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Chapter 16.

The impact of land use on carbon stocks and fluxes in Brazilian Amazonia: Implications for policy

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ABSTRACT

Research on carbon stocks and fluxes in Amazonia is advancing both through the collection of new data and through re-interpretation of older data. Factors affecting carbon stocks and fluxes include deforestation and forest degradation by logging and fire. Clearing and emissions in Brazilian Amazonia have declined substantially since their peak in 2004, but forces pushing in the other direction are expected from planned infrastructure and from recent weakening of the country's Forest Code and of its environmental licensing process. Emissions from forest degradation by logging and fire are growing and underappreciated concerns.

Keywords: Amazonia, Brazil, Climate change, Rainforest, Global warming, Greenhouse gas emissions, Tropical forest

1.) INTRODUCTION

Assessing impact of land use on carbon stocks and fluxes depends on quantification of the magnitudes and understanding the processes operating in all three of these sectors. This requires estimates of biomass and carbon stocks, the carbon fluxes from transformations such as deforestation and abandonment to secondary succession, and the associated models of land-use change needed to estimate the areas affected. Although significant progress has been made in these three areas in the past few years, much remains to be done. The social and physical changes themselves have been evolving, as have expectations regarding future changes in Brazilian Amazonia, or Brazilian Legal Amazon (BLA) (Figure 1). This chapter reviews progress on emissions estimates for deforestation and logging and for the magnification of these effects by extreme events. Future prospects for monitoring these processes are also reviewed. Finally, the chapter reviews land-use change, its modeling, recent developments and probable future drivers. This includes both the forces driving increased biomass loss and consequent carbon emission and efforts such as Reducing Emissions from Deforestation and Degradation (REDD) that are aimed at restraining forest destruction by using the value that avoiding these emissions has for global efforts to mitigate climate change.

[Figure 1 here]

2.) EMISSIONS ESTIMATES

2.1. Deforestation

There have been a number of advances in quantifying emissions from deforestation, but this is still the most uncertain portion of global emissions estimates.

Discrepancies are large among recent estimates of emissions (but see Gloor 2015; Grace 2015). Harris et al. (2012) estimated average annual gross emission from tropical deforestation over the 2000-2005 period at 0.81 Pg C (0.57-1.22 Pg C 90% confidence interval). This contrasts with an estimate of 2.2 Pg C by Baccini et al. (2012) for the 2000-2010 period as well as estimates by Houghton (2003) of 1.93 Pg C for 1980-1989 and 2.2 Pg C for 1990-1999. It also differs from the 'classic' value of 1.6 Pg C for the annual net emission from land-use change that persisted through a series of Intergovernmental Panel on Climate Change (IPCC) reports on the basis of an evolving series of rationales (see Fearnside 2000b).

The study by Harris et al. (2012) has claimed as positive points the fact that the study was limited to gross emissions (i.e., ignoring regrowth in the deforestation emission) and that it omitted soil carbon. The study also omitted the trace-gas emissions that, considering the global warming potentials used to express CO_2 equivalents under the 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), increased the impact of global warming of each ton of carbon emitted by deforestation by c. 15.3% ± 9.7% (depending on the emission factors used) as compared to a ton of carbon emitted by fossil fuels, which emit almost all of their carbon as CO_2 (Fearnside 2000c, pp. 143–145). This author holds the view that all components must be included based on the best available data, even if the estimates have substantial uncertainty. Excluding uncertain components does not increase the utility of the result for assessing the impact of land use on carbon stocks and fluxes – it only makes the result less relevant.

The trace-gas emissions depend on how much of the biomass is oxidized through combustion and how much through decay (e.g., Fearnside 2000c). For the portion oxidized through combustion, the amount emitted through flaming versus smouldering combustion is important, more trace gases being emitted by smouldering. Burn quality is an important factor in determining the biomass exposed to burning that is actually oxidized, the unburned biomass that will be subject to decay or to subsequent burning, and how much is converted to charcoal. Studies include those of Soares Neto et al. (2009), who found 23.9% burning efficiency in Alta Floresta, Mato Grosso, similar to other results from Amazonian burns. A study by Righi et al. (2009) in a transition forest in Feliz Natal, Mato Grosso in 2007 (a dry year) found a burning efficiency of 65%. Higher burning efficiencies in forests with lower biomass in the 'arc of deforestation' imply additional trace gas emissions (Fearnside et al., 2009).

