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Impacts of REDD+ on Forest Conservation in a Protected Area of the Amazon

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Abstract

REDD+ has emerged as a global strategy for reducing CO₂ emissions from deforestation and forest degradation and shows great promise for the Extractive Reserves of the Brazilian Amazon (RESEX). It is essential to assess whether REDD+ projects have effectively contributed to the conservation of these areas over time. To address this issue, we analyzed land use and cover dynamics in the RESEX Rio Preto-Jacundá (Rondônia) and its surroundings from 2004 to 2020 to evaluate the impacts of a certified REDD+ project. The following two trend scenarios were simulated: (i) pre-implementation (2004–2012), projected to 2020, and (ii) post-implementation (2012–2020), projected to 2028. Historical maps were derived from the TerraClass dataset, and future projections were generated using Markov Chains combined with Cellular Automata. Forest conservation was evaluated through structural metrics such as the number, size, and shape of forest fragments, and the type, frequency, and length of boundaries with other land uses, using ArcGIS tools and Patch Analyst. Carbon sequestration was estimated from the aboveground biomass values of primary and secondary forests. The results showed that the REDD+ mechanism did not achieve the expected environmental benefits, with a decrease in carbon stocks over time and potential negative effects on the richness and composition of local flora.

Keywords: carbon sequestration; extractive reserve; protected area; land use; land cover; forest fragmentation; greenhouse gas; climate change



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1. Introduction

REDD+ Projects (Reduction of Emissions from Deforestation and Forest Degradation + Conservation of Forest Carbon Stocks, Sustainable Management of Forests, and Enhancement of Forest Carbon Stocks) are environmental and economic management instruments that were formalized in 2007, during the 13th United Nations Conference on Climate Change (COP) [1]. Initially conceived in global climate negotiations as a result-based mechanism, they aimed to enable high-income countries to compensate low- and middle-income countries for verified reductions in carbon emissions [2].

Their strategy is to provide predictive analyses of carbon emissions, aiming to financially compensate countries that monitor, control, and promote the sustainable use of

resources by engaging local communities that conserve their forests [1]. Over time, REDD+ has evolved into a hybrid set of policies, programs, and projects operating at multiple scales, with objectives not only to reduce emissions but also to enhance carbon sequestration in forests [2].

Results-based payments remain the cornerstone of REDD+ initiatives [2]. Within this framework, the carbon market gained prominence, where it is possible to receive payment for the carbon not emitted into the atmosphere [3,4]. Currently, most REDD+ projects are linked to the voluntary carbon market, which operates under standards set by international certification entities. In 2016, 99% of carbon credits sold in this market were certified by third-party standards. Among the 13 standards in use at the time, the Verified Carbon Standard (VCS) was the most prevalent, certifying nearly 33 MtCO₂, equivalent to 58% of all credits traded [5].

The scientific literature has debated the efficiency of compensating low- and middle-income countries that seek to meet REDD+ objectives. For some researchers, these projects can lead to forest conservation and generate benefits such as climate change mitigation, biodiversity conservation, and poverty reduction [6–9]. However, others raise considerable criticism regarding their real environmental and social impacts [10–12]. This discussion is further expanded regarding understanding the impact of REDD+ certification in legally protected tropical forest areas [10,11].

Simonet et al. (2018) [13] suggest that REDD+ projects may constitute a promising strategy for reducing deforestation rates in the Brazilian Amazon. It is widely acknowledged that the severity of the environmental crisis that has plagued this region in recent years is marked by a period of severe dismantling of environmental policies in the country [14]. In 2021 alone, deforestation by clear-cutting in the Brazilian Legal Amazon reached the alarming figure of 13,235 km² [15]. Between 2019 and 2022, although 51% of deforestation occurred in public areas, only 29% happened in legally protected areas [16,17]. Thus, it becomes evident that legal protection can play a crucial role in reducing the likelihood of new deforestation and changes in land use and cover [17].

In the Brazilian Amazon, legally protected areas for sustainable use, such as the Extractive Reserves (RESEX) established in the 1970s, have the potential to become a valuable resource for both forest conservation and traditional extractive populations, who hold long-term usufruct rights to these public forests [18,19]. The RESEX model tries to reconcile forest conservation with sustainable use for the benefit of local communities [20]. However, as pointed out by Freitas et al. (2018) [21], RESEX faces significant challenges, such as improving the socioeconomic conditions of its inhabitants; combating poverty; reducing forest degradation and biodiversity loss; integrating Brazilian policies for oversight and management; and addressing the inefficiencies in planning and management of organizations responsible for environmental policies in the Amazon.

Contrary to expectations, deforestation records from the National Institute for Space Research (INPE) for the state of Rondônia (RO) indicate that many of its RESEX areas have permitted activities incompatible with sustainable use, such as cattle ranching and illegal logging, which may be restricting nature conservation values within their legal boundaries [15,21]. In 2021, RO was the state with the fourth highest deforestation rate in the Brazilian Legal Amazon [15], highlighting the importance of clarifying to what extent a REDD+ project in a protected area in this state, heavily pressured by human activities, is effectively achieving its objectives of preventing forest degradation and contributing to forest conservation.

In this sense, this study aimed to assess the impact of a REDD+ project certified in the RESEX Rio Preto—Jacundá (RO), considering the composition and configuration of land use and cover before and after the implementation of this environmental and economic

management instrument. The hypothesis is that the implemented REDD+ Project has altered the forest conservation trend in this area.

To test the hypothesis, we pursued four specific objectives: (i) to analyze land use and land cover change before and after the implementation of the project in 2012, identifying trends in deforestation and forest regeneration; (ii) to model future land cover scenarios, comparing trajectories with and without REDD+ intervention; (iii) to evaluate forest fragmentation and edge effects, to assess changes in landscape integrity and vulnerability of forest remnants; and (iv) to estimate aboveground biomass (AGB) carbon stocks, as an indicator of the project's contribution to climate change mitigation. Together, these objectives provide crucial information to understand the excessive or disordered land exploitation, forest degradation conditions, the vulnerability of fragments, and carbon stocks over time [22–25].

2. Materials and Methods

The RESEX Rio Preto—Jacundá is a legally protected area in the Brazilian Amazon, located in the state of Rondônia (RO), encompassing approximately 1000 km² (Figure 1), designated for traditional communities to sustainable use. Established in 1996, it includes two rubber forests for latex extraction [26,27].

