Chapter 15
Land Use, Land Cover and Land Use Change in the Brazilian Amazon (1960–2013)

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15.1 Introduction

The Amazon Basin in South America is home to the largest continuous remaining tropical rainforest, representing half the world's rainforest area, and is home to one-third of Earth's species (Tollefson 2008). Along with their rich biodiversity, the forests of Amazonia deliver important ecosystem services. For example, in Brazil, the forests of Amazonia alone contain more carbon stored than the amount of global human-induced fossil fuel CO_2 emissions of an entire decade (Öborn et al. 2011); therefore, they play an important role in the global carbon budget (Chambers et al. 2001; Loarie et al. 2009; Le Quere et al. 2009). In addition, the vegetation acts as an efficient 'pump water' in recycling water over the extension of the forest, and thus it is an important driver of the hydrological cycle and possibly a major contributor to regulating regional climate (Spracklen et al. 2012; Werth and Avissar 2002).

Despite recent reductions in the relative rates of deforestation[1] in Amazonia, deforestation continues at a high rate, and this process is leading to changes in the environment and society. In the past 40 years, the region has experienced drastic changes in its land use and land cover (LULC). Fostered chiefly by the replacement

[1] Deforestation is a process that begins with the intact forest and ends with the complete conversion of the original forest to other coverages. The first step is the removal of the noblest woods, and then the timber for the construction and, finally, the remaining softwoods are harvested for the production of plywood and boards. This process may take several years because the exploration of the forest is made generally by different enterprises, each one specialised in one phase (INPE 2008).

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of native vegetation by grazing land, sown with African grasses for cattle ranching and subsistence/family agriculture, more recently, large-scale agriculture such as soybean cultivation has become a major contributor to LULC change (Ometto et al. 2011). In general, deforestation and land conversion lead to the destruction of habitats and depletion of species, cause soil erosion and contribute to global climate change through the emissions of greenhouse gases (GHG).

Several studies have considered the future of the Amazon (Soares-Filho et al. 2010; Lapola et al. 2010; Gómez and Nagatani 2009; Malhi et al. 2008; Aguiar 2006; Soares-Filho et al. 2006; Laurance et al. 2001), following global concerns about biodiversity loss, deforestation-driven CO_2 emissions through the intensification of droughts and vulnerability to forest fires and major LULC changes. It appears that deforestation and global warming, acting synergistically, could lead to profound changes in the Amazon biome, and beyond. The potential shift in the energy and water cycles can cause changes in ecosystem structure (including biodiversity) and functioning, reducing the capacity of the forest to retain carbon and thereby increasing soil temperature and eventually affecting the regional hydrological cycle (Ometto et al. 2011).

Most of the above studies focused on Brazilian Legal Amazon (c. 5 million km^2), a legally designated entity that extends over nine federal states of Brazil (Fig. 15.1), whose inclusion in the designation in 1953 was underpinned by the similarities in their ecological structure, economic, political and social conditions. Currently, Brazilian Legal Amazon comprises the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins, including a part of Maranhão (west of the 44° west).

