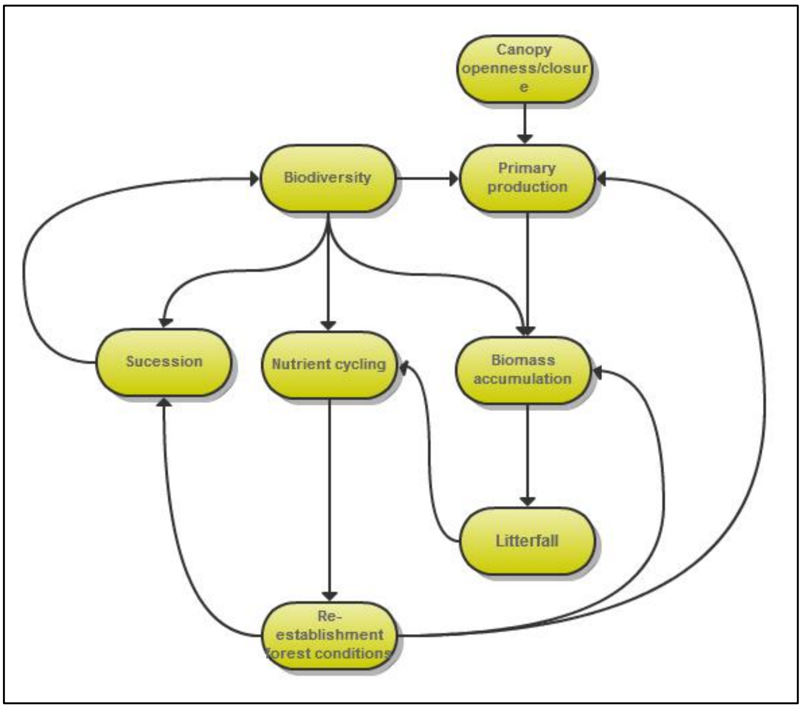

Figure 6: Feedback diagram showing processes involved in regeneration of tropical forest biodiversity (Lugo et al. 2004). The arrows represent an increasing effect.

Intermediate disturbance as a measure to maintain high biodiversity could be used in sustainable management of existing and recovering forest areas. According to Tollefson (2008), the future of the Amazon could lie in sustainable use of its resources. In addition, in areas with high diversity, both redundancy and stability are high, which strengthens the likelihood of persistence of the ecosystem (Odum 1989).

Monitoring land use, enforcing policies to prohibit illegal clearing and using forest sustainably are good measures to reduce impact of cattle ranching on biodiversity loss, according to Tollefson (2008). Except for measures to avoid more deforestation, it is also recommended to reduce (international) meat demand and to emphasize that sustainable management of pastures also contributes to protecting of forest species diversity.

5. Discussion

In this research paper was aimed at a comprehensive understanding of processes that are caused or disturbed by cattle ranching, and what implications this understanding has for management of forest, pastures, and restoration projects. There are nonetheless four remarks to be made.

First, the presented impacts of how cattle ranching activities affect biodiversity has been comprised of information found in different literature sources, but the magnitude of effects, for examples the ones shown in figure 5, has not been taken into account. It can be expected not all processes contribute equally to a loss of tropical forest biodiversity, and some effects could even amplify each other.

Second, in the literature nothing was found about the influence of for example cattle droppings on soil fertility and acidity of adjacent forest. Also, a lot of research focussed on losses of nutrients and biomass on cleared lands, but little is known about the effect of removal of nutrients and biomass for pastures on neighbouring forest and interior species.

Third, in this paper is mainly focussed on biodiversity as determent of ecosystem functioning, while Kahmen et al. (2004) for example found that plant community composition and structure were much better predictors for ecosystem health. Currently, too few studies looked at impacts of cattle ranching and/or deforestation on vegetation composition.

Last, although intermediate disturbance can enhance species diversity, little is known about the magnitude of needed disturbances. So when it comes to sustainable use of tropical forest resources, more information is required on what levels of disturbance are acceptable for preserving interior forest biodiversity.

5. Conclusion

The aim of this research paper was to analyse the effects of cattle ranching on biodiversity in the Brazilian Amazon and to bring forward management implications for conservation of interior species diversity. The impacts of cattle ranching on biodiversity include fragmentation, higher susceptibility to changing microclimate conditions at edges of forest, removal of nutrient stocks and disturbance of species interactions. Deforestation contributes to more fragments, smaller forest patch sizes, higher isolation and reduced interior habitat percolation. Both conversion from forest to pasture and the independent settlement pattern cause the greatest losses for interior forest species. At forest edges, microclimate conditions as humidity can be altered up to one kilometre into intact forest, causing mortality of (tree) species. Both removal of suitable habitat and keystone species can have very pervasive impacts on the complex tropical forest ecosystem. Clearing of forest also directly removes nutrients and biomass from the ecosystem. However, little is known so far about the magnitude of the impacts of deforestation on biodiversity and possible amplifications, the impacts of nutrient and biomass removal and cattle activities on adjoining (intact) forest and to what extent plant community composition is a (better) determent for tropical forest ecosystem functioning than biodiversity in general.

