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CARBON STOCK AND DYNAMICS IN NATURAL REGENERATION IN MANAGED FOREST IN THE CENTRAL AMAZON

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Resumo

Estoque e dinâmica do carbono na regeneração natural em floresta manejada na Amazônia Central. Cerca de 2% da biomassa viva acima do solo encontra-se na regeneração natural das espécies arbóreas. Apesar de ser um valor relativamente baixo, o diagnóstico do estrato inferior da floresta é importante no contexto atual das mudanças climáticas. O objetivo desse estudo foi avaliar os efeitos do manejo florestal no estoque e na dinâmica de carbono da regeneração natural 20 anos após a exploração em floresta na Amazônia Central. A coleta de dados foi realizada em três Unidades de Produção Anuais (UPA) que receberam a exploração nos anos de 1996, 1997 e 1998. Foram utilizados dados de inventários florestais contínuos realizados em 41 unidades amostrais, sendo quatro períodos de medições: um pré-exploratório e outros três pós-exploração. Foi estimado o estoque de carbono nas árvores com diâmetro à altura do peito entre 5 e 15 cm e foram calculados o Incremento Periódico Anual em carbono (IPA_c), as taxas de ingresso e mortalidade em carbono. O estoque de carbono variou de 10,80 ± 1,27 Mg ha^{-1} a 14,86 ± 0,81 Mg ha^{-1}. O IPA_c variou de 0,18 ± 0,03 Mg ha^{-1} ano^{-1} a 0,59 ± 0,25 Mg ha^{-1} ano^{-1}, com taxa de ingresso de 0,00% a 3,26% e mortalidade entre 3,35% e 13,84%. O estoque e o IPA_c não foram influenciados significativamente pelo manejo florestal aplicado à floresta, tendo como fator determinante apenas o tempo em sua dinâmica. Incluindo a regeneração natural, conclui-se que a floresta manejada é capaz de reaver o estoque de carbono perdido durante o processo de manejo florestal.
Palavras-chave: Mudanças climáticas, Biomassa florestal, Exploração florestal.

Abstract

Around 2% of the living biomass above ground is found in the natural regeneration of tree species. Despite being a relatively low value, diagnosing the lower stratum of the forest is important in the current context of climate change. The aim of this study was to evaluate the effects of forest management on the carbon stock and dynamics of natural regeneration 20 years after logging in a forest in the Central Amazon. Data collection was carried out in three Annual Production Units (APU) that received exploration in the years 1996, 1997 and 1998. Data from continuous forest inventories carried out in 41 sampling units were used, with four measurement periods: a pre-exploratory and three other post-forest exploration. The carbon stock was estimated in trees with a diameter at breast height between 5 and 15 cm and the Annual Periodic Increment in carbon (APIc) and the carbon entry and mortality rates were calculated. The carbon stock ranged from 10.80 ± 1.27 Mg ha^{-1} to 14.86 ± 0.81 Mg ha^{-1}. The APIc ranged from 0.18 ± 0.03 Mg ha^{-1} $year^{-1}$ to 0.59 ± 0.25 Mg ha^{-1} $year^{-1}$, with an entry rate of 0.00% to 3.26% and mortality between 3.35% and 13.84%. The carbon stock and APIc were not significantly influenced by the forestry management applied to the forest, with only time as a determining factor in its dynamics. Considering natural regeneration, it is concluded that the managed forest is capable of recovering the carbon stock lost during the forest management process.
Keywords: Climate change, Forest biomass, Forest exploration

INTRODUCTION

Tropical forests are identified as an important component in carbon dynamics at a global level, functioning as a carbon sink from the atmosphere (DENNING, 2021). It is estimated that these forests have biomass stocks of between 230 Pg and 260 Pg of Carbon, representing 40% to 60% of the stock in all terrestrial vegetation (SAATCHI *et al.*, 2011; BACCINI *et al.*, 2012). As a result, being the largest tropical forest area on the planet, the Amazon has received special attention regarding its contribution to this global dynamic, with its carbon stock reaching 30% of the total estimated for the planet (PIPONIOT *et al.* , 2016). However, according to Gatti *et al.* (2021), deforestation in the Amazon in recent years has allowed the forest to act as a source of carbon for the atmosphere, especially in the southeast of the region, due to burning to convert land use.

