



CONSERVATION
INTERNATIONAL

PROGRESS REPORT

2024

PROFESSIONAL PROFILE



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Combined effects of climate change and land cover alterations on mortality in the Brazilian Amazon

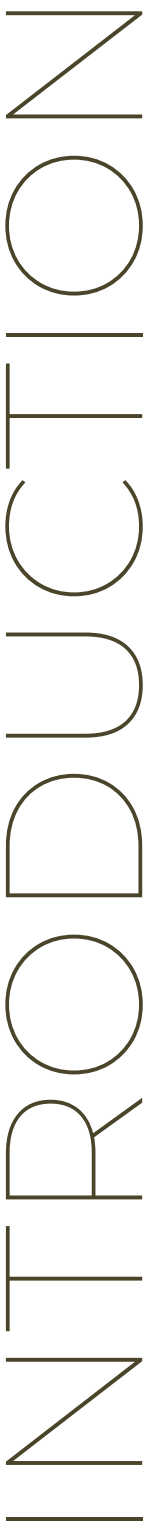
Alert: *This is the first version of the study. Further refined analyses will be conducted, including deeper investigations as opportunities are identified, aiming to enhance the results and interpretations presented.*

ABSTRACT

The Legal Amazon, covering 59% of Brazil's territory and hosting 8% of the South American population, faces growing challenges due to deforestation and climate change, which exacerbate risks of mortality associated with extreme heat. This study quantified excess deaths attributable to increased Land Surface Temperature (LST) in the region's municipalities using a Distributed Lag Non-Linear Model (DLNM) and mortality projections based on climate and land-use scenarios (SSP2_RCP4.5 and SSP3_RCP7.0). In the first stage, an exposure-response function was developed for the Legal Amazon capitals from 2001 to 2019 (Rio Branco, Boa Vista, Porto Velho, Macapá, Manaus, and Belém). In the second stage, future mortality impacts were projected considering climate and land-use scenarios. Under the SSP3_RCP8.5 scenario, projections indicate an Attributable Fraction (AF) of 4.8% for all-cause mortality and 5.7% for cardiovascular diseases, amounting to up to 2,209 annual deaths attributable to extreme heat. These findings highlight the region's vulnerability, particularly in urban areas, and underscore the urgency of climate mitigation and adaptation policies in the Amazon.



Combined effects of climate change and land cover alterations on mortality in the Brazilian Amazon



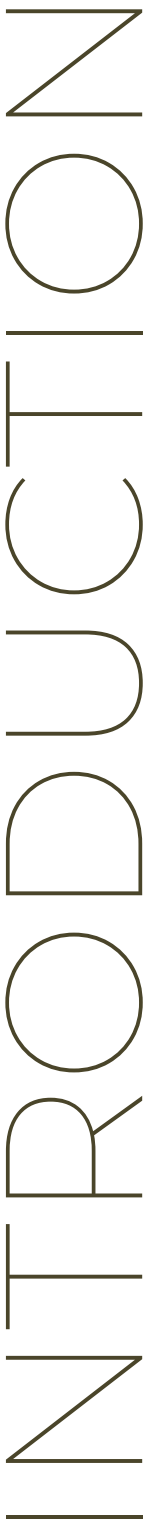
The Amazon rainforest, renowned for its unparalleled biodiversity, is home to about 8% of South America's population, distributed across cities, riverine communities, and indigenous villages. In Brazil, the territory known as the Legal Amazon encompasses the entire Amazon biome and parts of the Cerrado and Pantanal biomes, representing 59% of the national territory. It includes all states in the Northern Region (Acre, Amazonas, Amapá, Pará, Rondônia, Roraima, and Tocantins), Mato Grosso, and part of Maranhão (Amazônia 2030, 2021).

Over the past decades, the Legal Amazon's population has grown from 8.2 million in 1972 to 28.1 million in 2020, while experiencing accelerated forest cover loss driven mainly by agricultural expansion, cattle ranching, and logging activities. Studies indicate that forest cover loss in the Amazon may compromise the provision of local, regional, and global ecosystem services, including biodiversity conservation, climate regulation, and increased incidence of emerging and reemerging diseases as well as those linked to air pollution caused by biomass burning (Borma et al., 2022).

In 2023 and 2024, due to the unusual intensity of the El Niño phenomenon, the region faced a climate emergency characterized by changes in rainfall patterns and record local temperatures, along with critical episodes of air pollution from forest fires, extreme heat, and prolonged droughts. Specifically, regarding temperature, extreme heat has been linked to increased mortality from cardiovascular, respiratory, and metabolic diseases (Sousa et al., 2018).



Combined effects of climate change and land cover alterations on mortality in the Brazilian Amazon



Additionally, heat stress adversely affects mental health, reduces physical and cognitive capacity, and compromises labor productivity, particularly among heat-exposed workers (Silva et al., 2024; Mora et al., 2017).

In general, health effects and impacts are aggravated by socioeconomic and demographic factors, such as limited access to healthcare systems, inadequate infrastructure, and social inequalities that increase population vulnerability.

In the Amazon, these conditions are even more pronounced, as the region hosts communities that directly depend on the natural environment for subsistence and face significant barriers to adapting to environmental changes (Watts et al., 2021; Rocha et al., 2022).

Moreover, the combination of deforestation and global warming amplifies mortality risks, as shown by international studies correlating temperature increases with rising rates of preventable deaths (Barbosa et al., 2024).

Against this backdrop, this study aims to quantify excess heat-associated deaths in Brazilian Amazon municipalities according to climate change and land-use scenarios. By integrating data on deforestation, local temperatures, and mortality effects, this study seeks to provide robust scientific evidence to inform public policies and strategies for local climate mitigation and adaptation.

DATA AND METHOD

This is an epidemiological ecological study conducted in two methodological stages aimed at estimating the exposure-response function between Land Surface Temperature (LST) and general mortality (excluding external causes), cardiovascular diseases, and respiratory diseases.

The study also quantifies the impact of projected temperature increases on mortality, considering land-use and land-cover scenarios SSP2_RCP4.5 and SSP3_RCP7.0, as developed by Butt et al. (2023) for the Brazilian Amazon:

► Stage One: Estimation of the Exposure-Response Function

The exposure-response function was estimated using daily LST data obtained through the ERA5-Land reanalysis developed by the Copernicus Earth Monitoring Program (Copernicus Climate Change Service, 2019).

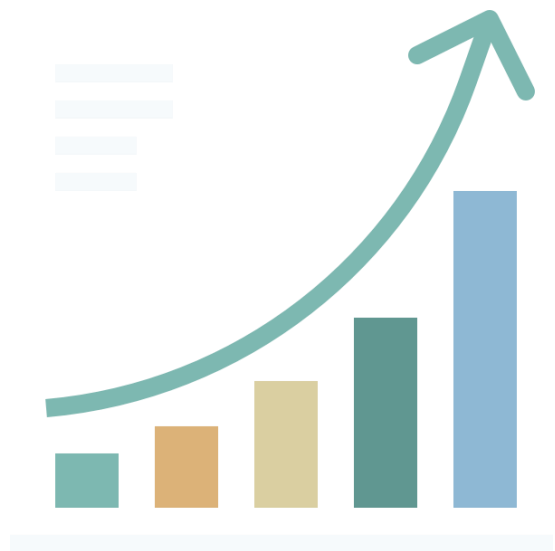
ERA5-Land provides a detailed database of meteorological and climatic variables with high spatial resolution (approximately 9 km) and daily temporal resolution. This database integrates real-world observations with numerical models to provide consistent and high-quality estimates of climatic variables, such as temperature, humidity, and precipitation.

DATA AND METHOD

► Stage One: Estimation of the Exposure-Response Function

In this stage, data were collected for six capitals of the Legal Amazon (Rio Branco, Boa Vista, Porto Velho, Macapá, Manaus, and Belém). For each capital, a time series of daily average LST values was constructed for the period between 2001 and 2019. The average was calculated using LST values from all pixels (1 km x 1 km resolution) within the urban polygons of each municipality, where most of the population resides.

The Distributed Lag Non-Linear Model (DLNM) was applied to estimate the relationship between daily mean LST variations and mortality. This approach accounts for the non-linear and lagged effects of the association through a cross-basis function (Gasparrini et al., 2010).



To model the relationship between LST and mortality, a natural cubic spline (NCS) with knots placed at the 10th, 75th, and 90th percentiles of the LST distribution was used. The lagged component was modeled with an NCS with three equally spaced knots on a logarithmic scale, considering a maximum lag of five days.

DATA AND METHOD

► Stage One: Estimation of the Exposure-Response Function

Seasonality and long-term trends were adjusted using an NCS with six degrees of freedom per year, while day-of-week effects were accounted for using an indicator variable. Absolute humidity was adjusted using an NCS with three degrees of freedom. Relative Risk (RR) estimates for mortality were calculated for different LST levels.

Additionally, a linear function was applied to estimate the mortality risk associated with each unit increase in LST, enabling projections of future mortality impacts under different climate change and land-use scenarios.

At the end of this stage, city-specific exposure-response functions were combined using a meta-regression approach as described by Gasparrini and Armstrong (2013). This produced a single estimate for the Brazilian Amazon region based on the studied outcomes.



DATA AND METHOD

► Stage Two: Projection of Mortality Attributable to LST Increase

Seasonality and long-term trends were adjusted using an NCS with six degrees of freedom per year, while day-of-week effects were accounted for using an indicator variable. Absolute humidity was adjusted using an NCS with three degrees of freedom. Relative Risk (RR) estimates for mortality were calculated for different LST levels.

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At the end of this stage, city-specific exposure-response functions were combined using a meta-regression approach as described by Gasparrini and Armstrong (2013). This produced a single estimate for the Brazilian Amazon region based on the studied outcomes.

Using the results from Stage One, the Attributable Fraction (AF) and the number of deaths related to LST increases were calculated for the following land-use and land-cover scenarios: a)"Middle-of-the-road narrative": Average LST in each pixel (1 km x 1 km) using ΔT for SSP2_RCP4.5; b)"Strong inequality": Average LST in each pixel (1 km x 1 km) using ΔT for SSP3_RCP7.0.

DATA AND METHOD

► Stage Two: Projection of Mortality Attributable to LST Increase

The Attributable Fraction (AF) is a metric widely used in environmental epidemiology to quantify the proportion of health outcomes, such as mortality, attributable to a specific exposure. In this study, a simplified AF calculation was used to estimate the impact of increased LST on general and specific-cause mortality under future climate and land-use scenarios. The simplified calculation is based on the relationship between future temperature increase (ΔT) and Relative Risk (RR), previously estimated for each unit increase in LST (equation 1):

$$\text{Equation 1: } AF = \frac{\Delta T \times (RR - 1)}{\Delta T \times (RR - 1) + 1}$$

RR_{future} values are adjusted for each expected LST increment (ΔT) based on the initial stage's relative risk calculations, enabling projections of mortality risks associated with different LST increases under various climate and land-use scenarios (equation 2):

$$\text{Equation 2: } AF = \frac{\Delta T \times (RR_{\text{future}} - 1)}{\Delta T \times (RR_{\text{future}} - 1) + 1}$$

Additionally, the absolute number of attributable deaths for each outcome can be estimated by multiplying the AF by the projected mortality for each municipality or region (equation 3). For this study, the average annual mortality from 2001 to 2019 was used as the baseline for the scenarios under investigation.

$$\text{Equation 3: } N^{\circ} \text{ of deaths} = AF \times \text{Mortality}_{\text{outcome}}$$

FIRST FINDINGS

The descriptive analysis of the variables used to estimate the concentration-response function is presented in **Table 1**.

Among the studied capitals, Boa Vista stood out as the hottest city with the highest thermal variability, showing an average LST of 27.5°C (SD 2.1°C), followed by Manaus (27.0°C) and Belém (26.9°C). Additionally, these cities exhibited high relative humidity levels, with average values close to 80%.

From a demographic perspective, Manaus is the most populous city, with 1,837,786 inhabitants, followed by Belém with 1,426,831 inhabitants. Together, these cities account for more than 68% of the total population among the analyzed capitals.

The population size is reflected in the total number of deaths. Manaus recorded the highest absolute number of deaths (137,300), followed by Belém (132,864). Cardiovascular disease (CVD) related deaths were most prevalent in Belém (36,528), while respiratory diseases (RD) had the greatest impact in Manaus, with 13,474 deaths.

Table 1. Descriptive analyses of variables used in Stage 1 for estimating the concentration-response function.

	Belém	Boa Vista	Macapá	Manaus	Porto Velho	Rio Branco	Total
LST (mean)	26.9	27.5	26.2	27.0	26.2	25.7	26.6
LST (sd)	1.4	2.1	1.4	1.3	1.3	1.7	1.6
Humidity (mean)	83.8	78.4	86.1	82.9	77.8	78.3	81.2
Humidity (sd)	7.6	10.4	7.5	7.9	11.8	10.6	9.9
Population (2010)	1426831	289576	412916	1837786	438458	350589	4756156
Death Total	132864	17249	24680	137300	31939	26394	370426
Death DCV*	36528	4851	5633	28477	8107	6366	89962
Death DAR*	20454	1704	2672	13474	3806	3900	46010

*DCV: Cardiovascular Disease; DAR: Respiratory Disease



FIRST FINDINGS

At the end of the first methodological stage, the short-term effects of daily average LST values on mortality from all causes (excluding external causes) and selected causes were estimated using data from the capitals of the Brazilian Legal Amazon (**Figure 1**).

The combined exposure-response curve demonstrated a non-linear relationship between LST and mortality, with increased risks observed at extreme temperatures, particularly above 29°C. Among the studied outcomes, deaths from cardiovascular and respiratory diseases proved to be sensitive indicators for assessing the impact of exposure to extreme LST levels.

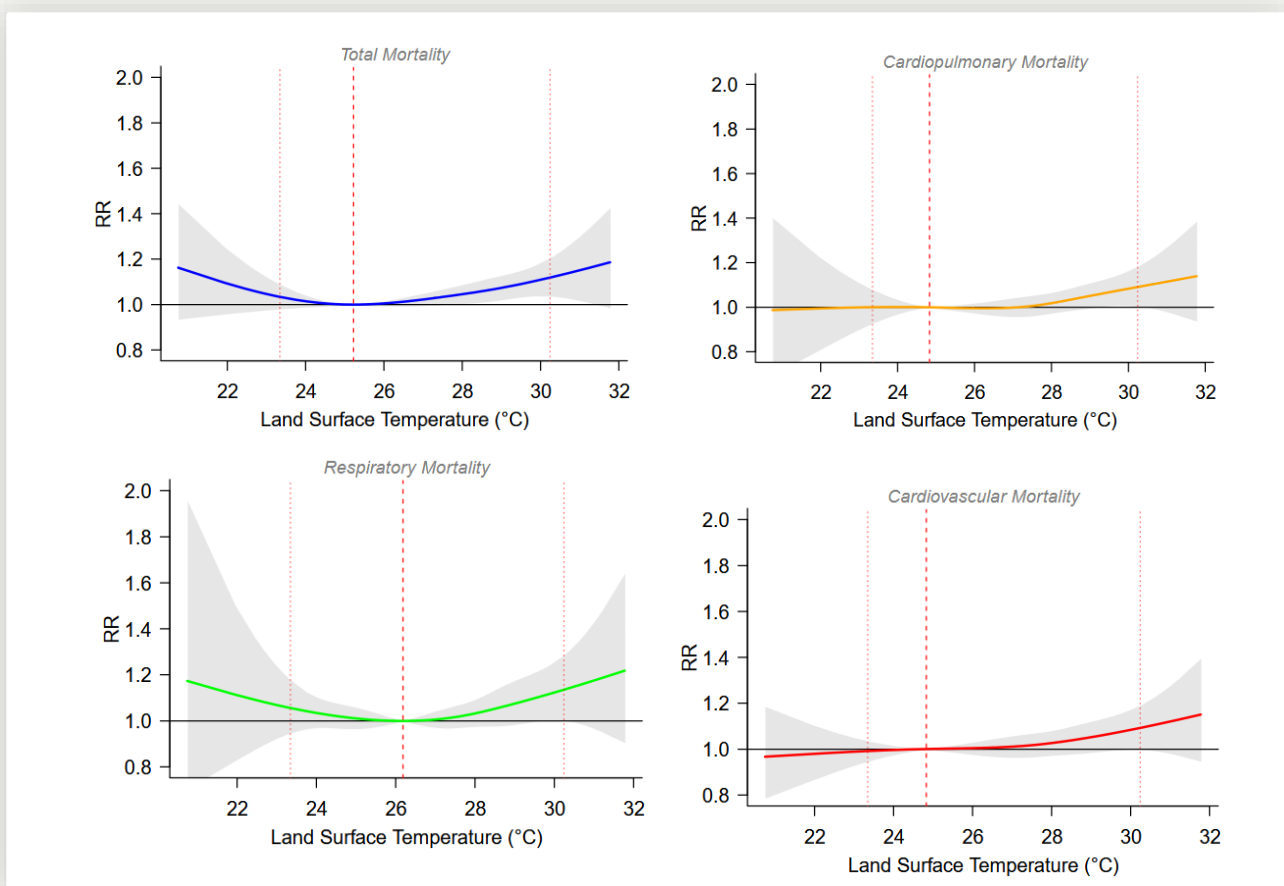


Figure 1. Combined exposure-response curves for the capitals of the Brazilian Legal Amazon during the period 2001–2019, using the Distributed Non-Linear Lag Model (DLNM).