2.2. Logging

2.2.1. Logging and emissions

Logging is a major factor of forest disturbance that has received much less research attention than deforestation, in part because of the greater difficulty of quantification by remote sensing. Merry et al. (2009) have simulated the future advance of logging, and Ahmed and Ewers (2012) have produced maps of remaining timber resources.

The question of how much carbon is emitted by logging is an important one, and it has not been adequately included in global emissions estimates and in national accounts. Brazil's first inventory included an estimate (not included in the inventory's accounting of national emissions) of only 2.4×10^6 Mg C per year (MCT 2004, p. 149), and logging emissions were completely omitted in the second inventory (MCT 2010). By contrast, Asner et al. (2005) estimated annual emissions from logging at 80×10^6 Mg C. An unpublished critique by researchers at Brazil's National Institute for Space Research (INPE) (Câmara et al. 2005) pointed out problems in interpreting the satellite imagery and suggested that the annual emission will be about half as much, or 40×10^6 Mg C. Both results provide confirmation that emissions are substantial, and they bracket the earlier estimate of 62×10^6 Mg C (Fearnside 2000a). In 1990 (the standard year for initial inventories under the UNFCCC), this represented 15% of the annual balance of emission from Amazonian deforestation and logging in Brazil (Fearnside, 2000a); the percentage today would be higher, since the deforestation rate in 2013 had declined to roughly half the rate in 1990, but logging activity has not declined.

2.2.2. Future prospects for monitoring logging

Progress has been disappointing in automatic interpretation of satellite imagery. One algorithm (Souza et al., 2005) tried and failed to win approval by the Brazilian Forest Service (SFB) for use in application on a regional scale. Graça et al. (2005) developed an algorithm that performed well in a limited area near Cláudia, Mato Grosso, but has not yet been translated into an automated form that can be easily applied on a regional scale. The CLASS algorithm (Asner et al., 2005) has a better computational implementation for large-scale 'operational' use. The algorithm needs to be complemented with local expertise to clean the results of areas of rock outcrops, hilltops and some seasonally flooded ecosystems (*várzea*) that were mistakenly identified as logging in the study by Asner et al. (2005) as pointed out by Câmara et al. (2005). A subsequent 'light' adaptation (ClassLite: Asner et al., 2009) is not designed specifically for logging, but rather for detecting biomass loss from any cause, including fire.

A key to identifying logging activity is the correct identification of the logging decks (small clearings where logs are stockpiled for loading on trucks). This has been hindered by the effect of shadows that often impede the algorithms from correctly identifying the decks. An important advance has been made by Maldonado et al. (2009), who developed an algorithm that eliminates the effect of shading, so that the logging decks stand out clearly.

Unfortunately, none of these algorithms has yet advanced to the point where regular estimates of degradation (biomass loss) from logging are available similar to those produced yearly for deforestation. The DETEX program of INPE is intended to monitor areas of logging, but, so far, the results of this effort are not posted on INPE's website, in contrast to the annual deforestation data from the PRODES program. It should be noted that logging interests are adamant that logged areas not be characterized as 'degraded', but rather as 'managed' areas. However, considering the definition of degradation as a reduction in biomass and carbon stock, logged areas are greatly degraded (e.g., Keller et al., 2004). They are also damaged in other ways as compared to undisturbed forest. In practice, logging often serves as a prelude to conversion to other uses, despite the discourse regarding sustainable management (e.g., Fearnside, 2003).

2.3. Extreme events

2.3.1. Extreme events and emissions

The impact of land-use change on carbon stocks and flows is aggravated by extreme events, especially droughts. Deforestation creates forest edges, where the microclimate is hotter and drier than in continuous forest, causing increased tree mortality due to water stress (Nascimento and Laurance, 2004). Droughts magnify this source of mortality. The edges are also the main entry point for forest fires (Cochrane and Laurance, 2002), which are also directly related to rainfall (Vasconcelos et al., 2013a; Nepstad et al. 2004). Amazonian droughts affect biomass both through mortality and though impeding growth (Gatti et al., 2014; Phillips et al., 1998, 2009, 2010). Tree mortality from forest-fire events has been estimated in on-the-ground studies by various authors (Table 1).

[Table 1 here]

Almost all Amazonian forest fires are at least partially the result of human activities, including both the ignition sources and, in many cases, the increased flammability of standing forest due to the impact of logging in increasing necromass and in opening the canopy (e.g., Gerwing, 2002; Berenguer et al., 2014). These factors make it possible for forest fires to develop whenever a major drought episode occurs, such as the El Niño events of 1997-1998 and 2003 and the Atlantic dipole events of 2005 and 2010 (Lewis et al., 2011; Marengo et al., 2008, 2011, 2015).

