SPATIOTEMPORAL VARIATION OF FIRE OCCURRENCE IN THE STATE OF AMAZONAS, BRAZIL, BETWEEN 1999 AND 2016

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Abstract - In the state of Amazonas, the wildland fires represents a huge risk for biodiversity conservancy since more than 95% of the state is covered by the Amazonia Rainforest, one of the largest and biodiverse tropical forest of the world. This study aims to analyze the spatiotemporal variation of fire occurrence in the state of Amazonas using data from NOAA-12 and AQUA-MT satellites for the period from 1999 to 2016. Based on the results, a significant uptrend was observed in the number of hot spots recorded over the years. The months with the highest occurrence were August and September. The results from this study should be used as basis for fire prevention activities in order to reduce the wildland fire occurrence in the state of Amazonas.

Keywords - Fire prevention, fire protection, hot spots, remote sensing.

I. INTRODUCTION

Wildland fires are any non-structure fire that occurs in vegetation or natural fuels and include prescribed (controlled) burns and wildfires [1]. They can be a major threat to the preservation of biodiversity, causing impact on the fauna and flora, and contributing, indirectly, with environmental degradation [2]. Moreover, the smoke often causes respiratory complications and represents, in some locations, a public health issue [3].

The detection of wildland fires via satellite began in the 1980s [4]. Images generated by the thermal and infrared sensors installed in the satellites are sent to a control center where are processed through detection algorithms [4]-[5]. In Brazil, the Weather and Climate Studies Research Center (CPTEC) of the National Institute for Space Research (INPE) generates and provides information on active-fires occurrence based on satellite data (hot spots). Although receiving images from various satellites in operation (NOAA-15, NOAA-18, NOAA-19, METOP-B, NASA, TERRA, AQUA, NPP-Suomi, GOES-13 and MSG-3), the "reference satellite" is used to compose a time series over the years and thus enable trend analysis focused on numbers for the same periods in regions of interest. From 1999 to August 2007, INPE used the NOAA-12 as the reference satellite, and from then on, the AQUA_M-T. The data from the reference satellite allows analyzes of spatial and temporal trends, since both use the same method and the same time of day to capture the images over the years [6]-[7].

Even though the use of satellite for detecting wildland fire has the advantage of wide range and access to remote areas, technical limitations impede the detection of small wildland fires with line front width usually less than 30 meters. Additionally, some situations, such as fires that started and ended during the passage interval of the satellites; presence of dense clouds above the burning area; surface fire in vegetation with closed canopy; and fire on mountainsides while the satellite only observes the opposite side, restrict the capacity of this technology. Therefore, the number of wildland fires recorded by satellites for a given region corresponds with only a part of the total number [6]-[8]-[9]. It is important to mention that satellite imagery cannot differentiate the unmanaged and uncontrolled wildfires from the controlled burns [10].

Wildfires in the state of Amazonas represents a huge risk for biodiversity conservancy since more than 95% of the state is covered by the Amazonia Rainforest, which is one of the largest tropical forest of the world and has the highest biodiversity [11]-[12]. The exact scope of the problem is difficult to determine and can only be assessed by satellite data, since local fire statistics in many cases are incomplete or misleading. Therefore, this study aims to analyze the spatiotemporal variation of fire occurrence in the state of Amazonas using data from the reference satellites for the period from 1999 to 2016. The information obtained with this study can be used by conservation agencies for the improvement of fire prevention and suppression activities, and for the development of public policy focused on wildfire prevention and nature conservation.

II. MATERIAL AND METHODS

2.1. Characterization of the study area

Amazonas is the largest of the Brazilian states and occupies a total area of 1,559,149.074 km2, greater than the size of France, Spain, Sweden and Greece combined. It is located in the North Brazilian region, bordering the states of Pará to the east; Mato Grosso to the southeast; Rondônia and Acre to the south and southwest; Roraima to the north. Three different countries also border the state of Amazonas:

Venezuela to the north, Colombia to the northwest and Peru to the west. It is the Brazilian state with the most preserved and the least deforested portion of the Amazonia Rainforest. The climate is equatorial and classified, in most part of the state, as "Equatorial rainforest, fully humid" (Af) according to updated classification of Köppen and Geiger [13].

2.2. Obtaining hot spot data

The records of hot spots in the state of Amazonas for the period 01/01/1999 to 12/31/2016 were obtained from INPE Satellite Monitoring Burning Program, using only data from the satellites of reference (INPE, 2017). The values were quantified for the entire state and separated according the month of occurrence and the municipality in which it was detected.

2.3. Wildland fire frequency

All Amazonas municipalities were grouped according to the classification proposed by [14] into five groups that indicate the wildland fire incidence (**Table 1**).

Table1: Classification proposed by [14] indicating the frequency of hot spots detected per area using INPE reference satellites.

