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The Sustainable Expansion of the Cocoa Crop in the State of Pará and Its Contribution to Altered Areas Recovery and Fire Reduction

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Abstract

The state of Pará, located in the Amazon region of Brazil, has observed in recent years an increase in cocoa (*Theobroma cacao*) cultivation and has become the largest producer in Brazil. Due to its physiological characteristics, cacao is cultivated in native forests understory or under the shade produced by fast-growing native tree species, serving as an important species for restoration of degraded areas. However, mapping and monitoring cocoa plantation using optical sensor images is a challenge given its botanical and arboreal characteristics that can be confused with other native species at various stages of secondary regrowth. Agroforestry systems are important components of sustainable production in the Amazon and our work sought to better describe the evolution of cocoa plantations in terms of their historical expansion, farming properties practices, land use transitions and fire regimes. Our findings to analyze the relationships between cocoa plantations and hotspots, data from the INPE's reference satellite between the years 2004 to 2020 were used in this study, polygons classified as cocoa areas, generated by the MapCacau research project, were used, in a total of 69,904 hectares distributed throughout the state of Pará. Finally, we used the protected areas' official limits in the State of Pará to analyze the plantations' occurrence in regions in discordance with environmental legislation. The data show that cocoa-producing properties are statistically fewer than non-producing properties, as well as having lower deforestation rates. In our study, we observed that 52,778 hectares (88.87%) of the cocoa area planted had already been deforested by the year 2008—the threshold of deforestation defined by Brazil's Forest Code. It was also possible to verify that approximately 20,900 hectares continue to be mapped as forest by PRODES, despite our field data identifying cocoa plantations shaded by explored forest in these areas. Regarding the crop's formation, the data show a tendency to convert pasture areas to cocoa plantations, proving that cocoa farming expansion in the State of Pará is an important activity for degraded areas recovery and not a main driver of deforestation. The finding that cocoa plantations are still classified as forest by PRODES and project TerraClass highlights the difficulty of mapping this crop using orbital images in a traditional way. Through this paper, it was possible to observe that due to the typical characteristics of perennial crops (cocoa), fire points showed a significant reduction in the mapped areas, highlighting that the expansion of cocoa plantations in the state of Pará contributed to soil protection, to the reduction of greenhouse gas emissions into, in addition to contributing to the generation of jobs and revenue. Finally, we found about 99.54% of the cacao plantations in the State of Pará are located outside of any preservation area, indigenous land or quilombola settlement.

Keywords

Amazon, Machine Learning, Participative Mapping, Pará, Cocoa Amazon, MapCacau

1. Introduction

Since the beginning of settlements and highway construction in the 1950s, the Eastern Amazon has gone through intense and dynamic land use change, becoming one of the most anthropized areas in the Amazon Biome. This has resulted in mature forest cover loss, reduction of biodiversity and a decrease in the forest potential to function as carbon sink [1]-[6]. However, in the last few decades improved land cover products, such as TerraClass and MapBiomas, show an increase in secondary vegetation areas along with a decrease in mature forest areas [7]. Areas of secondary vegetation also serve to absorb the demand for new opening areas reducing deforestation [8]. The expansion of secondary vegetation in older colonization areas in the Amazon may be associated with the productive system, such as a natural technique of soil fertilization [9].

Thus, there is a real need to add value to products originating from the forest (mature or secondary), to ensure both the biodiversity of fauna and flora, and for the healthy management of ecosystem services [10]. One evidence that points to the importance of the bioeconomy is the potentialization of the "Green Economy", which is the result of the balance between the rational exploitation of natural resources, the well-being of society, and the minimization of environmental risks, adding value to natural resources [11]. One example is the valorization by the international market of products labeled with "green seals". These are products that do not originate from areas of illegal deforestation and contribute both to enhancing the implementation of perennial crops in degraded areas and to enriching areas of secondary vegetation. By adding economic value to vegetated areas and preserving the environment. Based on this concept, Agroforestry Systems (AFSs) emerged, which in essence promote, in a sustainable way, the use of local species for food production as a source of income in the Amazon [12] [13].

[14] demonstrates that the implementation implantation of AFSs or Perennial crops (with trees or shrubs) enhances atmosphere carbon sequestration, contributes to the recovery of degraded areas and provides a sustainable source of income for family farmers.

In the state of Pará, one AFS that has gained emphasis is the cultivation of cocoa [15] for its great potential for enriching areas of secondary vegetation, a fact that ensures greater permanence of the feature in the landscape, as well as having great national and international demand for chocolate [16]. The state is the largest cocoa producer in Brazil responsible for 50% of the country's production [17], with an estimated production of 128,961 tons/year being most of it (68.57%) cultivated in family farming systems [18]. However, remote monitoring and identification of cocoa cultivation have proven to be a challenge due to its understory cultivation character, the prevalence of cloud cover and the territorial dimensions of the state. Mapping of agricultural land in the Amazon is regularly performed by research institutions, but these efforts tend to focus on annual crops and rely on optical images from medium spatial resolution sensors for which availability can be impacted by cloudiness making it difficult to identify targets, especially in the rainiest months [19].

One approach to reducing such challenges is participatory mapping, which has proven to be an effective technique for surveying spatial information. It consists of mapping assisted by the communities inserted in the study area with the objective of facilitating the identification of the desired features in the community's territory [20] [21] [22]. Participatory mapping combined with satellite images increases the accuracy of the mapping of cultivations that are difficult to identify by spectral or optical attribute through visual interpretation [23]. It is, therefore, an important tool in territorial planning, management and monitoring of understory crops given the limitations of spectral sensors.