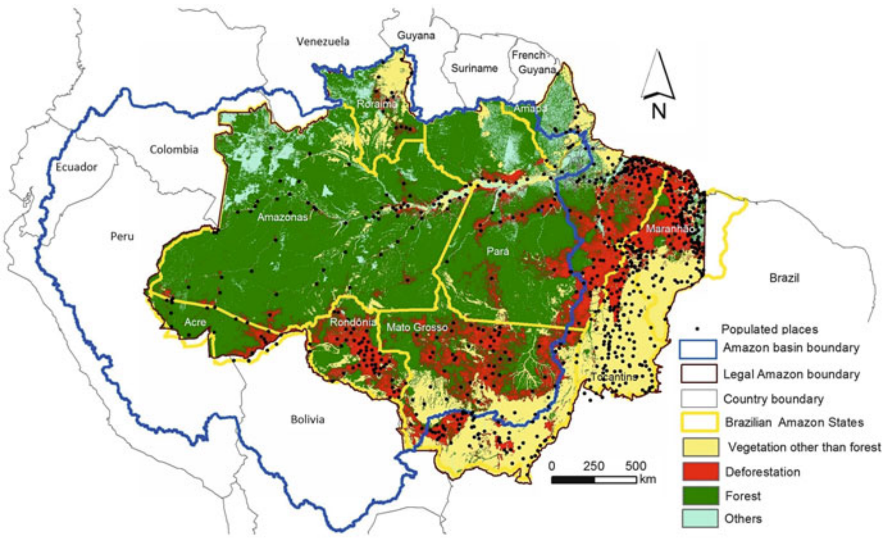

Fig. 15.1 The map of Brazilian Legal Amazon and its administrative division

In this chapter, we provide an overview of the extent and dynamics of land use and land use change of the Amazon Basin, with a focus on Brazilian Amazon, which occurred from 1960 to 2010, taking into account the environmental and social aspects related to the deforestation process. We provide some general information about deforestation rates and data sources available for their evaluation in all countries within the Amazon Basin.

15.2 Data and Information Sources Available on Land Use and Land Cover (LULC) Change

Until 1988, data on LULC change in Brazilian Amazon could be obtained from the agricultural census developed by the Brazilian Institute of Geography and Statistics (IBGE). Data were published in 1960, 1970 and every 5 years since then, 2006 being the latest census data released (IBGE 2006). The census data provided important information on land use (classes) at the municipality level but not in a spatially explicit format (Table 15.1).

Since 1988, the National Institute for Space Research (INPE) has been generating and compiling satellite data for monitoring LULC in Brazilian Amazon, as part of the Amazon Deforestation Calculation Program (PRODES). This system has provided a consistent and unique historical mapping of deforestation (INPE 2014a; Ometto et al. 2011).

PRODES has produced deforestation reports since 1978, using a mean deforestation rate from other data sources, such as IBGE until 1988; since 1997, the results have been presented in a spatially explicit format. From 2003 to the present, PRODES data and products (images, annual deforestation maps and deforestation statistics) are available on the Internet (INPE 2014a). Official statistics on deforestation rates for Brazilian Amazon are based on these data.

In addition to PRODES, other remote sensing products complement the deforestation and land use change-monitoring portfolio in Amazonia. DETER (INPE 2013) is an alert system developed by INPE that has been monitoring deforestation at a monthly basis since 2004, providing a reliable information source for decision-makers to implement rapid action on the ground. Based on indications of forest degradation obtained from DETER data, INPE has developed the DEGRAD system (mapping forest degradation in the Brazilian Amazon). The system uses LANDSAT and CBERS satellite images to map annually areas of degraded forest that are likely to be converted to clearcutting (INPE 2014b). TerraClass (INPE 2011) is a joint Project by INPE and the Brazilian Agricultural Research Enterprise (Embrapa) that uses the PRODES data for generating a LULC map of Brazilian Amazon every 2 years (INPE 2011). The data of TerraClass account for all the actual land use classes of converted land (see Table 15.1 for mapped land use classes).

Table 15.1 Land use classes considered in the deforested areas in Brazilian Amazon generated by TerraClass (2008)

Land use class	Definition
Annual crop	Extensive areas with a predominance of annual cycle crops, especially grains, with use of high technological standards, such as use of certified seeds, inputs, pesticides and mechanisation
Mosaic	Areas represented by an association of various types of land use and due to the spatial resolution of the satellite images, a discrimination between their components is not possible. In this class, family farming and subsystem of traditional pastures for livestock are carried out in conjugated form
Urban area	Areas resulting from population concentration forming villages, towns or cities with differentiated infrastructure in relation to rural areas and presenting density of roads, houses, buildings and other public facilities
Mining	Areas for extraction of valuable minerals or other geological materials with the presence of clearings and exposed soils, involving deforestation near superficial water bodies
Pasture	Pasture areas in the production process with a predominance of herbaceous vegetation and coverage of grass species between 90 % and 100 %
Pasture with shrubs	Pasture areas in the production process with a predominance of herbaceous vegetation and grass species coverage between 50 % and 80 %, associated with the presence of shrub with sparse vegetation with coverage between 20 % and 50 %
Pasture with areas of secondary regrowth	Areas that after clearcutting of natural vegetation and the development of some agro-pastoral activity are at the start of regeneration process of native vegetation, with dominance of shrubs and pioneer tree species. Areas characterized by high diversity of plant species
Eroded pasture (bare soil > 50 %)	Areas that after clearcutting of forests and the development of some agro-pastoral activity have a coverage of at least 50 % of exposed soil
Secondary vegetation	Areas that after the complete cut of forest vegetation are in advanced process of regeneration of shrub and/or trees or have been used for practising forestry or permanent agriculture with the use of native or exotic species
Other	These are areas that did not fit in the previous categories and that showed a differentiated coverage pattern such as rock outcrops, river beaches, sandbars and others
Areas with no data	Areas that have had their interpretation impossible by the presence of clouds or cloud shadow, at the time of passage for satellite image acquisition, in addition to areas recently burned