FIRST FINDINGS

The relative risk (RR) of the combined exposure-response curves for the Legal Amazon capitals from 2001 to 2019, considering different LST percentiles (P1, P5, P95, and P99) and the 7-day cumulative risk for each 0.1°C increment, is presented in **Table 2**. Higher temperatures (P95 and P99) were significantly associated with increased mortality risk for all causes and cardiovascular and cardiopulmonary diseases. Additionally, a 15% increase (RR = 1.015; 95% CI: 1.001–1.028) in mortality from all causes, excluding external causes, was observed for each 0.1°C increment in LST.

Table 2. Relative risk of the combined exposure-response curves for the capitals of the Brazilian Legal Amazon during the period 2001–2019 for percentiles (1, 5, 95, and 99) of land surface temperature and a 1°C increment. ¹7-day cumulative risk of exposure (lag7).

	Risk relative to mortality			
	Non-external	Cardiopulmonary	Cardiovascular	Respiratory
LST effect				
P1 (23.2°C)	1.034 (0.979-1.091)	1.001 (0.929-1.07)	0.990 (0.947-1.036)	1.056 (0.948-1.176)
P5 (24.2°C)	1.007 (0.992-1.023)	1.001 (0.986-1.016)	0.997 (0.987-1.008)	1.023 (0.971-1.077)
P95 (29.2°C)	1.086 (1.028-1.147)	1.061 (1.004-1.121)	1.060 (0.992-1.132)	1.086 (0.990-1.191)
P99 (30.2°C)	1.120 (1.039-1.206)	1.092 (1.009-1.182)	1.090 (1.000-1.189)	1.137 (1.004-1.288)
0.1°C¹ increment	1.010 (1.002-1.017)	1.015 (1.001 -1.028)	1.013 (1.002-1.024)	1.010 (0.992-1.028)



FIRST FINDINGS

In the second stage of the analysis, the attributable fraction (AF) and the average annual number of deaths associated with changes in LST in the Brazilian Amazon were calculated for the historical period (2001–2019) and future projections based on the SSP2_RCP4.5 and SSP3_RCP8.5 climate scenarios.

Projected changes in LST, particularly under the SSP3_RCP8.5 scenario, indicate significant increases in the attributable fraction and number of deaths. These projections show an AF of 4.8% (95% CI: 0.8–6.4) for all-cause mortality and 5.7% (95% CI: 0.4–10) for cardiovascular mortality.

From a population perspective under the SSP3_RCP8.5 scenario, an average of 2,209 deaths (95% CI: 460–3,626) per year from all causes could be attributable to increased LST combined with changes in land use and cover.

Table 3. Fraction and average number of deaths per year attributable to changes in land surface temperature (LST) in the Brazilian Amazon, according to climate change and land use/cover change scenarios.

	Period 2001-2019			SSP2_RCP4.5			SSP3_RCP8.5		
Fraction of attributable deaths									
	FAP	CI95%		FAP	CI95%		FAP	CI95%	
Non- external	1.0	0.2	1.7	2.9	0.6	4.8	3.9	0.8	6.4
Cardiopulmonary	1.3	0.2	2.3	3.7	0.6	6.5	5.0	0.8	8.8
Cardiovascular	1.5	0.1	2.7	4.3	0.3	7.5	5.7	0.4	10.1
Respiratory	1.0	-0.8	2.7	2.9	-2.5	7.5	3.9	-3.4	10.1
Average number of attributable deaths per year									
	Death	CI95%		Death	CI95%		Death	CI95%	
Non- external	707	142	1193	1976	408	3264	2209	460	3623
Cardiopulmonary	348	54	635	974	157	1721	1065	174	1858
Cardiovascular	289	20	532	796	56	1411	883	63	1545
Respiratory	75	-61	207	217	-188	566	229	-202	581



FIRST FINDINGS

The **Figure 2** illustrates the spatial distribution of mortality attributable to changes in LST, showing that municipalities in the southern and central-western regions of the Amazon exhibit the highest fractions of deaths, with values exceeding 7.5% under more extreme climate scenarios. These results highlight the regions most vulnerable to the impacts of climate change and land use/cover changes, particularly in terms of heat-related mortality.

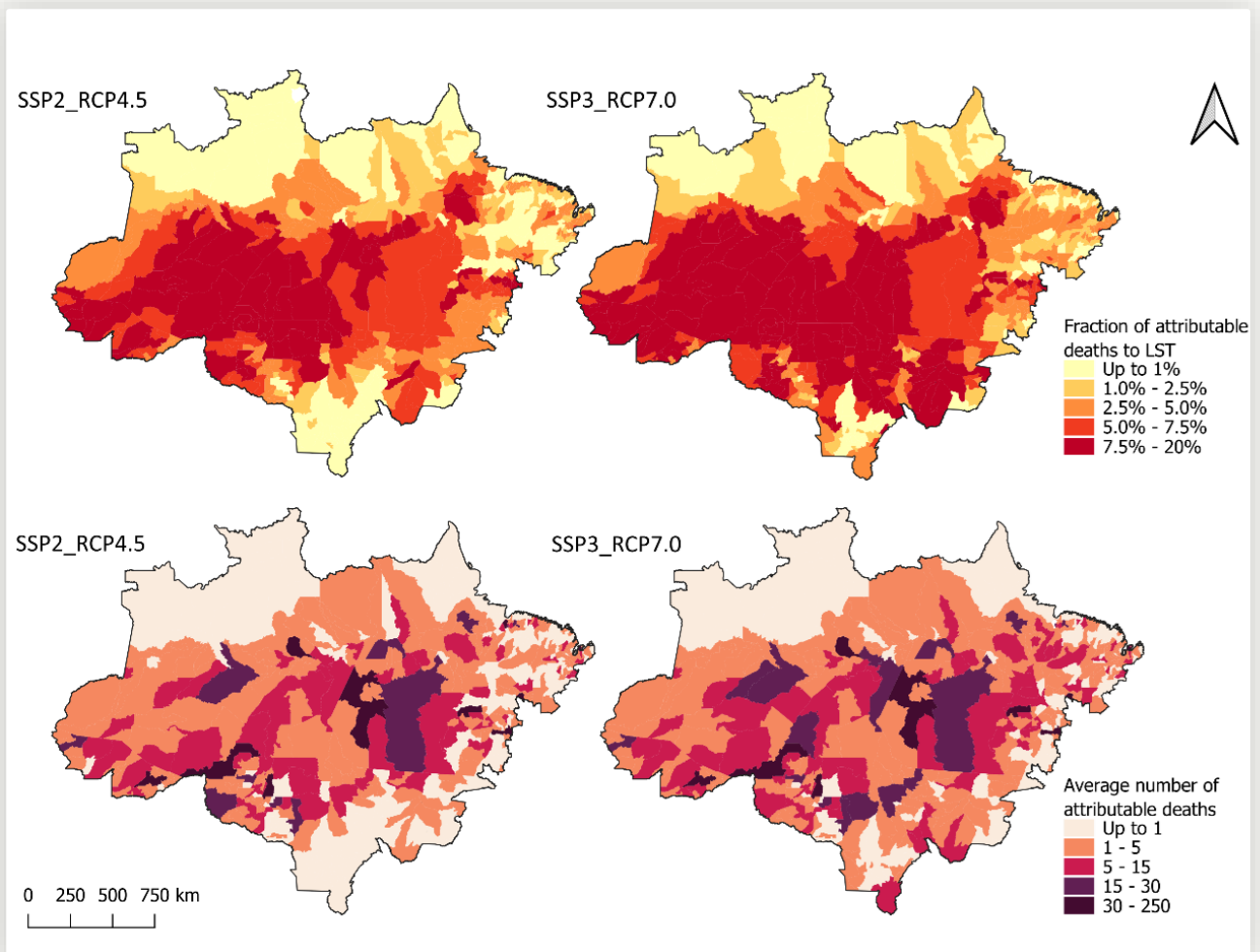


Figure 2. Fraction and average number of deaths per year attributable to changes in land surface temperature (LST) in the municipalities of the Brazilian Amazon, according to climate change and land use/cover change scenarios.

FIRST FINDINGS

The results of this study reinforce established evidence in the literature regarding the impacts of deforestation and climate change on mortality in tropical regions. Among the main findings, the risk of mortality from all causes and cardiopulmonary diseases stands out, particularly for land surface temperatures (LST) above 29°C.

Under the most extreme scenario (SSP3_RCP8.5), projections indicate an increase in annual deaths attributable to extreme heat in the Brazilian Amazon, highlighting the impact of the combination of forest loss and warming on human health.

The analysis of the association between LST and mortality emphasizes that the urban microclimate, represented by LST, can be a more sensitive predictor of mortality risk than air temperature in assessing the effects of climate change on public health.

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In general, LST can more robustly reflect localized variations, amplifying the impacts of extreme heat, particularly in densely urbanized areas with low vegetation cover (Avashia et al., 2021). With the projected increase in hot days and nights due to climate change, cities must devise specific strategies and policies to mitigate heat-related risks.

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FIRST FINDINGS

Recent studies show that deforestation in tropical regions not only raises local temperatures but also increases the risk of thermal stress. In extreme scenarios, the savanization of the Amazon could elevate the wet-bulb globe temperature index to levels beyond the human adaptation threshold by 2100, intensifying the impacts on the most vulnerable populations, such as those in northern Brazil, who already face significant socioeconomic challenges (de Oliveira et al., 2021). Additionally, the combined effects of deforestation and global warming could increase local temperatures by up to 3°C, amplifying public health risks (Vargas Zeppetello et al., 2020).

The increase in heat-related mortality in the Brazilian Amazon may be exacerbated by the heightened vulnerability of local populations, often characterized by limited access to healthcare resources and adaptation measures (Oliveira et al., 2021). Furthermore, deforestation not only contributes to rising local temperatures but also exacerbates other health risks.

In the studied region, local populations are frequently exposed to atmospheric pollutants from burning and forest fires during dry spells, which directly impact public health (Butt et al., 2020; Oliveira et al., 2023). These factors, combined with the direct effects of warming, increase the burden on local healthcare services. Thus, conservation and mitigation policies addressing both deforestation and the impacts of climate change are essential to reducing health risks for these vulnerable populations in the Brazilian Amazon.

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Climate Change and Land Surface Temperature: vulnerable population groups in urban areas and insights into green and blue infrastructure strategies for climate adaptation

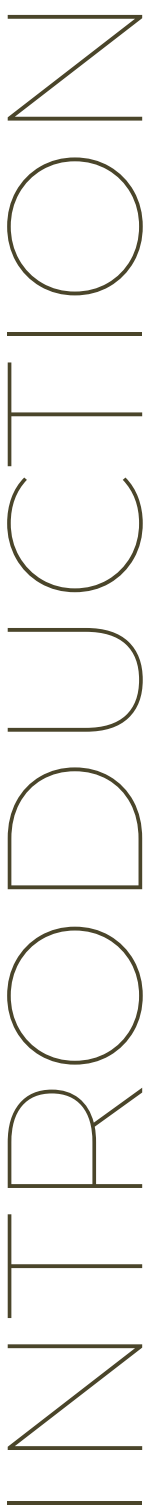
Disclaimer: This is the first version of the study. The data presented here will not be altered. Still, the analyses regarding exposure by race and ethnicity, as well as the categorization of urban settlements according to the possibility of presenting nature-based solutions, require more in-depth studies, which will be offered soon.

ABSTRACT

The study investigates the impacts of climate change on urban areas within the Brazilian Legal Amazon, emphasizing the relationship between land surface temperature (LST), socioeconomic vulnerabilities, and urban adaptation strategies. Analyzing baseline and projected LST scenarios (SSP2_RCP4.5 and SSP3_RCP7.0) alongside census and deforestation data, the research highlights significant disparities. Urban heat island effects predominantly affect wealthier neighborhoods due to extensive gray infrastructure, while lower-income populations in peripheral areas experience milder LST due to proximity to natural green spaces. However, these regions lack critical infrastructure. Results indicate that deforestation exacerbates LST, with a direct correlation between increased deforestation and higher temperatures. Socioeconomic analysis reveals a nuanced relationship where LST peaks in middle-class neighborhoods and declines in wealthier ones. The study advocates for implementing green and blue infrastructure to mitigate urban heat stress, ensuring equitable thermal comfort. These nature-based solutions should address both immediate infrastructure deficits and long-term climate resilience. Further work will refine demographic insights and explore comprehensive adaptation frameworks tailored to urban and environmental dynamics. The findings contribute to climate justice discourse and inform sustainable urban planning in climate-vulnerable regions.



Climate Change and Land Surface Temperature: vulnerable population groups in urban areas and insights into green and blue infrastructure strategies for climate adaptation



The low population density of the Brazilian Legal Amazon belies a complex landscape of profound socio-environmental disparities. Urban settlements occupy a mere 0.15% of the region's total area, with the six (06) state capitals comprising only 0.0125% of the territory. Despite this minimal spatial footprint, these urban centers comprise 18% of the Brazilian Legal Amazon's population, representing approximately 5 million of the region's 27.8 million inhabitants.

There are significant concerns regarding the escalating urban population and the imminent impacts of climate change, with rising temperatures emerging as a critical climate hazard directly linked to human health (Gasparrini et al., 2015; Al-Kind et al., 2023).

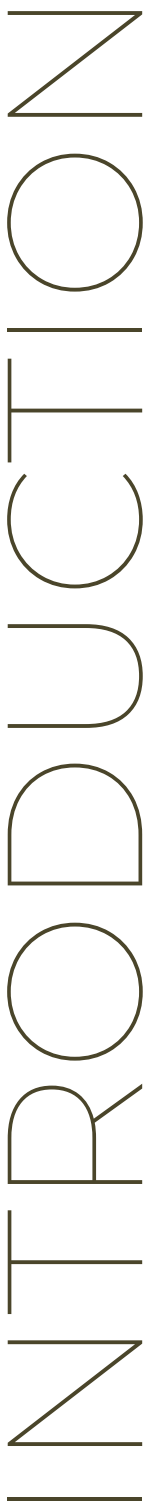
These risks are particularly pronounced for the Brazilian population (Requia et al., 2020; Silveira et al., 2021; Moraes et al., 2021), especially those inhabiting urban areas (Harlan and Rudell, 2011; Gostimirovic et al., 2023), where the urban heat island effect and limited adaptive capacity can exacerbate climate-related health vulnerabilities.

In general, urban and climate justice studies suggest that low-income populations are more vulnerable to the effects of high temperatures (Xu et al, 2020; Portner et al., 2022), and it is well-documented that the hottest urban areas tend to be occupied by socioeconomically vulnerable populations, as low-income families and colored communities (Hoffman et al, 2020; Wilson, 2020; Dialesandro et al., 2021).



Climate Change and Land Surface

Temperature: vulnerable population groups in urban areas and insights into green and blue infrastructure strategies for climate adaptation



In Brazil's largest cities, such as São Paulo and Rio de Janeiro, several urbanization processes, known as favela urbanization, created settlements characterized by a lack of green infrastructure, extremely dense with unplanned road paving, absent urban tree cover, lacking free and permeable spaces, and without setbacks between residences, which tend to be significantly hotter than planned neighborhoods (Perlman, 2010; Barros & Lombardo, 2016; Dias et al., 2022).

However, in the Brazilian Legal Amazon, the displacement of the most socioeconomically vulnerable population to the peripheries of state capitals reveals another reality: a large part of the low-income population lives in neighborhoods with lower temperatures compared to higher-income neighborhoods, primarily due to the near-complete absence of gray infrastructures, such as paving, and the proximity to rural areas that remain forested.

Given the complex urban peripheries of the Brazilian Legal Amazon, there exists an invaluable opportunity to generate transformative insights into green and blue infrastructure strategies and nature-based adaptation measurements.



Climate Change and Land Surface Temperature: vulnerable population groups in urban areas and insights into green and blue infrastructure strategies for climate adaptation

NOTICE OF PROTECTION

Thus, we analyzed the spatial relationship of a baseline dataset of Land Surface Temperature (LST) and the prediction of future LST based on the SSP2_RCP4.5 and SSP3_RCP7.0, developed by Butt et al. (2023), and socioeconomic information from Brazilian Census dataset, to estimate urban population exposed to high LST, the relationship between socioeconomic classes and LST and to categorize typologies of urban settlements that can be useful to provide advances in climate adaptation and climate justice.