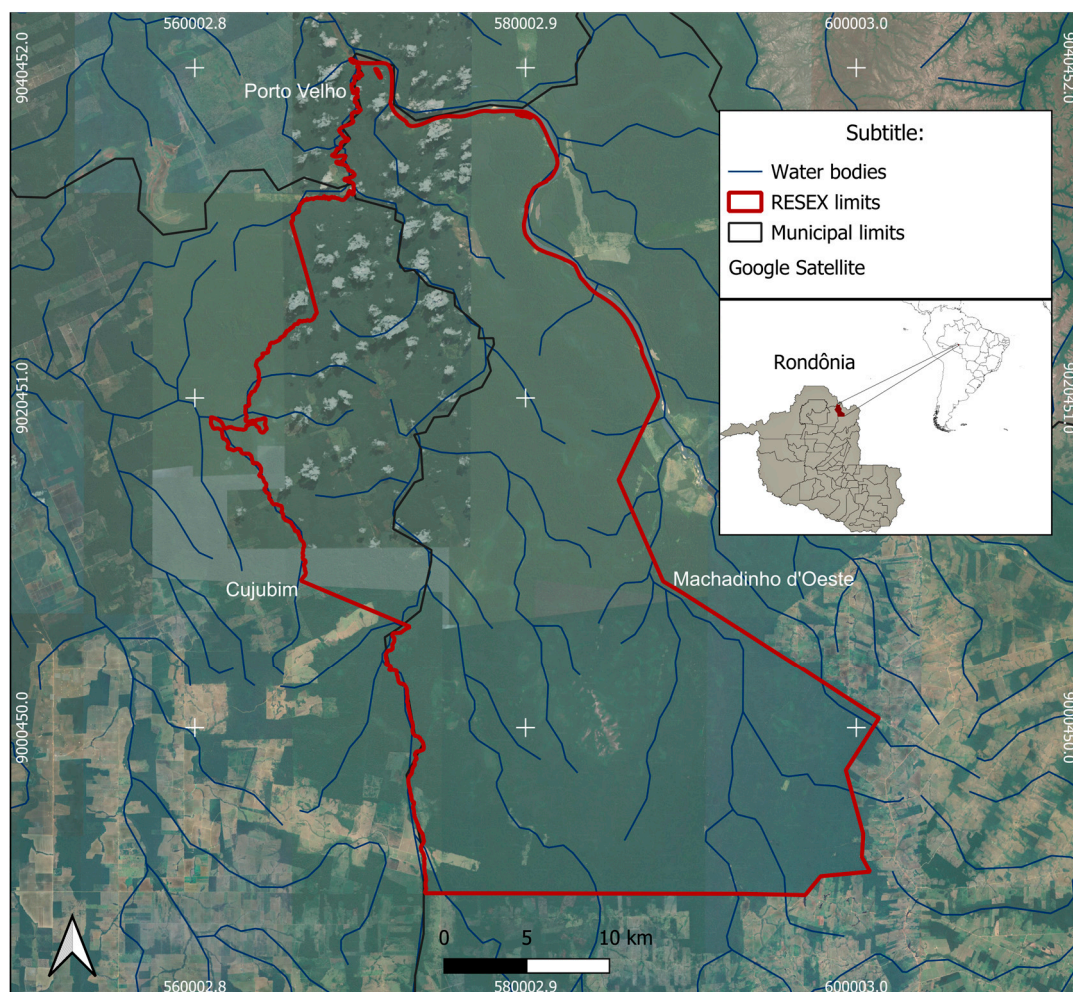


Figure 1. Extractive Reserve (RESEX) Rio Preto—Jacundá, located in the Southern Brazilian Amazon, in Rondônia state.

This area provides a wide range of ecosystem services. It regulates regional climate and hydrological cycles, and contributes to soil protection and nutrient cycling. In addition,

these forests provide cultural and educational values, as well as future potential for genetic resources and medicinal uses [28]. Furthermore, it belongs to the Mosaic of the Southern Amazon, which includes 21 other protected areas, making it an important region for biodiversity conservation and carbon storage, in addition to its relevance for the traditional population that relies on the forest for subsistence [29].

The population of RESEX Rio Preto—Jacundá is characterized as a low-income rural community engaged in diverse productive activities. However, it faces significant challenges in generating sufficient income solely from the sustainable use of natural resources [28]. In addition, low levels of education and precarious living conditions further constrain development. According to Bernardes et al. (2018), the Amazon, together with the northeastern semiarid region, is among the areas of Brazil with the highest concentration of rural populations living in extreme poverty [28,30].

According to the Management Plan of the RESEX, approved in 2017, the area faces strong pressure from illegal activities such as logging, land invasion for livestock, mechanized agriculture, predatory fishing, hunting, and mining, generating significant environmental damage [29]. Additionally, its buffer zone is directly influenced by agrarian settlements, private properties, and roads, which put pressure on the forest edge [29].

To promote sustainable uses and to reduce forest degradation, illegal deforestation, and greenhouse gas (GHG) emissions, the company Biofílica Ambipar Environment, in partnership with the residents' association of RESEX, implemented the REDD+ project in 2012 [31]. Aligned with the Climate, Community & Biodiversity (CCB) and Verified Carbon Standard (VCS), this initiative focuses solely on carbon credits within the forest area of the RESEX in 2012, corresponding to 942.89 km².

To assess the historical trajectories of the land use/land cover (LULC) before and after the implementation of the REDD+ project in 2012, we used spatial data from the TerraClass project library (2022) [16], by the Brazilian Agricultural Research Corporation (EMBRAPA, Brasília, Brazil) and National Institute for Space Research (INPE, São José dos Campos, Brazil), which employed Landsat 5–8 images and techniques such as linear spectral mixing models, slicing, and interpretation visual [32]. The thematic categories legend provided by INPE was adjusted to suit the objectives of this study, combining classes with similar structural characteristics (Table S1).

Maps of the RESEX and its surroundings from 2004, 2012, and 2020 were generated using ArcGIS® software version 10.4. We delimited the RESEX perimeter plus a 10 km buffer zone (BZ), excluding surrounding areas that did not cover the RO state.