Hence, management implications should have a holistic approach, aimed at conserving existing forest, sustainable management of pastures to avoid further losses, and regeneration to compensate for forest already lost. Forest size and connectivity between fragments are most essential in protecting biodiversity, though habitat preferences differ for each species. Sustainable pasture management is possible by using mulch to cover ground, agro forestry systems, or selectively slashing non-palatable secondary woody vegetation in stead of abandoning a pasture. For regeneration of forest it is vital to re-establish interior forest conditions by natural re-growth or reforestation, which will over time induce primary production, nutrient cycling, succession, and species diversity. Deep-rooting vegetation may be needed for uptake of nutrients from soils that have leached surfaces.

In conclusion, cattle ranching impacts biodiversity in several ways by driving deforestation activities. A broad approach is needed to preserve current forest, prevent further losses, and compensate for forest that is already lost.

6. Bibliography

Ayres, J.M. (1997). *Abordagens Inovadoras para Conservação da Biodiversidade no Brasil: Os corridors das florestas Neotropicais* (Pilot Program to Conserve the Brazilian Rainforest and Brazilian Ministry of Environment, Brasilia).

Barona, E., Ramankutty, N., Hyman, G. and Coomes, O.T. (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon, *Environmental Research Letters,* 5, 024002: pp. 9.

Bernarde P.S. & Macedo L.C. (2008). The impact of deforestation and pastures on the leaf-litter frog community in Rondônia, Brazil. *IHERINGIA SERIE ZOOLOGIA*, Volume: 98, Issue: 4, pp. 454-459.

Bond, J.W. (2010). Do nutrient-poor soils inhibit development of forests? A nutrient stock analysis. *Plant Soil*, 334, pp. 47–60.

Boswell, G.P., Britton, N.F. and Franks, N.L. (1998). Habitat fragmentation, percolation theory and the conservation of a keystone species, *Proc. R. Soc.,* London., B 265: pp. 1921-1925.

Broadbent, E.N., Asner, G.P., Keller, M., Knapp, D.E., Oliveira, P.J.C. and Silva, J.N. (2008). Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon, *Biological Conservation*, 141: pp. 1745 –1757.

Butler, R.A. (2010). *Brazil, tropical rain forest* [online]. [Consulted on May 7, 2011]. Available on the World Wide Web: www.mongabay.com.

Denyer, K., Burns, B. and Ogden, J. (2006). Buffering of native forest edge microclimate by adjoining tree plantations. *Austra. Ecol.,* 31: pp. 478–489.

Evans, E. (2000). *Mulching Trees and Shrubs.* [online]. [Consulted June 9, 2011]. Available on the World Wide Web: http://www.ces.ncsu.edu/.

FAO (Food and Agriculture Organization) (2007). Chapter 2. Livestock and annual crop production in wet-dry and humid tropical Brazil. *Integrated Crop Management.* Vol. 5: pp. 15-20.

Fujisaka, S., Escobar, G. and Veneklaas, K. (1997). Plant community diversity relative to human land uses in an Amazon forest colony. *Biodiversity and Conservation*, 7: pp. 41-57.

Grime, J.P. (1979). *Plant strategies and vegetation processes*. Chichester: Wiley.

Hohnwald, S., De Abreu, E.M.A., Krummel, T., Trautwein, J., Da Veiga, J.B., Wolly, C.B.A., De Azevedo, C.M.B.C. and Gerold, G. (2010). Degraded pasture distribution and woody enrichment strategies for pasture fertility preservation in the Bragantina region, North-Eastern Amazon, *Erdkunde,* 64, 1: pp. 17-31.

Inka`s Empire Corporation (2010). *White waters & Black. The two worlds of the Amazon* [online]. [Consulted June 12, 2011]. Available on the World Wide Web: http://www.arcanamundi.com/tours/brazil/manaus_expedition.html.

Kaimowitz, D., Mertens, Benoit, Wunder, S. and Pacheco, P. (2004). Hamburger connection fuels Amazon destruction. Cattle ranching and deforestation in Brazil's Amazon. *Center for International Forestry Research.*

Laurance, W.F. (2002). Mega-development trends in the Amazon: Implications for Global Change, *Environmental Management and Assessment* 61: pp. 113-120.

Lawton, J. H. & May, R. M. (Eds.) (1995). *Assessing extinction rates*. Oxford University Press.

Lugo, A.E., Silver, W.L. and Molina Colón, S. (2004). Biomass and Nutrient Dynamics of Restored Neotropical Forests, *Water, air, and soil pollution: Focus*, Volume: 4 Issue: 2, pp: 731-746.

MacArthur, R.H. & Wilson, E.O. (1967). The theory of Island Biogeography – Monographs in Population Biology. Princeton University Press, Princeton, New Jersey.

