Large Forest Fires in Northwest Portugal: Exploring spatial patterns between 2001 and 2020, based on Landsat data

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Abstract
In recent decades, in several parts of the world and under extreme weather conditions, we have witnessed the occurrence of numerous large-scale wildfires. This reality has also occurred in Portugal, burning thousands of hectares of forest, destroying infrastructures, and causing the regrettable loss of human lives. In view of this worsening panorama, we proceeded to the cartography of Large Forest Fires (LFF) in northwestern Portugal (larger than 100 hectares), in the period from 2001 to 2020, from the analysis of Landsat images and using Machine Learning tools and the Random Forest algorithm, in Google Earth Engine work environment. Based on the results obtained, an attempt is made to understand the LFF context in northwestern Portugal, as well as to analyse its spatial distribution and temporal evolution in the period under analysis. The conclusion is that about 158.741 ha burnt at least once and 40.9% of this area was affected by LFF a second time. The year of 2005 recorded the highest value of burnt area (73,025.1 ha). And the maximum recurrence observed, in the study area, was 7 occurrences, with a maximum recurrence of 6 times. The brush is the type of vegetation, in NUTS Ave, Alto Minho and Tâmega and Sousa, which presents more burnt area in LFF, while in Cávado, it is the forests that present the most extensive area covered by LFF. Thus, in 15 years for the study area, the most significant proportion of burnt vegetation corresponds to brush, being only in 5 years, forests were the class of the larger burnt area. In the current context of global changes and with large forest fires increasing in frequency, extent and intensity, its study and its temporal and spatial understanding are crucial, both at the regional and national scales.

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INTRODUCTION

Large forest fires (LFF) are a concern for today's societies and pose a direct threat to the environment, infrastructure, people and the economy (PARENTE; PEREIRA, 2016; WRIGHT; ROY, 2022). The last decades have witnessed the occurrence of several forest fires, under extreme weather conditions and in locations scattered around the globe, such as in Brazil in 1998, in Portugal in 2003, 2005, 2017 and 2022, in Greece in 2007 and 2018, in the United States of America in 2007, 2020, 2021 (California), in Australia in 2003 (Canberra) and 2009 (Victoria), in Russia in 2010, in Spain, Chile or Canada in 2022 (BENTO-GONÇALVES, 2022a; DE LA BARRERA et al., 2018; FERREIRA-LEITE et al., 2015; TEDIM et al., 2013, 2020; WILLIAMS et al., 2011).

In several regions around the world, wildfires have historically occurred, even in areas with less prone climates, resulting in significant environmental impacts at many levels (BALCH et al., 2022; BLOEM et al., 2022; FERREIRA-LEITE et al., 2013b; JONES et al., 2022; KHARUK et al., 2021; MANCILLA-RUIZ et al., 2021; OLIVEIRA et al., 2014; ROCES - DÍAZ et al., 2022; SIMON, 2004; TYMSTRA et al., 2021; WANG et al., 2022). In recent decades, Europe has faced a high number of forest fires and an extensive burnt area, with distinct spatial and temporal patterns resulting from changes in the availability of fuel material and weather conditions (FERNANDES, 2013; FERNANDEZ-ANEZ et al., 2021; PEREIRA et al., 2013; PEREIRA et al., 2014; SANTOS et al., 2023; TEDIM et al., 2018; VIEIRA et al., 2023; VILAR et al., 2016).

Portugal is one of the European countries most susceptible to and affected by forest fires (BROWN et al., 2018; LOPES et al., 2022; PARENTE; PEREIRA, 2016; PEREIRA et al., 2014; SANTOS et al., 2023). Until the 1970s fires were not considered a crucial problem for Portuguese forests (FERREIRA-LEITE et al., 2016). However, socio-economic changes that began in the 1950s and intensified in the 1970s, particularly the rural exodus, influenced forest dynamics (BENTO-GONÇALVES, 2022b; BENTO-GONÇALVES, 2021; FERREIRA-LEITE et al., 2016; FERREIRA-LEITE, 2013b; LOURENÇO, 2018; NUNES, 2012).

Oliveira et al. (2012) estimated that, on average, about 1.2% of the country's total area suffered fires annually over a 36-year period. According to Brown et al. (2018), fires in Portugal have a larger territorial expression compared to other Mediterranean countries, such as Spain or Greece.

In Portugal, fires are not evenly distributed across the territory, with the Northwest region having the highest incidence (NUNES et al., 2016). The Portuguese climate, with Mediterranean characteristics, which combines the hot season with the dry season, together with an Atlantic feature, with high amounts of precipitation in the cooler season, contributes to the abundant growth of vegetation, especially fine fuels, which feed forest fires, especially in summer (NUNES, 2012).

As already mentioned, in Portugal, during the 1950-70s there was a profound socio-economic transformation in the country, resulting, in the following decades, in an increase in the frequency, size, intensity and destructive capacity of fires, which culminated in the tragedies of 2017 (BENTO-GONÇALVES, 2022b; LOURENÇO, 2018).

In fact, as mentioned above, we have seen an increase in both the number and size of large forest fires and, especially, their destructive capacity. If until 1986 we had never registered a fire larger than 10 thousand hectares, 2003 saw the 20 thousand hectares mark and in 2017 the 40 thousand hectares mark (BENTO-GONÇALVES, 2022b).

In the 70s and 80s of the last century, the then Direção -Geral das Florestas (DGF - was the organisation responsible for forests in Portugal during this period) considered as major fires those whose burned area was greater than 10 hectares, when the dendrocaustological reality was quite different from the current one (BENTO-GONÇALVES et al., 2007). Currently, the official value has changed to 500 ha, by political decision contained in the Resolution of the Assembly of the Republic No. 35/2013, of March 19 (D.R. No. 55, Series I), continuing, however, the Instituto da Conservação da Natureza e das Florestas (ICNF- an organism of the indirect administration of the Portuguese State with the mission of contributing to the valorisation and conservation of aspects related to forest resources and Nature and Biodiversity) in its reports on forest fires, to highlight as large, those greater than 100 ha.

The cartography of areas affected by large forest fires, based on remote sensing technologies and geographic information systems (GIS), is a valuable tool that can be used to analyze geospatial characteristics of fire occurrence (SANTOS et al., 2023; WRIGHT; ROY, 2022). Thus, a better knowledge of the spatial patterns and temporal evolution of LFF is crucial to understand their dynamics and to contribute to the planning of adequate fire

2

prevention and land use strategies (MIRANDA et al., 2012; NUNES et al., 2016).

In this context, based on the cartography developed from Landsat satellite images, for the years 2001 to 2020, in which the LFF in the Portuguese Northwest (greater than 100 hectares) was mapped, with support in Machine Learning tools and Random forest algorithm, implemented in the Google Earth Engine work environment (SANTOS et al., 2023), we sought to understand the relationship between land use and LFF in the Northwest of mainland Portugal. To this end, we aimed to: (i) identify the areas covered by LFF in Northwest Portugal and (ii) the pattern of change in land use and land cover types, as a function of LFF, in the last 20 years, which allows us to analyze the spatial pattern of occurrence of LFF in Northwest mainland Portugal and its relationship with land use, over a 20-year period.

MATERIAL AND METHODS

Study area

The Northwest of Portugal is composed of 4 territorial units of level III (NUTS III), namely Alto Minho (AM), Cávado (C), Ave (A) and Tâmega e Sousa (TS) (figure 1), which corresponds to a territory covering approximately 6.748 km² and encompassing 35 municipalities (AM - Arco de Valdevez, Caminha, Melgaço, Monção, Paredes de Coura, Ponte da Barca, Ponte de Lima, Valença, Viana do Castelo, Vila Nova de Cerveira; A - Cabeceira de Bastos, Fafe, Guimarães, Mondim de Bastos, Póvoa de Lenhoso, Vieira do Minho, Vila Nova de Famalicão, Vizela; C - Amares, Barcelos, Braga, Esposende, Terras de Bouro, Vila Verde; TS - Amarante, Baião, Castelo de Paiva, Celorico de Bastos, Cinfães, Felgueiras, Lousada, Marco de Canaveses, Paços de Ferreira, Penafiel, Resende).

