Fearnside, P.M., E.M. Nogueira & A.M. Yanai. 2018. Maintaining Carbon Stocks in Extractive Reserves in Brazilian Amazonia. *Desenvolvimento e Meio Ambiente* (no prelo)

ISSN 1518-952x

Maintaining Carbon Stocks in Extractive Reserves in Brazilian Amazonia

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Contribuição para o número especial da revista *Desenvolvimento e Meio Ambiente* dedicada aos 30 anos da morte de Chico Mendes, editada por Mary Allegretti, Lúcia Helena de Oliveira Cunha e Marianne Schmink.

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ABSTRACT

Extractive reserves in Amazonian forest maintain carbon in stocks out of the atmosphere, thereby avoiding greenhouse-gas emissions that provoke global warming. This and other environmental services, such as recycling water and maintaining biodiversity, provide major rationales for creating these reserves and for according them priority in government programs. The importance of reducing carbon emissions from deforestation has been the principal motivation for the international funding that has been key to creating and supporting extractive reserves, notably in the cases of Germany through the PPG7 program and Norway through the Amazon Fund. Estimating the amount of carbon in these reserves, and the losses that have occurred from deforestation, is essential as an input to decision making affecting current and the potential for future extractive reserves. By 2014, there were 47 federal extractive reserves in Brazil's Legal Amazonia region, of which 45 were in the Amazonian Tropical Forest Biome, and 26 extractive reserves belonged to states, all of which were in the Amazonia Biome. In this study we provide data for each of the 73 extractive reserves in Legal Amazonia, based on biomass information by forest type calculated from RadamBrasil survey data, and deforestation from PRODES monitoring by LANDSAT or equivalent satellites (30-m resolution). The stocks represent carbon in the "pre-modern" biomass, that is, the biomass present in approximately 1970, or before substantial logging activity in the region. The carbon losses reflect deforestation only, not degradation of forest by logging and/or fire. The total area of extractive reserves in Legal Amazonia amounted to126,709 km^2, of which 4301 km^2 (3.4%) had been cleared by 2014. Those extractive reserves had a remaining carbon stock in forest vegetation (above and below-ground) of 2.1 billion tons. The carbon lost to deforestation totaled 74.9 million tons. Avoiding further carbon loss to both deforestation and degradation needs to be a high priority for the extractivists, as it is the value of the forest's environmental services that has the greatest potential for providing a means of support that is increasing in value and is inherently sustainable.

KEYWORDS: Environmental services, Ecosystem services, Biomass, Deforestation, RESEX

RESUMO

Manutenção de Estoques de Carbono em Reservas Extrativistas na Amazônia Brasileira

As reservas extrativistas na Amazônia mantêm carbono fora da atmosfera, evitando assim as emissões de gases de efeito estufa. Este e outros serviços ambientais, tais como a reciclagem de água e a manutenção da biodiversidade, fornecem importantes motivos para a criação dessas reservas e para a sua prioridade nos programas governamentais. A importância de reduzir as emissões de carbono do desmatamento tem sido a principal motivação para o financiamento internacional, que tem sido fundamental para criar e apoiar as reservas extrativistas, especialmente nos casos da Alemanha, através do programa PPG7, e da Noruega, através do Fundo Amazônia. Estimativas da quantidade de carbono e das perdas pelo desmatamento são essenciais como contribuição para a tomada de decisões que afetam as reservas extrativas atuais e as que possam ser criadas no futuro. Até 2014 havia 47 reservas extrativistas federais na Amazônia Legal, das quais 45 estavam no Bioma Amazônia, e havia 26 reservas extrativistas a nível estadual, todas no Bioma Amazônia. Fornecemos dados para cada uma das 73 reservas extrativistas na Amazônia Legal, com base em informações de biomassa por tipo de floresta calculadas a partir dos dados do Projeto RadamBrasil e desmatamento a partir do PRODES (imagens LANDSAT ou equivalente com resolução de 30 m). Os estoques representam o carbono "pré-moderno", isto é, na biomassa presente em aproximadamente 1970, ou seja, antes que substancial atividade madeireira afetasse a região. As perdas de carbono refletem apenas o desmatamento e não a degradação da floresta, como por exploração madeireira e fogo. As reservas extrativistas na Amazônia Legal totalizaram 126,709 km^2, dos quais 4301 km^2 (3,4%) foram desmatadas até 2014. As reservas tinham um estoque de carbono restante na vegetação florestal (acima e abaixo do solo) de 2,1 bilhões de toneladas. O carbono perdido pelo desmatamento totalizou 74,9 milhões de toneladas. Evitar novas perdas, tanto pelo desmatamento quanto pela degradação, precisa ser uma alta prioridade para os extrativistas, pois é o valor dos serviços ambientais da floresta que tem o maior potencial para fornecer um meio de sustentação que está aumentando de valor e que é inerentemente sustentável.

PALAVRAS-CHAVE: Serviços ambientais, Serviços ecossistêmicos, Biomassa, Desmatamento, RESEX

1. Introduction

Amazon forests provide environmental services that are important for the world and especially for Brazil, which stands to lose the most if the forests and their services are destroyed. These services include avoiding global warming, recycling water and maintaining biodiversity (*e.g.,* Fearnside, 1997; 2008). Here we treat the matter of forest carbon stocks, which is the environmental service that is the top priority for the international sources of funding that have created and supported extractive reserves and that can be expected to be key to future support. We present data on deforestation and carbon stocks in each of Brazilian Amazonia's extractive reserves and discuss how land use in these reserves is increasingly shifting from sustainable extraction of rubber and other non-timber forest products to expanding deforestation for cattle pasture. Maintaining forest and carbon stocks in extractive reserves requires reversing this trend. This will require greater social control by communities in the extractive reserves. The potential value of carbon stocks as a rationale for international support of extractive reserves should add to the motives for extractivists to increase their control and effectively limit deforestation in the reserves.

Creating protected areas is one of the most effective measures to ensure the maintenance of environmental services in tropical forests (Adeney *et al.*, 2009; Veríssimo *et al.*, 2011). In the Brazilian Amazon at least 2.2 million km^2 were delimited by 2014 as 718 protected areas, which include Conservation Units, Indigenous Lands and *Quilombola* Territories (Nogueira *et al.*, 2018a). "Conservation Units" encompass various kinds of areas for environmental protection as defined in Brazil's National System of Conservation Units, or "SNUC," and are divided into two groups: "integral protection" and "sustainable use" (Brazil, MMA, 2000). Extractive reserves are in the "sustainable use" category, which provides for the continued presence of the resident population and use of renewable natural resources such as forests in defined low-impact "sustainable" ways. "Indigenous Lands" are areas recognized as traditionally inhabited by indigenous people and are administered by the National Foundation for the Indian (FUNAI) under the Ministry of Justice, rather than by the Ministry of Environment. "*Quilombolas"* are the descendants of escaped African slaves who have maintained traditional communities and who have the same rights as indigenous peoples under Brazil's constitution.

Historically, priority areas for the establishing conservation units have mainly been determined based on ecological criteria such as indicators of biodiversity (*e.g.,* "hotspots"), endemism, rarity, or threats to species (Fearnside, 2015). Areas protected under the presumption of reconciling conservation with the presence of traditional resident populations were generally established based on the demands of social groups, such as indigenous peoples, *ribeirinhos* (riverside dwellers), rubber tappers and other communities dependent on non-timber forest products or on traditional fisheries (*e.g.,* Sustainable Use Conservation Units, Indigenous Lands and *Quilombola* Territories). However, in all of these cases, despite the particularities and different justifications adopted for the creation of each type of protected area, global climate change adds carbon stock as one of the arguments for maintaining and creating protected areas in the Amazon (Nogueira *et al.*, 2018a).

