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## Forest-fire risk indices and zoning of hazardous areas in Sorocaba, São Paulo state, Brazil

Leonardo Guimarães Ziccardi <sup>1,†</sup>, Cláudio  
Roberto Thiersch <sup>2</sup>, Aurora Miho Yanai  
<sup>1</sup>, Philip Martin Fearnside <sup>1</sup> and Pedro  
José Ferreira-Filho <sup>2</sup>

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**Abstract** Forest-fire risk indices and fire-risk maps are important tools used in protected areas to guide strategies for preventing and fighting fires. This study compares the performance of three fire-risk indices for accuracy in predicting fires in semi-deciduous forest fragments, creates a fire-risk map by integrating historical fire occurrences in a probabilistic density surface using the Kernel density estimator (KDE) in the municipality (county) of Sorocaba, São Paulo state, Brazil. The logarithmic Telicyn index, Monte Alegre formula (MAF) and enhanced Monte Alegre formula (MAF+) were employed using data for the period from 1 January 2005 to 31 December 2016. Meteorological data and numbers of fire occurrences were obtained from the National Institute of Meteorology (INMET) and the Institute for Space Research (INPE), respectively. Two performance measures were calculated: Heidke skill score (SS) and success rate (SR). The MAF+ index proved to be the most accurate for the study area, with values of skill score and success rate of 0.611 and 62.8%, respectively. The fire-risk map revealed two most susceptible areas with high (63 km<sup>2</sup>) and very high (47 km<sup>2</sup>) risk of fires in the municipality of Sorocaba. Identification of the best risk index and the generation of fire-risk maps can contribute to better planning and cost reduction in preventing and fighting forest fires.

**Keywords** Monte Alegre formula · risk map · forest protection · monitoring

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<sup>1</sup> Department of Environmental Dynamics, National Institute for Research in Amazonia (INPA)  
Av. André Araújo No. 2936, Manaus, Amazonas, CEP 69067-375 Brazil.

<sup>2</sup> Department of Environmental Sciences, Federal University of São Carlos (UFSCar)  
Sorocaba, Sao Paulo, CEP 18052-780, Brazil.

† Tel.: +55-(11) 97574-5141; email: leonardo.g.ziccardi@gmail.com

## 1 Introduction

The forest fire regime is an important component in maintaining the function and structure of many terrestrial ecosystems, but it can also be considered a threat responsible for important economic and environmental impacts (e.g. economic losses in the forestry sector, degradation of land cover and changes in atmospheric composition) [13, 26]. If, on the one hand, forest fires can have a positive effect in terms of biodiversity and species richness [21, 29, 57], on the other hand can they impede hydrological processes and interfere both with the dynamic equilibrium of forests and with the carbon cycle [41, 15]. Considering the current scenario for global warming and expected increased frequency of occurrence of extreme events in the light of climate change, there is a tendency for future increase in the frequency of forest-fire outbreaks, mainly as a result of plant demographic processes that can change the growth of tree species and affect carbon sequestration by forests [9].

Monitoring meteorological parameters allows adoption of measures to reduce the potential damage of forest fires [17]. The main sources of ignition are human activities that are closely linked to the means of access to the forest, with increase in fire risk near roads in rural areas [12, 13]. Railways can also be sources of fire ignition, especially in the dry season. Sparks resulting from friction between the wheels of the train and the rails can start fires in dry vegetation, subsequently spreading to adjacent forests [27, 58].

An efficient plan to prevent and fight forest fires requires tools that include mapping areas that are most vulnerable to fire (i.e., fire-risk mapping) and the creation of forest-fire risk indices [30, 55]. A fire-risk map reveals the risk areas and facilitates the logistics for countermeasures by enabling rapid analysis of the situation for decision-making to prevent and combat forest fires [10]. Fire-risk indices show in advance the likelihood of forest-fire occurrence, and the interpretation of these values is linked to prevention plans and pre-suppression of fire [44, 55].

Several methods exist to interpolate historical ignition points and create a continuous wildfire risk map. The Kernel density estimation (KDE) is a nonparametric method that has been broadly used over the last two decades, especially after Koutsias et al. (2004), de la Riva et al. (2004) and Amatulli et al. (2007) explored how this technique is efficient to preserve a more realistic pattern of fire occurrence under broad pixel resolution [1, 22, 39], allowing appropriate forest fire-risk mapping [24].

Identifying areas of greatest fire risk makes it possible to adopt preventive measures in a timely fashion. These include construction of firebreaks, restriction of access to these locations in critical periods, reorganization of management and allocation of resources to strategic points [46, 50].

Fire-prevention plans in Brazil are mainly focused on protected areas. This is because these areas are fundamental to conserving biodiversity and maintaining ecological processes [16].