Figure 1 - Study area, northwest Portugal.
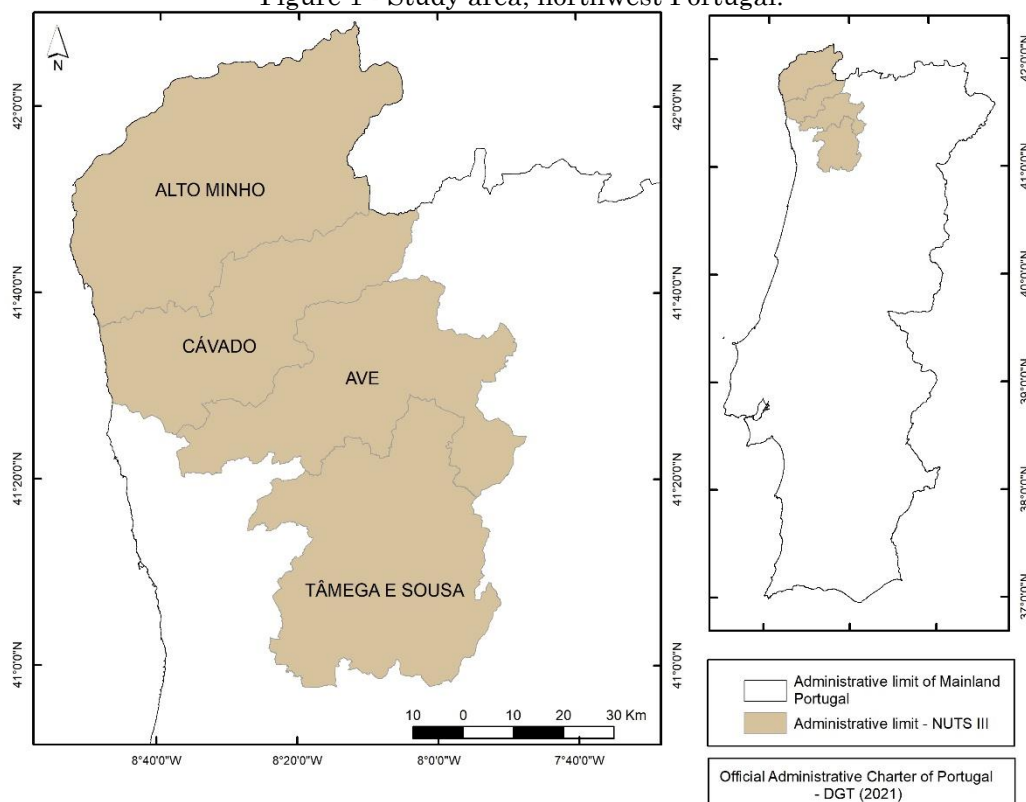
Source: The authors (2023).

The territory presents an urban-dispersed model, characterized by the predominance of diffuse urbanization and industrialization patterns where the plurifunctionality of land use (family farming and industry) are interconnected, giving rise to a diffuse model of industry - commerce - farming - services - housing (BENTO-GONÇALVES et al., 2011) (figure 2), in a context of more or less humanized landscapes (BENTO-GONÇALVES et al., 2006).

It is possible to observe that there is a marked human occupation in the westernmost

sector, near the coast and in the lowlands, which is characterized by high population densities. On the other hand, the easternmost mountain areas, endowed with orographic elements more unfavorable to the development of human activities, have a lower population density and a predominance of forest-agro-pastoral land occupation (figure 2) (BENTO-GONÇALVES et al., 2006; VIEIRA; BENTO-GONÇALVES, 2020).

Figure 2 - Land use and land cover (2018) in northwest mainland Portugal.
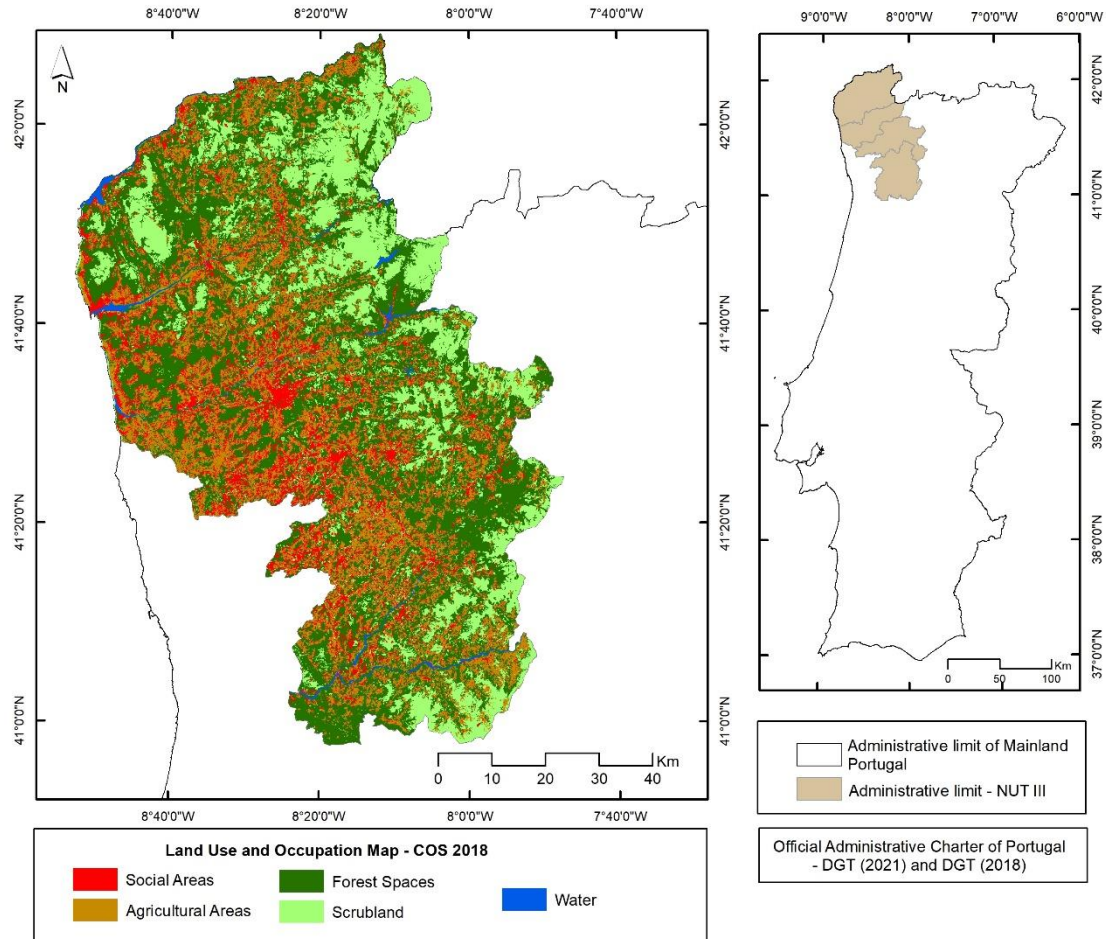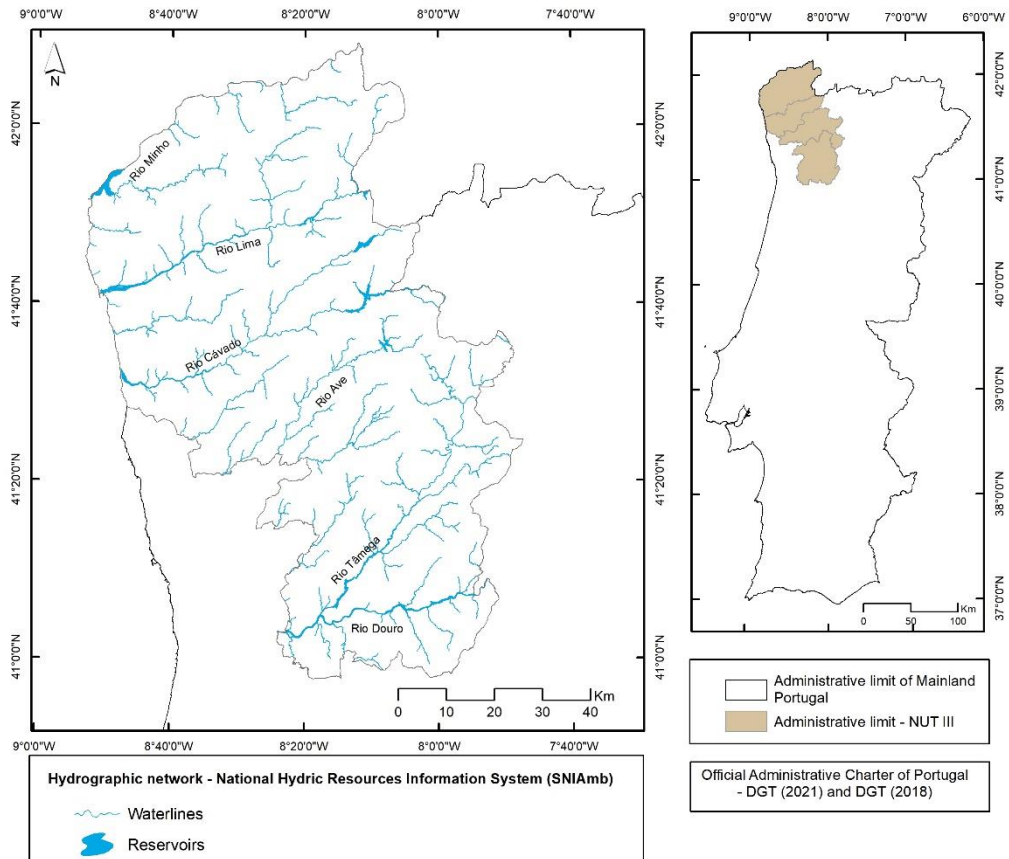

