

Supplementary material

Fire dynamics in an emerging deforestation frontier in southwestern Amazonia, Brazil

Débora Joana Dutra ^{1*}, Liana Oighenstein Anderson ¹, Philip Martin Fearnside ², Paulo Maurício Lima de Alencastro Graça ², Aurora Miho Yanai ², Ricardo Dalagnol ^{3,4}, Chantelle Burton ⁵, Christopher Jones ⁵, Richard Betts ⁵ and Luiz Eduardo Oliveira e Cruz de Aragão ^{6,7}

¹ National Center for Monitoring and Early Warning of Natural Disasters

² National Institute for Research in Amazonia

³ NASA-Jet Propulsion Laboratory, California Institute of Technology

⁴ Center for Tropical Research, Institute of the Environment and Sustainability, University of California

⁵ Met Office

⁶ Earth Observation and Geoinformatics Division, National Institute for Space Research-INPE

⁷ Geography, University of Exeter, Exeter, EX4 4RJ

* Correspondence: ddutra.ambiental@gmail.com

2. Materials and Methods

Table S1 – Composition of the study region with the area of each municipality included and its percentage of the municipality's territory. Source: Authors

Municipality	Area of the municipality (km ²)	State	The area included in the study region (km ²)	Percentage of the municipality in the study region (%)
Acrelândia	1,807.96	Acre	34.48	1.91%
Boca do Acre	21,938.59	Amazonas	21,938.59	100.00%
Bujari	3,034.90	Acre	855.13	28.18%
Lábrea	68,262.72	Amazonas	3,700.70	5.42%
Manoel Urbano	10,633.07	Acre	1,454.48	13.68%
Paiuni	41,624.44	Amazonas	8,084.03	19.42%
Porto Acre	2,604.92	Acre	2,058.17	79.01%
Sena Madureira	23,753.16	Acre	2,275.83	9.58%
Senador Guiomard	2,322.05	Acre	375.31	16.16%

Citation: Dutra, D.J.; Anderson, L.O.; Fearnside, P.M.; Graça, P.M.L.d.A.; Yanai, A.M.; Dalagnol, R.; Burton, C.; Jones, C.; Betts, R.; Aragão, L.E.O.e.C.d. Fire Dynamics in an Emerging Deforestation Frontier in Southwestern Amazonia, Brazil. *Fire* **2023**, *1*, 2. <https://doi.org/10.3390/fire6010002>

Academic Editor: James A. Lutz

Received: 21 October 2022

Accepted: 15 November 2022

Published: 21 December 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors.

Submitted for possible open access

publication under the terms and

conditions of the Creative Commons

Attribution (CC BY) license

(<https://creativecommons.org/licenses/by/4.0/>).

2.1 Methodology diagram

M1 - Diagram of data

• M1a –Land Use

We used the data from the MAPBIOMAS project to generate the land use map of the study region. Originally, the data contained 31 land-use classes, which were grouped into three classes:

1. Intact vegetation: old-growth tropical forest;
2. Productive land: agricultural and pasture areas;
3. Deforestation: clear-cut of old-growth forests (MapBiomass).

After the reclassification of MAPBIOMAS data, we created the class “regrowth” in the same raster, with secondary forest data from Silva Junior et al [1], which area based on MAPBIOMAS project data from the same collection (5) of land use data (see more details in Figure S1).

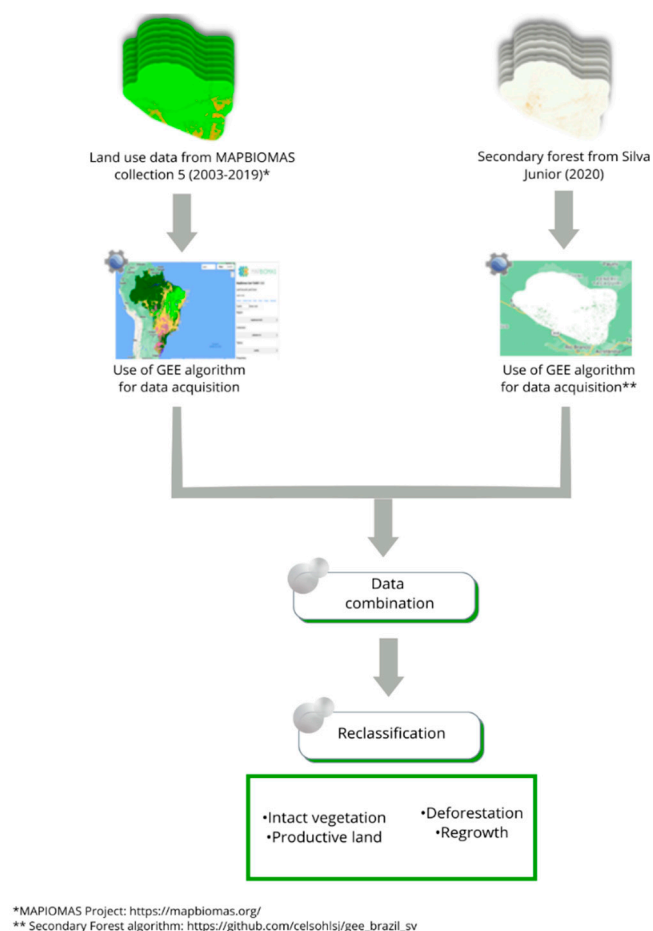


Figure S1 - Land use data acquisition diagram. Source: Authors

- **M1b**– Selection of Burned-area products
 - Burned area

We considered three global burned area products (MCD64A1 [1], GABAM [2], and GWIS [3]) for producing the combined product used in this study (see Table S2). Originally, these products were acquired from the same database (MCD64A1) and processed with the near-infrared (spectral range 1230 – 1250 nm) and mid-infrared (2105 – 2155 nm) band [4]. The differences between the products occur in the post-processing of the images. The application of these techniques seeks to reduce the overestimations and underestimations indicated by differences between the simulated and the real burned areas. However, it is important to emphasize that each product has an accuracy limit and errors of omission and commission that are evaluated in the validation process [2,11–13] (see Table S3).

Table S2 - Specifications of burned-area products. Source: Authors

Name	Developer	Time	Sensors/Inputs	Spatial Resolution	References
GABAM	Institute of Remote Sensing and Digital Earth,	1985-2020	MCD64A1, Landsat 8 - OLI	30 m	[1]

GWIS	Chinese Academy of Sciences	2001-2020	MCD64A1, MODIS, Copernicus-Proba-V and Fire CC1	Vector data	[2,3]
	Group on Earth Observations (GEO) and Copernicus Work Programs				
MCD64A1c6	NASA	2000-present	MODIS (surface reflectance and active fires)	500 m	[4]

Table S3 - Accuracy information for the three burned-area products

Name	Overall Accuracy	Omission Error	Commission Error	Validation Method	References
GABAM	93,92%	30,13%	13,17%	Used a semiautomatic classification method, manually refined, from Landsat 8, CBERS-4 MUX, and Gaofen-1 WFV data for 80 locations around the globe	[3]
GWIS	91%	between 9% to 21%	between 9% to 21%	In Brazilian regions, the GWIS products were compared with products developed by Tropical Ecosystems and Environmental Sciences (TREES) project for the region of Mato Grosso [5,6].	[7]
MCD64A1c6	99,70%	72,60%	40,20%	Global reference data were used for the period from March 1, 2014 to March 19, 2015 from 30m resolution images of Landsat data that were visually interpreted. These data were stratified, allowing a probabilistic sampling of these data in time and space to carry out the validation of the burned area data.	[4]

Considering the errors of omission and commission present in each product [2,11–13], we used the burned area data the different products to build our database for the study region. We did not perform data validation, but rather an intercomparison between the products [4]. We used the sum of all products in a 5km x 5km grid to minimize this problem. According to the methodology of Pessôa et al. [16], we used the non-parametric Kolmogorov-Smirnov statistic to analyze the significance of the data (p-value <0.05) and the fuzzy similarity to identify the burned areas that were common between the products.

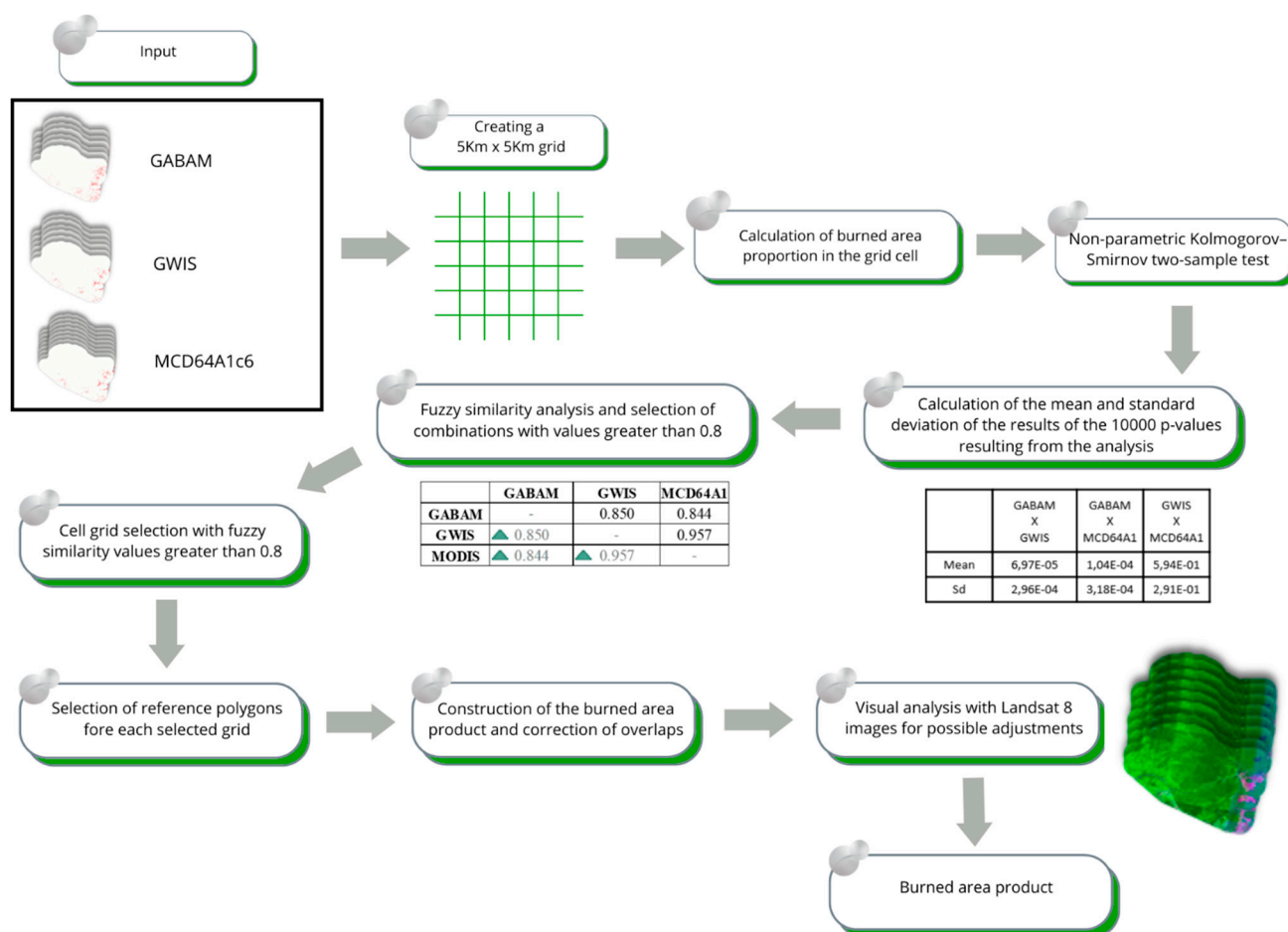
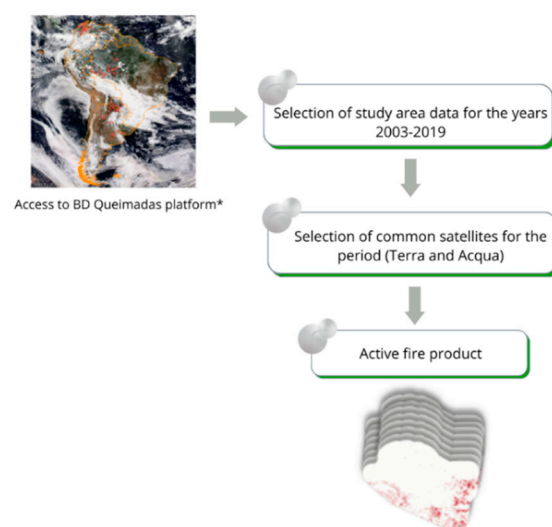