In the 2007 report, the IPCC (Intergovernmental Panel on Climate Change) announced four options to mitigate the effects of climate change in forest areas: forest management, reduction of deforestation, afforestation and reforestation. According to IPCC (2007), mitigation through forest management and avoided deforestation is better than afforestation and reforestation. In this sense, sustainable forest management is one of the possibilities presented for the use of forest resources, respecting the natural dynamics of the forest. The search to improve activities inherent to forestry exploration represents a potential solution to global climate change through the

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mitigation of carbon emissions from these forests (GRISCOM *et al.*, 2017). Ellis *et al.* (2019) propose a set of operations that can reduce carbon emissions from forests under management by up to 44% and deliver 4% of the national contributions determined for the Paris Climate Agreement from tropical countries, while maintaining wood supplies. Therefore, it is necessary to understand the forest regeneration processes after exploitation in order to establish parameters to be applied subsequently.

In the Amazon region, studies have proven that forest management compared to conventional forest exploration, without the use of appropriate techniques, reduces carbon emissions in exploited forests (AVILA *et al.*, 2018; ROOPSIND *et al.*, 2017; VIDAL *et al.*, 2016; WEST *et al.*, 2014). With this, the core of the discussion turns to knowledge about the natural regeneration of different forest ecosystems. The conduct of these studies takes into account the total remaining population, generally with diameters starting at 10 cm. However, it is also important to know about smaller individuals, ranging from 5 cm to 10 cm. Vinhote *et al.* (2020) verified changes in diversity and reduction in similarity of species from the regeneration of trees between 5 cm and 15 cm in diameter, thus attesting to an effect of forest management and confirming the importance of looking at this stratum of vegetation.

In the local context, in the central Amazon region, studies have also been carried out on the dynamics of carbon in exploited forests, always focusing on the extract with trees from 10 cm or 15 cm in diameter. The present study continues a series of analyzes of commercial timber forest management carried out in the Central Amazon (FREITAS *et al.*, 2019; SOUZA *et al.*, 2017; VASCONCELOS *et al.*, 2016; VINHOTE *et al.*, 2020) and it has the objective to evaluate the influence of management on the carbon stock and dynamics present in natural regeneration (trees between 5 cm and 15 cm in diameter).

MATERIAL AND METHODS

Study area

The study was conducted within the perimeter of the Dois Mil farm, a forest management area belonging to the Mil Madeireira Preciosas company Ltda., located in the municipality of Itacoatiara, state of Amazonas, Brazil (Picture 1). It has been carrying out forestry exploration since 1995, and for this research data from three Annual Production Units (APU) explored in 1996, 1997 and 1998 were used (APU B, APU C and APU D, respectively).

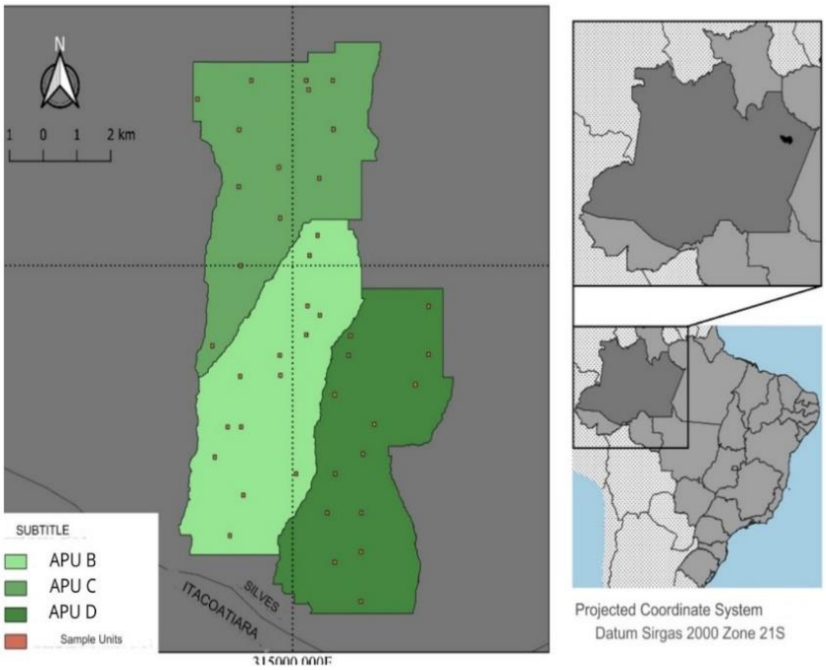

Figure 1. Study area: Annual Production Units (APU) B, C and D. Mil Madeiras Preciosas, Silves, Amazonas, Brazil.