Source: The authors (2023).

This region has unique and distinct characteristics in terms of its geography, climate, hydrology (figure 3), relief (figure 4), and biogeography. The structural elements that are present in this area establish a clear differentiation, both in terms of its geographical shape, climate, vegetation distribution and also in land use and cover, compared to the rest of the Portuguese continental territory (VIEIRA; BENTO-GONÇALVES, 2020).

4

Figure 3 - Hydrographic network in the northwest of mainland Portugal.

Source: The authors (2023).

Figure 4 - Orographic setting of the northwest of mainland Portugal.
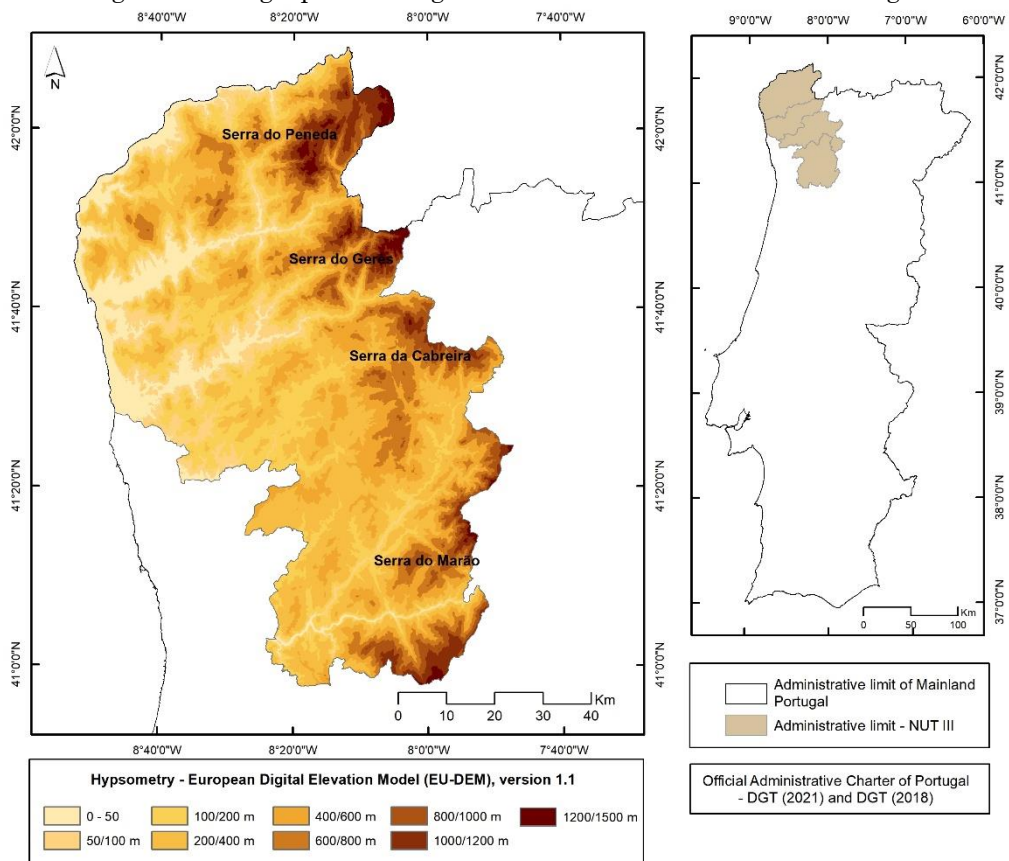
Source: The authors (2023).

It is a territory with Mediterranean characteristics but with a strong Atlantic influence. Temperatures are mild and the region has a significant average rainfall, due to its geographical location, proximity to the Atlantic Ocean and the presence of important mountain ranges (BENTO-GONÇALVES, 2006). Average annual rainfall values vary between 1000 mm and 3500 mm and increase with altitude and as we move away from the coast, which is the most striking feature of the region (COSTA, 2007; VIEIRA; BENTO-GONÇALVES, 2020). The region is characterized by cool winters and moderate to hot summers (BENTO-GONÇALVES, 2006; BENTO-GONÇALVES et al., 2011; DAVEAU, 1985). The average minimum temperature during the coldest month ranges between 2 and 4 ºC, with temperatures below freezing occurring for 15 to 30 days per year. The average maximum temperature during the warmest month ranges between 23 and 32 ºC, with temperatures above 25 ºC occurring between 20 and 120 days per year. The spatial distribution of air temperature is influenced by latitude, but mainly by local factors such as altitude, exposure, proximity to the sea and land cover.

Data

The data used in this paper is derived from the product developed by Santos et al. (2023), for the Northwest of Portugal (Burnt area), to map LFF. The mapping was based on images from the TM (Landsat 5), ETM+ (Landsat 7) and OLI (Landsat 8) sensors, for the period between 2001 and 2020. The cartography results from the use of Machine Learning algorithms in time series, for the detection of burnt areas (SANTOS et al., 2023). The Fourier harmonic model was used to define the outliers in the time series of the NBR spectral index, which represented pixels of possible burnt areas, and then the mask produced with the outliers in the time series was applied and the Random Forest classifier was used to classify LFF, which in this case were considered those above 100 ha, in accordance with the criterion used in the reports of the ICNF.

