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Deforestation of the Brazilian Amazon

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Summary:

Deforestation in Brazilian Amazonia destroys environmental services that are important for the whole world, and especially for Brazil itself. These services include maintaining biodiversity, avoiding global warming, and recycling water that provides rainfall to Amazonia, to other parts of Brazil such as São Paulo, and to neighboring countries such as Argentina. The forest also maintains the human populations and cultures that depend on it. Deforestation rates have gone up and down over the years with major economic cycles. A peak of 27,772 km^2/year was reached in 2004, followed by a major decline to 4571 km^2/year in 2012, after which the rate trended upward, reaching 7989 km^2/year in 2016 (equivalent to about 1.5 hectares per minute). Most (70%) of the decline occurred by 2007, and the slowing in this period is almost entirely explained by declining prices of export commodities such as soy and beef. Government repression measures explain the continued decline from 2008 to 2012, but an important part of the effect of the repression program hinges on a fragile base: a 2008 decision that makes the absence of pending fines a prerequisite for credit for agriculture and ranching. This could be reversed at the stroke of a pen, and this is a priority for the powerful "ruralist" voting block in the National Congress. Massive plans for highways, dams and other infrastructure in Amazonia, if carried out, will add to forces in the direction of increased deforestation.

Deforestation occurs for a wide variety of reasons that vary in different historical periods, in different locations, and in different phase of the process at any given location. Economic cycles, such as recessions and the ups and downs of commodity markets are one influence. The traditional economic logic, where people deforest to make a profit by producing products from agriculture and ranching, is important but is only a part of the story. Ulterior motives also drive deforestation. Land speculation is critical in many circumstances, where the increase in land values (bid up, for example, as a safe-haven to protect money from hyperinflation), can yield much higher returns than anything produced by the land. Even without the hyperinflation that came under control in 1994, highway projects can yield speculative fortunes to those who are lucky or shrewd enough to have holdings along the highway route. The practical way to secure land holdings is to deforest for cattle pasture. This is also critical to obtaining and defending legal title to the land. In the past it has also been the key to large ranches gaining generous fiscal incentives from the government. Money laundering also makes deforestation attractive, allowing funds from drug trafficking, tax evasion and corruption to be converted to "legal" money. Deforestation receives impulses from logging, mining, and especially road construction. Soybeans and cattle ranching are the main replacements for forest, and recently expanded export markets are giving strength to these drivers. Population growth and household dynamics are important for areas dominated by small farmers. Extreme degradation, where tree mortality from logging and successive droughts and forest fires replace forest with open non-forest vegetation,

is increasing as a kind of deforestation, and is likely to increase much more in the future.

Controlling deforestation requires addressing its multiple causes. Repression through fines and other command-and-control measures is essential in order to avoid a presumption of impunity, but these controls must be part of a broader program that addresses underlying causes. The many forms of government subsidies for deforestation must be remove or redirected, and the various ulterior motives must be combatted. Industry agreements restricting commodity purchases from properties with illegal deforestation (or from areas cleared after a specified cutoff) have a place in efforts to contain forest loss, despite some problems. A “soy moratorium” has been in effect since 2006 and a “cattle agreement” since 2009. Creation and defense of protected areas is an important part of deforestation control, including both indigenous lands and a variety of kinds of “conservation units.” Containing infrastructure projects is essential if deforestation is to be held in check: once roads are built, much of what happens is outside of the government’s control. The notion that the 2005-2012 deforestation slowdown means that the process is under control and that infrastructure projects can be built at will is extremely dangerous. One must also abandon myths that divert efforts to contain deforestation; these include “sustainable logging” and the use of “green” funds for expensive programs to reforest degraded lands rather than retain areas of remaining natural forests. Finally, one must provide alternatives to support the rural population of small farmers. Large investors, on the other hand, can fend for themselves. This author has long defended tapping the value of the environmental services of the forest as an alternative basis for sustaining both the rural population and the forest. Despite some progress, a variety of challenges remain. One thing is clear: most of Brazil’s Amazonian deforestation is not “development.” Trading the forest for a vast expanse of extensive cattle pasture does little to secure the wellbeing of the region’s rural population, is not sustainable, and sacrifices Amazonia’s most valuable resources.

Keywords: deforestation, development, Brazil, Amazonia, tropical forest, economic development, land use, REDD, environmental services, ecosystem services

What is deforestation?

“Deforestation” refers to converting “forest” into “non-forest,” and the meaning of the term therefore hinges on what is considered to be a “forest.” Semantic distinctions often confuse discussions of deforestation. Deforestation in official Brazilian data such as those from Project for Monitoring the Brazilian Amazon Forest by Satellite (PRODES), run by the National Institute for Space Research (INPE), refers to clearing of primary or old-growth forest, not clearing of secondary forests. Secondary forests refer to succession in previously clearcut areas (as distinct from the usage of this term in Southeast Asia to refer to logged forests). The PRODES surveys define forest based on vegetation types classified by the Brazilian Institute of Geography and Statistics (Brazil, IBGE, 2012), rather than by percentage cover (Brazil, INPE, 2013). The United Nations Framework Convention on Climate Change (UNFCCC), better known as the “Climate Convention,” defines forest as having at least 10% cover (IPCC, 2006, p. 4.74), thus allowing many types of *cerrado* (central Brazilian savanna) to be considered forest and its clearing as “deforestation.” Note also that the Climate Convention definition, which is based on the definition used by the Food and Agriculture Organization of the United Nations (FAO, 2012, p. 3), includes "temporarily unstocked" areas that have been completely clearcut but are intended to be allowed to regenerate, thus opening a loophole by making the definition of forest, and therefore of deforestation, dependent on knowledge of intent rather than being based solely on objective measurements verifiable by satellite.

An important distinction is "net" versus "gross" deforestation (e.g., Brown and Zarin, 2013). "Net" deforestation subtracts areas that are regenerating as secondary forests. Some interpretations also include silvicultural plantations, such as *Eucalyptus*, as counting towards reducing net deforestation, including Brazil's 2008 National Plan for Climate Change. This plan promised to end net deforestation by 2015 (Brazil, CIMC, 2008, p. 12), an objective that was not met. Zero or reduced "net" deforestation as a target carries a danger, as each hectare of plantation or regenerating trees effectively creates a license to clear a hectare of mature or primary forest elsewhere.

Brazil's commitment as part of the 2015 Paris accords refers to reaching zero "illegal" deforestation by 2030 (Brazil, 2015, p. 3). This is far from ending deforestation, as forest clearing can continue so long it is "legal." With advance of the Rural Environmental Register (CAR), all properties in the country should be registered long before 2030, making it easy to obtain permission for "legal" deforestation up to the limits specified by Brazil's current Forest Code (20% in Amazonia). Since many present and future properties in Amazon forest areas have little clearing, large amounts of "legal" deforestation can continue (Nunes et al., 2016).

Why is deforestation important?

Brazil' Amazonian deforestation is important to life throughout the world, both human and non-human. Deforestation impacts include loss of environmental services that, while these losses affect whole world, affect Brazil most (e.g., Fearnside, 1997a, 2008a). Environmental services of Amazonian forest include its roles in storing carbon, thus avoiding global warming (e.g., Fearnside, 2000, 2016a; Nogueira et al., 2015), in recycling water that is important for rainfall not only in Amazonia but also in non-Amazonian areas such as São Paulo (e.g., Arraut et al., 2012), and in maintaining biodiversity (e.g., Fearnside, 1999). In addition, Amazonian forests provide a variety of material products, such as timber, rubber and Brazil nuts; these provisioning functions currently support local populations and are also lost as opportunities for sustainable use when areas are deforested.

The vast size of Brazilian Amazonia (Figure 1) gives special importance to deforestation processes in this region. In many other parts of the world that were originally covered by tropical forests, deforestation has proceeded to the point where only tiny remnants remain. In these areas the clearing of the last hectares of what remains represents a tragedy for biodiversity. In the case of Amazonia, even despite the large area of remaining forest there is a significant impact on biodiversity from deforestation because the distribution of species is not uniform. Many species have ranges restricted to parts of the region where forest has already been reduced to small fragments (e.g., Hubbell et al., 2008; Michalski and Peres, 2005). Disappearance of species endemic to heavily deforested areas in eastern and southern Amazonia is already widespread (e.g., Moura et al., 2014).

Elimination of forest has different implications for biodiversity and climate. Fighting to save the last remnants of forest in heavily deforested areas is essential for biodiversity, but from the point of view of climate the dwindling area of remaining forest limits the potential impact of future deforestation. While impact on global warming is the same when a hectare of forest is cleared in any part of the world, assuming that forest biomass per hectare and other relevant parameters are the same, the equivalence is restricted to the emission from one year to the next. In the case of Amazonia, in addition to this yearly impact, the vast extent of remaining forest gives additional importance to deforestation processes because they can result in much greater future emissions. Any change in public policies in Brazil has a much greater potential impact, either positive or negative, as compared to other tropical countries. The various ways that Amazonian forest can be destroyed other than by deliberate human action give the region additional importance for global climate.

[Figure 1 here]

How fast has deforestation occurred?

Brazil’s Amazonian deforestation rates have varied widely over the decades since construction began on the Transamazon Highway (BR-230) in 1970, initiating the ‘modern’ era of deforestation. Between 1978 (the year of images for the first LANDSAT satellite survey) and 1988 (the next complete survey), deforestation averaged 21,050 km^2/year (see: Fearnside, 1990). Since then annual coverage has been available, with the single exception of 1993 (Brazil, INPE, 2017a). A long history of political interference with the monitoring program (Fearnside, 1997b) has largely been overcome, and the program, known as PRODES, currently has much greater transparency. Some discrepancies with other satellite estimates still remain as open questions (Fearnside and Barbosa, 2004), while other LANDSAT estimates are highly consistent (Souza et al., 2013). Deforestation rates have undergone major oscillations (Figure 2), mostly as a result of macroeconomic shifts (Fearnside, 2005a).