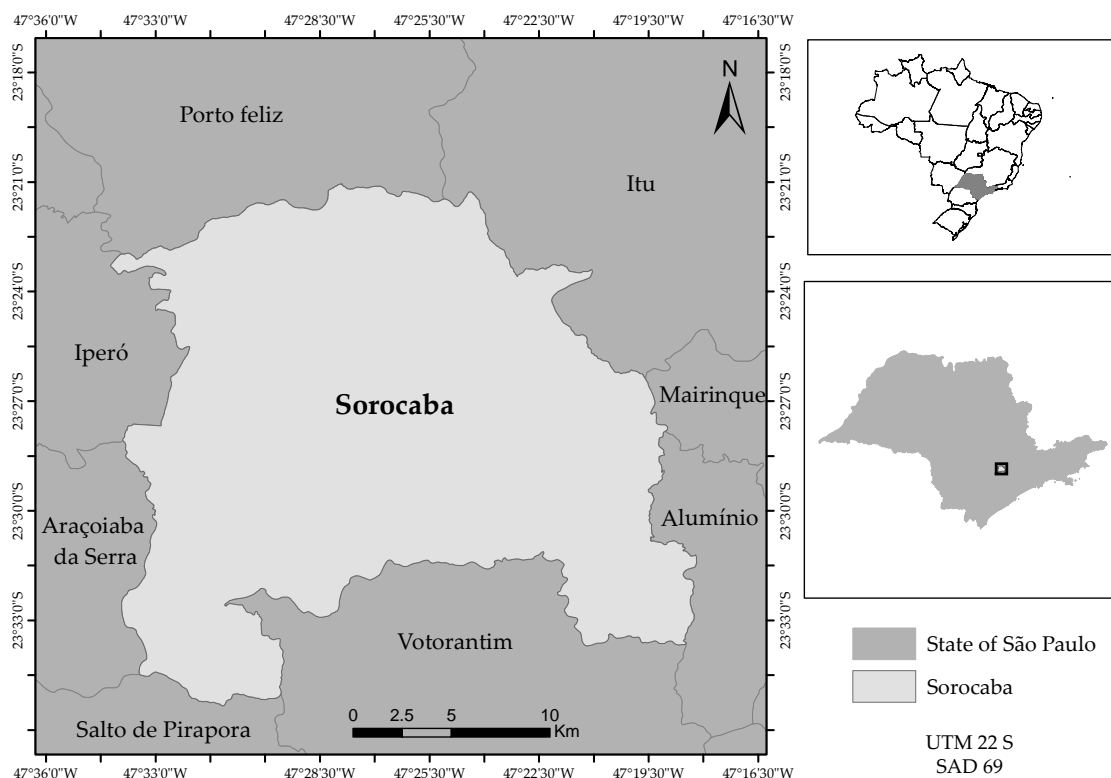
64 In addition to evaluating fire-risk indices, new models can be created to  
65 increase accuracy for the area under study. New tools can increase the efficiency  
66 of the resources allocated to protecting forests [55].

67 The objectives of the present study were to evaluate the accuracy of three  
68 fire-risk indices in semideciduous forest fragments, create a fire-risk map of  
69 the landscape in the municipality (county) of Sorocaba and determine the  
70 influence of roads and railways on the occurrence of fires.

## 71 2 Materials and Methods

### 72 2.1 Study site

73 This study was carried out in the rural portion of the municipality (county)  
74 of Sorocaba, São Paulo state, Brazil ( $47^{\circ} 31' 50''$  W to  $47^{\circ} 31'$  W and  $23^{\circ} 34'$   
75  $57''$  S to  $23^{\circ} 35' 25''$  S)(Figure 1).



**Fig. 1** Location of the municipality (county) of Sorocaba, São Paulo state, Brazil.

76 Sorocaba has 659,871 inhabitants and is one of the fastest growing cities in  
77 Brazil. Data released on July 1, 2017 as an estimate by the Brazilian Institute  
78 of Geography and Statistics (IBGE) show that, as compared to the estimate  
79 in 2016, the number of people living in Sorocaba increased by 1.13%, much  
80 more than the 0.77% growth in the country as a whole. In the last seven years,  
81 the city gained 73,246 new residents, and Sorocaba currently holds 13th place  
82 among Brazil's most populous municipalities (except for state capitals) [19].

83 The average elevation is 632 m with a maximum of 1028 m. The soil is clas-  
84 sified as red latosol (Oxisol) and vegetation is that of a transition (ecotone)  
85 between Cerrado (central Brazilian savanna) and Atlantic forest, the former  
86 being very degraded and characterized by small fragments in secondary suc-  
87 cession [14]. According to the Köppen classification, the climate is transitional  
88 Cwb (rainy and hot temperate with a moderately hot summer) to Cwa (sea-  
89 sonally dry with a warm to hot summer). Mean annual temperature is 22°C,  
90 and mean annual precipitation is 1310 mm [20].

## 91 2.2 Meteorological data and occurrence of fires

92 Daily records of average temperature (°C), relative humidity (%), wind speed  
93 ( $\text{ms}^{-1}$ ) and precipitation (mm) used for the preparation of risk indices were  
94 obtained from the INMET (National Meteorology Institute) database for the  
95 period from 1 January 2005 to 31 December 2016 (Appendix A, Figure A1).

96 The hotspots that indicate fires, with their respective dates of occurrence  
97 and locations (latitude and longitude), were obtained from the INPE (National  
98 Institute of Space Research) database of MODIS satellite (AQUA\_M-T) data  
99 with 1-km spatial resolution. Fire outbreaks were detected from the thermal  
100 signal composed of the wavelengths in the infrared range (Mid InfraRed-MIR)  
101 in a 500-m x 500-m pixel [40].

102 Occurrences were examined over the same period (1 January 2005 to 31  
103 December 2016). Fire data were deleted in the case of duplicates, and 83 days  
104 were disregarded due to absence of weather data. The result was 4300 days of  
105 observation and 69 records of forest-fire occurrence in the study area.

## 106 2.3 Fire-risk map

107 As there are no uninhabited regions in the municipality, the risk map developed  
108 for the area was based on fire hazard associated with anthropogenic factors.  
109 This was done using a continuous density map of occurrences of outbreaks in  
110 a historical series of events [30, 31]. Annual outbreaks of fires were mapped  
111 based on their respective coordinates using ArcGIS software, UTM Zone 22 S  
112 projection and Datum SAD 69 (22s).