Spatial data was also obtained for the burnt area and the number of occurrences, provided by the ICNF, and for the administrative boundaries of mainland Portugal and for the data referring to the land use and occupation chart (COS - the COS series started in 1990 and was updated for the years of 1995, 2007, 2010, 2015 and 2018, provided by the Direção Geral do Território (DGT), "General Directorate of Territory is a central service integrated into the direct administration of the State, under the Ministry of the Environment, Spatial Planning and Energy", (table 1). All cartographic data were transformed to the same cartographic scale.

Table 1 - Source and type of data used.

Data	File type	Source
NWPT burnt area	Vector	Santos et al. (2023)
Burnt area	Vector	ICNF (2022)
Occurrence of fires	Vector	ICNF (2022)
COS	Vector	DGT (2018)
Administrative boundary (CAOP)	Vector	DGT (2021)

Source: The authors (2023).

Data analysis

The cartographic information was manipulated and analysed using GIS software, more specifically ArcGis 10.7.1 from ESRI. For the analysis of the recurrence of LFF, using GIS software, the information related to the fires (Burnt Area) had to be organised by individual "layers", containing the year of their occurrence. Subsequently, the mentioned information was converted into raster images, classified into "burnt area" and "not burnt area", with pixel values 1 and 0, respectively. Next, the recurrence of the fire was calculated, and the result obtained was classified according to the following methodology: pixel value of 0, for areas never affected; areas affected 1 time have a pixel value of 1; areas affected twice by the fire have a pixel value of 2, corresponding to 1 recurrence; areas affected three times by the fire have a pixel value of 3, corresponding to 2 recurrences and so on. The resulting image was also vectorised and the areas of the different fire recurrences were calculated. The result allowed us to visualise the burnt areas and the pattern of recurrence over the years (FERREIRA-LEITE et al., 2016).

In order to understand the context of land use types, a relationship was established between the annual burnt area and the land use type by analysing the cartographic data provided by COS (Table 2). Then, a specific

6

analysis was carried out in relation to the type of use, considering only wild spaces, with the classes considered for this analysis presented in Table 3.

Table 2 - Relationship of COS year and years.

COS year	Burnt area
1995	2001 – 2006
2007	2007 – 2009
2010	2010 – 2014
2015	2015 – 2017
2018	2018 – 2020

Source: The authors (2023).

Table 3 - Relationship of the analysis classes for the land use type and the classes defined in the COS.

Analysis class COS		1st level COS	3rd level
Wilderness spaces	Forest	Forest	Hardwood forests
			Coniferous forests
		Agroforestry areas (SAF)	Agroforestry areas (SAF)
	Scrubland	Scrubland	Scrubland
		Open or sparsely vegetated areas	Sparse vegetation
	Pastures	Pastures	Improved pastures
			Spontaneous pastures

Source: The authors (2023).

RESULTS AND DISCUSSION

Burnt area by NUTS - annual variability

The data obtained from the time series of Landsat images, on the burnt area, revealed that a total of 158,741 ha of the Portuguese Northwest burned at least once in the period of the 20 years analysed (table 4), which represented about 23.5% of the studied territory (table 5). The temporal variability of the burnt area indicated that on average annually ~13,800 ha were affected by LFF (FERREIRA-LEITE et al., 2013a; PARENTE et al., 2016; SANTOS et al., 2023; TEDIM et al., 2015) (table 4).

Table 4 - Cumulative burnt area and average annual burnt area from 2001 to 2020 by NUT III and Wilderness areas.

NUTSIII	NUTS area (ha)	Wilderness spaces (ha)	Area burnt at least once (ha)	Cumulative burnt area 20 years (ha)	Average area burnt annually (ha) / Standard deviation
Alto Minho	221.884	159.355	64.436,7	108.647,8	5.432,4 / 7.684
Cávado	124.579	70.383	14.502,3	21.747,0	1.087,4 / 4.886
Ave	145.136	92.736	30.109,3	51.899,6	2.595,0 / 11.807
Tâmega e Sousa	183.152	113.732	49.692,7	95.262,1	4.763,1 / 22.457
Total study area	674.751	436.206	158.741	277.556,5	13.877,8

Source: The authors (2023).

Considering the total area of its territory, it can be seen that wild spaces have the largest extension in NUTS III Alto Minho (72%), followed by Ave (64%), Tâmega and Sousa (62%) and Cávado (56%) (Table 5). From 2001 to 2020, 29% of Alto Minho was mapped as having burned at least once, Tâmega e Sousa 27%, Ave 21%, and Cávado 12%. The annual average burnt area in NUT III Tâmega e Sousa is 2.6% of the Portuguese Northwest, followed by Alto Minho with 2.45%, Ave with 1.79% and Cávado with 0.87% (Table 5).

7

Table 5 - Wilderness areas, area burnt at least once, accumulated burnt area (20 years) and annual average burnt by NUT III.

NUT III	Wilderness areas by NUTS (%)	Area burnt at least once by NUTS (%)	Accumulated burnt area in 20 years by NUTS (%)	Annual average burnt by NUTS (%)
Alto Minho	72%	29%	49%	2,45%
Cávado	56%	12%	17%	0,87%
Ave	64%	21%	36%	1,79%
Tâmega e Sousa	62%	27%	52%	2,60%
Total study área	65%	23,5%		8%

Source: The authors (2023).

The annual burnt area, identified by us based on the defined methodology, varied over the 20 years, with the minimum value in 2014 (679.5 ha) (Figure 5) and the maximum in 2005 (73,025.1 ha) (Figure 5). There were 4 years (2010, 2013, 2016 and 2017) in which the burnt areas of LFF exceeded 20,000 ha. With regard to the annual values of the burnt area in LFF according to Santos et al. (2023), figure 5 also shows the annual values for LFF, indicated by ICNF, as well as the number of occurrences also recorded by ICNF. It can be observed that the values recorded by ICNF are always higher than those of Santos et al. (2023), but show similar behaviour. Although the highest annual value was recorded in 2005 (73025 ha), in the first decade analysed (2001 to 2010), it was in the second decade (2011 to 2020) that a higher number of annual occurrences of LFF was observed. However, it is interesting to note that the burnt area values indicated by ICNF are, as a rule, higher than those identified by the mapping carried out by Santos et al. (2023), probably as a result of the different methodologies implemented to obtain the data.