The various actors involved in creating extractive reserves have different motives and priorities. The extractivists themselves clearly have as a top priority securing their claim to the land against the threat of surrounding ranchers. Improving living standards and access to basic education and health services are also important priorities for extractivists. In arguing for extractive reserves, Chico Mendes always made clear that the environmental value of maintain the forest was also important to extractivists. Within the Brazilian government, individuals in the Ministry of Environment involved with extractive reserves vary in their priorities for creating these reserves. Reasons include the role of the reserves as a means of maintaining environmental values such as biodiversity, their role as examples of sustainability and in providing socioeconomic benefits to extractivists. These concerns are shared by other actors, such as environmental non-governmental organizations and academic scholars who study and write about extractive reserves. However, creating and maintaining Brazil's extractive reserves has always been heavily dependent on funding from international sources, and, as compared to other actors, the priorities of these funders are more focused on carbon and the role of Amazon forest in global climate change. The G7 Pilot Program to Conserve the Brazilian Rain Forest (PPG7), which ran from 1992 to 2008, was a critical funder in creating Brazil's current portfolio of extractive reserves, and climate was listed as a "global benefit" of the expected role of the extractive reserves component in reducing deforestation (World Bank, 1994). The World Bank's January 1992 Rain Forest Trust Resolution that established the PPG7 states that ''The overall objective of the pilot program is to…reduce Brazilian rain forests' contribution to global carbon emissions…'' (World Bank, 1992). This was clearly the highest priority for the country that contributed by far the most to the program: Germany. The issue of emissions was especially important in the five years prior to the December 1997 Kyoto Protocol (Fearnside, 2001). Since Norway's donations to the Amazon Fund began in 2008, this source has become an important contributor to creating and maintaining Amazonian protected areas, including extractive reserves (GEF, 2018). Effectiveness in reducing emissions has been a key element in arguing for international support for Brazil's Amazon Region Protected Areas Program (ARPA), including extractive reserves (Soares-Filho, 2016; Soares-Filho *et al*., 2010). For Norway, which donated 93% of the total received by the Amazon Fund by 2018, the criterion on which success is judged is reduction of Brazil's deforestation rate, which translates into reduced carbon emissions. In 2017, as stipulated in the agreement creating the Amazon Fund, the payment was reduced by half because the deforestation rate was on the rise (Rodrigues, 2017). The criterion is limited to the deforestation rate, not other indicators such as the living standards of forest dwellers or the sustainability of the population's economic activities. With Brazil's current draconian cutbacks of government funding for the environment, the Amazon Fund is essentially the only available source for financing measures to contain deforestation (Ortiz, 2018).

The extraction of natural products for the subsistence of traditional resident populations in the Amazon is an activity as old as the existence of traditional populations (Arruda, 1999; Homma, 2003). The various traditional forms of forest product extraction (*e.g.,* collection of plant products, fishing and hunting) have been a centuries-old subsistence practice of traditional forest-dwelling populations. Like the traditional forms of extraction, the current extractive reserves are characterized mainly by low-technology extraction (Drummond, 1996). The definition by law of areas for extractivism does not ensure that other forms of use and production by the resident populations are not used within these areas, nor does it mean that extractive activities are exclusive to these areas. In fact, extractive activities predominate in other categories of sustainable use units (*e.g.*, National Forests, Sustainable Development Reserves, Environmental Protection Areas) or other types of protected areas (*e.g.*, Indigenous Lands and *Quilombola* Territories).

Extractive reserves have allowed substantial areas of forest to be protected that would be unlikely to be protected if conservation units were created through expropriation, and resettlement and compensation of the residents. The extractive reserve model avoids the social injustices inherent in such a process and maintains the communities and the traditional culture of the extractivists (Fearnside, 1989). The long-term effect of this depends on both deforestation being avoided and an avoidance of degradation of the forest, as from logging and fire. Forest degradation can lower carbon stocks in Amazonian forest and consequently lower their benefit for avoiding global warming. Degradation is known to be taking place in some extractive reserves, and quantification of its impact on carbon stocks is a high research priority. Unfortunately, this forest maintenance has not always been as complete as expected, and processes in course in the reserves suggest that deforestation and degradation are likely to increase in the future in the absence of greater social control.

In this text, we present data on carbon in extractive reserves in the Brazilian Amazon, with new analyses from recent carbon estimates for all protected areas in Amazonia (Nogueira *et al.*, 2018a). Here we use these refined analyses to update and synthesize previous estimates of carbon stocks in Amazonian's extractive reserves (Moutinho *et al.*, 2012). In doing so we use the definition of "extractive reserves" to be those considered by the National System of Conservation Units (Brazil, MMA, 2000).

2. Methods

The Ministry of Environment (MMA) registry (Brazil, MMA, 2015) includes 47 federal extractive reserves in Legal Amazonia (of which 45 are in the Amazonia Biome) and 26 state extractive reserves (Figure 1), all of which are in the Amazonia Biome. Legal Amazonia is a 5 million km^2 administrative region, approximately ¾ of which is or was formerly covered by Amazonian forest and the remainder was covered by *Cerrado* savanna. The Amazonia Biome is virtually entirely contained within Legal Amazonia and includes the portion originally covered by Amazonian forest, plus enclaves of savanna within this area.

[Figure 1 here]

Vector maps of the extractive reserves were obtained from the Ministry of Environment database (Brazil, MMA, 2015). Spatially referenced digital maps of the each reserve were overlayed on vegetation and carbon maps, including cleared areas mapped up 2014. Carbon estimates for each reserve were analyzed using ArcGIS® software (ESRI, 2017). See Nogueira *et al.* (2018a) for more details on methods.

Carbon stocks in each reserve were estimated using based on the biomass per hectare in of each vegetation type in each reserve (Nogueira *et al.*, 2015; 2018a). Estimates include biomass stocks above and below ground (*i.e.*, carbon storage in roots but not soils) of the tree and non-tree components, both live and dead (necromass). Biomass estimates were derived mainly from interactions between forest wood volume data from the RadamBrasil surveys and wood-density data (Brazil, Projeto RadamBrasil, 1973-1983; Nogueira *et al.*, 2007). Additional biomass data, especially for forest types in southern Amazonia, were derived by applying allometric equations (Nogueira *et al.*, 2008a; 2008b; 2015). Original areas of each vegetation type in each reserve are estimated from the vegetation map of the Brazilian Institute of Geography and Statistics (IBGE) at a scale of 1:250,000 (Brazil, IBGE, 2012; see Nogueira *et al.*, 2015; 2018a). Deforestation losses were determined from 2014 PRODES data (Brazil, INPE, 2016). These data are freely available from the National Institute for Space Research (INPE) at 60-m resolution, which is degraded from LANDSAT-TM (30-m resolution) or equivalent satellite imagery. The lower limit for detection of deforestation is 6.25 ha. Additional details on the carbon estimation methods can be found in Nogueira *et al.* (2018a).

3. Results

Extractive reserves in Legal Amazonia totaled 126,709 km^2, of which 4301 km^2 (3.4%) had been cleared by 2014. The area of each extractive reserve and deforestation up to 2014 are presented in Table 1, while the original carbon stocks and the losses to deforestation are presented in Table 2. The carbon lost to deforestation totaled 74.9 million tons. Carbon estimates (both stock and loss) are for the remaining vegetation in 2014 and for the original vegetation cleared through 2014, respectively. These estimates do not consider post-clearing recovery by secondary vegetation. Table 3 summarizes the data for remaining vegetation and cleared areas and for carbon stocks and losses for federal extractive reserves, state extractive reserves, and for both types together.

