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Assessment of vegetation regrowth and spatial patterns and severity factors of wildfires in wildland-urban interface — the case of the large wildfire in Baião (2019)

Avaliação da regeneração da vegetação, de padrões espaciais e fatores de severidade dos incêndios na interface urbano-florestal — o caso do grande incêndio em Baião (2019)

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Abstract

Portugal is one of the Southern European countries most affected by forest fires, with recurrent events and frequent impacts. The demographic and social changes that have occurred in rural areas have driven land abandonment in recent years, which, in turn, influences forest management and wildland-urban interface (WUI) areas that are related to fires. The aim of this work is to develop a case study in the municipality of Baião based on the large wildfire (LWF) of 2019, by defining and mapping the WUI areas, evaluating the LWF recurrence and severity, and the vegetation regrowth in a period of 2 years in areas with different land uses affected by distinct fire severities. The study was organized into 4 stages: firstly, we mapped the fire occurrences and then the WUI areas. After fire mapping, the recurrence of wildfires was characterized and the last step corresponded to the evaluation of the severity of the LWF of 2019 and the evaluation of the vegetation regeneration, and different land use types. The WUI represents 26.7% of the territory of the municipality of Baião. From 2001 to 2021, the municipality registered 3,770 fire occurrences. In 2019, the LWF of Baião burned an area corresponding to 853 ha, which was affected by a total of 12 fires in the period between 1975 and 2019, resulting in a maximum degree of 11 recurrences for the same area. With regard to the direct impact of fire on vegetation and its subsequent recovery, we can see that 2 years after the LWF, the area occupied by the forest and shrub vegetation, which were hit by high severity, already showed significant levels of vegetation regrowth. As a main conclusion, the study contributes to widen the understanding of the patterns created by fire in different landscapes, and this information is valuable for forest managers to know the consequences (beneficial or not) and be able to plan prevention, restoration, and environmental education actions.

Keywords: Wildland-urban interface, Sentinel imagery, wildfire recurrence, wildfire severity, vegetation regrowth.

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Resumo

Portugal é um dos países mais afetados pelos incêndios florestais no sul da Europa, com eventos recorrentes e impactes frequentes. As mudanças demográficas e sociais que ocorreram nas zonas rurais levaram ao abandono das terras nos últimos anos, o que, por sua vez, influencia a gestão florestal e as zonas de interface urbano-florestal (IUF) que estão intimamente relacionadas com os incêndios. Assim, é objetivo deste artigo desenvolver um estudo de caso no município de Baião, com base no grande incêndio florestal (GIF) de 2019, definindo e cartografando as áreas IUF, bem como avaliar, a recorrência e a severidade do GIF e, num período de 2 anos, a regeneração da vegetação, em áreas com diferentes usos do solo e afetadas por diferentes severidades. O estudo foi organizado em 4 fases, sendo que na primeira se procedeu à cartografia das ocorrências de incêndios, na segunda à delimitação da interface urbano-florestal e, na terceira fase, à caracterização da recorrência dos grandes incêndios. A quarta fase correspondeu à avaliação da severidade do grande incêndio de 2019 e à avaliação da regeneração da vegetação, em função do uso do solo. O IUF representa 26,7% do território do município de Baião, durante os anos de 2001 a 2021 o município registou 3 770 ocorrências de incêndios. Em 2019, o GIF de Baião queimou uma área correspondente a 853 ha, apresentando um total de 12 incêndios entre 1975 a 2019, resultando um grau máximo de 11 recorrências para a mesma área. No que diz respeito ao impacto direto do fogo na vegetação e à sua posterior recuperação, podemos constatar que 2 anos após o GIF, a área ocupada pelas classes de floresta e mato, que foram atingidas com grande severidade, já apresentava níveis significativos de regeneração da vegetação. Perante isto, as principais conclusões consideram que os estudos nesta linha contribuem para a compreensão dos padrões criados pelo fogo em diferentes paisagens, sendo a informação valiosa para os gestores florestais compreenderem as consequências (benéficas ou não) e planearem ações de prevenção, restauração, e educação ambiental.

Palavras-chave: Interface urbano-florestal, imagens Sentinel, recorrência dos incêndios, severidade dos incêndios, regeneração da vegetação.

1. Introduction

In recent decades, fire regimes in Europe have changed due to the increase in the occurrence of extreme events of large wildfires (LWF), mainly in the south of the continent (Lopes et al., 2022; Turco et al., 2016). In the Mediterranean region, despite a downward trend in the annual burnt area (Lopes et al., 2022; Turco et al., 2016), LWFs have been considered one of the main disturbances in the environment with large burnt areas and growing socioeconomic and ecological impacts becoming more frequent lately (Tedim et al., 2015; Doerr & Santín, 2016; Fernandez-Anez et al., 2021; Guo et al., 2022; Lopes et al., 2022), because of a complex interaction of high temperatures, prolonged droughts, land abandonment, and fire suppression policies that have led to increased fuel loads (Fernandes, 2013; Ferreira-Leite et al., 2016; Lopes et al., 2022; Moreira et al., 2020).

Portugal is one of the countries most affected by recurrent wildfires, with significant impacts that are, being responsible for losses in the environment, economy, and human lives (Lopes et al., 2022; Guo et al., 2022; Parente et al., 2018; Meneses et al., 2018; Ferreira-Leite et al., 2017). Moreover, demographic and social changes in rural areas have caused land abandonment over the years, which, in turn, influences forest planning and wildland-urban interfaces (WUI) (Barbosa et al., 2022).

The WUI is an area where houses or urban areas meet or intermingle with wild vegetation or rural areas, and are prone to fires (Lampin-Maillet et al. 2009; 2010; Bento-Gonçalves & Vieira, 2020). In Portugal, the wildfires in WUIs are gaining relevance, especially in the 21st century, and with particular relevance after the tragic years of 2003, 2005, 2013 and 2017 (Bento-Gonçalves & Vieira 2020).