113 The Kernel density estimator (KDE) was used to determine critical areas  
114 for fire occurrence. This non-parametric density estimator produces a proba-  
115 bilistic density surface based on local information by superimposing a grid on

116 the data for each observed event [37, 18]. This tool adjusts for inaccuracies in  
 117 the locatures of hotspots and is appropriate for manipulating spatial data at  
 118 the scale of a municipality [22, 39].

## 119 2.4 Evaluation of the performance of fire-risk indices

120 The fire-risk indices are related to daily meteorological elements (Figure A2).  
 121 They are considered to be in cumulative form, providing reliable results for  
 122 the climatic characteristics of a region [49].

123 To determine the performance of each index it was necessary to define the  
 124 limit separating presence and absence of fire risk, for which the rating scales  
 125 of the indices were categorized in binary form. The indices indicate absence of  
 126 risk when the calculated value is less than the lower limit of the medium risk  
 127 class, while the presence of risk is indicated when the values are above this  
 128 limit [36].

129 The Monte Alegre formula (MAF) is a cumulative index that uses two cli-  
 130 matic variables for which values are easy to obtain, these being the number of  
 131 days without rain (an indirect measure of precipitation) and the relative hu-  
 132 midity at 13:00 h (1:00 pm). This index was developed based on data from the  
 133 central portion of the state of Paraná [47], which is adjacent to the state of São  
 134 Paulo where the current study was carried out. Use of MAF for determining  
 135 the daily risk of forest fires is notable for being relatively easy [48].

$$MAF = \sum_{i=1}^n (100/H_i) \quad (1)$$

136 Where:

137 MAF Monte Alegre formula  
 138 n Number of consecutive days with precipitation less than 13 mm  
 139 i Day number in a sequence of rainless days  
 140 H Percentage of relative humidity measured at 13:00 h

140 The index is subject to modifications in the calculation according to the  
 141 daily precipitation, which is necessary for obtaining cumulative values (Table  
 142 B1). Estimates of the degree of danger associated with the calculated value of  
 143 MAF should be interpreted according to a scale of risk (Table B2).

144 The enhanced Monte Alegre formula (MAF+) was developed from the  
 145 inclusion of wind speed ( $\text{ms}^{-1}$ ) as a variable modifying the MAF (Equation  
 146 2). As was the case for MAF, this formula was developed for central Paraná  
 147 [35].

$$MAF+ = \sum_{i=1}^n (100/H_i) * e^{0.04*v} \quad (2)$$

148 Where:

149

MAF+	Enhanced Monte Alegre formula
n	Number of consecutive days with precipitation less than 13 mm
i	Day number in a sequence of rainless days
H	Percentage of relative humidity measured at 13:00 h
e	Base of natural logarithms (2.718282)
v	Wind speed ( $\text{ms}^{-1}$ )

Since MAF+ is also cumulative in character, this index is subject to modifications in the calculation in accord with daily precipitation (Table B3). As is the case with MAF, the estimate of the degree of danger that is associated with the calculated value of MAF+ must be interpreted according to a scale of risk (Table B4). The variable corresponding to the wind speed (such as that at 13:00 h) is considered to be non-cumulative in the equation.

The logarithmic Telicyn Index (I) was developed in the former Union of Soviet Socialist Republics [51]. The two variables included in this index are air temperature and the dew point at 13:00 h. Like other indices considered in this study, the logarithmic Telicyn Index is also calculated cumulatively up to the moment of each precipitation event, after which a new calculation cycle begins:

$$I = \sum_{i=1}^n \log(T - r) \quad (3)$$

Where:

I	Telicyn index
T	Air temperature in °C
r	Dew point temperature in °C
log	Logarithm in base 10
n	Number of days without rain
i	Day number in a sequence of rainless days

The degree of danger related to the value calculated using Equation 3 must also be interpreted according to a scale of risk, and this index has only four classes of risk (Table B5). The logarithmic Telicyn index, the Monte Alegre formula (MAF) and the enhanced Monte Alegre formula (MAF+) were employed between 1 January 2005 and 31 December 2016. The predicted values for the occurrence of fires were obtained based on the scales for the three indices, the presence of risk being represented by the "medium," "high" and "very high" risk classes and the absence of risk by the "small" and "null" classes.

Comparison of the efficiency of the models was performed with two test parameters: the Heidke skill score (SS) and the success rate (SR). These parameters are based on a contingency table with observed and predicted values for occurrence of the events [34, 35, 36] (Table 1).

**Table 1** Contingency table used to obtain the parameters that allow determination of ability to rate the skill score (SS) and success rate (SR). Adapted from [43].

Fires	Observed	Not observed	Total
Predicted	(a)	(b)	$N_2=a+b$
Not predicted	(c)	(d)	$N_4=c+d$
Total	$N_1=a+c$	$N_3=b+d$	$N=a+b+c+d$

181 Where:

182

N Total number of observations ( $N = a + b + c + d$ )

a Days on which occurrence of fires was predicted and they occurred (correct prediction)

183

b Days on which occurrence of fires was predicted and they did not occur (incorrect prediction)

c Days on which non-occurrence of fires was predicted and they occurred (incorrect prediction)

184

d Days on which non-occurrence of fires was predicted and they did not occur (correct prediction)

