land

Communication

Diametric Growth of a Forest under Reduced-Impact Logging in the Eastern Region of the Brazilian Amazon

William Montero Flores [1], Isadora França [2], Graciliano Galdino Alves dos Santos [3,*], Izildinha de Souza Miranda [4], Eric Fabricio Santos Moraes [1], Gustavo Hernández Sánchez [5], Sandra Dezuite Balieiro Da Silva [6] and Emil José Hernández-Ruz [1]

1 Programa de Pós-Graduação em Biodiversidade e Conservação, Universidade Federal do Pará (UFPA), Rua Coronel José Porfírio, 2515, Explanada Xingu, Altamira CEP 68.372-040, PA, Brazil
2 Faculdade de Ciências Biológicas, Universidade Federal do Pará (UFPA), Rua Coronel José Porfírio, 2515, Explanada Xingu, Altamira CEP 68.372-040, PA, Brazil
3 Programa de Pós-Graduação Bionorte, Instituto de Ciências Biológicas (ICB), Av. Augusto Corrêa, Nº 1, Belem CEP 66.075-110, PA, Brazil
4 Programa de Pós-Graduação em Ciências Florestais, Universidade Federal Rural da Amazônia (UFRA), Avenida, Tancredo Neves, 2501, CEP. 917, Belem CEP 66.077-530, PA, Brazil
5 Instituto de Investigación y Servicios Forestales de la Universidad Nacional de Costa Rica (INISEFOR-UNA), Calle El Pedregal, El Carbonal, Barva 86-3000, Heredia, Costa Rica
6 LN Guerra Indústria e Comércio de Madeiras LTDA, Rua Municipalidade, 985, Belem CEP 66.050-350, PA, Brazil
* Correspondence: ggaldino@gmail.com

Abstract: Growth is a component of forest dynamics that encompasses changes in species composition, interactions between species, and stand structure. We evaluated the effect of the presence of lianas, crown shape, and light exposure on the periodic annual increment of trees (PAI) in two phytophysiognomies: the ombrophilous dense forest and the ombrophilous open forest with lianas. This study was conducted in the eastern Brazilian Amazon in 13 permanent monitoring plots of 50 m × 50 m (2500 m^2) in the same annual production unit. The area has been subjected to reduced-impact logging from 2014 to 2016. The increment in tree diameter varied significantly between both forests (opens forests: 1.28 cm yr^{-1}; dense forests: 0.82 cm yr^{-1}). Light exposure influenced the increment in tree diameter in the ombrophilous open forest with lianas, while the crown shape and light exposure significantly affected the ombrophilous dense forest. Our study emphasizes the usefulness of the periodic annual increment in exploring the differences between contrasting phytophysiognomies in a single annual production unit in the Brazilian Amazon that is subject to reduced-impact logging.

Keywords: periodic annual increment; phytophysiognomies; presence of lianas; crown shape; exposure to light; forest management

check for updates

Citation: Flores, W.M.; França, I.; Santos, G.G.A.d.; Miranda, I.d.S.; Moraes, E.F.S.; Sánchez, G.H.; Silva, S.D.B.D.; Hernández-Ruz, E.J. Diametric Growth of a Forest under Reduced-Impact Logging in the Eastern Region of the Brazilian Amazon. *Land* **2023**, *12*, 704. https://doi.org/10.3390/land12030704

Academic Editor: Thomas Panagopoulos

Received: 24 February 2023
Revised: 14 March 2023
Accepted: 15 March 2023
Published: 18 March 2023

1. Introduction

The Brazilian Amazon represents about one-third of the world's tropical forests and is home to thousands of tree species, of which approximately 350 are commercially extracted for timber purposes [1]. Richardson and Peres [2] found that, only in Pará state, trees belonging to 314 timber species were extracted from 824 management areas totaling some 124 million hectares. Production in Pará amounts to 17.3 million cubic meters of wood, representing 50% of all tropical wood sold from the Brazilian Amazon. This indicates that forest management is one of the main uses of land and economic activities of this ecosystem [3].

Achieving sustainable wood production while also prioritizing conservation has been a major challenge in Brazil. Logging in the Amazon boomed in the 1960s due to incentives from occupation policies in the "empty" region, initiating a long journey of deforestation and forest degradation [4,5]. Only in the 2000s, with several government initiatives to implement control of natural areas, was a law created, in 2006, regulating forest management [4]. In these almost 20 years, there has been a wide debate on how to refine these practices aiming to optimize production and respect the ecological characteristics of the trees.

Another challenge is that management plans do not accurately measure an area's potential growth since the growth rate of many forest species varies considerably. This often results in a lack of knowledge of the volumes to be extracted, which frequently leads to these amounts being assigned arbitrarily, making forest management an unsustainable practice in this country [6]. In addition, estimations of the population abundances of approximately 70 slow-growing commercial species tend to overstate the numbers of large trees (diameter at breast height (DBH) $\geq$ 50 cm) [7].

