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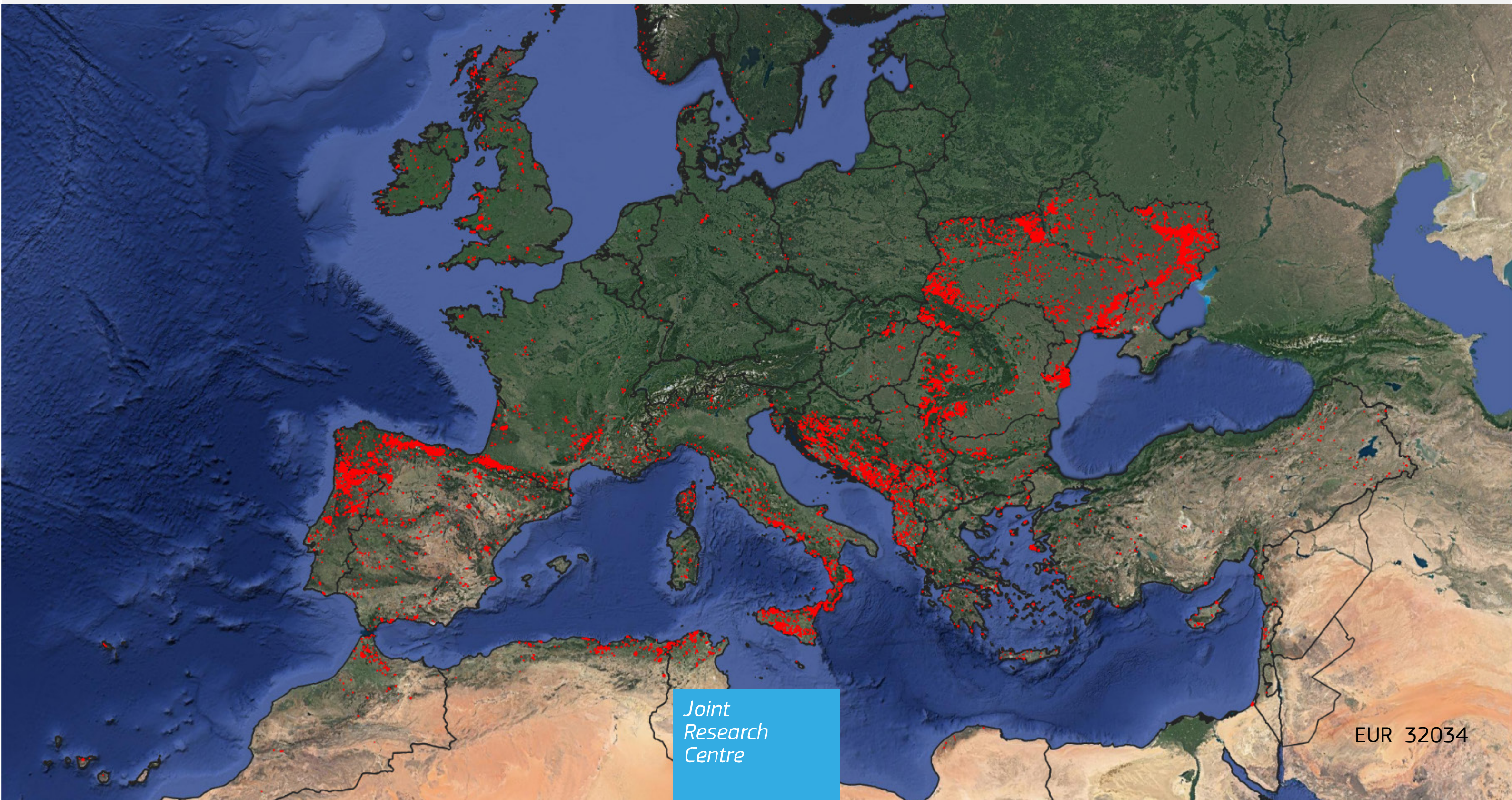
Report on the large wildfires of 2022 in Europe

2024



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- Cover page illustration, EFFIS – Distribution of burnt areas mapped in 2022

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Contents

Abstract

The year 2022 was marked by large wildfires that caused significant social, environmental and economic impacts. Describing some of the most impactful occurrences is essential, not only for historical record but also for drawing lessons that can be important for defining policies and improving strategies, tactics, and operations aiming at a more efficient fire management.

This report was developed within the European FirEUrisk Project, in association with the Joint Research Centre of the European Commission. It describes some of the largest European fires that occurred in 2022, with a special focus on the fire behaviour and the orographic, meteorological and operational conditions, among others, in which it spread. This analysis revealed the great disparity of policies and functioning capabilities that exist in European countries, many of which result from the importance that fires have in different territories. A reflection of lessons to be learned dedicated to each fire event indicates several aspects that can improve the fire management system, both at the national and European Union levels.

This report also includes a chapter dedicated to fires in Ukraine during 2022, when the country is at war. Naturally, all the constraints raised create additional challenges in the management of wildfires. It was considered that this experience brought learning that should be shared, so a specific chapter was dedicated to this issue.

Acknowledgements

The authors of this chapter would like to express their gratitude to the following people who provided data and testimony that were essential to the production of the report. We apologize in advance for any possible omission in the list of acknowledgements. Several people were interviewed who did not wish to be included in this list. To all, our thanks for their contributions to this report.

The production of this report, as well as the work involved, was funded by the Project FirEUrisk – Developing a Holistic, Risk-Wise Strategy for European Wildfire Management. This project has been granted funding from the European Union's Horizon 2020 research and innovation program under the Grant Agreement nº. 101003890.

Chapter	Acknowledgement
2. Overview of fires in Europe	We thank Jesus San-Miguel and the EFFIS team (Roberto Boca, Alfredo Branco, Marco Broglia, Tracy Durrant, Davide Ferrari, Pieralberto Maianti, Duarte Oom, Daniele de Rigo, Elena Roglia, Nicola Scionti, Maria Suarez-Moreno) for their contribution to this part of the report.
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4. Fire of Murça (Portugal)	The authors wish to express gratitude and appreciation to the Portuguese Ministry of Internal Administration for the request to participate in a Group of Experts to analyse the major fires that occurred in Portugal in the Summer of 2022 and for the support given to the research actions required and the access to information and data from all involved agencies. The support given by the following persons and institutions during this research and the corresponding field work is greatly appreciated: Mário Lopes, Mayor of Murça, Ricardo Inácio Commander of the Fire Brigade of Murça, Hugo Silva Commander of the Fire Brigade of Vila Pouca de Aguiar, Miguel Fonseca and Artur Mota from the Sub-regional Command of the National Authority of Emergency and Civil Protection. We would like to extend our gratitude to all relevant parties involved, including the civil protection agents and citizens that provided testimonies, data and insights to the elaboration of this report. Our gratitude to all CEIF-ADAI team that contributed during field work, data analysis, etc., in particular to Carlos Viegas, Thiago Barbosa, Catarina Matos, Babak Chehreh, Pegah Mohammadpour and Andreia Rodrigues.
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By fire event following the order of the respective chapter.

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Chapter 1. Introduction – Miguel Almeida (ADAI)

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Chapter 8. Penteli Attica Fire (Greece) – Nadia Politi, Athanasios Sfetsos, Diamando Vlachogiannis (NCSRD)

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Chapter 11. Fire of Razdel (Bulgaria) – Nina Dobrinkova, Vassil Vasilev, Nadya Tsvetkova (IICT); Yanko Boyanov (FSPP – Yambol); Ilian Gospodinov (NIMH).

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Chapter 13. Conclusions – Miguel Almeida (ADAI)

1 Introduction

In recent decades, the pattern of wildfires has undergone significant changes, marked by a notable increase in intensity, expanding burned areas, and heightened social, economic, and environmental impacts. This shift is especially evident in regions historically less affected by wildfires that nowadays register events of great magnitude that are difficult to control. Understanding the historical record of wildfires, both statistically and descriptively, is crucial for comprehending their evolution over the years. This knowledge allows for reflection on trends and the assessment of policy effects. Additionally, studying wildfires provides valuable insights to enhance fire management efficiency and mitigate associated impacts.

In 2022, Europe experienced weather conditions conducive to a severe fire season, particularly during extremely dry and heatwave-prone summer months. These conditions led to numerous large fires with significant social, cultural, and economic consequences. The Joint Research Centre highlights that 2022 marked the second-worst fire season in terms of impacts since 2000 (San-Miguel-Ayanz, *et al.*, 2023), when data registers from Copernicus had started, surpassed only by the dramatic year 2017. Mediterranean countries, above all Spain and Portugal, reported the highest burned areas. Nevertheless, all 27 European Union countries, except Luxembourg, recorded noteworthy wildfires (JRC, 2023).

Some areas with a nearly non-existent history of wildfires experienced concerning fire events in 2022. For instance, the typically wet region of SW Slovenia and NE Italy witnessed the worst fire in decades (LSA SAF, 2022). The increasing size of wildfires has led to more events crossing borders, becoming international in scope, and imposing coordinated operations involving forces from different countries with diverse firefighting methodologies. Consequently, beyond the growing size, intensity, and impacts of wildfires, additional challenges demand innovative perspectives, policies and strategies. This report aims to contribute to this new paradigm by compiling and analysing relevant wildfires in Europe in 2022. It seeks to extract lessons that can be instrumental in averting future disasters or mitigating impacts associated with similar events.

The outbreak of the war in Ukraine in 2022 has introduced a distinct reality to Europe. Among the various impacts stemming from a conflict, this report highlights the emergence of a new ignition source related to explosions of military origin. Additionally, the enforced confinement reduced citizen activities, and the exodus observed in areas with intense combats have altered ignition patterns and the self-protection capacity of communities. Moreover, the reduction in financial resources, challenges in mobility, and the allocation of civil protection resources to other emergencies, particularly rescue of people from collapsed buildings and medical care, have significantly diminished firefighting capabilities. An analysis of the fire situation during wartime and the operational response, navigating through the difficulties and opportunities posed by these constraints, is of paramount importance for the learning of all nations.

This report includes a dedicated chapter addressing the fire situation in Ukraine during times of war. Moreover, it reports and analyses 11 major wildfires or groups of wildfires that occurred in Europe during 2022, spanning Portugal, Spain, France, Italy/Slovenia, Germany/Czech Republic, Greece, Romania, and Bulgaria (Figure 1). The selection criteria considered their fire event size, associated impacts, the transnational nature of the burned area, and the historically low susceptibility of the regions where these fires occurred. Each wildfire is discussed in a dedicated chapter, beginning with a framing of the event and a characterization of the affected region, the orographic, meteorological, and land-use conditions of the burned area, the fire front spread, and the primary economic, social, or environmental impacts and cascading effects, culminating in a section dedicated to lessons learned. The sequence of the chapters describing the fire events followed an order from West to East, so not evidencing any other sequence related to the burned area dimension, impacts or other.

Figure 1. Fire events addressed in the study.

Data Source: background image adapted from European union Website (https://european-union.europa.eu/).

NOTES:

1) This report results from collaborative efforts between the Steering Committee of the European Horizon 2020 FirEUrisk project (www.fireurisk.eu) and the European Union Joint Research Centre. It follows a previous report (Almeida *et al*., 2021) by the same groups focusing on selected major wildfires in Europe in 2021.

2) To simplify the text exposition, all dates refer to the year 2022, except when another year is explicitly mentioned. The times mentioned are local times in the countries concerned – Portugal: UTC+01h; Spain, Germany, Czechia, Italy and Croatia: UTC+01h; Greece and Romania: UTC+03h.

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2 Overview of conditions in Europe in 2022

2.1 Assessment of weather conditions and fire strength in Europe in 2022.

The current section briefly outlines the 2022 fire season in Europe and compares it with previous years. We have concentrated on basic meteorological variables during the fire season and on the total fire originated $PM_{2.5}$ in 2022. Other variables, such as Fire Weather Index, are considered in other sections of the report.

2.1.1 Weather anomalies in 2022

Two key variables were taken as the most-representative for the fire season: mean temperature during the summer season (May-September), and total amount of precipitations during the same period. The variables were compared with previous years (Figure 2, Figure 3).

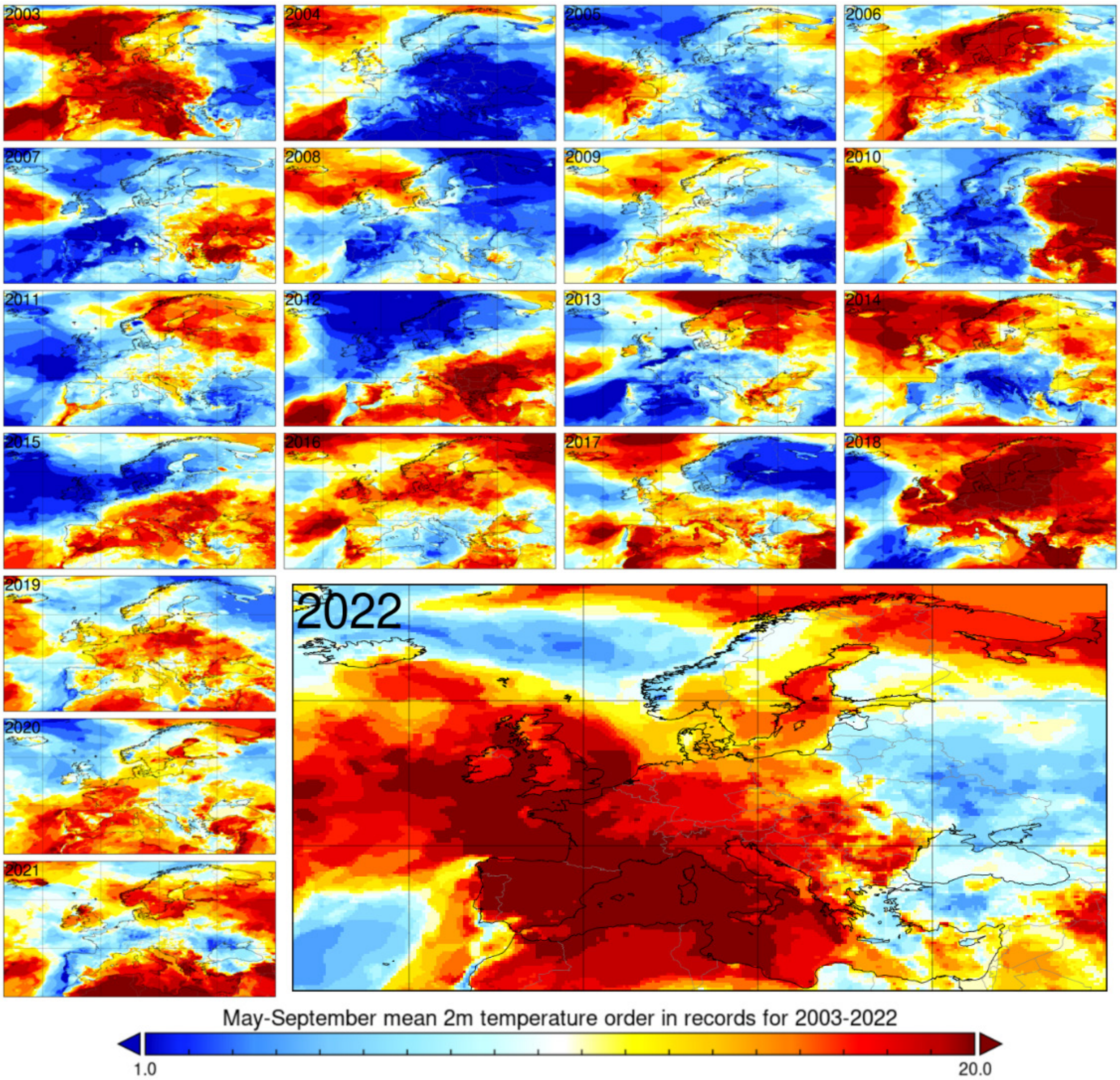

Figure 2. Percentile of the mean-summer near-surface temperature (at 2m above ground) in 2022. The rank 20 (dark red) means that 2022 was the hottest year since 2003 in this grid cell. Conversely, rank 1 (dark blue) denotes the grid cells where 2022 had the coldest summer since 2003.