185

186 The following parameters were obtained from Table 1:

187

C Observed number of correct predictions (hits), where  $C = a + d$

p Probability of having at least one event per day, where  $p = N_1/N$

q Probability of exceeding the limit value of the index, in which  $q = N_2/N$

188

E Expected number of hits, where  $E = N * (1-p) * (1-q) + N * p * q$

SS Skill score, where  $SS = (C-E)/(N-E)$

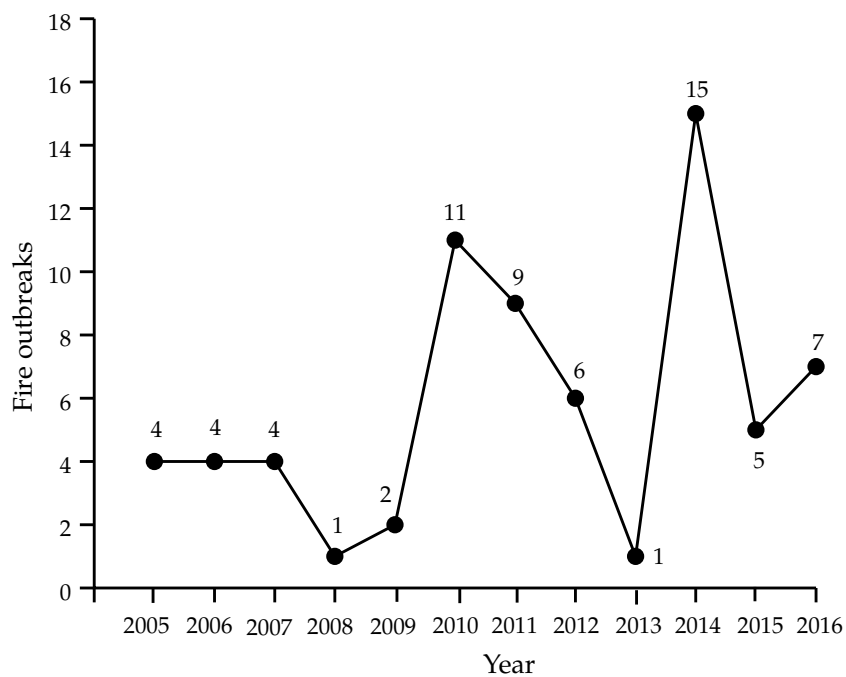
SR Success rate, where  $SR = C/N$

## 189 3 Results

### 190 3.1 Outbreaks of forest fires

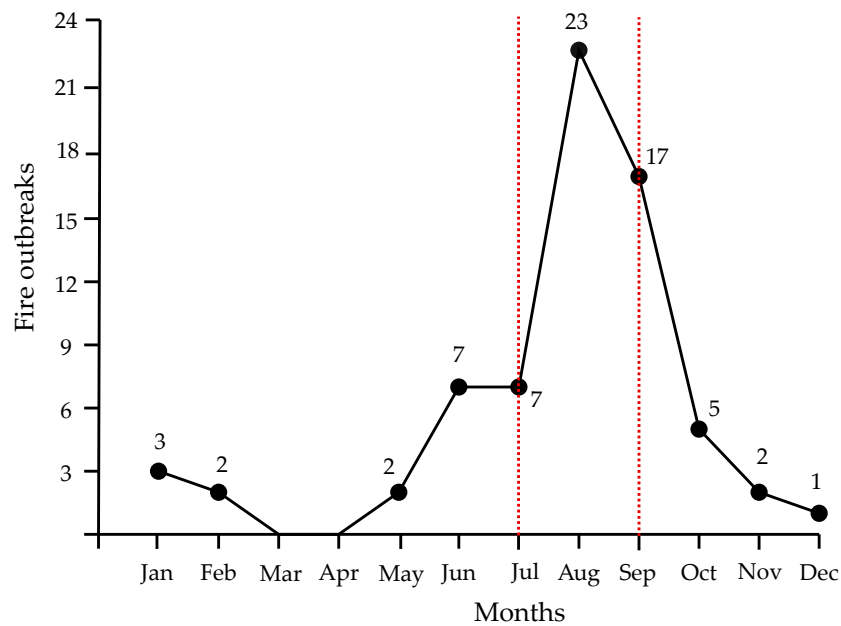
191 Of the 4300 days analyzed, 69 (1.6%) had occurrence of forest fires in the  
 192 study area. The largest number of forest-fire outbreaks (15) occurred in 2014,  
 193 while 2008 and 2013 had the fewest outbreaks (1) (Figure 2).





**Fig. 2** Yearly distribution of outbreaks of forest fires from 2005 to 2016 in the municipality of Sorocaba, São Paulo state, Brazil.

194 Considering the monthly analysis of the cumulative total of outbreaks in  
195 the study period, August was the month with the highest number (23) of fire  
196 occurrences. The three-month period with the largest number of outbreaks  
197 was July, August and September (47) (Figure 3).



**Fig. 3** Monthly distribution of outbreaks of forest fires from 2005 to 2016 in the municipality of Sorocaba, São Paulo state, Brazil. The red dashed lines represent the period with the greatest frequency of fires.

### 198 3.2 Performance of fire-risk indices

199 Performance of the indexes was quantified by the number of days from 2005  
200 to 2016 for which fires were predicted and the number of days when fires were  
201 observed. Days in the study period were segregated into different classes in  
202 accord with each forest-fire risk index (Table 2).

**Table 2** Distribution of days in fire-risk classes for each index from 2005 to 2016. Sorocaba, São Paulo, Brazil.

Index	Risk	Number of days per classes					Total
		Absent		Present			
		Null	Small	Medium	High	Very high	
MAF	Numbers of days	413	727	1124	1127	909	4300
	Percentage	9,60%	16,90%	26,10%	26,20%	21,10%	
	Total (%)	<b>26,50%</b>		<b>73,50%</b>			100%
MAF +	Numbers of days	1140	1124	718	585	733	4300
	Percentage	26,50%	26,10%	16,70%	13,60%	17,10%	
	Total (%)	<b>52,65%</b>		<b>47,35%</b>			100%
Telicyn	Numbers of days	1570	433	341	1956	x	4300
	Percentage	36,50%	10,10%	7,90%	45,50%	x	
	Total (%)	<b>46,60%</b>		<b>53,40%</b>			100%

203 The MAF showed the greatest numbers (3160 days or 73,50%) in the pres-  
 204 ence of fire-risk, considering the sum of "medium", "high" and "very high"  
 205 classes. A tendency for a greater number of days in the classes for absence of  
 206 risk was found for MAF+ (2264 days or 52.7%) as the sum of the "small" and  
 207 "null" risk classes (Table 2).