Figure S2 – Burned area diagram. Source: Authors

- M1c–Active Fires**

We used the data from the BDqueimadas project to create the active fires map of the study region. We selected the same active-fire pixel data from the BD Queimadas product in all temporal analyses (Terra and Aqua) (see more details in Figure S4).



*DB Queimadas Project: <https://queimadas.dgi.inpe.br/queimadas/bdqueimadas>

Figure S3 - Active fire diagram. Source: Authors

• M1d–Climatic data products

We used ERA 5 data for climate analysis in the study region, acquired through the Google Earth Engine platform. We consulted the literature to select the most frequent climatic data in fire studies in Amazon's regions, which we characterized by temperature and precipitation (see more details in Figure S4). We calculated the descriptive statistics of the data and applied the non-parametric Kendall and Sens-Slope tests to analyze the significance of the data concerning temporal frequency. We used climatic anomaly analysis to complement the trend test, since the results were not significant for the temperature and precipitation data but were significant for the precipitation and temperature anomaly data.

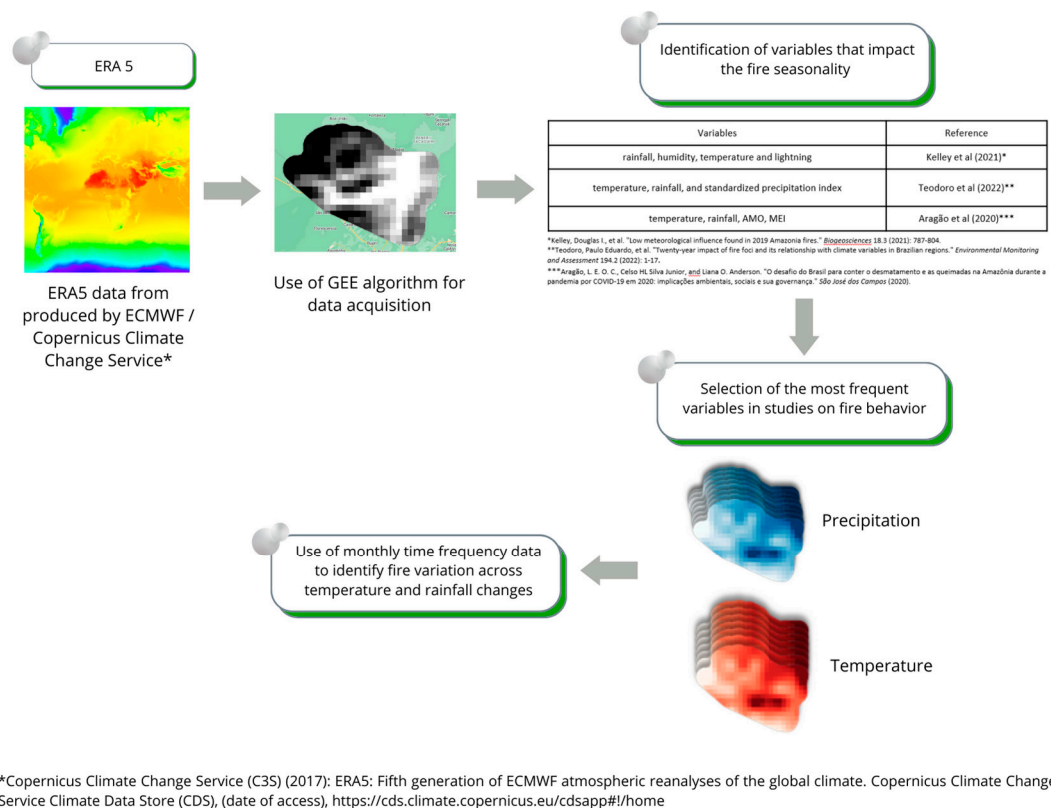


Figure S4 – Climate data diagram. Source: Authors

Item: Identification of variables that impact the fire seasonality (table)

Variables	Reference
Rainfall, humidity, temperature, and lightning	Kelley et al (2021)*
Temperature, rainfall, and standardized precipitation index	Teodoro et al (2022)**
Temperature, rainfall, AMO, MEI	Aragão et al (2020)***

*Kelley, D. I., et al. "Low meteorological influence found in 2019 Amazonia fires." *Biogeosciences* 18.3 (2021): 787-804.

**Teodoro, PE, et al. "Twenty-year impact of fire foci and its relationship with climate variables in Brazilian regions." *Environmental Monitoring and Assessment* 194.2 (2022): 1-17.

***Aragão, LEOC, CHL Silva Junior, and LO Anderson. "O desafio do Brasil para conter o desmatamento e as queimadas na Amazônia durante a pandemia por COVID-19 em 2020: implicações ambientais, sociais e sua governança." *São José dos Campos* (2020).

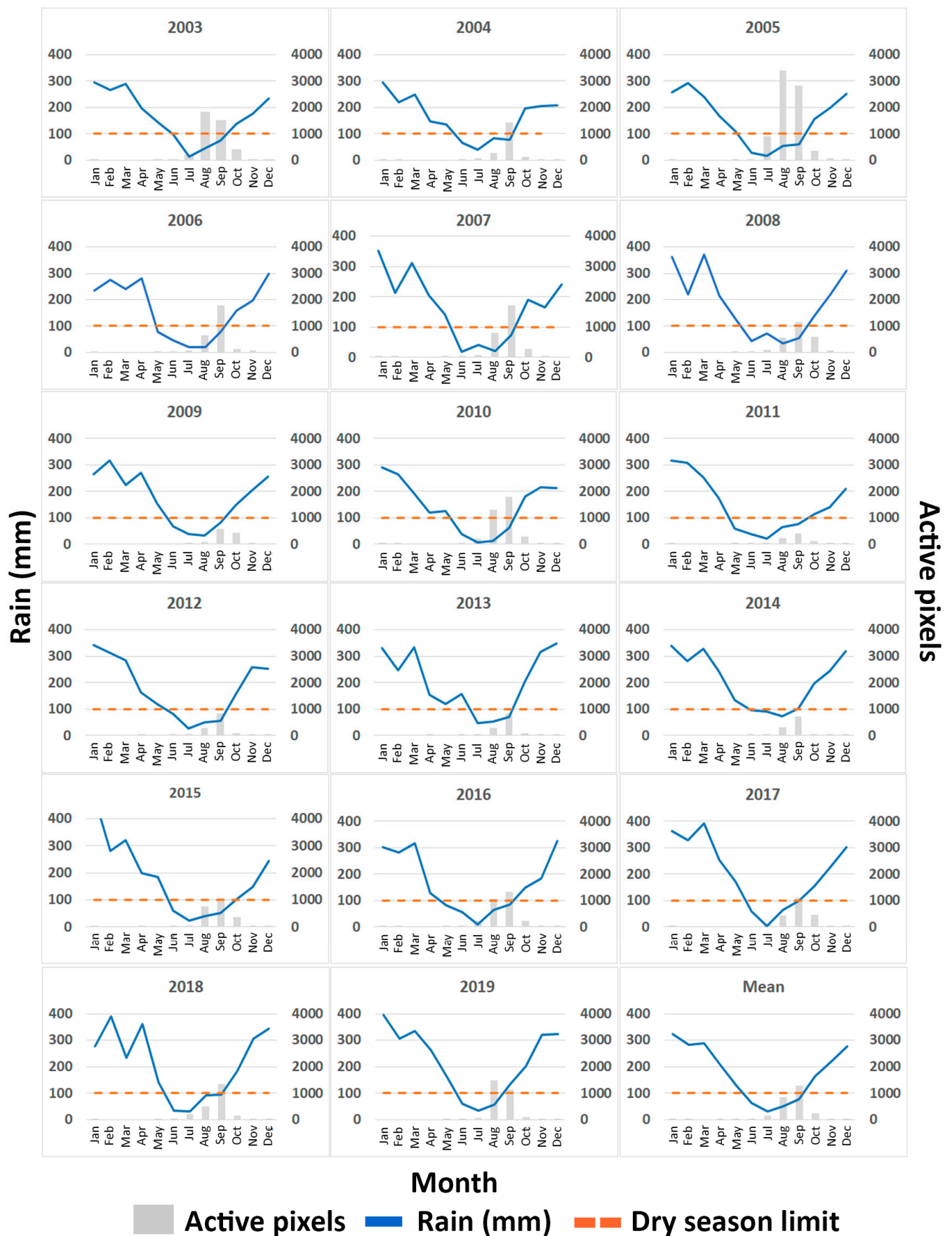


Figure S5 - Monthly counts of fire pixels and mm of rain over the analyzed time series (2003-2019)

