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Analysis of the relationship between the weather index of fire danger and occurrences of rural fires. Case study: centro region of portugal

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Abstract. The aim of this study was to design an approach for establishing a plausible relationship between FWI and the monthly average burned area (ABA) and the average number of ignitions (ANI) supported by geographic information systems (GIS). The application of these results will allow the projection of burned areas in forest fires in the future, making mitigation actions possible. This approach was applied to the region of Central Portugal, and to achieve the aims of the study, the following steps were completed: (1) geoprocessing the spatial data of the daily FWI indices, burned area and number of fire ignitions and (2) developing statistical regression models capable of reproducing the variability in burned area and ignition occurrence series from FWI data during the 2001–2017 period. The predicted equations for the burned area as a function of the FWI presented high coefficients of determination for most of the considered periods, thus allowing the projection, with a high degree of confidence, of the monthly burned area values according to the various future climate scenarios. The prediction of the average number of ignitions from the FWI values class proved to be effective for establishing highly adjusted forecast models for July and August. In the spatial analysis at the district level, the ABA and ANI estimation equations were obtained from the FWI values with determination coefficients above 0.90 for most of the districts. Significant differences were observed between the districts in the number of ignitions analysed.

Key words: burned area, climate, fire occurrence, FWI system, wildfires.

INTRODUCTION

Wildfires are one of the major natural hazards in various regions of the globe, such as the USA, Australia, and the Euro-Mediterranean region, and have devastating impacts on the economy, environment, public health and through the loss of life. In the Mediterranean region, wildfires are frequent, especially in the summer months, and have a significant impact on the landscape, vegetation, soil and air quality (Singh, 2016; Franco et al., 2018; Kala, 2023). The existing knowledge about wildfires on the Portuguese mainland suggests, through analysis that human activity (negligence or crime) is the cause of the fires, which are triggered in conditions of meteorological severity, in a spatial context of land abandonment in a significant part of the territory (Syphard & Keeley, 2015; Curt et al., 2016; Pereira et al., 2017; Kolanek et al., 2021).

Portugal is one of the Euro-Mediterranean countries with the largest burned area. During the study period from 2001–2017, the average value of the total burned area of the Portuguese mainland as a percentage of the total area burned in the five countries considered in the Euro-Mediterranean region (Portugal, Spain, France, Italy and Greece) was 36%, with several years (2003, 2005, 2010, 2013 and 2017) exceeding 50% (European Forest Fire Information System reports, 2001 to 2017).The mainland of Portugal is located on the Iberian Peninsula in the extreme southwest of continental Europe and has a total area of 89,102.51 km^2 (INE, 2023). It is subdivided into five NUTS II (Nomenclature of Territorial Units for Statistics): North (23.8% of the area), Centre (31.6%), Lisbon (3.6%), Alentejo (35.4%), and Algarve (5.6%). The interaction of biophysical and social factors influences fire activity or fire regimes (Bowman et al., 2011; Whitman et al., 2015; Syphard et al., 2018), so it is relevant the regional scale context to better understand the link between fire activity and climate or weather conditions (Fernandes. 2019).

Despite the investments made in firefighting resources, the mean values of the burned areas have increased in Portugal since 1980 due to the combined effects of climate and land use changes (Amatulli et al., 2013; Tonini et al., 2017; Bento-Gonçalves et al., 2018; Parente et al., 2022). This lack of viability in the primary sector in large areas of the territory has led to demographic changes in recent decades through the migration of the young rural population to urban areas. Vast areas of the northern interior and centre of Portugal were depopulated, leaving behind an aged population and abandoned agricultural and forest areas (Ganteaume et al., 2013; Nunes et al., 2016; Meneses et al., 2018).