Thus, the aim of this article is to characterize the properties of cocoa production. As well as identifying the relationship between cocoa plantations with deforestation, land use, fires and protected areas, in the state of Pará.

2. Study Area

The research area consists of state of Pará in the Brazilian Amazon, the largest cocoa producer in the country [17]. Pará has a territorial extension of 1.2 million km², of which 69% consisted of forest in 2019 and 22% of various land covers that replaced forest [24]. The 10 municipalities with the highest production, in percentage of the state's total cocoa harvest, are: Medicilândia (34.7%), Uruará (13.5%), Anapu (6.7%), Brasil Novo (6.2%), Placas (6.02%), Altamira (5.22%), Vitória do Xingú (4.04%), Senador José Porfírio (3.61%), Tucumã (2.85%), and Pacajá (2.76%). In addition to these municipalities, there is also a cocoa production in: Trairão, Tomé-Açu, São Félix do Xingu, São Domingos do Araguaia, Rurópolis, Ourilândia do Norte, Novo Repartimento, Itupiranga, Itaituba, Igarapé-Miri, Brejo Grande do Araguaia, Aurora do Pará, Acará, Abaetetuba and Água Azul do Norte (**Figure 1**). The mapped municipalities are divided into zones with distinct edaphoclimatic characteristics called: Transamazonica, Southeast Pará, Northeast Para and Baixo Tocantins [25]. It is noteworthy that the Medio Amazonas region still exists but was not included in this work.

3. Methods of Data Processing

3.1. Cocoa Mapping—MapCacau Project

The cocoa mapping described in this study is part of a project titled MapCacau

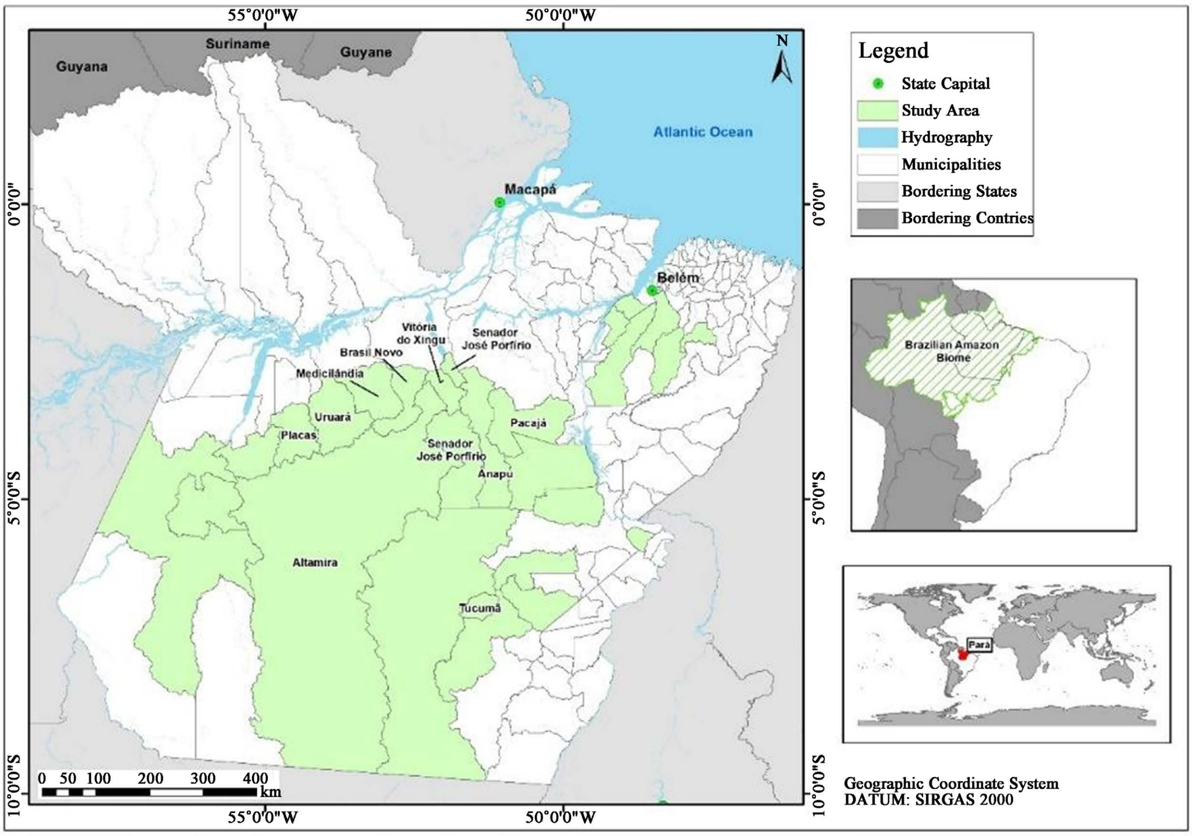

Figure 1. Location map of municipalities with cocoa production in the state of Pará.

led by the Brazilian EMBRAPA Amazonia Oriental. The detailed steps are presented in the following 3 subsections.

3.2. Satellite Images

Satellite images from the Planet series were used, provided by Secretary of State for Environment and Sustainability (SEMAS) and processed in the remote sensing laboratory of EMBRAPA Eastern Amazon.