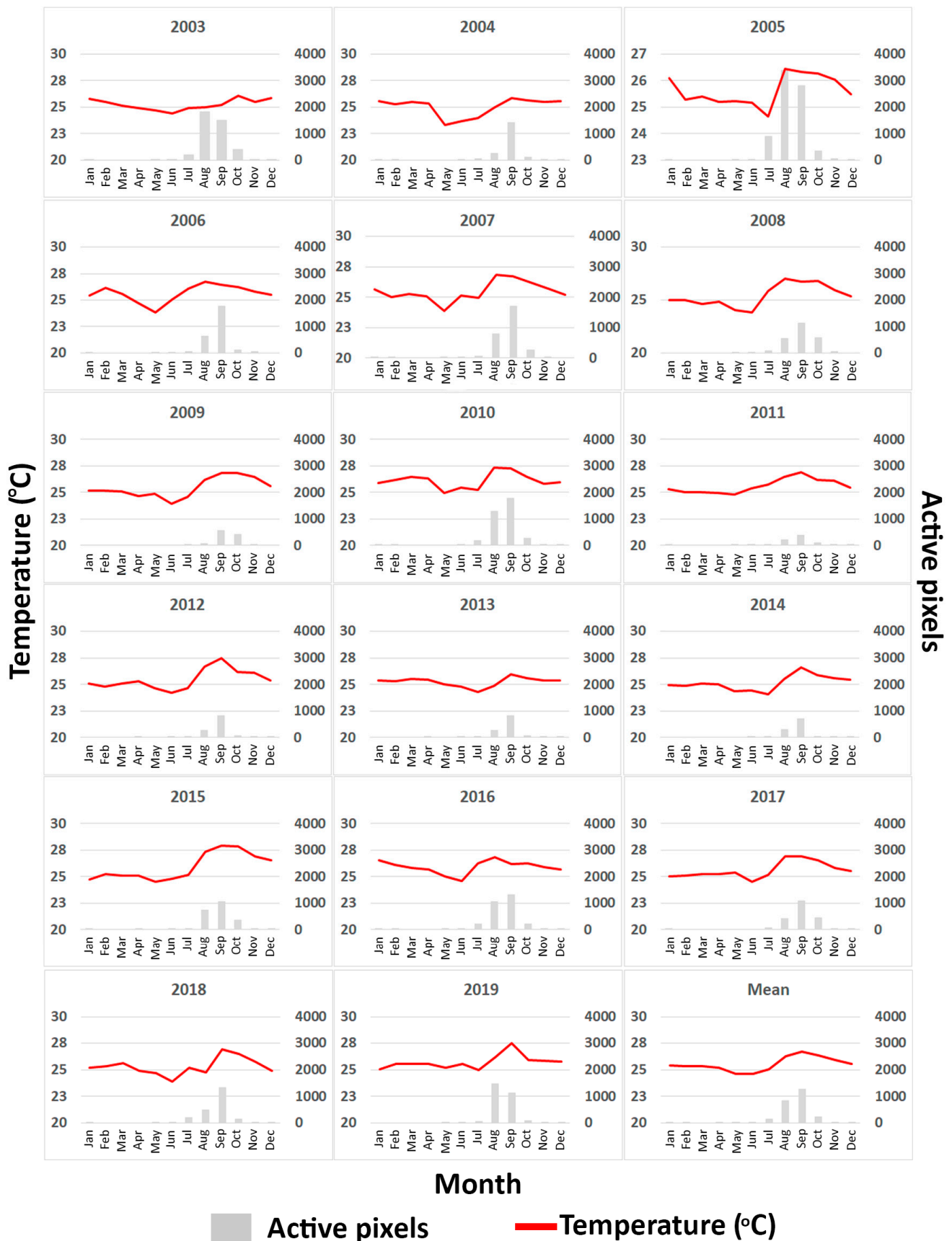


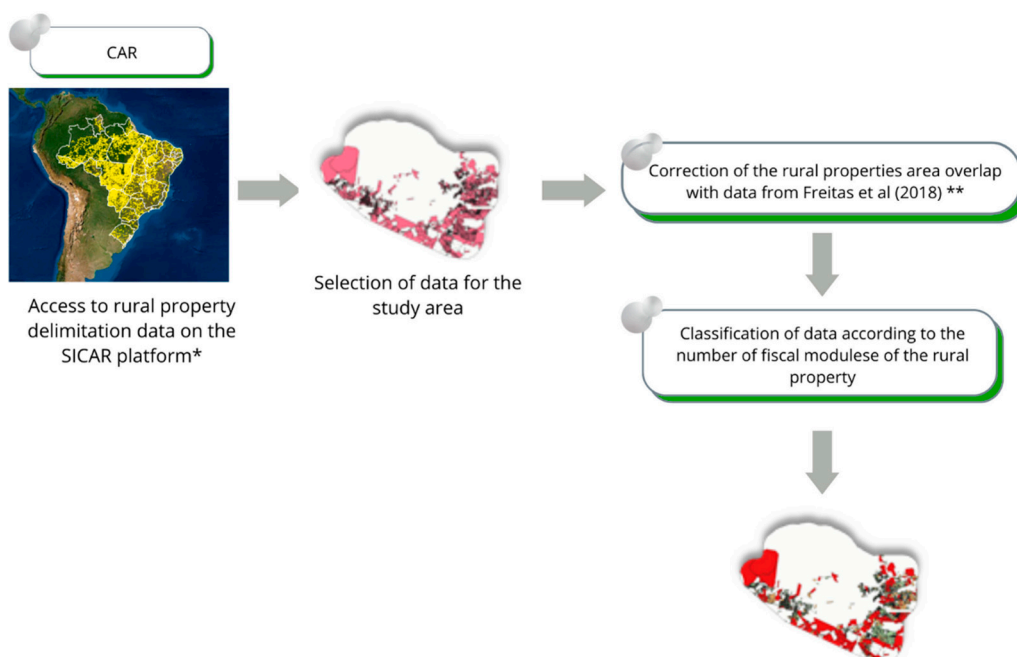
Figure S6 - Monthly counts of fire pixels and average temperature (°C) over the analyzed time series (2003–2019). Source: Authors

- **M1e**– Selection of land-tenure products
 - CAR

The Rural Environmental Registry (Cadastro Ambiental Rural, or "CAR") is a self-declaratory electronic public registry, which is regulated by law nº 12.651, 2012 and Normative Instruction MMA nº 2, of May, 5 2014 and integrates environmental information on "rural properties" about permanent preservation areas, legal reserves, restrictions on use, remaining cover of forest and of other native vegetation and consolidated areas. We used this information to create a "rural properties" grid of the study region, including the corrections of Freitas et al [55] to eliminate overlap in CAR polygons, and we reclassified the data concerning "fiscal modules" (see Table S3), which are defined by National Institute for Colonization and Agrarian Reform (INCRA). More details are provided in Figure S6.

Table S4 - Fiscal module sizes in the study region

Municipality	State	Fiscal Module size (ha)
Boca do Acre	Amazonas	100
Pauini	Amazonas	100
Lábrea	Amazonas	100
Acrelândia	Acre	100
Senador Guiomard	Acre	100
Porto Acre	Acre	70
Bujari	Acre	70
Sena Madureira	Acre	100
Manoel Urbano	Acre	100



*SICAR: <https://www.car.gov.br/publico/imoveis/index>

**Freitas, F.L.M. de; Guidotti, V.; Sparovek, G.; Hamamura, C. Nota Técnica: Malha Fundiária Do Brasil. In Atlas - A Geografia da Agropecuária Brasileira; 2018; Vol. 1812, p. 5.

Figure S7 - CAR diagram. Source: Authors

- Deforestation data

We used the data from the TERRABRASILIS project (PRODES and DETER) to create the new deforestation and old deforestation classes for the study region, where:

- New deforestation: areas with the recent removal of vegetation cover detected by the DETER project; and
- Old deforestation: areas with agriculture, pasture, and secondary forest, i.e., “consolidated areas” not surveyed by DETER project and classified as “non-forest” by PRODES.

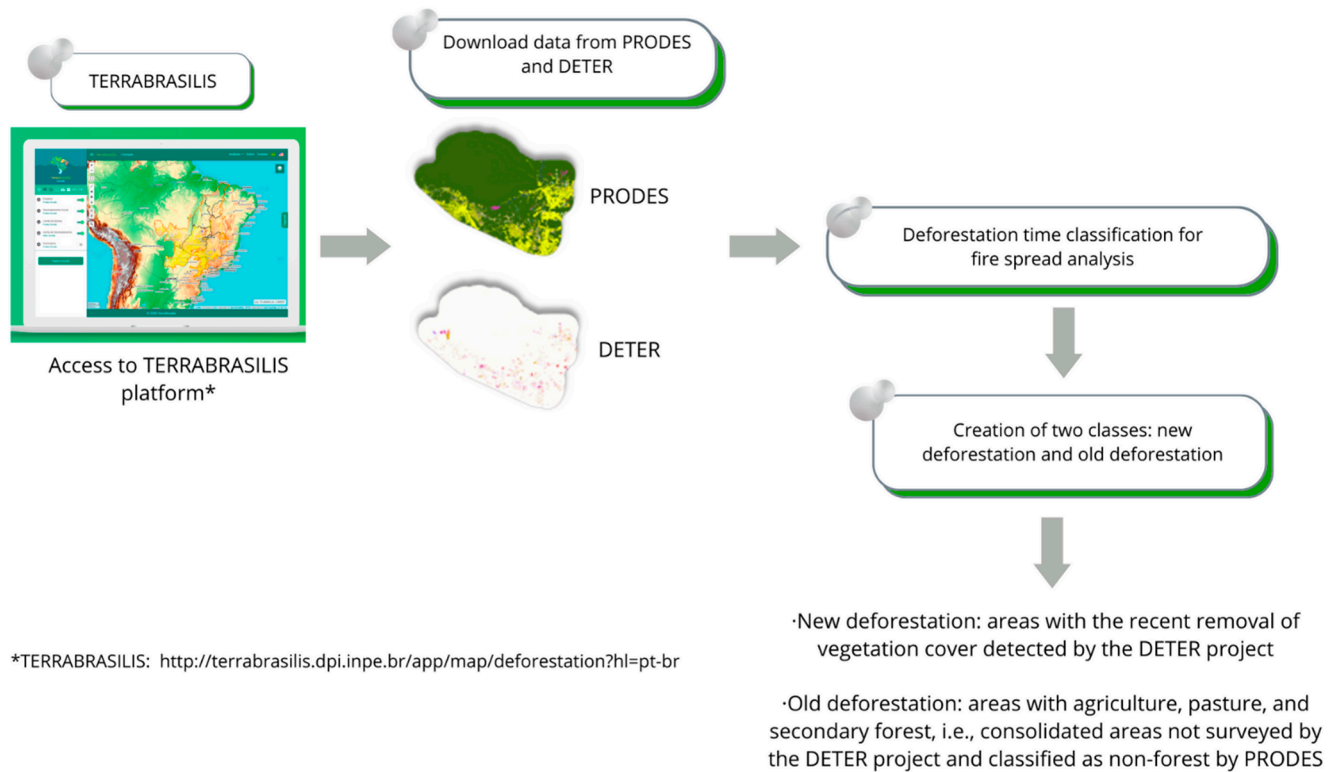


Figure S8 - Deforestation diagram. Source: Authors

○ Protected lands

We selected protected land, here define as undesignated forests, indigenous lands, conservation units, and the legal reserves and permanent protection areas (APPs) that are self-declared in the CAR, to analyze the expansion of fire and deforestation that overlapped with protected lands (more details see the Figure S8).