Category	Number of hot spots per area for a period of one year
Very Low	None or one hot spot for an area of 601 km^2 or more.
Low	One hot spot for an area between 301-600 km^2.
Average	One hot spot for an area between 151-300 km^2.
High	One hot spot for an area between 76-150 km^2.
Very High	One hot spot for an area of 75 km^2 or less.

III. RESULTS AND DISCUSSION

A total of 102,363 hot spots were detected by INPE reference satellites in the state of Amazonas between 1999 and 2016, generating an average of approximately 5.5 thousand per year. The year of 2000 presented the lowest record (852), while 2015 the highest (15,170). The annual records indicates a significant uptrend in the number of hot spots for the coming years (r^2 = 0,68; p < 0,01) (**Figure 1**).

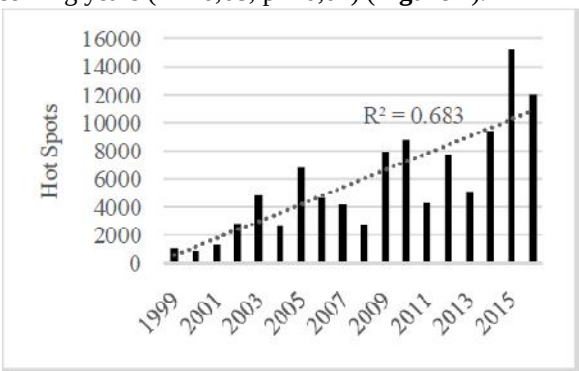


Figure 1 - Hot spots detected by INPE's reference satellites between 1999 – 2016 in the state of Amazonas, Brazil. The line indicates the linear tendency.

The month with the highest number of hot spots recorded was September, followed by August, October, November, July, December, January, February, March, June, May and April. According to the ANOVA test, the occurrence of hot spots was significantly different between the months of the year (F = 23.36, p <0.01).

The Tukey HDS test classified the months into three different groups (a, b and c) (**Figure 2**).

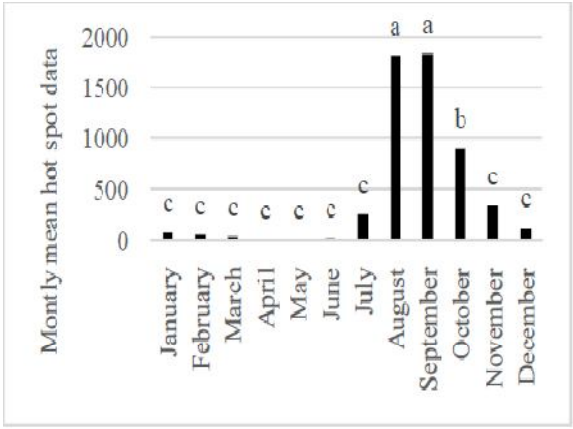


Figure 2 - Monthly mean hot spots registered by INPE's reference satellites between 1999 and 2016 in the state of Amazonas, Brazil. The months not grouped with the same letter are statically different based on the Tukey HDS test.

Hot spots were recorded in all municipalities in the state of Amazonas. The municipality with the highest incidents was Lábrea (14,602) and with the lowest (126), Amaturá. The complete list of the number of hot spots for each municipality, as well as their respective size and the hot spot density (number of hot spot per are) are described in the **Table 2**.

Although the municipality of Lábrea (9) had the largest number hot spots registered during the period evaluated, another eight municipalities, numbered from 1 to 8 (Table 1), presented a higher density.

Careiro da Várzea (1), only had 8.24% of the total number of hot spots recorded in Lábrea, however, due to its small territorial extension, the municipality was the one that, proportionally, registered the highest number of hot spots per area in the state of Amazonas. According to the classification of [14], Careiro da Várzea and another 6 municipalities, enumerated from 2 to 7, were classified as having a "Very High" incidence. The municipalities listed from 8 to 22 were classified as having a "High" incidence.

The municipalities from 23 to 31 were classified as having "Average" incidence. Those enumerated from 32 to 39 were grouped as having a "Low" incidence, and those from 40 to 62 as "Very Low" incidence (**Figure 3**).

Table 1 - List of Amazonas municipalities and their number of detected hot spots; mean annual hot spots; size; mean annual hot spot density and wildland fire frequency.