Figure 5 - Annual burnt area and number of occurrences of large forest fires from 2001 to 2020.
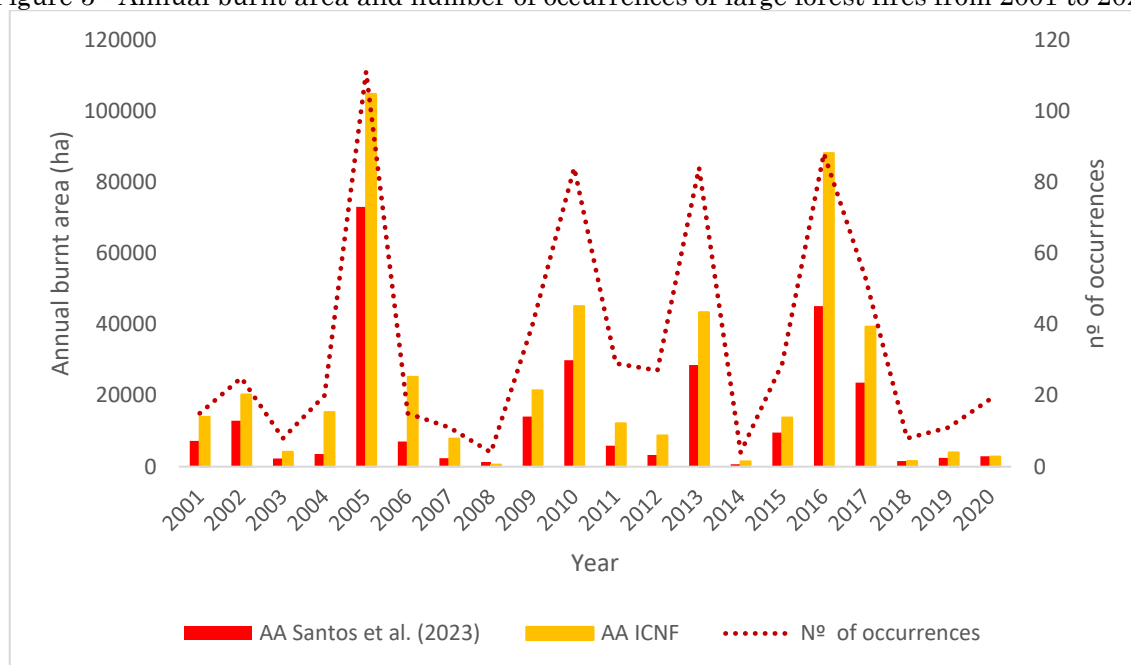
Source: The authors (2023).

After the 1970s of the 20th century, there has been a significant increase in the number of forest fires and the extent of the affected areas in Portugal. This can be attributed to several causes, including socioeconomic changes that resulted in the abandonment of large rural areas, making them prone to intense fires due to biomass accumulation. The systematic and recurrent use of fire by populations, although an ancient practice in Mediterranean culture where fire is an integral part of ecosystems, also

contributes to the occurrence of these fires (LOURENÇO, 1991; 2018).

In densely populated areas, such as the Portuguese Northwest, where there is a mixture of urban and rural areas, the existence of urban-forest interfaces increases the likelihood of fires, especially due to the ease of ignition. Studies show a significant relationship between population density and fire occurrence, especially in Mediterranean regions. Anthropogenic pressure in these areas results in the expansion of urban-forest interfaces and the demand for recreational activities, among many others, in natural spaces, which affects fire regimes (BADIA et al., 2011; GANTEAUME et al., 2013; GANTEAUME; JAPPIOT, 2013; LOURENÇO, 2018; MARTÍNEZ et al., 2009; NUNES et al., 2016; PARENTE et al., 2018).

Monthly burnt area

The information on the burnt area per month was obtained from the results presented by Santos et al. (2023), using the date of the pixels used to classify the burnt areas. These data refer to the date when the fire spot was first identified in the classification and are available in the vector file database. In this dataset, it is possible to identify the months in which most of the burnt area was detected, which helps to understand the monthly distribution of large fires in the Northwest region of Portugal (figure 6). Analysing the monthly data, it is observed that most fires occurred in the summer and early autumn months, reaching the maximum peak in July (average 2.57 ha), August (average 8.975 ha), September (average 5.357) and October (average 3.739 ha). These months correspond to the hottest and driest period in the region.

Figure 6 - Seasonal patterns of large forest fires in north-west Portugal by month for the period 2001-2020 (2 - February, 3 - March, 4 - April, 5 - May, 6 - June, 7 - July, 8 - August, 9 - September, 10 - October, 11 - November, 12 - December)
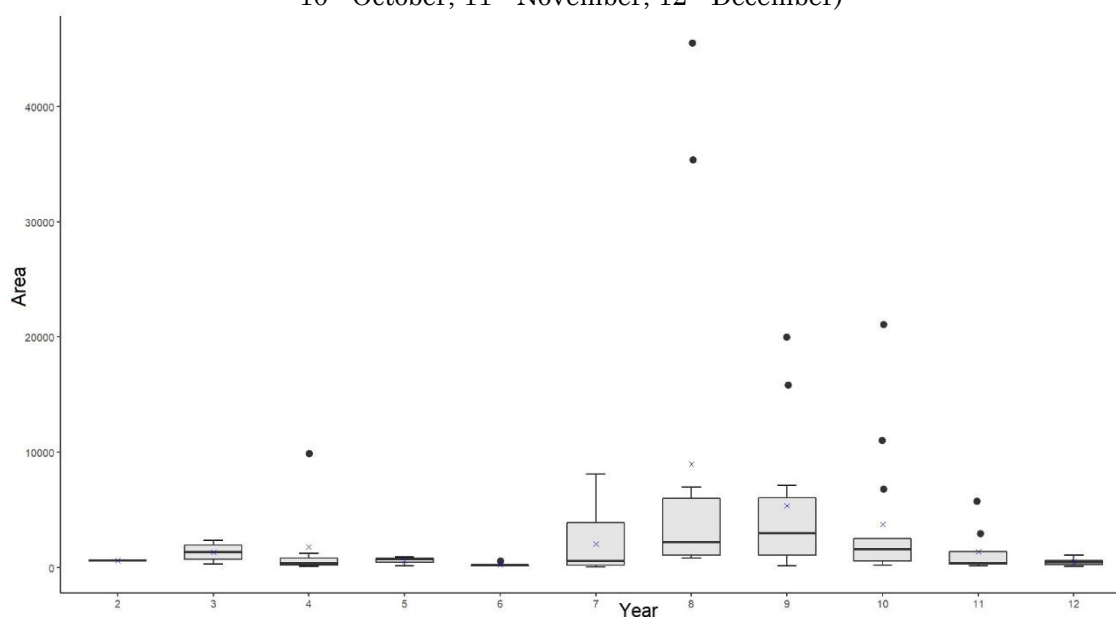
Source: The authors (2023).

The fundamental factor for maintaining high temperatures with strong air dryness, in addition to the joint circulation of Atlantic or European anticyclones with the summer thermal low, is the physiognomy of the thermal field. In other words, when, regardless of the type of anticyclone with which it is combined, either the axial Iberian or Afro-Iberian thermal trough which is located on the Portuguese coast, or in the context of this trough a low-pressure core is individualised immediately south of the Iberian Peninsula, the easterly flows carry continental tropical air masses with a predominantly Iberian trajectory or with a long trajectory in northwest Africa. At these low levels of atmospheric dynamics, the highest temperatures can be observed in association with the lowest relative humidity values in mainland Portugal, generalised even on the western coastal front (BOTELHO et al., 2014; FERREIRA-LEITE et al., 2017; PEREIRA et al., 2005).

However, it is important to highlight that in the first months of the year, especially in March, considerable values of burnt area were recorded (figure 6), drawing attention to events outside

9

the expected season of occurrence of LFF (FERNANDES; LOURENÇO, 2018), but which corresponds to the annual cycle of some northern regions, which include a secondary peak of fire activity centred on March, resulting from agricultural burning and slash-and-burns (AMRAOUI et al., 2015; PARENTE et al., 2016; TRIGO et al., 2013).

Incidence and recurrence of large forest fires

The mapping of the spatial distribution of burnt areas (Figure 7) confirmed the high vulnerability of this territory to LFF, with particular incidence in mountainous wilderness areas. The localisation of burnt areas in the region is influenced by the distribution of wild spaces (scrubland and forest stands), revealing a greater tendency to the occurrence of fires mainly due to the presence of large continuous vegetation patches, in particular in the mountainous areas in these spaces (MENESES et al., 2018).