The total burned area and the number of fire events showed high inter-annual variability that was linked to weather conditions, mainly in the spring and summer season. The favourable weather conditions for wildfires, in the Portugal mainland, are mainly related to the synoptic situations with E or NE circulation over Portugal (DaCamara & Trigo, 2018), which are characterised by very high temperatures and very low relative humidity. The occurrence of extreme weather (e.g., heat waves) and drought climate events accentuate the seasonal nature of the fire incidence in the Portuguese mainland (Parente et al., 2018).

Meteorological variables alone or in combination with vegetation and topographic data are frequently used to develop fire risk indices (Viegas & Viegas, 1994). The Canadian Fire Weather Index System, FWI, (Van Wagner, 1987) is one of the most widely used in different parts of the globe and describe how easily a fire will ignite and spread, and how difficult its control will be. In Europe, the FWI is the wildfire forecasting tool chosen by the European Forest Fire Information System (EFFIS), and it has been widely distributed and used. Comparison studies of several wildfire risk indices in southern European regions indicate that FWI performs well, especially in summer conditions (Viegas & Viegas, 1994). The Canadian Fire Hazard System (FWI) has been calibrated for application to Portugal (Viegas et al., 1999). For the use of wildfire risk indices, accurate knowledge of the consequences of the climate on fire risk is important. In the Portuguese mainland, between late spring and early autumn, the weather is generally hot and dry, and there are frequent droughts and conditions favourable to large areas of wildfires. The mean area of burned forest has a negative relationship with late spring and summer rainfall; on the contrary, winter and early spring precipitation contribute to the development of new vegetation that will increase the fine fuel load available in the summer, thus increasing the fire risk (Viegas & Viegas, 1994).

Seasonal forecasting of the wildfire risk index and forecasting associated with climate change are fundamental for the prevention and management of the methods and strategies to combat wildfires. The estimation of the area burned from the FWI values has been the subject of research of many authors (Jain et al., 2022; Grillakis et al., 2022; Yu et al., 2023). Studies evaluating the FWI index show that large burned areas or a high number of fire events usually occur at high values of the FWI index (Viegas & Viegas 1994; Viegas et al., 1999; Carvalho et al., 2010; Dimitrakopoulos et al., 2011). The results obtained from statistical studies using data from the FWI wildfire hazard index and the burned areas (or number of events) are essential for the trends prediction of these natural hazards in the future and for the mitigation of the negative impacts.

Currently, it is possible to forecast, using climate model results, the trend values of the FWI for an extended period in the future, for a given region. Nevertheless, to forecast burned area or number of forest fires in the future, considering a negligible variation of vegetation characteristics, it is necessary to understand how the changes in weather conditions, translated by the risk index FWI and its sub-indexes, might affect them. In the study of the influence of climate change on the burned areas prediction, a monthly analysis is usually used (Pereira et al., 2013; Kalabokidis et al., 2015; Lehtonen et al., 2016). The estimation of the area burned from the FWI values has been the subject of research of many authors (Flannigan et al., 2005; Tymstra et al., 2007; Ager et al., 2014). However, the influence of FWI on the number of ignitions is usually analysed by determining the fire occurrence probability (Pinto et al., 2020) or by using the FWI percentile class (De Jong et al., 2016). Several studies show that the analysis of meteorological data and burned area can help to identify regions with similar fire regime using burned area tendency (Silva et al., 2019; Artés et al., 2019; Shi & Touge, 2022), or fire activity and fire weather risk (Bedia et al., 2015; Jiménez-Ruano et al., 2019; Richardson et al., 2022).

The aim of this study is to design an approach for establishing a plausible relationship between FWI and the monthly average burned area (ABA) and the average number of ignitions (ANI), supported by geographic information systems (GIS), for the Centre Region of Portugal. The application of these results will allow the projection of burned areas in the future, making mitigation actions possible.