[Figure 2 here]

PRODES uses Landsat-TM satellite imagery (or equivalent) with 30-m resolution (Brazil, INPE, 2017a). The imagery is freely available on the INPE website, degraded to 60-m resolution (http://www.obt.inpe.br). Images are taken in the dry season (August in all but the extreme north of the region), and the “year” of the data refers approximately to the deforestation between 1 August of the previous year and 31 July of the nominal year. The lower limit for detection of clearings is 6.25 ha.

INPE also has a program called DETER (Detection of Deforestation in Real Time), which produces monthly data from MODIS imagery with maximum resolution of 250 m (Brazil, INPE, 2017b; Diniz et al., 2015). This only detects clearings 25 ha or larger. A similar MODIS-based monitoring program called SAD (Deforestation Alert Service) is run by the Institute for Man and the Environment in Amazonia (IMAZON), a non-governmental organization (NGO). The SAD data are released more quickly than the DETER data and are accompanied by more information on the deforestation processes in course (IMAZON, 2017). Results of the DETER program at INPE and the SAD program at IMAZON match well. Care is needed in drawing conclusions from the monthly data. They are more subject to having significant areas covered by clouds than in PRODES data, despite the much more frequent satellite passes by MODIS as compared to LANDSAT. More importantly, frequent headlines that deforestation in a given month is several hundred percent higher or lower than in the same month in the previous year can often be misleading. If the month in question is in the dry season, this can be very significant, but if it is in the wet season then large variation from a number near zero has little import, and the clearing detected is likely to be an insignificant portion of the annual total deforestation.

An important limitation of deforestation data is that forest degradation, as by logging and by tree mortality from droughts and fire, is not detected or counted unless it has reached the extreme condition of an open area with only a few scattered trees remaining, thus appearing as cleared on the satellite image. Extreme degradation of this type is counted as deforestation by all of the programs mentioned above. There has been a longstanding struggle over this issue between INPE and the state government of Mato Grosso, which insists that these areas are not "deforestation" because they were not deliberately clearcut. This is likely to become even more critical if a proposed law (PL4508/2016) is implemented to allow "sustainable" cattle ranching in legal reserves (Canal Rural, 2017). Degradation is monitored by IMAZON (e.g., Cardoso et al., 2017) and was monitored from 2007 to 2013 by the DEGRAD program at INPE (Brazil, INPE, 2014a).

Why is deforestation happening?

Economic cycles and land speculation

From 1988 to 1991 deforestation declined by half at the time of a deepening economic recession under president Fernando Collor, culminating with the government ceasing deposits in bank accounts in 1990, thus making funds unavailable for investment in deforestation (among other effects). Deforestation rose in the subsequent years with economic recovery, and reached a record rate of 29,100 km^2/year in 1995 as a consequence of the June 1994 Real Plan, a package of economic reforms that ended hyperinflation. Money that had been invested in the "overnight" (a 24-hour money market that could protect money from inflation) was suddenly available, and it was invested in deforestation, not, for example, in recuperating degraded pastureland. In the following two years deforestation fell dramatically, another consequence of the Real Plan. By essentially halting inflation, generalized land speculation became unprofitable (although land purchases in areas where roads would be built or upgraded could still yield quick fortunes). Even under the current inflation regime with much lower rates, clearing behavior is also frequently explained by speculative returns rather than solely by beef production (Carrero and Fearnside, 2011; Razera, 2005).

Land speculation is an important force in deforestation because the practical way to secure land holdings is to deforest for cattle pasture. Under hyperinflation, land values in Amazonia increased at rates faster than inflation, and the increase in land value could yield much more profit than that from raising cattle or other activities undertaken while holding the land (Hecht, 1985, 1993; Hecht et al., 1988). Land values in Amazonia and deforestation rates both fell by half after the Real Plan, providing an indication of how strong speculation had been as a driver. However, land speculation continues to be an important component in the profitability of extensive ranching (Bowman et al., 2012). Following the decline after the 1995 peak, deforestation rates increased to a new peak of 27,772 km^2/year in 2004 thanks to a strengthening economy and rising commodity prices. Beginning in 2005 there was a major decline in deforestation rates until 2012, after which the rate increased (with oscillations), reaching 7989 km^2/year in 2016 (Brazil, INPE, 2017a).

Commodities and governance

Understanding the causes of the 2005-2012 decline in deforestation rates is essential to the policy lessons that can be derived from this experience. The Brazilian government has repeated countless times that this decline is result of government action in inspecting and fining those who deforest illegally. However, although the decline represents the sum of a variety of factors (including governance measures), it is factors other than government measures that explain most of the decline. The decline occurred in two phases, the first from 2005 to 2007 and the second from 2008 to 2012. During the period up to 2007 deforestation rates tracked the prices of export commodities such as soybeans and beef, making these the primary drivers during this period (data in Assunção et al., 2015; see also Arima et al., 2014; Hargrave and Kis-Katos, 2013). For the 1995-2007 period, more than 75% of deforestation is explained by lagged prices of soy and beef (Arima et al., 2014). Most (70%) of the total 2005-2012 decline occurred by 2007. From 2008 onwards commodity prices recovered, while deforestation continued to decline to 2012, indicating that something had changed. An event in 2008 that coincides with the change is a resolution of the Brazilian Central Bank (BACEN 3545/2008), which blocks loans from government banks for agriculture and ranching in properties with fines pending in the environmental agencies (Börner et al., 2015; Fearnside, 2015a). The fines themselves have little effect, since they can be appealed almost indefinitely and are rarely paid (e.g., Lima et al., 2009). In contrast, the block on loans has immediate effect and no appeal; it also has its greatest impact on the largest actors. Another key event in 2008 was the federal environmental agency (IBAMA: Brazilian Institute for the Environment and Renewable Natural Resources) initiating a “blacklist” of municipalities with high deforestation; blacklisted municipalities had a significantly greater reduction in deforestation as compared to non-blacklisted municipalities over the 2009-2011 period (Arima et al., 2014), a trend that continued through 2012 (Cisneros et al., 2015). Blacklisted municipalities had additional requirements for obtaining licenses for legal deforestation, had more inspection effort focused on them by IBAMA, suffered restrictions on agricultural credit, and had additional impetus to hasten implantation of the Rural Environmental Register (CAR) due to increased assistance from NGOs in registering properties and because of local desire to avoid reputational costs (Cisneros et al., 2015).

The strength of governance measures varies with election cycles, with a tendency for enforcement of environmental regulations to be relaxed prior to major elections producing a significant relation between deforestation rates and elections (Rodrigues-Filho et al., 2015). The mere anticipation of such relaxation can stimulate clearing, as suggested by a dramatic surge in deforestation in Mato Grosso in 2002 in the months prior to election of Brazil’s largest soybean producer as governor of the state, thus curtailing the state government’s deforestation control program (e.g., Fearnside, 2005b).

Fiscal incentives

In the 1970s and 1980s, fiscal incentives offered by the Brazilian government were a major factor motivating deforestation by large ranchers (Binswanger, 1991; Mahar, 1979). Incentives included the right to invest in approved Amazonian ranches the funds that would otherwise be paid as taxes on the profits of enterprises elsewhere in the country, as well as generous loans at interest rates far below the rate of inflation and exemption from tax on the Amazonian income. Clearing forest was primarily a means of gaining access to these subsidies rather than for earning income from beef production. The effect of incentives continued long after official discourse stressed that the incentive program had been ended. A 1991 decree halted approval of new projects, but the already approved projects continue to receive the tax incentives (Fearnside, 2005a). Natural attrition, as by bankruptcy, has reduced the impact of the incentives by reducing the number of eligible ranches.

Land tenure

One of the most pervasive motives for deforestation is establishment and maintenance of land tenure (Fearnside, 1979, 2001a). Much of the land in Brazilian Amazonia is in the public domain. Aside from occasional land distributions to small farmers in official settlement programs (such as those on the Transamazon Highway) and to large ranchers in areas sold through bidding (such as the Agriculture and Ranching District of the Manaus Free Trade Zone [SUFRAMA]), land enters the private domain by first being illegally invaded either by small squatters or by large "*grileiros*" (land thieves or "land grabbers"), and eventually the government recognizes the claims and grants title. The key to gaining title is showing "improvement" (*benfeitoria*) on the land, which means deforesting and planting something, cattle pasture being the cheapest option per hectare. Even if one has title to land, if it is left in forest the owner can eventually expect to lose it, either through invasion by squatters or *grileiros* or by expropriation for a government settlement project.

The question of who is deforesting is essential to formulating policies that would be effective in containing the process. Deforestation is done for different reasons and by different actors in different parts of the region and in different historical periods in any given location. For example, land along the Belém-Brasília Highway (BR-010), built in the late 1950s and early 1960s, was first occupied by small squatters who were later expelled (often violently) and replaced by large ranchers (e.g., Foweraker, 1981; Valverde and Dias, 1967). Similar patterns unfolded in much of southern Pará beginning in the 1970s (Schmink and Wood, 1992). The Transamazon Highway (BR-230), built in the early 1970s, was settled in government colonization projects where small farmers received 100-ha lots (e.g., Moran, 1981; Smith, 1982). Many of these lots were later acquired by wealthier actors who use them as medium to large ranches (e.g., Fearnside, 1986a). A similar process took place along the Cuiabá-Porto Velho (BR-364) Highway in Rondônia (Fearnside, 1984). In Amazonia as a whole, large (officially defined in Brazilian Amazonia as > 1000 ha) and medium (101-1000 ha) sized actors have traditionally predominated in deforestation (Fearnside, 1993, 2008b), but the relative importance of small (≤ 100 ha) farmers has been increasing in recent years as indicated by the decreasing average size of new clearings (Rosa et al., 2012), and the deforestation slowdown since 2005 has disproportionately affected the larger actors (Godar et al., 2014). However, small farmers have demonstrated greater potential to stabilize their land use in a mosaic of agriculture, pasture and natural forest, and avoiding consolidation of small properties into large ranches represents a beneficial measure from the point-of-view of minimizing deforestation (Campos and Nepstad, 2006; Godar et al., 2012).