DATA AND METHOD

We used land surface temperature (LST) developed by Butt et al. (2023), to create rasters dataset as:

01

BASELINE

Average LST in each pixel (1km x 1 km) between 2001 and 2020

02

MIDDLE-OF-THE-ROAD NARRATIVE

Average LST in each pixel (1km x 1 km) using ΔT for SSP2_RCP4.5.

03

STRONG INEQUALITY SCENARIO

Average LST in each pixel (1km x 1 km) using ΔT for SSP3_RCP7.0

To analyze the LST in the state capitals, we used LST data (baseline and two future scenarios), classifying LST for each state capital, in a 1km x 1 km spatial resolution grid.

We also used deforestation data from Prodes (Almeida et al., 2023) to understand the relationship between deforested areas and LST, and used Census 2010 and 2022 (IBGE, 2010; 2022) to evaluate socioeconomic data.

Using spatial analysis tools, we combined socioeconomic and demographic data, such as population, income, and race, to assess the relationship between these data and LST.

FIRST FINDINGS

In this section, were presented the first results obtained from LST by Butt et al. (2023), Census data (IBGE 2010; 2022) and Prodes (Almeida et al., 2023).

➤ 3.1 Urban Analysis

Figures 1 and **2** show, on the right, LST (Land Surface Temperature) on a 1km x 1km grid classified in Natural Breaks for each state capital of the Brazilian Legal Amazon, and on the left, the areas with forest, deforested areas, and hydrography.



All spatial data were plotted at a 1:275,000 scale. In all capitals, it is possible to observe that the central areas are (up to 60°C) hotter than the peripheral areas.

FIRST FINDINGS

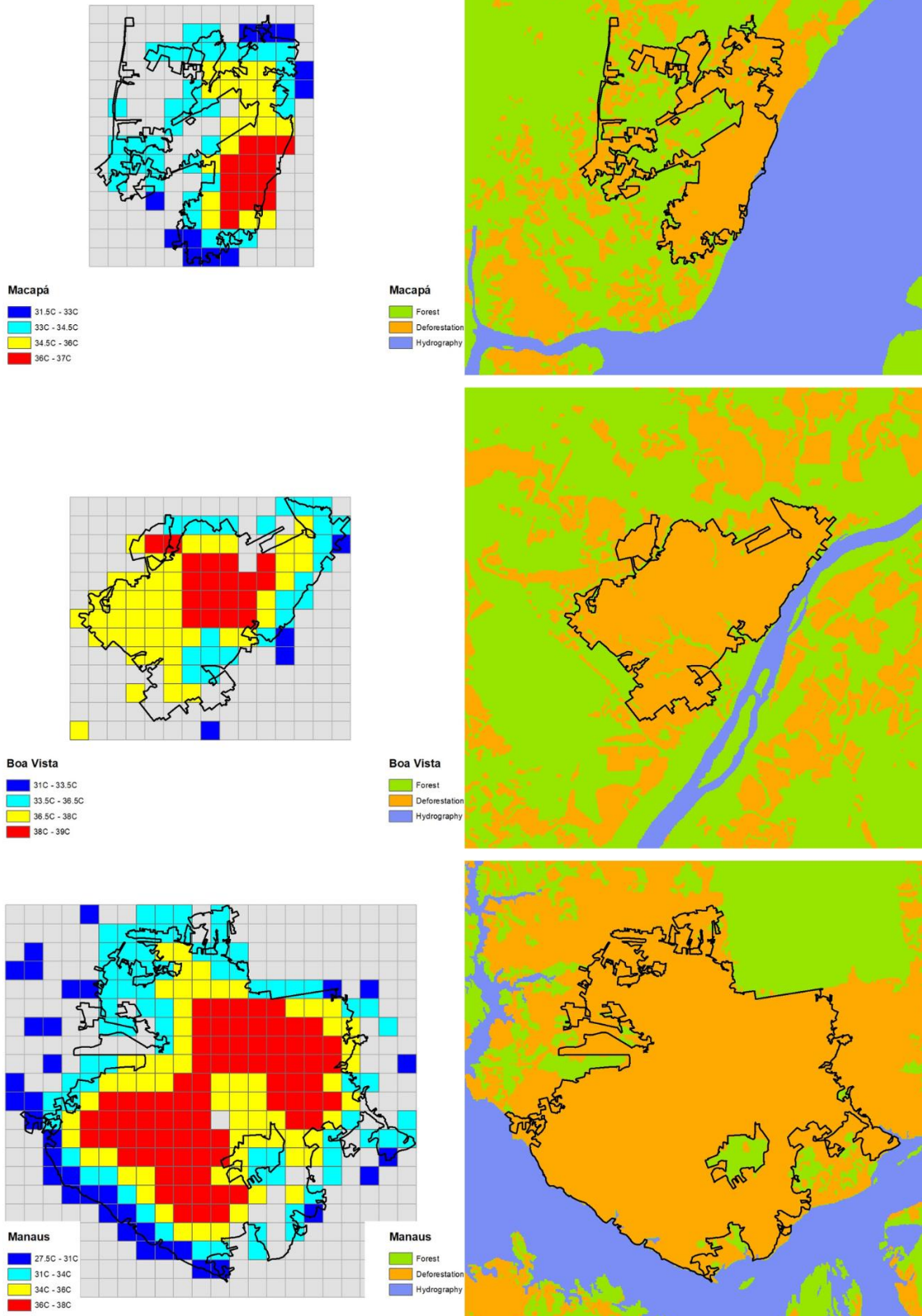
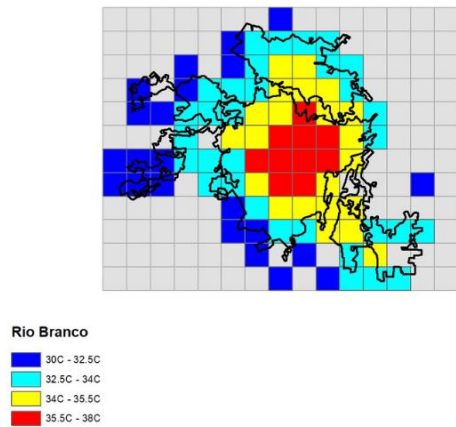


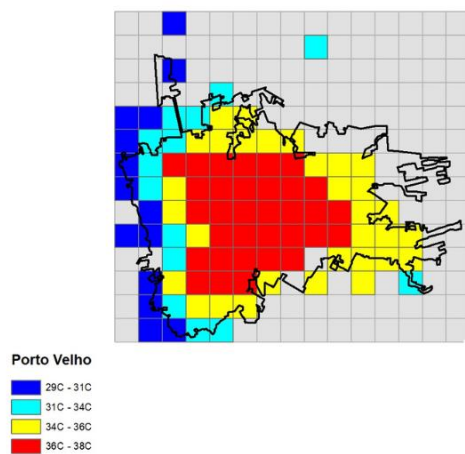
Figure 1: LST and Deforestation in Macapá, Boa Vista and Manaus.

FIRST FINDINGS



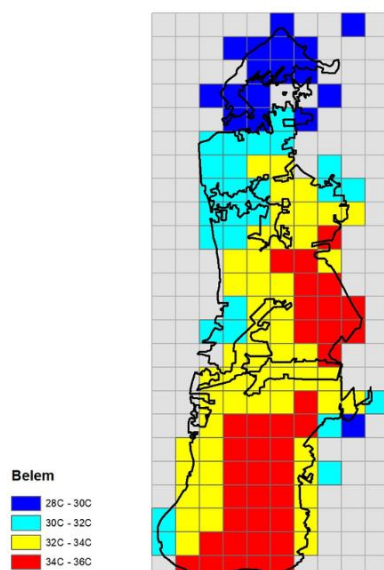
Rio Branco

- Forest
- Deforestation
- Hydrography



Porto Velho

- Forest
- Deforestation
- Hydrography



Belem

- Forest
- Deforestation
- Hydrography

Figure 2: LST and Deforestation in Rio Branco, Porto Velho and Belém.

FIRST FINDINGS

Also, it's important to understand the differences between LST in the six cities analyzed in this study, as **Figure 3** shows. The geographic and climatological aspects of each capital will be discussed in the next version of this document.

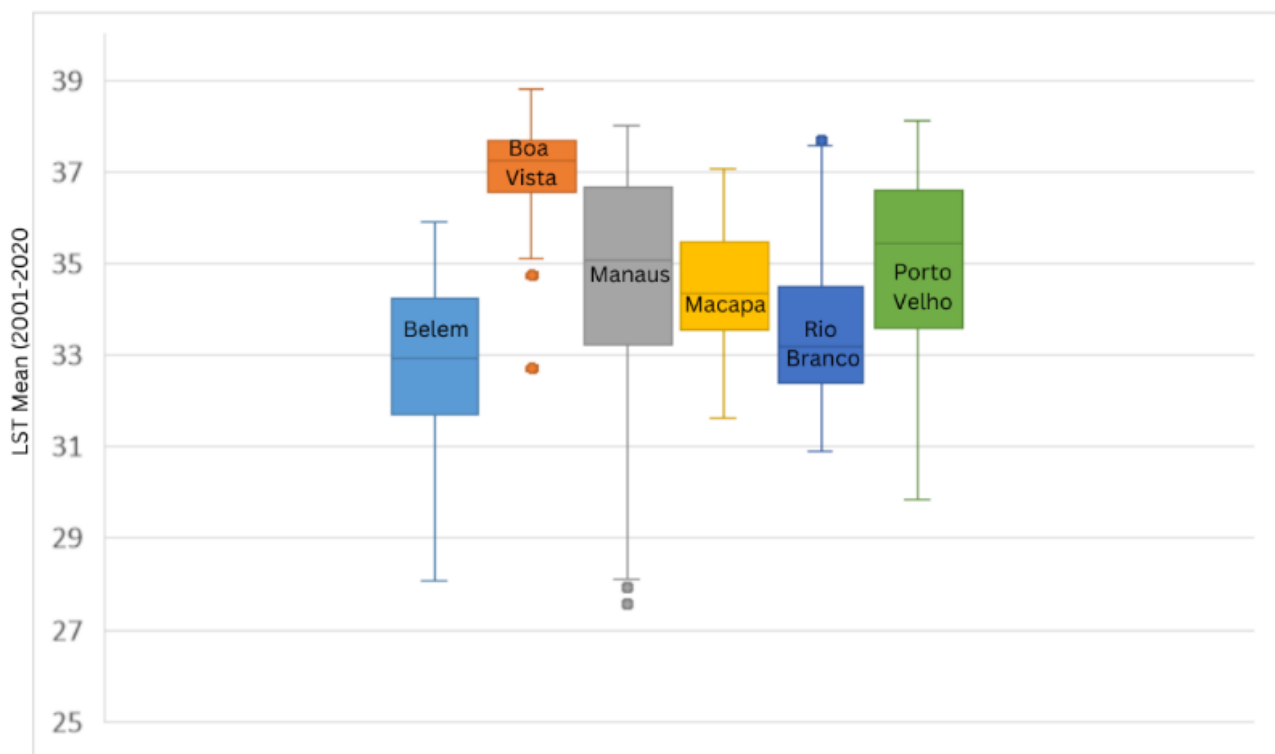


Figure 3: LST in the six state capitals

FIRST FINDINGS

➤ 3.2 Deforestation

Using the accumulated deforestation data from Prodes up to 2023, the deforested area in relation to the total area of each 1km x 1km grid cell was classified into 4 categories (25%, 50%, 75%, and 100% of the area occupied by deforestation in each cell) and analyzed about LST, with the results presented in **Figure 4**.

The median LST of ~33°C is the same for cells with 25% or 50% deforested area, and although those with up to 25% deforestation exhibit the larger distribution of LST, lower LST than the median, some of these cells have LST higher than those with 50% deforestation.

Cells with 75% and 100% deforestation show a median LST of ~34°C and ~35°C, respectively, and demonstrate LST increasing proportionally to deforestation.

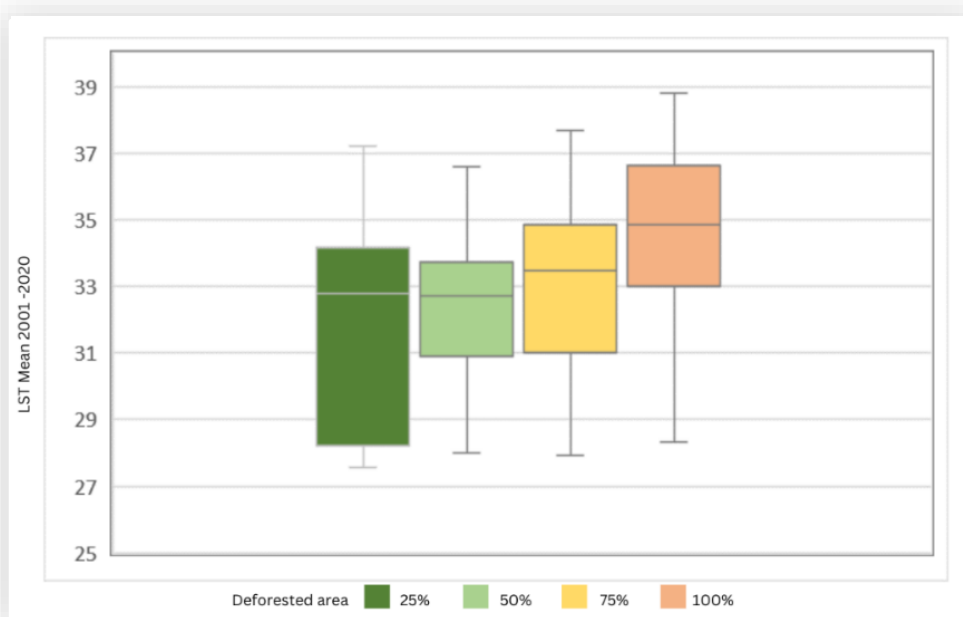


Figure 4: Distribution of deforestation and LST.

FIRST FINDINGS

➤ 3.3 Income

Due to the lack of household per capita income data at the census tract scale, we used the 2010 Census income data, anticipating the ability to update the values and their spatial distribution once the most recent Census data becomes available.

In 2010, the Minimum Wage was BRL 510.00 or approximately US\$283.00 per month, and in 2024, it increased to BRL \$1,640.00 or approximately US\$273.00 per month.

Families earning less than one minimum wage monthly are exposed to the lowest LST values, both in the median and overall distribution, except for a few outliers in other income classes.

LST gradually increases in proportion to the rise in monthly family income, with the high median being most representative of upper-middle-class families earning 5 to 8 minimum wages monthly.

Upon reaching families with more than 8 minimum wages monthly, the LST drops in the median, though remaining higher than in the three lowest income classes.

FIRST FINDINGS

► 3.3 Income

This result is primarily attributed to the fact that higher-income families tend to inhabit areas with more advanced urban infrastructure, characterized by paved streets, sidewalks with minimal tree cover, and high-rise building density. Lower-middle-income families typically inhabit similar urban spaces but in more commercial areas with greater urban mobility systems. In contrast, lower-income families predominantly reside in periphery zones at the urban-rural interface, with limited or no pavement.

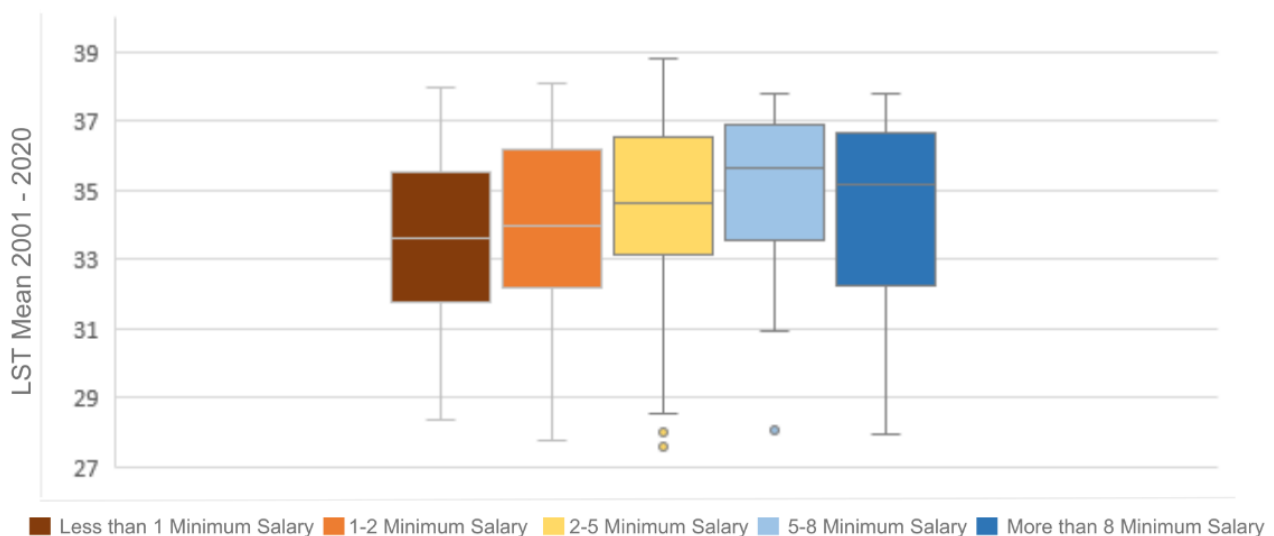


Figure 5: LST distribution by income. 1 the Minimum Salary in 2010 represented BRL \$ 510.00 or US\$ 283.00 per month.