Considering the effectiveness of these methods, images from Dove satellites were used, printed in 1:50,000 scale over an A1 size paper. To carry out the participatory mapping, image charts containing mosaics of high spatial resolution images from the Google Earth platform were printed, in order to provide producers with a more detailed view of the territory, and thus enable a better identification of the boundaries of their properties and plantations. Thus, the producers made the visual delimitation of their properties, and indicated their cocoa growing areas, with support from EMBRAPA's geoprocessing technicians. This procedure was replicated in all the municipalities analyzed in this project.

3.3. Environmental Rural Register

According to the Ministry of Environment brasilian (Ministério do Meio Ambiente 2022) the Environmental Rural Register (ERR) "is mandatory for all rural properties and integrates environmental information, being a database for control, monitoring, combating deforestation and environmental and economic planning".

This dataset is crucial for the identification of productive systems in the Amazon as it describes detailed land tenure information. Thus, we combine the land property delimitations obtained from ERR (https://www.car.gov.br/) with the satellite images and farmers's input to determine properties with established cocoa cultivation. From this analysis, we were able to determine cacao plantations' average size and how they relate to deforestation and fire occurrence between 2008 and 2019.

3.4. Participatory Image Classification Mapping (PICMM)

The Participatory Image Classification Mapping Method (PICMM) [20] [21] used here consists of a visual interpretation and delimitation of cocoa cultivation properties using Planet high spatial resolution satellite images overlaid with the ERR data. We chose to use of PICMM over traditional methods of digital classification given the limitation of an automatic classification of cocoa plantation using optical images due to the understory character of cocoa cultivation methods in the state of Pará.

The classification is performed jointly by the local cocoa producers and the technical staff from the EMATER and CPLAC rural extension institutions. This activity was conducted over 7 field missions in 8 municipalities along nearly 3000 km of roads in the State of Pará.

The information collected from farmers was digitized and a map with the cocoa producing property locations was generated. The mapping was validated with field data, in order to verify the accuracy and precision of classification.

The validation of the planting points occurred based on the proximity of the roads, and the possibility of access to the sites, because they were located on private properties, the initial proposal was to validate all the points indicated by the farmers or identified in the laboratory. The validation points enabled mapping rectification of cocoa plantation identified using PICMM.

The validation of the planting points occurred based on the proximity of the roads, and possibility of access to the sites, due to being located on private properties, the initial proposal was to validate all points indicated by farmers or identified in the laboratory.

The mapping of areas with cocoa cultivation proved to be effective through participatory mapping associated with high-resolution images in a research carried out by [23] [26].

3.5. Deforestation Data

The dynamics of land use in the Amazon respond to various drivers, among them the set of environmental laws, regulations, and enforcement [27]. Thus, we set the baseline for land use changes related to cocoa production to star. The expansion of a productive system in the Amazon normally raises discussions about the impacts on forest cover. The data generated by the National Institute for Space Research (INPE) regarding the Satellite Monitoring of Deforestation in the Brazilian Amazon Forest (PRODES-Amazônia) it allows an analysis of anthropic actions dynamics in the Amazon [24] [28]. The selection of samples from properties without cocoa production was random in the same amount as the total of properties with cocoa production. Deforestation data were cut for properties with and without cocoa production in order to identify whether there is a relationship between deforestation and expansion of cocoa plantations. It is important to emphasize that the data from INPE's PRODES (2008) was used as a baseline for the spatial analysis, as this is the date of creation of the Brazilian Forest Code [29].

3.6. Land Use and Cover

The land use data used in this work were obtained through the TerraClass project [30] for the years 2004, 2008, 2010, 2012 and 2014. Given the perenniality of the cocoa crop, it is important to observe the temporal dynamics of land use using consistent, public, and official data.

The use of TerraClass project data allowed qualifying the deforestation identified by PRODES that coincided with cocoa properties. Thus, for the multitemporal analysis of land use and land cover in cocoa properties, transition matrices were used [31] [32].

3.7. Active Fires (AF)

Even though the cocoa mapping was conducted for one snapshot in time (year

2019), it was used as a reference to evaluate the temporal behavior of fires in the surrounding areas of cocoa plantation in 2020 and at every 4 years going back to 2004. The assumption is that the implementation of cocoa changes the use and prevalence of fires in and around plantations as the land use evolves from more fire prone covers (ex: pasture) to cocoa.

The satellite active fires product used here combines data from the Aqua and Terra satellites and is the primary source for the National Institute for Space Research Burn Program (https://queimadas.dgi.inpe.br/). The data was obtained for years 2004 to 2020 at a 4-year time step and it consists of the geographical coordinates of the center of a pixel of 1 km by 1 km resolution, within which an active fire was detected. It's important to clarify that an active fire reported as occurring at a certain geographical coordinate could have in fact been detected anywhere within the 1 km by 1 km pixel or roughly within a 500 m radius of the reported coordinate.

We choose to evaluate the prevalence of fires in and around cocoa plantations by determining the smallest distance between an active fire and a mapped cocoa plantation for every fire within a year, following the methodology of [33]. The cocoa plantation and fires co-location steps consist of first establishing a Burning Influence Zone (BIZ) by defining a buffer of 500 m radius around a cocoa farm. This is done to enable the co-location of cocoa plantations with the 1 km by 1 km active fires spatial resolution used in this study. Then the BIZs are overlaid with the active fires and counted inside the BIZs and buffer.