[Tables 1, 2 & 3 here]

The original carbon density in tons per hectare (Mg ha^{-1}) estimated before clearing had occurred in the each extractive reserve is presented in Figure 2. The reserves had a remaining carbon stock in forest vegetation of 2.1 billion tons, with average carbon density per hectare estimated at 168 tons (Table 3). Average carbon density is higher average in the federal than in the state extractive reserves.

[Figure 2 here]

4. Discussion

4.1.Carbon as a foundation for maintaining forest

Using the value of carbon stocks to maintain forests has multiple environmental “co-benefits,” such as water cycling and biodiversity, as well as social benefits in maintaining traditional communities and cultures (e.g., Stickler *et al*., 2009). The benefits to local communities, in addition to their own value, have the additional importance in providing motivation for development of governance that is more effective, cheaper and socially much more attractive than the predominant means of controlling deforestation in the region through reliance on inspections and fines from government agencies. However, it is essential that this local governance actually work, as reflected in halting deforestation in the extractive reserves.

The stocks of carbon documented here represent only the first step in the long process of tapping the climatic value of the forest and transforming this value into a system that both maintains the forest and provides support to the resident population. We certainly do not have the answers to the many challenges involved in designing and institutionalizing such a system. Some lessons can be gained from existing projects in extractive reserves to pay for environmental services or to implant projects for Reducing Emissions from Deforestation and Degradation (REDD+).

The state of Amazonas has a "*Bolsa Floresta*" ("Forest Stipend" or "Forest Allowance") program financed by the Amazon Fund to provide small monthly payments to families in protected areas, including extractive reserves, plus considerably more substantial contributions to community associations and for infrastructure such as schools, solar panels and water tanks (e.g., Viana *et al.*, 2012;Bakkegaard & Wunder, 2014).The program does not have an explicit tie to carbon, but participating families sign an agreement to limit their future clearing to the small annual amounts they have been clearing in the past. However, a test of what happens when these agreements are violated has yet to occur. The beneficiaries of the program clearly have increased wellbeing as compared to those who live outside of protected areas, but the greatest potential benefit of the program has not yet materialized, namely stimulating traditional residents outside of protected areas to demand that government authorities create new sustainable-use protected areas so that these people can also benefit. The most critical location where this is needed is the vast area of public lands to the west of the Purus River that is now at risk from road-building plans associated with the BR-319 (Manaus-Porto Velho) Highway (Fearnside & Graça, 2006).

Another approach is REDD+, where avoided carbon emissions would be accounted for and compensated, presumably from the voluntary market (although in the future a REDD+ mechanism is expected under the UNFCCC). REDD is an extremely controversial topic, both in Brazil and globally (Fearnside, 2012a). Carbon accounting issues to assure that climate benefits are real include dealing with uncertainty in the measurement of carbon stocks and their changes (Fearnside, 2000), the "baseline" (reference scenario) used for attributing emissions reductions to a mitigation project (i.e., "additionality") (Yanai *et al.*, 2012; Vitel *et al.*, 2013), "leakage" (displacement of deforestation to locations beyond a project's boundaries) (Fearnside, 2009_leakage) and "permanence" (the time that carbon remains out of the atmosphere) (Fearnside *et al.*, 2000; Fearnside, 2002). These issues are substantial, but all have solutions (Fearnside, 2012b; Fearnside *et al.*, 2014). However, most opposition to REDD is not rooted in theoretical issues regarding carbon accounting, but rather in political issues regarding the distribution of financial and employment benefits (Fearnside, 2012a; 2013).

Extractive reserves have so far had a relatively minor presence among Brazil's REDD+ projects (e.g., Gomes, 2016). Two extractivist groups signed an anti-REDD statement in 2011: Sindicato dos Trabalhadores/as Rurais de Xapuri in Acre and Resex Renascer Tapajós-Arapiuns in Pará (Grupo Carta de Belém, 2011). One REDD+ project that is underway is the Resex Rio Preto Jacundá REDD+ Project (Biofílica Investimentos Ambientais AS, 2016). This follows the normal model for certified private-sector projects in the voluntary carbon market, with calculations of avoided emissions specific to the extractive reserve, in addition to claiming environmental and social co-benefits. In Amapá the Cajari Carbon Project is a state government initiative that also includes areas outside of the Cajari extractive reserve (IEF, 2018). The original proposal had carbon added to it to make it eligible for funding under a Petrobrás program, but the benefits ascribed to it by the project's managers are essentially entirely in the realm of social and sustainability gains without measurable links to carbon emissions (Superti & Aubertin, 2015). In Acre the state government's Incentive System for Environmental Services (SISA) seeks to reduce the state's loss of environmental services, including carbon stocks, hydrological services and biodiversity. Like the project in Amapá, it provides infrastructure and government services that encourage non-destructive economic activities but does not make payments to stakeholders (Neves *et al*., 2013). The Acre program includes extractive reserves among the many land categories in the state. The program has so far been funded by the Acre state government, but a memorandum of understanding with the US state of California foresees future financial flows on the basis of avoided carbon emissions (Palmer *et al*., 2017). Forest degradation in Acre is substantially increasing the state's carbon emission as compared to what was planned under SISA, as in the case of forest fires during the 2015 drought that affected an area of forest larger than all of the deforestation in the state between 2004 and 2015 (da Silva *et al*., 2018).

4.2. Deforestation and degradation

The 6.25 ha lower limit for deforestation detection by PRODES may bias our results for deforestation in the extractive reserves downward more than is the case for deforestation in other locations in Amazonia, such as settlement projects and areas dominated by large ranches. This is because the traditional clearings made in extractivist family collection areas ("*colocações*") are often smaller than this minimum area. In addition, clearings in *colocações* are scattered throughout the forest, unlike clearings in settlement projects, which are often contiguous with clearings by neighbors. Kalamandan *et al*. (2018) have recently shown the importance of small clearings, which are increasingly common throughout Brazilian Amazonia.

The biomass data used in this study are derived from RadamBrasil forest survey data transformed to biomass based on allometric equations, wood density and other information derived by Nogueira *et al*. (2008a; 2015; 2018a). Various other estimates of Amazon forest biomass exist, but they rely on much more limited ground-truth data than the almost 3000 1-ha RadamBrasil plots (see review in Fearnside, 2018). The same dataset used here for forest biomass is being used in Brazil's 3rd National Communication to the United Nations Framework Convention on Climate Change (see Bustamante *et al*., 2018).