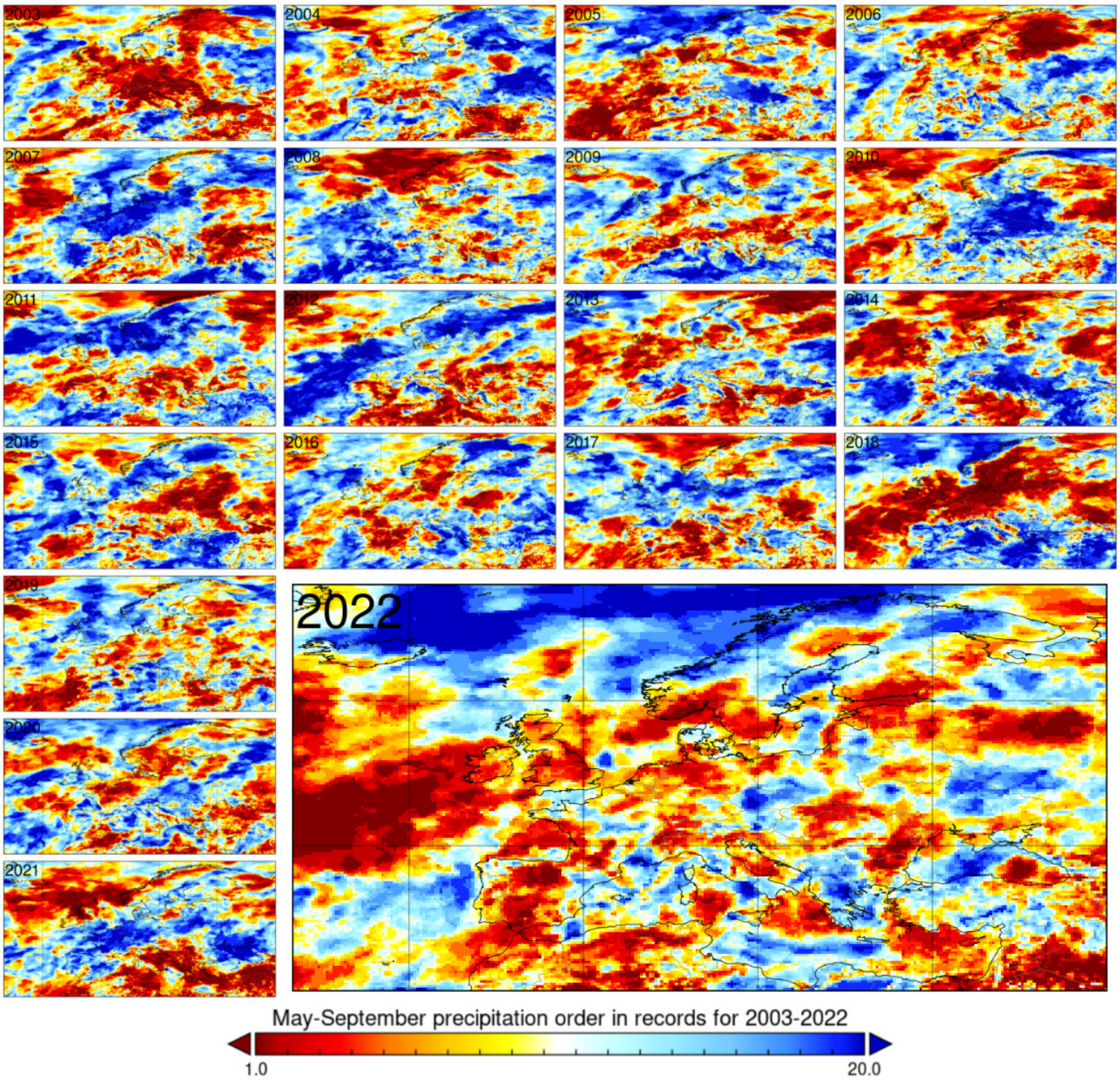

Figure 3. Percentile of the total precipitation amount during summer season 2022. The rank 1 (dark red) means that 2022 was the driest year in the corresponding grid cell. Conversely, dark blue (rank 20) denotes the grid cells where 2022 was wettest year out of 2003-2022 period.

Comparing Figure 2 and Figure 3, one can notice that summer of 2022 was both the driest and the hottest since 2003 in large areas of Spain, Portugal, and Southern France. In general, south-western Europe experienced one of its hottest summers. Precipitation-wise, the pattern is patchier: e.g., Catalonia, despite the record-hot summer, had about-median total precipitation amount, and some areas even received more rain than the 20-years median.

In contrast with South-Western Europe, the east of the continent was noticeably colder than the median – the rank 5-7 over e.g., Central Russia and Turkey, corresponds to 25% of mean summer temperature. The precipitation pattern was also very patchy, with near-record-dry and near-record-wet regions sometimes adjacent to each other.

Comparing the anomalies in different years, one can see that year-to-year variations of the mean-summer temperature are huge: the record-hot year can follow the record-cold one. A similar observation can be made for total precipitation.

This outline, being evidently limited in many dimensions, highlights the main features of 2022: hot summer with often low precipitation in the south-west and a cold one with or without sufficient rain in the east.

2.2 EFFIS Rapid Damage Assessment: 2022 results

The Rapid Damage Assessment module of EFFIS was set up to provide reliable and harmonized estimates of the areas affected by wildfires during the fire season. The methodology and the spatial resolution of the satellite sensor data used for this purpose, from the MODIS sensor, at 250 metre spatial resolution, allowed fires of about 30 ha or larger to be mapped. This methodology was enhanced in 2018 through the use of Sentinel 2 imagery, at 20 metre spatial resolution, which allowed the mapping of fires of about 5 ha or larger. In order to maintain the comparability of the area burnt nowadays with the area mapped prior to 2018, only the number and the area burnt by fires above 30 ha is used for the purpose of comparison of 2022 results with those of previous years.

Although the number of fires mapped in EFFIS is only a fraction of the total number of fires in the countries, the area burned by these fires represent approximately 95% of the total burnt area reported by the countries.

The fires mapped in EFFIS include all those fires that burned natural land. Only fires that burn agricultural land are excluded from the statistics published in the system. Accordingly, fires that burn grassland, shrub land and other wooded land are included in the EFFIS statistics. Agricultural or urban areas that may be affected by the fires are included in the total burnt areas. Information on each type of land cover that is affected by the fires mapped in EFFIS is provided for each fire event. However, total figures of burnt areas may not correspond with national statistics that consider only areas burned in forest areas.

In order to obtain the statistics of the burnt area by land cover type, the data from the European CORINE Land Cover database were used. Therefore, the mapped burnt areas were overlaid with the CLC data, making it possible to derive damage assessment results comparable for all the EU countries.

The total area burned in 2022, as shown by the analysis of satellite imagery, is shown in Table 1.

Figure 4 below shows the scars caused by forest fires during the 2022 season. In 2022, fires were mapped in 45 countries and a total burnt area of 1 401 084 ha was mapped, around 20% more than in 2021.

Table 1. Areas mapped in 2022 estimated from satellite imagery.

Country	***Area (Ha)***	***Number of Fires***
Austria	1034	8
Belgium	428	7
Bulgaria	15461	150
Croatia	34818	290
Cyprus	2650	23
Czechia	1438	2
Denmark	510	30
Estonia	2	1
Finland	372	33
France	74654	1089
Germany	5117	115
Greece	23942	230
Hungary	7960	92
Ireland	3409	69
Italy	68510	1426
Latvia	238	14
Lithuania	34	7
Malta	23	2
Netherlands	331	15
Poland	675	39
Portugal	112063	1236
Romania	162518	1432
Slovakia	374	10
Slovenia	4431	7
Spain	315705	1490
Sweden	515	37
EU27 Total	**837212**	**7854**

Country	***Area (Ha)***	***Number of Fires***
Albania	19591	307
Bosnia & Herzegovina	76473	578
Kosovo under UNSCR 1244	4430	98
Montenegro	26332	260
North Macedonia	4261	74
Norway	2867	84
Serbia	13292	235
Switzerland	235	2
Türkiye	17055	195
Ukraine	275414	2526
United Kingdom	22895	460
Non-EU total	**462845**	**4819**
Algeria	53148	157
Egypt	2163	13
Israel	239	5
Lebanon	249	22
Libya	207	9
Morocco	32680	103
Syria	596	21
Tunisia	11745	155
MENA total	**101027**	**485**
Overall total	**1401084**	**13158**

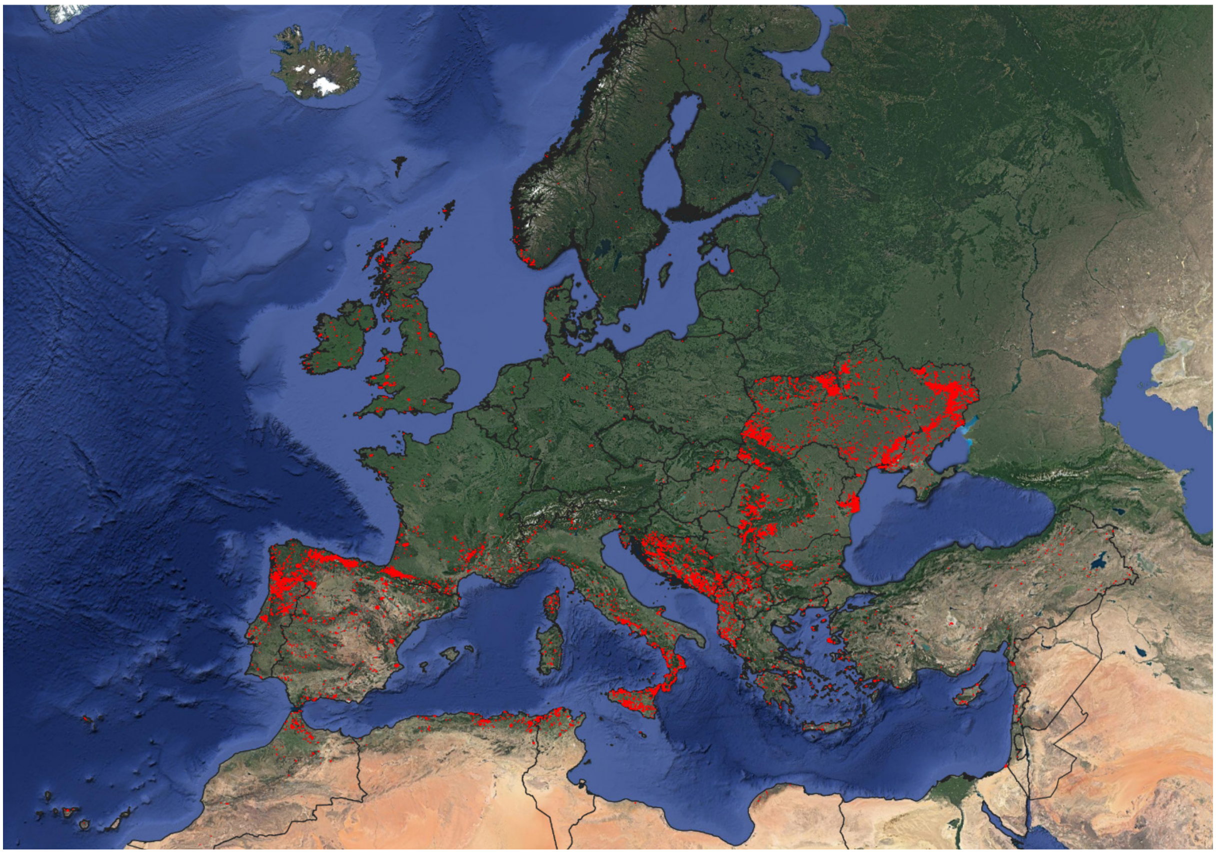

Figure 4. Burnt scars produced by forest fires during the 2022 fire season.

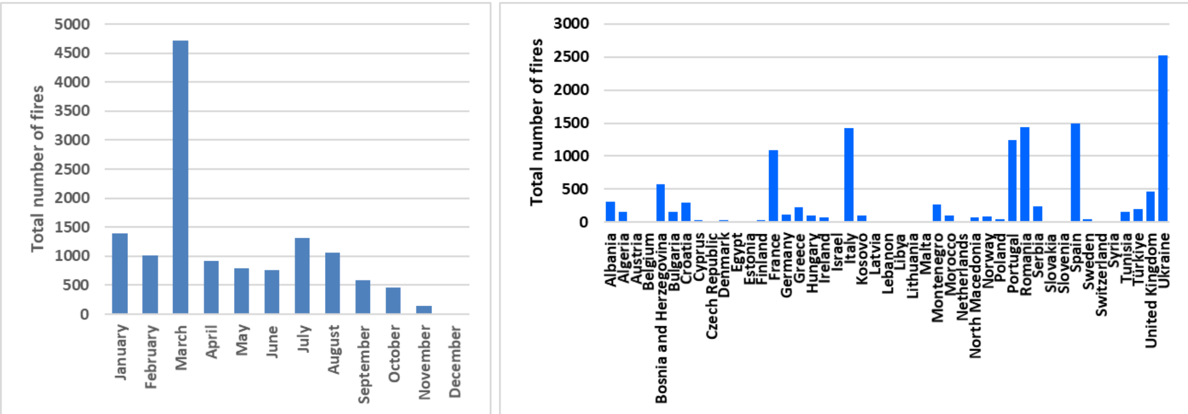

Figure 5. Total number of fires mapped by month and country in 2022.

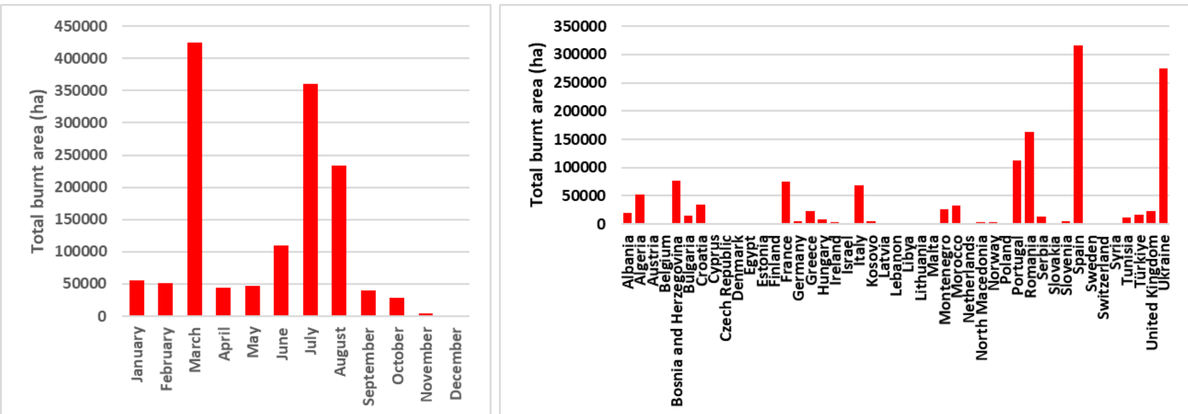

Figure 6. Total burnt area of fires mapped by month and country in 2022.

Damage to Natura2000 and other protected sites

Of particular interest is the analysis of the damage caused by fires to the areas protected within the Natura2000 network, as they include habitats of especial interest which are home for endangered plant and animal species. The category of Natura2000 areas only exists in the countries of the European Union, but some other countries also report equivalent protected areas. The area burnt within the Natura2000 sites and other protected areas for which there is information is presented below.

Country	Area (Ha)	% of Natura2000 Area	Number of Fires
Austria	1033	0.06752	7
Belgium	430	0.17938	7
Bulgaria	6135	0.01745	80
Croatia	12014	0.02607	125
Cyprus	92	0.09443	6
Czechia	1436	0.06888	1
Denmark	476	0.03286	26
France	23527	0.00324	583
Germany	4065	0.00914	103
Greece	9778	0.01424	133
Finland	11	0.01957	3
Hungary	4297	0.03888	46
Ireland	1352	0.04507	31
Italy	17914	0.01094	453
Latvia	155	0.08727	11
Lithuania	2	0.07612	1
The Netherlands	329	0.03858	15
Poland	543	0.01143	15
Portugal	41089	0.01478	441
Romania	102659	0.01211	686
Slovakia	112	0.05362	4
Slovenia	4396	0.08816	5
Spain	133329	0.00377	532
Sweden	135	0.01307	9
EU27 total	**365308**		**3324**
Algeria	9954	5.979709	10
Morocco	394	0.05166	6
UK	6177	0.092324	143
Non-EU total	**108723**		**159**
Total (all)	**474031**		**3483**

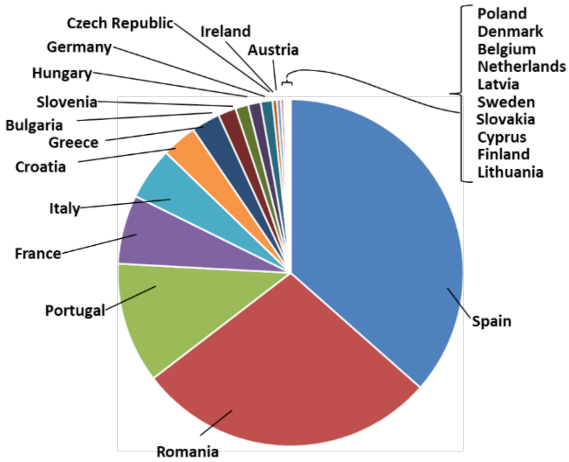

Figure 7. Total area burnt in Natura2000 sites in 2022.

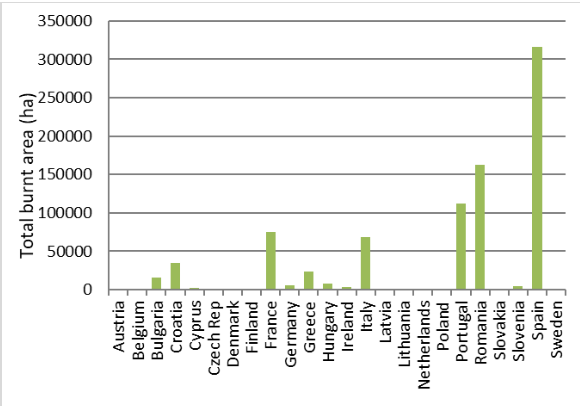

Figure 8. Total mapped burnt area in Natura2000 sites in 2022.

Fires were mapped in 24 of the 27 EU member states (all except Estonia, Luxembourg and Estonia) and three non-EU countries that had available information on protected areas..