Code / Rank	Municipality	Hot spots*	Mean Annual hot spots	Size (km²)	Mean annual hot spot density (km^2)	Wildland fire frequency
1	Careiro da Várzea	1203	67	2631.1	39.37	Very High
2	Boca do Acre	8355	464	22348.9	48.15	Very High
3	Autazes	2688	149	7599.3	50.89	Very High
4	Boa Vista do Ramos	732	41	2586.8	63.61	Very High
5	Barreirinha	1540	86	5750.5	67.21	Very High
6	Parintins	1559	87	5952.3	68.72	Very High
7	Careiro	1521	85	6091.5	72.09	Very High
8	Manaquiri	864	48	3975.8	82.83	High
9	Lábrea	14602	811	68229.0	84.11	High
10	Urucurituba	602	33	2906.7	86.91	High
11	Iranduba	453	25	2215.0	88.01	High
12	Itacoatiara	1810	101	8892.0	88.43	High
13	Apuí	10714	595	54239.9	91.13	High
14	Manacapuru	1436	80	7329.2	91.87	High
15	Manicoré	8695	483	48282.5	99.95	High
16	Alvarães	1054	59	5911.8	100.96	High
17	Silves	668	37	3748.8	101.02	High
18	Canutama	5005	278	29819.6	107.24	High
19	Guajará	1356	75	8904.2	118.20	High
20	Nova Olinda do Norte	818	45	5608.5	123.42	High
21	Novo Aripuanã	5372	298	41191.3	138.02	High
22	Humaitá	4058	225	33071.7	146.70	High
23	Anamá	241	13	2453.9	183.28	Average
24	Envira	1213	67	13369.3	198.39	Average
25	Nhamundá	1268	70	14105.6	200.24	Average
26	PresidenteFigueiredo	2275	126	25422.2	201.14	Average
27	Caapiranga	838	47	9456.6	203.12	Average
28	Rio Preto da Eva	511	28	5813.2	204.77	Average
29	Maués	3413	190	39988.4	210.90	Average
30	Uarini	866	48	10246.2	212.97	Average
31	Tefé	1950	108	23704.4	218.81	Average
32	Itapiranga	248	14	4231.1	307.10	Low
33	Eirunepé	908	50	15831.6	313.84	Low
34	Manaus	607	34	11401.1	338.09	Low
35	Tabatinga	164	9	3225.1	353.97	Low
36	São Sebastião do Uatumã	515	29	10741.0	375.41	Low
37	Ipixuna	629	35	13565.9	388.21	Low
38	Anori	217	12	5795.3	480.71	Low
39	Borba	1332	74	44251.2	597.99	Low
40	Amaturá	126	7	4758.8	679.83	Very Low
41	Beruri	452	25	17251.2	687.00	Very Low
42	Coari	1472	82	57921.6	708.28	Very Low
43	Pauini	968	54	43263.4	804.48	Very Low
44	Santo Antônio do Içá	263	15	12307.8	842.36	Very Low
45	Tonantins	127	7	6432.6	911.71	Very Low
46	Carauari	501	28	25767.3	925.77	Very Low
47	Codajás	347	19	18711.6	970.63	Very Low
48	Benjamin Constant	144	8	8793.4	1099.18	Very Low
49	Fonte Boa	185	10	12110.9	1178.36	Very Low
50	Urucará	337	19	27904.9	1490.47	Very Low
51	Tapauá	1021	57	89324.3	1574.77	Very Low
52	Maraã	181	10	16910.4	1681.70	Very Low
53	Itamarati	261	15	25275.9	1743.16	Very Low
54	Barcelos	1229	68	122475.7	1793.79	Very Low
55	São Paulo de Olivença	190	11	19745.8	1870.66	Very Low

56	Novo Airão	321	18	37771.2	2118.01	Very Low
57	São Gabriel da Cachoeira	903	50	109184.9	2176.44	Very Low
58	Juruá	157	9	19400.4	2224.25	Very Low
59	Jutaí	330	18	69551.9	3793.74	Very Low
60	Santa Isabel do Rio Negro	257	14	62846.2	4401.68	Very Low
61	Japurá	127	7	55791.5	7907.45	Very Low
62	Atalaia do Norte	164	9	76355.0	8380.43	Very Low