4. Results and Discussion

4.1. Characterization of Cocoa Plantations in the State of Pará

Figure 2 shows the 4 different sectors in Pará where the PICMM was conducted. The final mapped planted area is estimated at 699.05 km^2 (**Table 1**). The municipalities with highest cocoa production (in tons) are located along the Trans-Amazon Highway with Medicilândia and Uruará corresponding to over 50% of the entire state's production and equivalent to more than 62 thousand tons of cocoa [17]. Medicilândia is also the municipality with the largest planted area (24,957 ha) followed by Tucumã (11,885 ha), although cocoa yield in the latter is lower given its crops are in an earlier stage of development, corresponding to almost 3% (3,680 tons) [17].

The PICMM, part of the MapCacau initiative, identified 2002 properties where cocoa is produced in Pará. These properties were then cross-referenced with the Environmental Rural Register (ERR) data and an analysis of average property size was performed. We also randomly selected 2002 properties with production systems other than cocoa. **Figure 3** shows that properties where cocoa is produced, the properties are smaller than those with other production systems. These differences are statistically significant regardless of the region in Pará. Smaller properties are typically related to family systems [34] and this result is consistent with the latest Brazilian Agricultural Census that indicates that

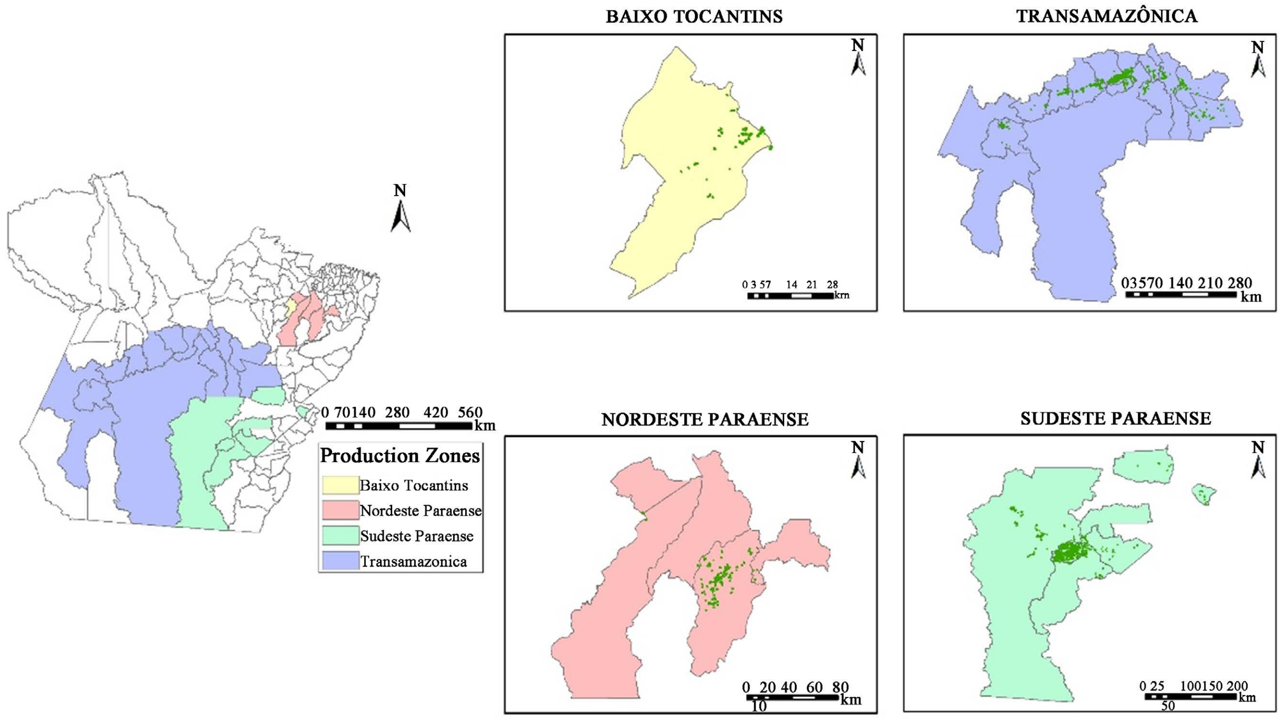

Figure 2. Mapped area of cocoa plantations in the State of Pará by productive regions.

Table 1. Cocoa plantation area in mapped municipalities.

Municipalities	Area (km²)	Percentage of total area (%)	Average production yield (kg/ha) (IBGE, 2019)	Municipalities	Area (km²)	Rate (%)	Average production yield (kg/ha) (IBGE, 2019)
Abaetetuba	0.78	0.1%	313	Ourilândia do Norte	10.33	1.5%	749
Acará	1.08	0.2%	680	Pacajá	6.56	0.9%	650
Água Azul do Norte	1.39	0.2%	733	Parauapebas	0.89	0.1%	800
Altamira	4.37	0.6%	1188	Placas	29.39	4.2%	750
Anapu	12.71	1.8%	1272	Rurópolis	3.26	0.5%	725
Aurora do Pará	1.12	0.2%	800	São Domingos do Araguaia	1.09	0.2%	900
Brasil Novo	70.5	10.1%	1108	São Félix do Xingu	13.6	1.9%	800
Igarapé-Miri	5.93	0.8%	349	Senador José Porfírio	5.85	0.8%	1121
Itaituba	2.47	0.4%	500	Tomé-Açu	40.03	5.7%	725
Itupiranga	0.28	0.0%	800	Trairão	2.51	0.4%	500
Medicilândia	249.57	35.7%	1014	Tucumã	118.85	17.0%	800
Moju	0.95	0.1%	450	Uruará	91.56	13.1%	1050
Novo Repartimento	11.6	1.7%	600	Vitória do Xingu	12.38	1.8%	1010
Total				**699.05**			