In 2019, the third largest wildfire in mainland Portugal struck in the municipality of Baião (ICNF 2022), located in NUT[1] III Tâmega e Sousa, in the north of the country. In Baião, some areas of its territory have WUI, largely resulting from the rural abandonment of agricultural and horticultural fields around the villages and houses, a pattern very much associated to aging population, favouring an increase of unmanaged forest and the prevalence of, natural growth, in areas closer to houses (Doerr et al., 2017).

In this context, the use of satellite images enables an efficient study of fire events (Brown et al., 2018; Roy et al., 2013), contributing to a perspective of analysis of pre and post-fire conditions such as the one that happened in Baião in 2019 (Santos et al., 2020). Data from the Sentinel satellite system of the European Space Agency (ESA) allow the

[1] Nomenclature of Territorial Units for Statistics.

assessment of wildfires impacts in greater spatial and spectral resolution provided by medium resolution and open access earth observation systems (Brown et al., 2018; Whyte et al., 2018; Huang et al., 2016).

After a fire, several changes take place in the environment as it burns the vegetation, leaving the soil partially or completely bare, modifies the moisture content, and ash deposition occurs (Parker et al., 2015; Pausas & Keeley, 2009; Santos et al., 2020; Veraverbeke et al., 2010). Remote sensing applications offer viable approaches to describe the changes as they contribute to detect them in the fire-affected landscape (Parker et al., 2015; Santos et al., 2020, 2023; Sunderman & Weisberg, 2011; Veraverbeke et al., 2014).

Thus, we proposed in this work to develop a case study in the municipality of Baião based on the LWF of 2019 by defining and mapping the areas of WUI as well as evaluating the recurrence, the severity of the LWF and the vegetation regrowth in a period of 2 years in areas with different land uses affected by distinct fire severities.

2. Materials and methods

2.1. Study area

The study area is in Baião, the easternmost municipality in the Porto district, in northern Portugal. Baião has 17,452 hectares and is located on the Douro - Tâmega interfluve, an area considered to be undergoing geomorphological and even economic transition, between the regions of Trás-os-Montes and Entre Douro e Minho (Leitão, 2011; Soares et al., 2023). In the municipality of Baião we can find the Castelo mountain range, part of the Aboboreira and Marão mountain ranges, and the Douro river at its southern limit (Figure 1) (Soares et al., 2023; Lucas, 2012).

The climate of Baião has characteristics of transition between Trás-os-Montes and the Portuguese northwest, and according to Koppen classification, it is in the domain of the temperate Mediterranean climate with rains in the winter and a dry and slightly hot summer (Csb) (Lucas, 2012).

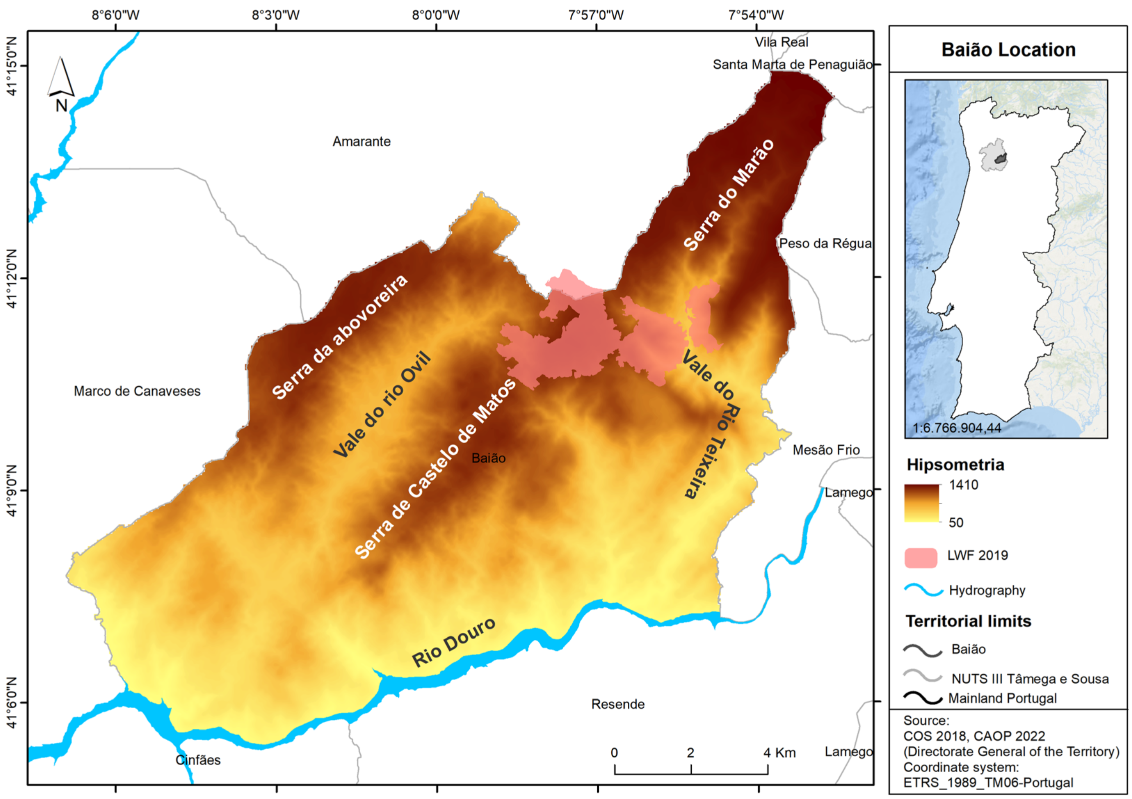

Figure 1
Location of the study area (municipality of Baião), main hills, and LWF 2019 area.

The altitude, the latitude and the relative proximity to the sea are the factors that have influence on local climate, causing abundant rainfall and a moderate temperature range. In the valleys, temperatures are moderate in winter and high in summer while in the highest points the winter is vigorous with milder temperatures in the summer period. The dominant winds are from the West and Southwest quadrants coming from the Douro and Tâmega valleys, which cool as they go up the slopes, leading to high precipitation in the highlands (Leitão, 2011).

3. Methodology

The study was organized in four stages. The first involved the mapping of fire occurrences, the second the mapping of the WUI, the third the characterization of the LWF[2] recurrence, and the fourth the evaluation of the severity of the LWF of 2019 and the vegetation regrowth according to land use.