208 The Telicyn risk index lacks the "very high" risk class and showed an  
 209 intermediate number of observed days in classes that indicate the presence  
 210 of risk, with 53.4%, considering the values of the "medium" and "high" risk  
 211 classes. However, the percentage of days in low-risk classes was 46.6%, showing  
 212 possible balance between classes (as was also the case for MAF+), probably  
 213 depending on the climatic characteristics of the region.

214 Based on integration between the observed fire outbreaks and the adjusted  
 215 scales of the risk indices, the values observed for fire occurrences were recorded  
 216 in a contingency table. This was used to calculate skill score (SS) and success  
 217 rate (SR) (Table 3).

**Table 3** Number of days predicted by the indices for forest-fire occurrence and observed outbreaks in satellite data from 2005 to 2016 in the municipality of Sorocaba, São Paulo state, Brazil.

Risk index		Days observed	Days not observed	Total
MAF	Predicted	66	3063	3129
	Not predicted	3	1168	1171
	Total	69	4231	4300
MAF+	Predicted	53	1604	1657
	Not predicted	16	2627	2643
	Total	69	4231	4300
Telicyn	Predicted	64	2209	2273
	Not predicted	5	2022	2027
	Total	69	4231	4300

218 For calculation of SR, the days with hits or misses were quantified for each  
 219 index. Hits were either days when occurrence of fire was predicted and one or

220 more outbreaks occurred or days when fire occurrence as not predicted and  
 221 no outbreak occurred.

222 The SR result obtained by MAF+ (62.8%) was higher when compared to  
 223 the other indices, with a SR value of 48.5% for the logarithmic Telicyn index  
 224 and 28.7% for MAF (Table 4). The SS values (Table 4) mirror the results  
 225 for SR, with MAF+ achieving the highest value (0.611), followed by Telicyn  
 226 (0.468) and MAF (0.264).

**Table 4** . Skill score (SS) and success rate (SR) values from 2005 to 2016 for fire-risk indices in the municipality of Sorocaba, São Paulo state, Brazil.

Risk index	SS	SR
MAF	0.264	28.70%
MAF+	0.611	62.80%
Telicyn	0.468	48.50%

### 227 3.3 Fire-risk map

228 The risk map drawn from the smoothed density of fire outbreaks in the study  
 229 period (2005 to 2016) identifies areas favorable for forest fires (Figure 4). The  
 230 values generated by the algorithms for calculating Kernel density were cate-  
 231 gorized into five classes for classifying risk levels. Interpretation of risk levels  
 232 (very low, low, moderate, high and very high) is a key step in delimitating  
 233 areas that are most vulnerable to fire as part of a prevention plan [13].

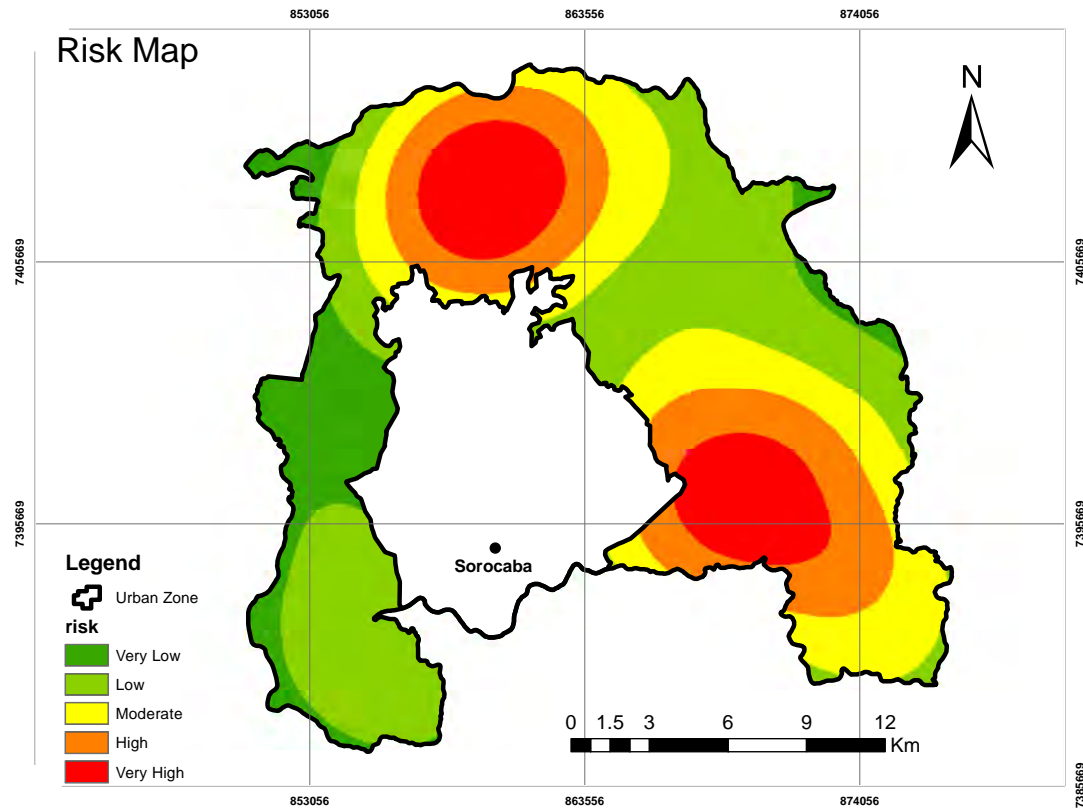


Fig. 4 Fire-risk map for the municipality of Sorocaba, São Paulo state, Brazil.