The total burnt area in EU Natura2000 sites in 2022 was 365 308 ha, the highest amount mapped in the last 10 years. The damage was particularly concentrated in two countries, Spain and Romania, which between them accounted for two thirds of the total area burnt in protected areas in 2022.

Affected land cover types

In 2022, around half of the total burnt area occurred either in Other Natural Land or Agricultural Land as identified by the 2018 CORINE Land Cover Type classification system and the 2019 Copernicus Globcover classification in regions where Corine was not available. A further 26% was mapped in forest (Broadleaf, Conifer or Mixed). (Figure 9, Figure 10).

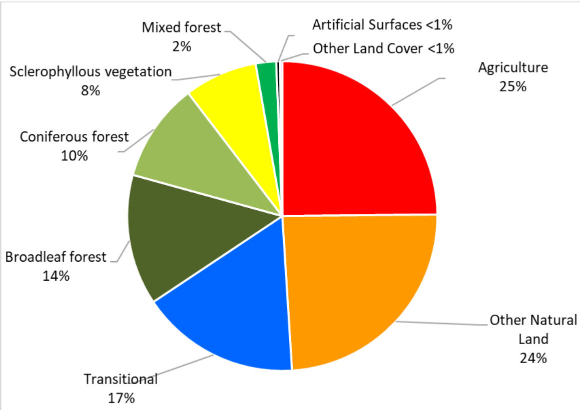

Figure 9. Proportions of land cover types affected in 2022 (all countries, ordered by total burnt area).

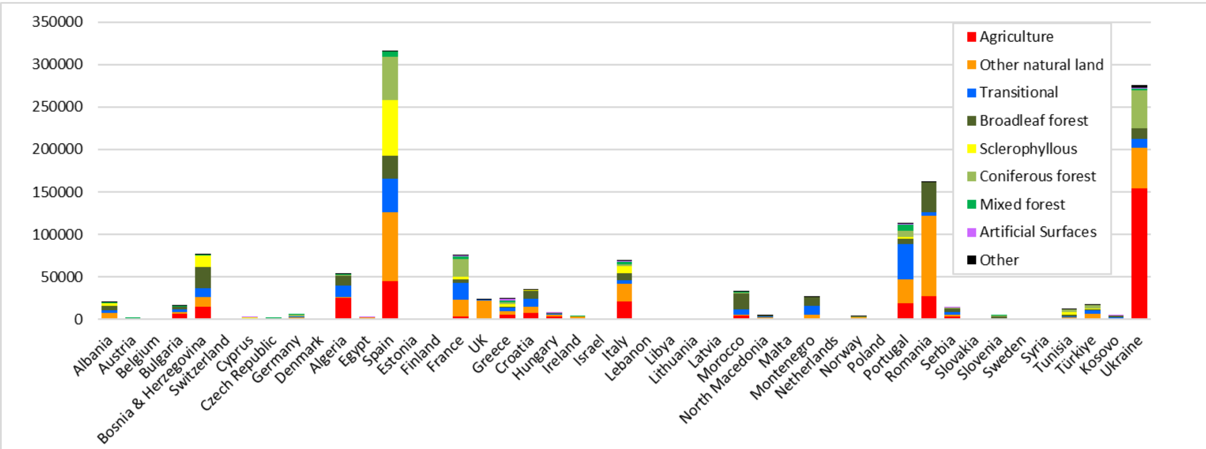

Figure 10. Burnt area in each country in 2022 by CORINE land class.

European countries

In 2022, fires were mapped in 26 of the EU27 countries (all except Luxembourg), burning 837 212 ha in total. This is well above the amount recorded in 2021 (449 342 ha).

There were two main peaks in the year: a first one in March when a very high number of fires occurred in almost every country, and a second larger peak in July from fewer but larger fires.

Of this total, 365 308 ha occurred on Natura2000 sites, three times the amount mapped in 2021. This is equivalent to around 44% of the total burnt area in these countries. Three quarters of the damage to protected areas came from three countries (Spain, Romania and Portugal).

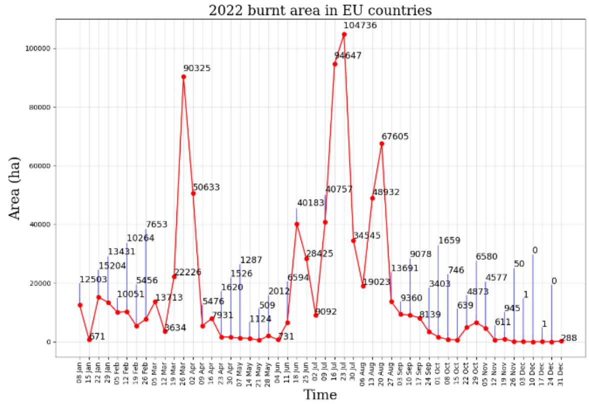

Figure 11. Burnt area weekly evolution in EU27 countries in 2022.

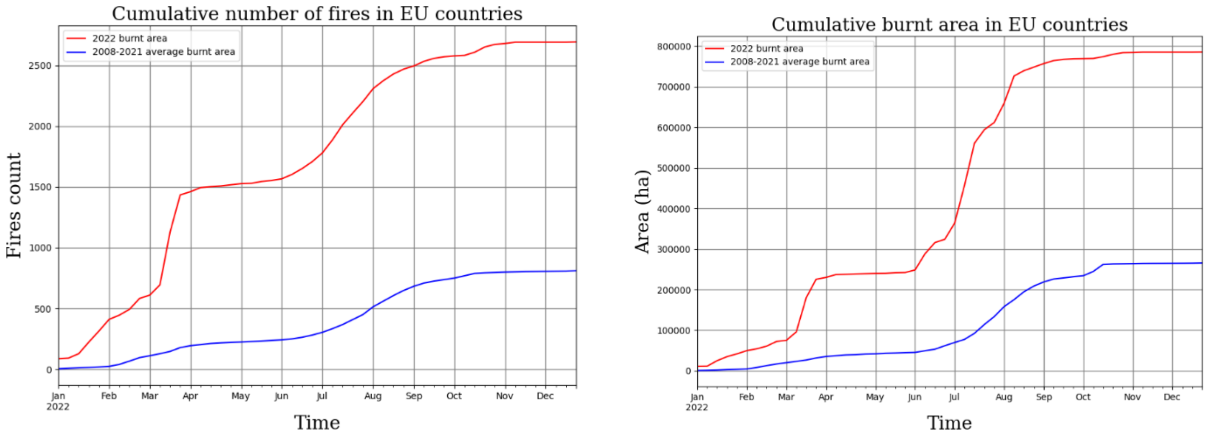

Figure 12. Cumulative number of fires and burnt area in 2022 in EU27 countries (red line) compared with 2008-2021 average (blue line). Fires are filtered to include on

Largest fires mapped by EFFIS in the 2022 season

The following table presents the fires over 3 500 ha that were mapped by EFFIS in 2022. Most of the largest fires of the year were mapped in July and August, but large fires also occurred from January to September. Those fires over 3 500 ha that are included as case studies in later sections are indicated.

Country	Starting date	PROVINCE	AREA_HA	
Spain	17/07/2022	Zamora	32528	Losacio fire, chapter 5
Spain	16/06/2022	Zamora	28046	Ríofrío de Aliste fire, chapter 5
Spain	15/08/2022	Castellón/Castelló	19362	
Portugal	06/08/2022	Beiras e Serra da Estrela	15134	Serra da Estrela Fire, chapter 3
Spain	18/07/2022	Zaragoza	14159	
Spain	14/07/2022	Lugo	13612	
France	07/07/2022	Gironde	13116	
Spain	15/07/2022	Ourense	12735	
Spain	11/07/2022	Cáceres	12687	
Morocco	13/07/2022	Ksar El Keb	12623	
Spain	13/08/2022	Alicante/Alacant	12111	
Portugal	15/08/2022	Beiras e Serra da Estrela	10126	Serra da Estrela Fire, chapter 3
Spain	14/08/2022	Zaragoza	9195	
Romania	18/03/2022	Tulcea	8683	See chapter 10
Morocco	25/07/2022	Larache	8369	
Portugal	17/07/2022	Alto Tâmega	7641	Murça fire, chapter 4
France	09/08/2022	Gironde	7566	
Romania	22/03/2022	Tulcea	7191	See chapter 10
Spain	19/06/2022	Navarra	7144	
Spain	15/07/2022	Ourense	7090	
Ukraine	11/05/2022		6968	See chapter 12
Romania	31/03/2022	Tulcea	6700	See chapter 10
Spain	18/06/2022	Navarra	6531	
Algeria	17/08/2022		6254	
Ukraine	24/03/2022		6252	See chapter 12
Algeria	17/08/2022		5979	
Portugal	21/08/2022	Douro	5850	
France	12/07/2022	Gironde	5806	
Spain	08/09/2022	Granada	5454	
Portugal	08/07/2022	Região de Leiria	5342	
Spain	08/06/2022	Málaga	5042	
Greece	21/07/2022	Evros	4604	Dadia fire, chapter 9
Bosnia & Herzegovina	15/03/2022	Bileća	4594	
Turkey	21/06/2022		4548	
Spain	16/07/2022	Ávila	4460	
Croatia	21/03/2022	Zadarska županija	4225	
Romania	21/01/2022	Tulcea	4037	See chapter 14
Slovenia	19/07/2022	Obalno-kraška	3988	Karst fire, chapter 6
Croatia	22/03/2022	Zadarska županija	3936	
Portugal	12/07/2022	Região de Leiria	3691	
Spain	28/08/2022	León	3619	
Algeria	17/08/2022		3593	
Ukraine	25/02/2022		3570	See chapter 12
Ukraine	27/04/2022		3536	See chapter 12
Bosnia & Herzegovina	20/03/2022	Bosansko Grahovo	3526	

Not all of the case studies described in the following chapters are among the largest fires mapped in the year, but were chosen because of their impacts on the population or on protected sites, or because they were unusual events for the region.

3 Fire of Garrocho / Serra da Estrela (Portugal)

Authors

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3.1 General Description

The Garrocho Fire Event, also known as the "Serra da Estrela Fire," was the largest wildfire in Portugal in the year 2022, with a total burned area of 24 333 ha (ICNF, 2022). It ranks as the sixth largest fire event ever recorded in Portugal. The cause of this fire is not publicly known, and the alert was given at 3:18 on August 6th, to near a river beach in Vila do Carvalho, in the municipality of Covilhã, in the central inland region of Portugal.

The fire primarily spread within the Natura Network Serra da Estrela Natural Park, affecting parts of the UNESCO World Geopark – Estrela Geopark - which holds a special place in the hearts of all Portuguese people. This fire also threatened and affected the area of the Zêzere Glacier Valley which, with its 13 kms of extension, is one of the largest in Europe. The national shock caused by the extensive burning in an ecologically and sentimentally valuable area was significant. Furthermore, it took a considerable amount of time, until the thirteenth day (August 18th), to dominate the fire, which caused great distress among citizens. The fire was officially declared extinguished on September 3rd.

Several favourable conditions contributed to the rapid and intense fire spread. The mountainous terrain with its typical irregular topography, characterized by steep slopes and canyons, created challenges that were increased by poor access in certain areas. Additionally, the period of drought and heatwave (July 29th – August 14th) at the time resulted in extremely low fuel moisture content. Moreover, strong winds, particularly between 09:30 and 21:00, further complicated firefighting operations.

The fire event had two main phases in its progression. In the first phase, it spread predominantly in NNE direction until it was declared dominated on August 15th, after burning approximately 15 000 ha. On the same day, there was a strong rekindling that progressed towards the SEE, reaching a final perimeter of approximately 150 km.

The damage at the wildland-urban interface was not extensive considering the vast burned area and the scattered buildings across the territory. However, this being one of the Portuguese regions with the highest activity in the primary sector, the social impacts were significant. The economic losses extended beyond agricultural and forestry activities, affecting various sectors. The tourism industry suffered significant impacts since Serra da Estrela, renowned for its natural beauty, attracts many tourists throughout the year. The effects on the tourism sector persisted beyond the duration of the fire due to cascading impacts, which will be described further ahead.

3.2 Characterization of the affected area

The Serra da Estrela Mountain includes the Serra da Estrela Natural Park (SENP), which covers a mountainous area located in the central-eastern part of Portugal, spread over the municipalities of Celorico da Beira, Covilhã, Gouveia, Guarda, Manteigas, and Belmonte, and is the most extensive Portuguese protected natural area. The SENP comprises a succession of plateaux stretching from Guarda in the northeast to the Serra do Açor's foothills in the southwest. It occupies an area of medium and high mountains, which includes the highest point of continental territory, at 1993 m of altitude. The uniqueness of the highest parts of the mountain and its geographical situation determines a reproductive isolation of populations of fauna and flora that leads to the differentiation into exclusive species, subspecies and varieties (CISE, 2023).

Starting in the Municipality of Covilhã, the Garrocho Fire spread to 22 parishes of the municipalities of Covilhã, Guarda, Manteigas, Gouveia, Celorico da Beira, and Belmonte (Mendonça *et al.*, 2023), covering an extensive area of the protected landscape (Figure 13).

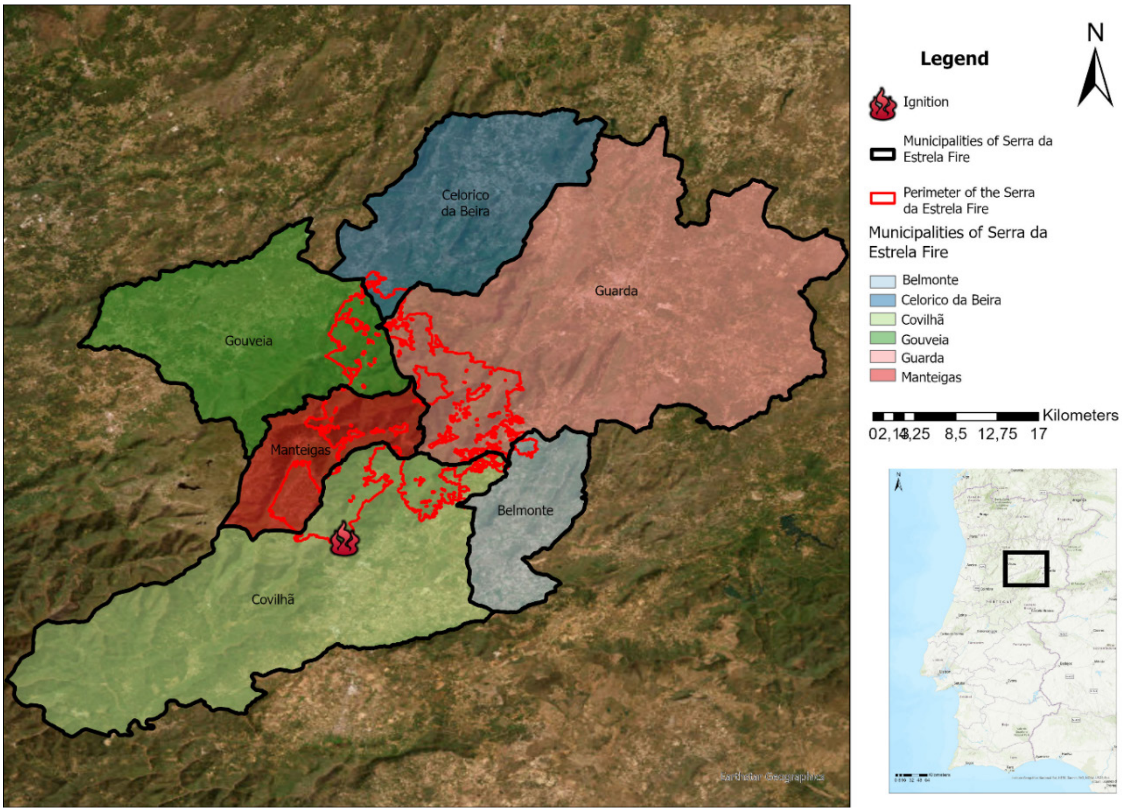

Figure 13. General view of the fire perimeter of the Garrocho wildfire (in black) and the representation of the six municipalities of Serra da Estrela affected by the fire (Celorico da Beira, Covilhã, Gouveia, Guarda, Manteigas, and Belmonte).

Data Source: (EPIC WebGIS Portugal)

The socio-economic markers of the affected municipalities indicate a decrease in the resident population in the 2011 to 2021 period (Table 2). Additionally, a large fraction of the population is more than 65 years old, and the proportion of young people (less than 15 years old) is low. A comparative analysis of these data with the average statistics for Portugal shows that this is a region has demographic difficulties, which has an impact on fire management.

Table 2. Some socio-economic indicators of the most affected municipalities of the Garrocho Fire.

Municipality	Residents (Var. 2011-2021)	Residents/km2*	Age > 65yrs	University education
Covilhã	46 521 (-10.3%)	83.8	29.8%	16.9%
Guarda	40 173 (-5.7%)	56.5	25.2%	7.5%
Manteigas	2 909 (-15.2%)	24.3	37.4%	--
Gouveia	12 222 (-13.0%)	40.8	38.2%	--
Celorico da Beira	6 583 (-14.4%)	26.7	34.9%	--
Belmonte	6 205 (-9.5%)	52.1	31.8%	--
Portugal	10 343 066 (-2.1%)	112.2	23.4%	19.8%

Source: (Pordata, 2023).

The Garrocho Fire was influenced by the three main factors of the fire triangle: a) fuels, b) weather/wind, and c) topography. Due to drought period and heatwave in Portugal, the vegetation was under water stress, and the natural fuel moisture content was very low.