- **Occurrence of wildfires**

In order to map the wildfire occurrences, we consulted the Portuguese database of wildfire occurrences available at the ICNF database, located at "https://geocatalogo.icnf.pt/", which provides information in vector format. Each occurrence is represented by an individual point and characterized by several attributes (e.g. location, date and time of ignition, size of the forest and non-forest burnt area, the geographic coordinates of the point of ignition and cause). The information was handled and analysed using the GIS software ArcGis 10.7.1 from ESRI.

- **Wildland-urban interface**

For the mapping of WUI, we considered the methodology developed by Lampin-Maillet et al. (2009; 2010) from the methodological guide "Characterization and mapping of dwelling types for forest fire prevention" (Lampin-Maillet et al., 2009; Bento-Gonçalves & Vieira, 2020; Lampin-Maillet et al., 2010), which was also applied for a study in the municipality of Fafe, in the northwest of Portugal. However, the adoption of this methodology placed some limitations regarding the use of the software developed for WUI mapping as it only works in Windows 2000, and, therefore, taking it into account, we adapted the methodology (Peixoto, 2019).

Table 1

Vegetation aggregation class and class ratio COS 2018

Code	Vegetation Aggregation	COS 2018 classes
0	null	Artificialized territory
		Agriculture
1	sparse	Pastures
		Shrubs
		Open spaces with little vegetation (sparse vegetation)
2	dense	Forest

Data on the vegetation was derived from the 2018 Land Use and Land Cover Map (COS), whereas the municipal government of Baião provided information on housing and buildings. The method used to characterize and map the WUI was based on 3 steps. The first stage was the characterization of the dwellings and in accordance with the definition of the dwelling types by Lampin (Lampin-Maillet et al. 2009; 2010). We made proximity calculations to determine the different types of dwelling density and counted them. Each building was classified as belonging to one of the four classes: isolated, scattered, dense clustered and very dense clustered dwellings. These classes considered the distance between the houses and the density of the houses located within a radius of 100 m around the dwellings.

In the second stage, we characterized and mapped the structure of the vegetation. For the aggregation of the vegetation, we considered the classes: null, sparse, and dense. Data was collected from the COS 2018 instead of the vegetation aggregation index used in the original methodology (Lampin-Maillet et al., 2009; 2010). We choose the COS 2018 based on some criteria: it provides free of charge data and information; it was elaborated for the entire country by the same entity following the same methodology; and the ease of making comparisons with the rest of the national territory (Peixoto, 2019). For this work, we considered the following COS 2018 classes shown in Table 1.

The third phase was intended to combine the two previous parameters (Lampin-Maillet et al. 2009; 2010). The calculation allowed the combination of different types of dwelling groups and different

[2] Although, currently, the official figure has been raised to 500 ha, by political decision contained in Parliament Resolution No. 35/2013 of 19 March (D.R. No. 55, Series I), in this study, in accordance with the criteria adopted in the reports of the Institute for Nature Conservation and Forests (ICNF), large wildfires are those larger than 100 ha.

vegetation classes, resulting in eight types of WUI for our study area. The cartographic information was handled and analysed using the GIS software, ArcGis 10.7.1 from ESRI.

- **Recurrence of LWF**

As for the recurrence of LWFs, we used the historical data provided by the Institute for the Conservation of Nature and Forests (ICNF) from 1975 to 2019. It allowed us to analyse the frequency of the wildfires along with their annual spatial patterns, and subsequently, to define the maximum patterns of recurrence.

With the use of GIS software, the information related to the occurrence of fires had to be organized by individual "layers" and the year of its incidence. This information was converted into raster images, classified into "burnt area" and "non-burnt area", with pixel value 1 and 0, respectively. Afterwards, the recurrence of fire was calculated, proceeding with the classification of the result obtained in agreement with the following methodology: pixel value 0 for areas never reached by fire; areas hit once assume pixel value 1; areas hit twice have a pixel value 2, and so on. The resulting image was also vectorized and the areas of different fire recurrences calculated (Ferreira-Leite at al., 2011).

4. Severity and regrowth of vegetation

For this step, we used data from the Sentinel-2A multispectral imager (MSI) satellite (table 2). The images were processed on the Google Earth Engine (GEE) platform (Tavakkoli Piralilou et al., 2022; Bar et al., 2020; Xulu et al., 2021). A spatial filter corresponding to the LWF threshold defined by the ICNF was applied to select images with 0% cloud cover. The bands used corresponded to the NIR interval (band B8A - 842 nm) with a resolution of 20m and SWIR (band B12 - 1610 nm) with a resolution of 20m.

The NBR spectral index was applied (Equation 1) (Key and Benson 2006; Santos et al. 2020; Escuin, Navarro and Fernández 2008; Saulino et al. 2020; Morresi et al. 2019) so as to thereafter calculate its multitemporal dNBR difference (Equation 2), which aimed to assess the severity of the burnt area through the relationship between pre-fire and post-fire NBR (Santos et al., 2020; Roy et al., 2006). The dNBR was also used to evaluate vegetation regrowth (Equation 3). This multitemporal index enhances the changes between NBR scenes, highlighting the presence of fire. Hence, when it is subtracted the post-fire NBR from other subsequent images, the recovery of vegetation is highlighted (Teobaldo & Baptista, 2016; Santos et al., 2020).

$$NBR = (nir - swir)/(nir + swir) \qquad \text{Equation (1)}$$

Where: nir corresponds to band B8A and swir corresponds to band B12 of sentinel-2A.

$$dNBRs = NBRpre - NBRport \qquad \text{Equation (2)}$$

$$dNBRr = NBRpost - NBRrecrecimento \qquad \text{Equation (3)}$$

Where dNBR is the difference of the Normalized Burn Ratio, and preNBR and postNBR are the Normalized Burn Ratio indices calculated for the pre-burn and post-burn scenes, respectively (Fernández-García et al., 2022). The severity levels proposed by Key and Benson (Key & Benson, 2006) were used to classify the indices of severity and regrowth of the vegetation (Santos et al., 2020).