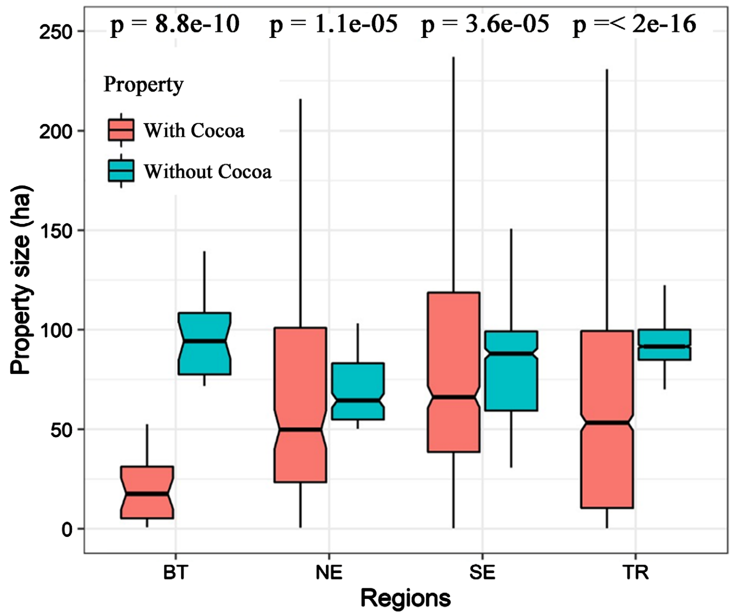

Figure 3. Average size of properties present in the ERR, with and without cocoa.

86.48% of the properties with cocoa plantations in the studied municipalities use family labor [35]. This is a trend in developing countries, estimating the involvement of more than 30 million smallholders worldwide in family production [23]. In addition, this generation of income and production in small rural properties fixes the man in the countryside, minimizing the rural exodus, which preserves local culture, food, and traditions [12] [13]. Scientific evidence indicates that smaller farms have smaller increases in surface temperature and reductions in rainfall compared to large farms [36].

4.2. Cocoa Plantations and Deforestation

Use under the Brazilian Forest Code of 2012, 50% - 80% of a property in the Amazon, must be kept under native forest cover as a Legal Reserve (LR). The Code stipulates that forest areas converted (beyond the maximum amount permitted) after July 2008, are required to be restored to native tree vegetation. Being cocoa a native tree of the Amazon, its cultivation is recognized as restoration under the law, which turned cocoa growing an attractive proposition to farmers [34]. 2008 was also the year the state of Pará passed legislation to promote cocoa production as a mean of restoration in degraded forest areas [12] [13]. Even though we lack information about the year the identified properties were implemented, it is fair to assume it was likely in the past 10 - 15 years given that the area cultivated nearly doubled from the 2000-2009 to the 2010-2016 period [37] in the state of Pará. We thus investigate whether properties currently identified by MapCacau were implemented in deforested land using the year 2008 as a baseline. The assumption is that cacao growing has increased since then motivated by both restoration demands required by law and by a growing market demand for sustainable Amazonian products [38].

By overlapping the identified cocoa growing properties in MapCacau with PRODES deforestation data from 2008, we found that 52,778 hectares (75%) of a total of 69,905 hectares identified had already been deforested by the year 2008, indicating that cocoa plantations did not directly replace forests for their implementation (**Figure 4**). The remaining 25% of properties were not necessarily implemented following deforestation as the pathway of land cover change may follow intermediate steps.

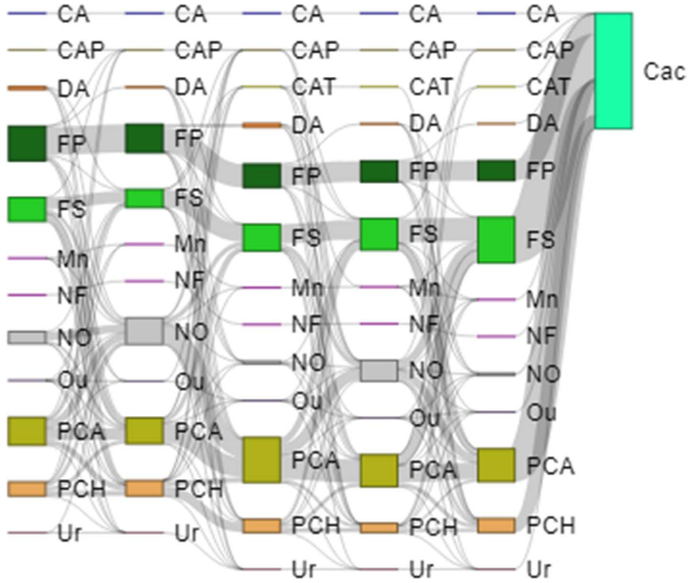

Figure 4. Sankey plot with the landscape trajectory of cocoa properties.

Table 2. Quantification of Sankey's graph usage trajectories.