The vegetation affected was composed predominantly of maritime pine forest (*Pinus pinaster*, 8 021 ha burned), shrub formations (7 158 ha burned), other coniferous species such as *Pinus nigra*, *Pinus sylvestris*, *Pseudotsuga menziezii* (939 ha burned), and broadleaves, such as black oak, holm oak, chestnut, beech, birch (2 322 ha burned) (Mendonça *et al*., 2023). The primary fuel management network had a good implementation rate, and the area previously subjected to prescribed burning (679 ha) was reasonable. This figure also shows that in certain parts of the burnt area access was scarce. As it will be seen, this aspect greatly complicated the initial firefighting operations when the fire still had a small area.

The history of Portugal's burned areas in the last twenty-two years shows a predominancy of burned areas and fires in the central region of the country, which despite having fewer ignitions in number, has a bigger extension of burned areas.

Serra da Estrela region has been cyclically affected by large forest fires as shown in Figure 14, which represents the number of times burned since 1975.

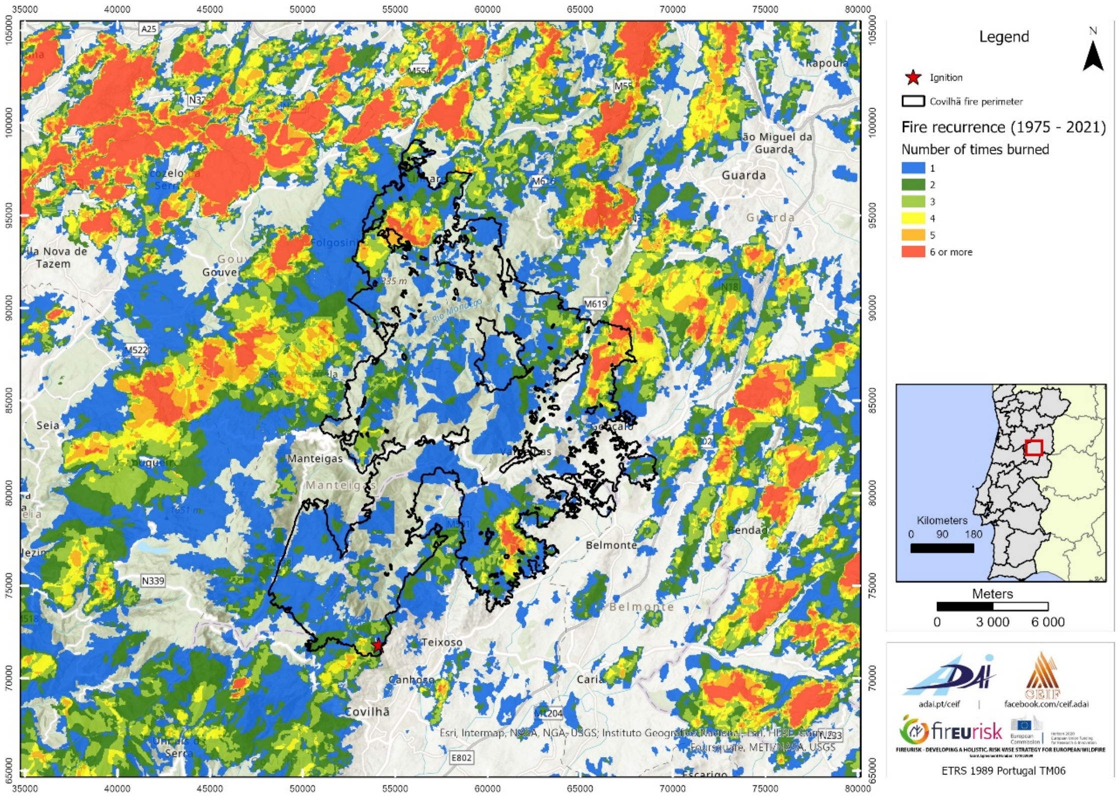

Figure 14. Fire recurrence of the region between 1975 and 2022.

The topography of Serra da Estrela (Figure 15 and Figure 16) was influenced by the geomorphology of granitic mountains and the erosion caused by watercourses and shaped by glacier valleys, and this was also an influencing factor for the fire behaviour. The landscape is dominated by extensive plateaux bordered by steep slopes, where the watercourses are installed, especially at the northern end of the mountain and surrounding areas. In the mountain's southern and southwestern sectors, the landscape is characterized by a succession of individualized undulating forms and a dense and very sinuous drainage network (CISE, 2023). This mountainous topography, characterized by steep slopes, canyons and ravines, increased the number of hot spots in a fire area that reached an outer perimeter of approximately 150 km in length. The Serra da Estrela fire affected altitudes between 444 m and 1 686 m, but 63.6% of the burned area was between 731 m and 1 275 m (Figure 15). The main affected basins were the Mondego River and the Zêzere River.

About 54% of the burned area has slopes between 11° and 25°. Slopes greater than 25° occupy 12.3%, which clearly hindered the direct firefighting (Figure 16). The slopes affected by the fire present a great diversity of exposure, but 43.3% are oriented to the east quadrant.

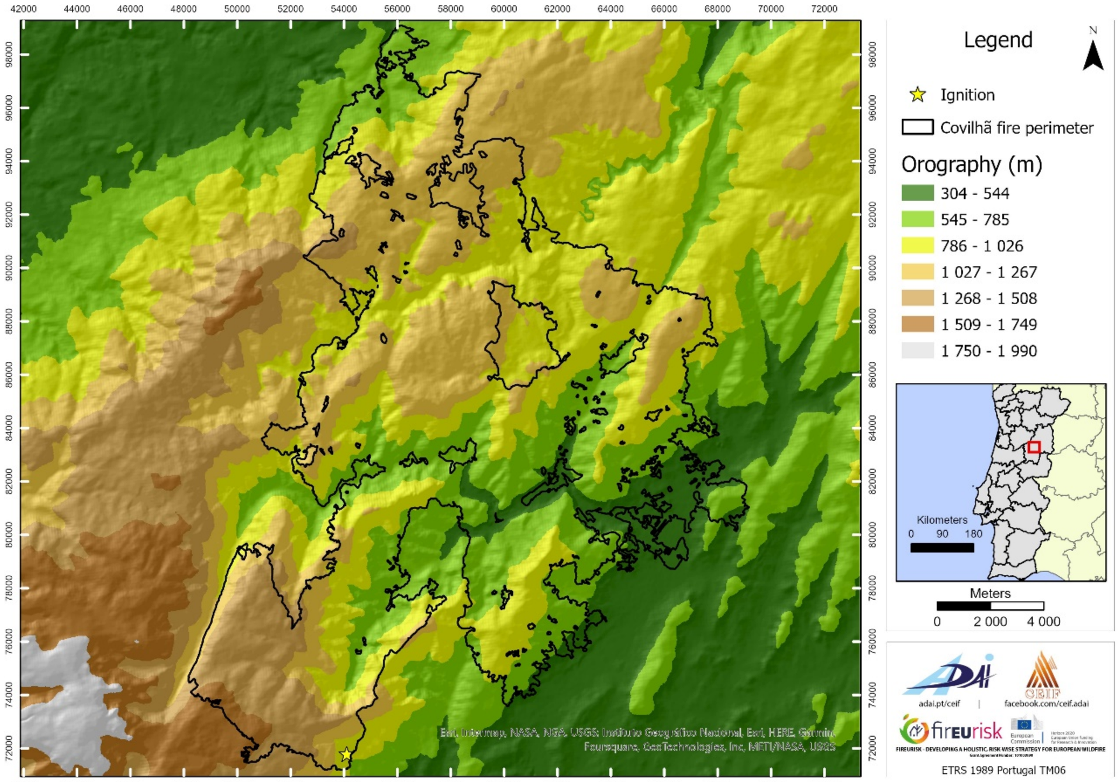

Figure 15. Orography map of Garrocho / Serra da Estrela.

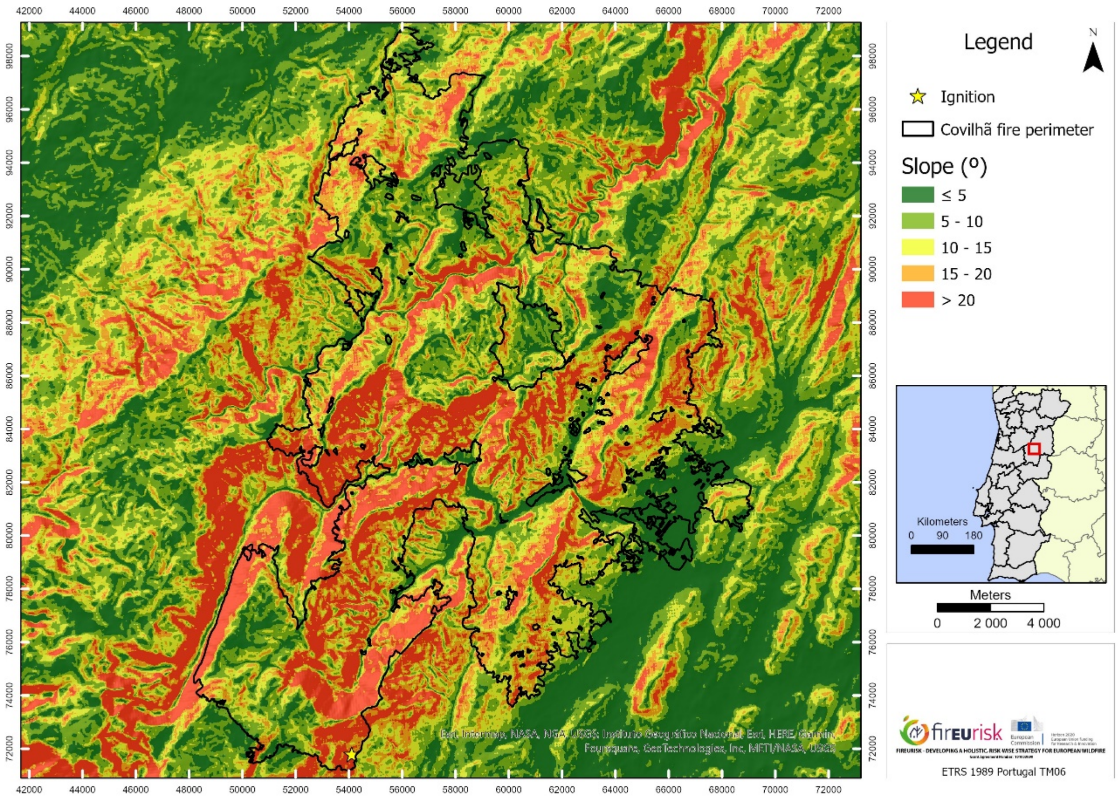

Figure 16. Slope map of Garrocho / Serra da Estrela.

Data Source: (EPIC WebGIS Portugal)

The territory affected by the fire has a low demographic density. The wildland-urban interface boundary is scattered through the Serra da Estrela landscape in small, dispersed villages and farms. The dispersion of buildings can make fire management operations difficult due to the insufficient firefighting resources to respond to all of the isolated and dispersed requests for help. Due the higher vulnerability and low capacity of self-defence, the average elderly population scattered through the territory also increases the need of assistance, so complicating the fire management operations.

3.3 Fire conditions

3.3.1 Meteorological data

The weather station of the of the Portuguese Institute of Sea and Atmosphere (IPMA) located in Covilhã (ID: 687), approximately 5 km from the ignition point, was used to analyse the conditions during the wildfire period (Figure 17).

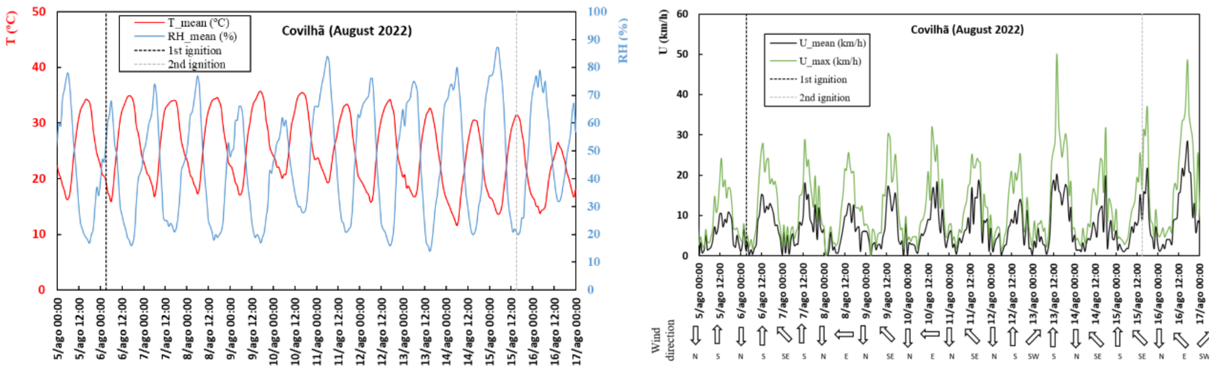

Figure 17. Meteorological parameters registered by the meteorological station of Covilhã (ID:687) during between August 5th and 17th: a) temperature (T) and relative humidity (RH) variation; b) windspeed (U) and wind direction.
Data source: IPMA.

The most critical wildfire period from August 5th to August 17th was marked by the persistence of high temperature (Figure 17a) driven by the heatwave that the country was facing and low relative humidity. However, on August 12th there was in general a slight decrease in temperature (T) and an increase in relative humidity (RH).

Windspeed in the wildfire period had a similar pattern; it increased in the early hours of the morning achieving its maximum at around 12:00 and 14:00 (Figure 17b). On 12th, 14th, 15th August maximum values were observed later around 17:00 and 18:00. The predominant wind in the early hours of the day was from N.

3.3.2 Fuel moisture content of dead fine fuels

Dead fine fuels moisture content was modelled for the Covilhã region using hourly meteorological data (air temperature and relative humidity) according to the methodology described in Lopes (2013). Figure 18 presents these results for the period from August 5th to August 17th. Additionally, in the same figure, the fuel moisture content variation for dead needles of *Pinus Pinaster* and dead leaves of *Eucalyptus globulus* measured daily (12:00) in Lousã, about 60 km SW from Serra da Estrela, is presented.

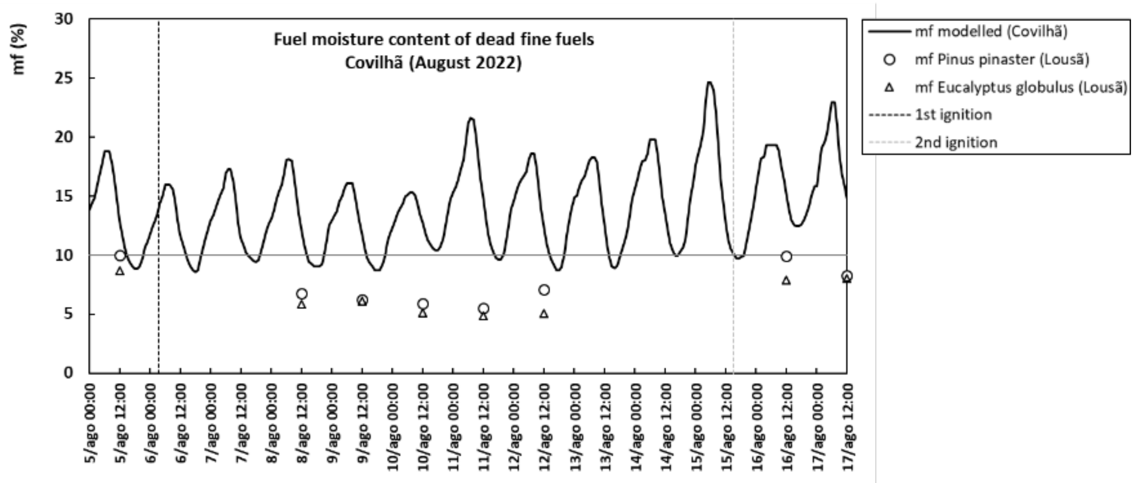

Figure 18. Fine dead fuel moisture (mf): modelled variation using the meteorological data from the weather station of Covilhã according to Lopes (2013); and mf of *Pinus pinaster* and *Eucalyptus globulus* measured in Lousã.
Data source: IPMA and ADAI/MCFIRE (PCIF/MPG/0108/2017)

From August 5th to August 17th, the *mf* modelled presents a well-defined daily cycle with lower values from 7:00 until 19:00), although with reduced ranges (8% and 20%). In this period, the *mf* modelled was lower than 10% between 12:00 and 19:00 for nine days, including on August 15th when an outstanding rekindling dramatically complicated the control of the fire. The *mf values* observed for Lousã are very low with an extreme day of 5.5% for *Pinus pinaster* and 4.8% for *Eucalyptus globulus* on August 11th. This was one of the lowest values ever seen in the monitoring that has been carried out in Lousã since 1986.

3.3.3 Fire danger

As presented in the fire danger analysis of the previous fires, in Portugal the RCM (Conjunctural and Meteorological Risk) is used to define the fire danger level of a region. The RCM results from the combination of two components: conjunctural and structural component and a meteorological component given by the Fire Weather Index (FWI) of the Canadian Fire Weather Index System.

Table 3 presents the FWI level according with classification of IPMA, 2023b and Viegas *et al. (*2004*)*. The classification of Viegas *et al. (*2004*)* was made at a district level, since the closest district to the ignition point is Guarda this analysis is presented for Guarda.