Table 2

Dates of Sentinel 2A images used to calculate wildfire severity and vegetation regrowth.

Sensor	Date	Goal
Sentinel 2A	23/08/2019	Pre-fire
	07/09/2019	Post-fire
	10/03/2020	Regrowth
	06/09/2020	Regrowth
	27/08/2021	Regrowth

5. Results and discussion

5.1. Distribution of the number of wildfire occurrences and WUI

The municipality of Baião recorded 3,770 wildfire occurrences from 2001 to 2021 (Figure 2). When analysing the annual distribution, it was observed that there was a downward trend, that is, a decreasing linear trend in the number of occurrences, with a R2 of 0.3068. Figure 3 illustrates the spatial distribution of wildfire occurrences, where is clear that ignitions were distributed throughout the entire territory.

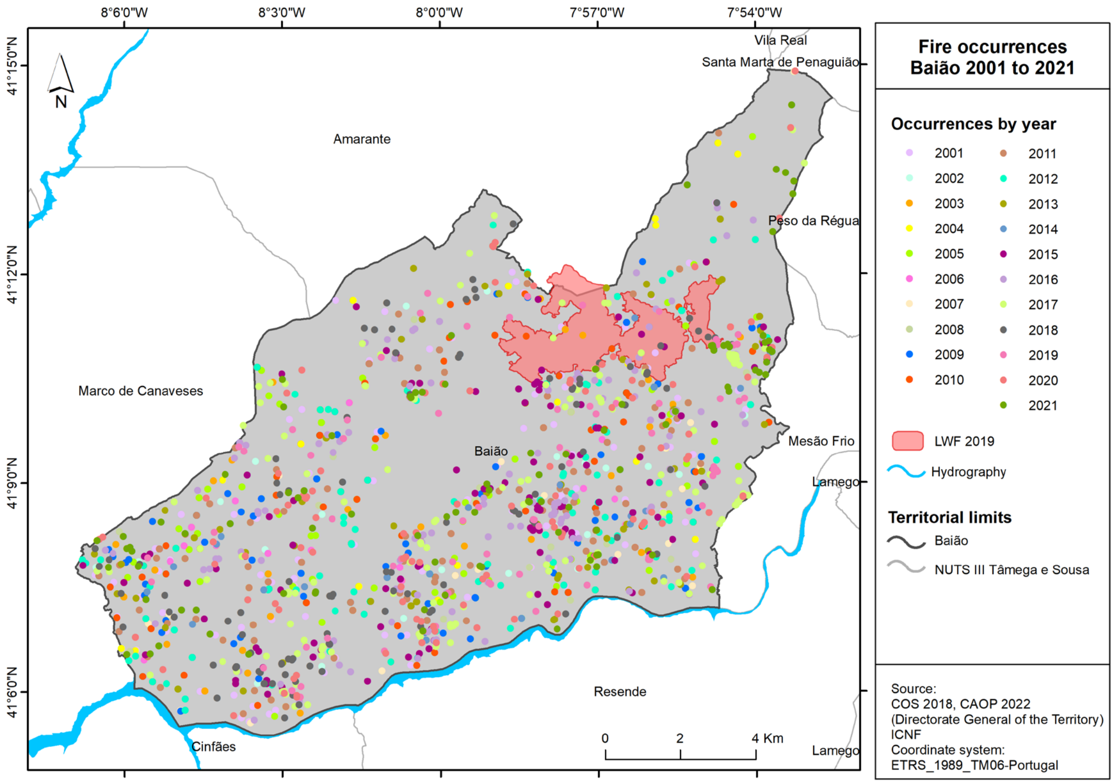

Figure 3
Spatial distribution of wildfire occurrences in the municipality of Baião between 2001 and 2021.

Based on the number of wildfire occurrences, we crossed the data with the WUI areas mapped for the municipality in figure 4. For the analysis in this work, we considered only the WUI with sparse and dense vegetation. We identified 885 occurrences, 4% corresponded to isolated housing & sparse vegetation, 13.3% to isolated housing & dense vegetation, 9.8% to scattered housing & sparse vegetation, 62.4% to scattered housing & dense vegetation, 1.6 % to dense housing & sparse vegetation, 5.6% to dense housing & dense vegetation, 0.5% to very dense housing & sparse vegetation and 2.8% to very dense housing & dense vegetation.

Socioeconomic factors such as depopulation, aging of the rural population, changes in forestry and agricultural policies as well as in land use caused by the abandonment of agriculture and horticultural fields influence the establishment of WUI around villages and dwellings (Doerr et al., 2017; Lucas, 2012). These dynamics and the success in extinguishing small and medium-sized fires are producing landscapes with higher flammability and more fuel loads, which contributes to new occurrences of larger and more severe wildfires (Tedim et al., 2013).

The WUIs represent 26.7% of the territory of the municipality of Baião. Around 4,945 homes are in the WUIs. Regarding the proportion of different types of WUIs, 7% refers to isolated housing & sparse vegetation, 21% to isolated housing & dense vegetation, 12.4% to scattered housing & sparse vegetation, 52.4% to scattered housing & dense vegetation, 0.8% to thick dense housing & sparse vegetation, 4.2% to dense housing & dense vegetation, 0.4% to very dense housing & sparse vegetation and 1.8% to very dense housing & dense vegetation.