Figura 1. Área de estudo: Unidades de Produção Anual (UPA) B, C e D. Mil Madeiras Preciosas, Silves, Amazonas, Brasil.

The area consists of Dense Ombrophylous Forest in Solid Ground, made up of large arboreal individuals, with woody lianas and epiphytes (IBGE, 2012). According to the Köppen classification, the region's climate is type “Am” (tropical rainy monsoon). Average annual precipitation varies between 1,355 mm and 2,839 mm. The rainiest months are from December to May and the driest from August to November – monthly rainfall never less than 50 mm. The average temperature varies from 25.6 °C to 27.6 °C, with an average relative humidity between 84% and 90%. There is a predominance of Yellow Oxisols in the region with a very clayey texture and hydromorphic soils, predominantly covered by dense lowland forest vegetation, with an emerging canopy (IBGE, 2015).

Forest monitoring and data collection

Forest dynamics were monitored through continuous forest inventories carried out in sampling units (SU) installed in the respective APUs, in a total of 41 APUs. These units are made up of permanent plots with standardized dimensions of 100 m x 100 m, subdivided into 100 subplots of 10 m x 10 m and were randomly allocated in the area.

In each APU, an inventory was carried out before forestry exploration (T0) and, subsequently, three post-exploration follow-up inventories (T1, T2 and T3) for APUs B and D and two for APU C (it was not possible to carry out of the third APU C inventory due to the SARS-CoV-2 pandemic). The average exploration intensity within the SUs was calculated for each APU, considering the volume of trees felled within these units.

20 subplots were randomly drawn within each SU, totaling 820 subplots (280 in APU B, 260 in APU C and 280 in APU D) with a total area sampled for natural regeneration of 8.2 hectares. Within the selected subplots, the diameters at breast height (DBH) of all individuals with 5 cm ≤ DBH < 15 cm were measured, which are classified as trees.

Biomass and carbon stock

The estimation of individual biomass was made using the equation proposed by Chave *et al.* (2014), described below:

$$AGB_{est} = e^{\left(1{,}803-0{,}976E+0{,}976\ln(p)+2{,}673\ln(D)-0{,}0299(\ln(D)^2\right)} \quad [1]$$

In which: AGB_{est}= Dry biomass above ground; ρ = Basic density (g cm^{-3}); ln = Neperian logarithm; D = DBH in cm; E = (0,178 TS - 0,938 CWD - 6,61 PS)10^{-3}; TS = Average temperature of the period; CWD = Climatological Water Deficit; PS = Average precipitation for the period.

The carbon estimate for each tree was made from the product between the dry biomass and the value of 0.5, considering that 50% of the dry weight of the trees are equivalent to the carbon present in them (HOUGHTON *et al.*, 2000).

Carbon dynamics

Carbon dynamics were assessed based on the Annual Periodic Carbon Increment (APCI) and the calculated Mortality and Inflow rates. The calculation of these variables was done with equations 2, 3 and 4, respectively.

$$APCI_{2-1} = \frac{C_2 - C_1}{(Year_2 - Year_1) + \left(\frac{Month_2 - Month_1}{12}\right)} \quad [2]$$

Where: APCI2-1: Annual periodic increase in carbon; C2 and C1: Carbon content at the end and beginning of the period, respectively; Year2 and Year1: Years at the end and beginning of the period, respectively; Month2 and Month1: Month at the end and beginning of the period, respectively.

$$R\% = \frac{Carbon\ in\ incoming\ trees}{Total\ carbon\ in\ previous\ measurement}\ x\ 100 \quad [3]$$

$$M\% = \frac{Carbon\ in\ dead\ trees}{Total\ carbon\ in\ previous\ measurement}\ x\ 100 \quad [4]$$

In which: R%: Carbon recruitment rate; M%: Carbon mortality rate.

