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FUTURE OF AMAZONIAN FORESTS: MODELING DEFORESTATION AND DEGRADATION BY 2050 IN BOCA DO ACRE

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ABSTRACT

Tropical forests play an important role in regulating the global climate, maintaining biodiversity, and supporting local livelihoods. Nevertheless, they are significant sources of carbon dioxide emissions due to deforestation and human activities. This study simulates the projected deforestation and forest degradation in Boca do Acre, Brazil, until 2050, driven by logging, wildfires, and land clearance for agriculture. Using the BC-DEGRAD model, we analyzed the spatial distribution of land cover change under a single future scenario. Our findings indicate that Boca do Acre is likely to lose approximately 3,800 km² of forest by 2050, with deforestation, fire, and logging impacting distinct land-use classes. This research provides vital insights for policymakers, aiding the development of effective conservation strategies and sustainable development initiatives in the region.

Key words — Slash-and-Burn, Wildfires, Logging, Amazon, Spatial Modeling.

1. INTRODUCTION

Tropical forests play a crucial role in global climate regulation, biodiversity conservation, and supporting local livelihoods [1]. However, they are also significant sources of carbon emissions due to deforestation and human activities [2, 3]. Rapid carbon release from these processes could lead to irreversible climate tipping points [4].

In 2023, President Lula's administration expanded the Amazon Deforestation Prevention and Control Plan (PPCDAm+) leading to a 22% drop in deforestation, according to PRODES data [5]. However, forest degradation from logging and fire remains a major concern, as highlighted in the proposed Amazon Deforestation and Degradation Prevention and Control Plan (PPCDDAM). Degradation, driven largely by selective logging and fires, can emit as much or more carbon as deforestation, while also contributing to biodiversity loss, altering hydrological cycles, and increasing the frequency of forest fires [6,7].

Spatially explicit environmental modeling is essential for predicting land-use change scenarios [8]. These models, when integrated with forest degradation (logging and forest fire), allow for a more realistic assessment of the impact of future land use and cover changes, providing insights that inform more effective public policies and conservation strategies, promoting sustainable development in the region and mitigating the impacts of deforestation and degradation.

The objective of this study is to simulate deforestation and forest degradation in Boca do Acre, focusing on logging, forest fire, and burning from 2021 to 2050.

2. MATERIAL AND METHODS

2.1. Study Area

The study focused on Boca do Acre, a municipality in the western of Legal Amazon covering 21,953 km², bordering the states of Acre and Amazonas. It is situated within the Abunã-Madeira Sustainable Development Zone (ZDS Abunã-Madeira) (Figure 1).

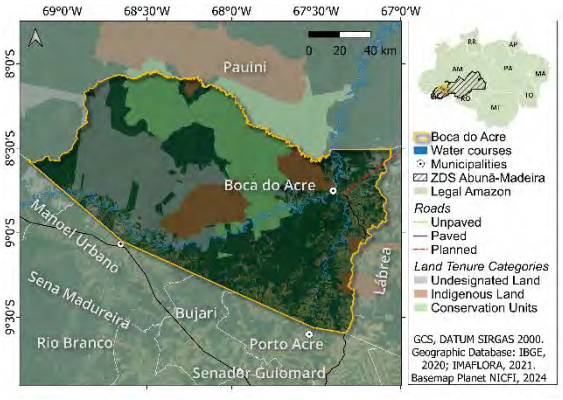

Figure 1. Study area.

The region has seen high deforestation rates due to cattle

ranching expansion in the last decade, increasing the occurrence of forest fire [9].

2.2. Modeling

The modeling process involves several steps (Figure 2): defining scenario assumptions, preparing spatial input data, and parameterization, which includes setting deforestation and degradation rates and weight of evidence coefficients. Calibration involves fine-tuning, such as selecting input variables and adjusting the allocation function for patches of change. A hindcast simulation is conducted to check model accuracy, followed by validation, comparing real and simulated maps using the Fuzzy Similarity Index, amount of change, and a null model [10]. Finally, the prognostic simulation projects future changes.