STUDY AREA

The study area is the Centre Region of Portugal (CRP) that contain approximately 50% of the burned area in Portugal's mainland during the 2001–2017 period. The Central Region of Portugal (CRP) is a very heterogeneous territory, with a different social and cultural population, concentrated mainly on the coast, and different economic and environmental characteristics, encompassing eight districts (Fig. 1). The Castelo Branco, Guarda, and Viseu districts, which belong to this Central region, have the highest percentage of days with fires over 1,000 ha (Fernandes 2019). The urban network and settlement model of the CRP are strongly determined by the morphological characteristics of the territory, which is crossed in the northeast-southwest direction by the Central Mountain Range and cut by numerous streams (Fig. 1).

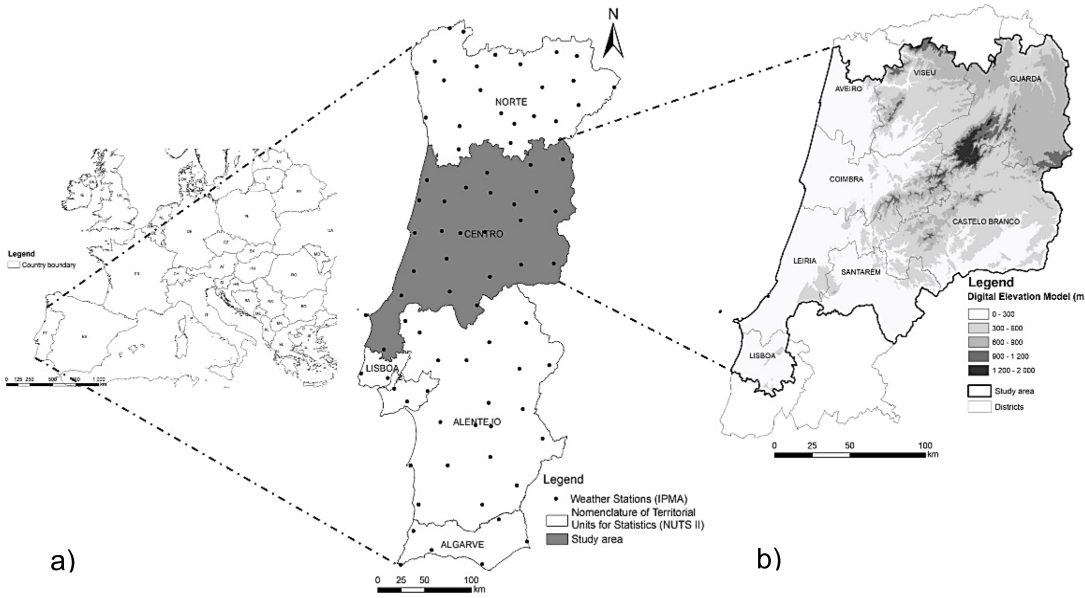

Figure 1. Central Region of Portugal (CRP).

The CRP is a region with about 46.7% of its territory covered with forests, with its area slightly increasing in the period from 1980 to 2010 (Alves et al., 2022). This trend was accompanied by a decrease in cultivated area and an increase in uncultivated areas. The forest areas in this period changed significantly, with a reduction of 8.5% in the area of the stands of soft wood species and an increase in the area of eucalyptus. This substitution was made because eucalyptus has a growth period (10 to 12 years) much shorter than that of maritime pine (40–45 years), reducing the probability of loss of yield from the recurrent fire cycle.

The region under study, CRP, is characterised by a temperate climate, with Atlantic influence on the west (coast), with rainy winters, and hot and dry summers (Köppen classification Csb), and with more continental influence, with very dry and very hot summers (Csa Köppen classification) in the east. These two subregions are separated by the ‘Montejunto Estrela’ mountain range. In the coastal sub-region, the average maximum temperature (1971–2000) in August, the hottest month, is below 30 °C, with a narrow range with an average maximum temperature between 20 and 25 °C, and a small altitude area (Serra da Estrela) with values between 17° and 20 °C. In the eastern interior sub-region, the average maximum temperature reaches values above 30 °C.