The losses are more severe when logging and fire are combined (e.g., Barlow and Peres 2006). In a study in Paragominas, Pará, Gerwing (2002, p. 136) found, as compared to 'intact' forest, 11.8% less total above-ground biomass (live + dead) in forest that had been moderately logged, 12.9% less in forest that had been heavily logged, 23.4% less in forest that had been logged and lightly burned, and 51.1% less in forest that had been logged and heavily burned. Berenguer et al. (2014, p. 6) found forest that had been logged but not burned to have c. 24.5% less carbon in above-ground biomass (live + dead), on average, than 'undisturbed' forest in Paragominas, while forest that had been both logged and burned had 48.2% less. In Santarém, the same study found that forests that had been logged but not burned had above-ground biomass carbon reduced by only 2.2%, while those that had only been burned had 5.6% less and those both logged and burned 22.2% less than 'undisturbed' forest.

The occurrence of fire is related to rainfall and soil water (Alencar et al., 2004; Aragão et al., 2008; 2016; Nepstad et al. 2004; Silvestrini et al. 2011). This indicates the likelihood of increased fires if Amazonia experiences the projected by dry-season rainfall decreases expected to result from continued global warming (Justino et al., 2011; Malhi et al. 2008, 2009b; Nepstad et al. 2008; Nobre and Borma, 2009). Among the consequences of this would be reduced capacity for REDD to provide benefits, both for climate and for local populations (Aragão and Shimabukuro 2010; Barlow et al., 2012).

Emissions from the major forest fires that occurred during the El Niño of 1997-1998 were estimated in Pará (Alencar et al. 2006) and in Roraima (Barbosa and Fearnside 1999). Potential emissions from the fires in south-western Amazonia during the 2005 Atlantic dipole drought were estimated by Vasconcelos et al. (2011, 2013b). All of these studies indicate major emissions.

Because forest fires represent a threat to Amazonian forest, it is important to understand the likely changes in fire frequency and area under climate regimes altered by global warming (Aragao et al. 2016). The distribution of fires of different sizes is important in helping to define the levels of atmospheric greenhouse gases that correspond to ‘dangerous’ interference with the global climate system, as required by Article 2 of the climate convention (UNFCCC, 1992). A study by Pueyo *et al.* (2010) has contributed to this in improving the mathematical characterization of fire-size distributions in Amazonian forest and savanna ecosystems under drought conditions. The study finds evidence of a critical transition to a megafire regime under extreme drought in rainforests.

The effect of increased forest fires under climatic regimes altered by projected global warming has been omitted from most modeled estimates of future emissions from Amazonia (e.g., Cox et al., 2004, 2008). Forest fires would both increase emissions and speed the demise of the forest, as compared to a scenario without fires. The effect of fire is not included in recent models that indicate resistance of Amazon forest to climates with as much as four times the pre-industrial atmospheric CO_2 concentration, based on CO_2 fertilization increasing tree growth and reducing water loss from transpiration (Cox *et al*., 2013; Good *et al.*, 2013; Huntingford, *et al.*, 2013). Fires can kill trees irrespective of their ability to survive drought alone (e.g., Fearnside, 2013a).

Emissions from forest fires are not included in national accounts under the UNFCCC (IPCC, 2006). However, if global warming is to be contained, it is necessary to have estimates of all emissions sources, including those that are wholly or partially the result of natural events. Only emissions that are ‘directly human induced’ are covered under the Kyoto Protocol (UNFCCC, 1997) and are considered to be the responsibility of the country where the emission occurred. The objective of the UNFCCC is to avoid ‘dangerous’ concentrations of greenhouse gases (UNFCCC, 1992, Art. 2). To keep concentrations within this limit, it is necessary to know the total that is being emitted in the world so that the quotas (‘assigned amounts’) negotiated for the different countries will be sufficient to limit the total increase, not just the increase that is deliberately emitted by society. If emissions, such as those of anthropogenic forest fires are not counted, then the quotas negotiated may be insufficient to contain global warming.

2.3.2. Monitoring fires

The interpretation of satellite imagery to detect and quantify damage from Amazonian fires has advanced using LANDSAT-TM imagery with 30-m resolution (e.g., Graça *et al.*, 2012; Aragao et al. 2016). INPE’s DEGRAD program uses 250-m resolution MODIS imagery to measure fire scars at least 25 ha in area (INPE, 2014a). These results are not yet posted on INPE’s website, but they are communicated to the Ministry of the Environment.