FIRST FINDINGS

➤ 3.3 Income



Ensuring precarious urban settlements in the Brazilian Amazon Forest have access to fundamental urban infrastructure is critical

Low-income neighborhoods predominantly suffer from severe infrastructure deficits, including inadequate environmental sanitation, limited access to potable water, and insufficient public transportation. While addressing these foundational challenges is crucial, it is equally important to develop innovative, nature-based urban infrastructure solutions that can mitigate urban heat disparities.

The goal is to prevent low-income neighborhoods from becoming urban heat islands, a pattern already observed in major Brazilian cities like São Paulo and Rio de Janeiro, and notably in areas such as Cidade de Deus in Manaus. By implementing strategic green and blue infrastructure, we can create more equitable urban environments that provide thermal comfort and improve the overall quality of life for marginalized communities.

These nature-based interventions should be integrated systems that address multiple urban challenges simultaneously: reducing heat stress, improving drainage, enhancing biodiversity, and creating public spaces that support community well-being.

FIRST FINDINGS

➤ 3.4 Urban infrastructure

Figure 6 shows examples of the most upscale neighborhoods and slums in Manaus, Belém, and Rio Branco.

In Manaus, the Ponta Negra neighborhood is characterized by houses in gated communities with a few buildings nestled in a densely vegetated area, presenting one of the lowest LST among all capitals. In contrast, the Cidade de Deus favela, located on the edges of the Adolpho Ducke reserve (Souza et al., 2023), has high population density and was urbanized to contain hydro-geomorphological disaster risks, with an LST of 35°C.

On the other hand, in Belém, both the Umarizal neighborhood one of the most expensive in the city, and the low-income Terra Firme neighborhood, show the same LST, around 32°C. In the Umarizal urbanization, urban tree cover stands out in lowering the LST, while in Terra Firme, the low population density and the significant presence of tree-filled (Silva Barros et al., 2018) backyards positively impact the LST.

Finally, in Rio Branco, the city's most expensive neighborhood is Via Parque, which, despite having a linear park along the edges of the Rio Branco (Bento, 2024), has an LST 3.5°C higher than the low-income Ilson Ribeiro neighborhood, which lacks paving and has a high presence of trees and backyards.

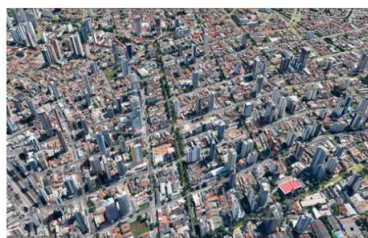
FIRST FINDINGS



➤ 3.4 Urban infrastructure



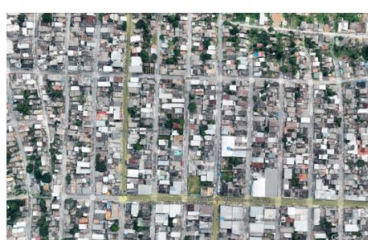
Manaus, AM - Ponta Negra 29C
More than 8 minimum salary



Belém, PA - Umarizal 32C
More than 8 minimum salary



Rio Branco, AC - Via Parque 35C
More than 8 minimum salary



Manaus, AM - Cidade de Deus 35C
Less than 1 minimum salary



Belém, PA - Terra Firme 32C
Less than 1 minimum salary



Rio Branco, AC - Ilson Ribeiro 31.5C
1 to 2 minimum salary

Figure 6: High and low neighborhoods in Manaus, Belem and Rio Branco.

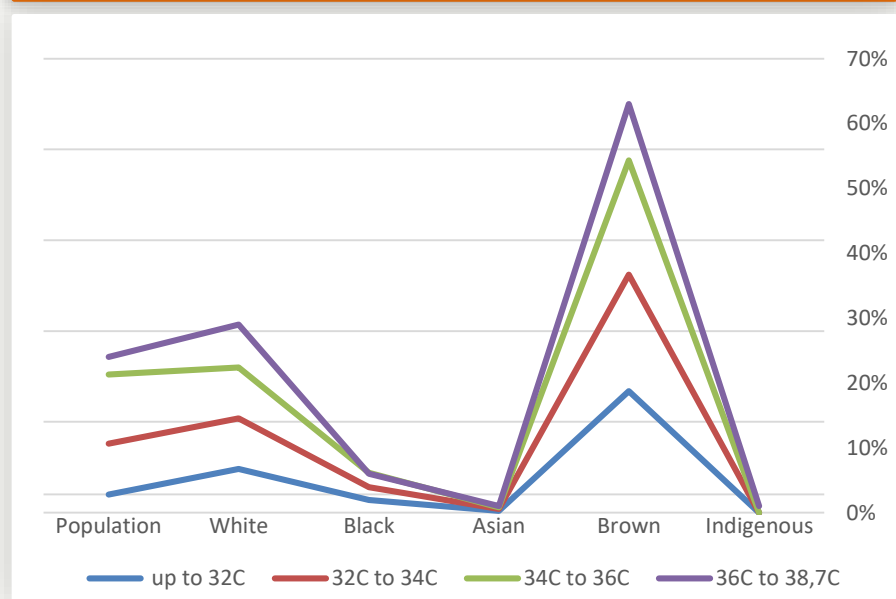
FIRST FINDINGS

➤ 3.5 Exposed population

Regarding the population exposed to high LST, the number of people and their race/ethnicity were analyzed. Future analyses will include age and gender demographic breakdowns of urban populations in the Brazilian Legal Amazon capitals, as shown in **Graphic 1**.

No specific race/ethnicity group stands out in exposure to almost of majority of the Brazilian Legal Amazon population considers themselves brown.

Graphic 1: Population exposed to LST by race



Despite being inexpressive, the only highlighted result is most of the Indigenous population in capitals are exposed to the highest LST, a fact that requires a deeper analysis of which cities and conditions these populations are in.

More in-depth demographic analyses are necessary, including more recent census data, to more clearly assess whether there are vulnerable groups according to race/ethnicity.

FIRST FINDINGS

► 3.6 Future scenarios

We used LST projections in two climate future scenarios, developed by Butt et al. (2023): The Middle of the Road narrative (SSP2) with the Representative Concentration Pathway (RCP) 4.5 and the scenario of Strong Inequality (SSP3) with the RCP7.0, as shown in **Figure 7**.

Using the same spatial analysis of the baseline (historical) data, is possible to observe that in Belém, Macapá, Porto Velho, and Rio Branco the SSP2_RCP4.5 will increase LST. In Boa Vista, it will decrease LST. The SSP3_RCP7.0 predicts a decrease of the LST in Belém, Boa Vista, and Rio Branco, while predicts an increase in Porto Velho and almost no change in Macapá. There's no data for Manaus in future scenarios.

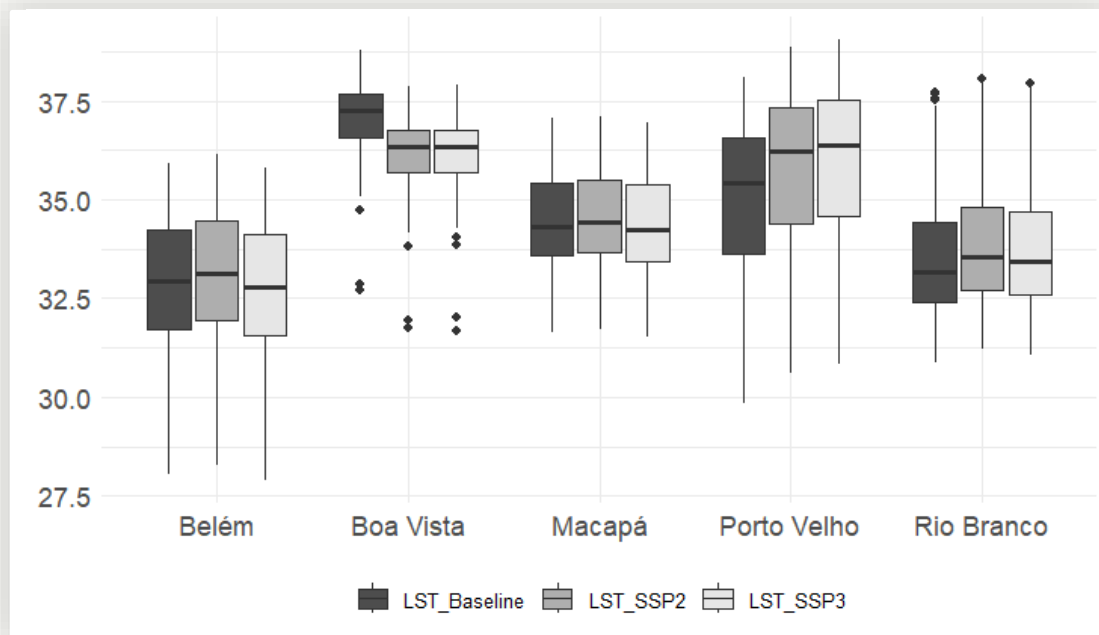


Figure 7: LST predictions using SSP2_RCP4.5 and SSP3_RCP7.0 developed by Butt et al. (2023) in 5 cities.

FIRST FINDINGS

► 3.6 Future scenarios

Observing, in **Figure 8**, the LST predicted by income, the SSP2_RCP4.5 scenario shows that the distribution over the population appears to drop in all socioeconomic classes, having the median a little higher in households in the 3 lower classes, no changes in families with 5 to 8 minimum salary and a little drop in the wealthiest households.

The SSP3_RCP7.0 appears to bring LST for all classes to a short decrease, impacting in higher median only for 5 to 8 minimum salary households.

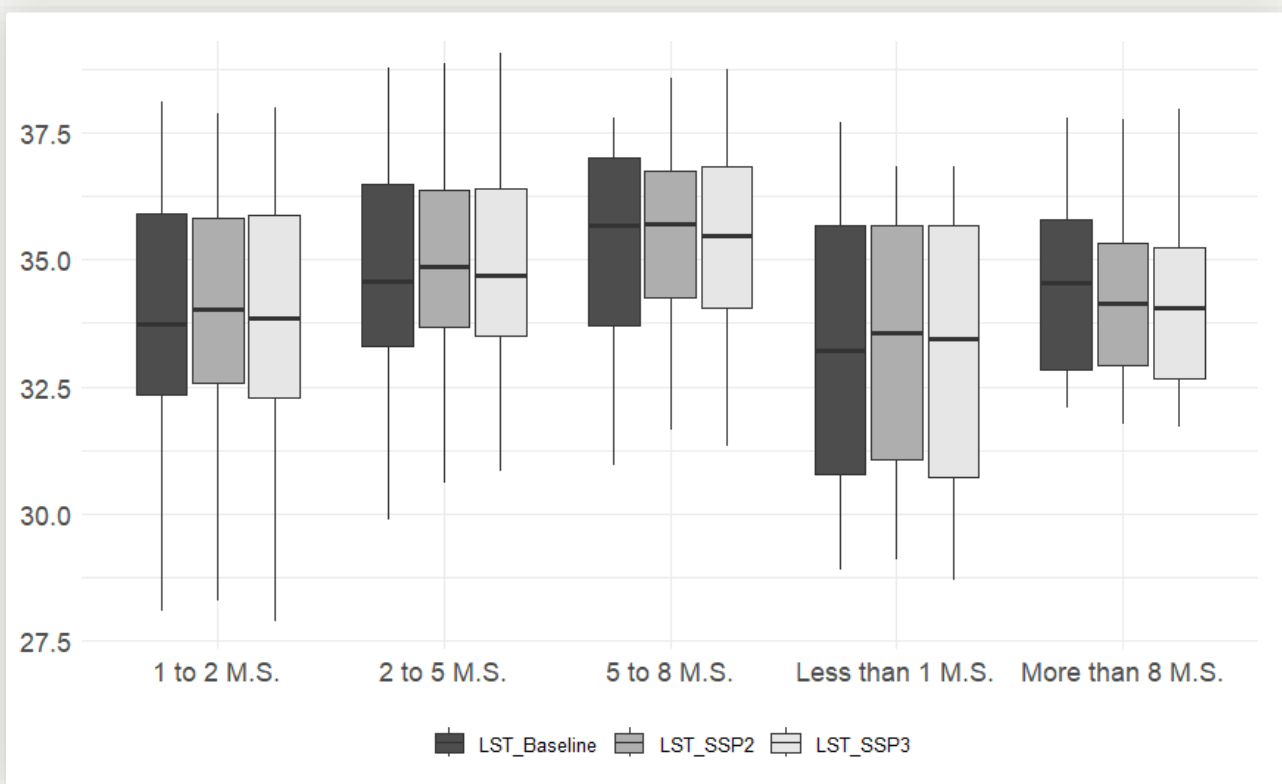


Figure 8: LST predictions using SSP2_RCP4.5 and SSP3_RCP7.0 developed by Butt et al. (2023) per income.

A discussion of the geographical and climatological characteristics of the 6 capitals, essential for this report, is ongoing, along with the urban fabric characteristics of each city. Also, we planned to expand the analysis to other large urban areas, as 100,000 to 250,000 inhabitants.

Other neighborhoods will be analyzed across the 5 income classes for the 6 capitals, which present the lowest LST for the baseline and future scenarios, that can contribute to discussions on green and blue infrastructure and climate adaptation to global temperature increase.

A categorization of nature-based solutions that ensure environmental sanitation, green and blue urban infrastructure will be presented based on these data.

Finally, to identify vulnerability, the living conditions of indigenous populations in the capitals will be analyzed more deeply, along with age and gender breakdowns of populations exposed to various LST in the historical data and future scenarios.

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Impacts of Deforestation and Climate Change on the Spatial Distribution of Human Rabies and Oropouche Fever Cases in the Amazon

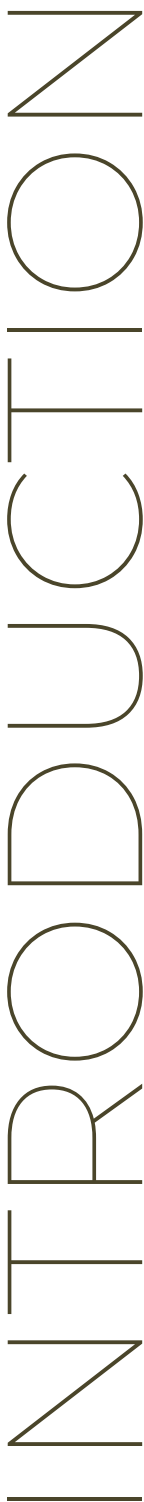
Alert: This is the first version of the study. More refined analyses will be conducted later, including specific in-depth evaluations based on identified possibilities, aiming to enhance the presented results and interpretations.

ABSTRACT

This study investigates the spatial and temporal distribution of human rabies and Oropouche fever in the Brazilian Amazon, focusing on the influence of deforestation and climate change. Human rabies, a fatal zoonotic disease, and Oropouche fever, an emerging arbovirus, pose significant public health risks. Both diseases are exacerbated by environmental changes such as habitat fragmentation and temperature anomalies. Using data from health records, climate models, and bat species distribution, the study employed advanced ecological niche modeling to analyze climatic suitability for disease occurrence under current and future scenarios (SSP2_RCP4.5 and SSP3_RCP7.0). Results highlight a correlation between prolonged dry conditions, elevated land surface temperatures (LST), and increased disease incidence. Rabies hotspots were concentrated in the southern Amazon, while Oropouche fever cases were more frequent in the northeastern region. Future projections suggest an expansion of climatically suitable areas for both diseases under high-emission scenarios, emphasizing the role of climate change in amplifying health vulnerabilities. The findings underscore the need for integrated public health strategies that address ecological and climatic factors, guiding targeted interventions and conservation efforts in the Amazon. Further research will refine models and incorporate additional variables to enhance predictive accuracy and inform regional public health policies.