Figure 7 - Spatial distribution of burnt areas in LFF' in the period 2001 and 2020.
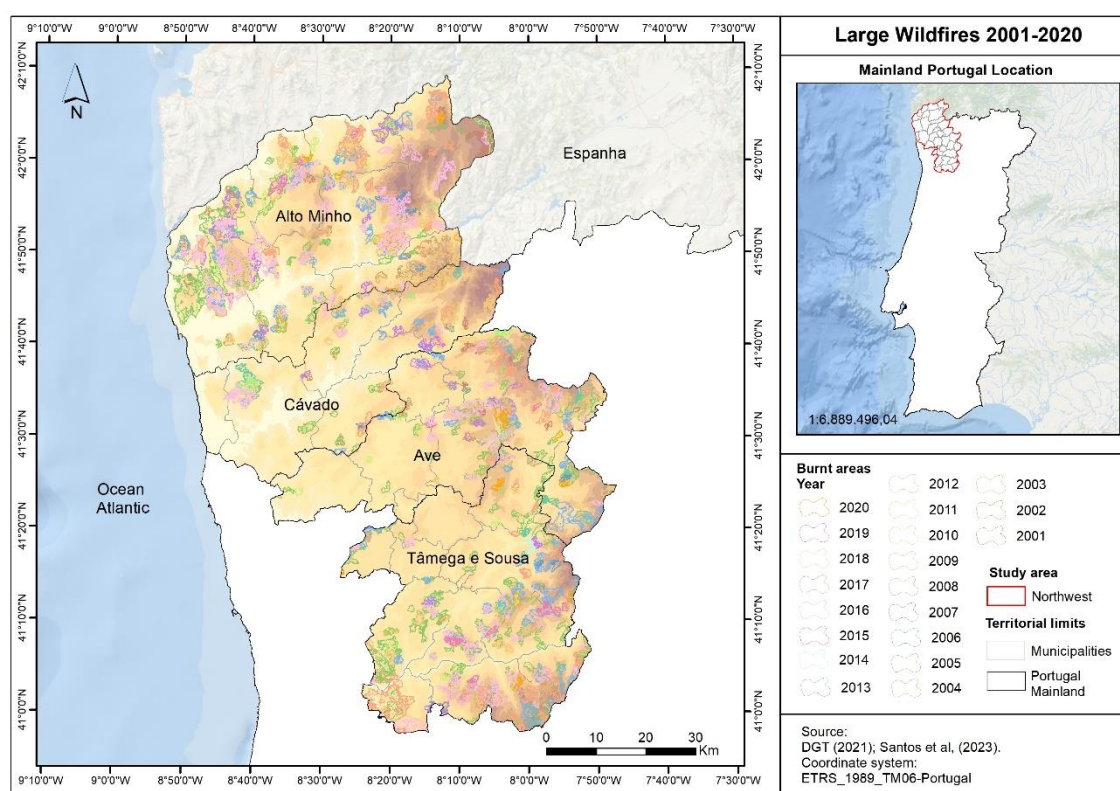
Source: The authors (2023).

Forest fires are recurrent events in mainland Portugal (FERREIRA-LEITE et al., 2016; FERREIRA-LEITE , et al., 2013b; GOMES, 2006; MENESES et al., 2018; NUNES et al., 2016; OLIVEIRA et al., 2012; PARENTE et al., 2018; SÁ et al., 2018). In this sense, and in order to know the spatial incidence of LFF, we prepared the recurrence map of large fires, which indicates the maximum number of incidences and recurrences, that is, the maximum number of times each area was travelled by LFF, in the period from 2001 to 2020 (figure 8).

Figure 8 - Spatial distribution of LFF recurrences between 2001 and 2020 in northwest mainland Portugal.
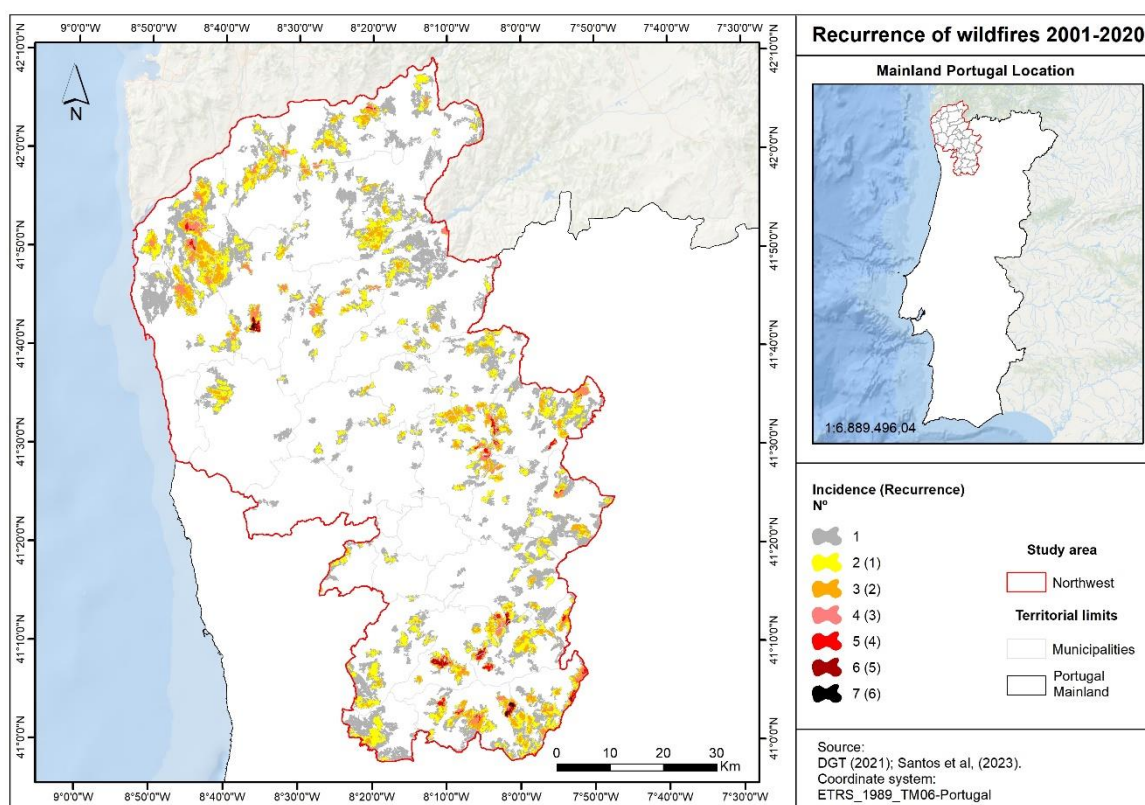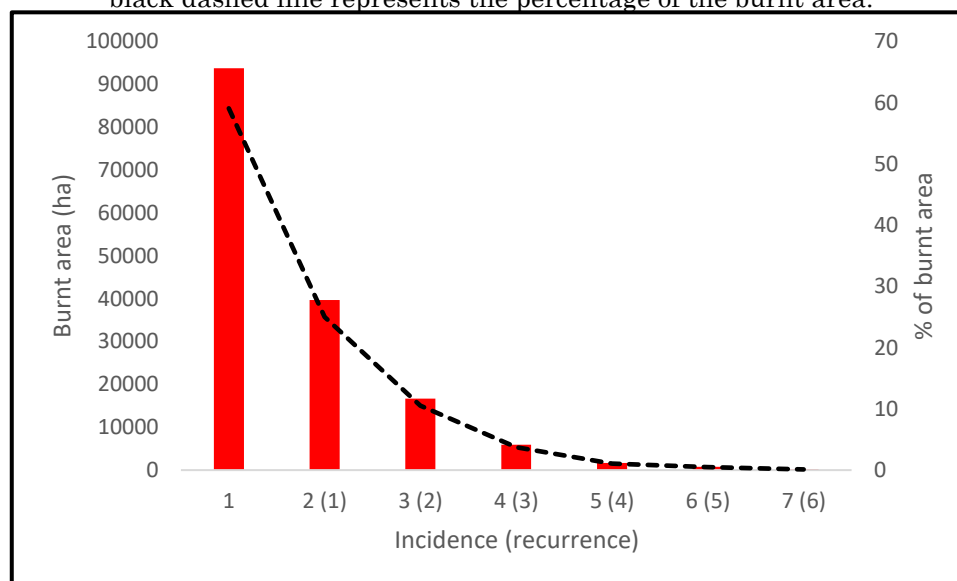

Source: The authors (2023).