Measuring growth variables is one of the oldest and most common tools used in forest management planning to predict wood yields [8]. Growth has long been considered to be influenced by biotic and abiotic factors that reflect the functioning of the whole tree [9]. Long-term studies show that persistent low growth can be considered a sign of a dying tree [10]. Furthermore, growth is one of the variables used to evaluate forest dynamics. Filha [11] notes that studies on forest dynamics are essential to understanding the changes in the floristic structure and composition after the first management cycle, and thus allowing planning to balance the needs of wood production and the conservation of the remaining forest. The main predictive factors of tree growth and the productivity of forests under reduced-impact logging in the Brazilian Amazon are light exposure, crown shape, and the presence of lianas.

Vidal et al. [12] and Vatraz et al. [13] showed that the remaining trees after logging grow at a faster rate, which is positively affected by light exposure and crown shape, while the presence of lianas restricts their growth. Pérez et al. [14] also noted that increased global temperatures have increased the presence of lianas in forest canopies. The greater presence of lianas results in more competition for light and nutrients and can increase tree mortality and damage, representing a threat to the growth and productivity of tropical forests.

Therefore, this study aims to (1) compare the periodic annual increment in tree diameter in eastern Amazon forest plots with two contrasting phytophysiognomies and subjected to reduced-impact logging and (2) assess how the periodic annual increment is affected by light exposure, crown shape, and the presence of lianas.

2. Materials and Methods

2.1. Study Area

The study area is located in the Uberlândia Forest Management Unit (Figure 1), which includes areas belonging to the municipalities of Portel, Bagre, Baião, and Oeiras, in Pará state, Brazil. A license to manage this area and extract timber was granted to the Grupo LN Guerra Company in 2011. The management plan was certified by the Forest Stewardship Council. The total effective management area comprises 128,934.69 hectares of primary forest, organized into 35 annual production units of approximately 3500 hectares each. The study was conducted in the tenth annual production unit (APU10) (S 3°10′–2°46′ W 50°21′–49°45′). The logging intensity approved in the management plan was 4.7 individuals/ha and an average volume of 29.04 m^3/ha. This area was subjected to logging in 2015 following the Brazilian legislation (30 m^3/ha in minimum forest felling cycles of 25 years) on average logging intensity that was 18.89 $\pm$ 4.1 m^3/ha in open forests and 16.61 $\pm$ 6.41 m^3/ha in ombrophilous dense forests.

APU10 contains forests that belong to two distinct phytophysiognomies, according to the vegetation classification of the Brazilian Institute of Geography and Statistics [15]. Specifically, 68.2% (2388.4 ha) is ombrophilous dense forest, which has a closed canopy, high biomass, and some emergent trees with heights ranging from 30 to 50 m. Meanwhile, the remaining 32.8% (1111.6 ha) is an ombrophilous open forest with lianas, with a lower and more open canopy than ombrophilous dense forest and understory [16]. This area is in the transition zone between the micro-regions of the central and eastern Amazon (northeastern Pará state) and the micro-region of the Lower Tocantins and Tucuruí [17]. According to the Köppen classification, the climate that predominates in the region is humid tropical, with a short dry season and a long wet season. Estimated annual rainfall varies between 1900 mm and 2400 mm [18].