Amazon forest biomass varies considerably across the region as a result of a complex interaction among factors such as soil chemical and physical properties, climate and disturbance history, including cutting and/or enrichment by pre-columbian human populations (Heckenberger *et al*., 2003, 2007; Malhi *et al*., 2004, 2015; Quesada *et al.*, 2011; 2012). Forest biomass is generally highest in central Amazonia, for example near Manaus, and lowest in areas close to the *cerrado* (central Brazilian savanna) (Nogueira *et al*., 2015). Soils have a general gradient from high fertility areas near the Andes in the west to lower fertility to the east, while rainfall has a gradient from high precipitation and absence of a dry season in the northwestern area near Colombia, to low precipitation and long dry seasons in the southeastern portion of the region (Malhi *et al*., 2004; 2006). More fertile soil is both associated with tree species with less-dense wood and causes trees to grow faster, thereby producing less-dense wood even within the same species (Nogueira *et al*., 2007). Another factor reducing biomass on more-fertile soils is trees being shorter for any given diameter (Nogueira *et al*., 2008b). Forests in western Amazonia have lower stature, reducing biomass (Feldpausch *et al*., 2012). Trees grow faster near the Andes with high soil fertility, but they also have higher mortality; this results in faster turnover and not higher biomass (Phillips *et al*., 2004). Forests in portions of Amazonia with long dry seasons have lower biomass not because of lower productivity, but rather because trees in these areas have higher mortality and shorter lifespans (Malhi *et al*., 2015). Non-forest vegetation can result either from climate, for example areas with an excessively long dry season (Hutyra *et al*., 2005; Salazar *et al*., 2007), or from very unfavorable soils such as white sand or hardpan (e.g., Lisboa, 1975). The pre-modern biomass in extractive reserves reflects the biomass in the places where they are located, but they are not evenly distributed across the region (Figure 1). Average pre-modern biomass carbon stock in extractive reserves of all types was 168 Mg C ha^{-1} in 2014 (Table 3), while the average in Brazil's Legal Amazon region was 148.8 ± 32.5 Mg C ha^{-1} and 164.0 ± 36.0 t Mg C ha^{-1} in the country's Amazonia Biome (Nogueira *et al*., 2015).

Moutinho *et al*. (2012, p. 134) have calculated a biomass carbon stock (above + below ground) for all Brazil's extractive reserves that had been established by 2008; values for each reserve are not presented, but total values are given by jurisdiction category that are equivalent to average stocks of 144.2 tons per hectare (Mg C ha^{-1}) in federal reserves, 142.2 Mg C ha^{-1} in state reserves and 143.7 Mg C ha^{-1} considering both types together. Our estimates are 174 tons per hectare in federal reserves (20.7% higher), 135 Mg C ha^{-1} in state reserves (5.0% lower) and 168 Mg C ha^{-1} in both types together (16.9% higher) (Table 3). Moutinho *et al*. (2012, p. 82) used above-ground forest carbon stocks based on the map by Saatchi *et al*. (2007) and added 20% to these values to represent below-ground carbon based on (Houghton *et al*., 2000; 2001). The Saatchi *et al*. (2007) map was based on ground-truth information on primary forests in Brazil at only 53 distinct locations, and almost half of these had a sample areas either < 1 ha or of unknown area (See Fearnside, 2018). The forest biomass values used in present study are based on the RadamBrasil measurements of trees in 2317 plots, each 1 ha in area (Nogueira *et al*., 2015).

The biomass and carbon values in Tables 1 and 2 are for "pre-modern" forests, that is, forests at the time of the RadamBrasil surveys (mainly in the 1960s and early 1970s). The RadamBrasil surveys were done in a period when very little damage had been done to the forest by logging. Forest fires had also been much less frequent than in recent decades. Logging preferentially removes large trees, thus lowering forest biomass (Sist & Ferreira, 2007; Mazzei *et al.*, 2010). Even when done with "reduced impact," logging operations can also kill many trees that are not harvested (Sist *et al.*, 2014). The disturbance from logging substantially increases the vulnerability of Amazon forests to fire (Uhl & Buschbacher, 1985; Cochrane *et al.*, 1999; Nepstad *et al.*, 1999). This can kill more trees (Barlow *et al.*, 2003; Vasconcelos *et al.*, 2013) and initiate a positive feedback process of successive fires and mortality events (Nepstad *et al.*, 2001; Barlow & Peres, 2006; Berenguer *et al*., 2014). In Acre and neighboring areas, fires also stimulate invasion by bamboo, further reducing forest biomass and carbon stocks (Silva *et al*., 2017).

Quantification of degradation losses in extractive reserves is lacking, as is also the case for most areas in Amazonia. Understory fires affected at least 2500 km^2 in the state of Acre during the 2005 drought (Brown *et al.*, 2006). In the Chico Mendes Extractive reserve fire caused the number of dead stems to be much greater in burned plots than in unburned plots studied by Barlow and coworkers (2012), but the lack of plots from before the fire prevented statistically significant quantification of biomass losses. Amazonian forest has very high natural variation in biomass between plots over short distances (Nascimento & Laurance, 2002; Fearnside, 2018). The droughts of the type that occurred in 2005 (Marengo *et al.*, 2008; Zeng *et al.*, 2008; Phillips *et al.*, 2009) and again in 2010 (Lewis *et al.*, 2011; Marengo *et al.*, 2011) are expected to increase dramatically in the coming decades under projected global warming (Cox *et al.*, 2008).

There is a tendency to view emissions from logging as directly human-induced but forest fire as a natural source. However, almost no fires are "natural." Not only are virtually all Amazonian fires caused by a human ignition source, a large proportion of them have their origin in forests that have been made susceptible to fire by logging. Fire represents a significant threat to projects intended to reward climate benefits through Reducing Emissions from Deforestation and Degradation (REDD+) (Aragão & Shimabukuro, 2010; Silva *et al.*, 2013).

The carbon loss values presented in Tables 2 and 3 represent gross values and do not include reabsorption of some carbon by the deforested landscape, including secondary forest. Calculations exist for this uptake for Brazilian Amazonia as a whole, but not specifically for extractive reserves. Secondary forests grow much more slowly if they are from degraded cattle pasture than if they are agricultural fallows (Fearnside & Guimarães, 1996; Wandelli & Fearnside, 2015). To the extent that extractivists are expanding cattle pastures, as in the case of the Chico Mendes Extractive Reserve in Acre, this slower rate of carbon uptake by secondary forest will predominate, as it does in most of Brazilian Amazonia.

In addition to its role in storing carbon, Amazon forest has also been acting as a carbon sink. In the 1990s this sink was believe to be very large, but correction of technical problems with early CO_2 flux measurements made from towers has resulted in much lower estimates for the magnitude of this sink (e.g., Araújo *et al.*, 2002). Monitoring of tree diameters in permanent plots has shown a basin-wide average uptake, although the magnitude varies among sites with the greatest increases near the Andes (Phillips *et al.*, 2009a; Lewis *et al.*, 2004). Estimates vary depending on methods (Grace, 2016). The sink is reversed under drought conditions (Phillips *et al.*, 2009b; Gatti *et al.*, 2014), and severe droughts are expected to increase markedly with climate change (Cox *et al.*, 2008; Latif *et al.*, 2015). There has been a decreasing trend in recent years: based on monitoring of 321 plots (mean plot area = 1.2 ha), the average magnitude of the Amazon forest sink has decreased from approximately 1.5 MgC ha^{-1} $year^{-1}$ in 1985 to 0.25 MgC ha^{-1} $year^{-1}$ in 2011 (Brienen *et al.*, 2015).

4.2. Challenges to controlling carbon loss

Protected areas represent a bulwark against climate change, and the need to avoid greenhouse-gas emissions is likely to be an increasingly important factor in decisions on creating and supporting these areas, including extractive reserves (Nogueira *et al.*, 2018b). The effectiveness of protected areas in maintaining their carbon stocks will be critical in determining the allocation of resources in global and national efforts to fight climate change.

Logging is a delicate issue in extractive reserves because, unlike extraction of non-forest timber products like rubber and Brazilnuts, logging is not inherently sustainable unless strict limits on harvest intensity can be guaranteed to be respected over the course of many human generations. This requires social controls that are strong enough to not be relaxed or abandoned when the forest's timber stocks are drawn down to a pre-established limit, and when both population increase and the continued rise in the individual residents' desire for material consumption translate into pressure to change or evade the forest management regulations (Fearnside, 2003).