Legend	Class	Area (ha)
CA	WATER BODY	37.83
CAP	PERENNIAL AGRICULTURE	59.63
CAT	TEMPORARY AGRICULTURAL CULTURE	0.5
DA	DEFORESTATION IN THE YEAR	1678.94
Mn	MINING	19.83
NF	NON FOREST	15.28
NO	NOT OBSERVED	7288.32
Ou	OTHERS	96.25
PCA	CULTIVATED BUSHING PASTURE	16,899.05
PCH	HERBACEA CULTIVATED PASTURE	8453.76
Ur	URBANIZED	11.99
FP	PRIMARY FOREST NATURAL VEGETATION	20,910.11
FS	SECONDARY FOREST NATURAL VEGETATION	14,434.13
Cac	COCOA	69,904.63

We proceed to determine the evolution of land cover classes for the entire sample of mapped cocoa properties for the years 2008, 2010, 2012 and 2014 using land cover classification of TerraClass using Sankey's method (**Figure 4**). The trajectory of land cover change reveals that 20,900 hectares, 29.9% of the total mapped with cocoa, continues to be mapped as forest by TerraClass in the year 2014 (**Table 2**). This suggests that the character of cocoa plantation, which is traditionally introduced in the understory of large trees, appear in satellite images as forests. This reinforces the modest alteration caused in the landscape with the introduction/expansion of the cocoa plantation, and thus contributing to the maintenance of a landscape with forest characteristics. This also highlights the difficulty of mapping cocoa plantations using only orbital images of optical sensors, in the traditional way, due to similar characteristics in the spectral responses.

We can also see those 14,434 hectares, 20.6% of the total mapped with cocoa, correspond to areas of secondary vegetation in TerraClass (**Table 2**). This result was expected, as the spectral behavior of secondary vegetation is similar to that of perennial crops cultivated in the understory of large trees [35]. The expansion of plantations in areas identified as secondary vegetation and explored forest highlights that the practice of natural shading, necessary for the development of the cocoa trees, has been practiced in some regions of the state.

Our results, however, bring up the issue discussed by [35] related to the possibility of increased deforestation in tropical regions in the production of commodities due to the integration of global markets. It is possible to observe a conversion, still small (2.4%) of forest areas for cocoa cultivation. This transition should be observed in the coming years and the target of government actions to curb such conversions that could be of great harm to the State due to the association of the expansion of the cocoa culture with the deforestation of the Amazon.

As important as understanding the relationship with deforestation, the work sought to identify the main types of land use that contributed to the formation of cocoa plantations over the years using the combination of data from the TerraClass project.

Despite the lack of TerraClass data for all the years worked, based on field surveys (**Table 2**), we can state that this is the dynamics of expansion in the region, as the data corroborates with the oral reports of the visited communities and mapped by the MapCacau project.

The high cost of converting the opening of new areas, through cutting and burning the forest, should also be considered as one of the factors responsible for this practice, as the use of areas that have already been altered relieves the producer of the cost of implementing the cocoa tree plantation.

Therefore, it can be seen that in the region there is a perception by the producer of economic and environmental advantages, in expanding their activities through areas previously explored by various productive activities, beyond forest exploitation regions (without cutting), as there is a need for cocoa plant culture to use shaded environments [15], especially in the first years of implementation because it reduces the investment cost, generating greater profit for the activity.

Another important aspect to be considered refers to inspection by the environmental agencies responsible for combating deforestation on rural properties. It is also important to emphasize the pressure exerted by society, exporters, and the State Government to reduce deforestation as it contributes positively to improving the region's image in relation to the proposed development model, that is, for producers to use areas previously altered for the expansion and consolidation of the sector [39] [40].

Another relevant aspect was the observation of the presence of secondary vegetation in this context, as one of the production models used in the Amazon is through the use of natural shading for cocoa farming, as well as for use in Agroforestry Systems. Normally, these systems are not mapped by the TerraClass project because they have a spectral behavior similar to natural regenerations in the Amazon.

With the identification of cocoa producing properties, it was possible to observe the lowest rates of deforestation in these properties compared to other properties that did not plant cocoa in the period between 2008 and 2019 (**Figure 5(a)** and **Figure 5(b)**). The characteristics of family farming in the Amazon, with a smaller amount of labor and less investment, can influence this dynamic, in addition to the observation that the expansion of the crop, preferably, occurs in areas with a history of past deforestation, corroborating the results of [41]. According to the author, the patterns associated with deforestation and secondary vegetation are linked to the size of the owner and the type of cultivation, with small producers tending to preserve more, as well as demonstrating their importance for the transformation of livestock landscapes into landscapes with forest characteristics, helping to preserve the environment. This result, together