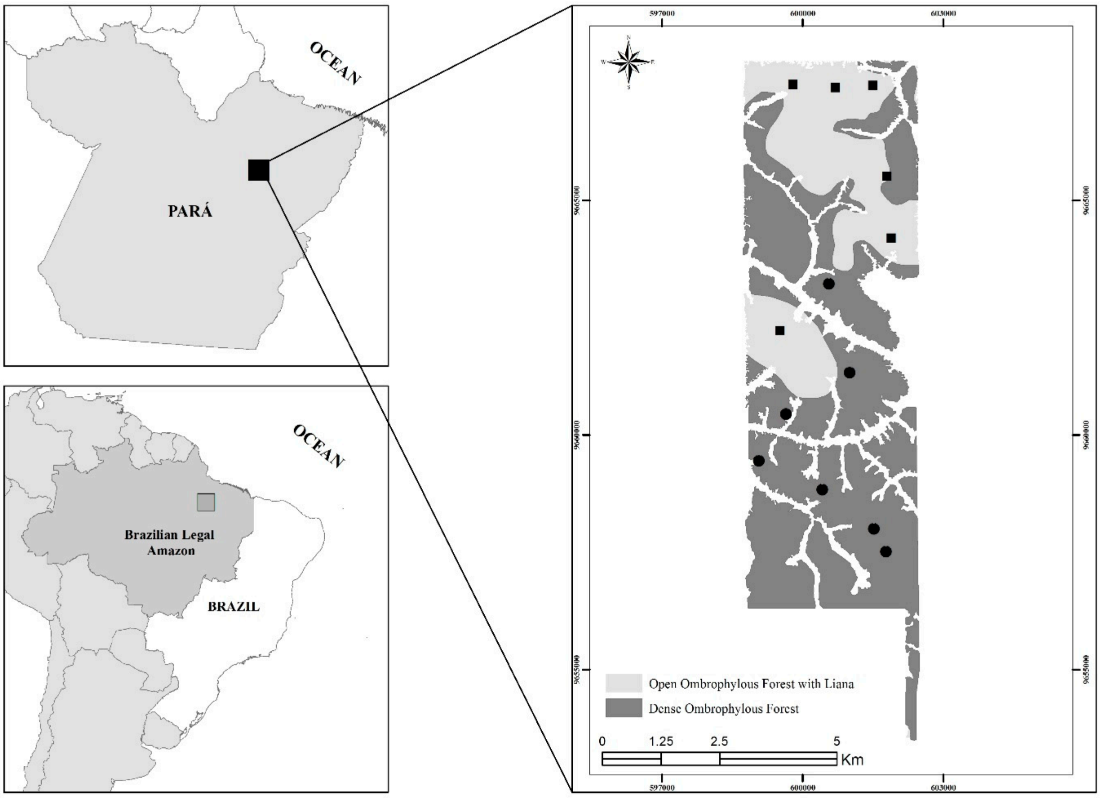

Figure 1. Localization of the Uberlandia Unit forest management area show the principal phytophysiognomies: ombrophilous dense and open forest. The dots in the figure on the right represent plots in ombrophilous dense (circle) and open forest (square).

2.2. Data Sampling

We worked with data from permanent sampling plots, which have been widely used to assess the effects of logging in tropical forests in the medium and long term, in studies of the dynamics and ecology of forests subject to forest logging [19]. This study was carried out in an area of 3500 hectares, possibly having a pseudo-replica effect. Therefore, the randomly distributed permanent plots were adopted in an attempt to obtain the highest representation of the forestry community.

A total of 13 randomly distributed permanent monitoring plots of 50 m $\times$ 50 m (2500 m^2) in size were established in the APU10, of which six were located in the ombrophilous open forest with lianas and seven in the ombrophilous dense forest. A dataset comprising two survey years (2014 and 2016) that included all plants with DBH $\geq$ 32 cm was supplied by the Grupo LN Guerra Company. The first survey was performed between January and February 2014, prior to logging, which took place in June–September 2015. The second survey took place after the extraction was concluded, in January and February 2016. Diameter measurements were taken at breast height (1.30 m) or above buttress roots. A metal plate was placed on each tree to mark the point at which the diameter was measured to ensure consistency in future surveys.

Eye-estimated light exposure (called light exposure throughout the text) was categorized as follows: LF—crown receiving full light; LP—crown with partial vertical light, covered by the crown of nearby trees; LD—crown with some side or diffuse light and covered by nearby trees; LN—not evaluated/no crown. Crown shape was recorded as CC—complete, normal crown; CIr—irregular crown; CIn—incomplete crown; CS—sprouts of trees; CN—no crown. The presence of lianas was recorded as follows: LiN– no lianas; LiH—with lianas but causing no harm to the tree; LiS—with lianas in the crown and stem, strangling the stem or covering the crown, affecting tree growth; LiW—lianas cut alive without damaging tree growth; LiD—lianas cut alive, damaging tree increment.

We collected samples in the study area of the plant species recorded in the inventory of the Grupo LN Guerra Company to corroborate the taxonomic identification, which was conducted in the herbarium of the Northern Agronomic Institute (IAN)—Embrapa Eastern Amazon, Pará state, where voucher samples that included flowers or fruits were deposited.

2.3. Data Analysis

We assessed periodic annual increments in trees with DBH $\geq$ 32 cm using the measurements taken before and after extraction. The data were divided by permanent plots, phytophysiognomy, and survey year. We assessed whether periodic annual increment was different between the plant communities in the contrasting phytophysiognomies and whether light exposure, crown shape, or presence of lianas affected periodic annual increment in each forest type. For this purpose, the periodic annual increment was calculated using the formula recommended by Imaña and Encinas [20] for all individuals measured in 2014 and 2016. Survivorship and health status following the extraction activities were determined with the trunk quality categories of the Embrapa manual [21]. Trees assigned a code of 1 were alive and unharmed, while codes 2 to 4 correspond to live trees with higher damage levels due to the management operations. These values were considered in the periodic annual increment calculation following Imaña and Encinas [20], as follows:

$$\mathrm{PAI} = (\mathrm{D2} - \mathrm{D1})/\mathrm{t}$$

where PAI is the periodic annual increment in diameter (cm), D2 is the diameter of the final measurement, D1 is the diameter of the initial measurement, and t is the time interval in years.

We identified the family distribution of periodic annual increment (gamma distribution) with the package fitdistrplus [22] and applied a GLM test (lme4 package [23]) to compare periodic annual increment between forest types. We then carried out a second GLM analysis to determine the effect of light exposure, crown shape, and presence of lianas as fixed factors and plots as a random factor. Statistical analyses were conducted using RStudio Software version 3.3.3 [24].

3. Results

3.1. Increment in Tree Diameter between Phytophysiognomies

A total of 1322 surviving individuals with DBH $\geq$ 32 cm were measured, comprising 105 species. Of these, 681 individuals were located in the six permanent plots (1.50 ha) of the ombrophilous dense forest, while 640 were located in the seven permanent plots (1.75 ha) of the ombrophilous open forest with lianas. Sixty-one species were found in both environments, of which 73% (45 species) had the highest periodic annual increment. This pattern reflects that a large proportion of species (45 out of 105 managed species) has intraspecific variation in the behavior of individuals, even though they are relatively close between each other.

The first GLM showed that the periodic annual increment varied significantly between the ombrophilous dense forest and ombrophilous open forest with lianas plots (p-value 1.47×10^{-9}; t = -6.091). The average periodic annual increment value in the ombrophilous open forest with lianas (1.28 cm yr^{-1}) was 56% higher than in the ombrophilous dense forest (0.82 cm yr^{-1}).