With this database, we simulated two trend scenarios of LULC (i): the scenario before the implementation of the REDD+ project (between 2004 and 2012), with a projection for 2020, and (ii) the scenario after the implementation of the REDD+ project (between 2012 and 2020), with a projection for 2028. These scenarios were built using Markov Chain (CM) associated with Cellular Automata (CA in QGIS® software version 2.18.18 and using the MOLUSCE plugin—Modules for Land Use Change Evaluation by the simulation algorithm Artificial Neural Network (ANN), with input parameters predefined by the plugin.

Evaluation Indicators

For a comprehensive evaluation of land use dynamics, forest conservation, and carbon outcomes under REDD+ implementation, while enabling comparisons between the RESEX and its Buffer Zone across different time periods and simulated scenarios, we adopted two main categories of evaluation indicators: landscape structure and carbon stocks.

Landscape structure indicators were based on trend modeling using transition matrices of historical LULC changes, allowing us to characterize shifts in forest conservation potential through structural measures of primary forest fragmentation. This included the

number, size, and shape of patches, as well as the type, frequency, and length of boundaries with other uses (Table S2). This set of landscape metrics was applied using ArcGIS® tools, such as the Patch Analyst Plugin and the procedure to identify and quantify the boundaries of land use/cover described by Hardt et al. (2018) [33]. The study of boundaries between patches allows us to understand the complexity of landscape interactions, especially those involved in the anthropogenic use of natural resources, which is a common source of environmental problems when harnessing landscape services [33].

Carbon indicators were assessed by calculating the carbon sequestration potential of both primary and secondary forests in historical maps and scenarios, using secondary data from Aboveground Biomass (ABS) estimates for primary forest (median 399.27 Mg.ha⁻¹) and secondary forest with 2–18 years (median 90.97 Mg.ha⁻¹) in Rondônia [34]. The AGB values of vegetation verified in each LULC map and scenario, for both RESEX and buffer zone, were converted into carbon stocks (tC.ha⁻¹) by a conversion factor equal to 0.49 [35]. These carbon stocks were then compared to the data provided by the REDD+ Project, indicating an average sequestration rate of 418.7 tCO₂.ha⁻¹ across all forest types, including both primary and secondary forests [31].

3. Results

3.1. Assessment of Historical Changes and Future LULC Trends

There was a 7.44% reduction in primary forest cover within the RESEX over the analyzed period (2004–2012–2020), particularly between 2012 and 2020, although this class continued to occupy more than 90% of the area (Figures 2 and 3). On the other hand, secondary forest fragments increased during the same period, partly due to the recovery of previously deforested areas (Figures 3 and 4a). Meanwhile, the area of pasture within the RESEX increased by 2016% over the considered period, likely reflecting the 512.6% increase in pasture around the RESEX (Figures 2, 3 and 4a). It is important to note that occupation mosaics increased from 2012 onwards, with exposed soil doubling in 2020, primarily in the central and northern regions of the RESEX (Figures 2 and 3).

Throughout the period analyzed, there was also a reduction in primary forest cover in the buffer zone (BZ) of the RESEX, with an estimated 29.76% loss of areas (Figure 3). Many of these areas were converted into pasture, with responses similar to those observed in the RESEX, although with greater intensity in the BZ due to initial expansion from the southwest portion of the RESEX extending to the entire southern arc of the BZ (Figures 2, 3 and 4b). Between 2012 and 2020, the coverage of exposed soil and regenerating areas with pasture increased, mainly due to the deforestation and degradation of primary forests (Figures 3 and 4b). On the other hand, the occupation mosaics in the BZ decreased by 95% over the years analyzed, while secondary forests increased by 688.16% (Figure 3).

The comparison of the 2020 reality with the trend scenario corresponding to the period before the implementation of the REDD+ project (between 2004 and 2012) indicates that there was a greater-than-expected loss of primary forest for the period: 6.96% within the RESEX and 19.22% in its BZ (Figure 3). Additionally, the coverages of pasture (5.29%), pasture with regeneration (0.03%), and secondary forest (2.22%) in 2020 were also higher than anticipated within the RESEX (Figure 3).

The second trend scenario, corresponding to the period after the implementation of the REDD+ project (between 2012 and 2020), indicates that by 2028, secondary forest and pasture classes are expected to continue increasing as more primary forest is lost (Figure 3). These results suggest that, compared to 2012, the year of the RESEX's establishment, by 2028, there would be a loss of 70.6 hectares of primary forest, with 10.41% occurring within the RESEX, despite legal protection.