An example of the problem of maintaining the previous patterns of non-destructive behavior that have characterized extractivists for over a century is shown by expanding areas of cattle pasture in the Chico Mendes extractive reserve in Acre (Salisbury & Schmink, 2007; Vadjunec *et al.*, 2009). Deforestation has increased, and a contingent of residents in the reserve has, in fact, become ranchers rather than extractivists (*e.g.*, Salomon, 2008; Carranca, 2014). By 2014 a total of 480.4 km^2 of deforestation had occurred in this reserve (5.2% of the original forest area) (Table 1), much of it in the last few years.

The reason that extractive reserves are created and receive priority in government services as compared to unprotected areas in the interior of Brazilian Amazonia is because of the environmental services. The reason is not the fact that people in extractive reserves have a right to services such as education and health care: although extractive populations have a right to these services, so too do populations outside of protected areas, and the sad fact is that, in practice, having these rights does not mean that the government will provide them in a timely fashion. The same amount of money spent could provide, for example, schools and health centers for many more people in one of the country's urban *favelas* than in remote areas in the Amazon forest. The residents of extractive reserves are providing a service by maintaining the forest, and it is important that they realize that this is the reason for the benefits they receive.

Rubber extraction itself is no longer lucrative enough by itself to make extractive reserves economically viable without some form of subsidy (Jaramillo-Giraldo *et al.*, 2017). This means that extractivists must continually demonstrate that they have social controls sufficient to avoid loss of environmental services in order to justify funds from sources that are motivated to invest in maintaining environmental services. It is a basic precept of any program for payment for environmental services that the recipients must have control over the land in question (Wunder *et al.*, 2009). Normally this refers to land ownership, as through a land title, but in the case of an extractive reserve it would apply an adequate level of control by the extractivist community organization over the activities that take place in the reserve (*e.g.*, Global Compass, 2014). If individual families are free to become cattle ranchers and expand their clearings at will, the basis for transforming the climatic value of the forest's carbon stocks into a means of support for the extractivist population is undermined. While a variety of opinions exists on compensating the climate benefits of maintaining tropical forests, this compensation is likely to become an increasingly high priority if the countries of the world are serious about containing global warming (Fearnside, 2012a).

Maintaining the carbon stocks documented in this study is the most visible of the environmental services upon which the future of these extractivist populations depends.

5. Conclusions

Extractive reserves in the Brazilian Amazonia contain substantial amounts of carbon. These reserves are not immune to deforestation and to forest degradation, and maintaining their carbon stocks and associated climate benefits requires active defense. This indicates the need for a level of social control within the extractivist communities that is sufficient to prevent deforestation and forest degradation in the reserves.

6. Acknowledgments

The authors' research is supported by Conselho Nacional do Desenvolvimento Científico e Tecnológico (CNPq: Proc. 305880/2007-1; 368 304020/2010-9; 573810/2008-7; 575853/2008-5), Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM: Proc. 708565) and Instituto Nacional de Pesquisas da Amazônia (INPA: PRJ15.125). This article is a contribution of the Brazilian Research Network on Global Climate Change, FINEP/ Rede CLIMA Grant No. 01.13.0353-00.

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Figure legends

Figure 1. Extractive Reserves in the Brazilian Amazonia listed up 2015 in the National Register of Conservation Units (Brazil, MMA, 2015). The reserve numbers correspond to the numbers in Tables 1 and 2.

Figure 2. Carbon density in tons per hectare ($Mg\ ha^{-1}$) in the Extractive Reserves in the Brazilian Amazonia, estimated before cleared had occurred.

Figures

Figure 1. Extractive Reserves in the Brazilian Amazonia listed up 2015 in the National Register of Conservation Units (Brazil, MMA, 2015). Reserve numbers correspond to those in Tables 1 and 2.

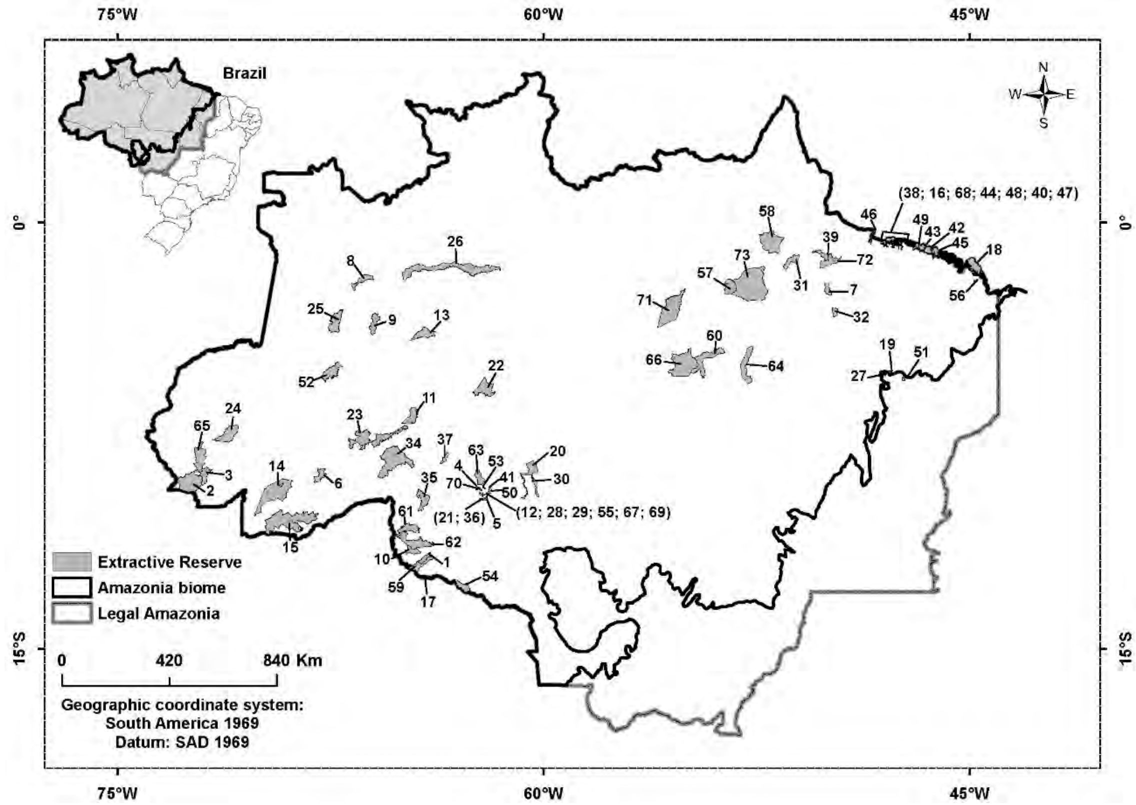

Figure 2. Carbon density in tons per hectare (Mg ha^{-1}) in the extractive reserves in the Brazilian Amazonia, estimated before clearing had occurred.