Table 3. Classes of the Fire Weather Index (FWI) values according with: a) IPMA for the Portuguese territory and, b) Viegas *et al*. (2004) for the district of Guarda, and FWI description according with (IPMA, 2023b).

Level	Limit values of FWI		Description according to IPMA (2023)
	IPMA (2023) for Portugal (a)	Viegas *et al*. (2004) for Guarda (b)	
1	<8.2	<8	Surface fires.
2	17.2	15	
3	24.6	25	High fire intensity with crown fires
4	38.2	50	
5	50.1	>50	Exceptional fire intensity with crown fires active, potential for spot fires and high difficulty of control.
6	64.0	-	Exceptional fire intensity with extreme difficulty of control
7	>64.0	-	

In Table 4 we compare the level of fire danger given by the FWI values and the RCM. This table presents the observed values for August 6th and the predicted values at 24h, 48h, and 72h in Guarda weather station (ID: 683).

Table 4. Fire Weather Index (FWI) and Conjunctural and Meteorological Index (RCM) observed and predicted for August 6th in Guarda weather station (ID: 683). The yellow colour in RCM indicates the Moderate (level 2) danger classification.

Day	FWI observed and predicted				RCM observed and predicted			
	Obs.	Predicted			Obs.	Predicted		
		24h	48h	72h		24h	48h	72h
Aug 6th	57.7	60.9	68.3	64.7	2	-	2	2

Data source. IPMA.

The predicted FWI at 72h and 48h of August 6th in Guarda had indicated an outstanding fire danger condition since the FWI was higher than 64, which means that any eventual wildfire would be expected to have an exceptional intensity with extreme difficulty of control (IPMA, 2023b). On August 6th in Guarda, the observed danger slightly decreased but still represented a *Maximum* fire danger (level 5) for both classifications. This danger level is characterized by "Exceptional fire intensity with crown fires active, potential for spot fires and high difficulty of control" (IPMA, 2023b). This danger condition was not accompanied by the RCM that predicted a *Moderate* condition (level 2). Also, the observed RCM was classified with *Moderate* level underestimating the real fire danger conditions of the day. The RCM has a daily changing component (weather/FWI) and an annually changing component (structural), on August 6th RCM seems to have underestimated the extreme weather predicted and observed by the FWI.

The wildfire danger conditions for the period August 5th to 7th was analysed using the fire behaviour indices of the Canadian Fire Weather Index System (ISI – Initial Spread Index, Buildup Index – BUI, FWI) as presented in Table 5a for the weather station of Guarda. These indices are interpreted on a danger scale based on IPMA classification (IPMA, 2023a) and they are presented in Table 5b where an increase in the index corresponds to an increase in fire danger.

Table 5. a) Fire behaviour indices (ISI – Initial Spread Index, Buildup Index – BUI, FWI – Fire Weather Index) in Guarda weather station (ID: 683) between August 5th and 7th; b) Danger scale for ISI, BUI and FWI.

(a) Indices values

Day	Aug. 5th	Aug. 6th	Aug. 7th
ISI	16.2	18.2	13.8
BUI	240.2	243.9	247.7
FWI	53.7	57.7	48.7

(b) Fire danger scale of the indices (IPMA, 2023a)

Level	1	2	3	4	5	6	7
ISI	2.0	6.0	12.0	17.0	23.0	30.0	>30
BUI	50.0	100.0	150.0	200.0	250.0	325.0	>325
FWI	8.5	17.2	24.6	38.3	50.1	64.0	>64

Data source: IPMA

On those days, the fire behaviour indices assumed extremely high values, especially the FWI on August 6th as presented before.

3.3.4 Resources allocation

Based on data provided by the Portuguese Civil Protection Authority (ANEPC) Figure 19 presents the variation of the firefighting resources allocated to the fireground: a) human resources (firefighters and other civil protection agents), and b) ground and aerial resources. The allocation in the fireground started on August 6th at the time of the first ignition until the closure of the occurrence report (September 3rd), the vertical line presents the time of the rekindling. Resources with incomplete information in the report were excluded (e.g., resources without date and hours of TO departure).

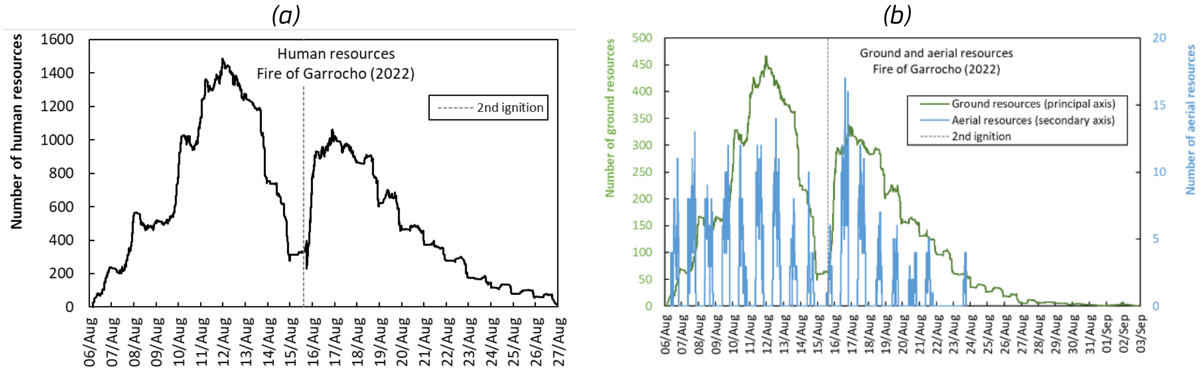

Figure 19. Evolution of the resources in the fireground of Garrocho: a) human resources, b) ground and aerial resources.
Data source: ANEPC

In total, this wildfire had allocated 2 272 human resources complemented by 1 733 ground vehicles and 539 aircraft. In the initial phase of the fire, the arrival of ground and air resources to the fire event was high with their maximum occurring on August 12th with 1 470 human resources, 466 vehicles and 14 aircraft (13:17). On August 15th, when the fire was close to be dominated, the number of resources also decreased. However, the rekindling observed in the afternoon of this day triggered a new large operational mobilization.

3.3.5 Fire behaviour

As expected, due to the rugged terrain, strong winds, and low fuel moisture content, the Serra da Estrela Fire was rich in episodes of extreme fire behaviour and relevant circumstances that can provide valuable lessons. To facilitate the presentation of the fire behaviour, the fire event was divided into five main phases of fire development (Figure 20), which will be detailed below.

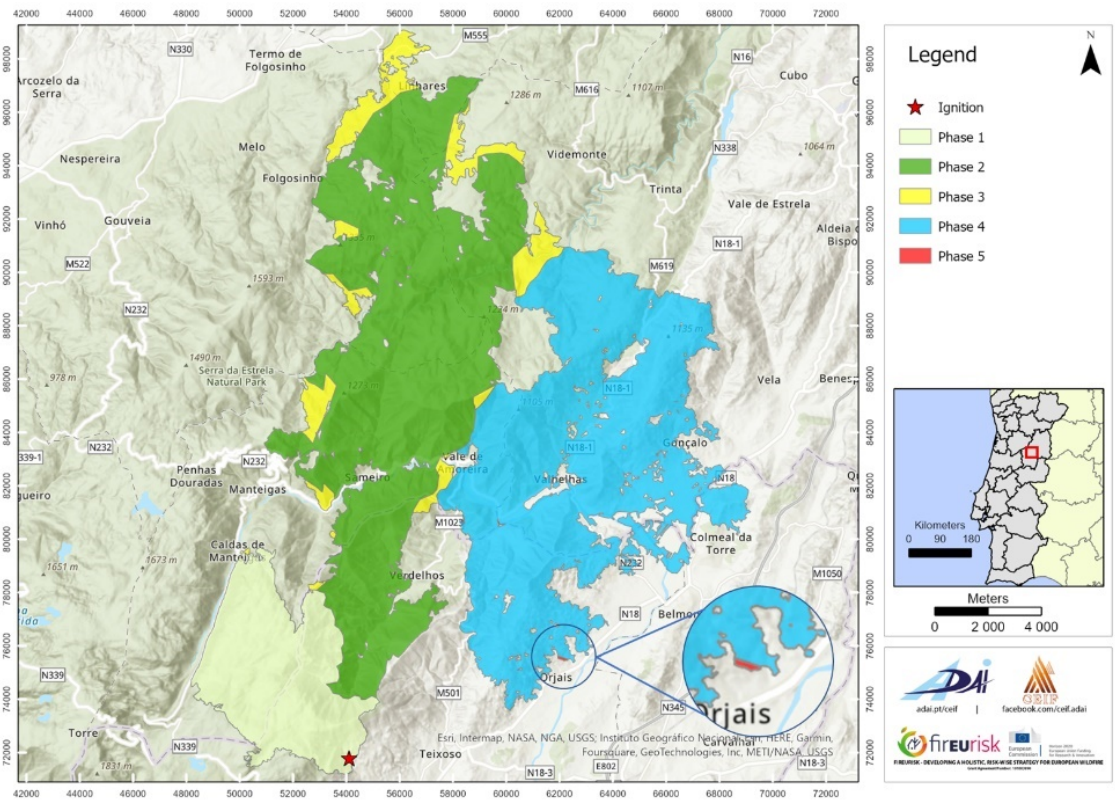

Figure 20. Evolution of the Serra da Estrela fire divided in five phases.

3.3.6 Phase 1: Initial fire spread [06Aug; 03:18 – 08Aug; 18:15]

As previously mentioned, the initial alert for this fire was given at 03:18, near the river beach in Vila Carvalho. The first means arrived on the scene about 30 minutes after the alert, finding a burning area of about 6 ha (Figure 21), so they immediately called for reinforcements.

The wind was not intense, but the fire was spreading in an area with a steep slope and difficult access, especially on the right flank where even sapper combat, particularly at night, was almost impossible. Consequently, on the left flank, firefighting was succeeding well, but the right flank was progressing almost unhindered during the night. In the morning of August 6th, the aerial firefighting resources heliborne teams arrived, allowing firefighting in the most difficult access areas such as the former left flank, which, with the increasing intensity and rotation of the winds, became the head of the fire.

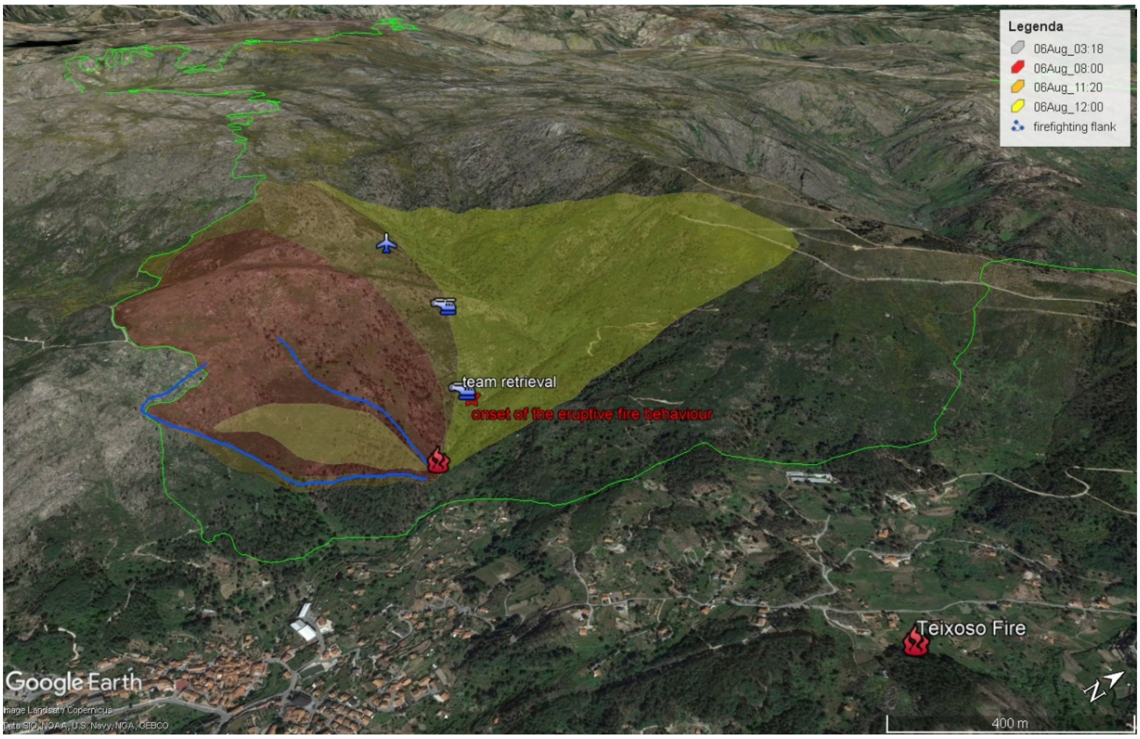

Figure 21. Evolution of the Serra da Estrela Fire until 12:00 of August 6th.

The fire crossed the water line and assumed the eruptive behaviour typical of a gorge.

By 11:20, the fire was practically contained, and expectations for a quick resolution were high. The area that required more attention was the right flank, parallel to the water line, which was being extinguished by a heliborne team using sapper equipment, supported by helicopter water drops (Figure 21). Although a longer operation was anticipated for this aerial resource, given the elevation difference and associated fuel consumption, by 11:30, this helicopter, along with its heliborne team, had to leave the fire scene to refuel. During the team's retrieval at the point indicated in Figure 21, turbulence was created, causing the fire to surpass the water line. It was not possible to determine whether the fire crossed the water line through spotting or direct heat transfer, but once it reached the opposite slope, the fire spread eruptively without any possibilities of control. Additionally, at around 11:40, about 1.3 km away, a new fire event emerged (Teixoso Fire), diverting firefighting resources. This new occurrence was promptly extinguished, but the Serra da Estrela Fire was out of control.

The fire spreads down the slope into the Glacier Valley and a tactical fire operation is carried out.

After spreading throughout the canyon in an eruptive behaviour, the fire moved towards NE, driven by the strong winds that decreased in intensity during the night. In this period, it crossed a 130 m wide fuel break, mainly through spotting. By the end of August 7th, the fire was slowly and with low intensity descending the slope of the Glacial Valley.

The fire history in this region indicates that when the fire crosses the Glacial Valley, it drives to a large and difficult-to-control fire. Since the wind was calm and expected to increase in intensity the following morning, a tactical fire operation was decided upon, across approximately 5 km parallel to the valley (Figure 22). The interaction between the low-intensity flames of the fire event and the flames caused by the tactical fire manoeuvre resulted in a high-intensity burn along the entire versant. This manoeuvre was successful in stopping the fire's spread in that area; however, the severe effects of the intense burn damaged the soil structure, making it susceptible to rockslides onto the road. Because of it, this road remained closed for several months with huge impacts on tourism. This is one of the cascade effects that will be addressed in Subchapter 3.6.

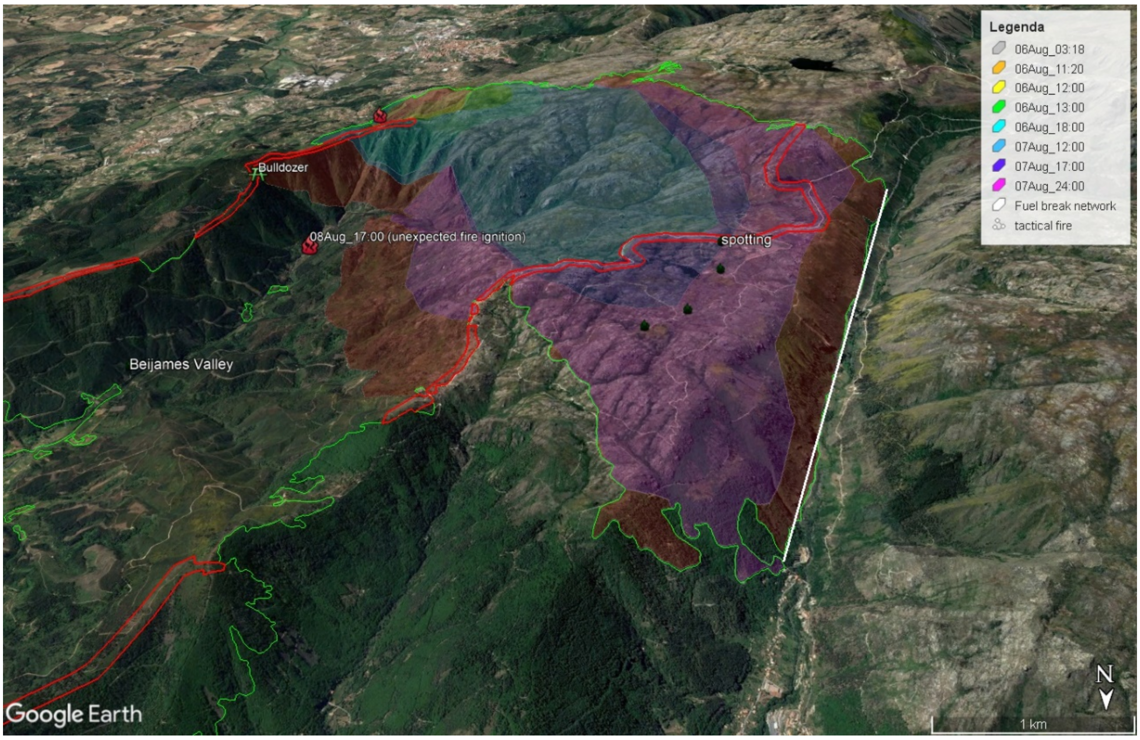

Figure 22. Evolution of the Serra da Estrela Fire until 17:00 of August 8th.