Impacts of Deforestation and Climate Change on the Spatial Distribution of Human Rabies and Oropouche Fever Cases in the Amazon



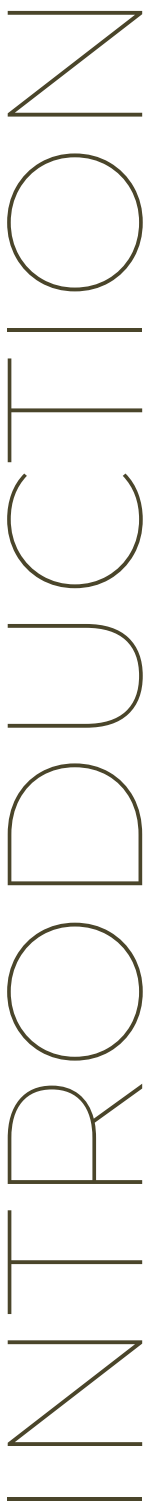
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Human rabies is a neglected disease with a significant public health impact, particularly in impoverished communities and low- and middle-income countries. With a global mortality rate of 98.4%, rabies accounts for approximately 60,000 annual cases across more than 150 countries (1,2). This acute disease affects the central nervous system and is clinically characterized as progressive encephalitis. Transmission primarily occurs through the saliva and secretions of infected animals, involving various mammalian species, which facilitates the disease's spread (3,4). Although mass vaccination campaigns for domestic animals and post-exposure prophylaxis have reduced global mortality, Brazil faces challenges in transitioning its epidemiological profile for rabies. There has been an increase in cases attributed to bats and other wild reservoirs (5).

In addition to rabies, other zoonoses, such as Oropouche fever, have epidemiological dynamics that are profoundly influenced by environmental factors, including deforestation and climate change (6).



Impacts of Deforestation and Climate Change on the Spatial Distribution of Human Rabies and Oropouche Fever Cases in the Amazon



Oropouche fever, caused by the Oropouche virus (OROV), is an emerging arboviral disease spreading in tropical regions of Latin America, including Brazil (7,8). Deforestation linked to agricultural and urban expansion has altered natural ecosystems, facilitating interactions between humans and vectors like the mosquito *Culicoides paraensis*, the primary virus transmitter. Research indicates that forest fragmentation affects biodiversity, reshaping host species distribution and increasing transmission risks (8,9).

Climate change exacerbates these challenges, directly impacting temperature and precipitation patterns. These changes influence the ecology of disease vectors and reservoirs, such as hematophagous bats (*Desmodus rotundus*), the main rabies transmitters in rural areas (10,11). Extreme temperatures can alter these bats' activity, feeding, and reproductive patterns, forcing migrations that increase proximity to humans and domestic animals. Furthermore, climatic phenomena like the El Niño-Southern Oscillation have been linked to rabies outbreaks in various regions (12,13). Combined with habitat loss, these environmental changes intensify zoonotic disease control challenges, requiring integrated strategies that address ecological and climatic factors (14).



Impacts of Deforestation and Climate Change on the Spatial Distribution of Human Rabies and Oropouche Fever Cases in the Amazon

NOTHING BUT THE BEST

Amazon region, where environmental factors such as deforestation and climate change play a central role in their dynamics. This study analyzed the spatial and temporal distribution of human rabies and Oropouche fever cases in the Amazon, utilizing reported cases along with climatic and environmental data. A literature review of bat species, key epidemiological reservoirs, was included to contextualize the findings within the region's ecological and climatic framework.

DATA AND METHOD

01 HEALTH DATA

Records of reported human rabies cases in the Amazon region from January 2001 to August 2023, and Oropouche fever cases for the year 2023, were analyzed. Human rabies data were provided by State and Municipal Health Secretariats through the Notifiable Diseases Information System (SINAN). Oropouche fever data were obtained via the Access to Information Law (LAI) using the Fala.BR platform, managed by the Federal Government.

Reported cases underwent georeferencing, generating central geographic coordinates (centroids) for the municipalities where notifications occurred. Analysis was conducted using Microsoft Excel spreadsheets to evaluate the spatial and temporal distribution of diseases in the Amazon region.

The Amazon, located in northern Brazil, is characterized by its vast territory and high biodiversity. This region presents significant geographical heterogeneity, influenced by climatic factors and natural resources, which play a central role in the dynamics of emerging diseases and zoonoses, such as human rabies and Oropouche fever.

DATA AND METHOD

02 BAT SPECIES DATA

A detailed literature review was conducted on bat species identified as positive for the rabies virus. The review included epidemiological data and scientific studies that identified the virus in various bat species in the Amazon. The sources included national and international literature, considering ecological factors such as habitat, diet, and movement patterns of the species.

03 ENVIRONMENTAL DATA

.....▶..... NUMBER OF DRY DAYS

A "Dry Day" was defined as any day with recorded precipitation below 1 mm. This definition was applied to the climatic analysis of the Amazon from 2000 to 2023 using CHIRPS data, resampled to a spatial resolution of 1 km for greater precision. Calculations were performed monthly to assess seasonal and interannual variations over the study period. The results were organized in NetCDF files.

03 ENVIRONMENTAL DATA

.....▶..... **MAXIMUM NUMBER OF CONSECUTIVE DRY DAYS**

Consecutive Dry Days (CDD), defined as the maximum number of consecutive days with precipitation below 1 mm, were calculated for the entire Amazon region from 2000 to 2023. CHIRPS precipitation data, resampled to a spatial resolution of 1 km, were used. Annual CDD values were compiled into NetCDF files for detailed drought condition analyses over time.

.....▶..... **ANOMALOUS ACCUMULATION**

This analysis aimed to determine the start and end dates of the rainy season, as well as its duration, using precipitation data from the Amazon between 2000 and 2023. Calculations employed CHIRPS data resampled to a 1 km spatial resolution, with a threshold of 2.5 mm as a reference for precipitation accumulation. NetCDF files were generated for each year of the analyzed period.

03 ENVIRONMENTAL DATA

.....▶..... LAND SURFACE TEMPERATURE

Land Surface Temperature (LST) data were used for climatic analysis in both current and future scenarios. For the current scenario, the annual mean LST was calculated for 2001–2020 at a 1 km spatial resolution across the Amazon. For future scenarios, LST projections based on CMIP5 socioeconomic scenarios were used: SSP2_RCP4.5 (intermediate narrative) and SSP3_RCP7.0 (high inequality scenario).

04 ECOLOGICAL NICHE MODELING

Ecological niche modeling was conducted using the biomod2 package in R (<https://www.R-project.org/>), recognized for its efficiency in ecological niche modeling and predictive projections. Six predictive modeling algorithms were applied: Generalized Linear Model (GLM), Generalized Additive Model (GAM), Classification Tree Analysis (CTA), Flexible Discriminant Analysis (FDA), Multivariate Adaptive Regression Splines (MARS), and Random Forest (RF).

04 ECOLOGICAL NICHE MODELING

- For rabies and Oropouche fever cases, presence/absence data were used.
- For bat species, presence data were combined with pseudo-absence data generated for regions with low environmental probability of occurrence.

In the current scenario (historical), detailed environmental data were utilized, including variables such as the number of dry days, maximum consecutive dry days, anomalous precipitation accumulation, and land surface temperature (LST). For future scenarios, only annual mean LST projections based on CMIP5 scenarios (SSP2_RCP4.5 and SSP3_RCP7.0) were used.

Model validation employed cross-validation by dividing the data into 80% for training and 20% for testing. Model performance was evaluated using metrics such as TSS and AUC-ROC. AUC-ROC values were classified as follows: 0.5–0.7 (low performance), 0.7–0.9 (acceptable performance), and above 0.9 (excellent performance). Only models with the best performance were selected for generating climatic suitability maps.

The resulting maps presented binary distributions (0 and 1), which were later integrated into consensus maps using an ensemble modeling approach. These maps indicated climatic suitability indices ranging from 0 (low suitability) to 1 (high suitability).

► Spatial Distribution of Rabies Cases and Bat Species in the Amazon

Human rabies is a zoonosis of significant public health relevance, particularly in regions where intense interaction occurs between human populations and bat species, such as in the Legal Amazon. Between 2001 and 2023, numerous cases of the disease were reported in the region, emphasizing the importance of understanding the spatial patterns of its occurrence and the associated risk areas. Figure 1 illustrates the spatial distribution of these human rabies cases, represented by green points, in relation to areas where bat species have been identified, marked by yellow points. The map highlights an overlap between human cases and bat distribution areas, with a higher density of events observed in the northeastern portion of the Amazon.

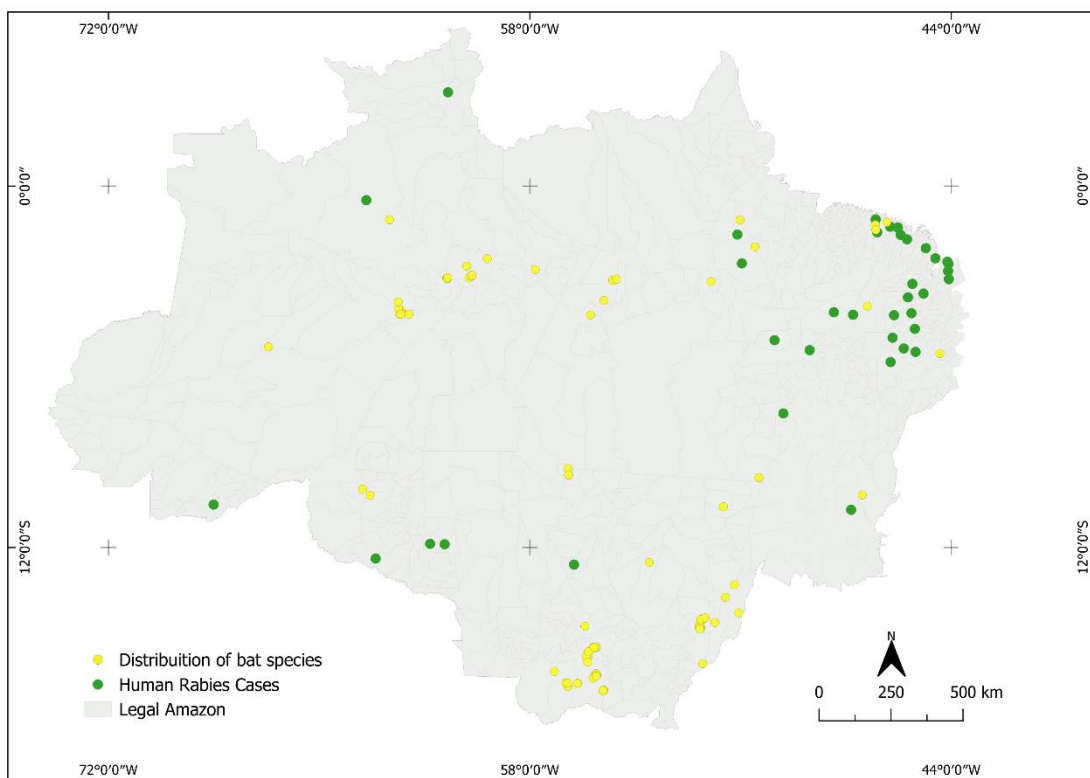


Figure 1: Spatial Distribution of Human Rabies Cases and Bat Species in the Legal Amazon (2001–2023).

FIRST FINDINGS

► Rabies: Descriptive Table with Environmental Data and Models

Table 1 presents the relationship between environmental variables and the occurrence of human rabies and bat species, using different statistical modeling algorithms (GLM, GAM, CTA, FDA, MARS, RF). The AUC-ROC values indicate model performance, with RF standing out as the algorithm achieving the highest values across all analyzed variables.

Table 1: Performance of Statistical Modeling Algorithms for Environmental Variables Associated with Human Rabies and Bat Species in the Amazon.

Dependent Variables	Climatic Variables	Statistical Algorithms					
		GLM	GAM	CTA	FDA	MARS	RF
Rabies Human	Dry Days	0.855	0.860	0.869	0.871	0.864	0.880
	CDD (Consecutive Dry Days)	0.830	0.835	0.840	0.842	0.837	0.845
	Anomalous Accumulation	0.684	0.736	0.714	0.735	0.720	0.780
	LST (Land Surface Temperature)	0.789	0.850	0.786	0.861	0.866	0.900
Bat species	Dry Days	0.603	0.737	0.688	0.658	0.785	0.997
	CDD (Consecutive Dry Days)	0.711	0.801	0.766	0.728	0.885	0.991
	Anomalous Accumulation	0.703	0.851	0.745	0.738	0.985	0.988
	LST (Land Surface Temperature)	0.666	0.704	0.689	0.699	0.736	0.997

► Modeling with Environmental Data in the Current Scenario

- **Human Rabies Cases: Number of Dry Days**

The definition of dry days, based on precipitation thresholds, enabled a detailed temporal and spatial characterization of dry conditions in the Amazon. The analysis revealed clear patterns of seasonal and interannual variability, with notable concentrations of dry conditions in specific regions and periods. Monthly aggregation of the data highlighted the extent and persistence of dry periods, providing critical insights into the dynamics of drought phenomena in the Amazon biome. The ensemble average produced robust results, with an AUC-ROC of 0.866, a sensitivity of 83.33%, and a specificity of 87.57%. The generated map identified areas in the Amazon with higher climate suitability for prolonged dry conditions under current climate scenarios. These regions, primarily located in the northern Amazon, were characterized by extended periods of low precipitation, with potential exacerbation under future climate scenarios.

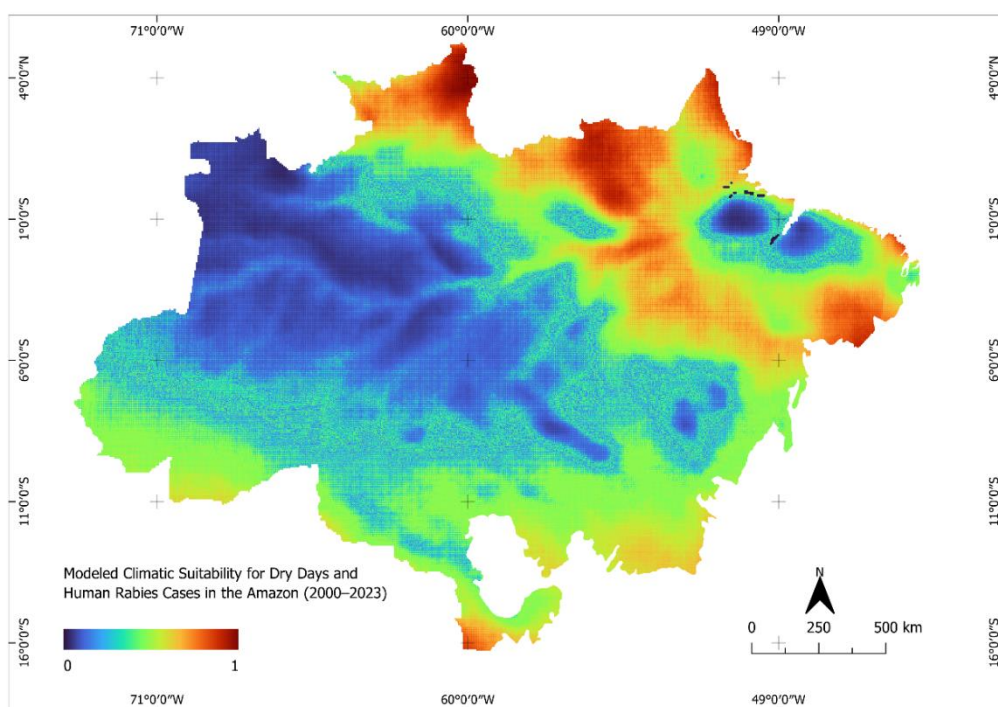


Figure 2. Modeled Climate Suitability for Dry Days and Human Rabies Cases in the Amazon (2000–2023).

► Modeling with Environmental Data in the Current Scenario

• Human Rabies Cases: Maximum Number of Consecutive Dry Days

The analysis of the maximum number of Consecutive Dry Days (CDD), based on the CDD index, allowed for the identification of critical drought patterns in different climate scenarios. The ensemble average produced robust results, integrating the individual model performances with high accuracy. The ensemble achieved a mean AUC-ROC of 0.850, with a sensitivity of 82.5% and specificity of 57%. The map generated from the predictions revealed regions with higher susceptibility to prolonged dry conditions, highlighted in red tones (Figure 3). These areas, characterized by reduced precipitation patterns, represent critical zones for the occurrence of intense droughts, providing strategic information for water resource management and the development of mitigation policies in highly vulnerable regions.