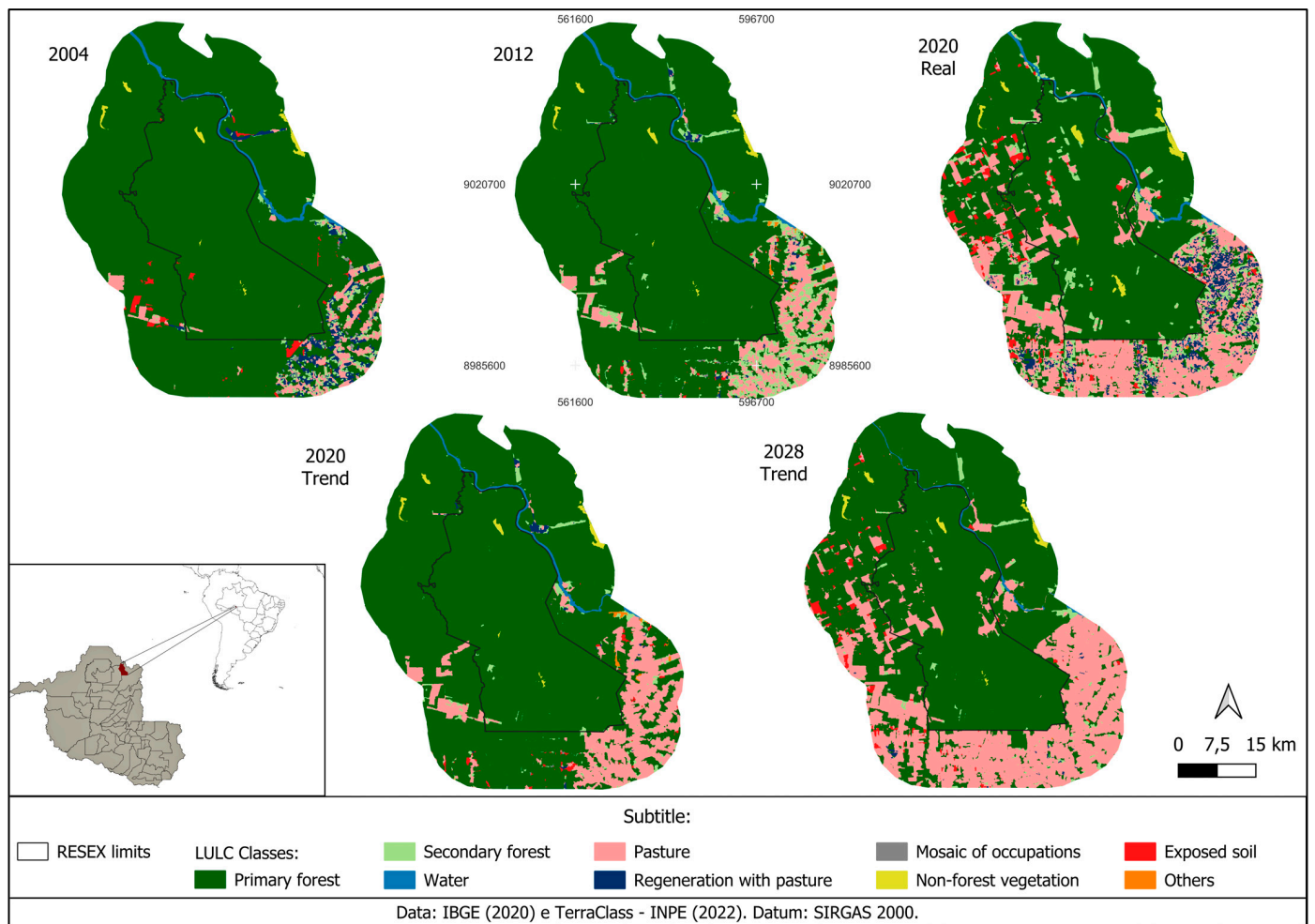


Figure 2. Historical maps and trend scenarios of land use and land cover for the Rio Preto—Jacundá Extractive Reserve (RESEX) and its surroundings, RO, Brazil.

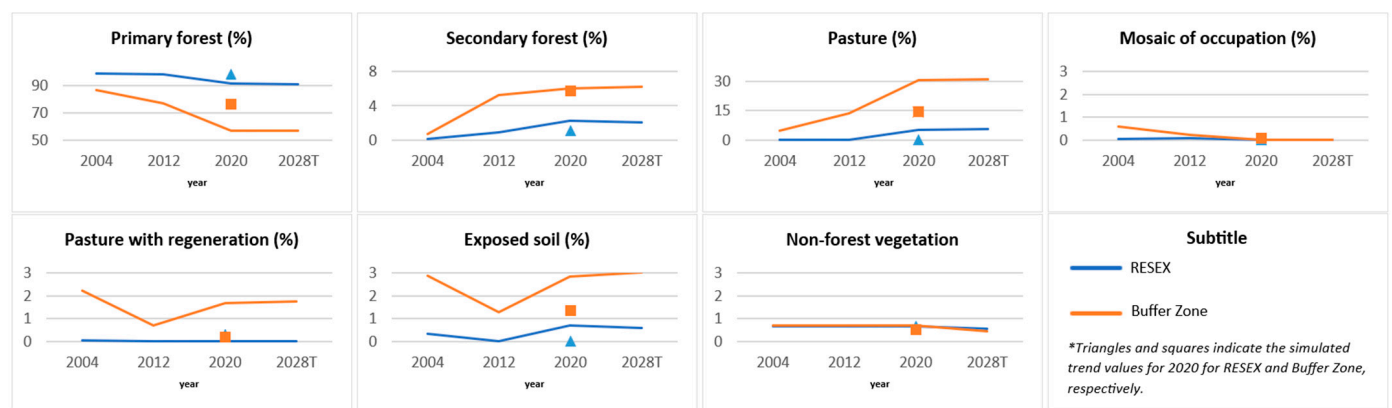


Figure 3. Percentage of land use and land cover classes in the Rio Preto—Jacundá Extractive Reserve (RESEX) and its buffer zone (BZ), RO—Brazil, for the years 2004, 2012, and 2020, and for the trend scenarios 2020 and 2028T.