#### 234 4 Discussion

235 Many forest-fire risk indices derived from daily meteorological variables have  
 236 been created around the world based on the assumption that climate-related  
 237 variables are the most important in determining fire risk [56]. The most fre-  
 238 quently cited fire-risk indices in the literature are the Russian Nesterov Index  
 239 [32], the Russian Logarithmic Index of Telicyn [51], the U.S. National Fire  
 240 Danger Rating System [11], the Swedish Angstrom index [7], the Canadian  
 241 Forest Fire Danger Rating System (CFFDRS) [52] and the Argentine index of  
 242 Rodriguez and Moretti [42].

243 In Brazil, FMA [47] is the index that is most used by forestry and envi-  
 244 ronment protection companies [54]. However, some studies have revealed that  
 245 this is not the most suitable index for certain Brazilian regions, especially the  
 246 north [45], northeast [54], mid-west [31] and even the southeast region [25],  
 247 which is close to where the index was created. This is because most of the

248 forest fire hazard indices based on empirical models are suitable only for local  
249 application because of the specific vegetation and climate from where they  
250 were developed [53].

251 The SS value obtained for MAF+ in the present study (0.611) was higher  
252 than the values found by Nunes [33] for the same index in Paraná for the  
253 period from 1998 to 2003 in the municipalities of Cambará, Telêmaco Borba,  
254 Guarapuava, Pinhais, Campo Mourão, Cascavel and Londrina (0.088, 0.117,  
255 0.133, 0.283, 0.302, 0.334 and 0.338, respectively). The SR values we found for  
256 MAF (28.7%) and Telicyn (48.5%) in Sorocaba were below that for Guara-  
257 puava, which had the smallest value (49.3%) of the 13 municipalities evaluated  
258 by Nunes [33] in the state of Paraná.

259 Much of the rural area of Sorocaba is under eucalyptus plantations, and  
260 the area of these plantations rose from 233,406 ha in 2002 [23] to 323,478  
261 ha in 2008 [5], an increase of 38.6% over this relatively short period. These  
262 areas have high risk of fires because, in addition to the availability of wood, a  
263 blanket of combustible material is offered by a continuous deposition of leaves  
264 and twigs on the soil surface [4]. Generally, the boundaries between zones of  
265 high and low risk of fires are consistent with the limits between continuous  
266 and fragmented forest [38].

267 Compared to the other indices, MAF+ showed the best performance in  
268 tests of SS and SR, as has also been reported for the period from 2003 to  
269 2006 in predicting outbreaks of fire in areas with eucalyptus cultivation in the  
270 northern portion of the state of Espírito Santo, Brazil, with values of 0.18 for  
271 SR and 53.5%, for SS [4].

272 MAF+ includes wind speed as a variable, which differs from the original  
273 formula (MAF). With inclusion of this variable, MAF+ reflects, in addition  
274 to the probability of ignition, the potential for fires to spread [35].

275 The forest-fire risk map revealed two areas with the highest occurrences  
276 of outbreaks, the northwest and southeast portions of the study area. Of the  
277 entire area of the municipality of Sorocaba (343.1 km<sup>2</sup>), 13.7% was classified  
278 as "very high risk" (47 km<sup>2</sup>) and 18.5% was classified as "high risk" (63 km<sup>2</sup>).

279 The northwestern portion of the municipality has eucalyptus plantations  
280 and lies next to the Ipanema National Forest; the northwest portion of the  
281 municipality also has a large number of roads. The high productivity of com-  
282 mercial plantations in these areas leads to a high concentration of biomass,  
283 which raises the risk of forest fires [6].

284 In the southeastern portion of the municipality, the large number of out-  
285 breaks recorded can be linked, in part, to the stretch of railway in association  
286 with a green area. Presence of the railway may therefore facilitate ignition  
287 and increase the risk of fires in adjacent vegetation in association with wind  
288 patterns [8].

289 The spatial statistical analysis of weights of evidence is able to capture the  
290 effect of distances of roads and railroads on fire outbreaks. It is a probabilistic  
291 method based on a Bayesian approach in log-linear form and is applicable  
292 when sufficient data are available to estimate the relative influence of different  
293 scenarios for the factors considered in the analysis [3]. However, the low spatial

294 resolution of MODIS does not allow discussion of distances of less than 1 km,  
295 making this analysis unfeasible for this data set.

296 One suggestion for future studies aiming to use this analysis is to obtain  
297 the hotspots that indicate fire through the LANDSAT 8 thermal band. The  
298 spatial resolution of this reference satellite is 30 m (i.e., with much more spatial  
299 detail than MODIS), but the temporal resolution is 16 days, leading to the  
300 omission of many fire outbreaks.

301 The scenario for fire in a given location is linked to the socio-economic,  
302 political and environmental context of the region. There is a strong connection  
303 between the fire regime and territorial dynamics at different temporal scales  
304 [28]. Recent studies also point to the existence of a relationship between the  
305 type of vegetation and the frequency and intensity of forest fires in any given  
306 location [2].

307 Because fire-prevention planning requires monitoring of where and when  
308 a fire is likely to occur [24], the forest-fire risk map and fire-risk indices are  
309 two objective tools that should be used together for efficient pre-fire planning.  
310 While the fire-risk map helps managers in planning fire prevention strategies  
311 for showing the most fire-susceptible areas (based on historical fire occur-  
312 rences), the indices indicate which days are most likely to the occurrence of  
313 forest fires (based on daily meteorological factors). Determining the best in-  
314 dex for application in municipalities that do not have an index specific to their  
315 location is fundamental for planning forest-fire prevention.