MATERIALS AND METHODS

This work was supported on meteorological stations observations and data available in ICNF database. The number of years (2001–2017) corresponded to the coexistence of data in both databases The spatial data of burned areas (vector format) and the ignitions database (date, duration, location) were produced by Nature Conservation and Forestry Institute (ICNF), the Portuguese Government Forestry.

The FWI was calculated based on the meteorological variables in 12 UTC (Coordinated Universal Time), which were obtained at 74 weather stations of the national meteorological network from Portuguese Institute for Sea and Atmosphere (IPMA) on the Portuguese mainland. The same weather stations were used for the entire period of this study, from 2001–2017. The meteorological input parameters for the calculation of the three intermediate indices of the index, which are the sub-indices related to the moisture content of different types of forest fuel, are air temperature, relative air humidity, wind intensity and the past 24 hours of rainfall. The three fuel moisture codes were each calculated with a daily step using the value from the previous day. These fuel moisture codes were used as inputs for two other sub-indices and finally to the FWI. The FWI system that was used is based on the 1985 formulation (Van Wagner & Pickett, 1985), which includes a day length correction value. Therefore, special attention was given to the critical period, set between the 1st of June and the 31st of October.

Spatial interpolation is a method for determining the values of properties areas without observations within areas covered by observations networks and is a common tool used in the study of meteorological variables. The spatial interpolation of daily FWI was performed by geostatistical methods using the Geostatistical Analyst extension of ArcGIS. This spatial interpolation is classified as a stochastic and local method (Li & Heap, 2014). The data set contains two variables of interest (FWI and altitude) and has a spatial correlation as expressed in the cross-variogram. The cokriging method has the advantage of the information being embedded in the cross-correlation of a second variable (covariable) to minimise the variance of the error estimation (Isaaks & Srivastava, 1989; Oliver & Webster, 2015). Cokriging is a multivariate variant of the ordinary kriging method.

The daily FWI maps were predicted by ordinary cokriging (exponential) using the calculated FWI as the first variable and the meteorological station altitude as the second variable (covariable). The suitable spatial resolution or horizontal cell size plays an essential role in spatial data quality, and thus, a resolution (2,650 m × 2,650 m) based on the point density of the input data was used for output raster maps (Hengl, 2006). The performance of the Geostatistical Analyst predictions was compared by two criteria: root mean square error (RMSE) and percentage bias (PBIAS).

Nevertheless, in the next step, the FWI daily maps of the Portuguese mainland were aggregated into average monthly and maximum monthly FWI maps. Thus, this process allowed us to create two FWI maps (average and maximum) for the period from the 1st of June to the 31st of October, in the years 2001–2017 and then to extract the average and maximum values of all raster cells in the zones defined as districts.

In critical period, the relationship between FWI and the incidence of wildfires or burned areas at the regional level was assessed by statistical regression models, according to the following four classes: (i) regional average of the average monthly FWI (FWI1); (ii) regional maximum of the average monthly FWI (FWI2); (iii) regional average of the maximum monthly FWI (FWI3); and (iv) regional maximum of the maximum monthly FWI (FWI4).

According to several authors, the FWI class approach offers an objective and quantitative index of the fire potential without considering the variation in fuel conditions and the terrain surface (Fernandes, 2019). In order to have a fixed scale of inter-months comparison, it was considered that the data organisation in classes is advantageous than the percentiles. The FWI classes created in this work differ from those suggested by EFFIS because daily FWI values exceeding 50 (extreme risk class) were observed in the entire area under study during several days. Thus, to visualise the index variation gradient, FWI classes with an amplitude of five values up to a maximum value of 95 were used. The regression equations were performed taking the central value of the considered FWI class.

The influence of the meteorological hazard index on the ABA and ANI values was performed for the critical period of fires in Portugal (June to October) and individually for each month of that period: June, July, August, September and October. The national civil protection system is organized in Portugal through district command of protection and rescue (CDOS). Thus, in order to provide technical information according to the level of organization of the civil protection system, the influence of the FWI on the district ABA and district ANI was also analyzed.