Other LULC datasets are available for the entire Amazon Basin (Table 15.2), including relevant parts of Bolivia, Ecuador, Peru, Colombia, Venezuela, Guyana, Suriname and French Guyana. The Terra-i system detects land cover changes resulting from human activities at 16-day intervals (Terra-i 2012). A regional initiative from the Amazon Geo-referenced Socio-environmental Information Network (RAISG) has used a standardised methodology for the whole Basin to produce

Table 15.2 Sources of land use and land cover change data for the Amazon Basin

Level	LUCC data	Description	Spatial/temporal resolution	Website	Source
Global	GLC2000	Vegetation map of South America (Global Land Cover 2000)	1 km/2000	http://www.gvm.jrc.it/glc2000	GLC (2003)
	GlobCover	Global composites and land cover map	300 m/2005–2006; 2009	http://due.esrin.esa.int/globcover/	ESA (2010)
Amazon Basin	Terra-i	Detects land cover changes resulting from human activities in near real time	250 m/2004 to 2011 update every 16 days	http://www.terra-i.org/terra-i.html	Terra-I (2012)
	RAISG	Deforestation map of the Amazon Basin	30 m/2000–2005 and 2010	www.raisg.socioambiental.org	RAISG (2012)
Brazilian Amazon	PRODES	Yearly deforestation map	60 m/yearly from 1988 to 2012	www.obt.inpe.br/prodes/	INPE (2013)
	DETER	Monthly deforestation alerts	250 m/monthly from	www.obt.inpe.br/deter/	INPE (2013)
	IBGE	Agricultural census data	Municipal level (not spatial data) every 5 years since 1960	www.ibge.gov.br	IBGE (2006)
	TerraClass	Land use map	30 m, 2008 available and 2010 only the report (missing spatially explicit data)	www.inpe.br/CRA	INPE (2011)
	DEGRAD	Forest degradation map	30 m/yearly since 2007	www.obt.inpe.br/degrade/	INPE (2014b)

deforestation maps for the years 2000, 2005 and 2010 (RAISG 2012). On the global scale, the GLC 2000 (https://ec.europa.eu/jrc/en/scientific-tool/global-land-cover) and the GlobCover (http://due.esrin.esa.int/page_globcover.php) are the most used map sources.

15.3 Occupation of Brazilian Amazon: Drivers and Trends in Deforestation

Apart from the impacts associated with indigenous settlements in Amazonia, dating back thousands of years, only in the past 40 years that the region experienced major changes in LULC. Nowadays, most of the deforestation is undertaken for cattle ranching, agriculture and creation/expansion of urban areas. Until the 1950s, the occupation of Brazilian Amazon was limited to the coastal region and the margins of the main rivers (Escada and Alves 2001), causing imperceptible deforestation at the regional scale. Economic activity was mostly related to the extraction of non-timber products, mainly rubber tapping (Costa 1997). Rubber became the first commodity produced in the region and had its golden years at the turn of the nineteenth and twentieth century and reached its decline by around 1920 (UICN 1995).

Government incentives to settle the region, underpinned by the construction of the Belém–Brasília highway in eastern Amazonia, caused the population to grow from 1 m to 5 m from 1955 to 1965 (Becker 1997). As part of the National Plan for Economic and Social Development (NPD), the main government strategies for the occupation of Amazonia included (1) infrastructure development (construction of roads, telecommunication, hydropower and urban areas) for spatial integration, (2) expropriation of land for implementation of mining and settlement projects and (3) subsidies to flow of capital and immigration (Becker 1997; Machado 1997). In the 1970s, the Trans-Amazônica and Cuiabá–Santarém highways—built alongside existing highways—formed the basic structure of road transportation within the National Integration Project (PIN) (Escada and Alves 2001).