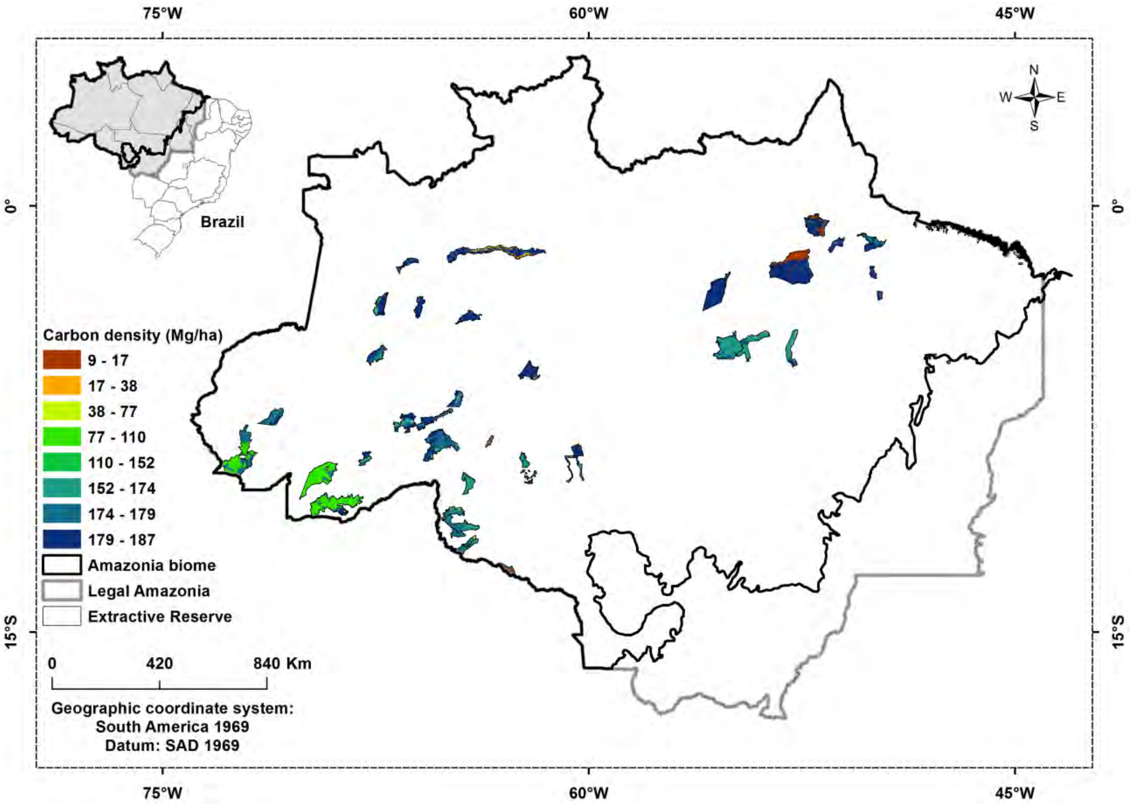

Table 1. Cumulative clearing of vegetation by 2014 for each extractive reserve analyzed in the present study in Brazil's Legal Amazonia and Amazonia biome regions.

No (see Fig. 1).	Name of Protected Area	Administrative level (federal or state) and protection category (integral protection or sustainable use) *	Initial total area**	Area covered by vegetation in 2014	Cumulative clearing of vegetation by 2014	Area mapped as deforested including overlapping watercourses***
			(in km^2)			
1	Reserva Extrativista do Rio Cautário	FSU	751.26	741.39	9.87	-
2	Reserva Extrativista Alto Juruá	FSU	5,378.07	5,222.58	155.49	0.218
3	Reserva Extrativista Alto Tarauacá	FSU	1,509.23	1,473.13	36.09	0.027
4	Reserva Extrativista Angelim	SSU	83.84	76.26	7.59	-
5	Reserva Extrativista Aquariquara	SSU	192.76	176.83	15.94	-
6	Reserva Extrativista Arapixi	FSU	1,337.08	1,310.56	26.52	1.965
7	Reserva Extrativista Arióca Pruanã	FSU	838.17	742.89	95.28	0.153
8	Reserva Extrativista Auatí-Paraná	FSU	1,469.49	1,452.89	16.60	0.106
9	Reserva Extrativista Baixo Juruá	FSU	1,780.39	1,754.02	26.37	0.691
10	Reserva Extrativista Barreiro das Antas	FSU	1,061.11	1,060.51	0.60	-
11	Reserva Extrativista Canutama	SSU	1,979.53	1,968.50	11.03	0.638
12	Reserva Extrativista Castanheira	SSU	96.61	92.12	4.49	-
13	Reserva Extrativista Catuá-Ipixuna	SSU	2,123.23	1,991.02	132.21	10.689
14	Reserva Extrativista Cazumbá-Iracema	FSU	7,553.46	7,471.24	82.22	-
15	Reserva Extrativista Chico Mendes	FSU	9,312.72	8,832.33	480.39	-
16	Reserva Extrativista Chocoaré-Mato Grosso	FSU	27.83	27.53	0.30	0.069
17	Reserva Extrativista Curralinho	SSU	16.62	15.75	0.87	-
18	Reserva Extrativista de Cururupu	FSU	1,572.35	1,350.71	221.64	35.255

19	Reserva Extrativista do Ciriáco	FSU	81.07	23.82	57.25	-
20	Reserva Extrativista do Guariba	SSU	1,480.84	1,479.70	1.14	0.003
21	Reserva Extrativista do Itaúba	SSU	16.04	15.47	0.58	-
22	Reserva Extrativista do Lago do Capanã Grande	FSU	3,043.07	2,998.64	44.43	1.001
23	Reserva Extrativista do Médio Purus	FSU	6,042.32	5,998.46	43.85	0.308
24	Reserva Extrativista do Rio Gregório	SSU	3,069.96	3,046.80	23.16	0.026
25	Reserva Extrativista do Rio Jutaí	FSU	2,755.13	2,735.89	19.24	0.338
26	Reserva Extrativista do Rio Unini	FSU	8,496.85	8,482.17	14.68	2.410
27	Reserva Extrativista Extremo Norte do Tocantins	FSU	90.70	5.23	85.47	-
28	Reserva Extrativista Freijó	SSU	6.29	5.39	0.89	-
29	Reserva Extrativista Garrote	SSU	8.66	8.48	0.18	-
30	Reserva Extrativista Guariba-Roosevelt	SSU	1,376.78	1,303.82	72.95	4.434
31	Reserva Extrativista Gurupá-Melgaço	FSU	1,454.16	1,430.78	23.38	0.332
32	Reserva Extrativista Ipaú-Anilzinho	FSU	558.34	375.79	182.55	0.367
33	Reserva Extrativista Ipê	SSU	8.19	6.58	1.62	-
34	Reserva Extrativista Ituxí	FSU	7,763.23	7,746.32	16.91	0.811
35	Reserva Extrativista Jaci-Paraná	SSU	2,003.20	1,373.32	629.88	-
36	Reserva Extrativista Jatobá	SSU	13.39	9.76	3.63	-
37	Reserva Extrativista Lago do Cuniã	FSU	506.04	503.95	2.08	0.061
38	Reserva Extrativista Mãe Grande de Curuçá	FSU	335.96	326.71	9.25	0.462
39	Reserva Extrativista Mapuá	FSU	937.47	908.35	29.12	1.061
40	Reserva Extrativista Maracanã	FSU	291.12	286.14	4.98	0.493
41	Reserva Extrativista Maracatiara	SSU	86.60	75.63	10.97	-
42	Reserva Extrativista Marinha Araí-Peroba	FSU	600.97	553.38	47.59	3.741
43	Reserva Extrativista Marinha Cae-Tétaperaçu	FSU	408.05	379.75	28.30	1.908
44	Reserva Extrativista Marinha Cuinarana	FSU	110.36	100.58	9.79	0.173
45	Reserva Extrativista Marinha de Gurupi-Piriá	FSU	693.81	621.86	71.95	10.445
46	Reserva Extrativista Marinha de Soure	FSU	295.79	287.37	8.42	0.258