RESULTS AND DISCUSSION

The inter-annual variation of fire ignitions is very high (Fig. 2) and is associated with the sharp variations in annual climatic conditions. In the period under review, the burned area in the CRP ranged from a minimum of 7,481 hectares (2008) to a maximum of 473,312 hectares (2017), with an annual average of 77,190 hectares.

The inter-annual variation of the burned area in the central region follows the same trend as that for the Portuguese mainland, showing the highest values of burned area in the years 2003, 2005 and 2017. The number of ignitions in both the central region and in the Portuguese mainland is very high when compared to the countries with similar soil and climatic conditions (San-Miguel-Ayanz et al., 2019). Between 2001 and 2017, 144,498 ignitions occurred in CRP, representing approximately 32.3% of the total ignitions recorded in the Portuguese mainland.

In the period under study, the number of annual ignitions varies between a minimum of 3,930 ignitions observed in 2016 and a maximum number of 12,874 ignitions recorded in 2005. The number of annual ignitions, although showing a great inter-annual variation, presents a decreasing trend, especially from 2013, possibly as a result of awareness campaigns.

The number of ignitions in both the central region and in the Portuguese mainland as a whole is very high when compared to countries with similar soil and climatic conditions. Between 2001 and 2017, a total of 144,498 ignitions occurred in CRP, representing approximately 32.3% of the total ignitions recorded in the Portuguese mainland (447,232 ignitions). In the analysed period, the ignition density was 19.7 ignitions per 100 km^2 for the study area and 23.0 ignitions per 100 km^2 for the national territory. The number of ignitions decreased over the analysed period. Between 2001 and 2006, the average number of annual ignitions in the central region was 8,706 ignitions per year (24 ignitions per 100 km^2); between 2007 and 2012, this value decreased slightly to 7,916 ignitions per year (21 ignitions per 100 km^2), decreasing substantially from 2013 to 2017 to 4,802 ignitions per year (13 ignitions per 100 km^2). In the Portuguese mainland, the average annual number of ignitions for the period 2001 – 2006 was 26,363 ignitions per year (29 ignitions per 100 km^2); between 2007 and 2012, this value dropped to 21,635 ignitions per year (23 ignitions per 100 km^2) and decreased substantially from 2013 to 2017 to 14,578 ignitions per year (16 ignitions per 100 km^2).

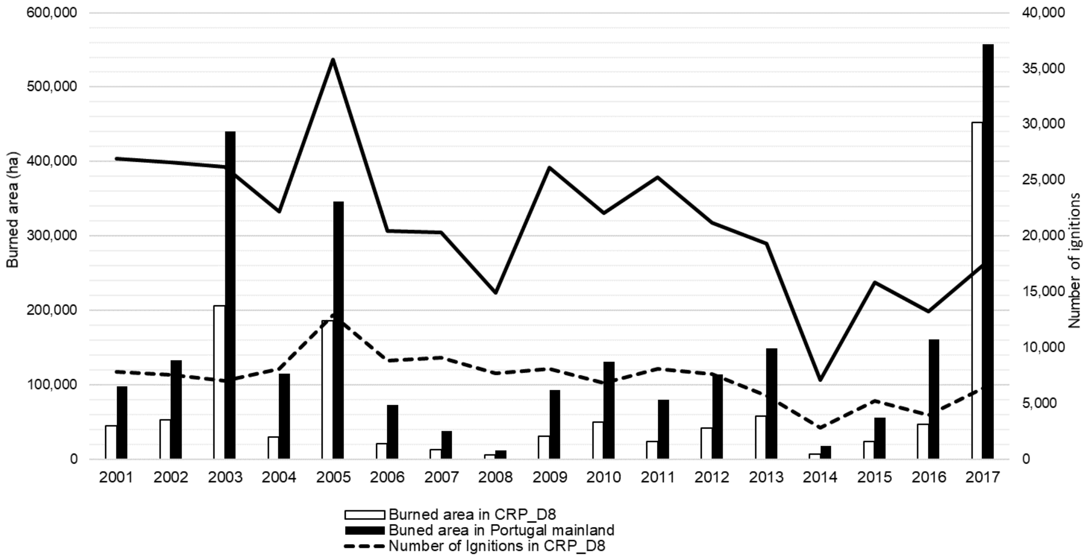

Figure 2. Annual evolution of the burned area and number of ignitions in the center region of Portugal (CRP) and in mainland Portugal.