Money laundering

Money from sources such as drug trafficking, truck hijacking, government corruption and income sources not declared to tax authorities can be invested in Amazonian deforestation with minimal risk. If the same funds were invested in the stock market or urban real estate, the inconsistency with declared income would soon be discovered by tax authorities. Illegal money forms a sort of cloud over Amazonia that affects what happens on the ground, often defying traditional economic logic. The "*terra do meio*," an area in Pará the size of Switzerland, has been essentially outside of the control of the Brazilian government for many years (e.g., Greenpeace, 2003; Taravella, 2008). The area has been dominated by drug traffickers, *grileiros* and other illegal actors (Escada et al., 2005; Fearnside, 2008b; Greenpeace, 2003; ISA, 2016; Schönenberg, 2002). In 2005, following the assassination of Dorothy Stang (a defender of Amazonian social and environmental causes), a "mosaic" of protected areas was created in the "*terra do meio*," but the environmental agencies have yet to establish a physical base in the area as planned since 2002. An example of deforestation that is inexplicable by traditional economic logic is provided by a 6239-ha clearing (known as the "revolver" for its shape) that suddenly appeared in 2003 in the "*terra do meio*" (Venturieri et al., 2004). The location was far from any roads and had been classified as one of the least-promising locations in all of Amazonia for profitable ranching based on the calculated farm-gate price of beef (Arima et al., 2005a, p. 50).

Logging

Logging is an important driver of deforestation, although its effect is delayed and is hard to show statistically because areas with active logging have little deforestation, while those where deforestation is in full swing no longer have timber available for logging. Logging facilitates deforestation by providing clandestine "endogenous" roads that are subsequently used for entry of deforesters (Arima et al., 2005b). It also provides much of the money that pays for the felling itself, both in the case of large actors and small ones (e.g., Veríssimo et al., 2002).

Mining

Mining is another deforestation driver. Gold miners (*garimpeiros*) attracted to areas with alluvial deposits can later stay on as squatters, or can invest proceeds in land or in clearing (e.g., MacMillan, 1995). Iron mining in the Carajás area justified a major government program to promote agriculture and ranching in the region and also feeds pig-iron smelters that draw wood from the surrounding region for charcoal (Fearnside, 1986b, 1989a). Bauxite mining, aside from the mine sites themselves, feeds an aluminum smelting industry that drives massive impacts from hydroelectric dams built to supply the smelters (Fearnside, 2016b). Dams are associated with increased deforestation in their surrounding areas (Barreto et al., 2011, 2014; Fearnside, 2014a).

Roads

Roads are the most powerful driver of deforestation (Kirby et al., 2006; Laurance et al., 2001; Pfaff, 1999; Pfaff et al., 2007; Soares-Filho et al., 2006). The construction or upgrading of a road increases migration to the area it accesses, increases the profitability of agriculture and ranching, and greatly increases land values, with consequent speculative deforestation and turnover of land owners in favor of more wealthy actors who deforest faster than the previous owners (Fearnside, 1987a,b). Deforestation follows roads, and the presence of deforestation then has a contagious effect, leading to further acceleration of deforestation along these routes (Rosa et al., 2013, 2014). Roughly 80% of the forest loss in Brazilian Amazonia has been in the "arc of deforestation," a crescent-shaped strip along the southern and eastern edges of the forest (Figure 3). New highways are bringing deforestation activity into the heart of the Amazon. The most critical case is the planned reconstruction of the abandoned Manaus-Porto Velho (BR-319) Highway, which would connect the arc of deforestation with central Amazonia, bringing the actors and processes from Rondônia to large areas in Amazonas and Roraima that have road access from Manaus, as well as opening the large block of intact forest in the western portion of the state of Amazonas through planned side roads (Fearnside and Graça, 2006). The environmental impact statement for this planned highway even presents Yellowstone National Park as the expected scenario for deforestation, with tourists driving through the area on a "park-highway" without cutting a single tree (see Fearnside, 2015b; Fearnside and Graça, 2009). The unreal nature of this portrayal of an Amazon frontier would be hard to exaggerate. Unrealistic "governance scenarios," such as this, serve as excuses for justifying licensing of highways that imply very real impacts.

[Figure 3 here]

Soybeans

Soybeans have been a major force in deforestation in Mato Grosso, with more recent advances in some parts of Pará, particularly the Santarém area (Barona et al., 2010; Fearnside, 2001b; Morton et al., 2006). In addition to direct conversion of forest for soy, this crop has a very important "indirect" impact. Soy advance into pasture in the *cerrado* (as well as in forest areas in northern Mato Grosso) has a prominent role in driving increased investment in clearing for ranches in Amazon rainforest areas in Pará (Arima et al., 2011; Richards et al., 2014). The Chinese have had a key role in driving the conversion of forest and *cerrado* (Fearnside et al., 2013). This comes primarily through exports, but also though land purchases and financing of transport infrastructure. Transport infrastructure is the main limitation on spread of soybeans from the currently most profitable areas in Mato Grosso, particularly to the west in Rondônia and Acre as well as in the portions of northern Mato Grosso still dominated by pasture (e.g., Vera-Diaz et al., 2008).

International finance has a significant role in speeding the advance of soy. In 2002 and 2003 the International Finance Corporation (IFC), which is the arm of the World Bank for financing private companies, granted Grupo André Maggi (Brazil's largest soy company) two US$30 million loans. The IFC classified the loans as "Category B" (low environmental risk), thus not requiring any environmental impact assessment or subsequent monitoring of impacts. This IFC classification allowed Rabobank (of the Netherlands) to grant Maggi two loans totaling US$330 million (Greenpeace, 2006, p. 18). Financing from the Brazilian government's National Bank for Social and Economic Development (BNDES) has also been a major force in the advance of soy (Greenpeace, 2006).

It should be noted that gross domestic product (GDP) is not a good predictor of deforestation. Statements associating GDP with clearing give the false impression that deforestation is an inevitable consequence of economic progress. The fraction of Brazil's economy that is contributed by new clearing on the Amazon frontier is minimal, although the large areas of soybeans in previously cleared areas are a significant contributor. The questionable nature of a link to GDP is shown by "decoupling" of deforestation rates from agricultural production during the 2005-2012 deforestation slowdown (e.g., Lapola et al., 2014; Nepstad et al., 2013, 2014).

Cattle ranching

Cattle production (as opposed to ulterior motives) is becoming more prominent in the mix of deforestation motives in Amazonia. This is behavior following the traditional economic logic, where actors deforest in order to earn profits from the sale of products from agriculture and ranching (e.g., Faminow, 1998; Margulis, 2004; Mattos and Uhl, 1994; Mertens et al., 2002). Forest conservation ultimately requires addressing the "underpinnings of the cattle economy itself" (Walker et al., 2000). Cattle ranching is even accelerating in "extractive reserves" created to maintain forests by supporting traditional populations of rubber tappers and Brazil-nut gatherers; ranching has proliferated in these areas and is replacing the economy based on non-timber forest products (Salisbury and Schmink, 2007). Rubber extraction is not economically viable without subsidies (Jaramillo-Giraldo et al., 2017).

Export in general is becoming more prominent as a predictor of deforestation at the municipality (county) level (Faria and Almeida, 2016). Increasing exports of beef are especially significant because of their great potential for expansion (McAlpine et al., 2009). Brazilian beef exports in frozen form were barred from virtually all international markets until recent years due to the presence of foot-and-mouth disease (Fearnside, 1987a). Brazilian Amazonia was thereby protected from the "hamburger connection" (Myers, 1981) that has driven much of the deforestation in Central America, an area that is free of the disease. Beginning in 1998, states in Brazil were successively certified as free of foot-and-mouth disease, starting with the non-Amazonian states in the south of the country (Kaimowitz et al., 2004). This created an indirect impact on Amazonia in that beef produced in southern Brazil could be exported while people in São Paulo, for example, could eat beef from Pará. Since 2015 all nine states in Brazilian Amazonia have been classified as having at most "medium" risk, in addition to being without clinical cases of the disease, but Amazonas, Roraima e Amapá have not been classified as "disease free" to allow direct exports from these states (Pithan e Silva, 2016). Brazil is the world's largest exporter of beef, and some is even exported as live cattle. In 2015 and 2016 accords with Russia, the United States and China have opened these markets to Brazilian beef. The full opening of the Chinese market is particularly significant, since its potential scale is essentially infinite from the perspective of Brazilian producers. In addition to dominating beef export to China, Brazil is also China's main supplier of leather; China is the world's largest manufacturer of shoes. In 2008 the value of Brazil's leather exports totaled US$1.9 billion, as compared to US$5.1 billion for beef (Greenpeace, 2009, p. 61).

The generous subsidies for ranching in the 1970s and 1980s were from the Brazilian government during the “economic miracle” period, and their later curtailment was coincident with a severe recession. As in the case of soybeans, international finance has contributed to speeding the current “modern” period of livestock production and processing. In March 2007 the IFC made a US$ 90 million loan to Bertin (Brazil’s largest slaughterhouse company at the time, later purchased by JBS), which supplies beef to Burger King, among many other outlets (Greenpeace, 2009; Rich, 2013). Brazilian government financing from BNDES has also been important in advancing the modern livestock industry in Amazonia.

Population growth

Increasing population has a significant effect on Brazil’s Amazonian deforestation (Laurance et al., 2002). However, interpreting the relationship is more complicated than might be thought. Studies that look at political units such as countries, states or municipalities, or arbitrary geographic units such as grid cells, will find results on population change and deforestation rate that go in both directions and will conclude that there is no relationship between these two variables. The first step to make sense of such data is removing the urban population from the analysis. While urban population has an effect, it is very distinct from the effect of direct deforestation actors. Then, there must be a breakdown by the different rural actors who are present before and after the land-use transformation under study, such as deforestation in a given period. These data do not exist for Brazil. The only solution is to obtain detailed information from case studies in specific locations. It is important that the locations chosen be ‘typical’ of large areas of deforestation. The places being converted to cattle pastures in Brazilian Amazonia represent an obvious priority.

Two key questions affecting the relationship of population and deforestation are: (1) who the actors are, such as ranchers versus small farmers, and (2) what population and land use is being replaced. If the situation is one of small farmers replacing “unoccupied” forest, then a greater population (of small farmers) translates into more deforestation. If it is ranchers replacing “unoccupied” forest, then the same relationship applies, although the number of people will be lower and the amount of deforestation per capita will be much greater. If the situation is one of ranchers replacing small farmers, then the human population will decrease and the rate of deforestation per capita will increase, resulting in a negative relationship between population change and deforestation rate.