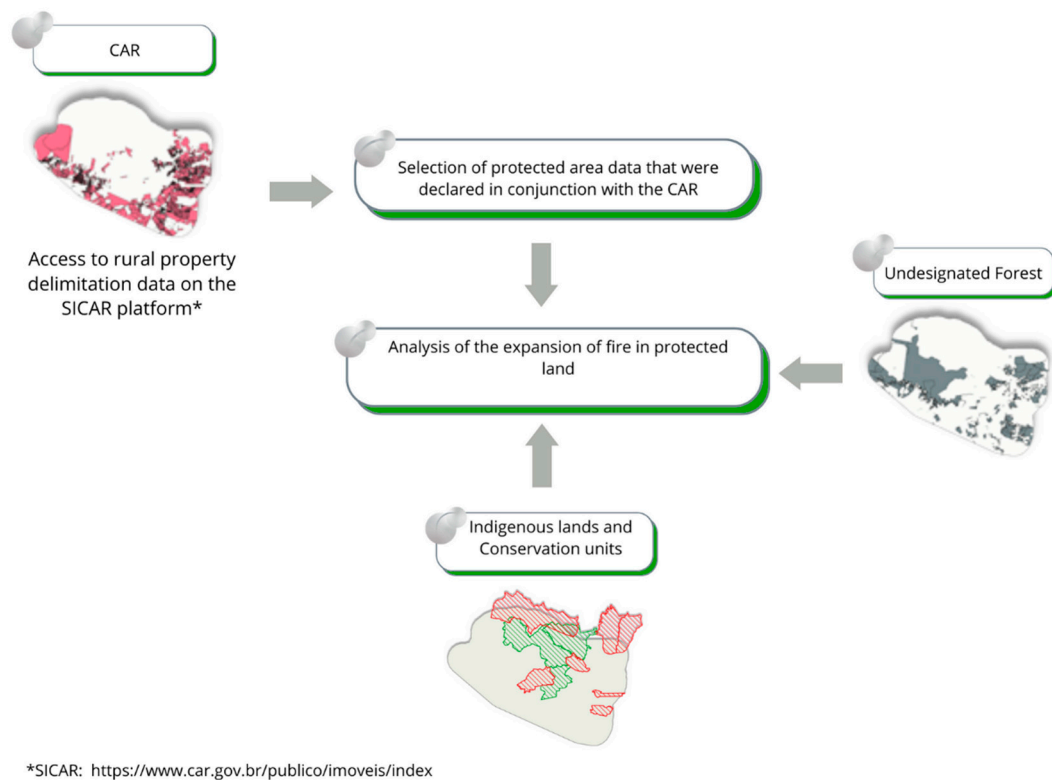


Figure S9 - Deforestation diagram. Source: Authors

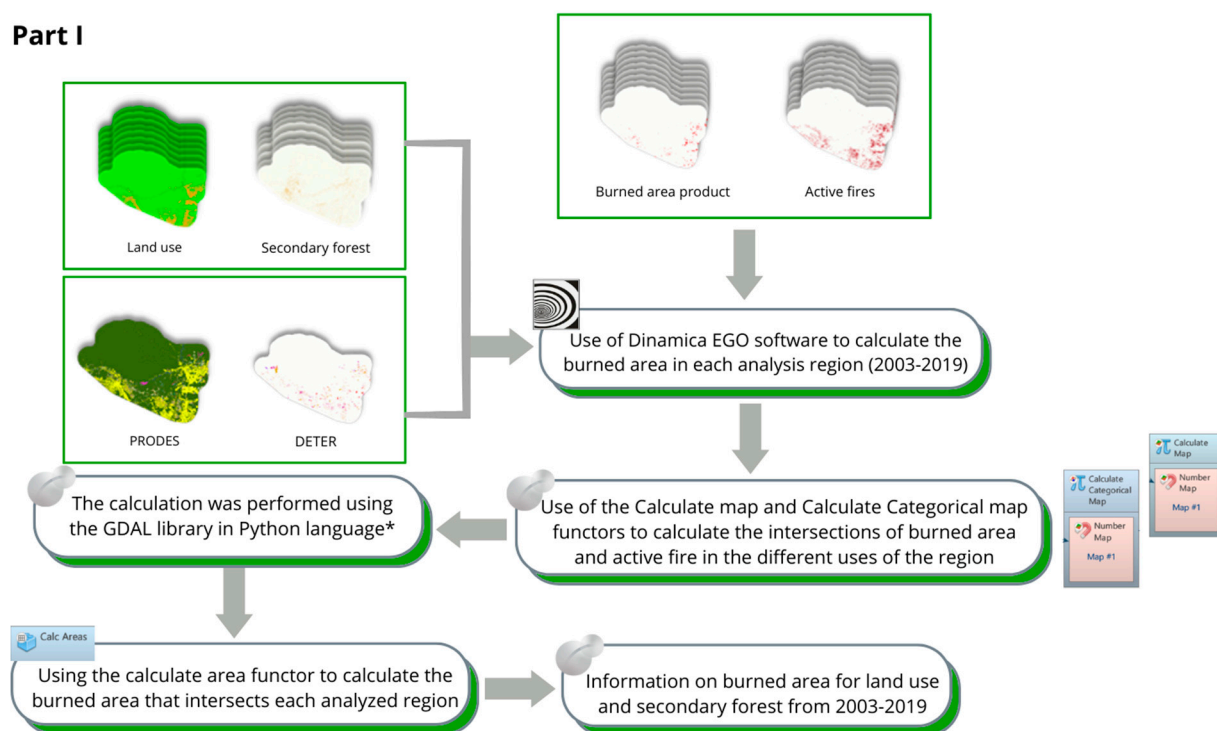
M2 - Diagram of Raster analysis

We separated the raster analysis into two inputs (represented by rasters and vector inputs) and used DINAMICA EGO 6 to create two processing models:

- Part I - with the input in raster format: we used DINAMICA EGO 6 to delimit the burned area and active fires in each region. For this process, we applied the 'Calculate map', 'Calculate categorical map', and 'Calculate area' functors to select the areas (see more details in Figure S9 and below in section §S2 Raster analysis topic).

- Part II - with the input in vector format: we converted the vector to raster and the 'ID' (number of property class identification) was the reference of the concerned analysis. We extracted the values by the 'Extract map values' functor with the 'ID' as a key to mapping the burned area values (in raster format). Finally, we use the create table to export the values to the table (see more details in Figure S9 and below in section §S2 Raster analysis topic).

Part I



*GDAL library: <https://pypi.org/project/GDAL/>

Part II

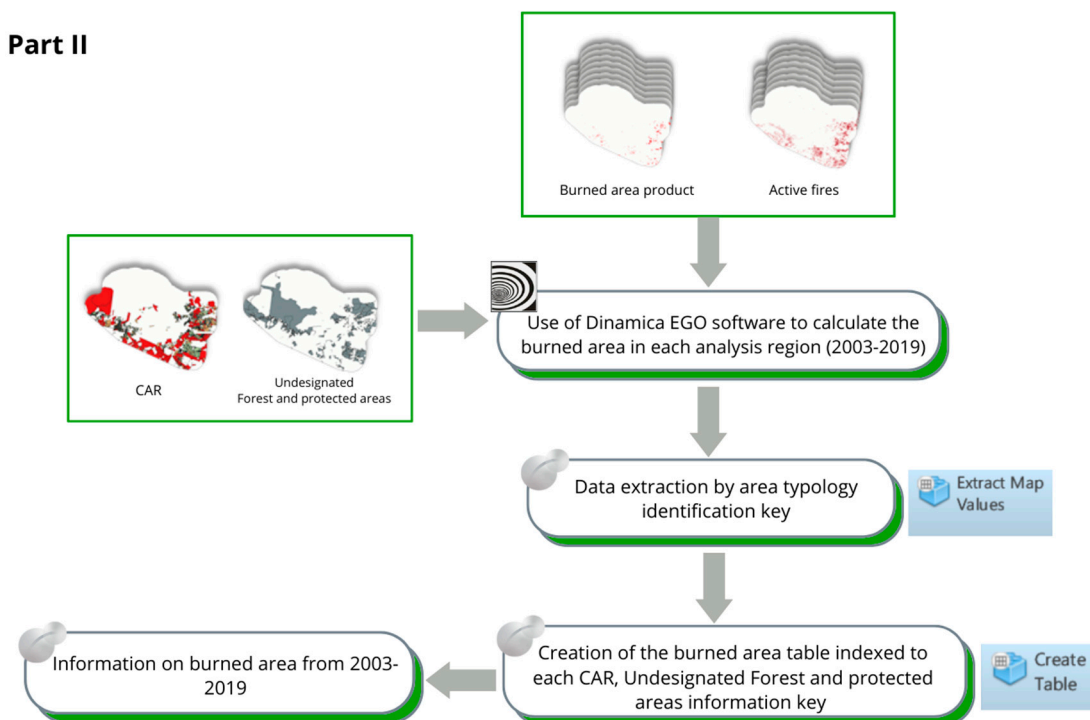


Figure S10 - Raster analysis diagram. Source: Authors

§S2 Raster analysis

- Data reclassification from the MapBiomass project and data selection according to each land category.

We used Dinamica EGO software to create a model (Figure S6) to reclassify MapBiomass data by land category, where the original MapBiomass map was separated into three categories: agriculture and pasture, forest and deforested areas. The map of burned areas was then merged with the new MapBiomass map to identify the distribution of burned areas in each land-use and land-cover category.

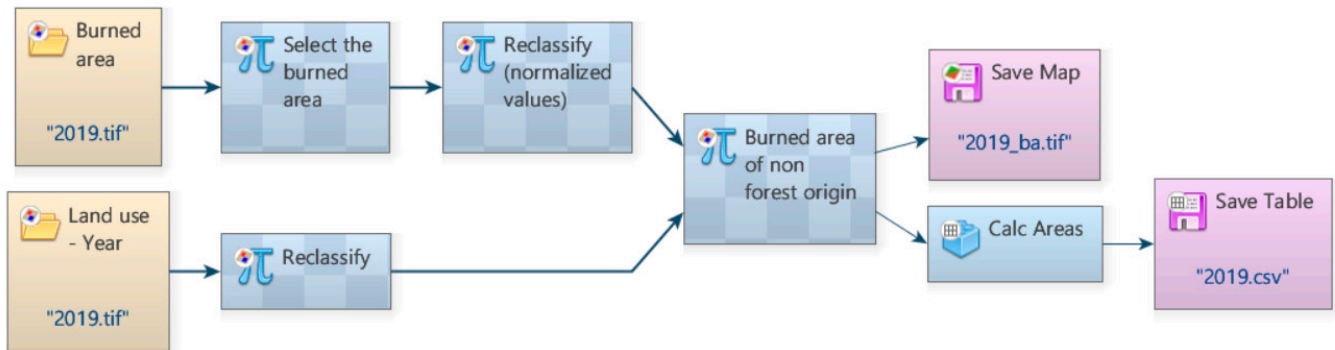


Figure S11 -Model developed in Dinamica-EGO software for MapBiomass data to reclassify and select burned areas by land category. Source: Authors

- Selection of the total area value according to the classification of each CAR “property”

We separated fire occurrences located inside the rural properties from the Rural Environmental Registry (CAR) [8,9] and calculated the all burned areas using Dinamica-EGO software (Figure S7). We studied fire spread in legally protected portions of rural properties (permanent preservation areas and legal reserves) and analyzed fire behavior in areas of old (management areas) and new deforestation in the study region with data from the TerraBrasilis project [10].