We can verify that the maximum recurrence observed in this area, over the 20-year period, was 7 incidences, i.e. there was a maximum recurrence of 6 LFF (figure 8), which demonstrates the fact that this territory is subject to frequent and sometimes large manifestations of forest fire risk (FERREIRA-LEITE et al., 2010). The analysis of forest fire recurrence data over a 20-year period revealed that 40.9% of the burnt area was affected by two or more fires between the years 2001 and 2020 (figure 9). The areas where LFF show the highest recurrence are, with particular incidence, the municipalities of Caminha, Ponte de Lima, Cabeceiras de Basto, Fafe, Amarante, Marco de Canaveses, Baião, Resende and Cinfães.

The recurrence of forest fires indirectly reflects all the variables involved in the process, ranging from the physical conditions of the environment to the direct and indirect causes of fires, mainly of human origin. In addition, recurrence is also related to the efficiency or otherwise of fire prevention, surveillance, detection and fighting measures (FERREIRA-LEITE et al., 2010; MENESES et al., 2018).

Figure 9 - Burnt area and percentage of burnt area by recurrence class between the years 2001 to 2020. The bars in red represent the value of the burnt area in hectares per occurrence class, the black dashed line represents the percentage of the burnt area.
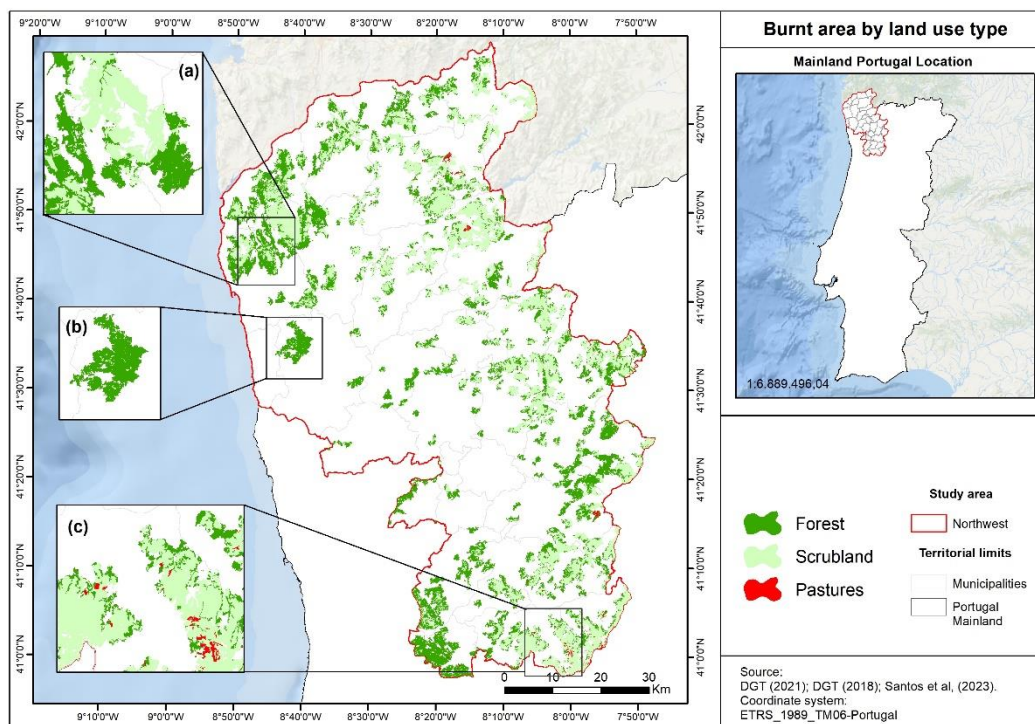

Source: The authors (2023).

Ferreira-Leite et al. (2016) reports that, in the Northwest region with high amounts of precipitation where biomass production is high, grasses and shrubs regenerate more quickly after fires. Some areas are also characterised by increased agricultural and pastoral pressure or intense land abandonment, which has triggered very significant changes in the landscape by promoting the spread of vegetation through natural regeneration. The increase in combustible biomass leads farmers and, in particular, livestock farmers/pastoralists to start fires to control the spread of shrubs and facilitate the regeneration of grasses (FERREIRA-LEITE et al., 2016).

Burnt area by land use type

The maps of the annual burnt areas were superimposed on the COS maps available for the mapped years, thus obtaining the annual burnt area by land use class (figure 10). The results showed that 58.9% of the LFF occurred during the 20 years studied affected the scrub type vegetation class, 40.7% the forests and only 0.4% of areas destined to pastures. There is also a set of islands of unburned vegetation, which partly explains the differences between the values mapped by Santos et al. (2023) and ICNF (figures 5 and 10a).

Figure 10 - Burnt area by land use class between 2001 and 2020. (a) Example of unburned vegetation islands in the municipality of Viana do Castelo, (b) example of burned area only in forest spaces in the municipality of Barcelos, (c) example of burned area with scrub, forest and pastures
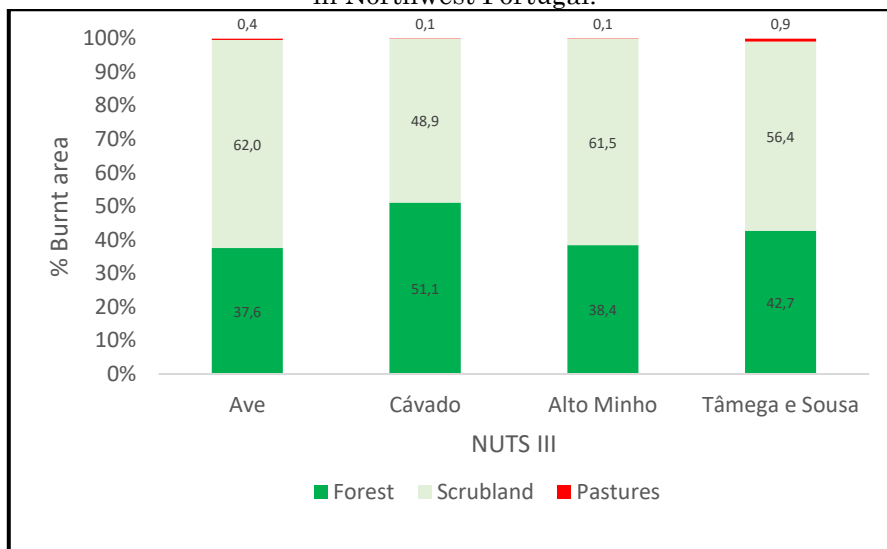

Source: The authors (2023).

Forest evolution in Portugal followed a similar pattern to that of the Mediterranean region where fire was used to destroy the original forest, giving way to pastures, and wood was used as fuel and as a raw material, particularly in construction (FERREIRA-LEITE et al., 2013a).

The abandonment of rural areas led to a reduction of the population in forest areas and introduced major changes in the traditional economy that was mainly based on agriculture, pastoralism and forestry. Forests were no longer managed, scrubland was no longer mown because it had no further use, and firewood was no longer used as a source of energy, leading to the accumulation of biomass in forests (FERREIRA-LEITE et al., 2013b; LOURENÇO, 1991, 2018). Thus, the social and economic changes and the changes in habits and customs that occurred, caused profound changes in the

relationship between communities and the nearest forests, thus paving the way for LFF (FERREIRA-LEITE et al., 2013a).