Figure 5 shows the distribution of land use types within the WUI areas. The predominant vegetation corresponds to the forest class, registering approximately 80%, chiefly in the scattered and isolated WUI. The main classes of use for the scattered and isolated WUI are maritime pine forest, representing 991.3 ha of the diffuse WUI, followed by 907.4 ha of other broadleaf forest, 551 ha of shrubs, 228.6 ha of other oak forests and 202 ha of

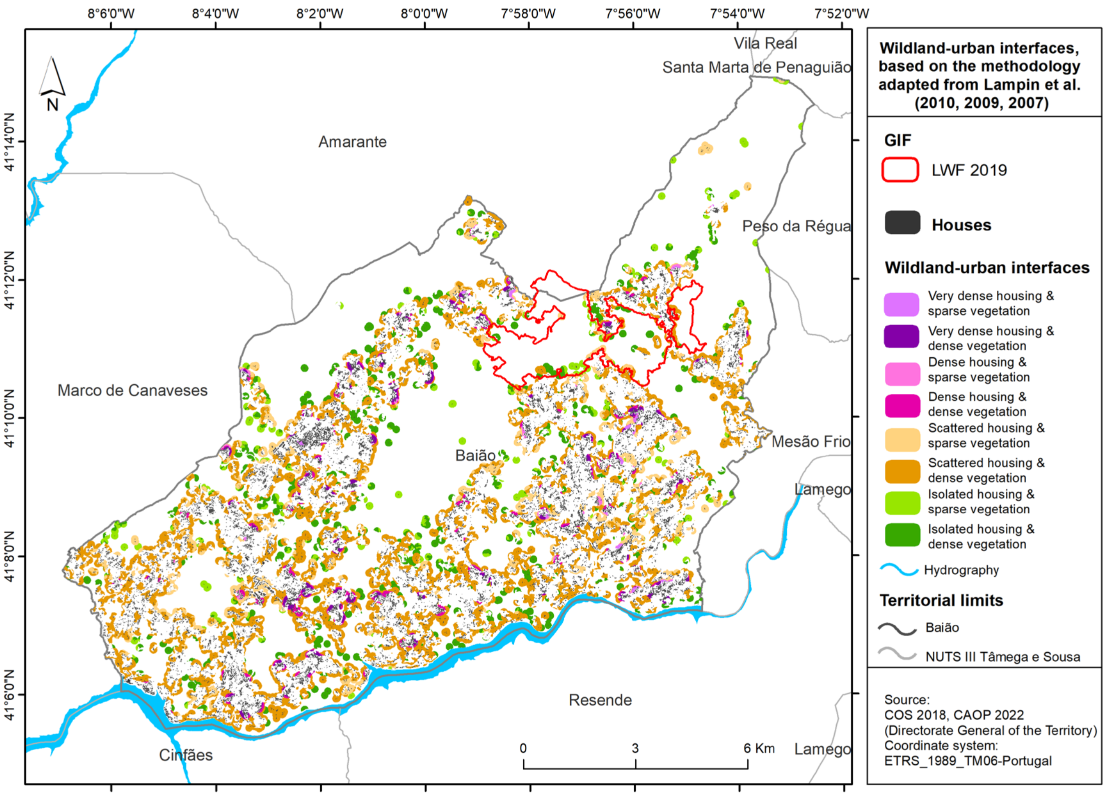

Figure 4
Cartography of WUI areas combining configuration of buildings and vegetation structure in the municipality of Baião.

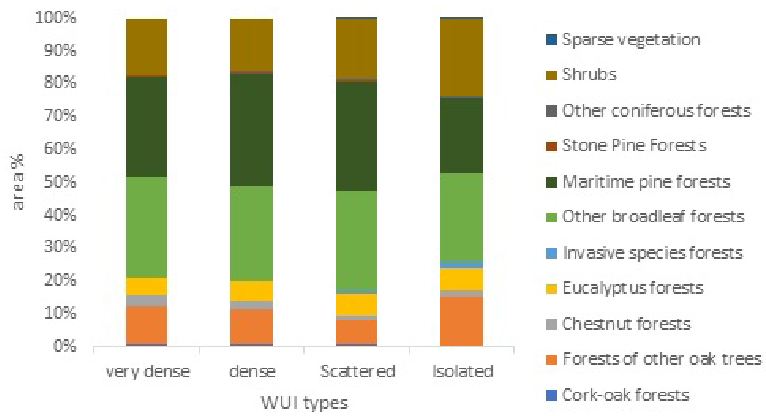

Figure 5
Land cover distribution according to WUI types in the municipality of Baião.

eucalyptus forests. The isolated WUI has 346 ha of other broadleaf forests, 303 ha of shrubs, 298 ha of maritime pine forest, and 190 ha of other oak forest.

In Baião, the plantations of eucalyptus and maritime pine, two highly flammable species, which have a generalized structure (large patches with contiguous crowns), are often devastated by fire. The context in which this territory is inserted in terms of anthropogenic activities has been emphasizing the problem of wildfires. In fact, with the abandonment of agricultural land, where pine and eucalyptus trees are planted or where shrub communities are allowed to grow, the "voids" necessary to prevent fire disappear. In addition to filling the "voids", there was a decrease in the number of cattle that used to make a valuable contribution to preventing rural fires by foraging shrubs when grazing (Leitão, 2011).

6. The large wildfire of Baião in 2019

According to data provided by the ICNF, up to October the 15th of 2019, 62 fires classified into the LWF category were registered in Portugal, which resulted in 27,284 hectares of burnt area, approximately 66% of the total burnt area. The LWF of Baião burnt an area corresponding to 853 ha in a single occurrence on 09/05/2019, turning into the third largest LWF that year as stated by the ICNF (ICNF 2022).

Figure 6 depicts the coincidence of the LWF limit that occurred in 2019 with the mapped WUI areas. The WUI is a priority area for fire prevention and extinguishing (Lampin-Maillet et al. 2009). As a matter of fact, there is a concern about the reduction of fuel in the immediate vicinity of the residences and plans for emergency evacuation. Thus, not only have the WUIs become the major focus of wildfire policy in Europe, but also in the United States (Lampin-Maillet et al., 2009).

Considering the burnt area associates to the LWF of Baião, and having by reference the COS 2018 data for the pre-fire situation, we could see that 0.3% of the burnet area affected artificialized territories, 4.1% of agriculture area, 0.4% area with pastures, 41.4% was forest (10.1% of other oaks, 2.2% of chestnut forest, 3.4% of eucalyptus forest, 8.6% of other hardwood forest, 17% of maritime pine forest, 0.2% of other softwood forest) and 53.8% the shrubs.

In the area corresponding to the 2019 LWF, we could identify twelve incidences and eleven recurrences of wildfires between 1975 to 2019 (Figure 7), which demonstrates that it is subject to frequent and sometimes major manifestations of the risk of wildfires (Ferreira-Leite et al., 2010).