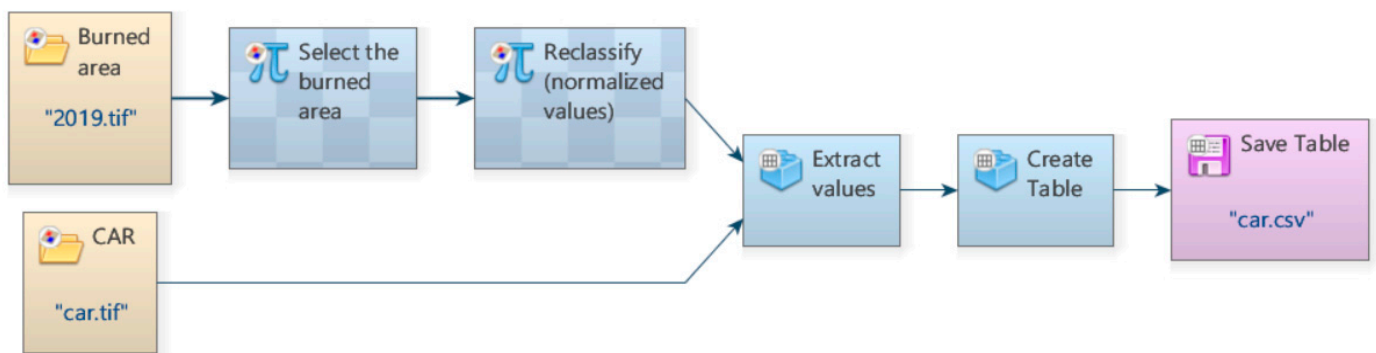


Figure S12 - Model developed in the Dinamica-EGO software for selecting and estimating the burned areas following the rural property size of their CAR data class. Source: Authors

- Selection of the total area value of secondary forest data

We identified fire occurrences in the secondary forest using the model created in Dinamica-EGO (Figure S8). This selects the burned areas and calculates the total area.

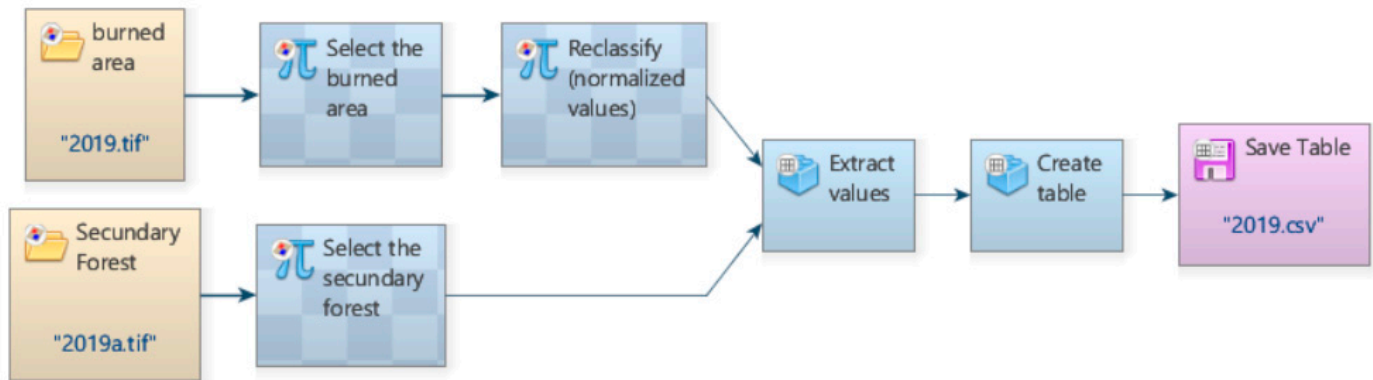


Figure S13 - Model developed in the Dinamica-EGO software for selecting and estimating the burned areas in secondary forests following their data classes. Source: Authors

- Analysis of the fire spread in protected areas (Conservation Units and Indigenous Lands)

We analyzed the burned area in protected areas to quantify fire spread in these territories in the period from 2003 to 2019.

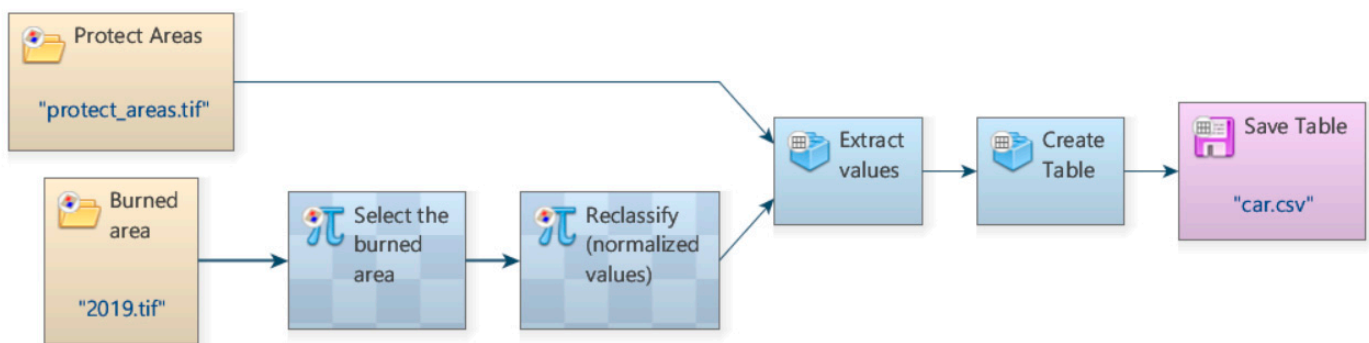


Figure S14 - Model developed in the Dinamica-EGO software for selecting and estimating the burned areas in secondary forests following their data classes. Source: Authors

M3 - Diagram of the statistical analysis

We applied a non-parametric test (Kendall tau and Sen's slope) to calculate the trend in raster values from 2003 to 2019 using RStudio software. The analyses were associated with burned area, deforestation, temperature anomalies, and precipitation anomalies. We calculated the temperature and precipitation anomalies because the precipitation and temperature variables were not significant in the first process of statistical analyses. We therefore used the PyQgis platform (in QGIS 3.16.5) to create a raster file of temperature and precipitation anomalies in the study region and use these variables for trend calculation. The analyses identified any increase or decrease in values in the temporal series and mapped the occurrence of positive trends associated with burned areas in the study region.

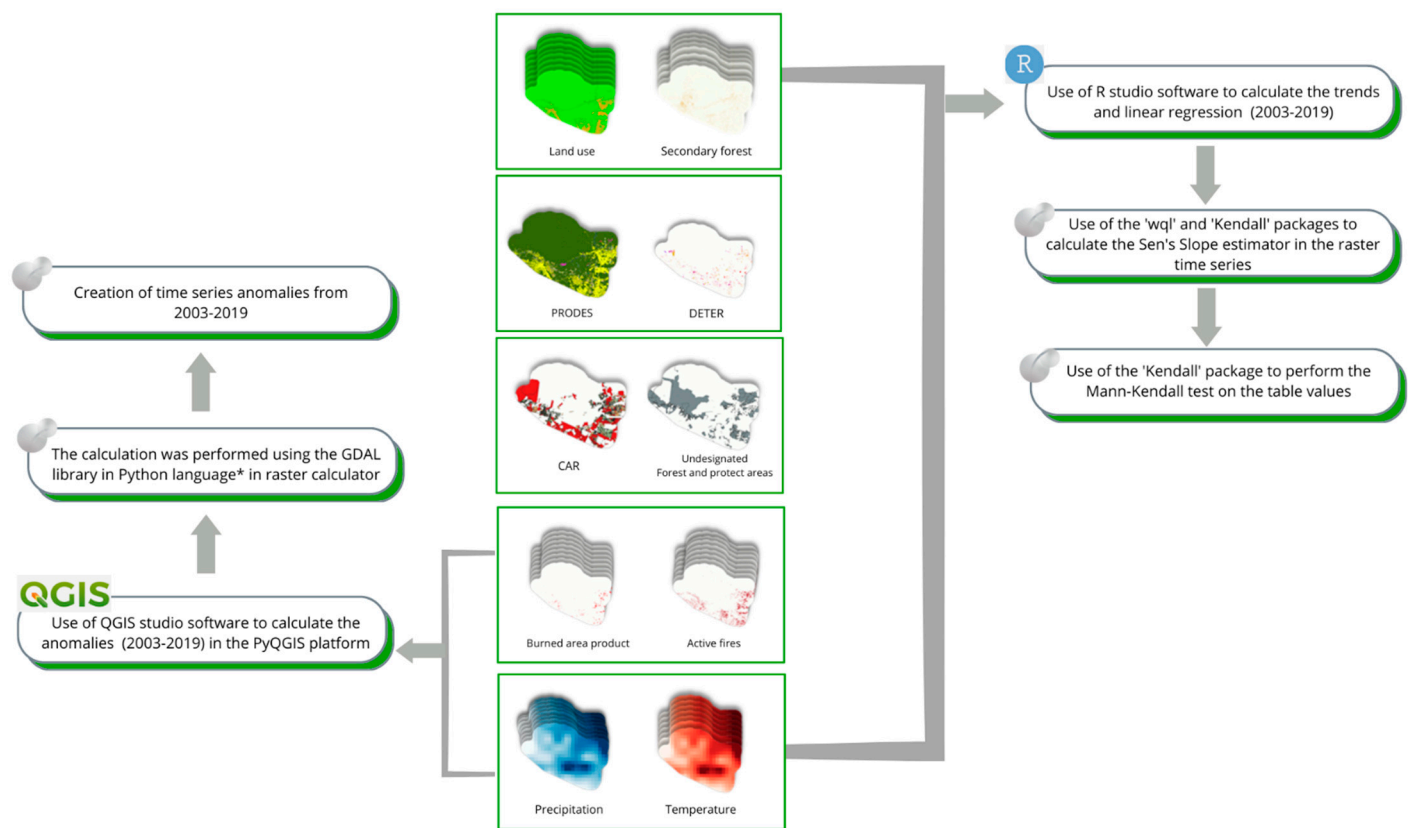


Figure S15 - Statistical analysis diagram. Source: Authors

3. Results

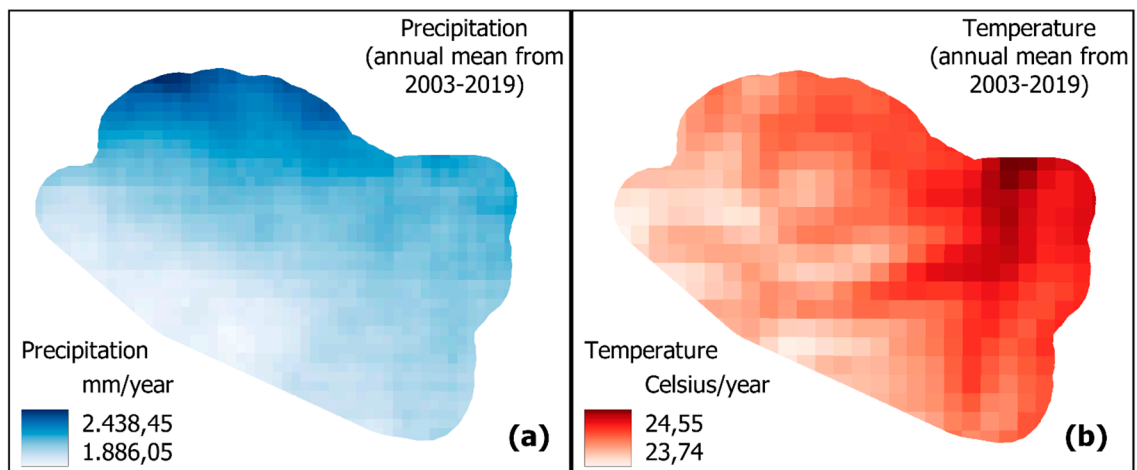


Figure S16 – Mean annual (a) rainfall, (b) temperature, (c) active-fire pixels, and (d) burned area in the period from 2003 to 2019