Interaction of the fire front with an unexpected fire hotspot, resulting in a new loss of fire control.

On the afternoon of August 8th, the fire spread was once again favourable. Using bulldozers, hoses, tactical fire techniques, and sapper equipment, at this time, the most active part of the fire was limited to two fronts at NE in the entrance of the Beijames River Valley (Figure 22 and Figure 23).

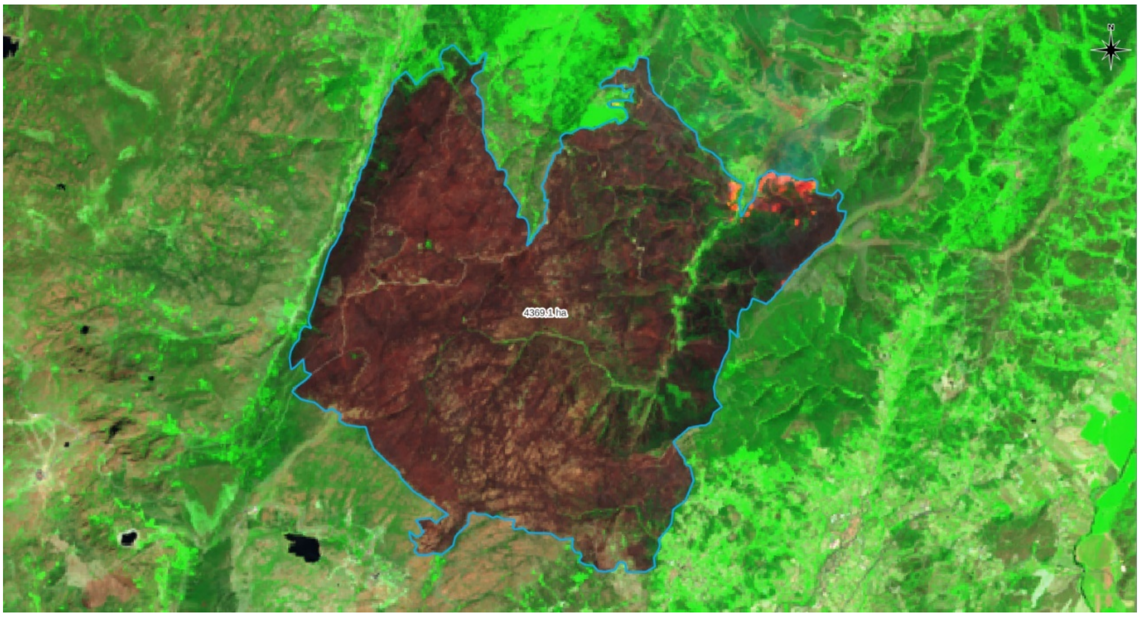

Figure 23. MODIS satellite image of the fire situation at 11:08 of August 8th. It is possible to see the most active fire perimeter at the entrance of the Beijames Valley, NE of the burnt area.

Unexpectedly, around 17:00, a new fire ignition occurred (Figure 22), allegedly caused by citizens seeking to protect a structure they believed was threatened by the fire. This ignition started to interact with the two fire fronts, leading to the loss of control over the situation and putting the safety of people at risk.

The effect that this new fire ignition may have had on the loss of fire control can be questioned, as the interaction of the two approaching fire fronts could have resulted in a similar episode. To clarify this doubt, two laboratory-scale tests were conducted. The scenario of the first test (Figure 24– top row) included only the two fire fronts that progressed nearly in parallel with late merging and interaction. In the second test (Figure 24 – bottom row), it is possible to observe the evident effect of the added ignition triggering a much more rapid and intense fire development. Thus, the unexpected new fire ignition had a decisive role in the abrupt fire intensification that was observed. In the field, once again, the fire event control was lost.

Figure 24. Sequence of frames from two laboratory tests in a canyon (water line slope: 15º; versant slopes: 30º) with the same fuel conditions: top row - two fire fronts; bottom row – two fire fronts and a fire ignition.

3.3.7 Phase 2: Fire spreads to NNE [08Aug – 12Aug]

The fire spreading throughout the Beijames Valley opened up on the two versants due to the firefighting efforts to protect the village of Verdelhos, which was located in the centre of the valley (Figure 25). By 24:00 on August 8th, due to the terrain configuration and the prevailing southwest wind, the fire reached the ridgeline in "Cabeço do Moreira" with great intensity. Then, by mid-day of August 9th, a short distance group of spot fires appeared on the descending slope after the ridgeline, and a long-distance group of spot fires started near the village of Sameiro at about 2.5 km. These more distant spot fires moved to NNE, driven by the wind. The short distance spot fires spread parallel to the ridgeline, possibly influenced by the flow induced by a horizontal vorticity resulting from the wind parallel to the ridgeline (Sharples & Hilton, 2020). Afterwards, when this fire front lost the vorticity influence, it started spreading to NNE driven by the wind, parallel to the fire front established by the spot fires that initiated near Sameiro. These two fire fronts merged after the canyon that culminates in Corredor de Mouros.

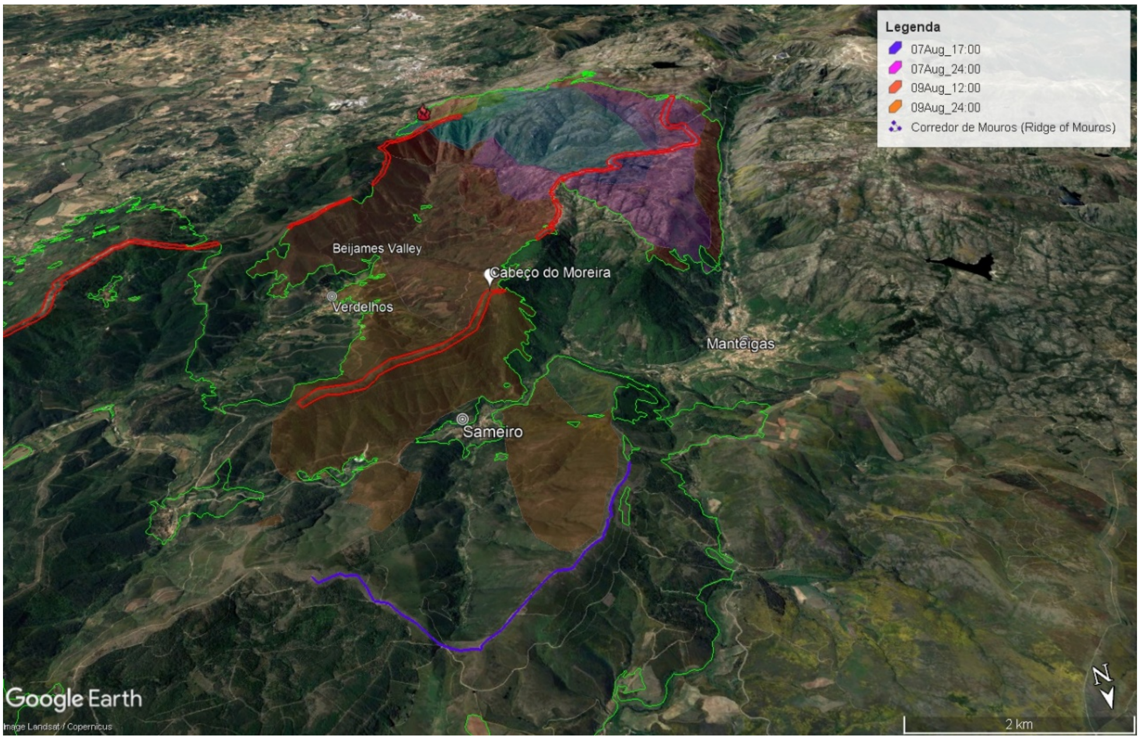

Figure 25. Evolution of the Serra da Estrela Fire until 24:00 of August 9th.

Although the two fire fronts merged, the fire continued spreading towards NNE with two main fire heads in direction to Videmonte and Linhares da Beira (Figure 26). Due primarily to the terrain configuration, a new fire front was also formed, heading towards Folgosinho.

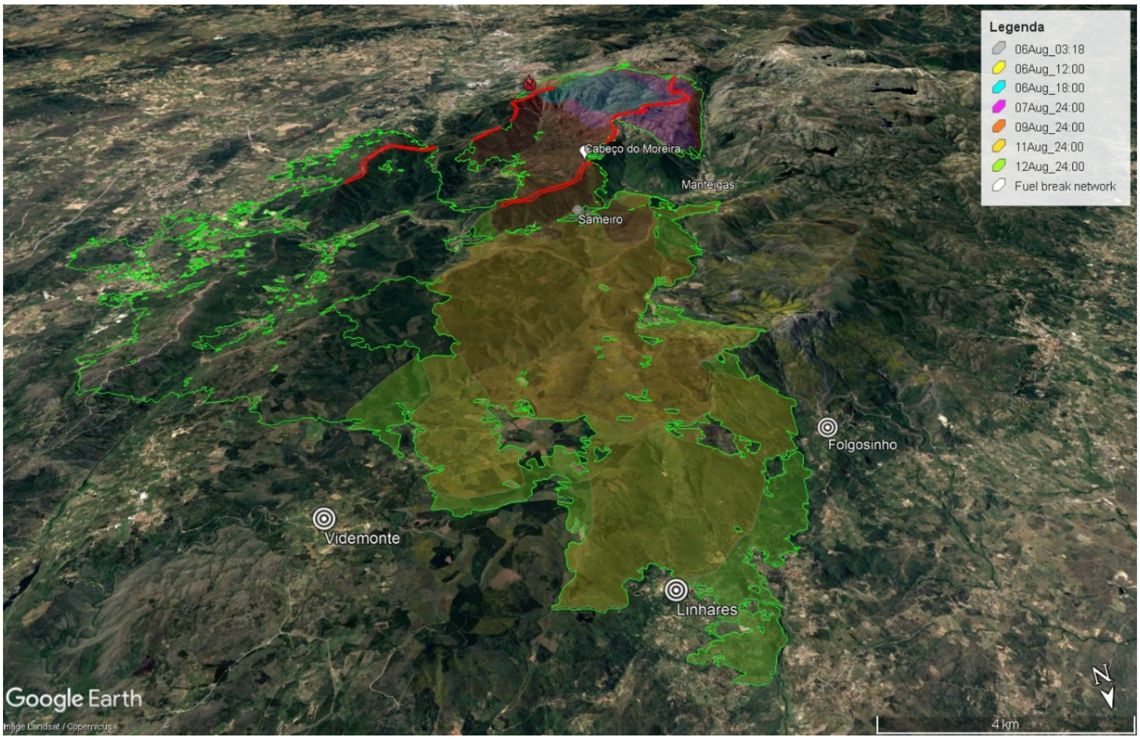

Figure 26. Evolution of the Serra da Estrela Fire until 24:00 of August 12th.

3.3.8 Phase 3: Intermediate resolution [13Aug – 15Aug]

Although the fire perimeter was very extensive, on August 13th, the fire was finally yielding to the fire management strategy. As mentioned earlier, the hottest points were in the fire fronts of Videmonte, Folgosinho, and Linhares da Beira, although several rekindling spots were observed. The firefighting resources were deployed to fight the active fire fronts and to consolidate the less active fire perimeter using water, bulldozers and tactical fire. The typical daytime wind slightly decreased in average intensity, although some gusts were still being recorded. Some firefighting resources started leaving the fire scene. On August 15th, at 15:44, the fire event was categorized by the authorities as "under control".

3.3.9 Phase 4: Rekindling, fire spreads to SEE [15Aug – 17Aug]

Several rekindlings were recorded in the previous days in Vale da Amoreira and there was awareness that a new ignition in that area could raise a new fire front that would be difficult to control. Therefore, this zone was considered critical, and many firefighting resources were pre-allocated in this area. Additionally, a double pass of a bulldozer was carried out along the perimeter of the burned area to create a fuel break, so minimizing the possibility of an eventual ignition spreading to unburned areas. This double fuel break was inappropriately made mid-slope, separating the burnt and unburnt area. This had influence on the rekindling that we will describe next. Perhaps the right thing to do in that situation would have been to burn the rest of the versant – the bottom part – but the intend was to avoid exposing that population to more fire and smoke.

At 15:47 on August 15th, just 3 minutes after the fire was reclassified as "under control," a rekindling was registered near the village of Vale da Amoreira. According to witnesses, a firefighting helicopter responding to this episode caused significant turbulence in the area that led to several spot fires. Three new ignitions stood out which followed distinct initial paths. The Spot Fire A (Figure 27) was promptly fought against and, although interacting with the initial front, it was confined to a small area. The Spot Fire B, approximately 750 m from the original fire front, started in grassland with an initial very fast spread, mainly to SE but covering the entire gorge where it was located. Driven by the topography and the turbulence caused by the meteorological wind in the Vale (Valley) da Amoreira, the Spot Fire C climbed the gorge to the north, gaining more prominence on the eastern slope. When the prevailing NW wind overlapped with the local turbulence, it pushed this fire front to SE, merging with Spot Fire B. A situation that had previously seemed under control, became completely uncontrolled, given the rate of spread and intensity with which the fire progressed.

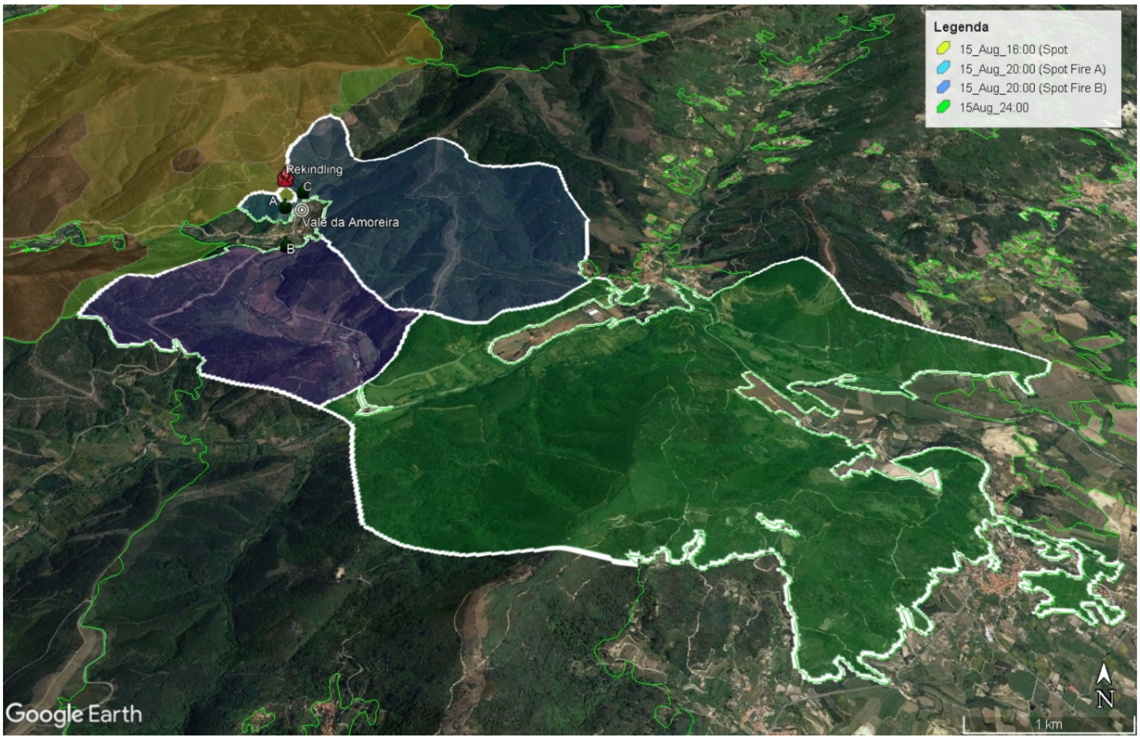

Figure 27. Evolution of the Rekindling at Vale da Amoreira by the 15:47 of August 15th. Fire perimeter by the 24:00 of August 15th.

Pushed by the wind, the fire continued to spread south-eastward, opening up new fronts to the northeast and southwest, guided by the topography, particularly the hydrographic basin of the Zêzere River, towards Famalicão da Serra, and the Sarzedo valley (Figure 28). In general, the fire was pushed into an extensive agricultural land strip along the Zêzere River. In this flatter and more humid terrain, firefighting conditions become more positive. The relative humidity and air temperature also become more favourable on August 17th.