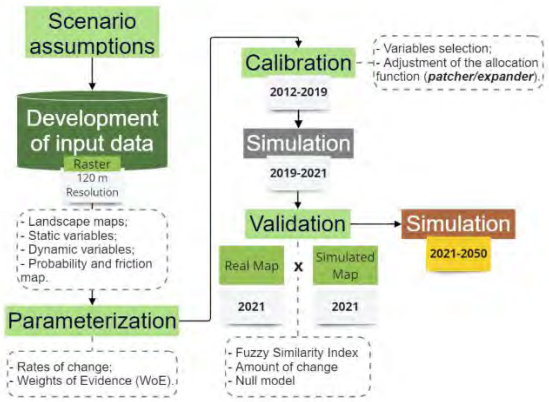

Figure 2. Flowchart of modeling steps.

2.1.1. BC-DEGRAD model

The deforestation and degradation simulation from 2021 to 2050 was performed using Dinamica EGO software version 8.0 [11]. This platform enables spatially explicit dynamic models based on cellular automata and calculates weights of evidence using Bayes' conditional probability [12,13]. The model uses biophysical and dynamic variables that influence land-use transitions over a period of time.

The BC-DEGRAD model, named as an acronym for 'Boca do Acre Degradation,' was developed specifically for this study and comprises three integrated submodels: logging, deforestation, and fire. The logging submodel simulates the transition of forest areas into logged zones, incorporating the construction of logging decks and roads. The deforestation submodel addresses the transition from forests, logged areas, or burned land to deforestation. The fire submodel simulates forest fire and burned areas. Together, these elements represent the dynamics of forest degradation and land-use change.

2.1.2. Scenario assumptions

The projected scenario assumes that the historical trend observed and calibrated from 2012 to 2019 will remain consistent through the final simulation year (2050). This scenario serves as a baseline in which the spatial patterns and rates of deforestation and degradation follow the trends observed from 2012 to 2019, and with no construction of planned highways in the region.

2.1.3. Input data

The model's input data include raster maps with a spatial resolution of 120 m. The landscape map consists of seven classes: forest, deforestation, logging, burned areas, forest fire, non-forest areas, and watercourses. The map, based on data from PRODES (Monitoring Program for Deforestation in the Brazilian Amazon), previous logging area mapping using the Linear Spectral Mixture Model [14], and fire scar products [15], serves as the foundation for simulating logging, deforestation, and fire. Static variables (e.g., land categories, soil, vegetation, slope, distance to rivers) and dynamic variable maps (e.g., updated road maps) [16] guide land-use transitions, while input tables include weights of evidence, transition matrices, and patcher/expander tables to control the spatial distribution of changes in the model.

2.1.4. Validation

The model achieved a minimum similarity of 50% within a 13 × 13-pixel window (1,560 m × 1,560 m), equivalent to approximately 2.4 km², given the study area's spatial resolution of 120 m [17]. Maximum similarity reached 54% in a 9 × 9-pixel window (135 m × 135 m). In contrast, the null model yielded lower results, with minimum and maximum similarities of 50% and 51%, respectively, within 25 × 25 and 19 × 19-pixel windows

2.3. Land categories

We analyzed the spatial distribution and the quantitative of degradation and deforestation for 2050 in protected areas (i.e., Conservation Units and Indigenous Lands), unknown lands, settlements (traditional and environmental distinctive), landholdings, and CAR (*Cadastro Ambiental Rural*) claims. Unknown lands are composed of undesignated lands—those without a specific designation—and areas lacking land tenure information in official systems. Environmental distinctive (ED) settlements are categorized as more sustainable, where activities are expected to adhere to sustainable practices (e.g., Agroextractivist Settlements Projects and Sustainable Development Projects), unlike traditional (T) settlements, which are not necessarily bound to such practices. Landholdings represent private properties, while CAR claims refer to areas registered in the CAR, including unregularized lands.