The distribution of the total burnt area by land use class shows differences between the 4 NUTS III regions that make up the northwest of mainland Portugal (figure 11). It can be seen that in the NUTS III region of Ave the land use class with the largest burnt area, with 62%, was scrubland, followed by forests with 37.6%. The same pattern was observed in the NUTS III of Alto Minho, with 61.5% of bushes and 38.4% of forests and in Tâmega e Sousa, with 56.4% of bushes and 42.7% of forests. The NUTS III of Cávado showed a different behaviour, having burned, in the 20 years under analysis, more forest (51.5%) than scrubland (48.9%). Regarding pastures, 0.9% was recorded for Tâmega e Sousa, 0.4% for Ave, and 0.1% for both Cávado and Alto Minho.

Figure 11 - Percentage (%) of total burnt area between 2001 and 2020, by land use class, in NUTS III in Northwest Portugal.
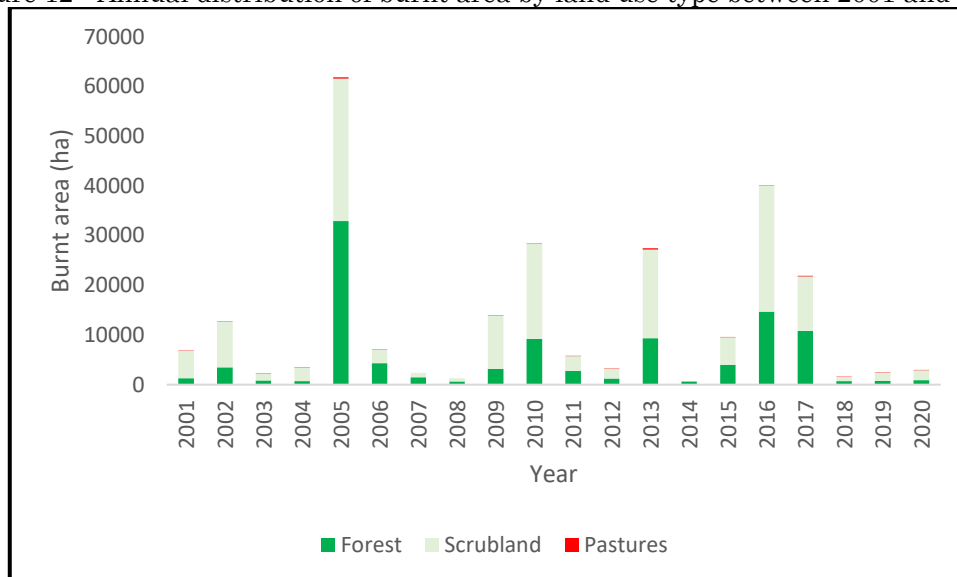

Source: The authors (2023).

The annual pattern of burnt area by land use type varied over time in Northwest Portugal (Figure 12), with the smallest area being recorded in 2014 (679.5 ha) and the largest occurring in 2005 (73025.1 ha). The other years in which the occurrences of large fires reached a value above 10,000 ha were: 2002, 2009, 2010, 2013, 2016 and 2017. Those with the smallest burnt area (less than 2,000 ha) occurred in the years 2003, 2007, 2012, 2014 and 2018. During the period studied, the average annual area burned in the "pastures" class was 49.5 ha, for the "forests" class was 5,201.7 ha, and for the "bushes" class was 7,536.9 ha.

Figure 12 - Annual distribution of burnt area by land use type between 2001 and 2020.
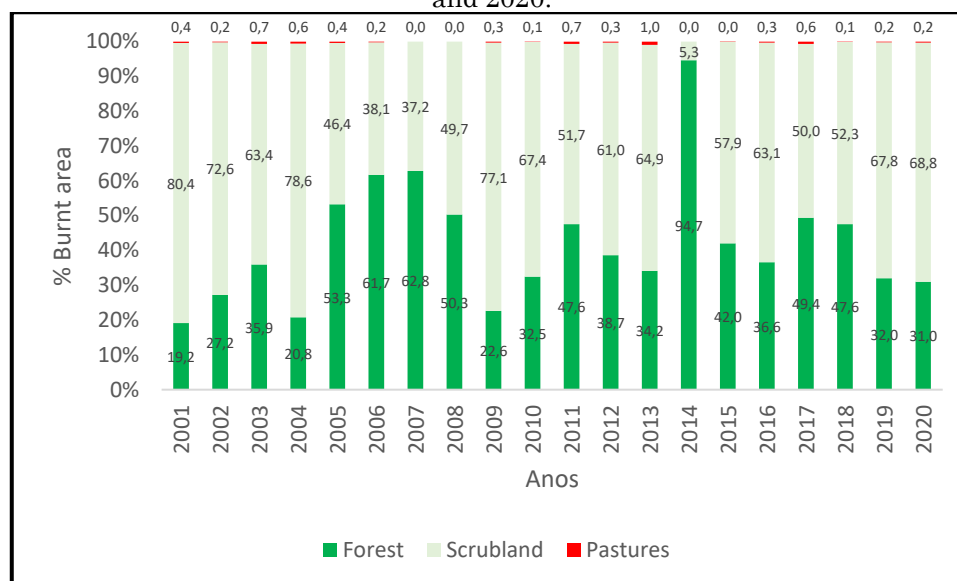

Source: The authors (2023).

In general, the land use class "scrubland" was the one with the highest burnt area over 15 years of the studied time series (2001, 2002, 2003, 2004, 2009, 2010, 2011, 2012, 2013, 2015, 2016, 2017, 2018, 2019, 2020). In the other 5 years (2005, 2006, 2007, 2008, 2014), the largest proportion of the burnt area was in the "forest" land use class (figure 13). This fact corresponds to what has been reported in several studies in the Mediterranean region (GANTEAUME et al., 2013; NUNES, 2012; NUNES et al., 2016; OLIVEIRA et al., 2014; OLIVEIRA et al., 2012; PAUSAS, 2004; SEBASTIÁN-LÓPEZ et al., 2008; TABOADA et al., 2021) and which is related to the renewal of pastures in mountainous areas (NUNES et al., 2016).

14

Figure 13 - Percentage (%) of the annual distribution of burnt area by land use class between 2001 and 2020.

Source: The authors (2023).

CONCLUSION

The understanding of the spatial and temporal distribution and type of land use affected by LFF, at the level of northwestern Portugal, can assist in decision-making, mainly with regard to preventive measures aimed at improving the surveillance, detection and prevention of LFF, as well as providing support for environmental and civil protection policies.

It was found that at least 158,741 ha of northwestern Portugal burned at least once, with the highest value of burnt area for the period studied in 2005. The maximum recurrence of LFF observed in this area was 7 occurrences, i.e. a maximum recurrence of 6 times, and 40.9% of the burnt area was affected twice or more by LFF during the 20 years under study. Scrubland was the predominant land use class burnt in the NUTS III regions of Ave, Alto Minho and Tâmega e Sousa, while in Cávado the most affected class was forests.

In temporal terms, it was found that, in 15 of the 20 years, the class most affected annually was scrubland, while forests were only affected in 5 of those years. In the current context of global change and with large fires increasing in frequency, extent and intensity, sometimes with catastrophic dimensions and consequences, it is crucial to study and understand them in time and space, both on a regional and national scale, as well as to understand the influences of natural and humans factors, studying the causes of ignitions and the conditions/characteristics that facilitate their spread. Thus, future research should address the return time of large fires, the severity reached and test future scenario models for the region.

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AUTHORS CONTRIBUTION