3.2. Other Factors Affecting the Increment in Tree Diameter between Phytophysiognomies

The GLM analysis showed that light exposure significantly affected the periodic annual increment in the ombrophilous open forest with lianas plots, with shade from nearby trees resulting in lower periodic annual increment values (p-value = 0.000154; t value = −3.785). Trees that had lost their crown also had lower periodic annual increment values (p-value = 0.009822; t value: −2.582). Although the average periodic annual increment was higher in the light exposure category LF (1.538 cm yr^{-1}) than in category LP (1.393 cm yr^{-1}), this increase was not statistically significant (Figure 2).

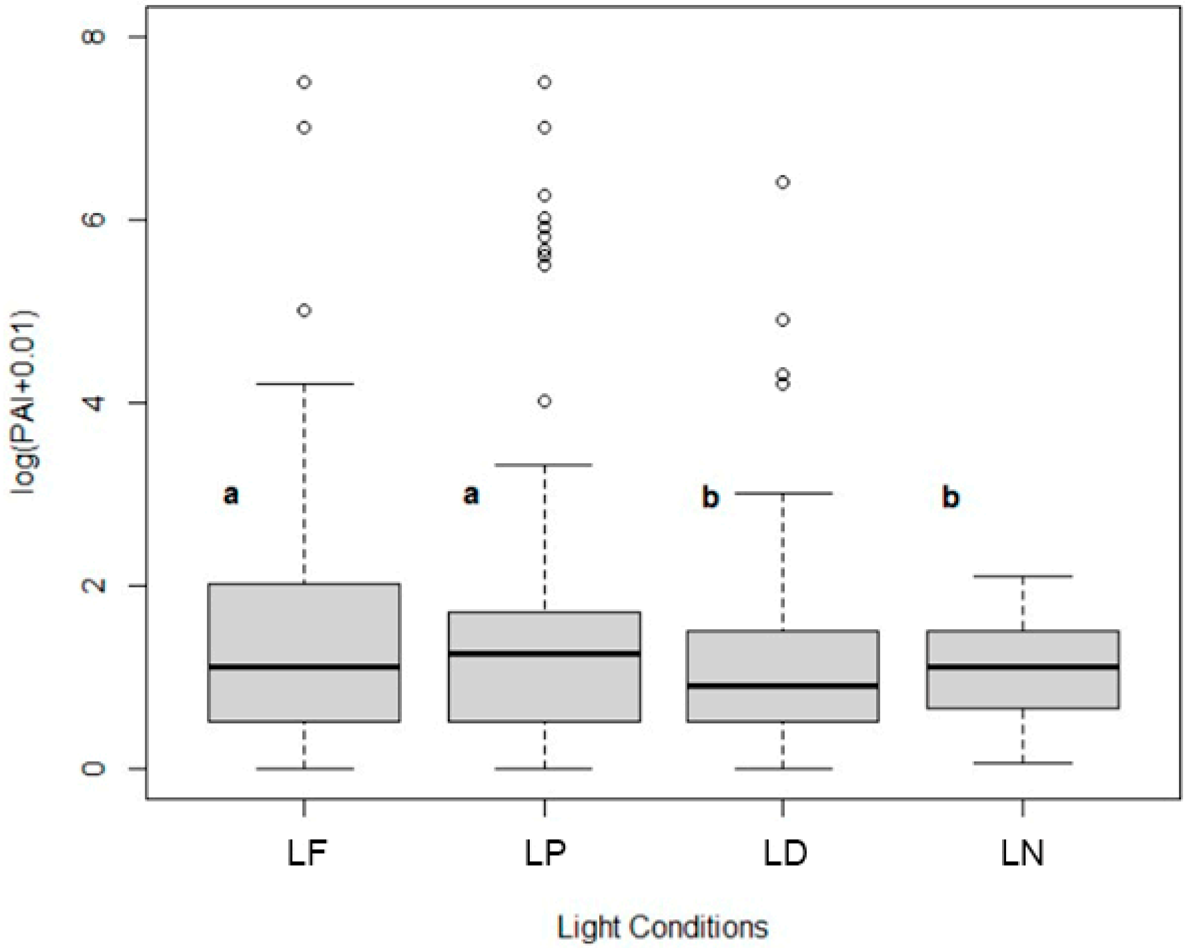

Figure 2. Generalized Linear Model analysis for light exposure in PAI (periodic annual increment) for individuals ≥ 32 cm of DBH in the ombrophilous open forest with lianas. LF—crown receiving full light; LP—crown with partial vertical light, covered by the crown of nearby trees; LD—crown with some side or diffuse light and covered by nearby trees; LN—not evaluated/no crown. Letters "**a**" and "**b**" represent statistical differences. The circles represents outlier values.

In the ombrophilous dense forest plots, both light exposure and crown shape significantly affected the periodic annual increment. We found periodic annual increments to be significantly lower in trees belonging to light exposure category LD (p-value = 8.96×10^{-6}; t value = −4.441). Similar to the ombrophilous open forest with lianas plots, the increase in the periodic annual increment between light exposure categories LF (1.109 cm yr^{-1}) and LD (0.816 cm yr^{-1}) was not significant (Figure 3).