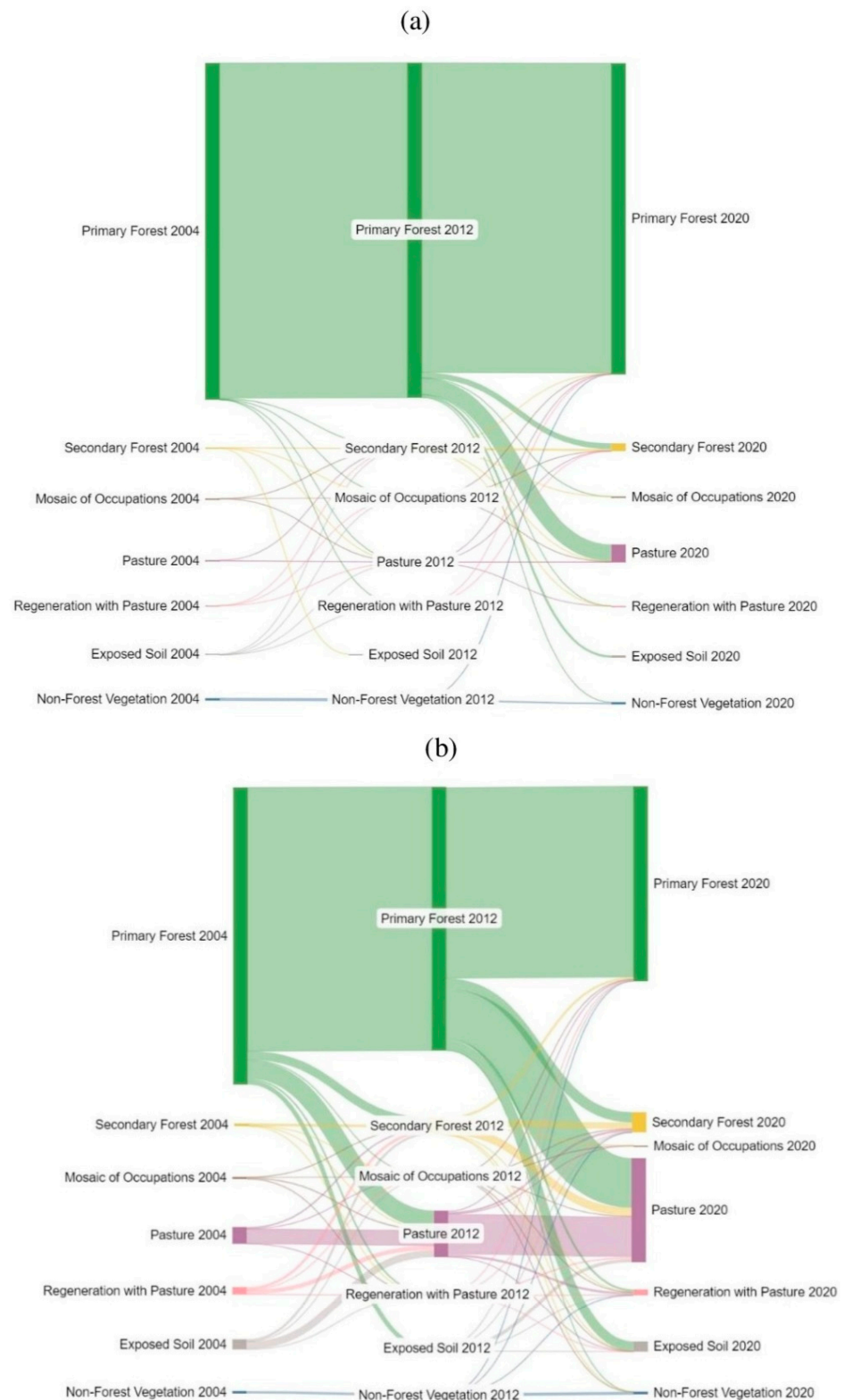


Figure 4. Land Use and Land Cover (LULC) class transition matrix between the years 2004, 2012, and 2020 within the Rio Preto—Jacundá Extractive Reserve (RESEX) (a) and its buffer zone (b), RO—Brazil.

3.2. Evaluation Indicators

Inside the RESEX, between 2004 and 2020, the number of primary forest patches (NP) increased from 2 to 78, with a 97.6% reduction in their mean patch size (MPS) and a doubling of edge density (ED), resulting in a 5% decrease in core areas (CAs) (Figure 5). These values are even more alarming considering that the boundary frequency (BFq) of

primary forest with other LULC classes increased by approximately 1144%, especially with pasture areas and secondary forest (Figure 6a), while the boundary length (BL) grew by 345.9% (Figure 6b).

Conservation metrics reveal that the interior of the RESEX had less fragmented forest than its buffer zone, with a lower number of patches (NP) and a larger mean patch size (MPS) (Figure 5). In the BZ, between 2004 and 2020, the number of fragments increased by 568.53% and the mean patch size decreased by 90%. Edge density (ED) increased by 82.76%, as did the frequency and length of boundaries (711.82% and 116.86%), with secondary forest boundaries accounting for more than 62% of the boundaries around the RESEX in 2020 (Figure 6b).

Comparing the reality with the trend scenario for 2020, which assumes the absence of the REDD+ project, the trend scenario represents a better forest conservation situation than what was verified in the actual condition after 8 years of the project. For both the RESEX and its surroundings, all metrics indicated more positive expectations for primary forest conservation than what occurred that year (Figure 5). Inside and around the RESEX, the number of forest fragments (NP) was more than twice the trend values without the project (Figure 5). Within the RESEX, the frequency of boundaries between the primary forest and pasture areas was 22.37% higher than demonstrated by the trend scenario (Figure 6b). In the BZ, the mean patch size (MPS) was 64.1% smaller than expected for 2020 (Figure 5), with boundary length between primary and secondary forests 7.58% smaller and 12.86% larger than pastures (Figure 6a).