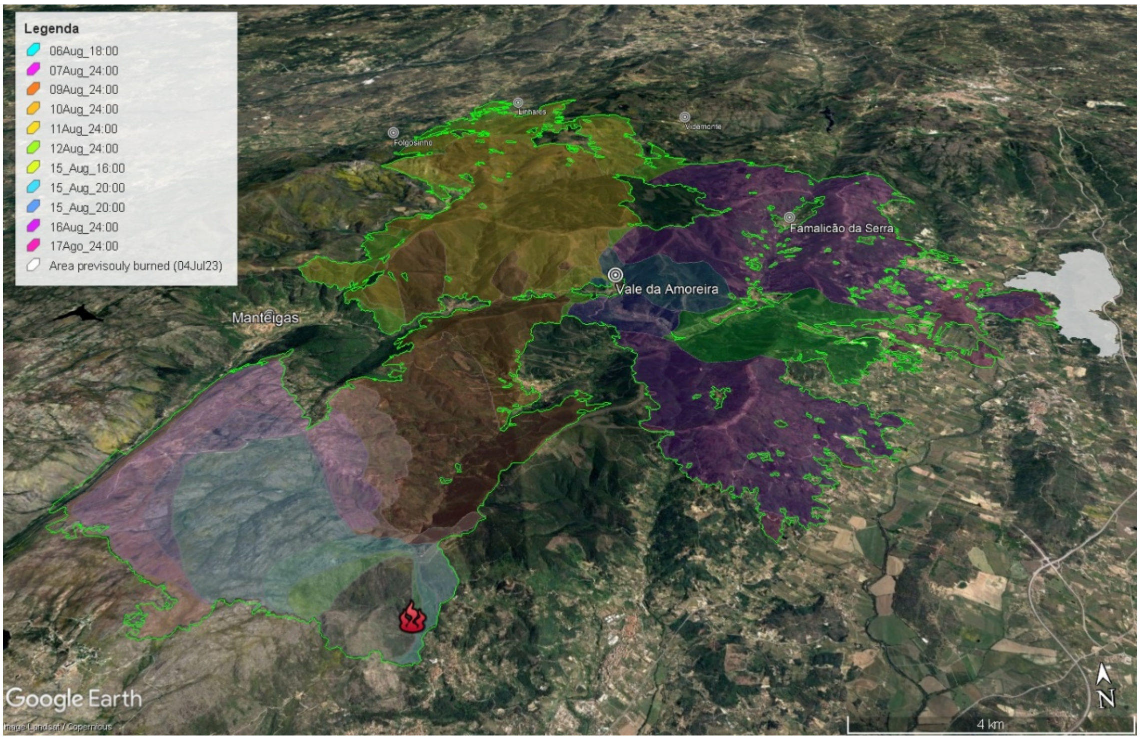

Figure 28. Evolution of the Serra da Estrela Fire – approximate final perimeter by the 24:00 of August 18th.

3.3.10 Phase 5: Final resolution [17Aug - 03Sep]

By August 17th, the situation was progressing encouragingly. The most concerning hotspots remained in Videmonte and in the fire front of approximately 5 km parallel to the Zêzere River. In this area, the priority was the defence of structures, as it was expected that the fire would drastically decrease in intensity when it reached the agricultural fields. There was still an area where the fire crossed the agricultural strip and the Zêzere River, but it encountered an area burned in the previous month, so was easily solved. The situation was more complicated near Videmonte, but the significant presence of firefighting forces was sufficient to resolve it.

The fire was definitively considered under control at 21:30 on August 17th. Naturally, several resources remained in the area to respond to the various rekindlings that occurred. The fire of Garrocho – Serra da Estrela was declared closed at 21:00 on September 2nd.

3.4 Fire management at the WUI

Despite the extensive burned area and sporadic progression of the fire with high velocity and intensity, the damage to infrastructure was relatively low. However, several houses were burned down, and various other equipment was destroyed. There is surely other damage that was not reported or to which we did not have access, but as presented in Table 6, in three out of the six directly affected municipalities, the recorded direct losses amounted to nearly 24 million Euros.

Table 6. Damage registered in the municipalities affected by the Serra da Estrela Fire.

Municipality	Damage registered
Celorico da Beira	Municipal/public infrastructures and equipment* Agricultural equipment and materials
Covilhã	Municipal/public infrastructures and equipment* (€5 128k) Equipment and industrial infrastructures in three villages (€433k) Dwellings in in six villages (€520k) Agricultural equipment and materials (€3 160k)
Gouveia	No information was obtained
Guarda	Municipal/public infrastructures and equipment* (€8 000k) 3 family tourist business (€250k) and 2 companies with damages to exterior equipment (€150k) 30 second dwellings and 6 primary dwellings (€1 000k)
Manteigas	No significant impacts recorded
Belmonte	No information was obtained

** Mostly composed of paths and municipal roads, traffic signs, municipal buildings and constructions, public drinking water distribution systems, solid waste collection containers, vehicles and other municipal vehicles.*

The utmost impacts resulting from a wildfire are usually associated with the loss of human or animal lives, and buildings. Fortunately, no fatalities or serious injuries directly related to the fire were recorded among people, and the loss of animals and buildings was relatively low considering the extensive burned area and the conditions in which the fire spread. This is largely due to the fire management strategy prioritizing the protection of houses and communities, especially during the day when the wind was stronger, and firefighting was more difficult. On the other hand, compared to recent years, there was a preference for confining people to the villages rather than carrying out mass evacuations. This confinement was facilitated by the existence of shelters or safe havens in most villages. These shelters and safe havens were predefined priorly under the national program "Safe Village, Safe People" (https://aldeiasseguras.pt/).

Even so, there were areas that had to be evacuated due to various reasons. In some cases, it was determined that there was enough time to safely evacuate the residents and move them to secure locations, considering the expected fire intensity. Moreover, certain tourist establishments with occupants who were presumed to have greater difficulties regarding the fire in a region less familiar to them than to residents were also evacuated. Table 7 shows the main people management actions to which we had access.

Table 7. Main actions of people management during the fire in Serra da Estrela.

Municipality	Damage registered
Celorico da Beira	Withdrawal of the most vulnerable people to hostels
Covilhã	From August 15th to August 17th, 71 people were displaced from Sarzedo, Vale Formoso and Aldeia do Souto
Gouveia	No information was obtained
Guarda	From August 15th to August 17th, people from Seixo Amarelo, Quinta da Sra. da Misericórdia and surrounding farms were displaced. In other settlements, several people were sheltered in place, while some people preferred to remain in the protection of their properties and goods.
Manteigas	On 10 August a hotel was evacuated for a few hours.
Belmonte	No information was obtained

Tens of dwellings were identified as having been severely damaged by the fire. In most cases, the roof was the construction component that first ignited, confirming the conclusions of Ribeiro *et al*. (2020). It is possible to observe that the burned structures are scattered, meaning that the fire did not spread continuously through the communities, destroying multiple buildings. Naturally, in addition to the protection provided by the firefighting agents, fuel management in the surrounding areas of the communities was crucial in preventing devastating effects caused by the fire. Figure 29 presents an example of the effectiveness of fuel management in a village surrounding, which prevented the fire from spreading and ensured that no damage was recorded to the buildings in that village.

(a) (b)

Figure 29. Image of the village of Sameiro (Manteigas) when threatened by a fire front (a) and after the passage of the fire (b). The effect of fuel management can be observed, as it delimited the burned area, ultimately saving the village (photos cordially provided by Manteigas City Council).

3.5 Cascading effects

This fire was part of a sequence of events commonly referred to as a cascade effect. Upstream of the cascading chain, the heatwave and drought experienced in 2022 in Portugal and several European countries played a significant role in the fire season, as previously described, and particularly in this fire. Among several subsequent events of the Serra da Estrela Fire, two stand out due to their strong economic, social and environmental impacts.

Flash flood in Sameiro

During the fire, there was a major concern regarding the protection of the Bosque das Faias (Beech Forest) in São Lourenço, Manteigas. This forest was planted in the second half of the XIX century with the aim of protecting the Village of Manteigas from the common flash floods of that time. During this fire, preserving this forest became crucial, not only for its natural value but also to prevent the cascade effect that would be exacerbated by the severe erosion often observed after fire events. However, to the east of São Lourenço lies the hydrographic sub-basin (Figure 30) that includes Sameiro, which was seriously affected by high intensity fires.

According with the climate report from IPMA, in September 2022 the precipitation occurring from 12th to 15th, during the passage of the Cyclone Danielle, was significantly high in the interior Central of Portugal, especially in Covilhã region where the total precipitation values accumulated in these 4 days (188.4 mm) exceeded by 3 times the average value of the month (58.9 mm). On September 14th the highest daily values of precipitation in 24 hours in the country were exceeded in Covilhã (92.5 mm) and Guarda (42.3 mm). Also, the amount of precipitation that occurred in 6 hours was higher than the normal value for the month. In Covilhã, from 09:00 to 15:00 the amount of precipitation was 60.9 mm, and in Guarda from 04:00 to 11:00 the amount was 42.3 mm (IPMA, 2022). This was the magnitude of precipitation amount in Manteigas, a region close to Covilhã and Guarda. The steepest areas where the fire had spread with high intensity one month before experienced significant erosion, and large amounts of ash, soil and burnt vegetation remnants were carried by the waters, causing floods and landslides of earth and rocks. One area where this impact was particularly experienced was the Sameiro sub-basin and specifically in the village with the same name. In here, the Sameiro Stream, a tributary of the Zêzere River, overflowed, causing extensive destruction in the village, including the sweeping away of vehicles and damage to various infrastructures (Figure 31).

Figure 30. Orographic framing of the Bosque das Faias (Beech Forest), the Manteigas sub-basin and the Sameiro sub-basin.

(a) (b)

Figure 31. Images showing the flash flood impacts in Sameiro. September 13th (a) and October 17th (b).

Rockslides in the Glacial Valley demands road cut off

Manteigas is a village where tourism plays an important role in the economy. All year seasons attract a large influx of tourists, as it offers nature and adventure tourism, as well as snow tourism. The Serra da Estrela Fire had significant impacts on the tourism sector, not only due to the transformation of the landscape but also due to the destruction of tourism supporting infrastructure (e.g., ATMs), which were quickly restored, as well as the destruction of some facilities such as campsites or the artificial ski slope (Figure 32).

(a) (b)

Figure 32. Images showing some direct impacts of the Fire of Garrocho on tourism infrastructures.

Located in the heart of the Serra da Estrela, many people use Manteigas as a logistical base. One of the most frequently used roads for tourist circulation is the Glacial Valley Road (EN338), which connects Manteigas to Torre – the highest point in mainland Portugal at an altitude of 2 000 m and a popular destination for winter sports.

Previously was mentioned the tactical fire action along the Glacial Valley Road, which was successful in blocking the fire spread in than flank but resulted in an episode where the fire spread intensely along the slope. This episode greatly weakened the soil, which, following the hard rainfall on September 13th described earlier, experienced significant erosion. As a result, numerous rockslides occurred, endangering users of the Glacial Valley Road. Consequently, the road had to be closed for several months until the slope achieved sufficient stabilization. This measure had a severe impact on the local tourism sector, particularly in Manteigas, as it drove to a much longer and time-consuming access route to Torre. This may have been one of the most significant economic impacts that Manteigas experienced as a result of the fire. At the time this chapter is being written, 10 months after the fire, there is still no forecast of when this road will be reopened.

3.6 Conclusions and lessons learned

The Serra da Estrela Fire was a highly challenging management event, as it aligned strong winds, rugged terrain, and very low vegetation moisture content. Fortunately, no human casualties were reported, which is the most positive outcome to register. There were several learning opportunities that can be extracted from this fire. Next, we will summarise some of the most important ones, considering the international scope of this publication.

Helicopter operations in critical areas should require special precautions.

This statement was confirmed by two situations at least – at 11:30 on 6th August and the reactivation in Vale da Amoreira (15:47 on 15th August) – in which the fire was close to resolution but ended up again out of control. It is relatively common to see helicopter manoeuvres causing a great turbulence that increases the fire and complicates the firefighting operations, as was confirmed here. It is important to study this phenomenon and the best way to carry out this type of manoeuvre, passing the lessons on to the pilots of these aircraft.

Tactical fire operations must consider the indirect impacts that result from them.

The use of tactical fire is highly effective, especially in areas that are difficult to access and where ground-based methods are complex. However, it is important to consider that these operations, when leading to episodes of high-intensity fire, can trigger cascading effects such as erosion and rockslides, as observed on the Glacial Valley Road. It cannot be stated that this maneuver was entirely wrong because it ultimately halted the fire's spread in that front, especially considering the forecasted strong winds the following morning.

However, that manoeuvre, which began around 23:00, could have possibly been delayed allowing the fire to descend most of the slope with low intensity, thus avoiding nearly the entire hillside being exposed to the intense interaction of both fire fronts – the wildfire and the tactical fire.

The use of fire not authorized by the event general commander can be highly negative to the firefighting strategy and can endanger people's lives.

Some citizens and civil protection agents resort to actions of tactical fire without the required approval of the general operations commander. In Portugal, the unauthorized use of tactical fire is considered a crime, except in exceptional situations such as the emergency defence of people's life. It is crucial to understand that an operation of this nature, when not properly coordinated, can jeopardize the entire fire management strategy and put the lives of people in the vicinity at risk. This is a challenge that requires a social action plan for its resolution, as sometimes it is deeply rooted in the society's culture.

Fuel management around communities is effective in protecting populations.

As mentioned, there have been no situations of inhabited villages being devastated by the fire, even when it reached a large scale and great intensity and speed. Here, an example was presented of several situations where the crucial role of fuel management zones around villages prevented the fire from entering the settlement. In certain cases, particularly when this zone was narrower, it enabled more effective action by civil protection agents who were safeguarding the communities.

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4 Fire of Murça (Portugal)

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4.1 General Description

The alert for the fire of Murça was given on July 17th at 16:35 near the settlement of Carva, in the municipality of Murça, district of Vila Real, in the Northeast of Portugal (see map in Figure 33), and its extinction was registered on July 21st, by 15:35, after having spread in an area of 7 185.78 ha, making it one of the largest fires of the year 2022 in Portugal.

This fire developed in a territory with diversified vegetation cover, with some periods of very intense fire spread. In this fire the only two fatalities associated directly to the fires of 2022 occurred, contradicting the goal of "zero deaths in forest fires", proposed in the National Program of the Portuguese Government.

The study of this fire will deal mostly with its propagation during its first day, in the afternoon of July 17th and in the late morning and afternoon of July 18th, during which, with its violent propagation, it was a serious threat to the safety of the population and of the operational agents and caused the death of two civilians.

In Figure 33 the general evolution of the fire from its origin on the July 17th to its resolution on the 21st is shown. The phases of more intense propagation occurred on July 17th and July 18th.

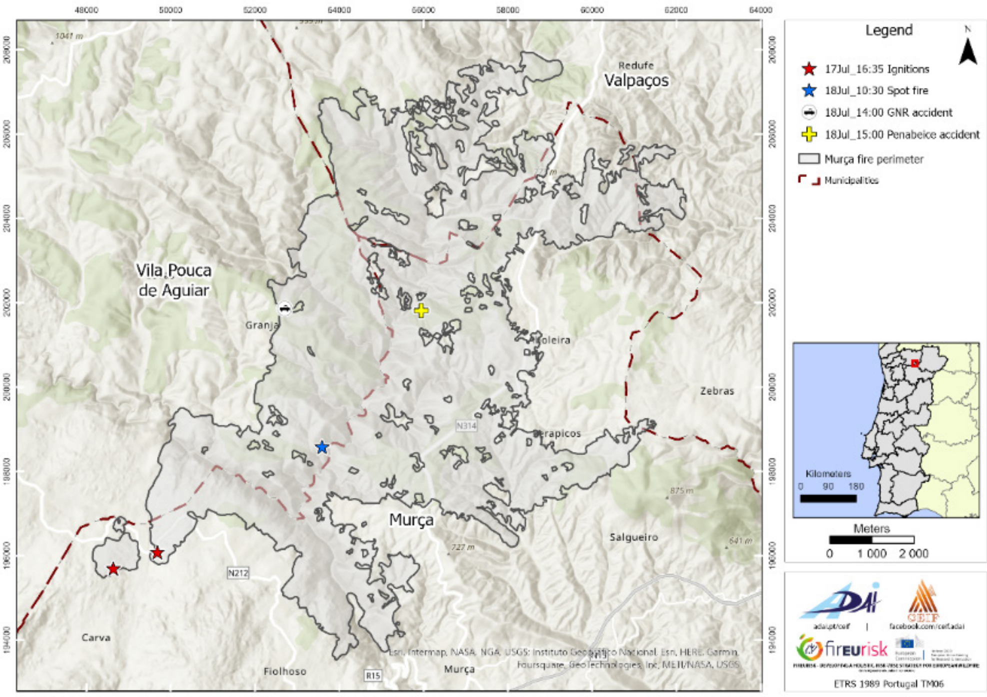

Figure 33. The final perimeter of the Murça fire from 17th of July to 21st, with a total area of 7 185.78 ha. The two ignition points are marked in the map. The yellow cross indicates the location of the two fatalities and the vehicle symbol marks the location of the incident with a fire truck that was destroyed by the fire. In the inset map the location of Murça in the Northeast of Portugal is shown.

4.2 Characterization of the affected area

The number of times that Murça region was burned (fire recurrence) between 1975 and 2021 is presented in Figure 34.