The area burned by each ignition showed an average value of 10.4 hectares per ignition between 2001–2006 and decreased in the following six years to 3.6 hectares per ignition (2007–2012). Between 2013 and 2017, there was a very significant increase to 20.1 hectares per ignition. This trend is similar to that observed in the national territory, which went from 3.5 hectares per ignition (2007–2012) to 11.6 hectares per ignition (2013–2017). The increase in the area burned by each ignition could be due to the higher climatic severity, especially the increase in the number of heat waves. Between 2001 and 2006, the six meteorological stations that frame the study area registered an annual average of 12 days with heat waves per meteorological station. This average value remained unchanged in the 2007–2012 period. Between 2013 and 2017, the heat waves registered by the meteorological station increased to 17 days.

The increase observed in this last period was caused mainly by the greater number of heat waves that occurred during autumn. This meteorological event caused the largest fires ever recorded in Portugal on the 15th of October 2017. As a consequence of this apparent climate change, the three traditional levels of preparedness to fight fires (DECIF, 2017) were extended - Bravo phase (15 May – 30 June), Charlie phase (01 July – 30 September) and Delta phase (01 October – 31 October), for five flexible levels of readiness distributed throughout the year, depending on the degree of severity and likelihood of occurrence of rural fires.

Temporal analysis

Considering the total sum of the burned area between 2001 and 2017 by months 95% of rural fires occur from June to October, which is considered the most severe season for forest fires. Almost half of the total burned area for the year occurs in the month of August, with approximately 45% of the total.

In the period 2001 to 2017, a significant negative trend of the number of occurrences is observed, but the same does not occur with the burned area. This leads to a positive trend in the average size of forest fires, with larger fires occurring in recent years.

For the period under analysis the best fit of mathematical models for BA prediction are obtained by exponential and potential models (Table 1). In the NI estimate, the trend towards stabilisation of the NI value towards to the higher FWI values, makes the logarithmic and potential models have very close determination coefficients, with differences below 0.025.

Table 1. Regression equations obtained, with the highest R^2, between the central value of the FWI class, respectively, with the average burned area (ABA) and the average number of ignitions (ANI) between 2001 and 2017

	Average burned area (ha)	R^2	Average number of ignitions	R^2
Critical period	$ABA = 41.911\ e^{0.127\ FWI_1}$	0.950	$ANI = 64.627 \ln (FWI_2) - 42.662$	0.932
June	$ABA = 0.0015 FWI_2^{3.7304}$	0.911	$ANI = 29.029\ FWI_2^{\ 0.3959}$	0.724
July	$ABA = 5E\text{-}05\ FWI_2^{4.6866}$	0.953	$ANI = 73.012 \ln (FWI_2) - 83.805$	0.910
August	$ABA = 1.3992 e^{0.1308 FWI_3}$	0.952	$ANI = 96.476 e^{0.0154 FWI_3}$	0.913
September	$ABA = 5E\text{-}07\ FWI_3^{5.44}$	0.926	$ANI = -0.4142\ FWI_1^2 + 20.278\ FWI_1 - 44.67$	0.738
October	$ABA = 15.217 e^{0.1957 FWI_2}$	0.912	$ANI = 0.5218\ FWI_4^{1.4543}$	0.756

* FWI_1 – Average FWI average; FWI_2 – Maximum FWI average; FWI_3 – Average FWI maximum; FWI_4 – Maximum FWI maximum: Critical period 656 samples; June 136 samples; July 136 samples; August 136 samples; September 136 samples; October 112 samples.