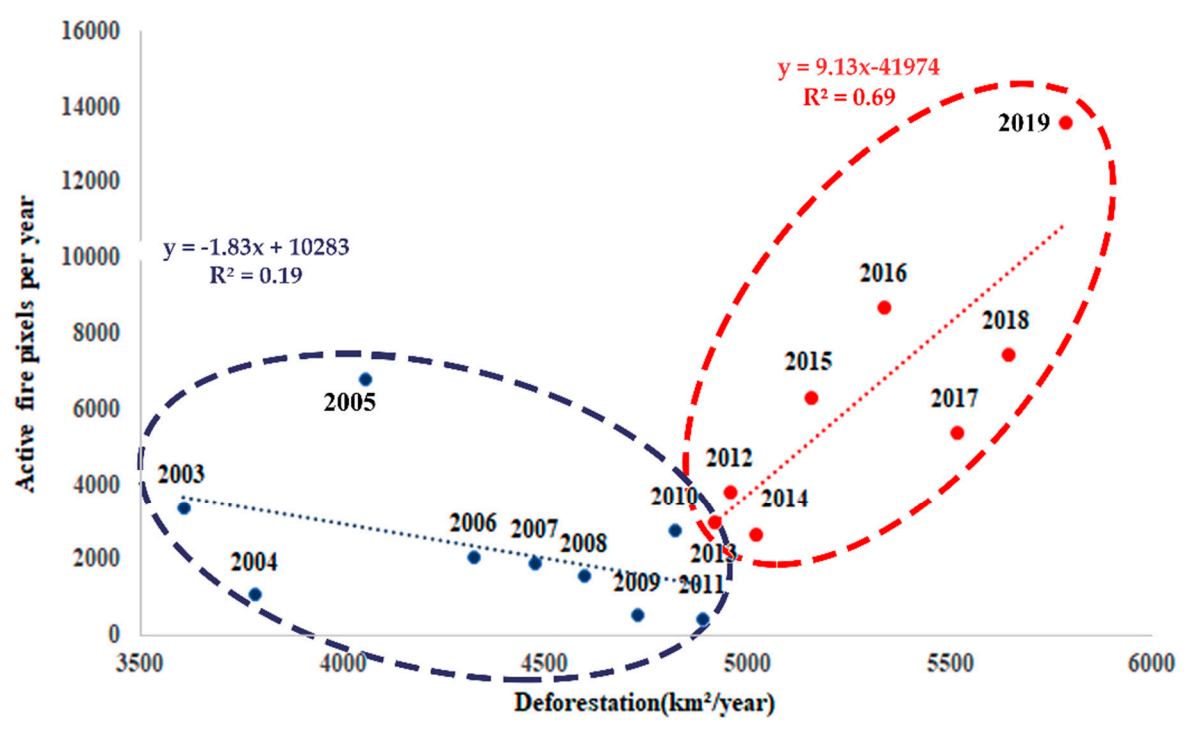


Figure S17 - Deforestation variation per km² for the study region in the period from 2003 to 2019, where in blue are the years before the new Brazilian Forest Code and in red are after new Brazilian Forest Code.

Table S5 - Analysis of variation in the burned area (km²) based on (a) land use from MapBiomas (2021) and (b) secondary forest from Silva Junior et al. (2020). Source: Authors

(a)	2003	2004	2005	2006	2007	2008	2009	2010	2011
Forest	348	141	681	246	253	234	46	419	33
Agriculture and pasture	684	103	1635	331	328	407	87	856	68
Deforestation	2.05	0.50	5.63	3.71	1.43	2.73	0.44	3.03	0.03
	2012	2013	2014	2015	2016	2017	2018	2019	-
Forest	135	90	74	199	413	226	166	295	-
Agriculture and pasture	143	114	90	297	537	213	248	343	-
Deforestation	1.25	0.17	0.19	6.83	2.46	0.98	0.46	1.55	-
(b)	2003	2004	2005	2006	2007	2008	2009	2010	2011
Extent	8.76	2.68	25.49	3.80	3.97	5.84	1.04	12.01	0.66
Lost	5.55	0.73	9.35	1.58	0.71	0.88	0.22	1.93	0.09
Increment	2.62	0.38	2.25	0.58	0.55	1.15	0.17	1.61	0.07
	2012	2013	2014	2015	2016	2017	2018	2019	-
Extent	3.24	3.62	1.86	9.79	13.28	4.50	3.62	11.37	-
Lost	0.45	0.74	0.42	1.80	4.03	1.25	1.26	1.58	-
Increment	0.48	0.84	0.17	0.85	0.59	0.30	0.55	4.61	-

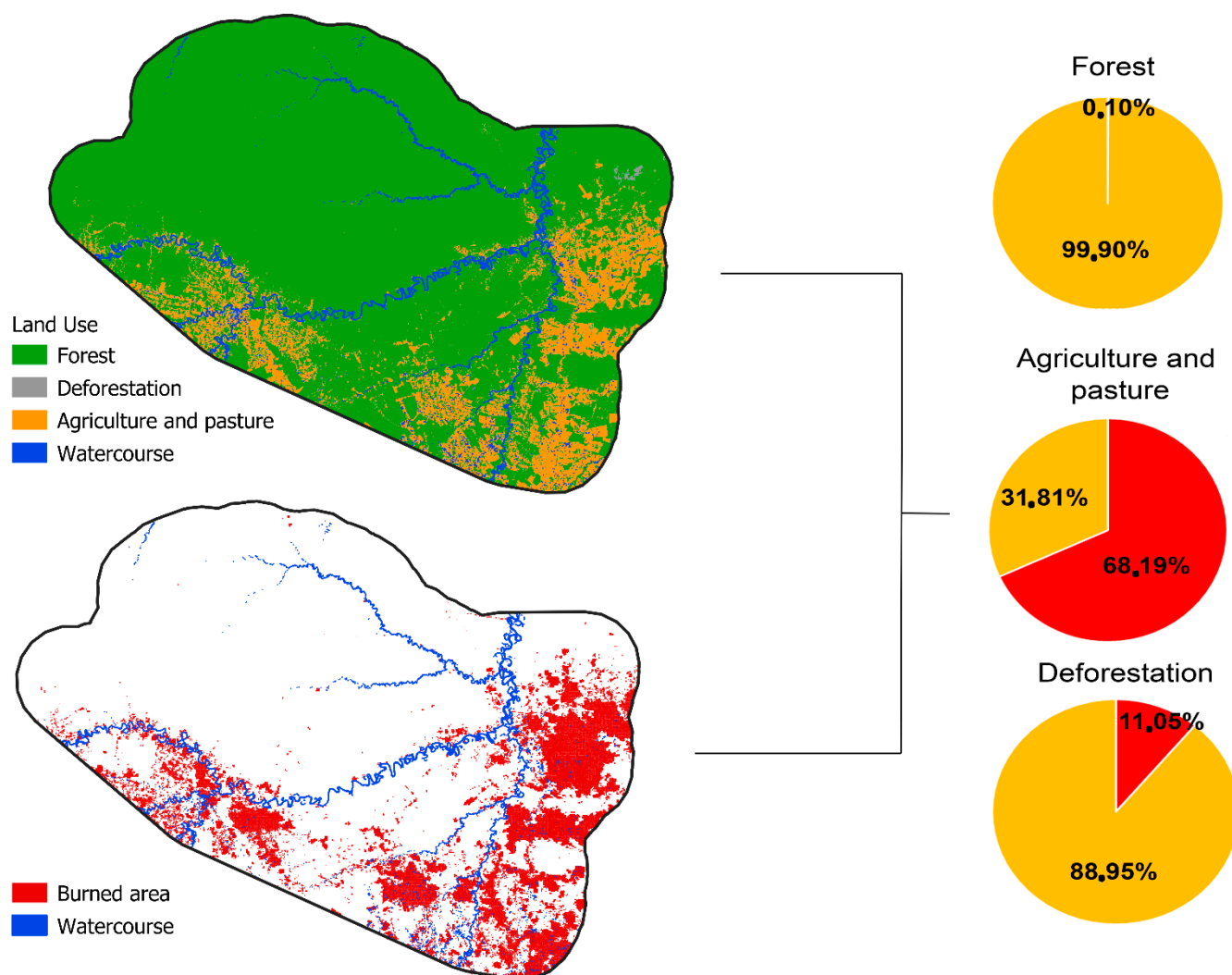


Figure S18 -Cumulative percentage of burned area in the study region for the period from 2003 to 2019. Source: Authors