Canopy damage has been mapped by Morton *et al.* (2011) for one LANDSAT scene in southern Amazonia using both LANDSAT and MODIS imagery. The algorithm that these authors developed is able to differentiate canopy damage from fires and from logging for areas above 1.5 ha using LANDSAT or 10 ha using MODIS, using a 4-year moving window to characterize the changes in each group of pixels over time. These developments offer hope that the spatial extent of fire damage can be quantified on a regional basis, thereby addressing an important source of uncertainty regarding Amazonian emissions from forest degradation (Aragao et al. 2016).

3. LAND-USE CHANGE

3.1. Modeling land-use change

Difficult as it is, the ability to understand and model land-use change is essential if effective governance measures are to be implemented to bring the process under control. The causes of Amazonian deforestation are many, and the relative importance of each varies among locations and over time in any given location (e.g., Fearnside, 2005, 2008a). The dynamics of clearing by small farmers depends on a variety of economic and demographic factors (Caldas *et al*., 2010; Perz and Walker, 2002). Roads are important factors for actors of all sizes, but the tens of thousands of kilometers of clandestine or 'endogenous' roads that have been built in the forest are particularly important for entry of small farmers (Brandão Júnior *et al*., 2007). Roads speed deforestation not only though clearing spreading laterally from the roadside, but also by allowing migration flows to areas far beyond the end of the road in question, as in the case of the proposed reopening of the BR-319 Highway that would reconnect Manaus and Porto Velho (Barni *et al*., 2015). Land speculation, which is also stimulated by roads, is a significant force in many parts of the region, including among small farmers in settlement areas established by the government (Carrero and Fearnside, 2011).

Cattle pasture is still the main replacement for forest in Brazilian Amazonia as a whole (McAlpine *et al*., 2010). However, soybeans are the major force driving land-use change in much of Mato Grosso and in smaller areas in eastern Rondônia and in the Santarém area of Pará (Fargione *et al.*, 2008; Gibbs *et al*., 2008; Fearnside, 2001; Morton *et al*., 2006). The role of China has recently become a dominant factor in the advance of soy (Fearnside *et al.*, 2013; Fearnside and Figueiredo, 2015). Even when soy is planted in former cattle pastures rather than in freshly felled forest, it has an indirect effect on deforestation by displacing ranching activity into rainforest areas, as has been shown statistically for movement of this activity from Mato Grosso to Pará (Arima *et al*., 2011). Note that Brazilian diplomats do not accept this effect and were successful in getting mention of it deleted from the summary for policymakers for the IPCC's Fifth Assessment Report (Garcia, 2014).

Quantifying the effect of protected areas on deforestation is particularly important as a guide to policy in this area. The conservation units created and strengthened under the Protected Areas in Amazonia (ARPA) program have been shown to have a significant effect in slowing deforestation (Soares Filho *et al*., 2009, 2010). Differences in effectiveness in resisting deforestation have been found for the various types of reserves, such as those under federal versus state-level control and 'integral protection' versus 'sustainable use' categorization in Brazil's National System of Conservation Units (SNUC) (Vitel *et al*., 2009). Indigenous areas have consistently been found to be the most resistant to deforestation, and in many areas in the arc of deforestation, indigenous areas represent the only forest that remains standing (Nepstad *et al*., 2006a).

The SimAmazonia model in the DINAMICA software by Soares Filho *et al.* (2006) has been an important tool for visualizing likely trends over the 2000-2050 period. However, for assessing the impact of specific development projects, such as opening a highway or creating a reserve, a number of additional features are needed. In the case of highways, these projects act as forces increasing the total amount of deforestation that takes place, not merely in redistributing the location of a given amount of deforestation activity that has been calculated separately based on macro-economic indicators such as expected growth in gross domestic product (GDP). Simulations using DINAMICA indicate a substantial impact from currently planned highway projects, such as the re-opening of the BR-319 Highway that would connect the arc of deforestation in Rondônia with Manaus in central Amazonia (Fearnside *et al.*, 2009; see also Fearnside and Graça, 2006). In the case of reserves, there can be a significant distortion in the expected amount of deforestation in the reserve area. When the baseline deforestation is calculated by multiplying a deforestation rate expressed as a proportion of the forest area in a large sub-region (in one case representing about one-third of Brazilian Amazonia) a large total area to be deforested each year results; when this is spatially allocated based on attractive features such as presence of roads and of previous clearings, the large area to be deforested is placed in a single corner of the sub-region, producing unrealistically high clearing rates for this particular location. This is the case for the Juma Sustainable Development Reserve (RDS Juma) in the state of Amazonas, which is the location of the first Reducing Emissions from Deforestation and Degradation (REDD) project (Yanai *et al.*, 2012).