May, R. M. (1990). *How many species?* Phil. Trans. R. Soc. Lond. B 330: pp. 293-304.

Metzger J.P. (2002). Landscape dynamics and equilibrium in areas of slash-and-burn agriculture with short and long fallow period (Bragantina region, NE Brazilian Amazon). *Landscape Ecology*, 17: pp. 419-431.

Metzger J.P. & Décamps H. (1997). The structural connectivity threshold: an hypothesis in conservation biology at the landscape scale. *Acta Ecol*., 18, pp. 1-12.

Miller, G.T. Jr. & Spoolman, S. (2009). *Living in the Environment: Principles, Connections, and Solution*. Cengage Learning Inc.

Morell, V. (1997). The Life Machine. *Earth,* Volume 6, Issue 4: pp. 1-6.

Nee, S. (2002). "Thinking big in ecology". *Nature* 417: pp. 229-230.

Negrôes, N., Revilla, E., Fonseca, C., Soares, A. M.V. M, Jácomo, A.T.A. and Silveira, L. (2011). Private forest reserves can aid in preserving the community of medium and large-sized vertebrates in the Amazon arc of deforestation, *Biodiversity Conservation* 20: pp. 505–518.

Nepstad, D., Moutinho, P. R. S. and Markewitz, D. (2001). "The recovery of biomass, nutrient stocks, and deep soil functions in secondary forests", in McClain, M.E., Victoria, R.L. and Richey, J.E. (Eds.), *The Biogeochemistry of the Amazon Basin*, Oxford University Press, England, pp. 139–155.

Odum, E.P. (1989). *Ecology and Our Endangered Life Support Systems*. Sinauer Associates, Inc., Sunderland, MA.

Oliveira Filho, F.J.B. de, & Metzger, J.P. (2006). Thresholds in landscape structure for three common deforestation patterns in the Brazilian Amazon, *Landscape Ecology* 21: pp. 1061–1073.

Skole, D. & Tucker, C.J. (1993). Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988. *Science* 260: pp. 1905-1910.

Soares Filho et al. (2006). Modelling conservation in the Amazon. *Nature.* Volume: 440, Issue: 7083, pp: 520-523.

Rocha, J. (2005). *Deforestation paves way in Brazil.* BBC News, Brazil. Saturday, 8 January, 2005 [Online]. [Consulted on June 14, 2011]. Available on the World Wide Web: http://news.bbc.co.uk/2/hi/programmes/from_our_own_correspondent/4155609.stm.

Rolf, S., Vlek, P.L.G., De Abreu Sá, T. D., Vielhauer, K., Coelho, R.F.R. and Fölster, H. (2004). Nutrient balance of shifting cultivation by burning or mulching in the Eastern Amazon - evidence for subsoil nutrient accumulation. *Nutrient Cycling in Agroecosystems,* 68: pp. 257–271.

Souza, I.F. de, Souza, A.F., Pizo, M.A. and Ganade, G. (2010). Using tree population size structures to assess the impacts of cattle grazing and eucalypts plantations in subtropical South America, *Biodiversity Conservation* 19: pp. 1683–1698.

Stone, A.I., Lima, E.M., Aguiar, G.F.S., Camargo, C.C., Floer, T.A., Kelt, D.A., Marques-Aguiar, S.A., Queiroz, J.A.L., Ramos, R.M. and Silva Júnior, J.S. (2009). Non-volant mammalian diversity in fragments in extreme eastern Amazonia. *Biodiversity Conservation,* 18: pp. 1685-1694.

Taylor, L. (2004). *The Healing powers of Rainforest Herbs.* Square One Publishers, Inc. Garden City, New York.

Tollefson, J. (2008). Brazil goes to war against logging, *Nature* Volume 452: pp. 134-135.

Terborgh, J., Lopez, L. and Nuñez, V.P. (2001). Ecological Meltdown in Predator-Free Forest Fragments. *Science*, Volume 294, Issue 5548: pp. 1923–1926.

Townsend, C.R., Begon M. and Harper, J.L. (2000). Essentials of Ecology. John Wiley and Sons Ltd.

Veríssimo, A. Cochrane, M.A., Souza Jr., C. (2002). National Forests in the Amazon. *Science,* Volume 297, Issue 5586.

Vilela et al. (2004). In: FAO (Food and Agriculture Organization) (2007). Chapter 2. Livestock and annual crop production in wet-dry and humid tropical Brazil. *Integrated Crop Management.* Vol. 5: pp. 15-20.

Wallace A.R. (1878). *Tropical nature and other essays*. London, UK: MacMillan.

Ward, D., Boone Kauffman, J. and Cummings, D (1998). Fire in the Brazilian Amazon 2. Biomass, nutrient pools and losses in cattle pastures, *Oecologia*, Volume 113, Issue 3: pp: 415-427.

Wieder, W. R., Cleveland, C.R. and Townsend, A.R. (2009). Controls over leaf litter decomposition in wet tropical forests. *Ecology* 90: pp. 3333–3341.