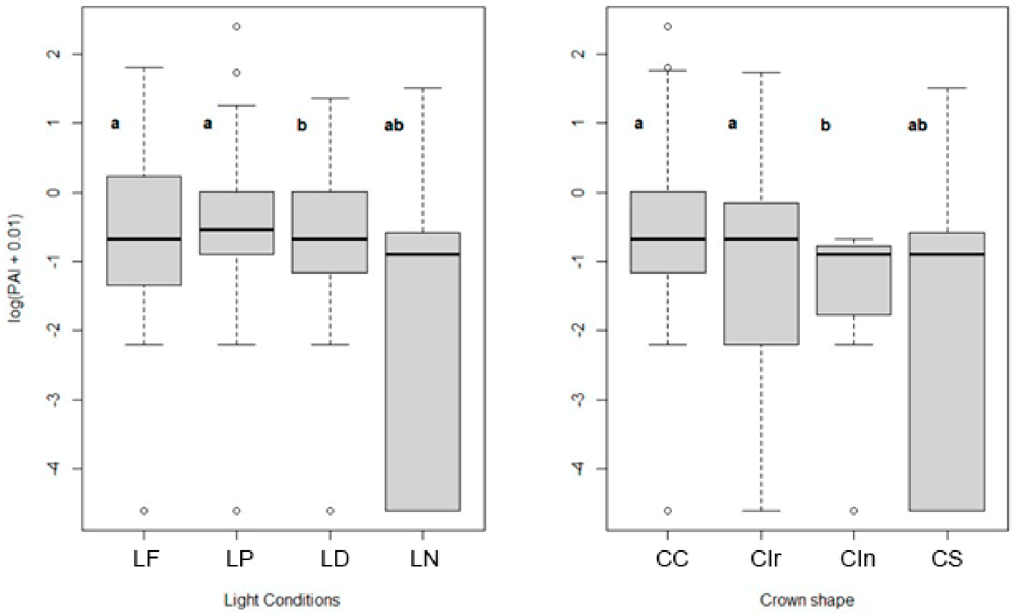

Figure 3. Generalized Linear Model analysis for light exposure, crown shape, and presence of lianas in PAI for individuals $\geq$ 32 cm of DBH in the ODF. LF—crown receiving full light; LP—crown with partial vertical light, covered by the crown of nearby trees; LD—crown with some side or diffuse light and covered by nearby trees; LN—not evaluated/ no crown. Crown shape was recorded as CC—complete, normal crown; CIr—irregular crown; CIn—incomplete crown; CS—sprouts of trees. Letters "**a**", "**b**", "**ab**" represent statistical differences. The circles represents outlier values.

4. Discussion

4.1. Increment in Tree Diameter between Phytophysiognomies

The periodic annual increment analyses showed that annual growth rates were 56% higher in the ombrophilous open forest than in the ombrophilous dense forest. Few large individuals and frequent clearings characterize ombrophilous open forests; high luminosity also predominates at lower strata, unlike dense forests, which have more large trees with interconnected, dense canopies [15].

The higher light exposure in the ombrophilous open forest seems to favor faster growth than in dense forests (Figure 2). This variation reflects plasticity in species' adaptations to different environmental conditions [25]. It is possible that, in dense ombrophilous forests, individuals invest in growing higher because they need to reach the canopy to obtain light. Meanwhile, the greater light exposure in the lower strata of open ombrophilous forests with lianas allows individuals to invest in greater DBH. This light-dependent growth strategy has been observed in the tropical forests of Indonesia by Harja et al. [26], who showed that trees under total light exposure conditions grew 30% less tall than trees under shading conditions.

Pereira et al. [27] analyzed the periodic annual increment in the diameter of 257 species in managed and non-managed areas of the Tapajós National Forest belonging to different DBH classes. The authors found that the highest diameter class (DBH > 45 cm) experienced the greatest periodic annual increment, a finding that was most pronounced in managed areas. This difference may have been due to the opening of the forest canopy by management, which resulted in larger trees receiving more light. Another study reported the highest tree diameter increments in individuals with DBH < 70 cm, especially in the periods immediately following forest management, due to the opening of clearings that stimulated the remaining trees [28]. These findings indicate that our results may be related to changes associated with forest management operations.

A comparison of our results with those of other studies in the Brazilian Amazon [12,13] shows that the forests of the Uberlândia Forest Management Unit have higher periodic annual increment values than elsewhere in the region (Table 1). This difference may be due to our study being restricted to individuals with DBH ≥ 32 cm, which grow faster under management [29,30].

Table 1. Comparison of studies on the periodic annual increment (PAI) for ombrophilous forests in the Brazilian Amazon, considering open and dense forests.