3.2. Monitoring deforestation

There has been a trend to smaller clearings detected by INPE’s PRODES program (using LANDSAT-TM with 30-m resolution), with increasing percentages of the area deforested each year being in clearings with smaller areas. Deforestation estimates with higher resolution sensors will be needed to capture small clearings (LANDSAT-TM has a detection limit of 6.25 ha for clearings). High-resolution sensors, such as IKONOS or Quick Bird, will also be needed to monitor the narrow strips of forest along watercourses that are still considered as areas of environmental protection (APPs) under the Forest Code as revised in 2012. The Ministry of the Environment and INPE have plans for compiling a higher-resolution mosaic that would at least be able to detect the 30-m wide APPs of large properties, but not the 5-m wide APPs of small properties. Satellite monitoring linked to Google Earth, aided by on-the-ground input from civil society via the internet, is expected to increase the speed and accuracy of deforestation monitoring (Tollefson, 2009).

Information on land uses in deforested areas has long been a limitation in quantifying net emissions of greenhouse gases. The limitation of deforestation monitoring to just two classes, forest and non-forest, does not allow quantification of the stock and uptake of carbon in the deforested landscape, forcing calculations of emissions to rely on extrapolations from samples in small areas. Especially important are estimates of areas of secondary forest and of degraded pasture. An important improvement is the Terra Class dataset (EMBRAPA and INPE, 2011; INPE, 2014b; Ometto et al. 2016).

3.3. Recent developments in the region

Changes in deforestation rates have a direct relation with carbon emissions and the rate of depletion of carbon stocks. Deforestation rates in Brazilian Amazonia declined markedly from 2004 (when 27.8×10^3 km^2 were cleared) to 2014 (when 4.8×10^3 km^2 were cleared) (INPE, 2015). Note, however, that deforestation soared in the three months following the July cutoff of the official annual deforestation estimate for 2014 (Fearnside, 2015). This was followed by the rainy season in Amazonia, when, although deforestation rates were also much higher than in previous years, the effect is insignificant in terms of the annual total. Whether or not the upturn of deforestation beginning in August 2014 signals a sustained rebound, the basic forces driving deforestation continue to grow on the long term.

The decline in deforestation rates after 2004 was the result of a variety of different forces, with significant differences depending on the location and the year in question. From 2004 to 2008 the slowdown can largely be explained by the decline in international prices of commodities such as soy and beef and a rise in the value of the Brazilian real relative to other currencies, thus decreasing the profitability of exporting commodities that drive Amazonian deforestation (Fearnside, 2009a). From 2009 onwards the trend in deforestation rates diverged from those of commodity indicators, indicating that government regulatory measures were having a significant effect (Assunção *et al*., 2012; Hargrave and Kis-Katos, 2011).

Despite the decreases in deforestation rates since 2004, a number of changes point in the direction of greater future deforestation. These include the continuing increases of the Amazonian population and of investment in the region, the planning and construction of ever more highways, dams and other infrastructure projects, and some notable changes weakening environmental protections. One is the revision of the Forest Code (*Codigo Florestal*), as finally passed on 25 September 2012 (Law No. 12.651/12). This greatly reduces (or eliminates) requirements for maintaining forest along watercourses and on steep hillsides and, by effectively pardoning most of the past violations, creates the expectation that deforestation in violation of the present regulations will eventually be pardoned in future ‘amnesties’ (Fearnside, 2010; Metzger *et al*., 2010; Vieira and Becker, 2010; Sparovek *et al*., 2012). Another serious setback for environmental protection is the weakening of the environmental impact statement and licensing process by the precedents set in 2011 and 2012 in the cases of the Santo Antônio and Jirau Dams on the Madeira River and the Belo Monte Dam on the Xingu River (Fearnside, 2012a, 2013b, 2014). By allowing infrastructure projects to be approved over the objections of the technical staff of the licensing agencies, and by granting licenses without having satisfied the ‘conditionalities’ that had been established as preconditions, the door is opened to approving any project no matter how great its impacts may be. Other setbacks include a virtually complete halt to creation of new protected areas after 2010 (Alencastro, 2014), continued reduction or rescinding of existing protected areas (Bernard *et al.*, 2014), and a 72% cut in government funds for controlling deforestation in 2015 (Leite, 2015).