The recurrence data analysed showed that 84.3% of the burnt area was affected twice or more times by wildfires between 1975 and 2019 (Figure 8). The areas where the LWF occurred in 2019 presented the highest recurrence corresponding to the shrub type vegetation. The recurrence indirectly reflects

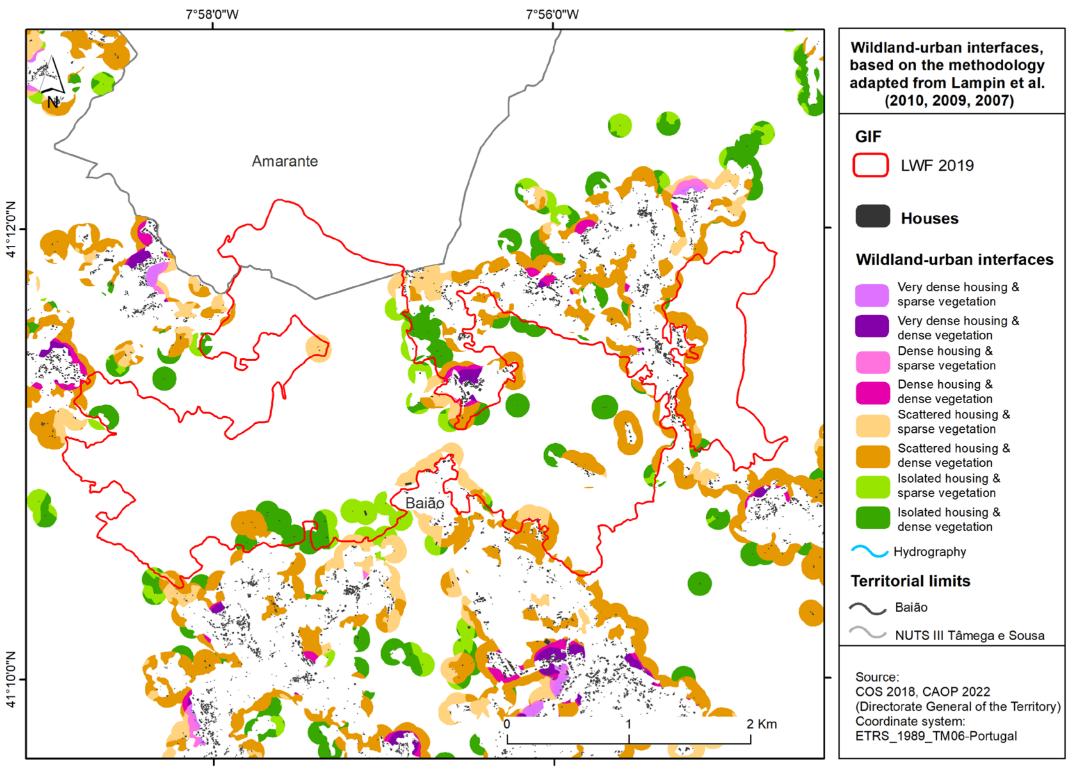

Figure 6
Area burned by the 2019 LWF and the cartography of the WUI areas combining the configuration of buildings and the vegetation structure for the municipality of Baião.

all the variables involved in the process, from the physical conditions to the direct and indirect causes of fires, primarily of human origin, also passing through the efficiency of prevention and combat (Ferreira-Leite et al., 2010; Meneses et al., 2018).

Based on the application of the dNBR spectral index to the Sentinel-2A images, we could distinguish the different degrees of severity experienced by the action of the fire (Figure 9a). For the area affected by the LWF, 40% corresponded to a high severity class, 25.25% to a moderately high severity class, 16.6% to a moderately low severity class, 12.95% to a low severity class, and 5.13% of the area was not burnt (Table 3).

The spatial pattern of the fire severity in the burnt area is often determined by vegetation, topography, weather and duration of the fire (Guo et al., 2022; Fang et al., 2015; Fernández-García et al., 2022; Lentile et al., 2006). Weather is typically considered to play a key role in the distribution of wildfire severity, while terrain and vegetation are the main factors that affect the heterogeneity of spatial patterns of wildfire severity at local scale (Wu et al., 2013; Guo et al., 2022). Topography influences fire behaviour by changing microclimatic conditions and forest characteristics (Guo et al., 2022), leading to different spatial patterns of fire severity. Certain aspects of vegetation characteristics, such as type, structure, and load, have important effects on wildfire occurrence and behaviour (Guo et al., 2022; Birch et al., 2015)

With regard to the slopes of the study area, it can be seen that 5% of the total area, where, during the period under study, the vegetation returned to photosynthetic activity, presented slopes between 0 and 5 degrees, 15% presented slopes between 5 and 10 degrees, 21% slopes between 10 and 15 degrees, 44% slopes between 15 and 25 degrees and 15% between 25 and 44.5 degrees.

In the evaluation of vegetation regeneration after 6 months of the wildfire (Figure 9b), we identified that 40.7% of the area showed high vegetation growth and 20.8% low vegetation growth, 22.4% had a response equivalent to a burnt area, and 17.8% of the area still has the characteristics of a burnt area (Table 4).