Location	Physiognomy	Forest	DBH (cm)	PAI (cm)	Monitoring (Years)	Reference
Itacoatiara, Silves y Itapiranga-AM	ODF	RIL	≥15	0.27	18	[30]
Paragominas, Para	ODF	RIL	≥10	0.32	10	[31]
Paragominas, Para	ODF	RIL	≥10	0.21	8	[11]
Paragominas, Para	ODF	CO	≥10	0.26	8	[11]
Marcelândia,-Mato Grosso	OOF	RIL	≥17	0.34	6	[27]
Paragominas, Para	ODF	CO	≥10	0.33	3	[10]
Paragominas, Para	ODF	MC	≥10	0.37	3	[10]
Paragominas, Para	ODF	RIL	≥10	0.63	3	[10]
Portel, Para	ODF	RIL	≥32	0.82	2	PS
Portel, Para	OOF	RIL	≥32	1.28	2	PS

ODF, ombrophilous dense forest, OOF, ombrophilous open forest; RIL; reduced-impact logging; CO, control area with no interventions; PS, the present study.

Table 1 shows that the periodic annual increment in diameter tends to decrease over monitoring time in various managed forests of the Brazilian Amazon, a finding that our study repeats. This effect could also have been influenced by the statements made above [31,32], and by the time affecting their growth, which in natural forests is usually expressed as periodic increments in tree diameter and can vary according to the forest type.

4.2. Other Factors Affecting the Increment in Tree Diameter between Phytophysiognomies

We found that light exposure and crown shape affected tree diameter growth in both forests (Figures 2 and 3). Individuals with high shade or damaged crowns had lower periodic annual increment values. Meanwhile, the presence of lianas had no effect on the periodic annual increment. These results echo the findings of Vidal et al. [12] and Vatraz et al. [13], who surveyed trees in the eastern Amazon with DBH ≥ 10 cm three and eight years following extraction, respectively. Souza et al. [32] showed similar findings in a dense forest of the western Amazon surveyed between 16 and 18 years after forest operation for individuals with DBH ≥ 15 cm.

Likewise, Acosta et al. [31], when studying a dense forest of the Tapajós National Forest after 16 years of management operations, showed that trees under full vertical light had the greatest increases in diameter, followed by those under lateral light. Oliveira and Braz [33] found similar results to the present study when analyzing a managed dense forest of the western Amazon, considering trees with DBH > 10 cm. These authors found that tree diameter increased at greater rates in individuals with better crown shape and light exposure.

The latest Brazilian government manual for the Brazilian vegetation types [15] describes ombrophilous open forests as having frequent clearings, few large trees, a lower layer composed of smaller trees, and abundant lianas covering trees and connecting their crowns. Our results indicate that, in this environment, the individuals studied were of intermediate sizes (DBH ≥ 32 cm) and hence were not limited in their growth by the presence of lianas. This was the case even though 55% of trees in the study area had lianas [1].

In the dense ombrophilous forest plots, although 37% of the trees had lianas and the literature describes negative impacts of liana infestation on tree growth [1,34], we found no significant difference between trees with and without vines. This behavior is probably the result of liana management actions. Removal experiments have confirmed that lianas reduce tree growth and other biological characteristics via shading and root competition [35,36]. Liana cutting has been employed as a forest management strategy in the Amazon [37]. This treatment avoids greater damage at the time of tree harvesting by breaking the connection between lianas [38]. In addition, canopy gaps created in the forest will be less likely to become covered by the stems of fallen lianas [37,39].

4.3. Implications for Management

This study showed that:

1—The two vegetation types showed different rates of diameter growth. Indeed, individual species had different growth rates, which has implications for forest management practices. Since this study showed significant differences in tree diameter increments between the ombrophilous dense forest and ombrophilous open forest with lianas, we also suggest that forest management must adopt a typology approach.

2—Low levels of exposure to light and canopy damage caused negative effects on tree growth. Practices that increase light availability, e.g., creating clearings, are widely recognized as beneficial for the regeneration (seedlings and saplings) of species. However, no regulations mandate the application of silvicultural techniques that mitigate the negative effects of light availability on adult individuals of species of commercial interest, ensuring the growth of individuals and the regeneration of exploited species.

3—The management of lianas seems to have an important effect in reducing their negative impacts on both forests.

5. Conclusions

This study found that periodic annual increments in diameter had significant differences between contrasting vegetation types. Crown shape and light exposure affected the periodic annual increment, with lower growth rates among individuals under high shade or which suffered severe damage or total loss of the crown (due to natural or anthropic causes).

Our study is novel because it compares increments in tree diameter between two phytophysiognomies in the same annual production unit, under different conditions. Since we detected significant differences between the forest types (open forests with higher diameter increment), we encourage the scientific community to carry out new studies on forest dynamics using a similar approach to better understand these ecosystems and their response to management operations. This will allow suitable management practices in the reduced-impact systems applied in the Brazilian Amazon and will maximize the economic and biological potential of its forests.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12030704/s1.

Author Contributions: Conceptualization, W.M.F. and E.J.H.-R.; methodology, W.M.F. and E.J.H.-R.; software, G.G.A.d.S.; investigation, E.F.S.M. and W.M.F.; resources, E.J.H.-R. and S.D.B.D.S.; writing—original draft preparation, W.M.F.; writing—review and editing, I.F., I.d.S.M., G.H.S. and S.D.B.D.S.; supervision, E.J.H.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by a scholarship for the first author awarded by PAEC OEA-GCUB and PPGBC/UFPA/CAPES. It also received assistance from LN Guerra in logistical support and database access. Support from PAPQ/UFPA program Procedure No 23073.011035/2019-34 provided funding to translate the article into English.

Data Availability Statement: Data is contained within the article or supplementary material.