One theory regarding population is that increasing rural-urban migration will result in abandonment of large areas that are currently used for agriculture and ranching, leading to establishment of secondary forests and recovery of biodiversity (Wright and Muller-Landau, 2006). Unfortunately, other than existence of significant rural-urban migration (Parry et al., 2010), this theory bears little resemblance to events in Amazonia (Fearnside, 2008c). Those who migrate to cities are usually riverside inhabitants who do very little deforestation. Were larger actors to give up their operations and move to cities, their land would be sold to others who would continue to use the cleared areas (sometimes with intervals under secondary succession). Cattle pasture requires very little labor once established, and a small population can occupy a very large area.

Household dynamics

Household processes among small farmers result in deforestation independent of profit-seeking motives that could be used as levers by incentive programs in order to change clearing behavior. These include household demographic changes and the economic circumstances of each family (Caldas et al., 2007). At the stage in the household life cycle when labor capability is at a maximum as well as demand for consumption to support dependents, deforestation advances at maximum speed and is unlikely to be influenced by outside policy interventions. Minimization of risks takes precedence over maximizing profits (Walker et al., 2002).

Extreme degradation

Forest can be converted to non-forest (i.e., deforested) by extreme degradation rather than by clearcutting. Degradation is becoming increasingly prevalent in Brazilian Amazonia and has not been affected by the forces that shifted deforestation rates to a lower plateau after 2004 (Souza, Jr. et al., 2013). Logging is a major factor that, even prior to the deforestation "slowdown," affected a larger area each year than the annual clearcut (Asner et al., 2005). Logging has increased since the slowdown began, rather than decreasing in parallel with deforestation (e.g., Silvestrini et al., 2011), making the post-slowdown area subjected to logging each year far greater than what is deforested outright. Logging makes forests more susceptible to entry of fire because it leaves slash and unintentionally killed trees in the forest to serve as fuel, as well as opening canopy gaps that allow entry of sunlight and wind, thus hastening the drying of the fuel bed (Cochrane et al., 1999; Nepstad et al., 1999; Uhl and Buschbacher, 1985). This sets in motion a positive-feedback process that successively degrades the forest by repeated entry of fire (Barlow and Peres, 2006; Nepstad et al., 2001). Droughts are major factors in facilitating Amazonian forest fires, with or without logging (Alencar et al., 2006; Aragão and Shimabukuro, 2010; Barbosa and Fearnside, 1999; Barlow and Peres, 2008; Barlow et al., 2003; Berenguer et al., 2014; Vasconcelos et al., 2013). Droughts also degrade forest by killing trees for lack of water, even in the absence of fire (Lewis et al., 2011; Nepstad et al., 2007; Phillips et al., 2009). Severe droughts are becoming more frequent in Amazonia for various reasons (Marengo and Espinoza, 2016), and projections of climate change indicate the likelihood of substantial future increase in these events (e.g., Malhi et al., 2008). Loss of biodiversity caused by anthropogenic disturbances may even double the losses caused by the deforestation itself, as shown by study in Pará finding median losses from perturbation larger than those from deforestation in three of the five areas of endemism in this state (Barlow et al., 2016). In addition to degradation from logging and fire, hunting threatens wildlife (Antunes et al., 2016) and removes animals essential for the reproduction and dispersal of trees (Peres et al., 2016).

The post-slowdown deforestation surge

Following the 27,772-km^2/year peak of deforestation in 2004, the rates fell by 84% to 4571 km^2/year in 2012. This engendered a dangerous illusion in Brasília that deforestation was under control, and that the government could therefore build roads, dams and other infrastructure without putting the forest at risk. Unfortunately, this was never the case. Deforestation rates have trended upwards since 2012 and jumped by 29% in 2016. The underlying forces behind deforestation have increased each year, with ever more population, investment and roads that give deforesters access to the forest.

More international markets were opening for Brazilian beef during this period, and exports were expanding. The reversal of the deforestation decline in 2012 coincided with the enactment of a major weakening of Brazil's "Forest Code," reducing restrictions for clearing near rivers and on steep hillsides and pardoning vast areas of illegal clearing done by 2008, with significant environmental and social consequences (Metzger et al., 2010; Soares-Filho et al., 2014). Most importantly, this demonstrated the extraordinary influence of the "ruralist" block (representatives of large landholders) and created an anticipation of future "amnesties."

The 1965 Forest Code (Law 4771/1965), a package of regulations governing deforestation, was replaced by Law 12,651/2012. In 2011 the initial vote in the House of Deputies, where representation is proportional to population, approved the revision by a ratio of seven to one. Since 85% of Brazil's population is urban, the vast majority of the electorate has no financial stake in being allowed to deforest more, especially in risk-prone locations. Opinion polls showed 80% of Brazil's population opposing any change in the Forest Code (Lopes, 2011). The power of money from soy and other agribusiness interests is believed to be the most logical explanation for the outcome (Fearnside and Figueiredo, 2016).

The most noteworthy at the time of the deforestation surge in 2016 was the political uncertainty during and after the impeachment of President Dilma Rousseff, who was forced to step aside when her trial began in March 2016, culminating in her formal impeachment in August 2016. The uncertainty in 2016 offered an opportunity for rapid advancement of legislative initiatives to remove environmental restrictions, and this continued following the formal transfer of presidential powers (Fearnside, 2016c). Other factors may have contributed. The value of the Brazilian real relative to the US dollar decreased by 12% from January to May 2016 (the period when decisions regarding deforestation are usually made), thus increasing the attractiveness of exporting soy and beef. Beef prices rose by 5% and soy prices rose by 12.5%. The May 2016 soy price was 18% above the May average for the preceding five years. These economic factors would have contributed to the 2016 surge, but the magnitude of the surge suggests that it also had roots in the spectacular rise in political power of the ruralists, which had begun well before the end of the previous presidential administration (Fearnside, 2017a).

Similarities and differences in the changes in deforestation rates among the nine states in Legal Amazonia are revealing. Deforestation rates increased in all states except Amapá and Mato Grosso. Amapá is insignificant, since this state only accounted for 0.3% of the total deforestation in 2016. Deforestation in Mato Grosso in 2016 was 1508 km^2, although this was 5.8% less than in the preceding year. Mato Grosso has a substantial influence from soybeans, whereas in the other states the vast majority of clearing is for pasture. The importance of Mato Grosso relative to other Amazonian states has been decreasing, from 43.1% of the total deforestation in 2004 to 18.9% in 2016, reflecting the dwindling areas of remaining forest in places that are topographically favorable for mechanized agriculture. Other factors leading to decreased clearing in Mato Grosso include the predominance of large properties in this state; these properties are more sensitive to repression measures than are smaller ones (Godar et al., 2014). The distribution of the 2016 surge among Amazonian states suggests a continuation of trends to increased prominence of ranching relative to direct deforestation for soybeans, and of greater importance of smaller properties relative to larger ones.

How can deforestation be controlled?

Repression

Inspection and punishment of illegal deforestation is an important part of any effort to control the process because lack of this form of action fosters an assumption of impunity, with far-reaching consequences. Monitoring capabilities are important to these efforts, and the advent of the DETER program in 2004 provided an essential tool to allow reaction within a meaningful time period (Assunção et al., 2013). Since 2003 Brazil's command-and-control program is under the Plan of Action for Prevention and Control of Deforestation in Legal Amazonia (PPCDAm) (Brazil, MMA, 2013). The program has had measurable effects (Arima et al., 2014).

Amazonian deforestation can be controlled, but the unfounded notion that it is under control and so new roads, dams and other infrastructure projects can be built without increasing deforestation is very dangerous. The official government interpretation that the 2005-2012 decline proves that deforestation is under control has been repeated countless times. However, falling commodity prices (rather than governance measures) account for nearly all of the decrease in deforestation rates between 2005 and 2007, which represents 70% of the total through 2012 when the downward trend ended. Deforestation rates did not continue to decline after 2012, despite frequent official statements implying that the decline continued.

The effect of the repression program since 2008 rests on a fragile foundation: the 2008 Central Bank resolution linking government bank loans to an absence of pending fines (Fearnside, 2015a). This is because the "ruralist" block has enormous influence in the national legislature, and revocation of this Central Bank resolution is one of its priorities. The effectiveness of the repression program could literally be removed at the stroke of a pen.

An example of the potential for repression of deforestation to have an effect on clearing rates is provided by a state government program from 1999 to 2001 in Mato Grosso (Fearnside, 2003a). While deforestation was increasing in Amazonia as a whole, the trends turned from increases to decreases in Mato Grosso in municipalities that had significant amounts forest still available for clearing (deforestation will tend to zero independent of any repression program in municipalities with little left to clear). However, after the election of Brazil's largest soy entrepreneur as governor in 2002, the program was gutted and entered into a phase of "institutional subversion" (Rajão et al., 2012).

It is important that direct deforestation control measures, such as fining property owners who clear without required licensing and restricting credit in municipalities (counties) that are "blacklisted" for illegal deforestation, can have a significant effect (e.g., Tasker and Arima, 2016). The Brazilian foreign ministry's long opposition to any form of international payment for avoiding deforestation was based on the belief of key individuals that controlling deforestation was impossible (Fearnside, 2012a). Indeed the succession of "packages" of control measures implemented after each rise in clearing rates seemed to have no effect. Brazil changed its position in 2007, after the "slowdown" in deforestation was well underway.