One year later (Figure 9c), we identified that 60.83% of the area showed high vegetation growth,

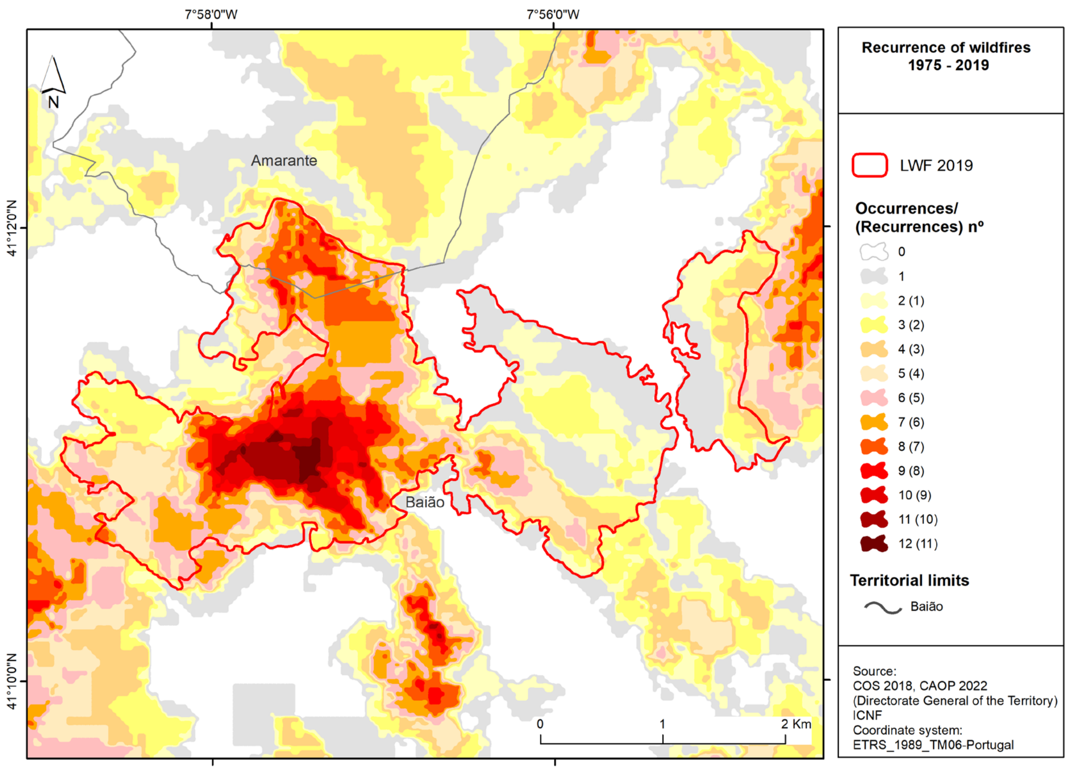

Figure 7
Spatial distribution of wildfire recurrences between 1975 and 2019 in the area burned by the 2019 LWF in municipality of Baião.

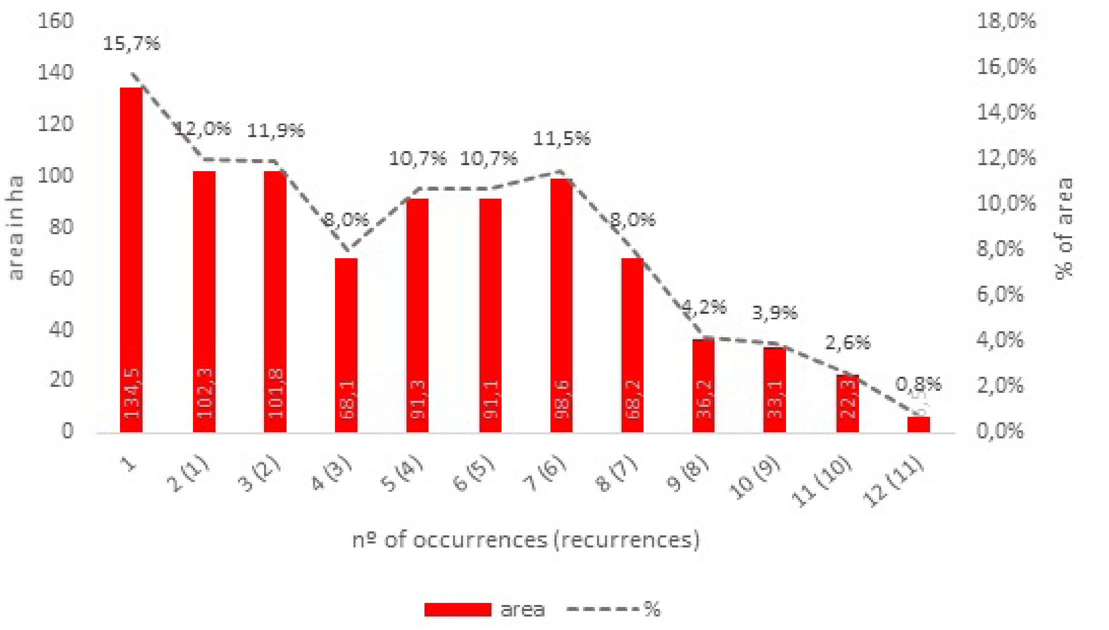

Figure 8
Area and percentage of the burnt area by class of recurrence from 1975 to 2019. The red bars represent the value of the burnt area in hectares, and the dashed line the percentage of the burnt area.