Acknowledgments: The authors thank PAEC/OEA, PPGBC/UFPA/CAPES for providing a scholarship to the first author, the company LN GUERRA for all the logistical support and providing the data for the study, the herbarium IAN of EMBRAPA for the help in the identification of the collected botanical material, and PAPQ/UFPA program Procedure No 23073.011035/2019-34 for covering the cost of translation of the article into the English language. We thank UFPA for paying the publication fee, process 23073.017721/2023-03.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Reis, L.P.; Ruschel, A.R.; Coelho, A.A.; Luz, A.S.; Da Silva, R.C. Avaliação do potencial madeireiro na Floresta Nacional Tapajós, após 28 anos de exploração. *Pesqui. Florest. Bras.* **2010**, *30*, 265–281. [CrossRef]
2. Richardson, V.A.; Peres, C.A. Temporal decay in timber species composition and value in amazonian logging concessions. *PLoS ONE* **2016**, *11*, e0159035. [CrossRef]
3. Braz, E.M.; Mattos, P.P.; Verde, M.F.; Basso, R.O.; Canetti, A. *Otimização do Ciclo de Corte na Floresta Amazônica sob o Ponto de Vista Econômico*; Comunicado Técnico N. 402; Embrapa: Belém, Brasil, 2017; 7p.
4. Banerjee, O.; Macpherson, A.J.; Alavalapati, J. Toward a policy of sustainable forest management in Brazil: A historical analysis. *J. Environ. Dev.* **2009**, *18*, 130–153. [CrossRef]
5. Garrett, R.D.; Cammelli, F.; Ferreira, J.; Levy, S.A.; Valentim, J.; Vieira, I. Forests and sustainable development in the Brazilian Amazon: History, trends, and future prospects. *Annu. Rev. Environ. Resour.* **2021**, *46*, 625–652. [CrossRef]
6. Braz, E.M.; Schneider, P.R.; Mattos, P.P.; Selle, G.L.; Thaines, F.; Ribas, L.A.; Vuaden, E. Taxa de corte sustentável para manejo das florestas tropicais. *Ciên. Flo.* **2012**, *22*, 137–145. [CrossRef]
7. Zimmerman, B.L.; Kormos, C.F. Prospects for Sustainable Logging in Tropical Forests. *Bioscience* **2012**, *62*, 479–487. [CrossRef]
8. Vanclay, J.K. *Modeling Forest Growth and Yield: Applications to Mixed Tropical Forests*; CAB International: Copenhagen, Denmark, 1994; 312p.
9. Cook, E.R. A Time Series Analysis Approach to Tree Ring Standardization (Dendrochronology, Forestry, Dendroclimatology, Autoregressive Process). Ph.D. Thesis, The University of Arizona, Tucson, AZ, USA, 1985; 190p.
10. Bigler, C.; Bugmann, H. Growth-dependent tree mortality models based on tree e rings. *Can. J. For. Res.* **2003**, *33*, 210–221. [CrossRef]
11. Filha, I.G. Manejo florestal: Questões econômico-financeiras e ambientais. *Est. Avan.* **2002**, *16*, 91–106. [CrossRef]
12. Vidal, E.; Viana, V.N.; Batista, J.L. Crescimento de floresta tropical três anos após colheita de madeira com e sem manejo florestal na Amazônia oriental. *Sci. For.* **2002**, *6*, 133–143. Available online: http://www.ipef.br/publicacoes/scientia/nr61/cap12.pdf (accessed on 10 October 2019).
13. Vatraz, S.; Carvalho, J.O.; Silva, J.N.; Castro, T.C. Efeito da exploração de impacto reduzido na dinâmica do crescimento de uma floresta natural. *Sci. For.* **2016**, *44*, 261–271. [CrossRef]
14. Pérez, E.I.; Duran, R.; Gerhard, G. Las relaciones liana-árbol: Repercusiones sobre las comunidades arbóreas y sobre la evolución de los árboles. *Interciencia* **2012**, *37*, 183–189.
15. IBGE (Instituto Brasileiro de Geografia e Estatística). *Manual Técnico da Vegetação Brasileira*, 2nd ed.; IBGE: Rio de Janeiro, Brazil, 2012; 272p.
16. Santos, I.V.; Balieiro, S.; Mattos, R.; Ramos, Y.; Santos, R.N.; Quadro, A.G. *Relatório Técnico de Identificação, Manejo e Monitoramento de Florestas de Alto Valor de Conservação (HCVS) da Unidade de Manejo Florestal-UMF Uberlândia*; Grupo LN Guerra: Portel, Brasil, 2016; 103p.
17. Almeida, R. Amazônia, Pará e o mundo das águas do Baixo Tocantins. *Estu. Avan.* **2010**, *24*, 291–298. [CrossRef]
18. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.; Sparovek, G. Köppen's Climate Classification Map for Brazil. *Meteor. Zeits.* **2013**, *22*, 711–728. [CrossRef]
19. Sist, P.; Rutishauser, E.; Claros, M.P.; Shenkin, A.; Herault, B.; Blanc, L.; Baraloto, C.; Baya, F.; Benedet, F.; da Silva, K.E.; et al. The Tropical managed Forests Observatory: A research network addressing the future of tropical logged forests. *Appl. Veg. Sci.* **2014**, *18*, 171–174. [CrossRef]
20. Imaña, E.J.; Encinas, B.O. *Epidometría Forestal*; Universidade de Brasília, Departamento de Engenharia Florestal: Brasília, Brazil, 2008; 72p.
21. Silva, J.N.M.; Lopes, J.C.A.; Oliveira, L.C.; Silva, S.M.A.; Carvalho, J.O.P.; Costa, D.H.M.; Melo, M.S.; Tavares, M.J.M. *Diretrizes para Instalação e Medição de Parcelas Permanentes em Florestas Naturais da Amazônia Brasileira*; Embrapa-CPATU: Belém, Brazil, 2005; 68p.
22. Delignette-Muller, M.L.; Dutang, C. Fitdistrplus: An R Package for Fitting Distributions. *J. Stat. Softw.* **2015**, *64*, 1–34. Available online: http://www.jstatsoft.org/v64/i04/ (accessed on 20 June 2019). [CrossRef]
23. Bates, D.; Maechler, M.; Bolker, B.; Walker, S. Fitting Linear Mixed-Effects Models Using lme4. *J. Stat. Softw.* **2015**, *67*, 1–48. [CrossRef]
24. RStudio Team. RStudio: Integrated Development Environment for R. RStudio Team: Boston, MA, USA, 2015; Available online: http://www.rstudio.com/ (accessed on 20 June 2019).
25. Sultan, S.E. Phenotypic plasticity for plant development, function and life history. *Trends Plant Sci.* **2020**, *5*, 537–542. [CrossRef]
26. Harja, D.; Vincent, G.; Mulia, R.; Van Noordwijk, M. Tree shape plasticity in relation to crown exposure. *Trees* **2012**, *26*, 1275–1285. [CrossRef]
27. Pereira, C.J.; Macedo, S.J.; Alves, L.J. Growth rate of a terra firme rain forest in brazilian amazonia over an eight-year period in response to logging. *Acta Amaz.* **2004**, *34*, 209–217. [CrossRef]
28. Gourlet-Fleury, S.; Mortier, F.; Fayolle, A.; Baya, F.; Ouédraogo, D.; Bénédet, F.; Picard, N. Tropical forest recovery from logging: A 24 year sil-vicultural experiment from Central Africa. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2013**, *368*, 20120302. [CrossRef]