While promoting the integration and the connectivity to regional and national markets, the construction of roads has led to high deforestation rates (Almeida 2009; Fearnside et al. 2009). The depletion of native vegetation during 1970s predominantly occurred along major roads and around new areas of human settlements (Skole and Tucker 1993; Machado 1997; Alves 2002; Fearnside 2005), primarily in south-eastern Amazon (Fig. 15.3), a region commonly known as the ‘arc of deforestation’ (Becker 2005; Ometto et al. 2011). Following opening the roads, logging, cattle ranching and small- and large-scale agriculture were the most common activities that have led to increasing deforestation (Aguiar 2006; Aguiar et al. 2012), reaching a total area of 152,000 km^2 deforested by the end of the 1970s (INPE 2002).

In the 1980s, the process of occupying of Amazonia included the expansion of agribusiness, mining and several settlement projects (Kitamura 1994). Tax incentives were a strong driver of deforestation (Fearnside 2005). Between 1978 and 1988, net deforestation in the Amazon region reached 360,889 km^2, a significant increase compared with the decade before (Fig. 15.4; INPE 2002).

The initial expansion of large-scale agriculture started in southern Brazilian Amazon, affecting the areas of the Cerrado ‘biome’ in the 1990s (Aguiar 2006); it changed the patterns of land use and the regional economy (Carvalho et al. 2002). The expansion of world markets improved access to local credit and government incentives, such as tax exemptions and funding for agricultural research. The improvement of market channels and infrastructure rapidly encouraged the expansion of mechanized agriculture with cash crops for export (Valdes 2006; Brown et al. 2004; Barbier 2004; Madi 2004). From the late 1990s to 2004, there was a significant increase in deforestation rates. This trend reflected the large-scale agriculture boom, especially in the states of Mato Grosso, Pará and Rondônia,

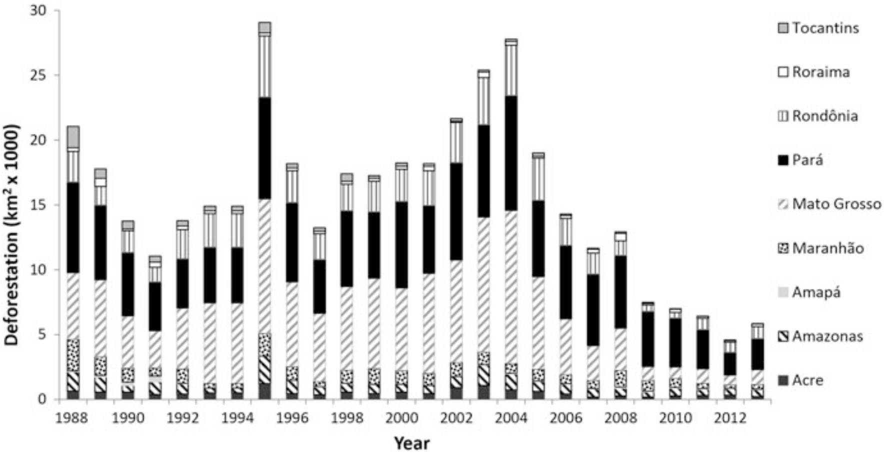

Fig. 15.2 Total deforested area per federal state in Brazilian Legal Amazon, from 1988 to 2013. Data from TerraClass 2010 (INPE 2011) and PRODES (INPE 2014a)