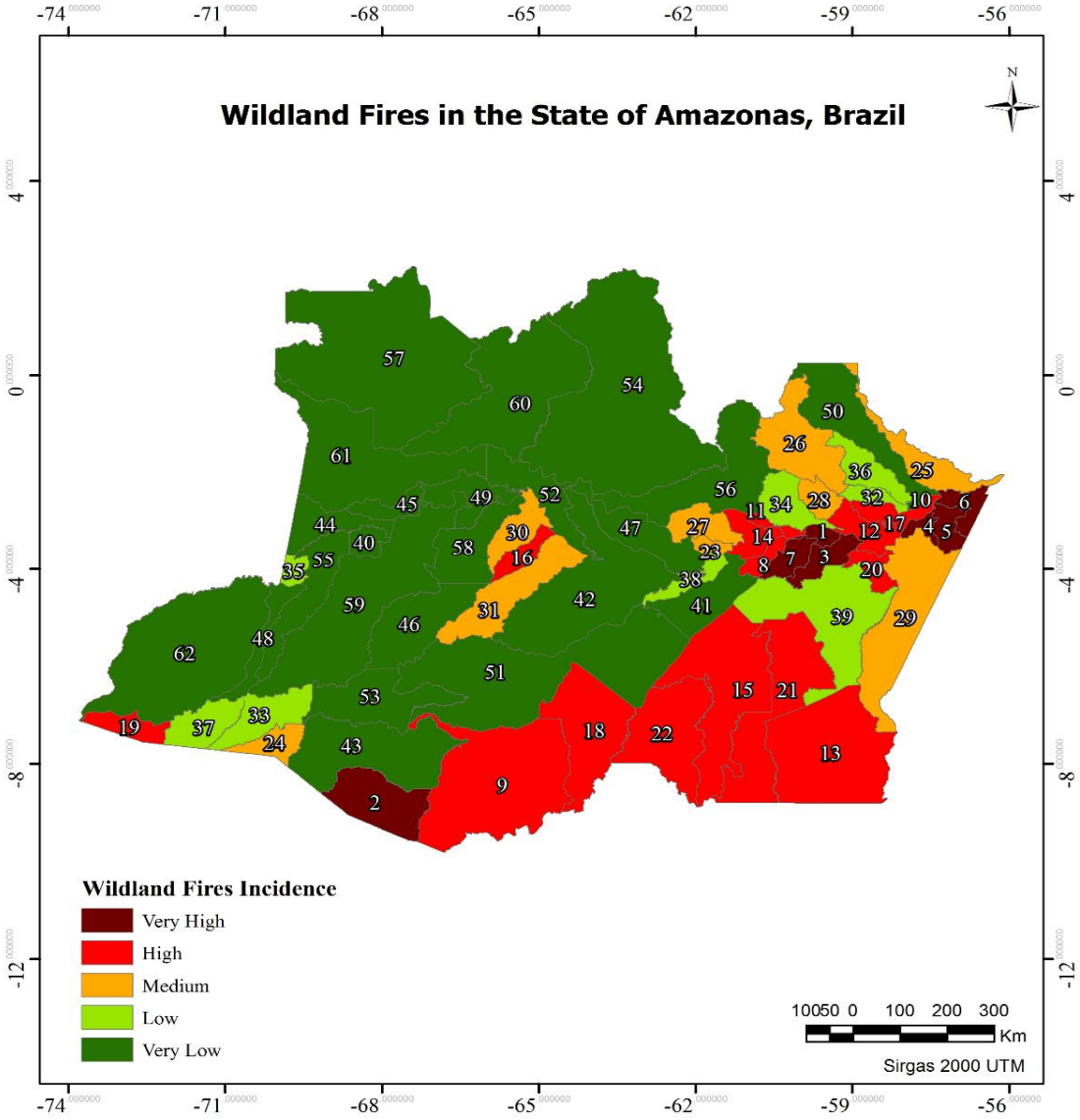


Figure 3 - Wildland fire incidence in the municipalities of the state of Amazonas based on the classification proposed by [14].

The highest hot spots recorded in the months of August and September follows the pattern observed in most of the South America continent [15]. According to [16], [2], and, [17] the period from July to November comprises the main wildland fire season in Brazil, which in most part of the country is cold and dry. However, it is important to mention that some regions of Brazil, such as the "Zona da Mata", for example, a coastal strip of the Brazilian Northeast (up to 300 km from the coast) that extends from Rio Grande do Norte to southern Bahia, differ from the national standard, presenting the main wildland fire season from January to March [14].

In Amazonas, the predominant climate is equatorial and differs in some aspects from the predominant tropical Brazilian climate. There, winter usually has high temperatures, higher than in summer, but with a very small intra-annual variation. In most of the state, the hottest months are August and September [18]. In all municipalities rainfall is very high, with an annual value rarely below 2,000 mm. However, seasonality is present and during the winter, mainly in the months

of August and September, some municipalities may present precipitation below 50 mm per month [18]. Due to low rainfall and high temperatures during this period, the fuel load becomes drier and, therefore, susceptible to burn.

The map indicating the wildland fire incidence in the municipalities of the state of Amazonas (Figure 3) can be used to estimate the future risk of wildland fire occurrence. The analysis of the spatial distribution of the hot spots during the years is one of the main variables that can be used in the mapping of the future risk of fire in vegetation [14]-[19]. The proposed map can also be used together with other thematic maps, using Geographic Information Systems (GIS), thus allowing a better interpretation of the factors responsible for the wildland fire occurrence [14]-[20]-[21].

CONCLUSIONS

The temporal analysis indicate an uptrend in the number of hot spots through the years. Therefore, it is essential the development of preventive policies and strategies to minimize the wildland fire,especially in the regions of the state that presented a higher incidence of hot spots.If nothing is done, the Amazonia Rainforest and its biodiversity will eventually be lost forever.

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