29. Teixeira, L.M.; Chambers, J.Q.; Silva, A.R.; Lima, A.J.; Carneiro, V.M.; Dos Santos, J.; Higuchi, N. Projeção da dinâmica da floresta natural de Terra firme, região de Manaus-AM, com o uso da cadeia de transição probabilística de Markov. *Acta Amaz.* **2017**, *37*, 377–384. [CrossRef]
30. Oliveira, E.K. Dinâmica de Uma Floresta Tropical Manejada na Amazônia Oriental. Master's Thesis, Universidade de Brasília, Brasilia, Brasil, 2016; 181p.
31. Acosta, D.H.; Silva, J.N.; Carvalho, J.O. Crescimento de árvores em uma área de terra firme na flora nacional de Tapajós após a colheita de madeira. *Ciên. Agrá.* **2008**, *50*, 63–76.
32. Souza, M.A.; Azevedo, C.P.; Souza, C.T.; França, M.; Neto, E.L. Dinâmica e produção de uma floresta sob regime de manejo sustentável na Amazônia Central. *Floresta* **2007**, *47*, 55–63. [CrossRef]
33. Oliveira, M.V.; Braz, E.M. Estudo da dinâmica da floresta manejada no projeto de manejo florestal comunitário do PC Pedro Peixoto na Amazônia Ocidental. *Acta Amaz.* **2006**, *36*, 177–182. [CrossRef]
34. Ingwell, L.L.; Wright, S.J.; Becklund, K.K.; Hubbell, S.P.; Schnitzer, S.A. The impact of lianas on 10 years of tree growth and mortality on Barro Colorado Island, Panama. *J. Ecol.* **2010**, *98*, 879–887. [CrossRef]
35. Whigham, D. The influence of vines on the growth of Liquidambar styraciflua L. (sweetgum). *Can. J. For. Res.* **1984**, *14*, 37–39. [CrossRef]
36. Ewango, C.E.N.; Bongers, F.; Makana, J.R.; Poorter, L.; Sosef, M.S.M. Structure and composition of the liana assemblage of a mixed rain forest in the Congo Basin. *Plant Ecol. Evol.* **2015**, *148*, 29–42. [CrossRef]
37. Gerwing, J.J. Testing liana cutting and controlled burning as silvicultural treatments for a logged forest in the eastern Amazon. *J. Appl. Ecol.* **2002**, *38*, 1264–1276. [CrossRef]
38. Vidal, E.; Johns, J.; Genving, J.J. Vine management for reduced-impact logging in eastern Amazonia. *For. Ecol. Manag.* **1997**, *98*, 105–114. [CrossRef]
39. Rocha, E.X.; Schietti, J.; Gerolamo, C.S.; Burnham, R.J.; Nogueira, A. Higher rates of liana regeneration after canopy fall drives species abundance patterns in central Amazonia. *J. Ecol.* **2020**, *108*, 1311–1321. [CrossRef]