Statistical analysis

The descriptive statistics of the data were performed considering a completely randomized sampling. Analysis of Variance (ANOVA) was performed to assess whether the carbon averages for each period inventoried presented significant differences between the APUs considered in the study. As a post-hoc test, the Tukey test was applied to identify which means differed from each other.

ANOVA with repeated measures was also applied to evaluate the interaction Forest Management versus time in carbon stock and APIc of the total natural regeneration stand, grouping all APUs, with the purpose of identifying whether these variables are influenced by management forestry in the different APUS over the years. In this analysis, periods T0, T1 and T2 were considered due to the failure to carry out a forest inventory at APU C in period T3. All statistical analyzes were performed considering a probability level of 95% (α = 0.05).

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RESULTS

The sampling units with the highest exploration intensity were those of APU B (Table 1), which presented statistical equality to APU D. Despite having the lowest exploration intensity, with fewer trees cut, APU C was the most affected by the opening of infrastructure, in which 10 subplots were reached by skid trails and two by storage yards. In the other APU, only one subplot in each unit was affected, one due to the opening of a branch (APU B) and the other due to a skid trail (APU D).

Table 1. Month/year of continuous forest inventories carried out in the Annual Production Units in a logged forest in the Central Amazon.

Tabela 1. Mês/ano dos inventários florestais contínuos realizados nas Unidades de Produção Anual em floresta manejada na Amazônia Central.

APU	Nº SU	I.E.** ($m^3.ha^{-1}$)	Inventory Before Exploration (T_0)	Inventories After Exploration		
				T_1	T_2	T_3
B	14	39,45 ± 12,27[a]	12/1996	05/1998	08/2014	08/2019
C	13	13,85 ± 7,94[b]	10/1997	08/2001	12/2014	-
D	14	29,17 ± 11,10[ab]	04/1998	10/2001	12/2014	11/2019

Graphic subtitle: I.E.: Exploration intensity within the sampling units. ** Significant difference at the 99% probability level. Means with the same letters do not differ according to the Tukey test (α = 0,05). The T3 inventory at APU C would be carried out in March 2020, however, it was not possible due to restrictions imposed by the SARS-CoV-2 (COVID-19) pandemic.

In each inventory carried out in the study area, 8,529 individuals were measured, representing an average of 13,02 ± 2,10 $Mg.ha^{-1}$ of carbon above ground level. APU C was the one with the highest carbon stock in all the years in which data was collected in this unit (Table 2).

Table 2. Mean (± error) of carbon stock in natural regeneration per Annual Production Unit (APU) and year of measurement. Year of logging: B-1996, C-1997 and D-1998.

Tabela 2. Média (± erro) do estoque de carbono na regeneração natural por Unidade de Produção Anual (UPA) e ano de medição. Ano de exploração: B-1996, C-1997 e D-1998.

APU	T_0 ($Mg.ha^{-1}$)	T_1 ($Mg.ha^{-1}$)	T_2 ($Mg.ha^{-1}$)	T_3 ($Mg.ha^{-1}$)
C	14,62 ± 0,78 a	13,84 ± 1,16 a	14,86 ± 0,81 a	*
D	12,51 ± 0,90 b	11,64 ± 1,01 b	13,96 ± 0,87 a b	13,69 ± 1,10
B	12,13 ± 1,08 b	10,80 ± 1,27 b	13,22 ± 1,00 b	12,23 ± 1,20

Graphic subtitle: Means in the same column with the same letters are not statistically different according to the Tukey test (α = 0,05). T_0 = pre-exploration inventory; T_1 = first post-exploration inventory; T_2 = second post-exploration inventory; T_3 = third post-exploration inventory. * The T3 inventory at APU C was not carried out due to restrictions imposed by the SARS-CoV-2 pandemic.

The largest increases in carbon occurred in the first period evaluated (Table 3), which comprised the inventory before exploration (T0) and the first one after (T1). On the other hand, the largest increases were observed for a period of more than 10 years, between T1 and T2, in all APUs. The largest and smallest increases were observed for APU B. In APU B and D, in which the third post-exploration inventory (T3) was possible, an increase in IPAC was observed for an interval of five years.