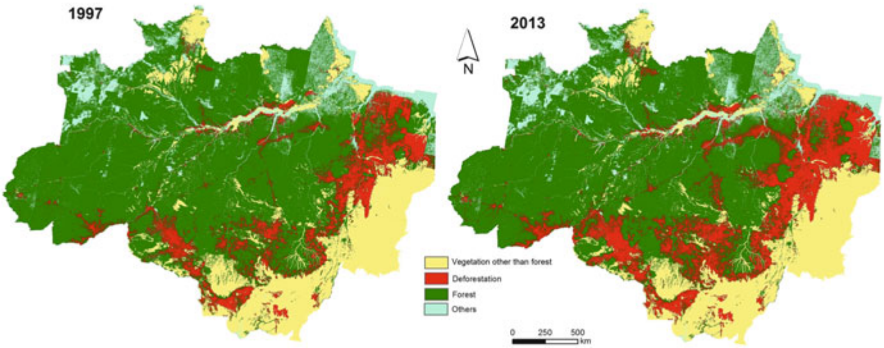

Fig. 15.3 Land use and land cover change from 1997 to 2013 in Brazilian Amazon. Data from PRODES (INPE 2014a)

leading to a deforestation rate of ca. 18,161 km^2 $year^{-1}$ for 1995–1996 and 27,772 km^2 $year^{-1}$ for 2004 (Fig. 15.2; INPE 2014a).

Due to several factors, such as policy formulations and pressure from the international community, since 2005 there has been a significant reduction in the annual deforestation rate in Brazilian Amazon, with 12,911 km^2 in 2008, 7464 km^2 in 2009, 4571 km^2 in 2012 (the lowest deforestation rate since 1988) and 5843 km^2 in 2013 (Fig. 15.2; INPE 2014a). The reduction was observed in all states, although Pará continued to be a state with a high absolute rate of deforestation until 2010 (Fig. 15.3, Table 15.2). Nonetheless, Maranhão has the highest accumulated deforestation on an area basis (Table 15.3). In total, 18.8 % of Brazilian Amazon has been converted from its natural vegetation (mainly tropical rainforest and cerrado)

Table 15.3 Deforested area per federal state in Brazilian Amazon until 2010. Data from TerraClass 2010 (INPE 2011)

State	Total area (km^2)	Deforested area (km^2) until 2013	Percentage of deforested area
Acre	164,170	20,455	12
Amapá	142,814	4925	3
Amazonas	1,559,160	32,799	2
Maranhão	262,297	111,351	42
Mato Grosso	903,385	209,143	23
Pará	1,247,794	257,869	21
Rondônia	237,581	86,821	37
Roraima	224,296	9871	4
Tocantins	271,849	30,271	11
Brazilian legal Amazon	5,013,347	763,505	15

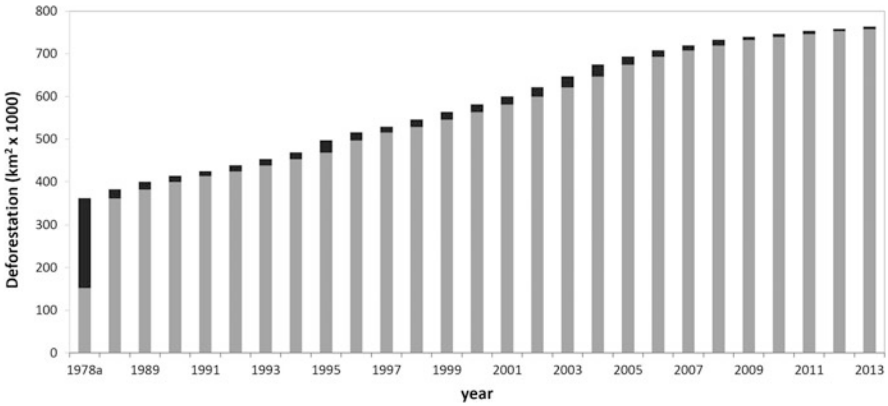

Fig. 15.4 Accumulated deforestation from 1978 to 2013 (*grey*) and annual deforestation (*black*) in Brazilian Amazon. Data from PRODES (INPE 2011) and TerraClass 2010 (INPE 2011). (**a**) Data for 1978 is from PRODES (INPE 2002). It is assumed that the deforestation reached 152,200 km^2 until 1978

to another land cover type through land use by 2013 (INPE 2013), of which 60 % occurred in the period from 1990 to 2010 (Fig. 15.4).