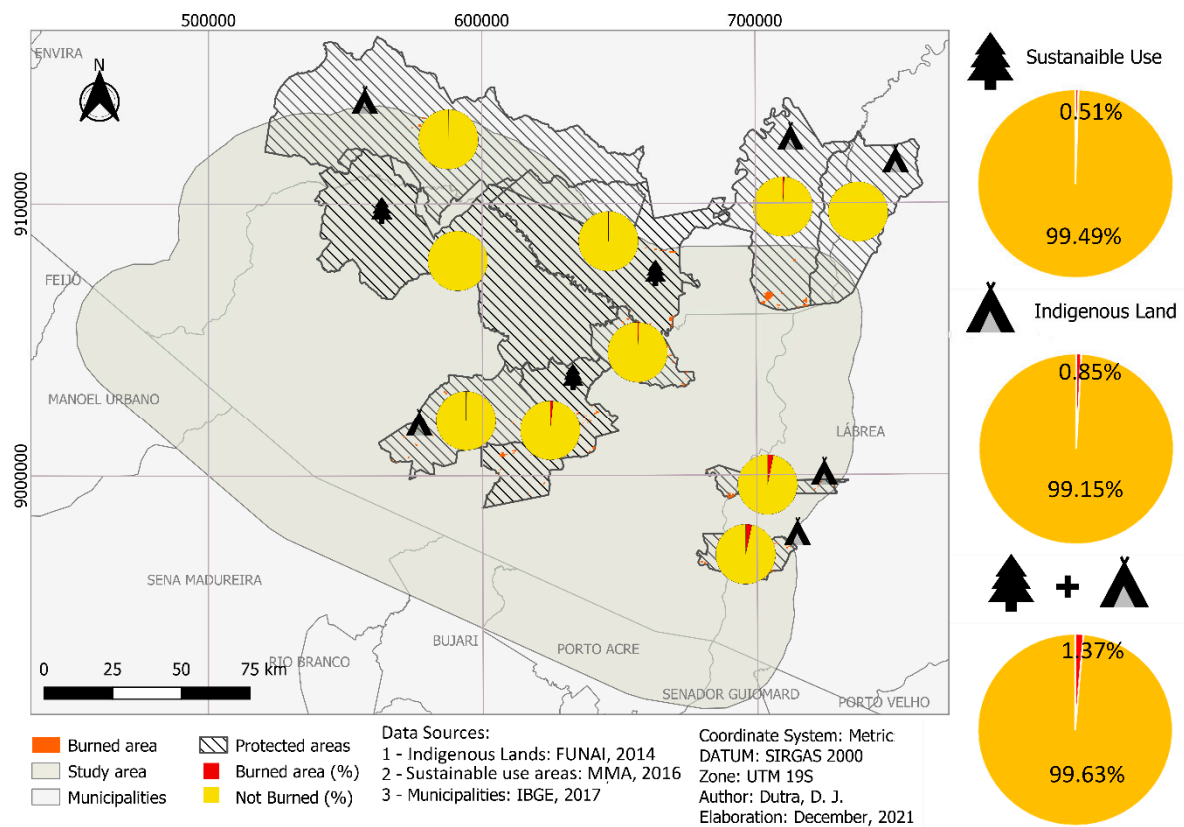


Figure S19 - Percentage of the burned area in the time series (2003-2019) in protected areas in the study region. Source: Authors

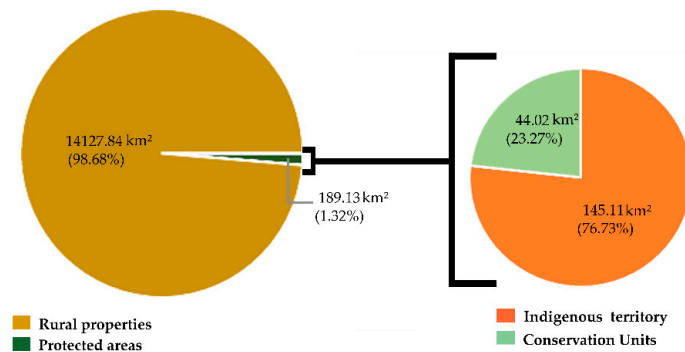


Figure S20 - Analysis of burned areas from 2003 to 2019 and in protected areas (Conservation Units and Indigenous Lands).

		2003 (km ²)	2004 (km ²)	2005 (km ²)	2006 (km ²)	2007 (km ²)	2008 (km ²)	2009 (km ²)	2010 (km ²)	2011 (km ²)
Indigenous territory	Seruini/Mariene	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00
	Apurinã	4.53	0.00	6.01	0.81	1.51	3.71	0.57	2.60	0.00
	Peneri/Tacaquiri	0.00	0.00	0.00	4.83	0.00	1.83	0.00	0.00	0.00
	Inauini/Teuini	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.03
	Camicua	4.87	0.00	0.49	0.52	0.26	0.00	0.00	1.10	0.00
	Igarapé	0.07	0.00	1.10	0.00	0.00	1.10	0.00	0.78	0.00
Conservation Units	Boca do Acre	2.56	0.00	0.39	3.91	0.29	4.98	1.91	3.26	0.14
	Flona de Purus	0.00	0.00	0.66	3.53	0.00	0.00	0.00	0.26	0.23
	Flona de Mapiá-Inauini	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.28	0.05
Rural properties	Resex Arapixi	3.23	0.00	3.91	4.35	0.26	0.00	0.00	1.82	0.03
	Large									
	Medium	938.91	216.48	2064.26	531.15	506.26	537.12	116.01	1057.58	102.54
	Small									
	Others **	88.83	32.23	264.98	39.38	79.51	103.02	15.80	224.96	0.00
Total (Km ²)		1043.00	248.71	2341.87	589.03	588.37	651.75	134.29	1292.64	102.63
		2012 (km ²)	2013 (km ²)	2014 (km ²)	2015 (km ²)	2016 (km ²)	2017 (km ²)	2018 (km ²)	2019 (km ²)	Burned area (%)
Indigenous territory	Seruini/Mariene	0.00	1.61	0.00	0.00	1.54	0.00	0.00	0.00	0.03%
	Apurinã	8.69	0.76	0.00	0.57	10.15	8.08	1.72	3.10	0.50%
	Peneri/Tacaquiri	0.00	0.91	0.26	1.31	6.46	0.00	4.92	5.75	0.25%
	Inauini/Teuini	0.00	0.00	0.00	0.00	3.83	0.00	0.00	0.00	0.04%
	Camicua	0.00	0.08	0.00	0.00	0.00	0.28	2.69	1.79	0.11%
	Igarapé	0.26	0.00	0.00	0.26	0.00	1.85	0.68	0.00	0.06%
Conservation Units	Boca do Acre	1.35	3.75	0.28	1.61	9.05	4.94	0.00	2.07	0.38%
	Flona de Purus	0.00	0.49	0.00	0.83	6.18	0.54	0.24	4.22	0.16%
	Flona de Mapiá-Inauini	0.00	0.09	0.28	0.00	0.00	0.00	0.00	0.81	0.02%
Rural properties	Resex Arapixi	2.07	1.64	0.52	1.04	1.36	0.55	3.48	0.52	0.23%
	Large	30.87	37.18	19.64	74.29	144.96	84.61	99.83	143.36	17.33% *
	Medium	14.77	25.88	23.03	39.01	55.50	43.49	42.38	48.33	7.98% *
	Small	74.24	53.90	46.38	125.90	269.13	126.36	109.55	175.05	26.77% *
	Others **	149.68	111.13	76.22	264.24	450.89	173.72	154.87	258.28	23.35%
Total (Km ²)		281.93	237.42	166.61	509.06	959.05	444.42	420.36	643.28	100.00%

*Percentage of burned area in the “rural properties” based on CAR claims from 2012 to 2019

**Regions that did not burn in indigenous territory, conservation units and “rural properties”

Percentage of burned area in the indigenous territories, conservation units and rural properties

Percentage of burned area rural properties from 2003 to 2019

Percentage of burned area rural properties based on CAR claims from 2012 to 2019

Figure S21 - Analysis of burned areas in protected areas (Conservation Units and Indigenous Lands) and different classes of rural properties. Source: Authors

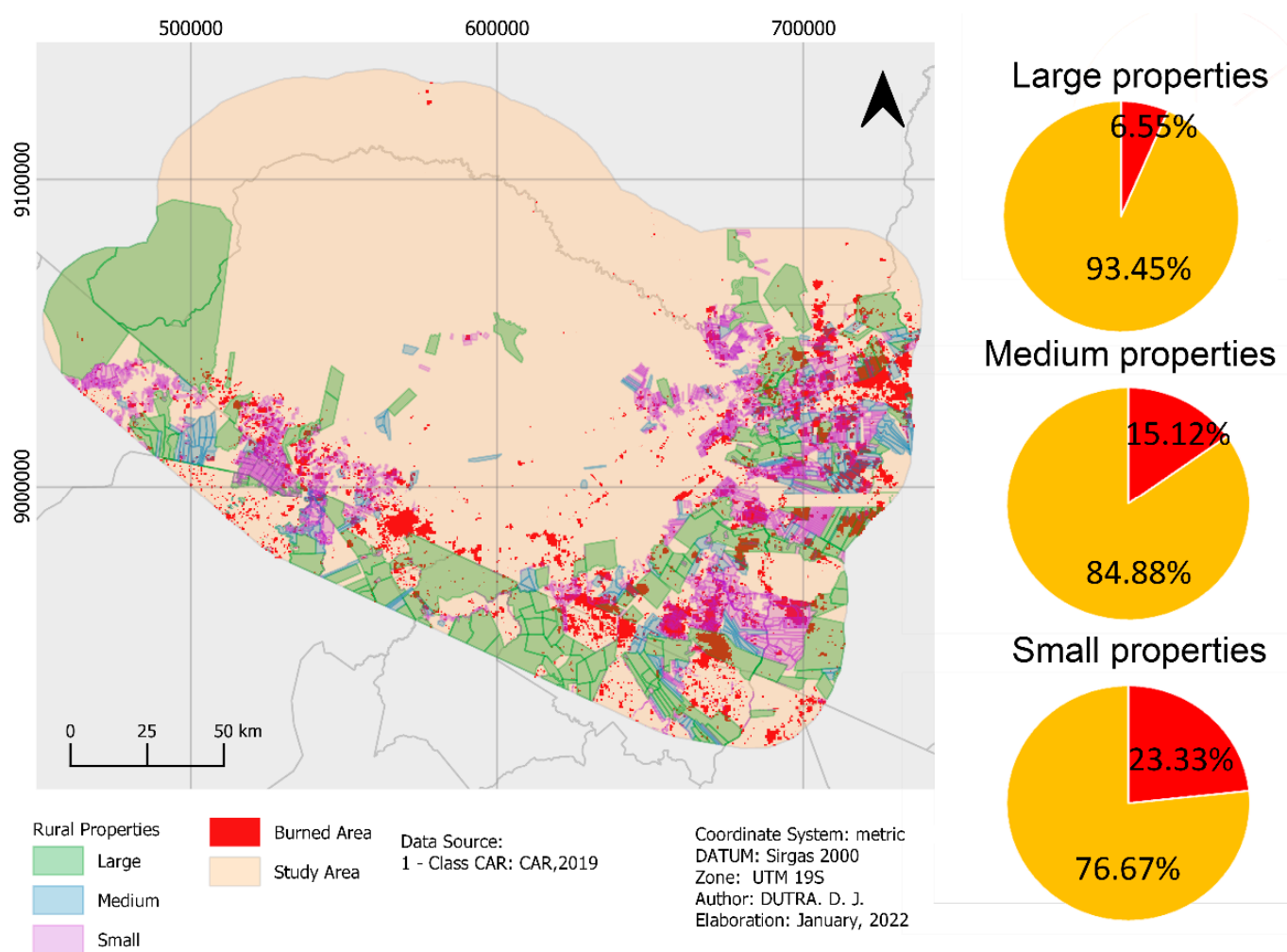



Figure S22 - Percentage of burned area in the classes of rural properties identified by the CAR for the period from 2003 to 2019.
Source: Authors