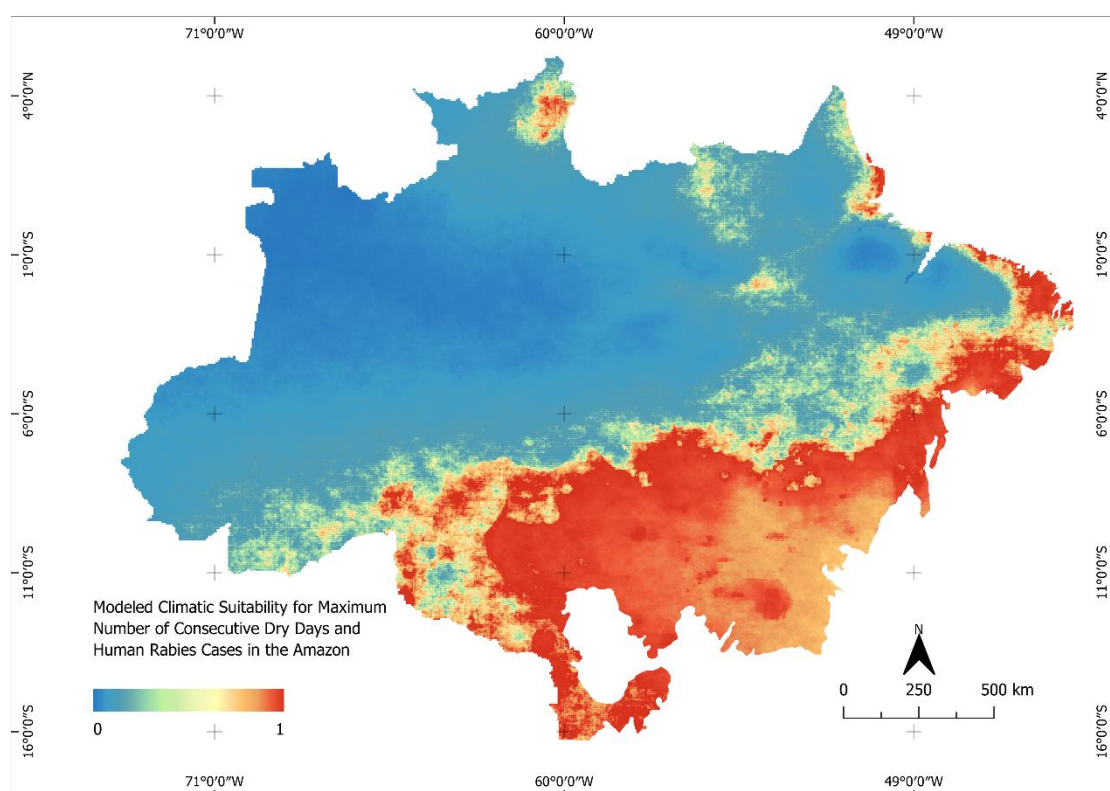


Figure 3. Modeled Climate Suitability for the Maximum Number of Consecutive Dry Days and Human Rabies Cases in the Amazon.

► Modeling with Environmental Data in the Current Scenario

- **Human Rabies Cases: Land Surface Temperature**

The climate modeling of Land Surface Temperature (LST) revealed spatial and temporal patterns of thermal anomalies in the Amazon, associated with the occurrence of human rabies cases. The results demonstrated substantial variability in climate suitability for rabies incidence, allowing the identification of regions with higher and lower susceptibility.

The ensemble analysis showed robust performance, with an AUC-ROC value of 0.888, sensitivity of 82.76%, and specificity of 82.76%. These indicators reflect the model's ability to accurately discriminate areas of higher risk for human rabies occurrence, minimizing classification errors. Figure 4 highlights areas of higher climate suitability for rabies cases, concentrated in the southern and southeastern Amazon, while regions in the north show lower climate suitability, reflecting hotspots of significant LST anomalies.

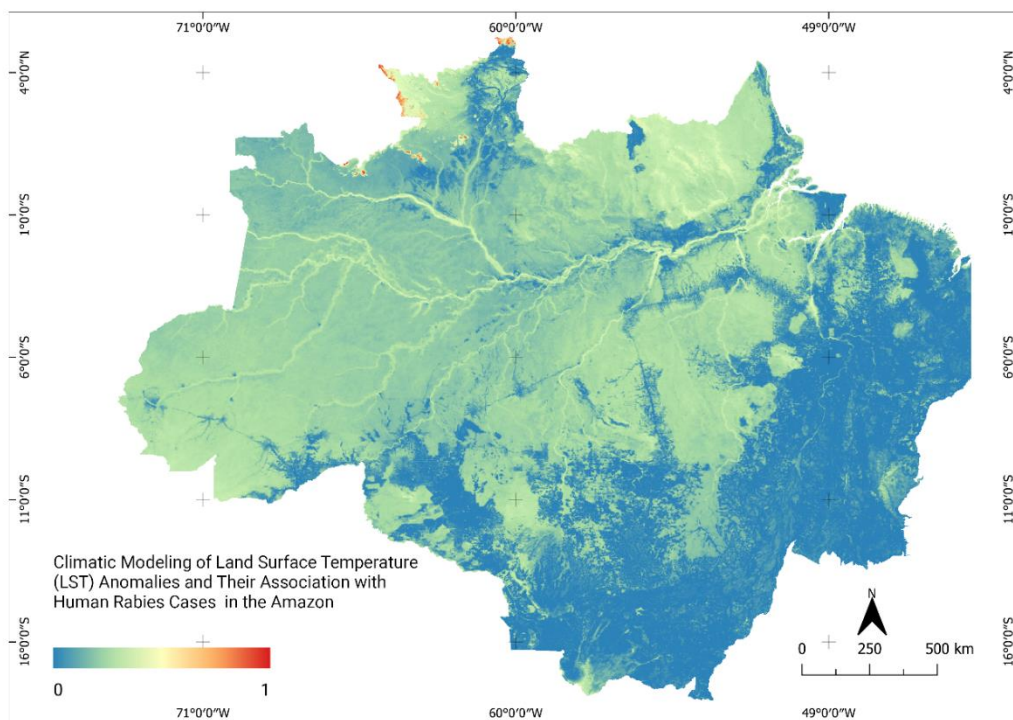


Figure 4. Climate Modeling of Land Surface Temperature (LST) and Its Association with Human Rabies Cases in the Amazon.

FIRST FINDINGS

► Modeling with Environmental Data in the Current Scenario

- **Human Rabies Cases: Land Surface Temperature**

Future analyses of Land Surface Temperature (LST) under the SSP2 and SSP3 climate scenarios project substantial changes in thermal anomalies in the Amazon, with the identification of areas of higher and lower climate suitability. In the current scenario, areas of higher climate suitability are concentrated in the southern and southeastern parts of the region, characterized by moderate thermal anomalies. In the SSP2_RCP4.5 scenario, there is a gradual expansion of these areas toward the north and west of the Amazon, indicating a moderate intensification of climatic conditions but maintaining a distribution similar to that observed in the current scenario.

On the other hand, in the SSP3_RCP7.0 scenario, a drastic change occurs, with a significant increase in areas of higher climate suitability, now covering almost the entire Amazon. This widespread increase reflects higher emissions and less environmental control associated with SSP3, resulting in a high density of critical regions with severe thermal anomalies compared to the current and SSP2 scenarios.

FIRST FINDINGS

► Modeling with Environmental Data in the Current Scenario

- Human Rabies Cases: Land Surface Temperature

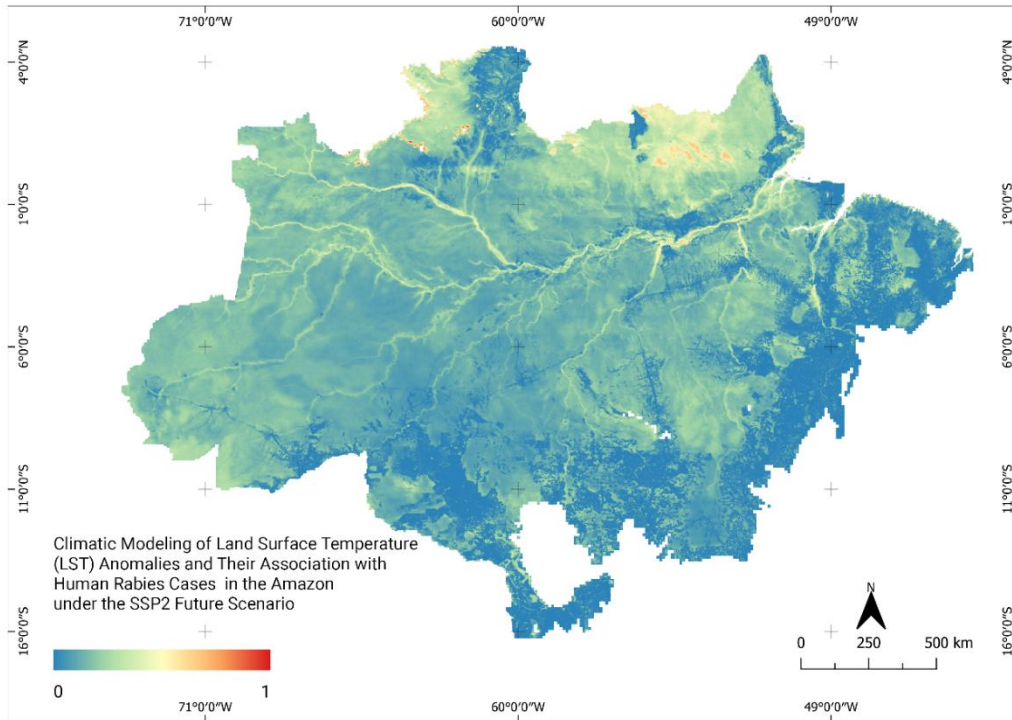


Figure 5. Climate Modeling of Land Surface Temperature (LST) and Its Association with Human Rabies Cases in the Amazon under the SSP2_RCP4.5 Scenario.

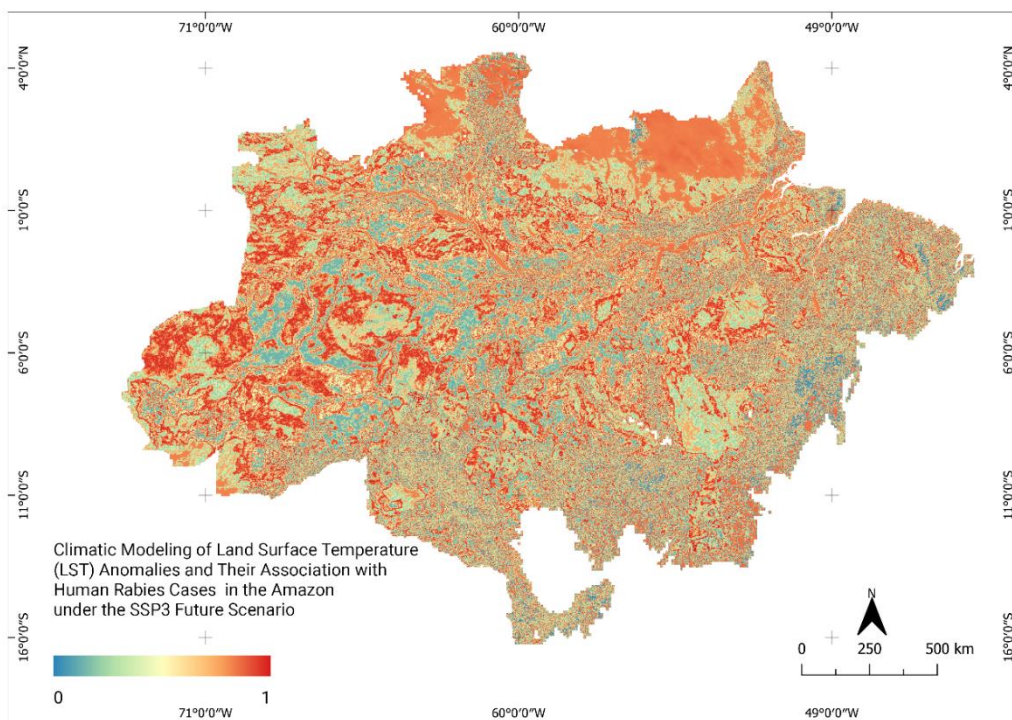


Figure 6. Climate Modeling of Land Surface Temperature (LST) and Its Association with Human Rabies Cases in the Amazon under the SSP3_RCP7.0 Scenario.

► Modeling with Environmental Data in the Current Scenario

- **Bat Species Distribution: Number of Dry Days**

The climate modeling of Dry Days, based on precipitation thresholds, enabled a detailed characterization of dry conditions and their relationship with bat species distribution in the Amazon. The analysis revealed distinct spatial patterns, with areas of higher climate suitability concentrated mainly in the central and southern parts of the region. These areas are associated with persistent dry conditions, representing environments conducive to the presence of bat species. The ensemble results showed robust performance, with an AUC-ROC value of 0.855, sensitivity of 58.82%, and specificity of 80.87%, demonstrating a high predictive ability in identifying areas suitable for bat presence. The generated map identifies critical regions in the Amazon that are highly suitable for the occurrence of bat species due to the persistence of dry periods, providing valuable insights for ecological management and conservation strategies.

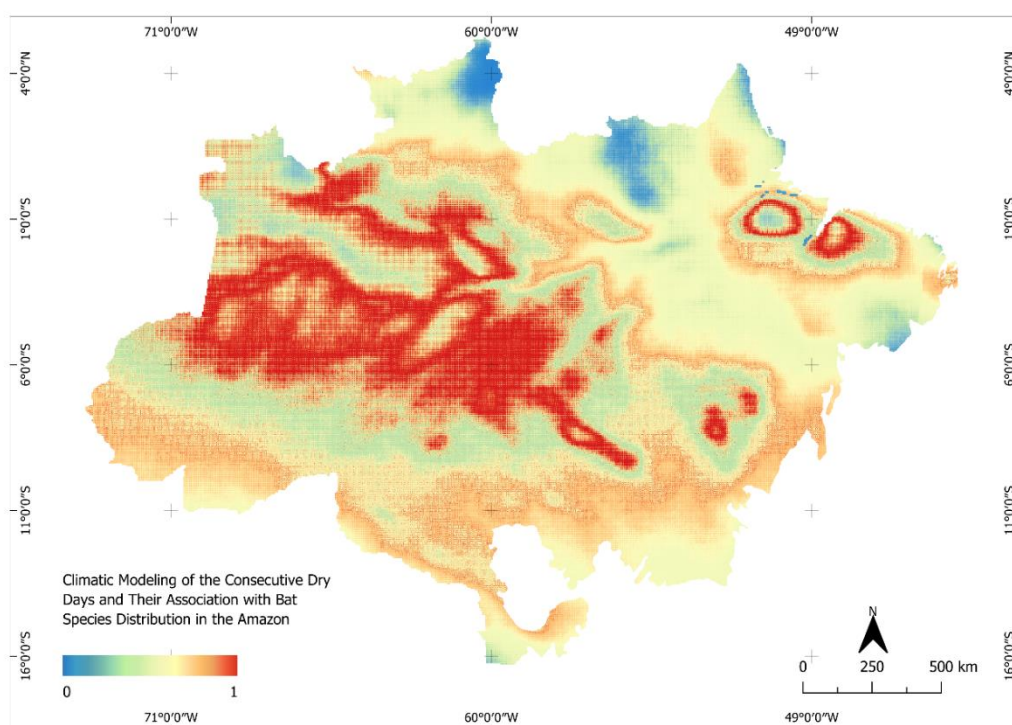


Figure 7. Climate Modeling of Consecutive Dry Days and Its Association with Bat Species Distribution in the Amazon..

► Modeling with Environmental Data in the Current Scenario

• Bat Species Distribution: Maximum Number of Consecutive Dry Days

The climatic modeling of the maximum number of Consecutive Dry Days (CDD) revealed critical climatic suitability patterns for the distribution of bat species in the Amazon. The map presented highlights the modeled climatic patterns of the maximum number of CDD in the Amazon, associated with the distribution of bat species. Areas of higher climatic suitability, indicated by red and orange tones, are predominantly concentrated in the southeastern and eastern regions of the Amazon. These areas reflect more prolonged periods of low precipitation, suggesting higher climatic susceptibility for the analyzed species. The ensemble's performance achieved an average AUC-ROC of 0.950, with sensitivity of 97.05% and specificity of 88.625%, confirming the high precision in identifying the most favorable climatic regions for the distribution of bat species.