3. RESULTS

The projected deforestation and forest degradation up to 2050 indicated that these impacts will be concentrated in the southern and eastern region of Boca do Acre (Figure 3). These changes are also clustered around roads and rivers, which serve as key access routes. Degradation from forest

fires occurred mainly near of previously cleared and burned areas.

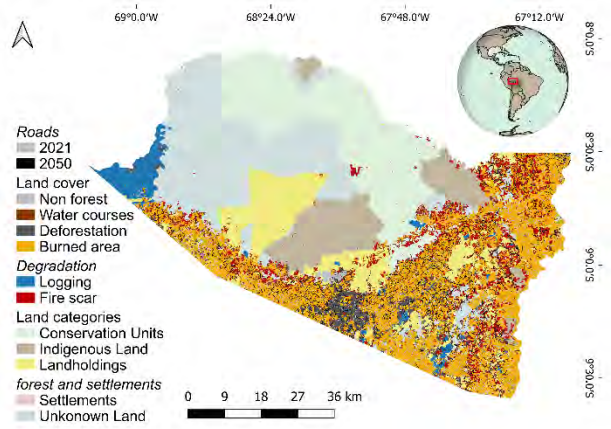

Figure 3. Projected deforestation and degradation in Boca do Acre for 2050. The classes shown represent cumulative changes by the year 2050. The burned area corresponds to deforested regions where fire has occurred.

By 2050, Boca do Acre is expected to lose about 3800 km² of forest compared to 2021. Of this, around 1700 km² (44.7%) will be deforested, 1900 km² (50%) affected by fires, and 299 km² (7.9%) by logging (Figure 4).

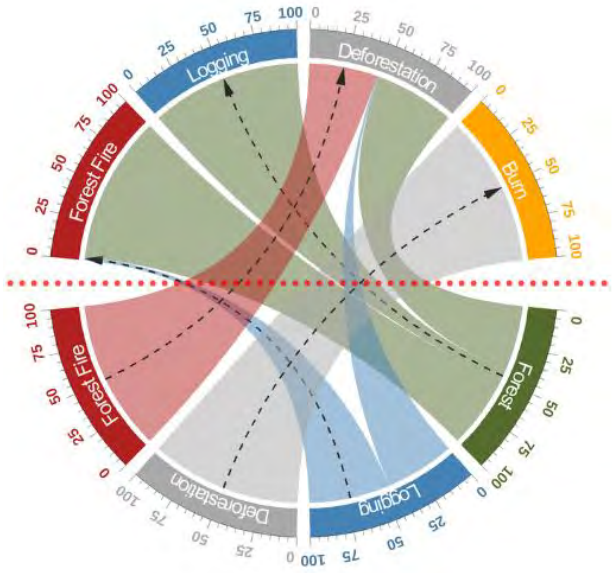

Figure 4. Chord diagram showing land cover transitions projected to 2050. Arrows indicate the transition direction, with proportions shown as colored bands in percentages. The red dotted line separates destination classes in 2050 (top) from origin classes in 2021 (bottom).

Of the logged areas, 47 km² (15.7%) are likely to be burned, and 40 km² (13.4%) may be deforested later. Fires in deforested areas will span 3000 km², or ten times the logged area, representing 95% of the total deforested region by 2050.

Additionally, 1400 km² of forest fire is expected to be cleared by the end of the period.

Environmentally distinctive (ED) settlements showed 32.9% (720 km²) of their area affected by deforestation, fire, or logging by 2050 (Figure 5). Out of this total, 21.6% is related to forest loss by deforestation. Burned areas show the highest percentages, reaching 14.8% in traditional settlements. Despite having a lower relative percentage than ED settlements, landholdings experienced the largest total change. CAR claims, which total 424 km², representing 10.3% and 19.2% of their areas, respectively.