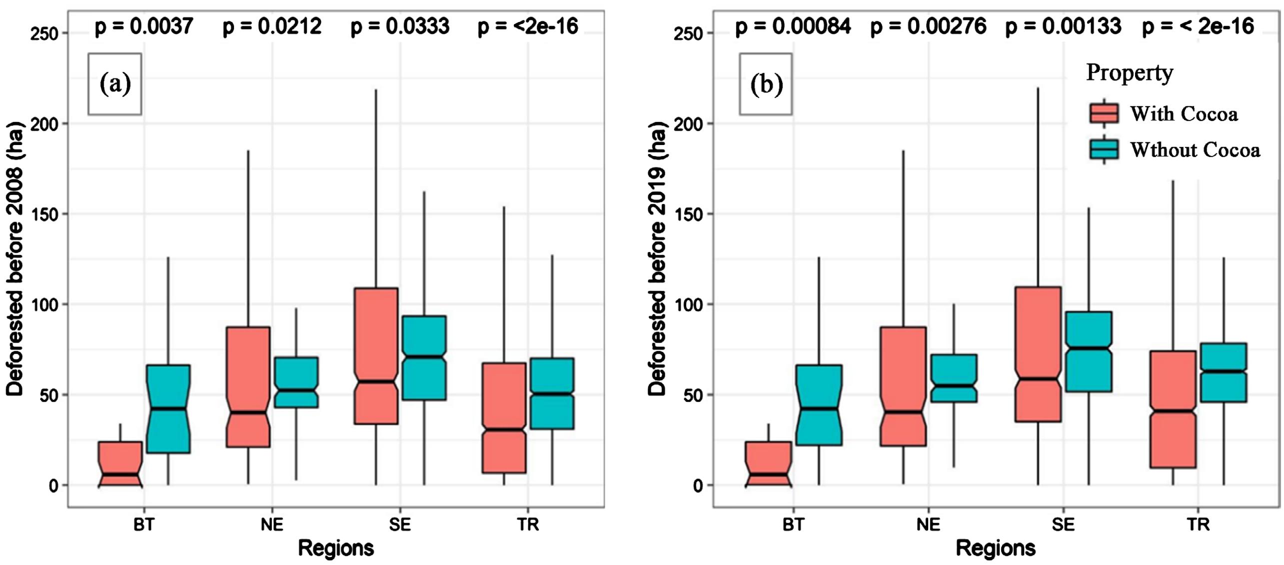

Figure 5. Deforested area on properties with and without cocoa, by zone: (a) until 2008 (b) until 2019.

with the size of the property, corroborates the information provided by local technicians when they state that the cocoa plantation has expanded into family properties, as well as being in accordance with the last agricultural census (2017), which points out about 86.48% of cocoa properties are in this category. Thus, farming is extremely important to generate income for the communities and provides an improvement in the quality of life of producers due to the gains obtained from the almond's sale.

The observation that cocoa-producing properties deforest significantly less than the others (**Figure 5(a)** and **Figure 5(b)**) and that 75% of the current area mapped with cocoa by the MapCacau Project was already deforested in 2008 led to the search for answers to explain how the expansion of the activity is happening in the State of Pará. Thus, it was possible to prove the importance of cocoa plantations for altered areas recovery, as well as favoring the emergence of agroforestry landscapes, also being an extremely important activity for the maintenance of exploited primary forests.

Furthermore, agroforestry systems with cocoa promote a storage of 2.5 times more carbon than cocoa in monoculture, as well as promote protection against temperature extremes [34]. Therefore, we see the importance of agroforestry systems, which are considered essential to reduce the vulnerability of agricultural systems to climate change [42]. This information is in line with the observations carried out in the field referring to the reports of technicians stating that the conversion of primary forest for the planting of cocoa is not observed.

Regarding the formation of cocoa plantations, the work shows that there is a tendency to convert pasture areas to cocoa plantations, proving that the expansion of cocoa plantations in the State of Pará is an important activity for the altered areas recovery.

4.3. Cocoa Plantations and Fires

Even though cocoa mapping was based on field information collected between the years 2018 and 2019, the plantation polygons were used to evaluate fire occurrence in and around cocoa cultivated land at an interval of 4 years between 2004 and 2020 (**Figure 6**). This approach rests in the assumption that the introduction of cocoa will result in changes in fire occurrence as the land use evolves from land covers, such as pasture, that use fires to manage pests to cocoa plantation.

Section the occurrence of fires in the studied regions. Based on these polygons, it was possible to observe that over the years, there is a significant increase in the minimum distance between the hotspots and the current cocoa polygons.

Considering that our data show the expansion of plantations in altered areas, such as pastures, we conclude that since the introduction of cocoa, there is a reduction in the practice of using fire on the property, increasing the distance from plantations once the losses for the producer are great due to the high investment of money and labor to introduce and maintain this productive system.

Based on the results presented in **Table 3**, it was possible to identify an amplitude

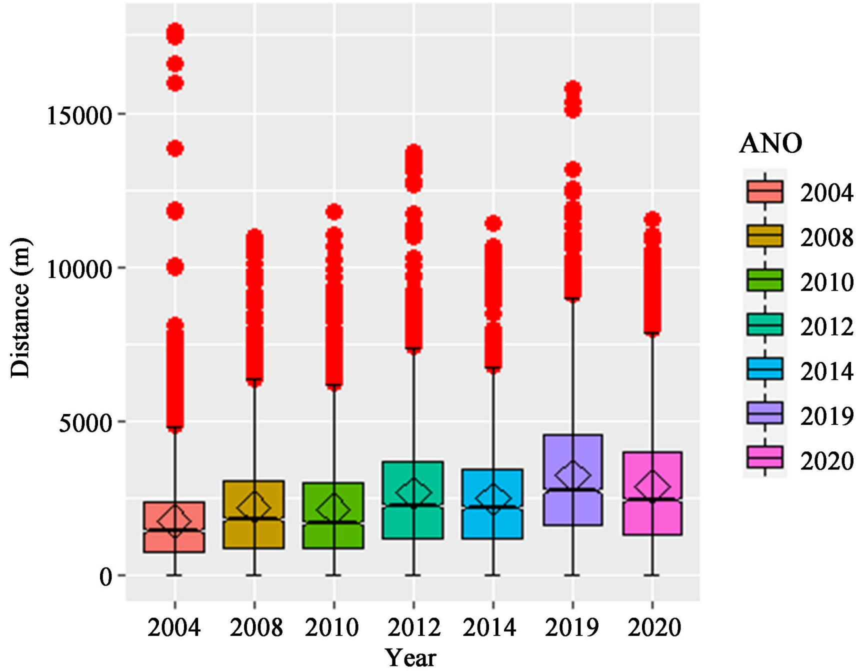

Figure 6. Minimum distance between hot spots and cocoa properties.