Table 3. Mean (± error) of the Annual Periodic Increment (APIc) and annual rates of carbon ingress and mortality in natural regeneration per Annual Production Unit (APU) in a logged forest in the Amazon.
Tabela 3. Média (± erro) do Incremento Periódico Anual (IPAc) e taxas anuais de ingresso e mortalidade em carbono na regeneração natural por Unidade de Produção Anual (UPA) em floresta manejada na Amazônia.

APUS	Period	(APIc $Mg.ha^{-1}.year^{-1}$)	Admission Rate (%)	Mortality (%)
B	T_0 - T_1	0,59 ± 0,25	1,19	13,84
	T_1 - T_2	0,18 ± 0,03	3,24	3,35
	T_2 - T_3	0,33 ± 0,06	0,95	4,95
C	T_0 - T_1	0,45 ± 0,05	0,00	4,52
	T_1 - T_2	0,25 ± 0,03	2,71	4,01
D	T_0 - T_1	0,51 ± 0,05	0,00	6,07
	T_1 - T_2	0,23 ± 0,02	3,26	3,59
	T_2 - T_3	0,42 ± 0,05	1,76	5,20

Mortality rates were higher than entry rates at all intervals. The first period analyzed in APUs C and D stands out, in which there was no entry. An inversely proportional variation is observed in the dynamics of entry and mortality. Between the first and second periods (T1-T2) there was an increase in the admission rate, while a decrease was observed for mortality when compared to the first period evaluated (T0-T1). In APUs B and D, which have a third observation period (T2-T3), it is possible to observe a new change, in which the entry rate reduced and mortality increased.

For the total population, grouping data from the 41 permanent plots, the stock of 13,05 ± 0,61 $Mg\ ha^{-1}$ carbon before forestry exploration (T_0), 12,86 ± 0,65 $Mg.ha^{-1}$ in the first inventory after exploration (T_1) e 13,65 ± 0,63 $Mg.ha^{-1}$ for the second post-exploration inventory (T_2). In this situation, it is verified that carbon stocks in natural regeneration differ from each other when evaluated as a function of time. For the time x APU interaction, no significant influence was found, therefore, the influence of forest management applied was equal in the three Annual Production Units (Table 4).

Table 4. ANOVA for repeated measures over time for the carbon stock of the total stand (considering input and mortality) in the measurements performed at T_0, T_1 and T_2.
Tabela 4. ANOVA para medidas repetidas no tempo para o estoque em carbono do povoamento total (considerando o ingresso e a mortalidade) nas medições realizadas em T_0, T_1 e T_2.

Source	GL	SQ	QM	Fcal	Pr>F
APU	2	41,869	20,935	11,006	$0,000^{**}$
Error	38	72,278	1,902		
Time	1	17,443	17,443	11,851	$0,001^{**}$
Time * APU	2	5,187	2,594	1,762	$0,185^{ns}$
Error	38	55,927	1,472		

Graphic subtitle: ** Significant at the 99% probability level; ^{ns} Not significant (α = 0,05).

The APIc for settlement in the period T_0-T_1 de 0,52 ± 0,08 $Mg.ha^{-1}.year^{-1}$ it is different from that calculated for the period T_1-T_2, which is equal to 0,22 ± 0,02 $Mg.ha^{-1}.year^{-1}$. This variable is influenced only by the time factor, since the time x APU interaction was not significant (Table 5).

Table 5. ANOVA for repeated measures over time for the APIc for the total population, considering ingress and mortality, for the T_0-T_1 and T_1-T_2 intervals.
Tabela 5. ANOVA para medidas repetidas no tempo para o IPAc para o povoamento total, considerando ingresso e a mortalidade, para os intervalos T_0-T_1 e T_1-T_2.

Source	GL	SQ	QM	Fcal	Pr>F
APU	2	0,007	0,004	0,184	0,833^{ns}
Error	38	0,727	0,019		
Time	1	1,759	1,759	53,313	0,000**
Time * APU	2	0,152	0,076	2,301	0,114^{ns}
Error	38	1,254	0,033		

Graphic subtitle: ** Significant at the 99% probability level; ^{ns} Not significant (α = 0,05).