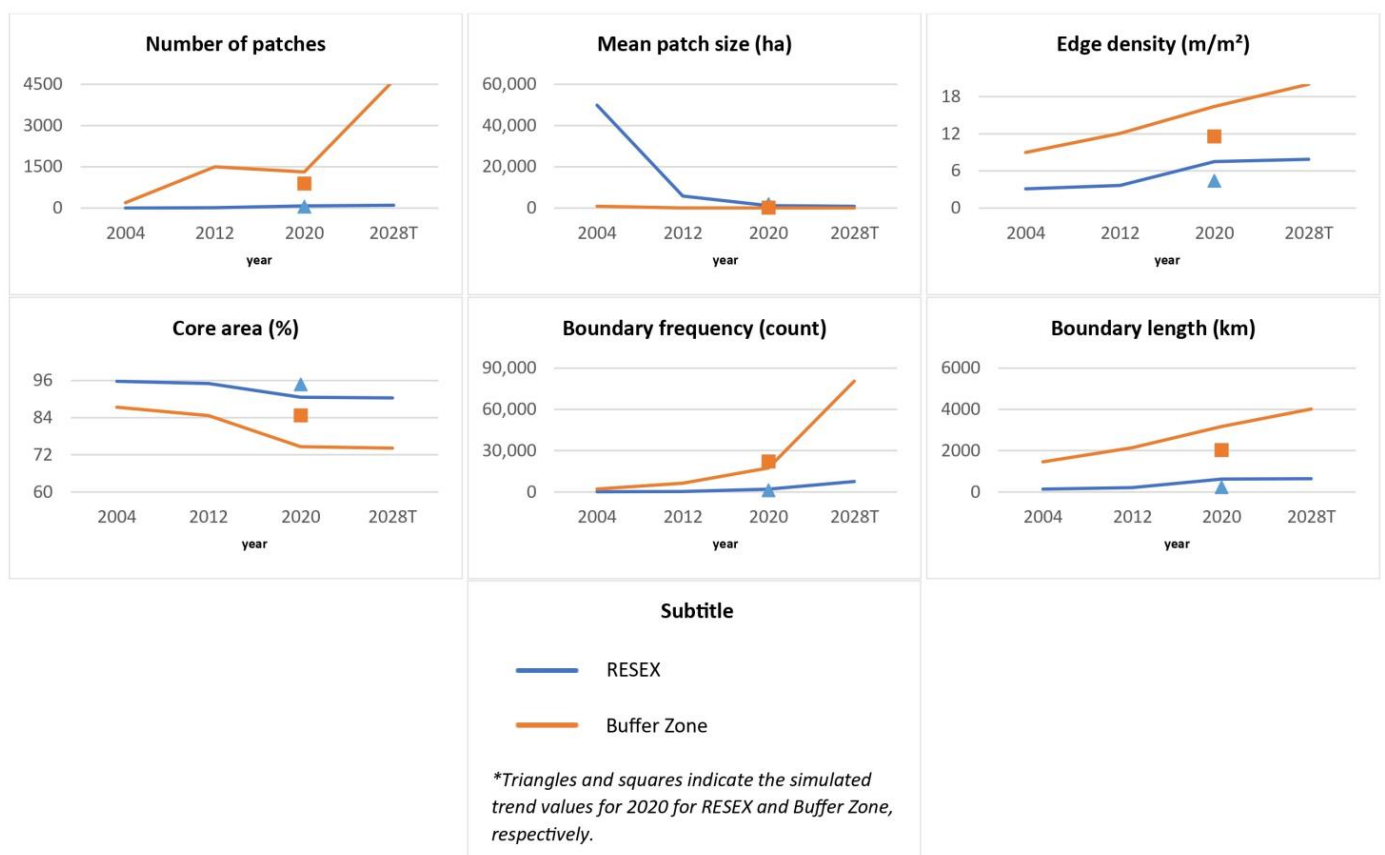


Figure 5. Landscape metrics of the primary forest area in the Rio Preto—Jacundá Extractive Reserve (RESEX) and its Buffer Zone (BZ), RO—Brazil.

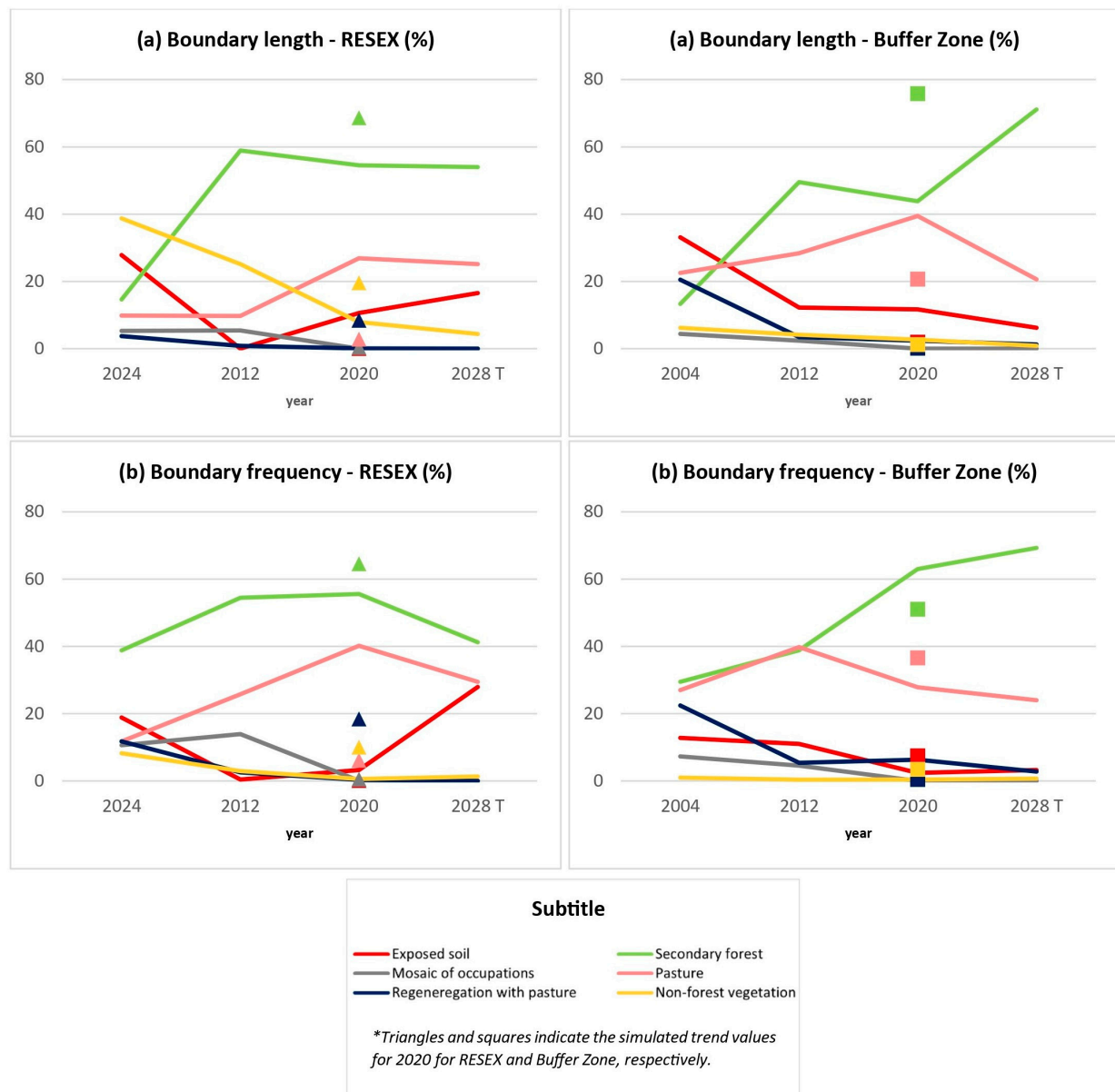


Figure 6. Length (a) and Frequency (b) of boundaries between primary forest and other LULC classes in the Rio Preto—Jacundá Extractive Reserve (RESEX) and Buffer Zone (BZ), RO—Brazil.

The expectation for 2028 is that forest fragmentation will continue to increase both within the RESEX and its surroundings, along with edge density, boundary length, and boundary frequency (Figure 5). Compared to 2004, by 2028, the number of patches (NP) would increase by 6050% in the RESEX and 860% in the BZ. The core area in the RESEX will be less than 90% of its area, but the mean patch size (MPS) could be 12.2 times larger within the RESEX than in its surroundings (Figure 5). Compared to 2012, both the frequency and lengths of boundaries between primary forests and exposed soils would increase within the RESEX by more than 20 times and 358 times, respectively, while in the surroundings, there would be a decrease of 36.87% in frequency and 60.49% in length (Figure 6).