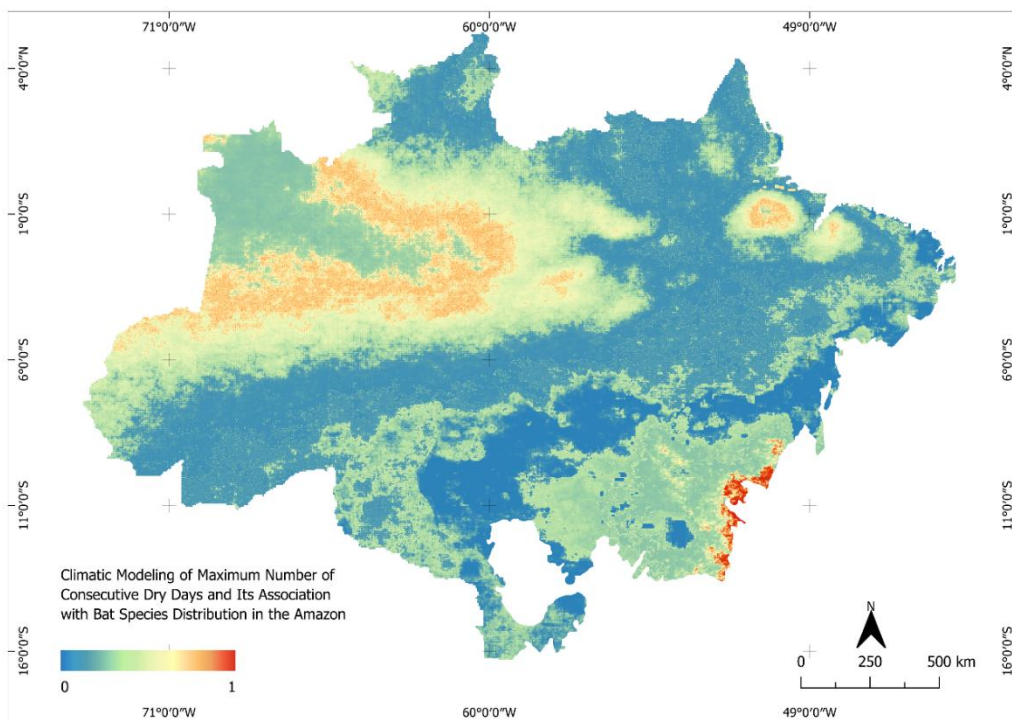


Figure 8. Climatic Modeling of the Maximum Number of Consecutive Dry Days and its Association with the Distribution of Bat Species in the Amazon.

► Modeling with Environmental Data in the Current Scenario

• Bat Species Distribution: Land Surface Temperature

The climatic modeling of Land Surface Temperature (LST) revealed spatial patterns of thermal anomalies in the Amazon, associated with the distribution of bat species. The analysis highlighted regions with higher climatic susceptibility, indicating critical areas for biodiversity conservation. The ensemble average performance was robust, with an AUC-ROC value of 0.724, sensitivity of 78.08%, and specificity of 58.63%. Figure 9 highlights areas of higher climatic suitability (in reddish tones), primarily concentrated in the southern and eastern parts of the Amazon, while regions in the central and northern areas show lower suitability (in greenish tones). These results are crucial for planning conservation strategies and monitoring species, considering the impacts of climate change on habitats in the Amazon region.

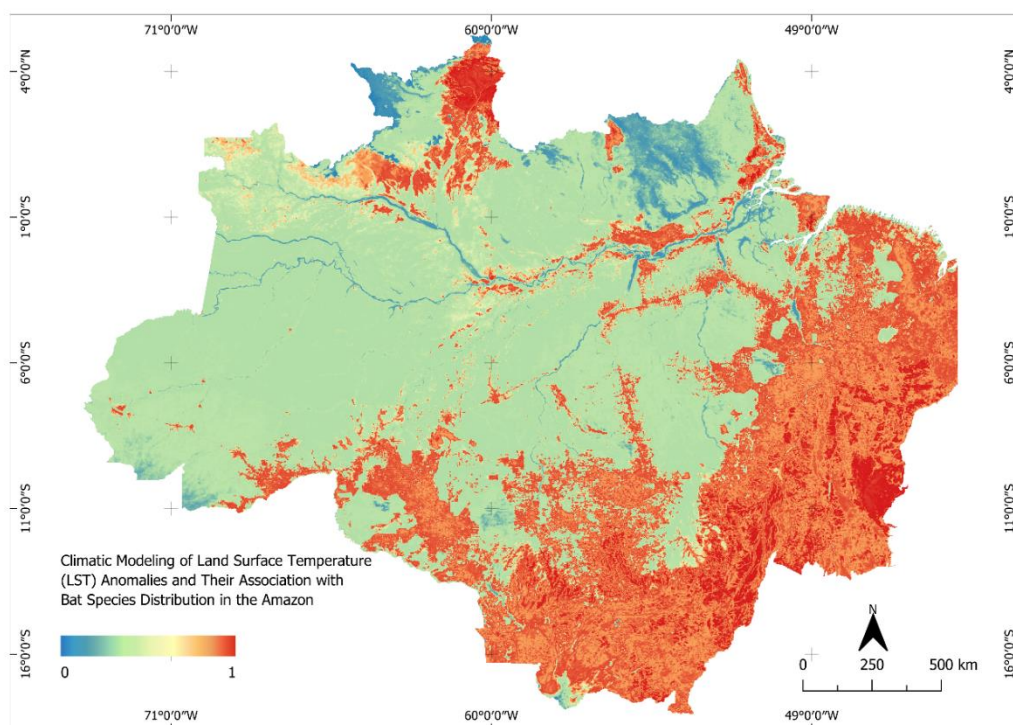


Figure 9. Climatic Modeling of Land Surface Temperature (LST) Anomalies and Its Association with Bat Species Distribution in the Amazon.

FIRST FINDINGS

► Modeling with Environmental Data in the Current Scenario

- **Bat Species Distribution: Land Surface Temperature**

The analyses of Land Surface Temperature (LST) anomalies for the SSP2_RCP4.5 and SSP3_RCP7.0 climate scenarios reveal significant changes in the thermal conditions of the Amazon, highlighting distinct patterns of climatic suitability for bat species. In the current scenario, areas of higher suitability are primarily concentrated in the southern and southeastern parts of the region, characterized by moderate thermal anomalies.

In the SSP2 scenario, there is a gradual expansion of climatic suitability areas towards the north and west of the Amazon, with moderate intensification of thermal conditions. This pattern reflects a relative balance between climate mitigation measures and emissions (Figure 10). On the other hand, the SSP3 scenario projects a substantial expansion of the areas of highest climatic suitability, which will cover nearly the entire Amazon (Figure 11). This change is associated with high emissions and less environmental control, resulting in more severe climatic conditions and a high density of critical regions with pronounced thermal anomalies, surpassing the patterns observed in both the current scenario and the SSP2.

FIRST FINDINGS

► Modeling with Environmental Data in the Current Scenario

- Bat Species Distribution: Land Surface Temperature

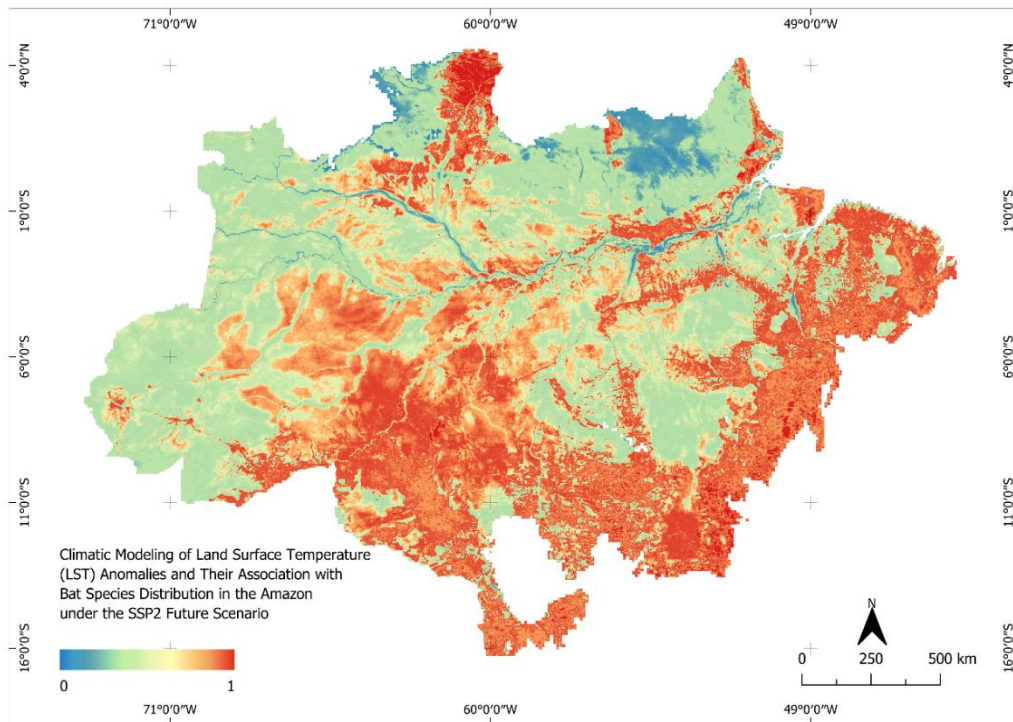


Figure 10. Climatic Modeling of Land Surface Temperature (LST) Anomalies and Their Association with the Distribution of Bat Species in the Amazon under the Future SSP2_RCP4.5 Scenario.

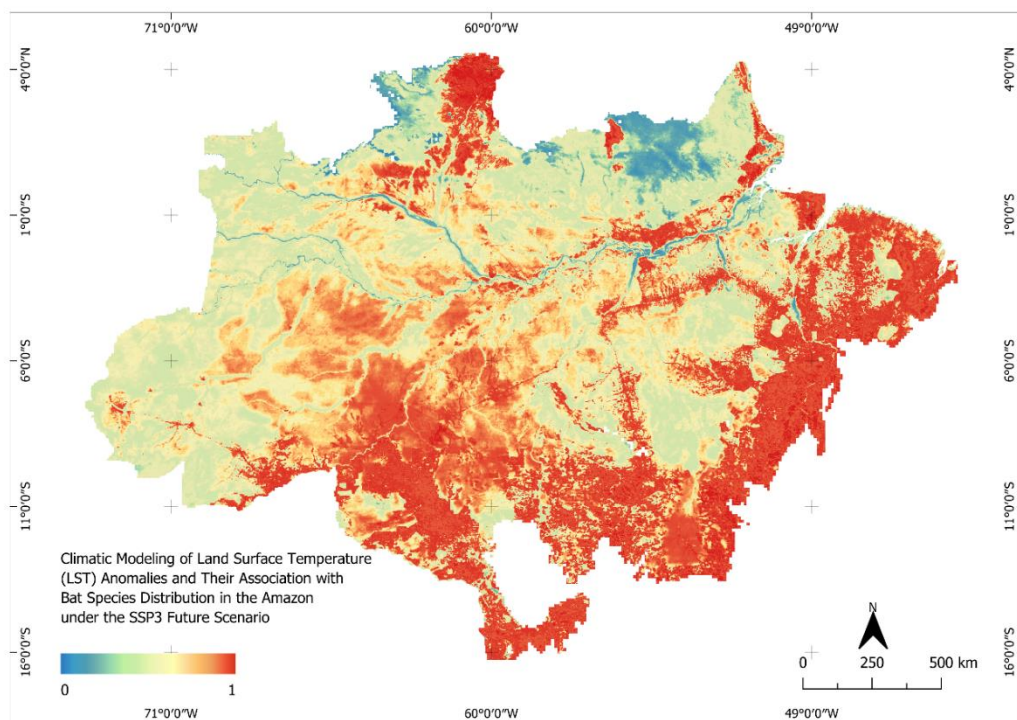


Figure 11. Climate Climatic Modeling of Land Surface Temperature (LST) Anomalies and Their Association with the Distribution of Bat Species in the Amazon under the Future SSP3_RCP7.0 Scenario.

► Oropuche: Spatial Distribution of Oropouche Cases

Figure 12 illustrates the spatial distribution of human cases of Oropouche fever in the Legal Amazon region for the year 2023. The red dots represent the geographic locations of the reported cases, while the gray outline delineates the boundaries of the Legal Amazon. A significant concentration of cases is observed in the northeastern region and in parts of the southern and southwestern Amazon, indicating epidemiological hotspots. This spatial distribution reflects the complex interplay of environmental, social, and climatic factors that facilitate the proliferation of *Culicoides paraensis*, the primary vector of the Oropouche virus.

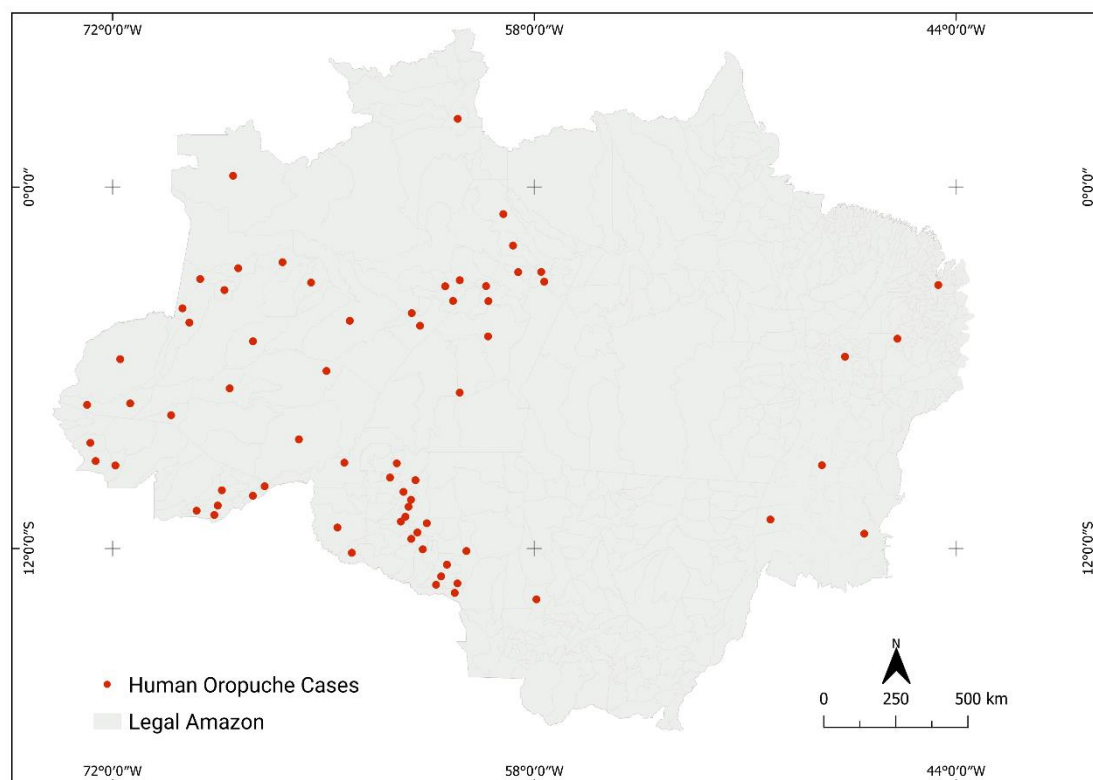


Figure 12. Spatial Distribution of Oropouche Cases in the Legal Amazon.

FIRST FINDINGS

► Oropouche: Descriptive Table with Environmental Data and Models.

Table 2 presents the relationship between climatic variables and human Oropouche fever cases, modeled by different statistical algorithms (GLM, GAM, CTA, FDA, MARS, RF). The values presented correspond to the performance coefficients (fit values) of each algorithm for the considered climatic variables. The performance coefficients highlight the RF algorithm, which achieved the highest values, especially for the CDD and LST variables, demonstrating its superiority in predicting epidemiological patterns.

Table 2: Performance of Statistical Models Applied to Climatic Variables in Predicting Human Oropouche Fever Cases.

Dependent Variables	Climatic Variables	Statistical Algorithms					
		GLM	GAM	CTA	FDA	MARS	RF
Oropouche Human	Dry Days	0.616	0.650	0.648	0.620	0.678	0.710
	CDD (Consecutive Dry Days)	0.760	0.762	0.672	0.762	0.784	0.882
	Anomalous Accumulation	0.645	0.654	0.873	0.645	0.814	0.913
	LST (Land Surface Temperature)	0.685	0.736	0.778	0.736	0.684	1.000

► Modeling with Environmental Data in the Current Scenario

• Oropuche: Number of Dry Days

The climatic modeling of the number of Dry Days revealed distinct spatial patterns, with areas of greater climatic suitability predominantly located in the central-northern region, where the persistence of dry conditions may be associated with an increase in reported cases (Figure 13). The areas represented in reddish tones indicate higher climatic suitability, mainly concentrated in the central and northern regions of the Amazon, where prolonged dry conditions may facilitate the spread of the virus. The ensemble mean results showed acceptable performance, with an ROC value of 0.657, sensitivity of 50.289%, and specificity of 73.874%..