316 MAF+ had the best result among the indices examined in this study.  
317 However, Brazil is a country with a wide diversity of climates, which is reflected  
318 in the different results of the various indices of forest-fire risk in different  
319 regions of the country.

## 320 5 Conclusions

321 Depending on climatic patterns in the region under study, one risk index may  
322 be more suitable than another for the prediction of fire events. The MAF+  
323 index had the best performance in the municipality of Sorocaba, with a skill  
324 score (SS) value of 0.611 and a success rate (SR) of 62.3%. This indicates that  
325 wind speed is an important variable and should be considered for determining  
326 the degree of fire hazard in this region.

327 By developing a risk map, it was possible to identify the areas that are  
328 favorable for occurrence of forest fires. These areas are mainly in the north-  
329 western and southeastern portions of the municipality. The risk of forest fires  
330 in Sorocaba is associated with local climatic conditions, with the network of  
331 roads and with the railway that crosses the municipality.

332  
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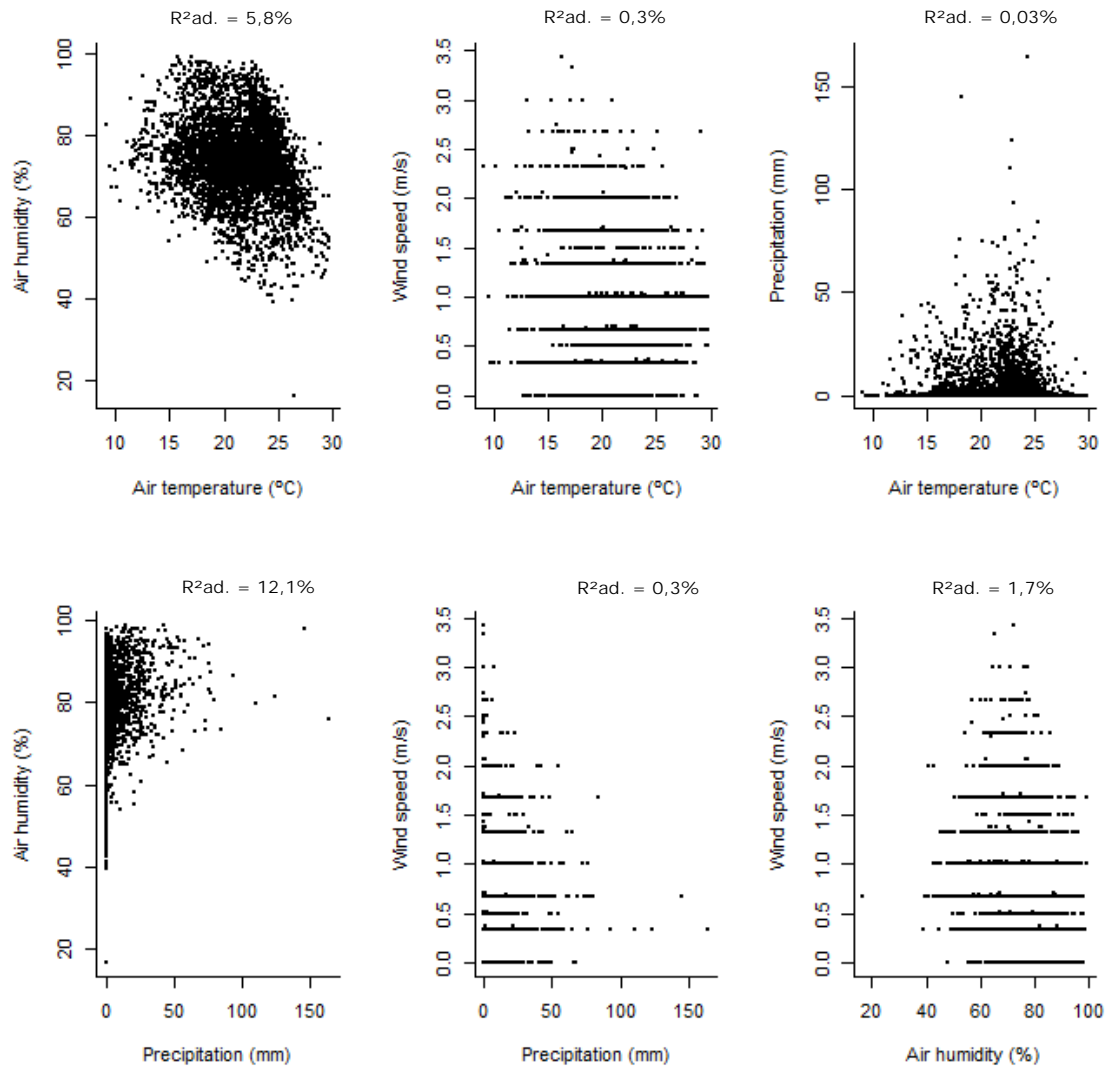