DISCUSSION

For the management area evaluated here (Picture 1), other studies were carried out related to carbon stock in vegetation. Vasconcelos *et al.* (2016) estimated an average of 165.7 Mg.ha-1 of carbon above ground considering trees from 15 cm dbh. Freitas *et al.* (2019) estimated 32.9 Mg.ha-1 of carbon in the necromass. The present study contributes to complement the representation of natural regeneration in the above ground carbon stock in this area under forest management. Adding the three components listed here, there is 211.62 Mg.ha-1 of carbon above ground, with natural regeneration contributing 6.15% of this stock.

For Condé *et al.* (2022) forest management does not alter the remaining carbon stock of a forest, it is depending on the intensity of exploration. APUs B and C presented, respectively, the highest and lowest intensity of exploration (Table 1). At the same time, APU C showed the smallest reduction in carbon stock between the first and second inventory and APU B showed the greatest reduction. Losses in carbon stock after forestry exploration are expected due to the impact caused by activities inherent to this process, especially natural regeneration. As it contains small trees, a large part of the impacts are directed towards this vegetation, since these trees tend not to cause a domino effect on their adjacent trees, or to do so to a lesser extent, contributing to a lower impact from exploration. This variation can also be understood by the mortality rate between the first two inventories, where in APU B it is three times higher than in APU C (Table 2).

In the T2 inventory, it is possible to observe that in all APUs, natural regeneration recovered the carbon stock from before exploration. In the same area, Souza *et al.* (2017) observed this recovery for the basal area of trees, a variable correlated with carbon. West *et al.* (2014) also found, in their study in a management area, that in an interval between 16 and 18 years post-exploration, the carbon stock reached values higher than those observed in the pre-exploration inventory (Table 2). However, in APUs B and D, where it was possible to carry out the third post-exploration inventory, a reduction in carbon stock was observed, a fact also observed by Vidal *et al.* (2016). Comparison with other studies allows a broader understanding of the Amazon forest in relation to local contexts, understanding how the dynamics of loss and gain in carbon stock occur over time. This knowledge is another motivating factor that makes it even more important to look at the smaller vegetation stratum, since, even to a lesser extent, it contributes to the carbon dynamics in a forest.

As it is a less targeted vegetation stratum, the variation in carbon stock in natural regeneration observed in other studies must take into account methodological differences, since the vegetation stratum to be considered may vary. Lima *et al.* (2012) they consider trees with DBH between 5 and 10 cm as natural regeneration, thus estimating carbon stocks for two areas in the Amazon of 5.5 and 5.05 Mg.ha-1. Stas *et al.* (2017) estimated 16.50 Mg.ha-1 of carbon for individuals with DBH <10 cm in tropical forest in Indonesia. Despite the differences in vegetation stratum, there is a similarity between the stocks observed in the present study.

As a first immediate effect of forestry exploration, there is the death of individuals due to the felling of trees selected for cutting, with natural regeneration receiving a large part of this impact due to their smaller size. This operation allows us to understand the highest mortality rate in the first period under analysis, which includes the pre-exploration inventory and the first period after, especially in APU B, with a rate that is almost 130% higher than that in APU D and more of 200% in relation to APU C. It is understood that the higher exploration intensity (Table 1) provided this result. Furthermore, in the year of operation of this APU, the company carried out an exploration aimed at individuals of the Acariquara species (Minquartia guianensis Aubl.) with the purpose of fulfilling a specific purchase order, a factor not repeated in the other Units, which is understood as a factor for the greater intensity of exploitation and higher mortality rate. This type of situation (specific requests according to the consumer market) is something that differs from studies under experimental management, highlighting the importance of looking at this type of environmental service.

Avila *et al.* (2018) they say that the reduction of competition for resources such as nutrients and light as a positive factor for increasing the increase in biomass. The first due to the removal of larger trees that required more nutrients, the second due to the opening of the forest canopy. Vasconcelos *et al.* (2016) found that in the present area under study, the increase in carbon in trees was mainly influenced by exposure to light, in which trees with a crown completely exposed to light showed the largest increases, in addition to the influence of the shape of the tree crown as well in this greater increase. These factors must be taken into account when monitoring and executing forest management practices. Therefore, it is believed that the higher Annual Periodic Increment values observed in the first monitoring interval are due to the opening of clearings with the felling of commercial trees, which provide light entry for the natural regeneration trees and the removal of trees from larger plants that competed and demanded more nutrients. Since commercial management targets trees with larger diameters, cutting these leaves room for the development of smaller individuals.