Table 3. Annual number of hotspots in cocoa producing municipalities and number of hotspots in areas of influence of fires.

Year	Hot Spots		Proportion of BIZ Hot Spots in relation to the total
	BIZ (+)	Total	(%)
2004	465	30.629	1.52
2005	492	34.104	1.44
2006	383	25.341	1.51
2007	395	29.264	1.35
2008	357	22.455	1.59
2009	275	18.647	1.47
2010	353	26.478	1.33
2011	168	11.254	1.49
2012	225	16.735	1.34
2013	116	8.190	1.42
2014	183	14.844	1.23
2015	280	18.908	1.48
2016	160	11.838	1.35
2017	253	23.698	1.07
2018	129	10.318	1.25
2019	124	15.730	0.79

of the global percentage of hot spots in the BIZ marked between the intervals of 0.79% - 1.59%. The average value of the series was 1.32% and the average of the last 5 years (2015-2019) was 1.19% of hot spots in the BIZ. Thus, it shows a tendency to a constant reduction in the number of hotspots in the analyzed series, presents increase from 1.52% to 0.75% in the period (**Table 3**). This can be associated with the planting of cocoa, a crop sensitive to burning, which makes rural producers avoid using fire on their properties.

Thus, it is possible to infer that cocoa cultivation or multi-stratified crops centered on cocoa have a low global association with the occurrence of hot spots and that even over time this number showed a clear and constant tendency to decrease. It can be inferred about the role of cocoa plantations in reducing the expansion of fire use, even in surrounding areas.

4.4. Discussion

The use of PICMM, as part of the MapCacau (Phase I), has proven to be an effective method for the mapping of the cocoa crops in the State Pará, where such information is relevant for the design of socio-economic policies and subsidies for producers as well as rural development line of credit for cocoa crops.

In addition, the PICMM proved to be relevant in the mapping of understory cultures, since the automated mapping of perennial plant crops presents difficulties to obtain satisfactory results due perennial plants have relative spectral similarity with native forest and secondary vegetation [43] [44], depending on the type of crop.

According to [45], crop mapping offers a range of specific benefits for producers, industry and government, besides understanding the distribution and location of crops is essential information to allow the establishment of expansion zones and technical assistance. The use of new sensor products with higher spatial resolution and machine learning technologies has been used as an alternative with acceptable results, however, still adding a relative degree of uncertainty. Therefore, the validation of data in the field is relevant.

Since cocoa is an understory crop, it is a plant that needs temporary or permanent shading, which is essential for its growth, development, and production [46]. It should be added that the AFSs preserve carbon, and on average, the areas with AFFs have 40 to 60 $Mg \cdot ha^{-1}$ of carbon, especially if there are species of Açai (*Euterpe oleracea*), Cocoa (*Theobroma cacao*), and Cupuaçu (*Theobroma grandiflorum*) with high vegetation cover in advanced development [14] [47].

In this way, it is important to highlight that cocoa planting in the state of Pará differs from planting in the Ivory Coast and Ghana countries, the largest cocoa producers in the world, since in both countries there was destruction of forested areas and occupation of Protected Areas (PA) for implementation of cocoa crops [23]. In the state of Pará cocoa plantations occur in only one environmental protection area, Triumph of Xingu, located in the municipality of São Félix do Xingu, representing only 0.46% of cocoa plantations.

5. Conclusions

The news about the advance of deforestation in the Amazon, and particularly in the state of Pará, has international repercussions, exposing to the world not only the weaknesses of the biome, but above all, the criminal action of certain groups that seek to generate income in an easy way such as the illegal logging.

The understanding that currently deforested areas in the state are sufficient for sustainable production need, increasingly, to be part of development strategies not only of local producers, but above all, of decision-makers when preparing appropriate public policies for the Amazon environment.

Thus, the work proved that the region could develop productive activities through perennial crops such as cocoa, both in agroforestry systems and under fragments of exploited forest and secondary vegetation, maintaining high productivity.

This activity, in addition to reducing the pressure for new deforestation, provides the recovery of degraded areas and avoids the emission of greenhouse gases into the atmosphere due to the reduction of fires. Allied to these environmental conditions, we can prove that the expansion of the cocoa production chain has generated formal jobs and income in all regions of the state, contributing to the reduction of social inequalities that are so present in the Amazon.

Further studies are needed with hybrid mapping methods for perennial crops, such as cocoa, methods that combine machine learning processes, participatory mapping and field validation. Studies in this direction have been carried out in joint projects between Embrapa Amazônia Oriental and national and international institutions.

Furthermore, it is important to continuously monitor the expansion of the cocoa activity in the Amazon, with the establishment of public policies to promote sustainable development, and biotechnologies that add value to the maintenance of plant remnants and ecosystem services, as well as promote the social and economic well-being of family farming.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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