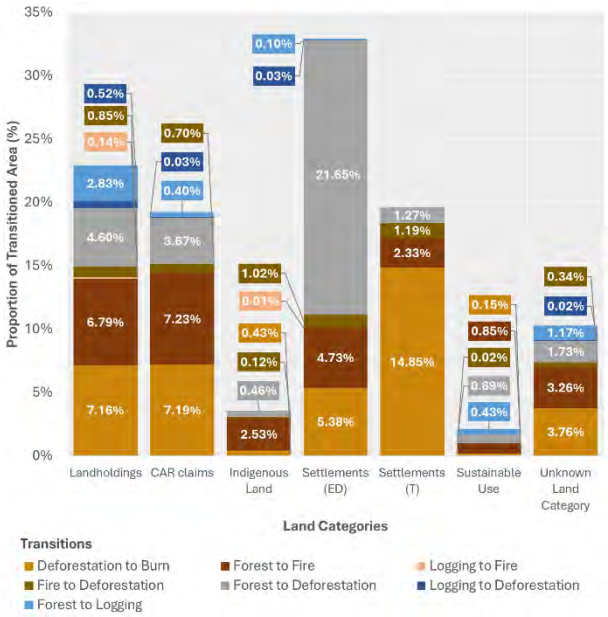

Figure 5. Proportions of the area transitioned by land categories (%). ED refers to environmentally distinctive settlements, and T to traditional settlements.

4. DISCUSSION

The projection results mirror patterns identified during the calibration period, highlighting the relationship between access routes and both deforestation and degradation. In Boca do Acre, deforestation and degradation are closely linked to established access routes, such as road networks and rivers, which facilitate the activities of deforestation actors and the expansion of the cattle ranching frontier [18]. Additionally, the proximity of burned areas to pastures or recently deforested regions reflects prevalent practices in the region, where slash-and-burn techniques are commonly used to prepare land for agriculture and ranching [19]. This practice often results in severe consequences, as fires can easily spread from cleared areas into adjacent forests [20].

While our study did not find a significant correlation between logging activities and increased fire occurrence—contrary to findings from other regions—this may be attributed to historical management practices in the study area [21]. Most logged areas during the calibration period were subject to forest management plans, potentially mitigating the

risk of fire spread. Nonetheless, it is critical to acknowledge that the increasing effects of climate change are likely to elevate fire risks in these landscapes [22].

ED settlements, despite their sustainable intentions, exhibited substantial land-use changes, indicating that the pressures of deforestation and degradation are similar to traditional settlements areas because the main activity is for cattle ranching and the agents of deforestation are similar. The patterns in Boca do Acre align with broader trends noted across the Amazon, suggesting that land-use policies must adapt to the dynamic interplay of economic activities and ecological conservation [23, 24].

Finally, it is important to recognize that the projections from this study may not fully encapsulate future scenarios, as significant forest loss and fire incidents have already been documented in Boca do Acre [9]. Continued monitoring and adaptive management strategies will be essential to address these challenges effectively and ensure the sustainability of forest resources.

5. CONCLUSIONS

Deforestation and forest degradation were shown to be rapidly increasing in the municipality of Boca do Acre. Modeled projections based on these findings reveal the pressing need for comprehensive land-use management strategies in Boca do Acre and in areas of Amazonia where similar processes are underway. The anticipated loss of forest cover illustrates the profound impact of logging, wildfires, agricultural expansion, and practices like slash-and-burn on local ecosystems and climate regulation. By addressing both deforestation and forest degradation, this research provides future scenario projections that emphasize the importance of including degradation as a critical element in land-use and conservation planning. Additionally, the findings serve as a robust foundation for informed decision-making, underscoring the value of environmental modeling in developing effective strategies.

6. ACKNOWLEDGMENTS

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