Remove or redirect subsidies

Subsides take many forms besides the notorious fiscal incentives that massively subsidized large cattle ranches in the 1970s and 1980s. Low interest loans are provided for actors of various sizes, including small farmers. A large subsidy that often goes unrecognized results from periodic "amnesties," forgiving debts for farmers both large and small whose crops have failed due to weather events or other general misfortunes, thus transferring the risk of these agricultural activities to the taxpayers (e.g., Fearnside, 2001a). Of course a wide array of other government expenditures provides transport infrastructure and other services in remote locations, generally with only a minimal return to the government in the form of taxes. In the case of small farmers, the fact that a substantial fraction of the economically disadvantaged portions of Brazil's rural population depends on government "*bolsas*" (stipends), such as the "family stipend" (*bolsa família*), and on rural retirement benefits for elderly family members, represents a substantial subsidy that maintains families in agricultural activities even when they are unprofitable in their own right. Although closely tied to electoral politics, these income-redistribution programs are based on poverty-reduction objectives that apply to both rural and urban residents throughout the country as a matter of social justice. Government stipends maintain important deforestation actors, such as "*sem terras*" (organized landless workers). These actors have a key role in settlement establishment and deforestation (Simmons et al., 2010). Government settlement projects are heavily subsidized (Peres and Schneider, 2012). Even at the low levels of deforestation of small farmers, rural residents emit much more greenhouse gases than do urban residents, and the impact of larger actors is very much greater (Fearnside, 2001c). Preventing rural-urban migration is seen as socially desirable, both by rural people who want to stay where they are and by urban residents who fear the social impact of burgeoning cities. However, municipality-level data in Amazonia indicate a positive effect of urbanization on wellbeing as measured by the human development index (Caviglia-Harris et al., 2016). The questions of how much rural subsidy is appropriate and of what types are extremely delicate ones.

Remove ulterior motives

Land speculation is a motive for deforestation that has essentially no benefit for the country and that leads to substantial environmental damage. It needs to be stopped by government actions such as taxes and fines.

The present system of land-tenure establishment, which is based on deforestation, must end. Brazil has yet to make the transition from the centuries-old custom of "regularization" of *de facto* possession of illegal land claims to one where the population assumes as a matter of course that illegal occupation of land will not eventually result in a land title. A significant setback occurred in 2009, with Provisional Measure (MP) 158 (Law No. 11,952) creating the "*terra legal*" ("legal land") program that legalizes claims up to 1500 ha (which can hardly be considered a small farm). Large illegal claims are often subdivided among the various members of an extended family to gain legal title within the limits of the program. The amount of land potentially to be legalized totals 67 million ha, or half the size of the state of Pará (see

Fearnside, 2013a). Most pernicious, the program leads to the logical assumption of present and future *grileiros* and squatters throughout the region that their claims will eventually be legalized by subsequent regularization programs. Achieving the goal of Amazonia becoming a landscape with land tenure defined and secure is essential for many reasons, including encouraging more sustainable behavior by landholders and assuring the rights of exclusion that must underlie any program for payment for environmental services, but a path to reaching this goal without provoking the perverse assumption of an eternally moving "line in the sand" has yet to be found. The ‘‘closing of the frontier’’ in 1890 in the western United States (Turner, 1893) has yet to have its parallel in Brazilian Amazonia, and a way must be found to achieve this by means other than simply running out of land (Fearnside and Graça, 2006).

Land-tenure establishment is handled by the National Institute for Colonization and Agrarian Reform (INCRA), which in recent years has acted almost entirely reactively, resettling squatters and "*sem terras*" (members of organized landless movements) in official settlement areas (e.g., Fearnside, 2001a). Settlements represented 13.5% of all deforestation up to 2011 in 1911 settlements included in a study by Schneider and Peres (2015). In a study by Yanai et al. (2017) covering 3325 settlements, the settlements accounted for of 21% of the deforestation up to 2013. This process has no natural stopping point, since the number of landless farmers in the country exceeds the capacity of the entire Amazon region if distributed in settlement areas (Fearnside, 1985). Caldas et al. (2010) expressed the implications most eloquently: "… it is time to recognize past mistakes and adapt the land policy to the new reality in the Amazon that takes into consideration the environmental problems that current laws are causing. If we do not act now, the future of the poor in the region will not change; and the same cyclic processes of land occupation and degradation will occur until no forest will remain to support life in the region."

Soy moratorium

On 24 July 2006, three months after the Greenpeace (2006) "Eating Up the Amazon" report, Cargill and other major soy exporters of were convinced to sign a "soy moratorium" committing them not buy soy grown in the Amazon on land deforested after 2006 (a cutoff relaxed to 2008 in 2013). The moratorium was successively renewed, and in 2016 it was made permanent. It has had a measurable effect in reducing new forest clearing for soy (Adario, 2016; Gibbs et al., 2015). However, the soy moratorium cannot be credited with the overall decline in deforestation rates in aAmazonia (the "slowdown"), as has sometimes been implied. The departure of overall deforestation rates from what is explained by commodity prices only began in 2008, not in 2006. The direct conversions affected by the moratorium are only a portion of the impact of soy. The moratorium does not include the *cerrado*, where soy expansion continues unfettered. The displaced deforestation from pastures converted to soy (either in the *cerrado* or in the Amazon forest) causes increasing clearing of Amazon forest for pasture not only by means of the "invisible hand" of the economy, with ranchers responding to price signals, but also directly by migration of the ranchers themselves to rainforest areas. When an area becomes more profitable to use as soy than as pasture, for example in Mato Grosso, ranchers do not switch to become soy planters. Instead the ranchers (who represent a distinct cultural group in Amazonia: Hoelle, 2015) will sell their land to a buyer with a soy-planting background (often arriving from non-

Amazonian states such as Rio Grande do Sul), and the rancher will use the proceeds of the sale to buy a much larger area of cheap land in Pará to establish a new ranch.

Another limitation is that significant markets exist outside of the exporting companies that participate in the soy moratorium. Since 2013 the main destination for Brazilian soy has been China, where purchases are little influenced by environmental impacts in other parts of the world. There are also domestic markets, including the market for soy oil in Brazil’s biodiesel program (Fearnside, 2009a).

Cattle agreement

In June 2009 Greenpeace released a report entitled “Slaughtering the Amazon” (Greenpeace, 2009), and four months later the “cattle agreement” was signed by major slaughterhouses: JBS (Friboi), Bertin, Minerva and Marfrig. There were actually two agreements: in July 2009 a “term of adjustment of conduct” (TAC) was signed, and in October 2009 a “zero deforestation agreement” (G4). The agreements have been found to have had an effect in reducing deforestation despite problems with “laundering” cattle (Gibbs et al., 2016). “Laundering” cattle occurs when a non-participating ranch moves its cattle to a participating ranch, from which the cattle are sold to one of the signatory slaughterhouses. Improbably high cattle production per hectare of pasture is a sign of ranches acting as intermediaries. This is a “common and accepted practice” and is not prohibited by the cattle agreement (Gibbs et al., 2016, p. 8). The monitoring system only tracks properties, not individual cows (which would need to be identified by ear tags, for example). The cattle agreement is most relevant for beef being exported to other countries, although the adherence of Brazil’s largest supermarket chain (Pão de Açucar) in 2016 is an important milestone in the domestic market (Charoux, 2016). Earlier, 35 Brazilian supermarket chains had discontinued beef purchases from offending slaughterhouses, and similar commitments had been made by some leather buyers (Arima et al., 2014, p. 467). As with soybeans, the fact that China is the major destination for beef undermines any possibility of pressure from consumers there affecting adherence.

An example of the problems with the cattle agreement is provided by JBS (João Batista Sobrinho), which, including the fusion of Friboi and Bertin on 27 October 2009, is the world’s largest processer of cattle products. Shortly before the cattle agreement, Greenpeace reported a large number of cattle purchases by Bertin from ranches that had been embargoed (Greenpeace, 2009). After the cattle agreement, the federal prosecutor’s office found a similar pattern of violation by JBS (Greenpeace, 2011); in 2012 JBS recommitted to the cattle agreement.

Protected areas

Creating and defending protected areas is an important component of any strategy to contain deforestation. “Protected areas” in Brazil include both “indigenous lands,” which are under the National Foundation of the Indian (FUNAI), and “conservation units,” which are under the Ministry of the Environment (MMA) if federal, or under equivalent state-level agencies if created by the state governments. Since advent of the National System of Conservation Units (SNUC) in 2000, conservation units are classified into categories as “integral protection” and “sustainable use” (Brazil, MMA, 2015). The first category is for various kinds of parks and reserves that exclude human residents, while the second category includes forests for timber management, "extractive reserves" for rubber tappers and other collectors of non-timber forest products, and "sustainable development reserves" with riverside dwellers and other traditional residents. Overlap sometimes occurs between indigenous territories and conservation units, leading to conflicts between government agencies and between the resident populations and the agencies. A case in point is a national forest (for timber management) that was created on the Tapajós River without considering the Munduruku indigenous residents, who are struggling to have the area declared as an indigenous land (Fearnside, 2015c).

Protected areas have a significant effect on preventing deforestation (Ferreira et al., 2005; Ricketts et al., 2010; Veríssimo et al., 2011; Walker et al., 2009). Location with respect to the arc of deforestation is important in this effect (Nolte et al., 2013), and the defensibility of the sites chosen should be an essential criterion in selecting areas (Peres and Terborgh, 1995). The category of the protected area, together with its administration at the state or federal level, affects reserve effectiveness in preventing deforestation (Vitel et al., 2009). Locational effects and political pressures can obscure these differences (Pfaff et al., 2015). Indigenous lands have the best record in excluding deforestation (Nepstad et al., 2006). In the case of the Amazon Protected Areas Program (ARPA), which created and fortified a series of conservation units beginning in 2002 to meet an objective of protecting 600,000 km^2 of Amazonian forest, the reserves have been shown to imply a reduction in deforestation (Nepstad et al., 2006; Soares-Filho et al., 2010).

Sites can be selected to create barriers in order to block the advance of deforestation. For example, in 2004 a 30,000 km^2 "mosaic" of protected areas was created by the state of Amazonas in order to block entry of deforestation from Mato Grosso. Another example is the "armored zone" ("*zona blindada*") along the proposed BR-319 (Manaus-Porto Velho) Highway. This is supposed to act in a way similar to the armor on a tank to prevent deforestation from perforating the barrier of reserves paralleling the highway. While the reserves themselves may resist deforestation, planned side roads cutting through them would simply take deforesters to unprotected areas beyond the line of "armor" (Fearnside et al., 2009). Reserves are needed in the large area that would be exposed to this migration to the west of the Purus River (Graça et al., 2014). Similarly, new reserves are needed in Roraima in areas that would receive migrants from the arc of deforestation as a result of opening the BR-319 (Barni et al., 2015).