Some important causes of deforestation were associated with the demand for new land for agriculture and cattle ranching (Carvalho et al. C; Bickel and Dros 2003; Fearnside 2005; Baccini et al. 2012; Barona et al. 2010) (Fig. 15.5). In some cases, however, the area of cropland expanded at the expense of pastureland. As a result of international market pressure on curtailing soy produced on recently cleared land, the Brazilian Association of Vegetable Oil Industries (ABIOVE) and National Association of Cereal Exporters (ANEC) proposed the refusal of soy derived from land deforested in Brazilian Amazon after 2006 (known as the

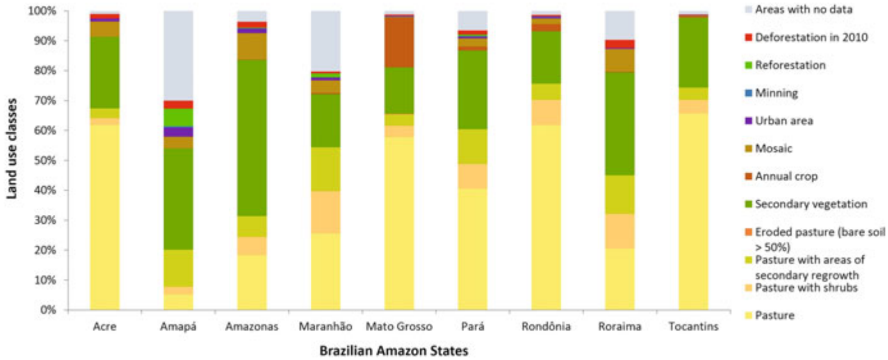

Fig. 15.5 Percentage of thematic land use classes per state in deforested areas of Brazilian Amazon. Data from TerraClass 2010 (INPE 2011)

'soy moratorium'). It has been suggested that the increase in soybean production in south-eastern Amazonia has, to some extent, displaced animal husbandry further to the north, where it subsequently has caused deforestation (Barona et al. 2010). Not all agree that this indirect land use change has been the case (Mueller 2003; Brandao et al. 2005).

Along with a reduction in deforestation rates, there has been a decrease in observed forest degradation recently, as shown by the results published for the years 2007, 2008, 2009 and 2010 by the DEGRAD and PRODES systems. The extent of degraded areas were 15,987 km^2 in 2007, 27,417 km^2 in 2008, 13,301 km^2 in 2009 and 7508 km^2 in 2010 (INPE 2014a, b). The states with higher accumulated deforestation according to INPE (2014a) are Maranhão (42 % considering only the area of the state within the Legal Amazon), Rondônia (37 %), Mato Grosso (23 %) and Pará (21 %) (Table 15.2).

Land use of the deforested land in Brazilian Amazon in 2010 was pasture (45.8 %), pasture with regeneration of woody vegetation (8.2 %), secondary woody vegetation (22.3 %) and cropland (5.4 %) (INPE 2011). The sequence of land use established after deforestation (e.g. forest to pasture, crops to pasture or pasture to secondary vegetation) and the time lag among the land uses are critical for land planning and development strategies. As well, this information is fundamental to deepen the understanding of the deforestation process, its drivers and the policies that can contribute to a sustainable use of the soil and Amazon conservation.

15.4 The Impacts of Land Use Change

The direct and indirect consequences of major changes in land use can affect human societies within Amazonia and beyond. Changes in ecosystem productivity, hydrological regime and climate are some of the impacts of deforestation that go beyond the regional and continental boundaries (Fearnside 2005; Betts 2001; Bonan 2002; Foley et al. 2011; Davin et al. 2007). At the global scale, LULC is an important driver of the carbon and nitrogen cycles (Galloway et al. 1995; Denman et al. 2007; Sutton et al. 2013). It has been estimated that 35 % of anthropogenic emissions of CO_2 during the past 150 years has been a direct result of changes in LULC (Houghton 2003). In relation to nutrients, the increase in reactive nitrogen, derived from anthropogenic activities, has surpassed by far the rates of biological nitrogen fixation in all natural terrestrial systems and is estimated that atmospheric deposition will have doubled by 2050 compared with that in the early 1990s (Galloway et al. 2004). Nitrogen deposition is thought to become one of the main drivers, along with LULC and climate change, of biodiversity loss at global scale (Sala et al. 2000). According to Galloway et al. (2004), in the early 1990s, a small region of south-east South America received inorganic N deposition over 1000 mg N m^2 $year^{-1}$. By 2050, this area is expected to grow significantly, and there will be a large region receiving >2000 mg N m^2 $year^{-1}$.