Proportionally, the carbon stock provided by the RESEX forests has always been higher than that of the BZ (Table 1). Considering that from 2004 to 2028, all results point to a decrease in primary forest areas and an increase in the fragmentation of remnants, it is estimated that by 2028, the carbon stock could decrease by 6.95% in the RESEX, 33.93% in the BZ, and 4.65% in the REDD+ Project polygon. Comparing the reality of 2020 with the trend constructed for the same year, assuming the project's absence, the REDD+ Project

does not have the expected effect on carbon stock, i.e., it does not provide an equal or higher stock value after 8 years of its implementation, which could also affect the future trend of forest conservation.

Table 1. Estimate of carbon stock for primary and secondary forest areas within and surrounding (BZ) the RESEX Rio Preto—Jacundá (according to biomass data from Alves et al., 1997 [34]), and within the REDD+ Project polygon (according to the project's biomass data).

Year and Scenario	tC.ha ^{−1} RESEX	tC.ha ^{−1} BZ	tC.ha ^{−1} REDD+ Project
2004	191.8	169.97	418.75
2012	191.2	152.5	418.7
2020—(Real scenario, with project)	178.99	114.07	399.65
2020—Trend without project	191.71	151.27	420.5
2028—Trend with project	178.46	112.29	399.27

4. Discussion

The deforestation occurring in the RESEX Rio Preto—Jacundá during the analyzed period (2004 to 2020) follows the trend observed in most other RESEXs in the state of Rondônia (RO), as noted by Silveira and Hardt (2023) [11]. This study suggests that, from 2015 onwards, 16 out of 25 of these legally protected areas exhibited deforestation rates higher than those observed for the entire state. This indicates a possible failure to comply with their conservation value, attributed to the conduct of activities incompatible with sustainable use, such as cattle ranching and illegal logging.

In Amazonian RESEXs, deforestation continues to be the greatest threat, mainly due to extensive cattle production [36–38]. Thus, the 2016% increase in cattle ranching areas from 2004 to 2020, with an equivalent conversion of 5.04% of the area, totaling approximately 5 thousand hectares, is not exclusive to the RESEX Rio Preto—Jacundá. This was also observed by Spínola and Carneiro Filho (2019) [38] in the RESEX Rio Ouro Preto/Rondônia, which had 5.3% of its area converted to pasture between 2004 and 2014.

As observed in the RESEX Rio Preto—Jacundá and its Buffer Zone, according to Smith et al. (2020) [39], secondary forest areas have increased throughout the Brazilian Amazon due to the abandonment of agriculture in previously deforested areas. It is crucial to legally maintain and protect the primary forests of this region to mitigate climate change, as they represent an effective and low-cost nature-based climate solution [39,40]. However, their continued destruction has been the main contributor to the disruption of the regional carbon balance.

The situation in the BZ of the RESEX Rio Preto—Jacundá is concerning due to the continued reduction in primary forest cover, with a 29.76% reduction between 2004 and 2020, while pasture areas increased. It is noteworthy that the losses in both quantity and quality of forests in these areas are more significant than those recorded within the RESEX, highlighting the fundamental role of this RESEX in conservation. When analyzing the amount of forest in the RESEX Chico Mendes/Acre, Milien et al. (2021) [41] obtained results similar to this study, indicating a loss of approximately 30% greater in the immediate surroundings than within its interior. These results are significant indications that, without legal protection, environmental degradation in the Brazilian Amazon could be considerably more intense and detrimental. Furthermore, they highlight the urgency of public policies and governmental actions to combat anthropogenic pressures on the Buffer Zones of protected areas, especially in the Southern Arc of deforestation, of which the RESEX Rio Preto—Jacundá is a part. Considering that the BZ is an area where human activities are subject to specific regulations and restrictions to minimize negative impacts on the protected area [18], it is important to highlight that the effective enforcement of Brazilian federal

legislation could curb illegal deforestation activities. This enforcement would ensure the conservation of this and other RESEX areas in RO, preventing the advance of both formal and informal market interests.

The RESEX Rio Preto—Jacundá is also committed to a REDD+ Project with the expectation of conserving the forest and maintaining its carbon stocks and sequestration. However, the forecast for deforestation between 2013 and 2028 by the REDD+ Project, before the commencement of its proposed activities, was 57.8 km² [31], a value lower than the 78 km² of primary forest loss estimated in this study for the period from 2012 to 2028.

According to West et al. (2020) [10], the RESEX Rio Preto—Jacundá, as well as the Suruí/Rondônia protected area, experienced one of the largest cumulative losses of forest cover after the implementation of the REDD+ Project. From the perspective of primary forest conservation, it was observed that trends before the REDD+ Project were comparatively more favorable than those observed after its implementation, although it cannot be stated that the values are of high significance.

The increase in forest fragmentation and the consequent reduction in patch size in the RESEX and its surroundings indicate a potential impact on forest biodiversity [42]. The isolation resulting from this fragmentation can trigger substantial changes in the richness and composition of bird, amphibian, and bee populations in these forests, with a significant loss of phylogenetic diversity [42,43]. Furthermore, the temporal variations in fragmentation rates, core area sizes, and forest recovery in the studied area highlight an unbalanced dynamic in the territory, suggesting the possibility of fire action with seasonal and cyclical effects, as demonstrated by Valente and Laurini (2023) [44] in territories of the Brazilian Amazon between 2002 and 2022. The heterogeneity in the transformations observed in the analysis of LULC dynamics in the RESEX and its surroundings hinders the understanding of their effects on conservation, as well as complicating planning and management by local governments. Consequently, the implementation of uniform governmental actions may be ineffective in curbing deforestation in the region.

An increase in the quantity and extent of boundaries between forest and anthropogenic uses can be interpreted as an indicator of growing external pressures on the forest, which may result in the continuation of fragmentation processes [33]. This dynamic implies a situation where human activities are increasingly encroaching on forest areas, thereby heightening the risks of negative effects and alterations in the structure and function of the forest ecosystem. According to Mu et al. (2020) [45], in the Brazilian Amazon, boundaries between primary forest and abandoned pastures, and between primary forest and previously deforested areas, tend to expand secondary forest areas, as has been occurring in the RESEX Rio Preto—Jacundá since 2004.