Creation of protected areas is, in many cases, a question of now or never. Once population moves into and claims an area, it becomes politically impossible to create protected areas. One of the choices that must always be made is whether to prioritize creation of areas in the integral-protection versus the sustainable-use category. Because it is much easier to obtain political and local support for creating sustainable-use areas, these often best serve the objective of obtaining large areas of protected forest within a time frame that avoids loss of the option to create a protected area at all (Fearnside, 2011). Depending on circumstances, creating integral-protection protected areas can also cause social injustices. However, it is also possible to go too far in the direction of reduced protection in order to garner support. The SNUC includes as one of its protected area types the "environmental protection area" (APA). This type, in practice, has almost no restrictions on use, even including urban areas. Creating APAs results in maps with large areas colored in green but does little to actually protect the forest. Instead it offers an easy escape for interest groups intent on averting the restrictions of a protected area, since they can always demand that a proposed protected area be an APA rather than one of the types with more real protection (e.g., Câmara, 2000; Pádua, 2011).

Protected areas are not as protected as is often assumed (Table 1). Deforestation takes place within these areas, including indigenous areas (e.g., Fearnside, 2005b; Nogueira et al., 2017). There is also a tendency for the government to downgrade or downsize existing reserves, or even revoke them completely (Bernard et al., 2014; de Marques and Peres, 2015). An example is provided by protected areas that would be affected by planned dams in the Tapajós River basin (Fearnside, 2015d). Another is a proposed law by legislators from the state of Amazonas to revoke protection from 10,000 km^2 of the "mosaic" of conservation units in the deforestation hotspot in the southern part of the state (ISA, 2017a,b).

[Table 1 here]

Since both human and financial resources are always very limited for protected areas, one of the perennial dilemmas is whether to give priority to creation of new areas or to invest in staffing and defending existing areas. In the current situation in Amazonia, the better option is to maximize creation of new areas, even if they are only "paper parks" with only a token government presence. This is needed to obtain larger areas before opportunities are foreclosed. Even "paper parks" have a significant effect in inhibiting deforestation because their legal status makes it much less likely that potential invaders will be successful in gaining a future land title, as compared to their invading forest in an area that is not legally protected.

Depending on whether a protected area is near or far from the deforestation frontier, its effect on deforestation will be either immediate or delayed. The priority for reserve creation will depend on the objectives that motivate the decision. It is often said that those primarily concerned with maintaining biodiversity and those primarily concerned with avoiding climate change share a natural alliance in that protecting tropical forest achieves both goals. However, this identity of interests can break down when choices must be made. If the priority is protecting biodiversity, the objective is likely to be seen in terms of a measure such as the number of species that will be maintained over a long time, theoretically permanently, making creation of large inexpensive reserves far from the frontier the best choice (Fearnside, 2003b; Fearnside and Ferraz, 1995). In terms of climate change, the priority is likely to be measured in terms of reduced emissions over a short time period, making reserves nearer the frontier the best choice. The financial costs and other obstacles at each distance from the frontier will determine the ideal location, which is likely not to be at either extreme in terms of distance from the frontier. In practice, the type of protected area is associated with distance from the frontier, with sustainable-use areas more likely to be closer to the frontier than integral-protection areas, giving the former a greater short-term effect in avoiding deforestation (Pfaff et al., 2014).

The 2015 Paris accords have fundamentally changed the criteria for choices based on climate benefits: the objective is expressed as keeping mean global temperature from rising above a value "well below" the benchmark of 2°C over the preindustrial average, whereas before the objective was expressed in terms of Article 2 of the Climate Convention, which specifies "stabilization" of greenhouse-gas concentrations at a level to avoid "dangerous interference with the global climate system." Because stabilization can take many years, even centuries, the time scale is entirely different. Assuming that diplomats and decision-makers are serious about complying with the Paris accords, what counts is what happens in the next 20 years. In terms of protected areas, relevant benefits will be from those near the frontier. The fact that many protected areas are far from the frontier means that their climatic benefit is decreased by the Paris accord as compared to other forms of mitigation with quicker returns. Another factor decreasing the importance of protected areas is the effect of "leakage," or the displacement of impacts, in this case deforestation, to locations beyond the boundaries of a mitigation project. Leakage from reserve creation is of two types: "in-to-out" leakage where deforesters leave the area to continue clearing forest elsewhere, and "out-to-out" leakage, where potential squatters and *grileiros* chose areas to invade elsewhere in the forest because the reserve decreases their chances of gaining title. Deforestation that has been displaced by leakage will continue until available forest is exhausted in the landscape outside of the reserve, after which the climatic benefit that was lost through leakage will be recovered assuming that the reserve is effective in excluding deforesters (Fearnside, 2009b). The impact of leakage on decreasing the climatic value of a reserve increases with increasing value attributed to time, as through a discount rate. Reserves as a mitigation option therefore decrease in value with the Paris accords. By contrast, other options substantially increase in value, such as refraining from building hydroelectric dams, which are an energy source that has very high initial emissions and that emits methane, a short-lived gas with high impact while it remains in the atmosphere (Fearnside, 2015e, 2017b).

Contain infrastructure projects

An essential part of any plan to contain deforestation in Amazonia is the limitation of new infrastructure projects such as roads and dams. This is often unmentioned in plans for limiting deforestation, such as Brazil's PPCDAm (Brazil, MMA, 2013) and National Plan for Climate Change (Brazil, CIMC, 2008). Vast plans for new infrastructure imply more, not less, deforestation -- one cannot expect deforestation to decrease if new projects go ahead regardless of impacts. The pattern of assuming that unrealistic governance scenarios will play out in practice is a formula for environmental disaster (e.g., Fearnside, 2007; Fearnside and Graça, 2009).

Decisions on new infrastructure represent a key element that is in the control of the government. The decision to build a road, for example, is made by a handful of government authorities, as contrasted with the individual decisions of the thousands of actors who will determine the deforestation consequences once the road is built. The decision-making process for infrastructure projects is therefore critical. Decision-making is distinct from licensing, although licensing is also important. At present, environmental licensing in Brazil is largely limited to suggesting minor changes in project design or compensation measures, not the existence or not of the infrastructure project in question. This author has long argued the need to reform this system such that environmental and social costs and benefits are transparently assessed and democratically debated before the actual decision to build a project is made (e.g., Fearnside, 2014b). Among the changes needed to have a more rational decision-making system is removal of the underlying causes of the current bias for large expensive projects regardless of impacts. This requires changes in the regulation of political campaign contributions (Fearnside, 2016b). It also requires revocation of the "security-suspension" laws stemming from Brazil's military dictatorship period that allow any judicial decision to be overturned in the interests of the "public economy" (Fearnside, 2015d). Despite its problems, Brazil's environmental licensing system is far better than the practice before this system was implemented in 1986; however, environmental licensing faces a series of immediate threats that could result in its being effectively abolished by the National Congress (Fearnside, 2016c; Ferreira et al., 2016).

Abandon myths that divert efforts to contain deforestation

A variety of myths tend to divert efforts to control forest loss in directions that fail to achieve this objective or that are counterproductive. One is the idea that "sustainable logging," or "sustainable forest management," will motivate long-term maintenance of the forest. It is simply assumed that what is called "sustainable forest management" is really sustainable (e.g., Brazil, MMA and MCTI, 2014). However, fundamental contradictions result in the behavior of the managers not being sustainable, no matter what their discourse or promises may be (Fearnside, 1989b, 2003b). This is because trees in tropical forests grow at rates that are limited by biology and have no relation to the rates at which money can be made in alternative investments. In practice, the trees are in competition with a wide range of other possible investments (including first-cycle forest-management projects elsewhere), and it is more profitable for the manager to exploit the potentially renewable resource as quickly as possible and invest the proceeds in an option with a faster return elsewhere (e.g., Clark, 1973, 1976). The first cycle, which is what is in course in virtually all forest-management projects in Brazilian Amazonia, is inherently more profitable than subsequent cycles because the large forest trees that have been growing for centuries at no cost to the manger are there for the harvesting, whereas the situation will change in a future equilibrium when the manager can only harvest what grows while the management area is being defended and maintained. In addition, based on the population biology of the trees, the current rules for management projects are unlikely to maintain forest indefinitely even if followed as theoretically envisioned (Kageyama, 2000). Furthermore, the theoretical 30-year cycle in *terra firme* (unflooded upland) forests has been subverted by inclusion of loopholes that imply a virtual zero probability of continuation after the first cycle. An example is provided by a project in Acre managing 12,000 ha (Fearnside, 2015f). Instead of dividing the area into 30 plots, one to be harvested in each year of the cycle, the manager was allowed to harvest the entire area in only six years. Theoretically the land would sit unused for 24 years before beginning the second cycle. The chances of this happening are obviously slim, and they are even less given that the area was later sold for a settlement project. The chances are even less in the case of small management projects (up to 100 ha under management) in the state of Amazonas, which allow the entire area to be harvested in the first year, theoretically followed by a 29-year wait for another cycle.

Another myth that diverts efforts to contain deforestation is the notion that intensification of agriculture and ranching will cause actors to stop deforesting. There are good reasons for intensification, but land sparing is not one of them. The subsidies and marketing advantages that can be garnered from this discourse represent attractions for endorsing this path, but it goes against economic logic. The idea that people's ambitions are limited by a "full-stomach" effect, where one stops expanding production once minimal requirements are met, does not apply to individuals who are integrated into modern economies, as are almost all actors in Amazonian deforestation. Land sparing through intensification has been proposed by a number of authors (Sánchez et al., 1982; Strassburg et al., 2014; Zarin et al., 2016), but the prospects of this strategy having the desired environmental result are poor (Fearnside, 1987c). Unfortunately, there is no evidence that the response to a productivity increase would be restoration of forest. If pasture were to produce more, then the ranchers would simply export this excess – not keep the total production of their properties constant and reduce their areas of pasture. In fact, since the more highly productive pastures would presumably be more profitable than the present ones, the tendency would be to do just the opposite – expand the area of pasture by clearing more (Fearnside, 2002; Kaimowitz and Angelsen, 2008). Pasture area in Brazil is not restrained either by a limited desire of ranchers to make more money or by global markets for beef.