47	Reserva Extrativista Marinha Mestre Lucindo	FSU	250.57	241.01	9.56	0.183
48	Reserva Extrativista Marinha Mocapajuba	FSU	202.95	187.37	15.58	0.432
49	Reserva Extrativista Marinha Tracuateua	FSU	274.84	265.67	9.17	0.053
50	Reserva Extrativista Massaranduba	SSU	61.75	56.29	5.46	-
51	Reserva Extrativista Mata Grande	FSU	114.32	8.09	106.22	-
52	Reserva Extrativista Médio Juruá	FSU	2,515.87	2,491.43	24.44	0.275
53	Reserva Extrativista Mogno	SSU	24.13	23.19	0.94	-
54	Reserva Extrativista Pedras Negras	SSU	1,264.74	1,262.81	1.92	0.026
55	Reserva Extrativista do Piquiá	SSU	12.79	11.44	1.35	-
56	Reserva Extrativista Quilombo do Frechal	FSU	93.38	-	-	-
57	Reserva Extrativista Renascer	FSU	2,096.64	1,949.22	147.42	0.072
58	Reserva Extrativista Rio Cajari	FSU	5,324.00	5,205.95	118.05	0.114
59	Reserva Extrativista Rio Cautário	SSU	1,509.77	1,458.02	51.76	0.118
60	Reserva Extrativista Rio Iriri	FSU	3,989.88	3,914.17	75.71	1.807
61	Reserva Extrativista Rio Ouro Preto	FSU	2,046.32	1,856.73	189.59	-
62	Reserva Extrativista Rio Pacaás Novos	SSU	3,504.43	3,483.40	21.04	-
63	Reserva Extrativista Rio Preto-Jacundá	SSU	1,197.67	1,123.02	74.66	0.262
64	Reserva Extrativista Rio Xingu	FSU	3,030.01	2,992.11	37.90	3.303
65	Reserva Extrativista Riozinho da Liberdade	FSU	3,249.03	3,195.23	53.80	-
66	Reserva Extrativista Riozinho do Anfrísio	FSU	7,360.83	7,324.97	35.86	0.114
67	Reserva Extrativista Roxinho	SSU	10.39	9.45	0.94	-
68	Reserva Extrativista São João da Ponta	FSU	34.09	32.53	1.57	0.059
69	Reserva Extrativista Seringueira	SSU	4.76	4.31	0.45	-
70	Reserva Extrativista Sucupira	SSU	28.18	27.10	1.08	-
71	Reserva Extrativista Tapajós Arapiuns	FSU	6,742.07	6,226.19	515.88	4.500
72	Reserva Extrativista Terra Grande Pracuúba	FSU	1,948.64	1,891.63	57.01	0.732
73	Reserva Extrativista Verde Para Sempre	FSU	12,893.12	12,502.10	391.01	3.707

* FSU = Federal Sustainable-Use conservation unit, SSU = State Sustainable Use conservation unit.

** Total area in each Extractive Reserve was calculated from vector map available from Brazil, MMA (2015). For some reserves the total area calculated from the vector maps may differ from the total area given in other official documents.

*** The estimates of carbon loss and the stock in the remaining vegetation in 2014 may, in certain reserves areas, be affected by the overlapping of classes (*e.g.*, watercourses, forest, non-forest and deforestation), which differ between the carbon map (Nogueira *et al*., 2015) and the maps of the Project for Monitoring Deforestation in Amazonia (PRODES) and the Project for Monitoring Deforestation of the Brazilian Biomes by Satellite (PMDBBS) (Brazil, IBAMA 2015; Brazil, INPE 2016).

Table 2. Carbon estimates in extractive reserves analyzed in the present study in Brazil's Legal Amazonia and Amazonia Biome regions.

No. No (see Fig. 1).	**Conservation unit name** (from Brazil, MMA, 2015)	**Administrative level (federal or state) and protection category (integral protection or sustainable use)***	**Total area (km^2)****	**Remaining carbon stock in 2014*****	**Carbon loss by 2014*****	**Mean remaining carbon per hectare in 2014**	**Mean carbon loss per hectare**
				In tons of carbon (Mg C)			
1	Reserva Extrativista Alto Juruá	FSU	5,378.07	66,908,282.39	2,141,349.71	128.11	137.71
2	Reserva Extrativista Alto Tarauacá	FSU	1,509.23	21,702,762.84	605,196.66	147.32	167.67
3	Reserva Extrativista Angelim	SSU	83.84	1,243,246.47	124,596.56	163.04	164.21
4	Reserva Extrativista Aquariquara	SSU	192.76	3,092,121.51	271,966.79	174.87	170.66
5	Reserva Extrativista Arapixi	FSU	1,337.08	23,082,733.04	427,684.81	176.13	161.26
6	Reserva Extrativista Arióca Pruanã	FSU	838.17	13,327,812.99	1,704,869.02	179.41	178.93
7	Reserva Extrativista Auatí-Paraná	FSU	1,469.49	26,020,305.79	298,928.93	179.09	180.10
8	Reserva Extrativista Baixo Juruá	FSU	1,780.39	31,860,965.08	441,805.57	181.65	167.52
9	Reserva Extrativista Barreiro das Antas	FSU	1,061.11	17,940,786.12	10,469.34	169.17	174.68
10	Reserva Extrativista Canutama	SSU	1,979.53	33,518,352.57	185,156.61	170.27	167.82
11	Reserva Extrativista Castanheira	SSU	96.61	1,501,989.16	73,855.26	163.04	164.46

12	Reserva Extrativista Catuá-Ipixuna	SSU	2,123.23	36,518,136.66	2,250,566.84	183.41	170.23
13	Reserva Extrativista Cazumbá-Iracema	FSU	7,553.46	81,960,423.68	1,037,123.80	109.70	126.14
14	Reserva Extrativista Chico Mendes	FSU	9,312.72	103,274,116.79	6,492,564.96	116.93	135.15
15	Reserva Extrativista Chocoaré-Mato Grosso	FSU	27.83	300,129.52	3,911.72	109.00	132.24
16	Reserva Extrativista Curralinho	SSU	16.62	253,333.48	12,410.76	160.85	142.02
17	Reserva Extrativista de Cururupu	FSU	1,572.35	5,830,764.79	2,410,374.22	43.17	108.75
18	Reserva Extrativista do Ciriáco	FSU	81.07	356,954.46	871,643.15	149.88	152.25
19	Reserva Extrativista do Guariba	SSU	1,480.84	27,360,330.39	20,985.73	184.91	183.97
20	Reserva Extrativista do Itaúba	SSU	16.04	252,093.24	9,477.60	163.00	163.98
21	Reserva Extrativista do Lago do Capanã Grande	FSU	3,043.07	52,820,587.02	702,257.75	176.15	158.05
22	Reserva Extrativista do Médio Purus	FSU	6,042.32	10,529,7471.09	774,240.15	175.54	176.55
23	Reserva Extrativista do Rio Cautário	FSU	751.26	1,1226,638.19	123,392.35	151.43	125.04
24	Reserva Extrativista do Rio Gregório	SSU	3,069.96	53,994,332.52	402,518.08	177.22	173.78
25	Reserva Extrativista do Rio Jutaí	FSU	2,755.13	48,217,575.21	260,006.11	176.24	135.17