These results improve on the estimates made by other authors. Relations between meteorological data and burned areas in Portugal were also performed through the application of FWI sub indexes. Some authors based on the Monthly Severity Rating and on the Build Up Index, from FWI, explaining 44% of the variance if the monthly area burned in Portugal (Amatulli et al., 2013). Other authors have used cumulative precipitation and Daily Severity Index (DSR) getting determination coefficients of 0.62 for July and 0.64 for August (Menezes, 2010). Other authors have explained the monthly burned area in the European Mediterranean basin from monthly averages of the Initial Spread Index (ISI) and Drought Code (DC) obtaining for Portugal coefficients of determination of 0.87 (Camia & Amatulli, 2009).

The ratio of the FWI to the average number of ignitions has an adjustment lower than that determined for the average burned area, in particular for the months of June, September and October. The estimate of the mean number of ignitions from the FWI values was obtained with a coefficient of determination values above 0.90 for the critical period and for the months of July and August. The coefficient obtained for these periods shows that there is a direct relationship between the increase in the FWI value and the increase in the mean number of ignitions. In the months of June, September and October, the values of the determination coefficients are lower, showing that in these months, factors other than meteorological factors may explain part of the ANI variation.

Due to the high inter-annual variation, the use of the prediction models obtained in this work should be carried out in the future, not for particular years, but to verify the adjustment to climate time series.

Spatial Analysis

Each district of CRP region has a set of immutable characteristics (orography) or slowly changing characteristics (soil occupation and population) that can define regional standards for the mean number of ignitions (ANI) and the average burned area (ABA) during the study period.

The regression equations are able to estimate ABA and ANI monthly with a high confidence level, $R^2 > 0.90$, in most of the studied districts (Table 2). These results improve the estimates made by other authors (Carvalho et al., 2008; Carvalho et al., 2010).

Table 2. Regression equations obtained, with the highest R^2, between the central value of the FWI class, respectively, with the mean burned area (ATBA) and the mean number ignitions (ANI) between 2001 and 2017

District	ABA (ha)	R^2	ANI	R^2
Aveiro	$ABA = 15.711\ e^{0.146FWI_1}$	0.773	$ANI = 45.557\ e^{0.0809\ FWI_1}$	0.968
Viseu	$ABA = 4E\text{-}05\ FWI_3^{4.5257}$	0.965	$ANI = 0.0804\ FWI_3^{2.0726}$	0.959
Guarda	$ABA = 0.0010\ FWI_3^{3.7405}$	0.901	$ANI = 0.8453\ FWI_3^{1.3491}$	0.876
Coimbra	$ABA = 6.7314\ e^{1.0099\ FWI_1}$	0.903	$ANI = 3.2761\ FWI_2^{1.171}$	0.971
Castelo Branco	$ABA = 7.9976\ e^{0.7393\ FWI_1}$	0.899	$ANI = 17.865\ e^{0.2551\ FWI_1}$	0.965
Leiria	$ABA = 0.5687\ e^{0.148FWI_3}$	0.923	$ANI = 6.6404\ FWI_2 + 3.7255$	0.939
Santarém	$ABA = 0.2070\ e^{0.1357FWI_4}$	0.954	$ANI= 41.4310\ e^{0.039FWI_1}$	0.907
Lisboa	$ABA = 11.796\ FWI_1^{0.7485}$	0.789	$ANI = 0.9763\ FWI_3^{1.3866}$	0.768

* FWI_1 – Average FWI average; FWI_2 – Maximum FWI average; FWI_3 – Average FWI maximum; FWI_4 – Maximum FWI maximum: samples 82 by district.

The Lisbon district is one of the eight analyzed districts with the lowest adjustment coefficients for ABA and ANI. These values are due to the fact that this district concentrates the burned area (62.7%) as well the number of ignitions (56.5%), in September and October, in conditions of low meteorological danger (FWI).