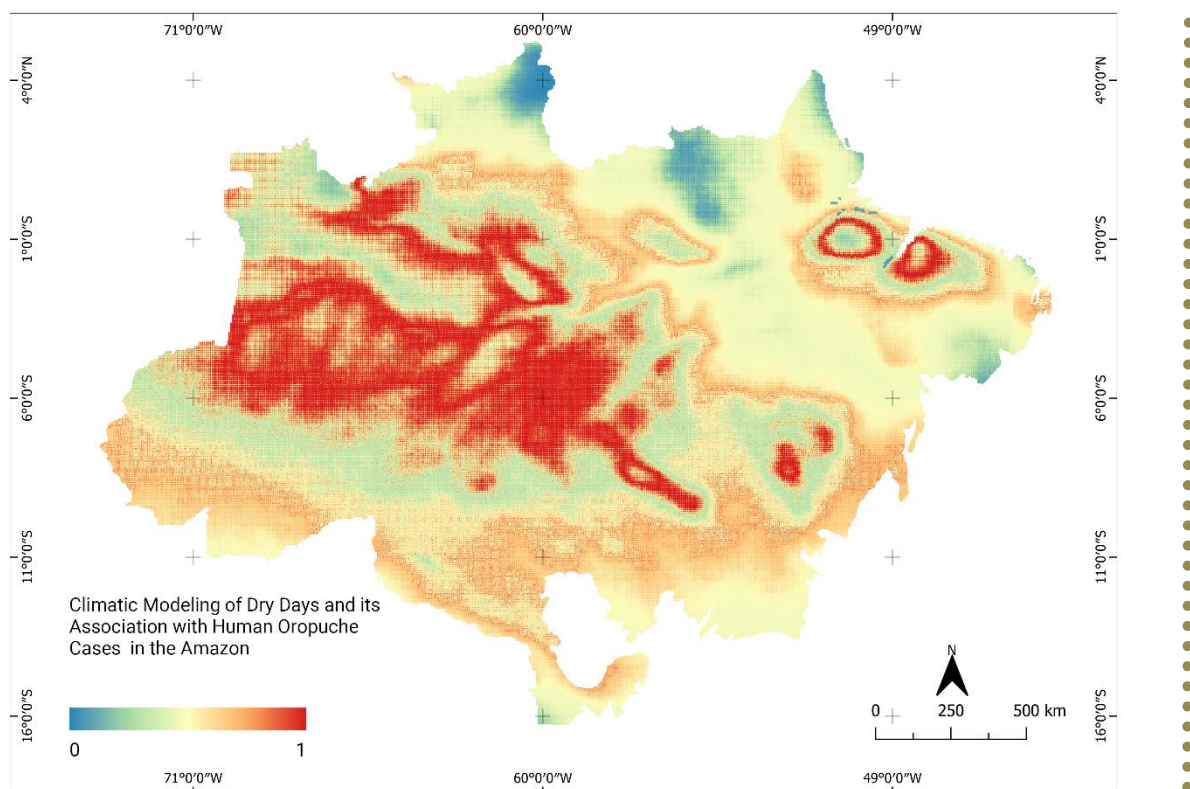


Figure 13. Climatic Modeling of Dry Days and its Association with Human Oropuche Cases in the Amazon.

► Modeling with Environmental Data in the Current Scenario

• Oropuche: Maximum Number of Consecutive Dry Days

The climatic modeling based on the maximum number of Consecutive Dry Days (CDD) revealed critical patterns of climatic suitability associated with the occurrence of Oropouche fever in the Amazon. The ensemble mean results achieved an average AUC-ROC of 0.883, with a sensitivity of 83.81% and specificity of 71.17%. The map presented illustrates the relationship between the CDD and the distribution of human cases of the disease (Figure 14). Areas represented in red tones indicate regions with higher climatic suitability, characterized by longer dry periods, while areas in blue tones represent regions with wetter conditions, less favorable for the disease. It is observed that the northern and western regions of the Amazon concentrate areas with the highest CDD values, indicating climatic conditions conducive to the spread of Oropouche fever.

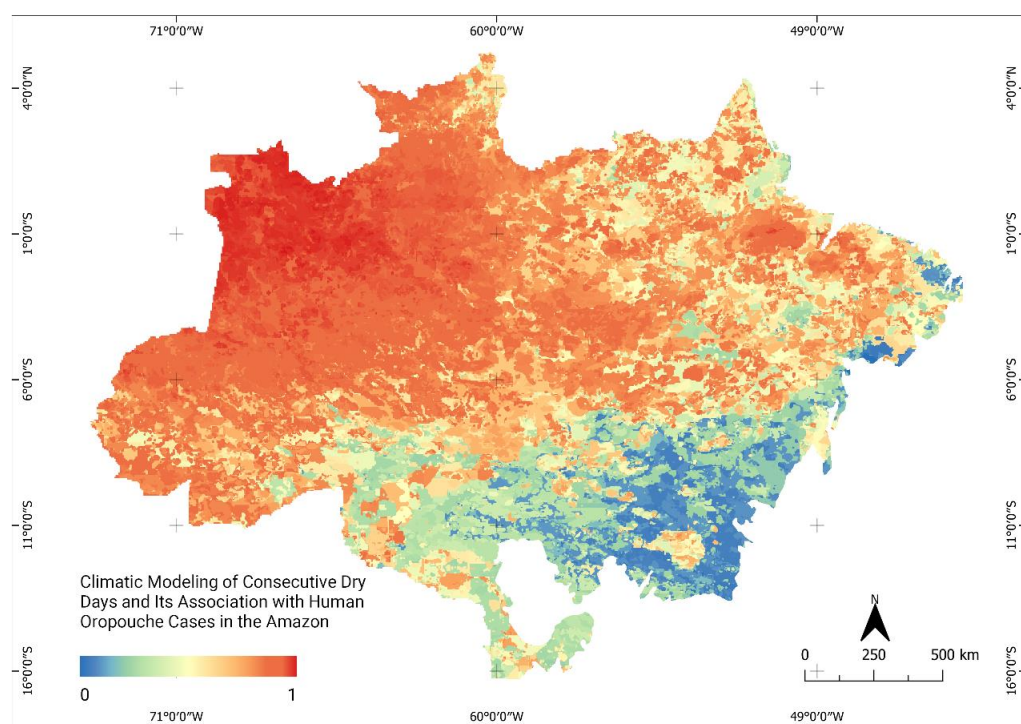


Figure 14. Climatic Modeling of the Maximum Number of Consecutive Dry Days (CDD) and its Association with Human Oropouche Fever Cases in the Amazon.

► Modeling with Environmental Data in the Current Scenario

• Oropuche: Land Surface Temperature

The climatic modeling of the Land Surface Temperature (LST) highlighted thermal anomaly patterns associated with the occurrence of human Oropouche fever cases in the Amazon. Areas of higher climatic susceptibility, represented in reddish tones, are primarily concentrated in the northern and northeastern regions of the Amazon (Figure 15). In contrast, areas with lower climatic suitability, depicted in bluish tones, are located predominantly in the central-southern part of the region. The ensemble mean performance was robust, with an AUC-ROC value of 0.911, sensitivity of 97.83%, and specificity of 77.88%..

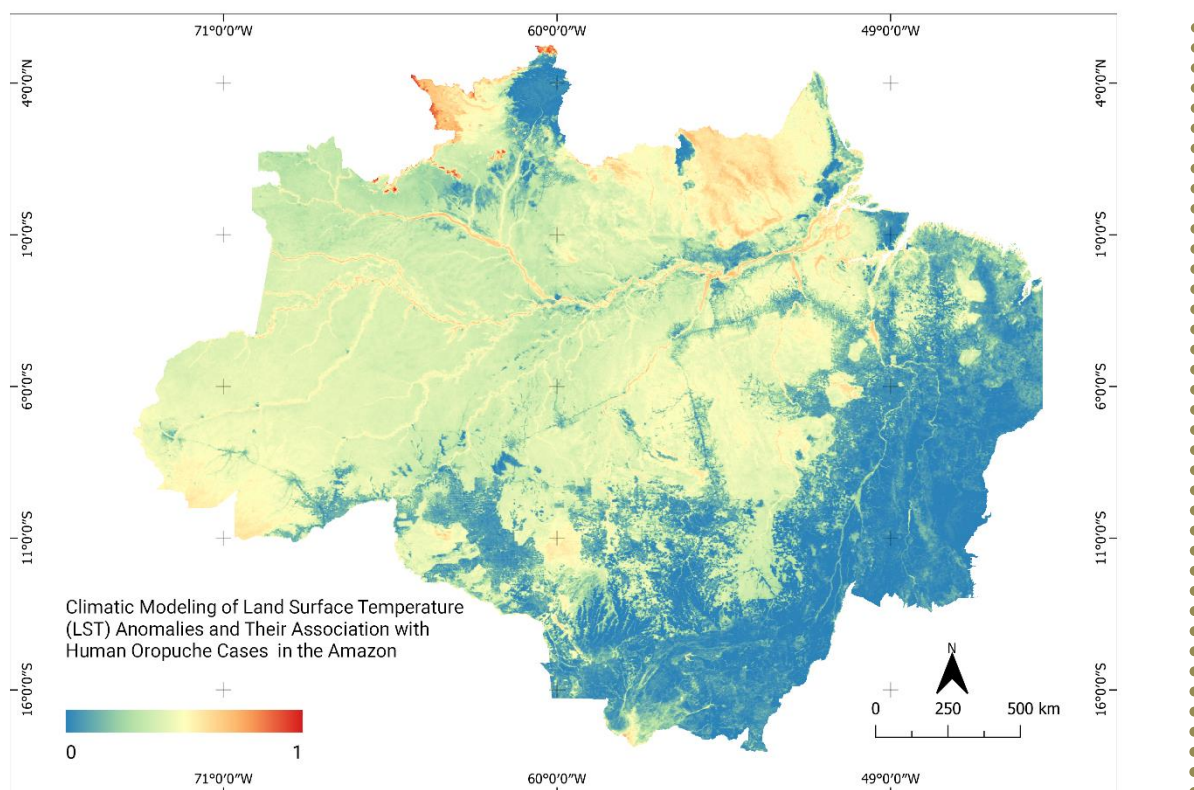


Figure 15. Climatic Modeling of Land Surface Temperature (LST) and its Association with Human Oropouche Cases in the Amazon.

FIRST FINDINGS

► Modeling with Environmental Data in the Current Scenario

- **Oropuche: Land Surface Temperature**

Analyses of Land Surface Temperature (LST) anomalies for the future climate scenarios SSP2_RCP4.5 and SSP3_RCP7.0 indicate significant changes in the thermal patterns of the Amazon region, highlighting potential impacts on the ecosystem and the distribution of human Oropouche cases. In the SSP2_RCP4.5 scenario (Figure 17), thermal conditions reflect a moderate balance between emissions and climate mitigation strategies, with a gradual expansion of areas with greater thermal anomaly to the north and west of the Amazon.

This pattern suggests a moderate transition that may intensify areas of climatic susceptibility, gradually impacting human populations and local biodiversity. In contrast, the SSP3_RCP7.0 scenario (Figure 18) projects more drastic changes, with a significant increase in areas of high thermal anomaly across almost the entire Amazon. This scenario, characterized by high emissions and less environmental control, reveals a worsening of climatic conditions, with a substantial rise in critical regions marked by severe thermal anomalies.

► Modeling with Environmental Data in the Current Scenario

- Oropuche: Land Surface Temperature

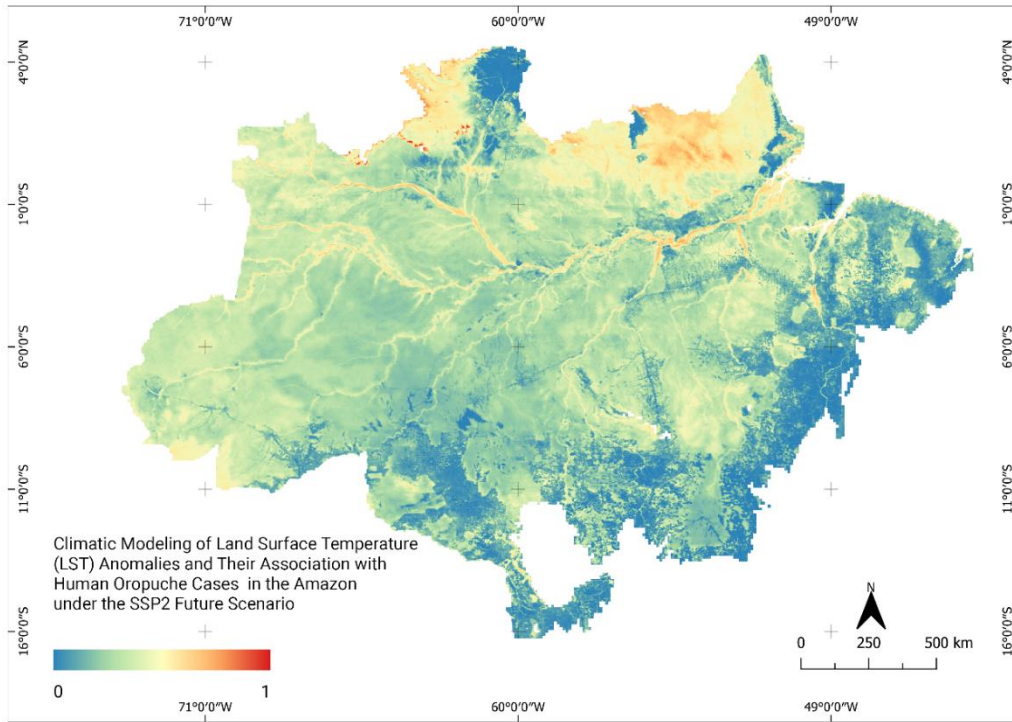


Figure 17. Climatic modeling of Land Surface Temperature (LST) anomalies and its association with human cases of Oropouche fever in the Amazon under the future scenario SSP2_RCP4.5.

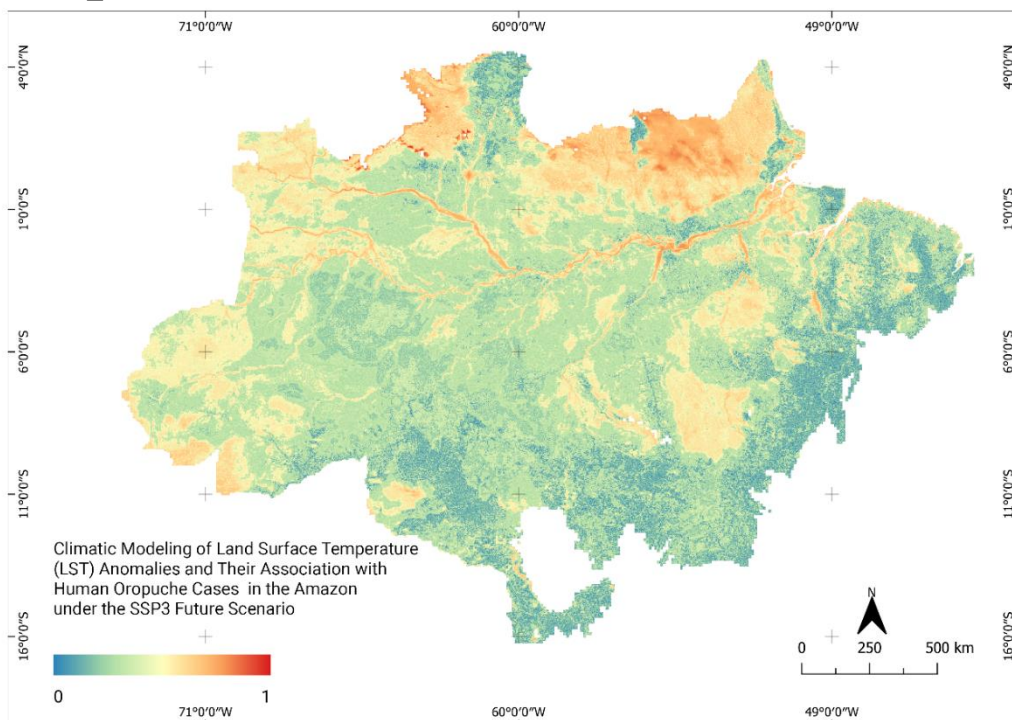


Figure 18. Climatic modeling of Land Surface Temperature (LST) anomalies and its association with human cases of Oropouche fever in the Amazon under the future scenario SSP3_RCP7.0..

The models highlighted critical areas of climatic susceptibility for human rabies in the southern and southeastern regions, where factors such as thermal anomalies and prolonged dry periods showed a strong correlation with the increase in cases. The ensemble for the land surface temperature (LST) variable achieved an AUC-ROC of 0.888, demonstrating the model's ability to distinguish risk areas.

For Oropouche fever, the results indicated epidemiological hotspots in the northern and northeastern Amazon, with greater climatic suitability in areas marked by prolonged drought and thermal anomalies. The ensemble for the maximum number of consecutive dry days (CDD) reached an AUC-ROC of 0.883, showing high accuracy in identifying critical regions for the spread of the disease. The analysis of bat distribution showed a significant relationship with reduced precipitation patterns, with areas of greater suitability concentrated in the central and southern Amazon.

Although the results are promising, this is a preliminary analysis, and future refinements will be needed to improve the accuracy of the models and deepen the interpretations. Subsequent studies will incorporate additional variables, refined algorithms, and more detailed future climate scenarios, contributing to support public policies and conservation strategies in the face of climate change and anthropogenic pressures in the region.

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