26	Reserva Extrativista do Rio Unini	FSU	8,496.85	12,3929,412.47	160,485.31	146.11	109.32
27	Reserva Extrativista Extremo Norte do Tocantins	FSU	90.70	40,550.28	1,495,622.94	77.55	174.98
28	Reserva Extrativista Freijó	SSU	6.29	88,121.11	14,619.82	163.37	164.04
29	Reserva Extrativista Garrote	SSU	8.66	140951.33	2954.67	166.21	165.16
30	Reserva Extrativista Guariba-Roosevelt	SSU	1,376.78	20,414,313.68	1,137,847.42	156.57	155.97
31	Reserva Extrativista Gurupá-Melgaço	FSU	1,454.16	25,824,283.63	417,166.42	180.49	178.40
32	Reserva Extrativista Ipaú-Anilzinho	FSU	558.34	6,720,226.33	3,296,893.84	178.83	180.60
33	Reserva Extrativista Ipê	SSU	8.19	107,224.94	264,55.61	163.00	163.65
34	Reserva Extrativista Ituxí	FSU	7,763.23	135,952,750.18	284,113.13	175.51	168.02
35	Reserva Extrativista Jaci-Paraná	SSU	2,003.20	22,451,152.12	10,269,651.72	163.48	163.04
36	Reserva Extrativista Jatobá	SSU	13.39	160,663.53	60,273.70	164.56	166.26
37	Reserva Extrativista Lago do Cuniã	FSU	506.04	6,986,437.54	27,952.55	138.63	134.25
38	Reserva Extrativista Mãe Grande de Curuçá	FSU	335.96	2,255,473.75	111,633.38	69.04	120.72
39	Reserva Extrativista Mapuá	FSU	937.47	15,809,893.73	496,800.61	174.05	170.62

40	Reserva Extrativista Maracanã	FSU	291.12	2,127,369.63	68,453.46	74.35	137.43
41	Reserva Extrativista Maracatiara	SSU	86.60	1,286,028.43	182,697.00	170.05	166.49
42	Reserva Extrativista Marinha Araí-Peroba	FSU	600.97	4,002,430.87	637,049.29	72.33	133.87
43	Reserva Extrativista Marinha Cae-Tétaperaçu	FSU	408.05	2846214.82	336005.31	74.95	118.71
44	Reserva Extrativista Marinha Cuinarana	FSU	110.36	1,172,922.68	159,676.46	116.62	163.17
45	Reserva Extrativista Marinha de Gurupi-Piriá	FSU	693.81	4,239,732.86	783,714.68	68.18	108.93
46	Reserva Extrativista Marinha de Soure	FSU	295.79	1,721,784.17	110,254.96	59.91	131.00
47	Reserva Extrativista Marinha Mestre Lucindo	FSU	250.57	1,859,552.18	121,455.12	77.16	127.09
48	Reserva Extrativista Marinha Mocapajuba	FSU	202.95	1,685,593.15	240,203.98	89.96	154.20
49	Reserva Extrativista Marinha Tracuateua	FSU	274.84	2,232,085.10	127,398.44	84.02	138.90
50	Reserva Extrativista Massaranduba	SSU	61.75	917,409.72	88,927.47	162.98	162.99
51	Reserva Extrativista Mata Grande	FSU	114.32	121225.44	1591330.06	149.81	149.81
52	Reserva Extrativista Médio Juruá	FSU	2,515.87	44,135,068.05	424,826.37	177.15	173.83
53	Reserva Extrativista Mogno	SSU	24.13	378,342.46	15,288.81	163.12	163.28

54	Reserva Extrativista Pedras Negras	SSU	1,264.74	1,2718,751.49	31,791.33	100.72	165.19
55	Reserva Extrativista do Piquiá	SSU	12.79	211,272.68	24,743.53	184.76	183.22
56	Reserva Extrativista Quilombo do Frechal (2)	FSU	93.38	1,419,198.73	-	-	-
57	Reserva Extrativista Renascer	FSU	2,096.64	31,854,327.45	23,80740.11	163.42	161.50
58	Reserva Extrativista Rio Cajari	FSU	5,324.00	75,332,338.93	2,136,443.45	144.70	180.98
59	Reserva Extrativista Rio Cautário	SSU	1,509.77	21,841,639.46	814,979.93	149.80	157.47
60	Reserva Extrativista Rio Iriri	FSU	3,989.88	61,143,694.56	1,226,100.70	156.21	161.94
61	Reserva Extrativista Rio Ouro Preto	FSU	2,046.32	29,755,917.86	3,161,176.32	160.26	166.74
62	Reserva Extrativista Rio Pacaás Novos	SSU	3,504.43	59,191,089.96	367,549.19	169.92	174.72
63	Reserva Extrativista Rio Preto-Jacundá	SSU	1,197.67	1,8595,789.83	1,264,426.95	165.59	169.36
64	Reserva Extrativista Rio Xingu	FSU	3,030.01	45,019,486.22	595,846.46	150.46	157.22
65	Reserva Extrativista Riozinho da Liberdade	FSU	3,249.03	46,813,193.54	924,148.32	146.51	171.77
66	Reserva Extrativista Riozinho do Anfrísio	FSU	7,360.83	122,380,199.93	613,672.46	167.07	171.14
67	Reserva Extrativista Roxinho	SSU	10.39	154,125.76	15,322.54	163.07	163.28

68	Reserva Extrativista São João da Ponta	FSU	34.09	426,031.84	25,696.86	130.97	164.19
69	Reserva Extrativista Seringueira	SSU	4.76	70,297.69	7,364.03	163.19	164.52
70	Reserva Extrativista Sucupira	SSU	28.18	441,690.93	17,863.84	162.99	164.84
71	Reserva Extrativista Tapajós Arapiuns	FSU	6,742.07	115,546,785.37	8,859,338.94	185.58	171.73
72	Reserva Extrativista Terra Grande Pracuúba	FSU	1,948.64	34,156,598.13	1,044,412.24	180.57	183.19
73	Reserva Extrativista Verde Para Sempre	FSU	12,893.12	178,775,725.20	6,993,238.69	143.00	178.85

* IL = Indigenous land, MT = Maroon territory, FSP = Federal Strictly Protected conservation unit, FSU = Federal Sustainable-Use conservation unit, SSP = State Strictly Protected conservation unit, SSU = State Sustainable Use conservation unit, MSP = Municipal Strictly Protected conservation unit, MSU = Municipal Sustainable Use conservation unit.
** Total area in each conservation unit was calculated from vector maps from Brazil, MMA (2015). Total areas calculated from the vector maps for some conservation units may differ from the areas given in official documents.
*** The estimates of carbon loss and the stock in the remaining vegetation in 2014 may, in certain reserves areas, can be affected by the overlapping of classes (*e.g.*, hydrography, forest, non-forest and deforestation), which differ between the carbon map (Nogueira *et al*., 2015) and the maps of the Project for Monitoring Deforestation in Amazonia (PRODES) and the Project for Monitoring Deforestation of the Brazilian Biomes by Satellite (PMDBBS) (Brazil, IBAMA 2015; Brazil, INPE 2016).
(1) In these reserves it was not possible to calculate the amount of carbon stored.
(2) Carbon values refer to original carbon stocks without any carbon loss due to clearing. In these reserves a total loss of original vegetation cover may have occurred.

Table 3. Remaining areas covered by original vegetation and deforested areas, together with their respective carbon stocks and losses, in extractive reserves in Brazil's Legal Amazonia region.

Administrative level	No of reserves	Initial total area*	Area covered by vegetation in 2014	Cumulative clearing of vegetation by 2014	Area mapped as deforested including overlapping watercourses*	Remaining carbon stock in 2014	Carbon loss by 2014	Mean remaining carbon per hectare in forest in 2014	Mean carbon loss per hectare deforested
		In square kilometers (km^2)				In tons of carbon (Mg C)			
Federal	47	106,528	103,210	3,224	89	1,794,744,514	57,956,751	174	179.8
State	26	20,181	19,104	1,077	16	258,573,101	16,895,210	135	156.9
Federal + State	73	126,709	122,314	4,301	105	2,053,317,615	74,851,961	168	174.0

* See notes in Table 2.