Deforestation, at the local scale, also causes loss of biodiversity, soil erosion, nutrient depletion and soil compaction. The degradation of soil quality results in low agricultural productivity (Martinelli et al. 2012) and increases the risk of further land clearing for extensive agriculture at the expense of native forest ecosystems (Sutton et al. 2013). Alterations to the hydrological regime have also been observed after deforestation. Conversion of forest can heavily impact the hydrological dynamics by increasing run-off, creating flash floods that can be followed by periods of greatly reduced stream flow. Regular flooding patterns are important for natural freshwater ecosystem functioning, for the riparian ecosystems as well as for floodplain agriculture (Fearnside 2005).

Deforestation reduces the options for sustainable forest management for timber or presently little-valued genetic or pharmacological resources (Fearnside 2005). The Amazon forest 'biome' is rich in biodiversity, for instance, comprising more than 50,000 vascular plant species, of which 30,000 are endemic (Vieira et al. 2008). Habitat fragmentation may directly drive the loss of fauna and flora, unbalancing ecological productivity (Tollefson 2013). Furthermore, biodiversity has an inherent value beyond the market value of diverse forest products (Fearnside 1999). The impact of continued deforestation on biodiversity is much greater in areas with little remaining forest, fragmented landscapes and high levels of endemism. According to Fearnside (2005), if Amazonian deforestation were allowed to continue unbridled, the same levels of risk to biodiversity would apply that had already happened to the Atlantic forest (see, e.g. Tabarelli et al. 2012).

Changes in vegetation canopy height alter the temperature and humidity balance leading to different patterns of precipitation that can feedback negatively to agricultural production (Ometto et al. 2011). Werth and Avissar (2002) found that deforestation effects in the Amazon were strong, with reductions in precipitation, evapotranspiration and cloudiness.

In addition, deforestation promotes the production of GHG from soils previously covered by native forests (Houghton 1999; McGuire et al. 2001; DeFries et al. 2002; Achard et al. 2004; Potter et al. 2008; Ometto et al. 2011). Along with C emissions, other GHGs are emitted from deforestation. Steudler et al. (1996)

showed that forest-to-pasture conversion resulted in a net source of CH_4 from soil of about 10 kg CH_4 ha^{-1} $year^{-1}$. According to Hao and Ward (2012), about 85 % of the total anthropogenic CH_4 emitted originates in the tropics, mainly resulting from agriculture, cattle husbandry, fuel wood use and deforestation. The Amazon is not a major contributor of nitrous oxide (N_2O) to the atmosphere, the exception being forest fires. However, the upland ('terra firme') Amazonian forest soils are estimated to emit about 15 % of global non-anthropogenic emissions (Davidson and Artaxo 2004).

Since early 1980s, Brazil has been one of the top GHG emitters, overall, due to the intense rate of deforestation at the contact zone between Amazon forest and Cerrado 'biomes'. The recent decreasing trend in deforestation rates in Brazilian Amazon has resulted from important commitments that the country has made during international climate change negotiations. The proposed reduction of 80 % in emissions derived from deforestation, in relation to a decadal mean (MMA 2009), is about to be achieved. The implications of these actions point to the necessity of profound changes and an alternative development plan for Brazilian Amazon, including capacity building, education and opportunities for economic activities, in particular at community level. At a more immediate timescale, incentives to aid the regrowth of secondary vegetation in areas illegally deforested could have the potential for the region to become a carbon sink.

15.5 Conclusions

Despite the recent decrease in deforestation rates in Brazilian Amazon, sustained efforts towards better land management are required to maintain efforts to harmonise economic development, social expectations and environmental conservation. Together, deforestation and global warming lead to profound changes in the forest structure with effects not only on the local environment, but beyond, potentially affecting human societies. Furthermore, deforestation causes changes in ecosystem productivity, hydrological and the climate regime. Investments in satellite monitoring together with studies on the impacts of deforestation are critical tools to understand and manage important processes for maintaining critical ecosystem services provided by the ecosystems of Brazilian Amazon.

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