Another diversion of efforts to contain Amazonian deforestation is investment in subsidizing what as known in Brazil as "recuperation of degraded areas," i.e., restoring tree cover in non-productive areas that have already been deforested. This should not be a current priority because, under current conditions in Amazonia, it is much more expensive to recuperate a hectare of forest than to avoid a hectare of deforestation, while the benefits in terms of both carbon and biodiversity are much less (Fearnside, 2003b). Severe limits restrict the recuperation of degraded lands through sustainable uses such as agroforestry (Fearnside, 1995). One is the difference in scale between the extent of degraded pastures in Amazonia and the capacity of markets and input sources to support agroforestry. Another is the logic from the viewpoint of a farmer making decisions on agroforestry: if a hectare is planted in a degraded pasture it will produce very little compared to what it would produce if another hectare of forest is cleared and planted.

Provide alternatives

It is not enough to prohibit deforestation and punish violations – alternatives must be offered for supporting the small farmers who sustain themselves by clearing forest, both for subsistence and commercial production. However, there is no need to provide alternatives for investors (Fearnside, 1989c). These larger operators can very well fend for themselves in switching to other types of investment without a need for subsidies with funds intended for environmental purposes.

The current economy of rural Amazonia is almost entirely based on destruction of the forest: selling timber and replacing forest with crops or pasture. Over the past three decades this author has argued for tapping the value of the environmental services of the forest as an alternative basis for the rural economy. While the environmental services such as avoiding global warming, recycling water and maintaining biodiversity are worth much more to human society than the money gained from destroying the forest, institutional mechanisms are lacking to transform these services into a monetary flow and to use this flow to support the rural population without provoking perverse social effects. Some progress has been made towards the goal of obtaining monetary flows through international negotiations under the Climate Convention, but the social side of this mechanism – how money would be used once obtained – is completely unresolved. Payment for environmental services (PES) is viewed as the most direct way of providing conservation incentives and avoiding perverse effects on equity (Börner et al., 2010; Ferraro and Kiss, 2002). Need for land-tenure regularization is an unavoidable prerequisite for PES to function (Wunder et al., 2009), which creates both dangers and new opportunities to induce environmental compliance (Duchelle et al., 2014). In terms of cost effectiveness, command and control is still the cheapest option for reducing deforestation in Brazilian Amazonia, but PES, if directed to small actors, offers a way of reducing or avoiding negative social impacts (Börner et al., 2015).

One cannot simply pay people for doing nothing or distribute money and goods to local communities without creating conflicts and destroying cultures. The recent disastrous case of compensation distributions to indigenous communities affected by the Belo Monte Dam offers a concrete example (e.g., Fearnside, 2017c,d; Heurich, 2013). Subsidizing purchases of non-timber forest products from extractive reserves has been suggested as one possible support mechanism (Fearnside, 1989d). Current discussions of REDD+ (Reducing Emissions from Deforestation and Degradation) involve a series of controversies, including questions of how accounting for carbon benefits is done both at the proposal stage and at later stages for verification and payment (Fearnside, 2012a,b; Vitel et al., 2013; Yanai, et al., 2012). Resolution of the various open questions regarding the quantification and institutional mechanisms for rewarding the environmental services of Amazonian forests, including their carbon benefits, remains a top priority for creating an alternative to deforestation on the scale and within the timeframe that this alternative is needed (Fearnside, 2013b).

Is Brazil's Amazonian deforestation "development"?

The term "development" implies a change with an effect that increases human wellbeing. This is not to be confused with "growth," which refers to an increase in the throughput of matter and energy in a human society and may or may not benefit wellbeing (Daly, 1996). Fortunately, development does not necessarily require growth, which is subject to sever planetary limits (e.g., Steffen et al., 2015). Limiting factors within Amazonia restrain many types of use (Fearnside, 1986a, 1997c; Fearnside and Leal Filho, 2001). In order to be "sustainable development," the productive systems must continue to yield their benefits for a very long time, theoretically indefinitely, the Brundtland Commission's (1987) caveat regarding non-renewable resources notwithstanding. Many of the most common land uses, such as extensive cattle pasture, are unsustainable (e.g., Fearnside, 1983). In the case of cattle pasture, which dominates deforested areas in most of Brazilian Amazonia (Brazil, INPE, 2014b; Fearnside, 1996), the human population supported per unit area of deforestation is minimal: the productivity and financial benefit is small, and even less is a local benefit (Fearnside, 2005a, 2013a, 2016d). The question of who benefits is, of course, critical to defining what is development; this author has argued that the people living in Amazonia must be benefited in order for undertakings in the region to be considered "development" (Fearnside, 1997d).

The sequence of changes in human wellbeing as Amazon deforestation progresses has been characterized as a "boom-and-bust" pattern, where indicators of wellbeing increase in the early phase of deforestation, followed to a decline after the frontier has passed such that the median human-development index (HDI) by municipality (county) returns to a low level similar to that before the deforestation "boom" (Rodrigues et al., 2009). This conclusion was based on a cross-sectional study of statistics from the United Nations Development Programme (UNDP) for 286 municipalities from 1991 to 2000. Celentano et al. (2012) reached a similar conclusion based on 399 municipalities using the same data source (also up to 2000), although these authors also found that HDI could rise again after the crash in a second turning point. The "boom-and-bust" pattern has been contested by Weinhold et al. (2015), who found that the pattern in the cross-sectional data is explained by spatial correlation because the pre-frontier phase is largely represented by poor municipalities with abundant forest in western part of the state of Amazonas while the post-deforestation "bust" is largely represented by heavily deforested areas in the state of Maranhão, where the persistent poverty of northeastern Brazil explains the low HDI rather than the assumed sequence based on municipalities elsewhere. The boom-bust effect disappears without these municipalities in the analysis, and extending the analysis to 2010 also eliminates the effect; Weinhold et al. (2015) also emphasize that none of the five existing longitudinal studies of specific cases shows a "boom-and-bust" pattern. Caviglia-Harris et al. (2016) also analyzed these municipal data for 1991, 2000 and 2010, finding that cross-sectional analysis shows a "boom-and-bust" but that a panel analysis indicates instead a "decoupling" of HDI from deforestation.

An important aspect of municipal-level HDI data is that only the population that is present at the time of each census is considered. There are both winners and losers with the arrival and with the passage of the deforestation frontier. Many of the transformations involve a substitution of the resident population, with one set of residents being either expelled or bought-out by the next. For example, small farmers may be replaced by cattle ranchers, who at a later phase may sell their land to soybean planters from other parts of the country, as has occurred in many areas in Mato Grosso. The municipalities dominated by soybeans in Mato Grosso have some of the highest HDI values in Brazil, but the initial population of these areas is no longer present and is not among the beneficiaries: only the winners remain (Fearnside and Figueiredo, 2016).

Both extensive cattle ranching and soybeans occupy vast areas but support few people as compared to family agriculture. However, in the approximately 3000 settlements that have been established to support small farmers (Yanai et al., 2017) the sequence of developments is not so different in environmental terms. The vast majority of the land that the settlers deforest soon becomes cattle pasture, even if it is first planted a time or two in annual food crops (e.g., Diniz et al., 2013; Fearnside, 1986a, 1989e). Altering this pattern will require changes in the way land tenure is established, eliminating the tradition of legalizing invasions whether by small squatters or large *grileiros* (Fearnside, 1979, 2001a). It will also require an end to using Amazonia as a dumping ground for the country's social problems, such as the presence of millions of poor landless farmers. Brazil's Amazon forest was originally the size of Western Europe, and the 784,666 km^2 that had been deforested by 2016 is the size of France and the United Kingdom combined. This alone is more than sufficient to feed the Brazilian population. Brazil is the world's largest exporter of beef, and one of the top exporters of soybeans, meaning that the production of these products is already far beyond the amount needed to feed the country's population, and every hectare that is now being deforested for pasture and soy is for export. This means that deforestation can be reduced without affecting Brazil's food supply. In other words, "zero deforestation" is possible.

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Figure Legends

Figure 1 – Brazil's Legal Amazon region and locations mentioned in the text.

Figure 2 – Deforestation rates in the originally forested portion of Legal Amazonia (data from Brazil, INPE, 2017a).

Figure 3 -- Deforestation through 2015 in Legal Amazonia and the Amazonia biome (data from Brazil, INPE, 2017a). The "arc of deforestation" is the heavily impacted crescent-shaped area along the eastern and southern edges of the forest (deforestation shown in red).

Table 1. Protected areas in Legal Amazonia[(a)]

Administrative level	Classification	Number of areas	Total area (km^2)	Original vegetation [(b)] in 2014 (km^2)	Percent cleared [(b)] (%)
Federal	Indigenous lands	371	1,120,261	1,103,049	1.54
	Integral protection conservation units	48	324,155	320,947	0.99
	Sustainable use conservation units	100	307,034	298,628	2.74
State	Integral protection conservation units	50	124,292	123,199	0.88
	Environmental Protection Areas (APAs)	35	143,688	116,584	18.86
	Sustainable use conservation units excluding APAs	71	259,131	256,693	9.94
Total		675	2,278,561	2,219,100	2.61

(a) Values summed from Nogueira et al. (2017), which includes area and carbon data for each protected area.
(b)All original vegetation, including non-forest vegetation such as *cerrado* (savanna).