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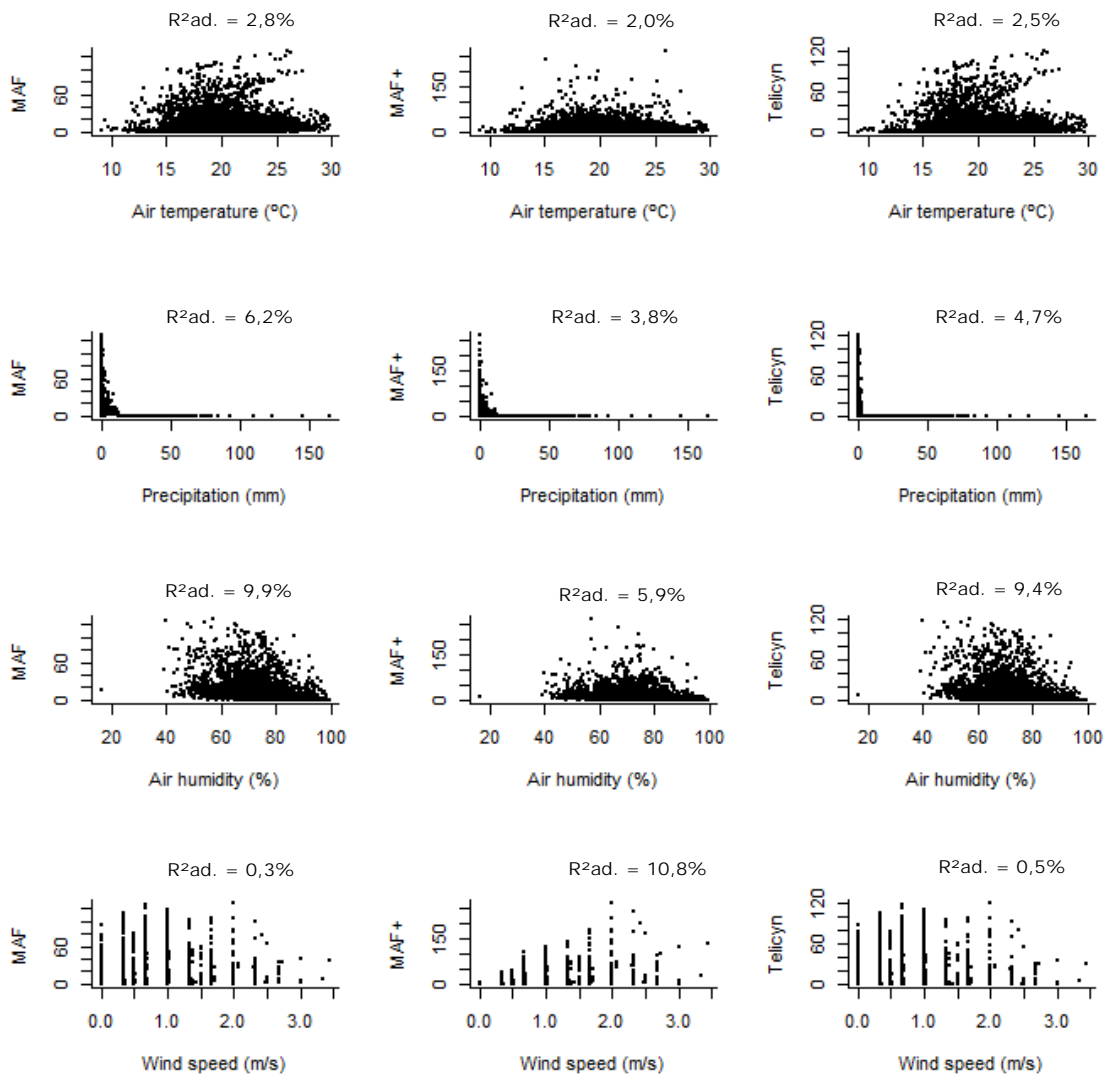
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546 **A Appendix**547 **A.1**

**Fig. 5** Relationships between environmental variables, where  $R^2_{ad.}$  is the adjusted R-squared. Data are from Brazil's National Institute of Meteorology (INMET).

548 A.2



**Fig. 6** Relationships between environmental variables and fire indices, where  $R^2_{ad.}$  is the adjusted R-squared.

549 **B Appendix**550 **B.1****Table 5** Modification of calculation of the MAF on the basis of daily precipitation.

Daily precipitation (mm)	Change in calculation
$\leq 2.4$	None
2.5 to 4.9	30% reduction in the MAF calculated for the previous day and sum of (100/H) for the day
5.0 to 9.9	60% reduction of the MAF calculated for the previous day and sum of (100/H) for the day
10.0 to 12.9	80% reduction of the MAF calculated for the previous and sum of (100/H) for the day
$> 12.9$	Calculation interrupted (MAF = 0) and summing resumed the following day

551 **B.2****Table 6** Scale of risk classes associated with the calculated values of MAF.

Calculated value of MAF	Forest-fire risk
$\leq 1.0$	Null
1.1 to 3.0	Small
3.1 to 8.0	Medium
8.1 to 20.0	High
$> 20.0$	Very high

552 **B.3****Table 7** Modification of calculation of MAF+ as a function of daily precipitation.

Daily precipitation (mm)	Change in calculation
$\leq 2.4$	None
2.5 to 4.9	30% reduction in the MAF calculated for the previous day and sum of (100/H) for the day
5.0 to 9.9	60% reduction of the MAF calculated for the previous day and sum of (100/H) for the day
10.0 to 12.9	80% reduction of the MAF calculated for the previous and sum of (100/H) for the day
$> 12.9$	Calculation interrupted (MAF = 0) and summing resumed the following day

553 B.4

**Table 8** Scale of risk classes associated with the calculated values of MAF+.

Calculated value of MAF	Forest-fire risk
$\leq 3.0$	Null
3.1 to 8.0	Small
8.1 to 14.0	Medium
14.1 to 24.0	High
$> 24.0$	Very high

554 B.5

**Table 9** Scale of risk classes associated with the calculated values of Telicyn.

Calculated value of Telicyn	Forest-fire risk
$\leq 2.0$	Null
2.1 to 3.5	Small
3.6 to 5.0	Medium
$> 5.0$	High