The increase in edge density observed over the years is concerning, as it suggests that fragmentation in Amazonian forests has increased, facilitating human movement and resulting in pressures for new deforestation. This necessitates initiatives for the restoration or preservation of contiguous forests [46]. Furthermore, the edge areas of tropical forests are also critical as they are sources of carbon emissions due to the potential increase in tree mortality [47]. According to Haneda et al. (2025) [48], REDD+ projects covering smaller areas in the Brazilian Amazon are more vulnerable to carbon losses caused by the edge effect, with a 100 ha project potentially losing up to 5% of its carbon stock.

The decrease in carbon stock in RESEX can be primarily attributed to the occupation of boundaries. This may have hindered the efforts of the REDD+ Project to reduce GHG emissions by more than 3 million tCO₂ between 2013 and 2020 [31]. Despite this decrease, it was found that the carbon stock estimates in the REDD+ Rio Preto—Jacundá Project across the RESEX are not accurate, with value discrepancies that can be explained by the conduct of distinct forest inventories based solely on random sampling units (plots) for

forest areas. Other works could integrate field inventory plots with measurements of vegetation structure collected by airborne Light Detection and Ranging (LiDAR) to estimate aboveground carbon with more fidelity [48,49].

In this regard, Asner et al. (2013) [49], when analyzing a REDD+ Project in Panama, found that carbon inventories based only on a few field plots as sampling units did not accurately reflect the heterogeneity of carbon stocks. This discrepancy between actual and estimated values can compromise the integrity of global carbon stock mappings, which should be conducted with high fidelity to advance the management of these resources and encourage international actions for climate change mitigation [49]. Nonetheless, in the specific case of the RESEX Rio Preto—Jacundá, even considering these limitations that must be acknowledged, the gap between actual carbon stock values and those predicted by the 2020 and 2028 scenarios is alarming. Although projections to 2028 provide valuable insights, they are subject to uncertainties inherent to predictive models, especially in dynamic frontier regions like Rondônia, where deforestation is influenced by multiple factors, including economic pressures, land use dynamics, and, most importantly, policy changes [11,50,51].

According to Zwick (2019) [52], for REDD+ Projects to be effective in reducing deforestation while simultaneously generating income for traditional communities, it is necessary to have adaptable baselines and methodologies, diversified funding sources, integration into a jurisdictional approach, governmental cooperation, and simplification of these projects. In contrast, Furtado et al. (2024) [53] argue that policies based on forest carbon offsets and the carbon market do not contribute to reducing deforestation, generate territorial conflicts, and further intensify extractive capitalism in the Brazilian Amazon. Local communities' rights, livelihoods, and benefits must be at the center of REDD+ projects to avoid causing or worsening social conflicts [54].

In this context, whether REDD+ is worth preserving will depend primarily on its ability to address not only technical aspects of carbon accounting and environmental integrity but also its social justice dimensions [55]. The importance of a comprehensive and collaborative approach is highlighted by these considerations to address challenges and promote environmental and socio-economic sustainability, both regionally and for protected areas such as the RESEX Rio Preto—Jacundá. Although our study did not assess the social dimension directly—e.g., through engagement with traditional communities or surveys—the literature suggests that addressing social aspects is crucial for the long-term effectiveness of REDD+ projects.

Despite the efforts of REDD+ projects to meet these needs, research such as that by Correa et al. (2020) [56] highlights that even the world's largest REDD+ Project, the Amazon Fund, has failed to demonstrate the effectiveness of its impacts on forest conservation. The authors note that the low deforestation rates in the municipality of Alta Floresta/MT are not positive consequences of this instrument. On the other hand, there are studies demonstrating that these projects can conserve tropical forest cover when incentivized, particularly through the legal regulation by governments [7,57,58].

Regarding these considerations, Gallo, Brites, and Micheletti (2020) [59] believe that, although REDD+ Projects in Brazil bring visibility to the importance of combating deforestation and forest degradation, they will only be effective when the country addresses the deep-rooted causes and drivers of deforestation through regulatory frameworks and political commitment. Overall, our results suggest that the levels of deforestation, fragmentation, and carbon loss observed post-2012 remain higher than ideal for a conservation unit with a REDD+ Project. In contrast, the Buffer Zone highlights that areas outside strict protection are subject to much greater pressures, underscoring the need for complementary strategies to ensure the broader landscape can maintain forest cover and carbon stocks.

5. Conclusions

The indicators of this study suggest a trend of reduced forest conservation both within and around the RESEX Rio Preto—Jacundá between 2004 and 2028. Although the expectation of conservation for the RESEX is relatively more optimistic than for its Buffer Zone (BZ), a greater-than-expected loss of forest was observed for a protected area with the occurrence of a REDD+ Project.

The comparison of trends before and after the implementation of the REDD+ Project demonstrated that this instrument may not be achieving its objectives of generating environmental benefits, particularly in mitigating climate adversities. Despite being established for 8 years (2012–2020), in 2020, both the study area and its surroundings were still experiencing the conversion of primary forests into pastures and secondary forests, demonstrating that substantial challenges remain, particularly regarding landscape fragmentation and pressures from the surroundings.

The structural changes observed in primary forests, particularly the continuous increase in the number of fragments and the frequencies and lengths of boundaries between the forest and anthropogenic uses, indicate a future scenario prone to negative ecological effects on the richness and composition of the local flora. Additionally, this scenario may affect carbon stocks in the RESEX Rio Preto—Jacundá and thus alter the expected decrease in tons of carbon per hectare, rendering the REDD+ project's expectation of reducing GHG emissions by more than 3 million tCO₂ between 2013 and 2020 unrealistic. The data collected for both the RESEX and its BZ highlight the lack of public policies for sustainable development that combine conservation with the social and territorial interests of this region. This lack of integration represents a significant challenge in the search for effective conservation strategies and the sustainable use of natural resources, as proposed by the RESEX protection model in Brazil.

The main driver of deforestation in the RESEX Rio Preto—Jacundá remains cattle ranching, intensified by weak enforcement and limited public policies. For REDD+ to be more effective in this context, it must move beyond technical carbon accounting to incorporate stricter legal enforcement, sustainable land use alternatives, and the active engagement of traditional communities, aligning conservation goals with local social and economic realities.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/earth6040128/s1>, Table S1: Legend of adjusted thematic classes in land use and land cover maps of the RESEX Rio Preto-Jacundá and its surroundings, RO—Brazil (adapted from TerraClass, 2022 [16]). Table S2: Description of selected Landscape Metrics to characterize forest conservation potential [60,61].

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