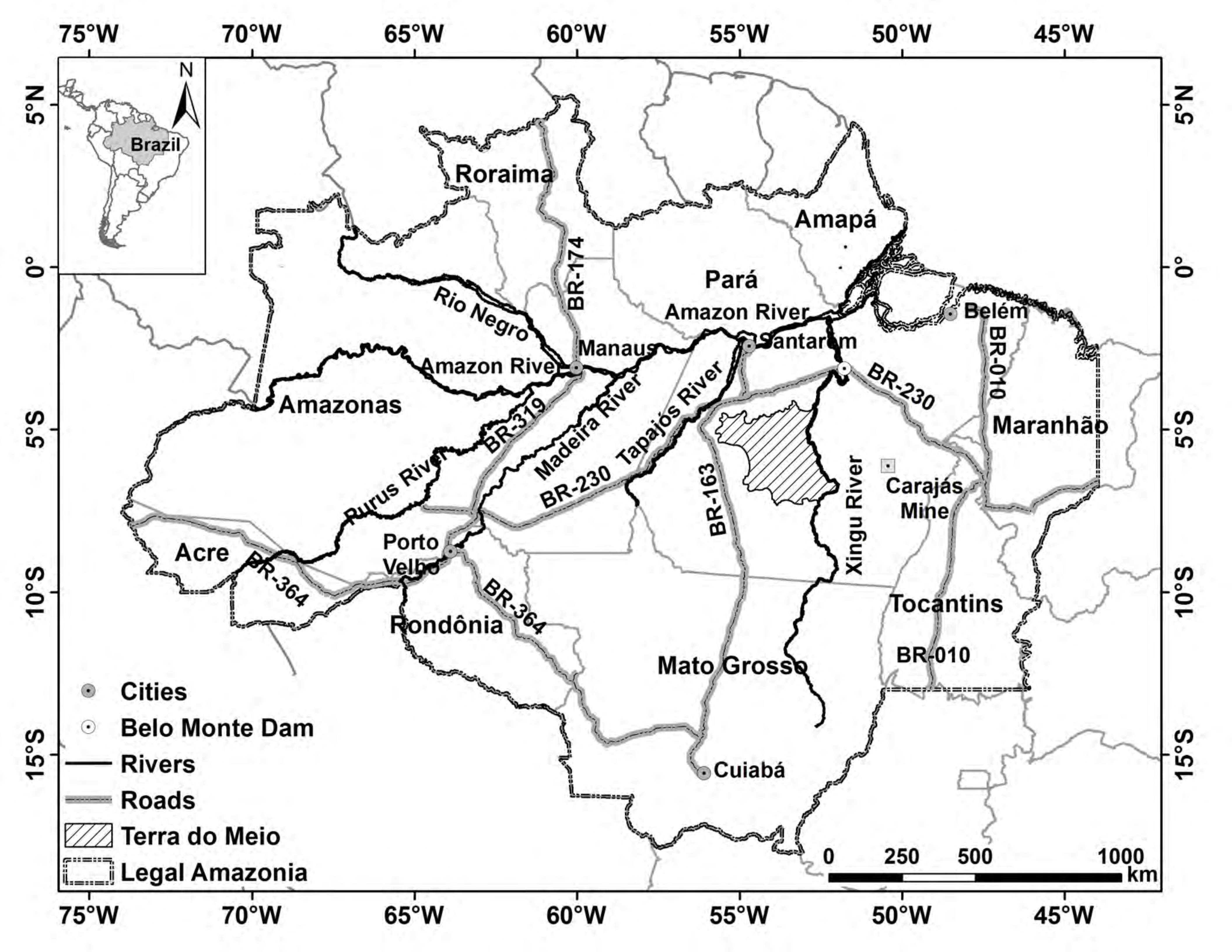
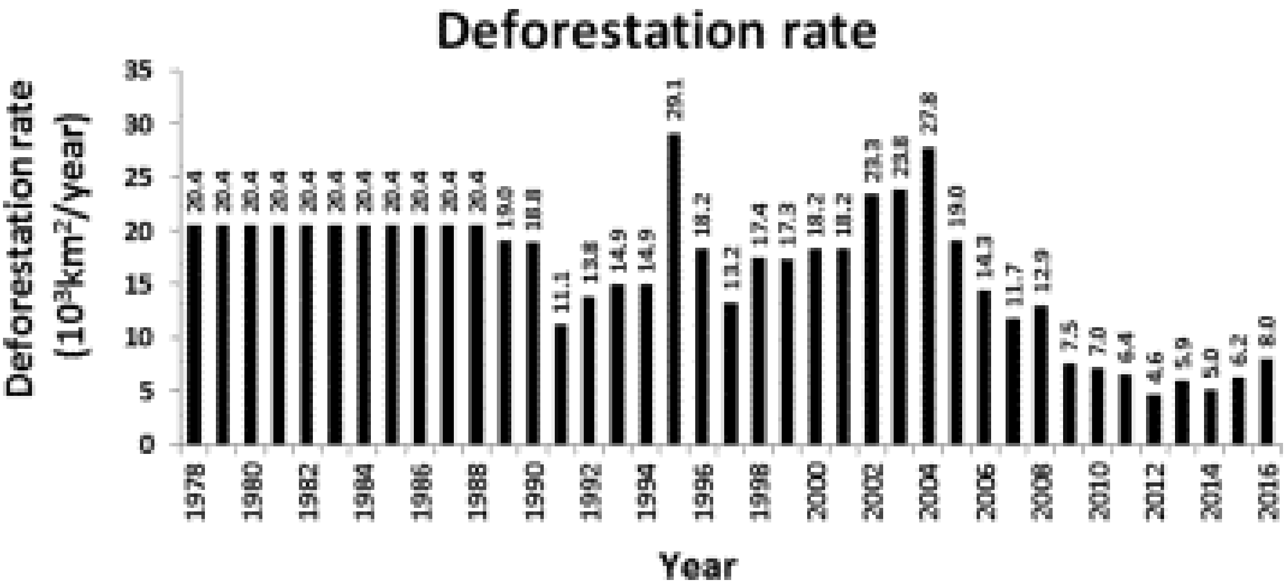
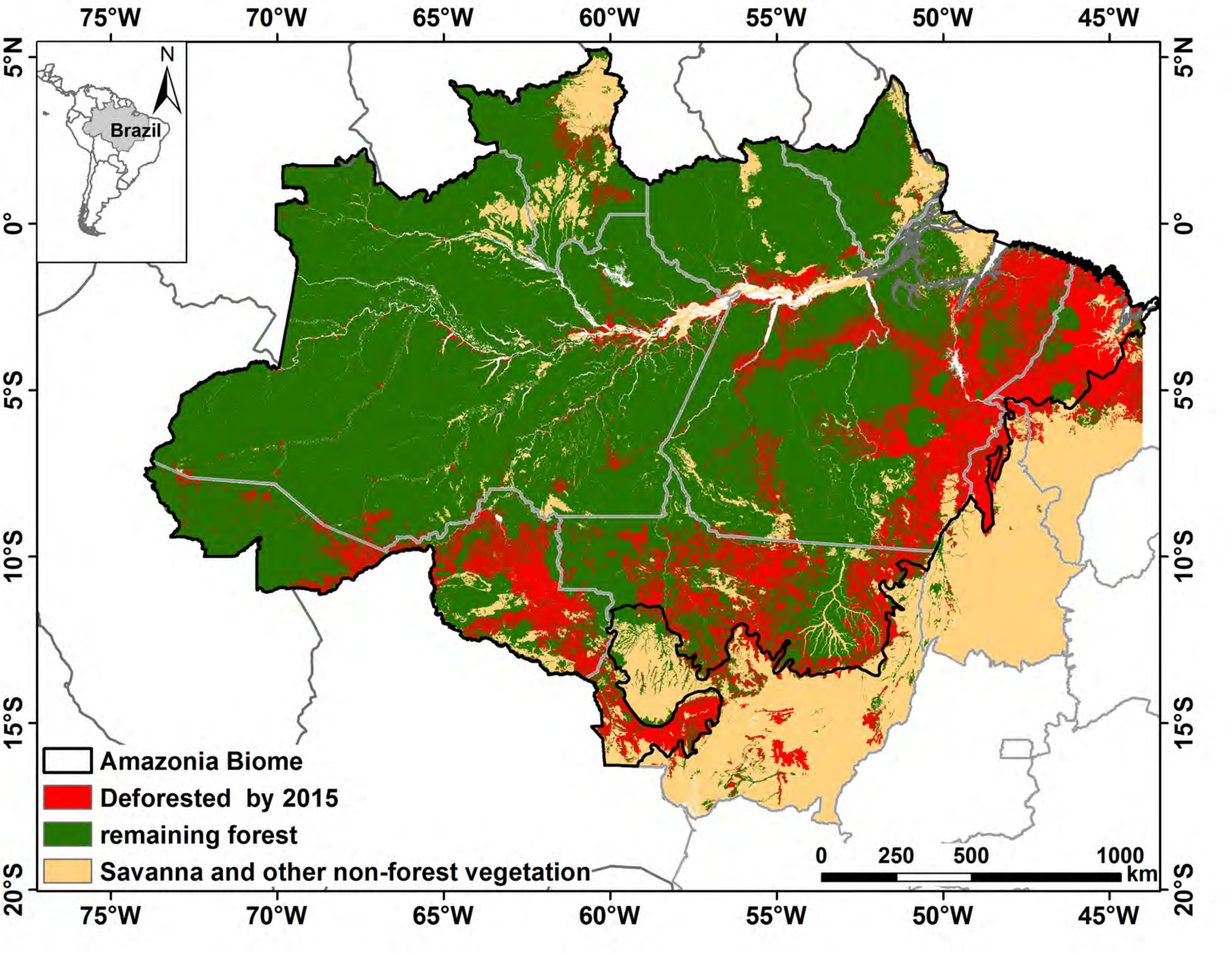

75°W
70°W
65°W
60°W
55°W
50°W
45°W
5°N
0°
5°S
10°S
15°S
N
Brazil
Roraima
Amapá
Pará
Amazonas
Maranhão
Acre
Rondônia
Mato Grosso
Tocantins
BR-174
Rio Negro
Amazon River
Manaus
Santarém
Belém
BR-010
BR-230
BR-319
Madeira River
Tapajós River
Purus River
BR-163
Xingu River
Carajás Mine
Porto Velho
BR-364
Cuiabá
Cities
Belo Monte Dam
Rivers
Roads
Terra do Meio
Legal Amazonia
0
250
500
1000
km

Figure 2




75°W
70°W
65°W
60°W
55°W
50°W
45°W
5°N
0°
5°S
10°S
15°S
20°S
N
Brazil
Amazonia Biome
Deforested by 2015
remaining forest
Savanna and other non-forest vegetation
0
250
500
1000
km