The highest number of ignitions occurred in most districts in the month of August. The districts in the northern part of CRP (Aveiro, Viseu and Guarda) had the second most ignitions in September, while the southern districts of this region have a higher number of ignitions in the month of July. The differences found among districts may be due to the use of fire in the elimination of agricultural residues and renewal of pastures, as in the Guarda and Viseu districts, or to a greater intensity of incendiary acts, as in Coimbra, Santarém and Viseu (Ferreira-Leite et al., 2016).

The size of the burned area is strongly influenced by the meteorological severity of the region (FWI), the type of vegetation of the terrain and the conditions of the terrain (slope and exposure) and the accessibility of the terrain (distance to roads). In the study region, climatic severity increases from the coastal zone to the interior as we pass from the softer temperatures, higher precipitation levels and higher relative humidity of the Atlantic climate influence, to the interior already marked by a climate of continental influence from high temperatures in a dry environment during the summer.

The RCP districts that were most affected by the fires were the districts of Guarda (312,220 ha), Castelo Branco (279,872 ha) and Coimbra (263,696 ha). The occurrence of burned areas in these regions can be explained by the existence of a high fuel load in the soil, mainly of forest biomass, due to the lack of forest management. The small size of the properties generates reduced yields and makes private owners unable to carry out the necessary forestry interventions. These areas, with high slopes and low accessibility, are marked by dense and continuous forests over large areas of the territory, where the presence of fine fuels from the moors and heathlands and from transitional woodland-shrub increases the susceptibility of the region to large fires. The interior areas of the district of Castelo Branco have the highest values of FWI for the July and August months (FWI = 39.3) but have a small burned area due to the existence of flat orography with small forest areas that are often limited by irrigated arable land, permanent crops and agro-forestry areas. In this way, the high meteorological danger is associated with a diverse mosaic in the territory, in which the discontinuity of the forest biomass fuel limits the extent of the burned areas.

The Aveiro and Lisbon districts, although characterized by a high number of ignitions, had burned areas that were quite low compared to those of the other districts. The data showed a reduced area of fires near the coast even though it has a high surface area occupied by coniferous forest. This occurrence is due to the existence of lower values of the meteorological hazards than those observed in the inland regions and also the benefits from densely populated flatland areas with good accessibility that have a significant part of the land covered by permanent crops and agricultural land. These strata serve as buffer zones for fires because they have higher soil water content from crop irrigation during the warmer months.

The value of the ABA determination coefficient in the district of Aveiro was hampered by the occurrence of a high area value burned in August 2016 in an intermediate FWI class. In this month it burned the equivalent of 38.3% of the area burned in this district in the period under study. Due to the size of the burned area the ABA estimative is strongly biased, decreasing the statistical adjustment of the exponential model.

CONCLUSIONS

The number of ignitions and the size of burned areas make the Portuguese mainland one of the main countries affected by rural fires. The FWI is one of the leading indices used by European organizations to estimate meteorological fire danger. In this study, the FWI class organization allowed the determination of the average number of ignitions and burned areas associated with each of the FWI classes, reducing the influence of other factors, such as topography or distance from the fire station to ignition sites.

The predicted equations for the burned area as a function of the FWI presented high coefficients of determination for most of the considered periods, thus allowing the projection, with a high degree of confidence, of the monthly burned area values according to the various future climate scenarios. The prediction of the average number of ignitions from the FWI values class proved to be effective for establishing highly adjusted forecast models for July and August as well as for the critical period.

In the spatial analysis at the district level, the ABA and ANI estimation equations were obtained from the FWI values with determination coefficients above 0.90 for most of the districts. Significant differences were observed between the districts in the number of ignitions analysed.

This work will allow, in future, in climate change scenarios, to predict the effect that rural fires may have on the study area. The establishment of estimation equations for ABA and ANI at district level will provide regional command posts with information on the number of ignitions and the average area expected under different weather conditions.

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