Of great concern is proposed legislation limiting the authority of the executive branch of the federal government to enforce environmental regulations and to create new indigenous areas and conservation units. Requiring congressional approval would effectively make it impossible to create more protected areas in the foreseeable future. As demonstrated by the recent weakening of the Forest Code, the national congress is currently dominated by the ‘ruralist block’ (representatives of large land holders).

3.4. Future forces in land-use change

A variety of forces can be expected to affect future trends in Amazonian land-use change. Brazil's National Plan for Climate Change (PNMC), and the 'voluntary objectives' Brazil announced at the 2009 Conference of the Parties of the climate convention held in Copenhagen, call for a reduction of the annual deforestation rate to 5×10^3 km^2 by 2020 (CIMC, 2008). This reduction is substantial as compared to the 19.5×10^3 km^2 annual deforestation rate used as the baseline for the plan, but is much less so as compared to recent rates (5.8×10^3 km^2 in 2013). Nevertheless, achieving this will require significant governance efforts given the likely forces acting to increase deforestation in the coming years. These include the effects of planned reconstruction of key highways (together with the opening of side roads): the Santarém-Cuiabá (BR-163) and the Manaus-Porto Velho (BR-319) Highways (Fearnside, 2007; Fearnside and Graça, 2006). Roads are generally the key drivers in Amazonian deforestation (e.g., Arima *et al*., 2008; Perz *et al*., 2008; Southworth *et al*., 2011). The effect of planned dams is already being felt (Barreto *et al*., 2011). Planned waterways for transport of soybeans can be expected to strengthen this deforestation force (Fearnside, 2002). The effect of biofuels, including oil palm, may be significant (Fearnside, 2009b). Increasing Brazilian exports of beef, along with investments in both deforestation and in pasture intensification, represents another significant trend (McAlpine *et al*., 2010).

Various possible forces have been suggested as acting to reduce deforestation pressure in the future. These include increasing urbanization (Wright and Muller-Landau, 2006); however, various factors make this effect much less than claimed, especially the fact that most of the people moving to cities are not from the major groups of actors in Amazonian deforestation (Fearnside, 2008b). Another is the effect of a moratorium on soy purchases from land deforested for this crop (Gibbs *et al*., 2015a; Nepstad *et al*. 2014). Certification of cattle ranches and slaughter houses is also being promoted as a means of decreasing deforestation pressure (Gibbs *et al*., 2015b; Nepstad *et al*., 2006b, 2014; Newton *et al*., 2014). Note, however, that a variety of practices allowing 'leakage' and 'laundering' reduce the effectiveness of these agreements at present (Gibbs *et al*., 2015b). Similar challenges face timber certification that is promoted both by the government and by NGOs as a means of encouraging sustainable forest management (e.g., Barreto *et al*., 1998). The net effect of the spread of "sustainable" forest management is much more complicated than is often portrayed because of economic contradictions and regulatory loopholes that can make the management plans a mere front for obtaining authorization for harvesting and transporting the logs, but with future conversion to deforested land uses as the ultimate result (Fearnside, 2003).

One of the most controversial topics regarding future deforestation is the potential role of reducing emissions from deforestation and degradation (REDD). Potential benefits include reducing clearing in private properties (Stickler *et al*., 2009) creating protected areas (Nepstad *et al*., 2011) and implementing a variety of policy changes for reducing deforestation (Moutinho *et al*., 2011a,b). Challenges include the proper accounting for leakage (Fearnside, 2009c; Yanai *et al*., 2012) and a series of unresolved controversies ranging from how the carbon accounting is done to how the resulting funds are used (Fearnside, 2012b,c). Many have strong opinions on REDD, favoring either throwing it out altogether or working to fix its problems. Strong reasons to solve the very real problems that face REDD include the still significant amounts of carbon emitted annually by Amazonian deforestation, the very large stocks of carbon in the remaining forest at risk of future emission, the lower cost and greater speed of avoiding deforestation emissions as compared to many other mitigation options, and the substantial non-carbon environmental benefits and social gains from maintaining Amazonian rainforest.

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Figure legend:

Figure 1 – Brazilian Amazonia and locations mentioned in the text. Dams: (1) Jirau, (2) Santo Antônio, (3) Belo Monte; Cities: (4) São Paulo, (5) Santarém, (6) Cuiabá, (7) Porto Velho, (8) Claúdia, (9) Manaus, (10) Belém; Other: (11) PDBFF, (12) Ducke Reserve, (13) RDS Juma.