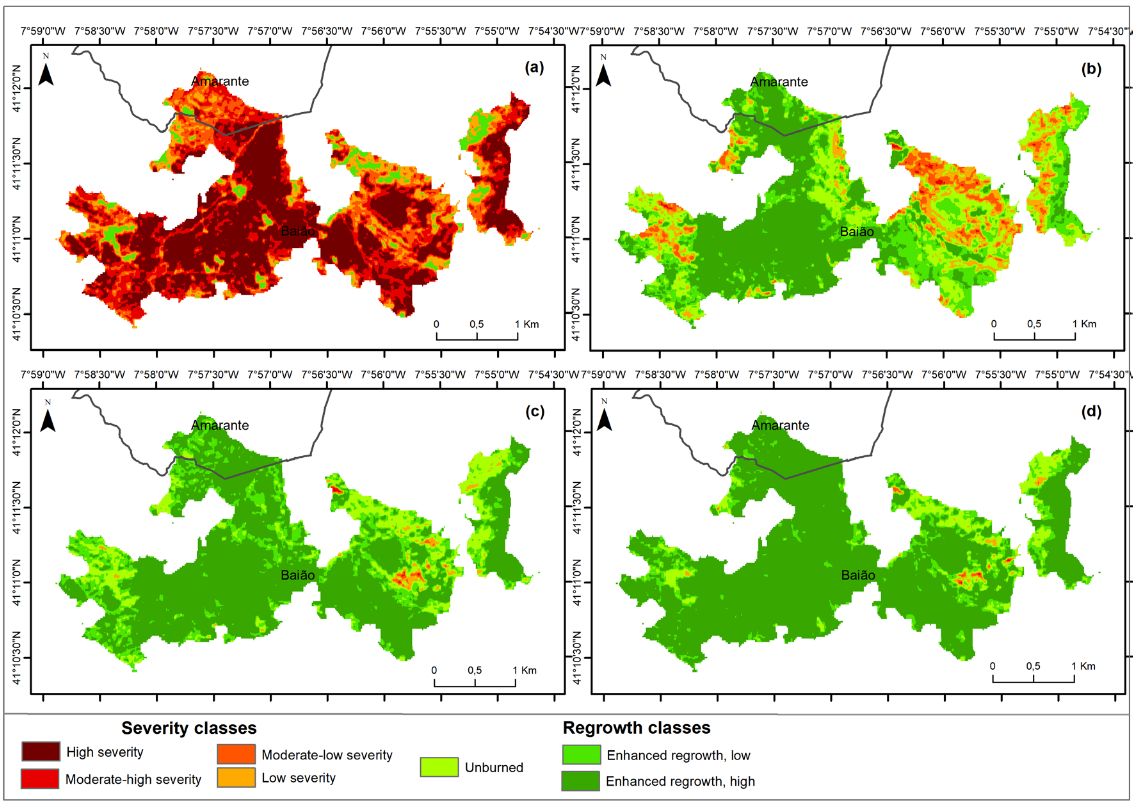

Figure 9
Severity and regrowth maps obtained using dNBR derived from Sentinel-2A images.

20.61% low vegetation growth, 14.97% had a response equivalent to an unburnt area and, 3, 59% of the area still has the characteristics of a burnt area (Table 4). However, within two years after the wildfire (Figure 9d), 76.27% of the area registered high vegetation growth, 12.15% low vegetation regrowth, 8.97% continued with the spectral behaviour of an unburnt area and 2.61% with burnt area characteristics.

In terms of the type of land use and occupation concerning 6 months after the wildfire, 6.3% (53.8 ha) of forest area and 31.8% (271.4 ha) of the area occupied by shrubs in the pre-fire stage showed vegetation regrowth. One year after the wildfire, 17.6% (150.4 ha) of forest area and 43.4% (370.2 ha) of the area previously occupied by shrubs showed vegetation regrowth. In two years after the wildfire, 40.6% (346.6 ha) of the area previously occupied by forest and 53.3% (454.5 ha) of the area occupied by scrubs showed vegetation regrowth (Table 5).

We verified that two years after the LWF, the area occupied by forest and shrub classes, which were affected by high severity, already showed significant levels of vegetation regrowth corresponding to approximately 100% of the area occupied by this class. An increase was registered in the upper-class regrowth, going from 15% to 42% in forest areas, from 6 months to 1 year, and from 58% to 80% in shrub areas, also from 6 months to 1 year, and in the second year of analysis 98% of the forest area and 99% of the scrubland area showed photosynthetic activity, with vegetation returning to the area burnt by the LWF in 2019 (Table 5).

Table 3

Different degrees of severity of the 2019 LWF in the municipality of Baião.

Class	Acre	Percentage
High severity	457.88	40.05%
Moderate-high severity	288.64	25.25%
Moderate-low severity	189.76	16.6%
Low severity	148.12	12.96%
Unburnt	58.88	5.15%
Total	**1143.28 ha**	**100%**

7. Conclusion

LWFs cause major landscape degradation in the Mediterranean region. Studies addressing this issue contribute to the understanding of the patterns created by wildfire in different landscapes. Moreover, historical information on fire severity and vegetation regrowth obtained from Sentinel-2A imagery can provide valuable data for effective natural resource management.

Table 4

Different vegetation regrowth classes for the LWF area in Baião.

	6 months		1 year		2 years	
Class	Acre	Percentage	Acre	Percentage	Acre	Percentage
High severity	0	0%	0	0%	0	0%
Moderate-high severity	6.16	0.54%	1.88	0.16%	0.88	0.08%
Moderate-low severity	62.84	5.5%	11.16	0.98%	8.28	0.72%
Low severity	134.4	11.76%	27.92	2.44%	20.64	1.81%
Unburnt	256.08	22.4%	171.2	14.97%	102.52	8.97%
Enhanced regrowth, low	234.48	20.51%	235.68	20.61%	138.96	12.15%
Enhanced regrowth, high	449.32	39.3%	695.44	60.83%	872	76.27%
Total	**1148.28 ha**	**100%**	**1143.28 ha**	**100%**	**1143.28 ha**	**100%**

Table 5

Vegetation regrowth for the LWF in Baião by the forest and shrub classes.

	6 months		1 year		2 years	
Class	Acre	Percentage	Acre	Percentage	Acre	Percentage
Forest	53.8	6.3%	150.4	17.6%	346.6	40.6%
Scrub	271.4	31.8%	370.2	43.4%	454.5	53.3%
Total	325.2 ha	38.1%	520.6 ha	61%	801.1 ha	93.9%

For the case study carried out in the Baião municipality, with the mapping of the areas of wildland-urban interfaces (WUI), we can understand the dynamics established in the municipality and its relationship with the distribution of housing and vegetation types. The territories classified as WUI present a high rate of ignitions and characteristics that make the combat difficult, so they will be more prone to the occurrence of a LWF. The 2019 LWF is an example of this, having its limits very close to WUIs. The 2019 GIF showed varied severity gradients, with 40% achieving high-severity, 25% moderate-high, 16% moderate-low and 12% low-severity.

This is valuable information for forest managers to understand the consequences (beneficial or otherwise) and plan prevention, restoration, and environmental education actions. The LWF area in the Baião municipality burned recurrently (maximum of 11 recurrences), and is an area heavily affected by fires (84% of the area has burned at least once). Even with good vegetation recovery rates, it is urgent to develop studies on the multiple and varied impacts of fires. Two years after the fire, 100% of the area occupied by the forest and shrub classes, which were affected by high severity, already showed significant levels of vegetation regrowth.

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