New Deforestation										
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Large	Forest	0.00	0.09	0.60	3.02	6.75	3.28	0.00	8.13	31.08%
	Agriculture and pasture	0.00	0.11	1.13	4.00	5.54	2.38	20.04	15.32	68.92%
	Deforestation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01%
	Total	0.00	0.21	1.73	7.02	12.29	5.67	20.04	23.45	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Medium	Forest	0.00	0.21	0.37	3.59	0.38	0.37	5.28	4.74	64.28%
	Agriculture and pasture	0.00	0.01	0.54	3.65	0.07	0.83	3.21	0.00	35.72%
	Deforestation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%
	Total	0.00	0.23	0.91	7.23	0.45	1.20	8.48	4.74	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Small	Forest	0.32	0.00	0.81	0.00	9.83	2.34	4.20	13.23	70.06%
	Agriculture and pasture	0.11	0.00	1.72	2.89	2.93	1.35	4.13	0.00	29.94%
	Deforestation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%
	Total	0.43	0.00	2.52	2.89	12.77	3.70	8.33	13.23	
Old Deforestation										
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Large	Forest	16.02	15.61	11.57	28.66	60.82	43.31	35.76	57.29	47.67%
	Agriculture and pasture	14.84	21.37	6.34	36.81	71.71	35.64	44.02	62.58	51.97%
	Deforestation	0.01	0.00	0.00	1.80	0.14	0.00	0.01	0.04	0.35%
	Total	30.87	36.97	17.91	67.27	132.67	78.94	79.79	119.91	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Medium	Forest	8.06	9.99	7.75	14.28	18.10	19.69	13.88	13.98	39.28%
	Agriculture and pasture	6.71	15.67	14.36	17.38	36.86	22.60	20.01	29.57	60.62%
	Deforestation	0.00	0.00	0.01	0.11	0.09	0.00	0.00	0.04	0.09%
	Total	14.77	25.65	22.12	31.78	55.05	42.29	33.90	43.59	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Small	Forest	37.09	21.38	19.49	47.81	94.35	50.85	34.46	67.10	39.77%
	Agriculture and pasture	36.71	32.52	24.34	75.13	161.93	71.71	66.72	94.60	60.18%
	Deforestation	0.01	0.00	0.02	0.07	0.09	0.11	0.04	0.12	0.05%
	Total	73.81	53.90	43.86	123.01	256.36	122.66	101.22	161.82	
Total burned area in rural properties										
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Large	Forest	16.02	15.7	12.17	31.68	67.57	46.59	35.76	65.42	45.83%
	Agriculture and pasture	14.84	21.48	7.47	40.81	77.25	38.02	64.06	77.9	53.85%
	Deforestation	0.01	0	0	1.8	0.14	0	0.01	0.04	0.31%
	Total	30.87	37.18	19.64	74.29	144.96	84.61	99.83	143.36	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Medium	Forest	8.06	10.2	8.12	17.87	18.48	20.06	19.16	18.72	41.27%
	Agriculture and pasture	6.71	15.68	14.9	21.03	36.93	23.43	23.22	29.57	58.64%
	Deforestation	0	0	0.01	0.11	0.09	0	0	0.04	0.09%
	Total	14.77	25.88	23.03	39.01	55.5	43.49	42.38	48.33	
		2012 (Km ²)	2013 (Km ²)	2014 (Km ²)	2015 (Km ²)	2016 (Km ²)	2017 (Km ²)	2018 (Km ²)	2019 (Km ²)	Burned area (%)
Small	Forest	37.41	21.38	20.3	47.81	104.18	53.19	38.66	80.33	41.13%
	Agriculture and pasture	36.82	32.52	26.06	78.02	164.86	73.06	70.85	94.6	58.83%
	Deforestation	0.01	0	0.02	0.07	0.09	0.11	0.04	0.12	0.05%
	Total	74.24	53.9	46.38	125.9	269.13	126.36	109.55	175.05	

 Percentage of burned area in “rural properties” based on CAR claims and land use


 Percentage of burned area in “rural properties” based on CAR claims and land use from 2003 to 2019

Figure S23 - Burned area by land-use type in “rural properties,” separated by old and new deforestation

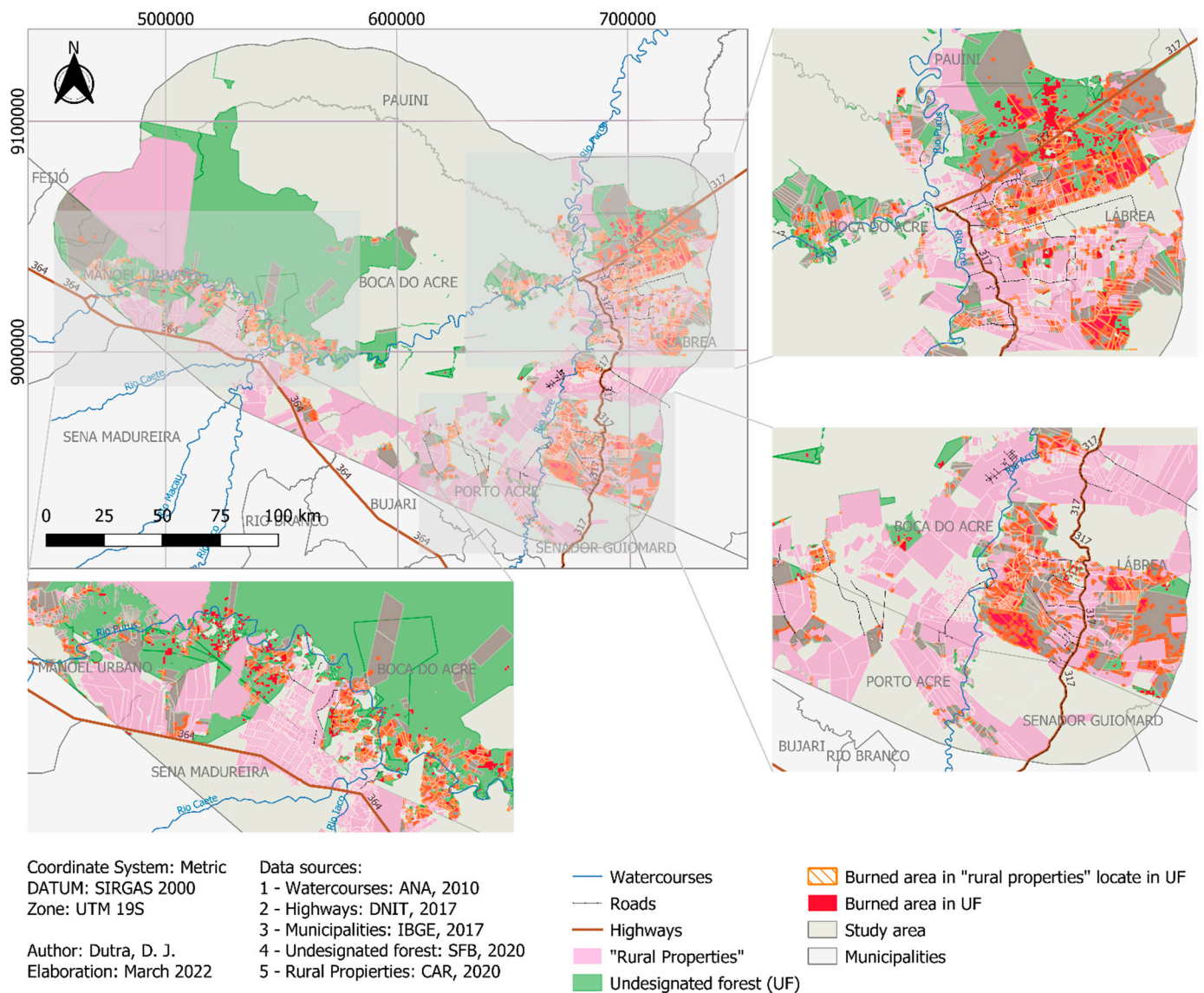


Figure S24 - The burned area in the undesignated forest for the period from 2003 to 2019. Source: Authors

4. References

1. Silva Junior, C.H.L.; Heinrich, V.H.A.; Freire, A.T.G.; Broggio, I.S.; Rosan, T.M.; Doblas, J.; Anderson, L.O.; Rousseau, G.X.; Shimabukuro, Y.E.; Silva, C.A.; et al. Benchmark Maps of 33 Years of Secondary Forest Age for Brazil. *Sci. Data* **2020**, *7*, 1–9, doi:10.1038/s41597-020-00600-4.
2. Giglio, L.; Boschetti, L.; Roy, D.P.; Humber, M.L.; Justice, C.O. The Collection 6 MODIS Burned Area Mapping Algorithm and Product. *Remote Sens. Environ.* **2018**, *217*, 72–85, doi:10.1016/j.rse.2018.08.005.
3. Long, T.; Zhang, Z.; He, G.; Jiao, W.; Tang, C.; Wu, B.; Zhang, X.; Wang, G.; Yin, R. 30m Resolution Global Annual Burned Area Mapping Based on Landsat Images and Google Earth Engine. *Remote Sens.* **2019**, *11*, 1–30, doi:10.3390/rs11050489.
4. Boschetti, L.; Roy, D.P.; Giglio, L.; Huang, H.; Zubkova, M.; Humber, M.L. Global Validation of the Collection 6 MODIS Burned Area Product. *Remote Sens. Environ.* **2019**, *235*, 111490, doi:10.1016/j.rse.2019.111490.
5. Anderson, L.O.; Cheek, D.; Aragao, L.E.; Andere, L.; Duarte, B.; Salazar, N.; Lima, A.; Duarte, V.; Arai, E. Development of a Point-Based Method for Map Validation and Confidence Interval Estimation: A Case Study of Burned Areas in Amazonia. *J. Remote Sens. GIS* **2017**, *06*, doi:10.4172/2469-4134.1000193.
6. Anderson, L.O.; Aragão, L.E.O. e C. de; Lima, A. de; Shimabukuro, Y.E. Detecção de Cicatrizes de Áreas Queimadas Baseada No Modelo Linear de Mistura Espectral e Imagens Índice de Vegetação Utilizando Dados Multitemporais Do Sensor MODIS/TERRA No Estado Do Mato Grosso, Amazônia Brasileira. *Acta Amaz.* **2005**, *35*, 445–456, doi:10.1590/S0044-59672005000400009.
7. Artés, T.; Oom, D.; de Rigo, D.; Durrant, T.H.; Maianti, P.; Libertà, G.; San-Miguel-Ayanz, J. A Global Wildfire Dataset for

-
- the Analysis of Fire Regimes and Fire Behaviour. *Sci. Data* **2019**, *6*, 296, doi:10.1038/s41597-019-0312-2.
8. Dutra, D.J.; Oighenstein, L.A.; Fearnside, P.M.; Yanai, A.M.; Graça, P.M.L.A.; Silva, R.D. da; Pessoa, A.C. de M.; Aragão, L.E.O. e C. de Comparison of Regional Scale Burned Area Products for Southwestern Brazilian Amazonia. In Submitted in Proceedings of the GEOINFO 2022; GEOINFO 2022: São José dos Campos, 2022; p. 12.