In all time intervals considered, the annual periodic increase in carbon is positive, indicating that trees from natural regeneration are growing and incorporating carbon. However, a lower APIc is observed for the T1-T2 interval in all APUs, an interval that covers the period of 16, 17 and 18 years after exploration. Extensive monitoring intervals tend not to capture seasonalities in forest dynamics, such as occasional storms and periods of drought, which can increase tree mortality and reduce tree growth (HIGUCHI *et al.*, 2011) or even favorable situations for incorporation carbon in the population. During this period, the highest percentages of carbon inflow can be observed, almost equal to mortality rates, something not observed in other periods, in which inflow is well below mortality. After exploration, the reduction in carbon stock persists for a few years due to the high mortality rates of trees damaged during operations (SHENKIN *et al.*, 2015). It is believed that the tendency for a higher mortality rate in relation to entry in all periods evaluated is due to smaller individuals and/or in the initial stages of development that make up natural regeneration, being more subject to damage caused by exploration, initially, and by subsequent natural events in the forest.

The level of disturbance provided by forest management is one of the main drivers of vegetation dynamics, therefore, the greater the impact on the forest, the lower the recovery of carbon stocks (VIDAL *et al.*, 2016; WEST *et al.*, 2014). Studies have indicated the importance of remaining vegetation in the dynamics of post-exploration carbon recovery to the detriment of settlement management techniques (AVILA *et al.*, 2018; van der SANDE *et al.*, 2017), which reflects the importance of having a control over the intensity of exploration of these forests. The analysis carried out here with data from the three APUs combined shows dynamics similar to that of the individual units, in which in the T1 period there is a reduction in the carbon stock, but in a period between 16 and 18 years after exploration, the stock is already greater than T0. As well as APIc, in which in the first post-exploration period it is higher than in subsequent years. The variation in stock averages and increase in total population were influenced only by the time elapsed, a result also observed by Vasconcelos *et al.* (2016) for carbon stock in trees from 15 cm dbh. Therefore, despite being different between the APU The level of disturbance provided by forest management is one of the main drivers of vegetation dynamics, therefore, the greater the impact on the forest, the lower the recovery of carbon stocks (VIDAL *et al.*, 2016; WEST *et al.*, 2014). Studies have indicated the importance of remaining vegetation in the dynamics of post-exploration carbon recovery to the detriment of settlement management techniques (AVILA *et al.*, 2018; van der SANDE *et al.*, 2017), which reflects the importance of having a control over the intensity of exploration of these forests. The analysis carried out here with data from the three UPAs combined shows dynamics similar to that of the individual units, in which in the T1 period there is a reduction in the carbon stock, but in a period between 16 and 18 years after exploration, the stock is already greater than T0. As well as IPAc, in which in the first post-exploration period it is higher than in subsequent years. The variation in stock averages and increase in total population were influenced only by the time elapsed, a result also observed by Vasconcelos *et al.* (2016) for carbon stock in trees from 15 cm dbh. Therefore, despite being different between the UPAs, the intensity of exploration adopted in the forest management developed in this area is not negatively impacting the carbon stock in the remaining natural regeneration.s, the intensity of exploration adopted in the forest management developed in this area is not negatively impacting the carbon stock in the remaining natural regeneration.

CONCLUSIONS

- The carbon stock in natural regeneration recovered and remained higher for a period of up to 23 years after exploration. As a result, this layer of vegetation serves as a carbon sink for the atmosphere.
- Targeting the impact of forest management towards natural regeneration did not affect the carbon dynamics of this vegetation component, in which only time was the preponderant factor explaining the variations between periods.

- The quantification of carbon in natural regeneration provides an approximation of the field reality, expanding the understanding of the environmental services provided by forest management, especially regarding whether the forest is a source or sink of carbon after exploration.

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