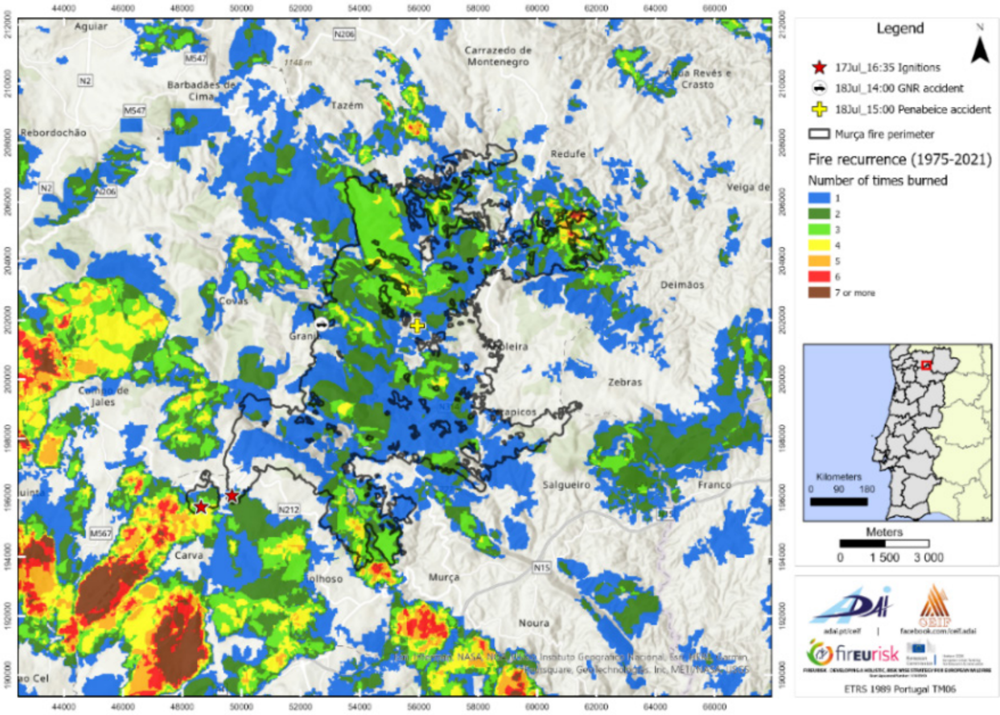

Figure 34. Fire recurrence in the region affected by the wildfire of Murça between 1975 and 2021.

The area where the Murça wildfire occurred was not affected by many fires from 1975 to 2021. It is observed that most of the burned area in 2022 had only burned once since 1975. The number of times that an area burned in the region is larger on the SW side of the fire perimeter, namely where one of the ignitions occurred.

The number of years without wildfires until 2022 in the region of Murça (statistics from 1975 to 2021) is presented in Figure 35.

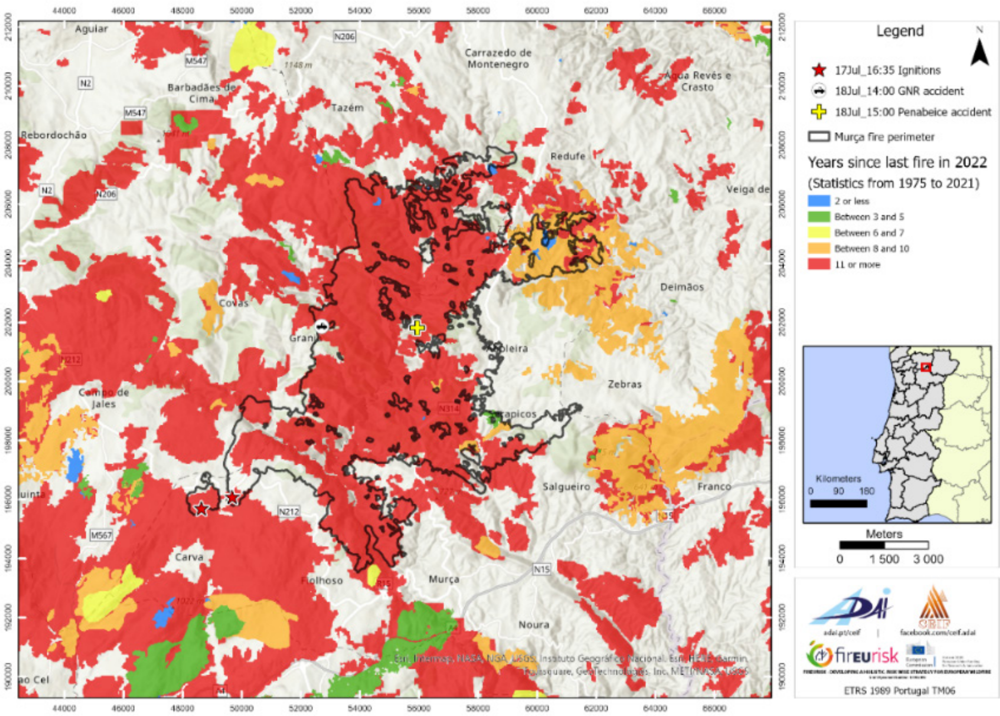

Figure 35. Number of years since the last wildfire in Murça in 2022 (statistics from 1975-2021).

Most of the area had not burned at least since 2010 or before (11 years or more without fires). In 2022, the amount of fuels in this area and the meteorological conditions in the Portuguese territory (drought and the passage of a heatwave) that led to a higher dryness state of the fuels, contributed to the high intensity fire propagation that was observed in the wildfire of Murça.

The orography in the area affected by the wildfire of Murça is very heterogeneous (Figure 36). The fire propagation occurred mainly in areas with altitudes between 323 m and 900 m.

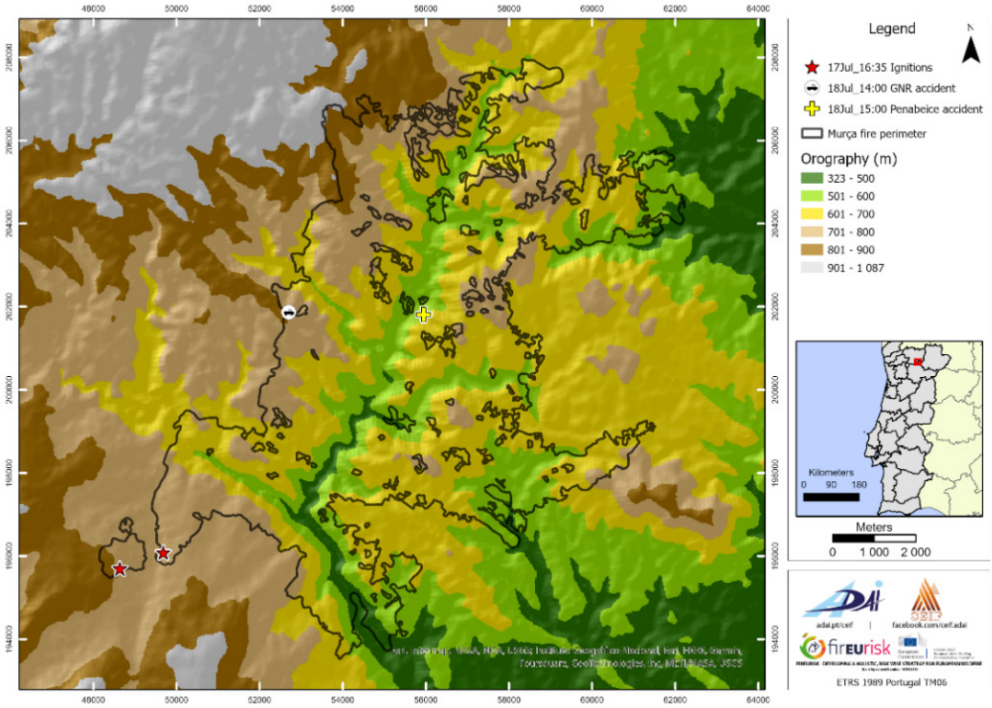

Figure 36. Orography in the area of the wildfire of Murça.

The slope in the region of the wildfire of Murça is presented in Figure 37. The slopes are also very variable in this region. The ignitions occurred at 10º to 15º which also is the most represented slope class in the burned area. The GNR accident occurred in a slope of around 5º and the Penabeice accident occurred for the highest slope class (15º-20º).

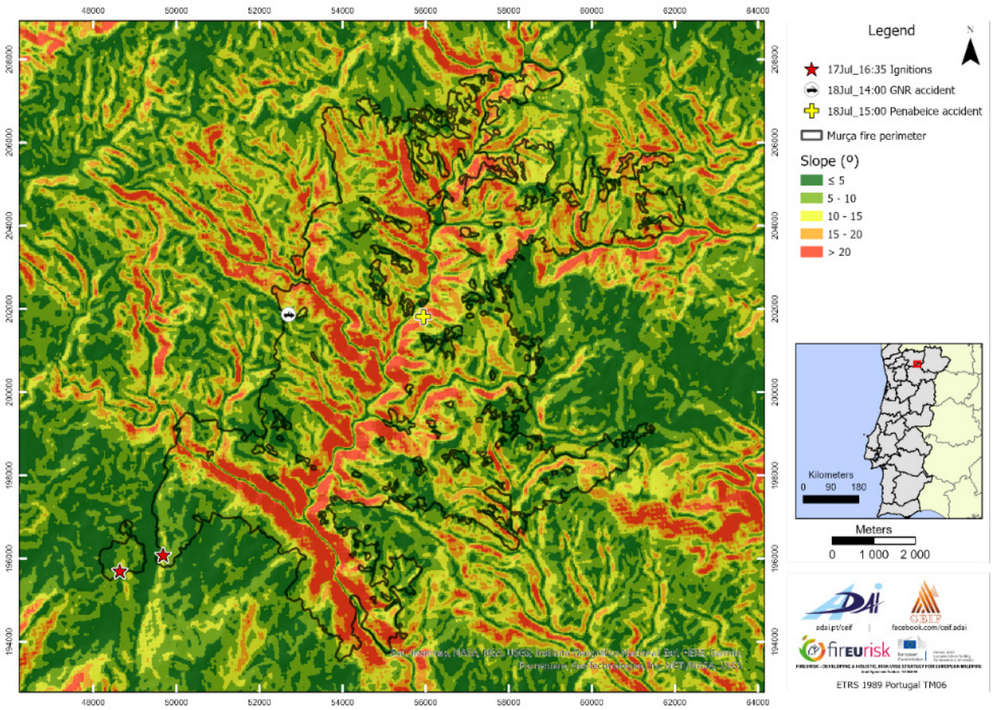

Figure 37. Slopes in the area of the wildfire of Murça.

The characterization of the land use in the area of the Murça wildfire is presented in the map of Figure 38. The map was carried out using thematic maps provided by the Portuguese General Directorate of the Territory (DGT), namely the conjunctural land use chart that has been updated for 2021 (COSc 2021) having an annual production and update frequency, and a raster format with 10 m pixels. Table 8 presents the respective percentage values of land use. The most representative land use classes in the region are: shrubland, maritime pine and spontaneous herbaceous vegetation.

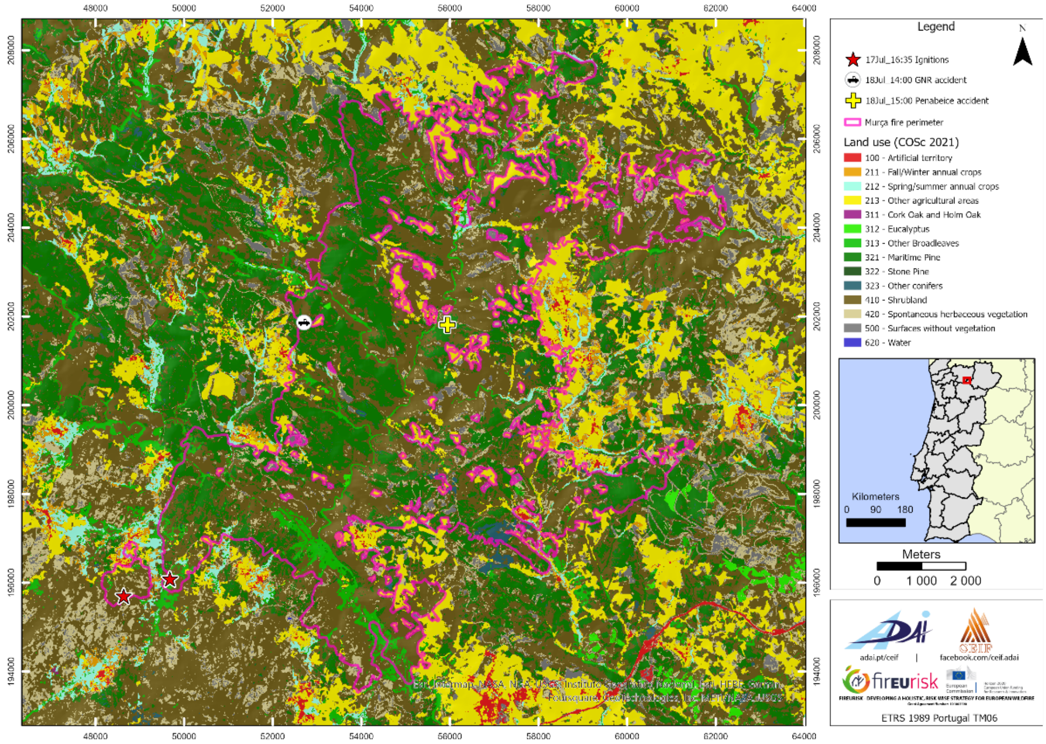

Figure 38. Land use in the area of the wildfire of Murça.

Table 8. Percentage per class of land use in the area of the wildfire of Murça (ordered from the highest to the lowest value).

Class of land use	Percentage of land use
410 - Shrubland	54.06%
321 - Maritime Pine	25.74%
420 - Spontaneous herbaceous vegetation	6.99%
313 - Other Broadleaves	4.47%
213 - Other agricultural areas	4.27%
500 - Surfaces without vegetation	2.28%
323 - Other conifers	0.92%
212 - Spring/summer annual crops	0.71%
211 - Fall/Winter annual crops	0.44%
312 - Eucalyptus	0.09%
100 - Artificial territory	0.01%
620 - Water	<0.01%
322 - Stone Pine	<0.01%

Fire propagation occurred mainly in shrubland areas (54%), forest areas (Maritime Pine – 26%) and herbaceous areas (7%). Also, broadleaves (4.5%) and agricultural areas (4.3%) are representative of the wildfire area in Murça.

As can be seen in Figure 38, although the fire affected some agricultural areas, the fire propagation stopped in these areas namely to the north, east and south of the perimeter of the fire.

4.3 Fire conditions

4.3.1 Meteorological Conditions

The weather station of the Portuguese Institute of Sea and Atmosphere (IPMA) located in Vila Real (ID: 567), approximately 23 km from the ignition point, was used to analyse the conditions during the wildfire period. Figure 39 presents the temperature of the air (T) and the relative Humidity (RH) between July 3rd and July 22nd.

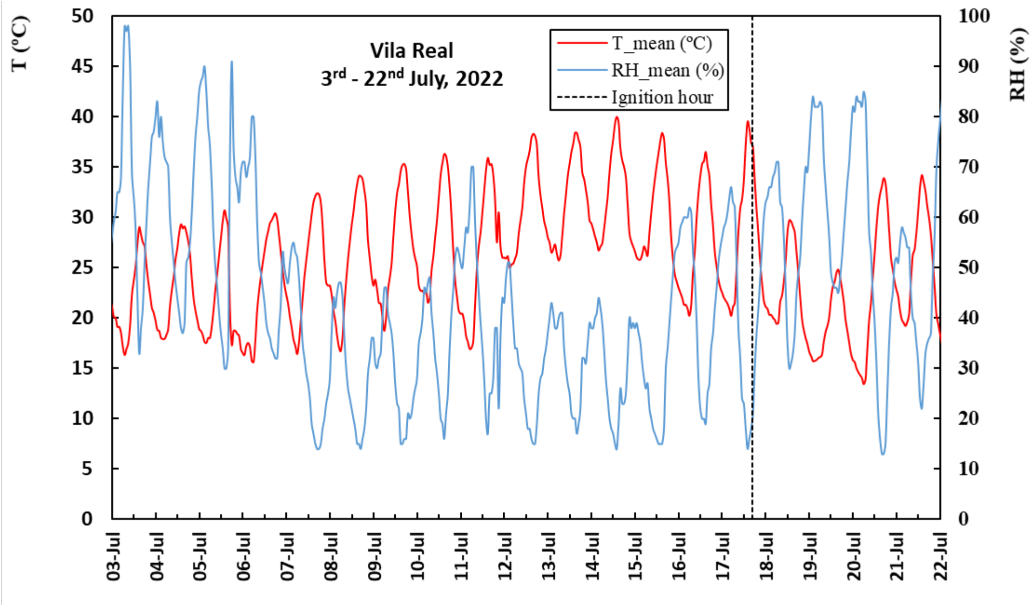

Figure 39. Temperature of the air (T) and Relative Humidity (RH) registered by the meteorological station of Vila Real (ID:567) between 3rd and 22nd July.
Data source: IPMA

In the period from the 3rd to 17th of July, the air temperature in the Vila Real region had been increasing, with maximum values of 28°C on the 4th to 39.5°C on the 17th. The relative humidity of the air ranged between 15% and 48% (July 12th and July 16th), corresponding to very low values. These meteorological conditions in the days preceding the wildfire were driven by the heatwave that the country was facing between July 2nd and July 18th.

The wildfire started on July 17th at 16:35 where the temperature reached a maximum value of 39.5°C, with the relative humidity dropping to 14%. On July 18th the maximum temperature was 29.7°C and the minimum humidity was 30% at 13:00.

In Figure 40a) and in Figure 40b) the hourly evolution of the average and maximum wind speed (U), and the direction of the wind, respectively are presented. Wind data is important to understand the fire spread; for this reason the data are presented from the ignition day.

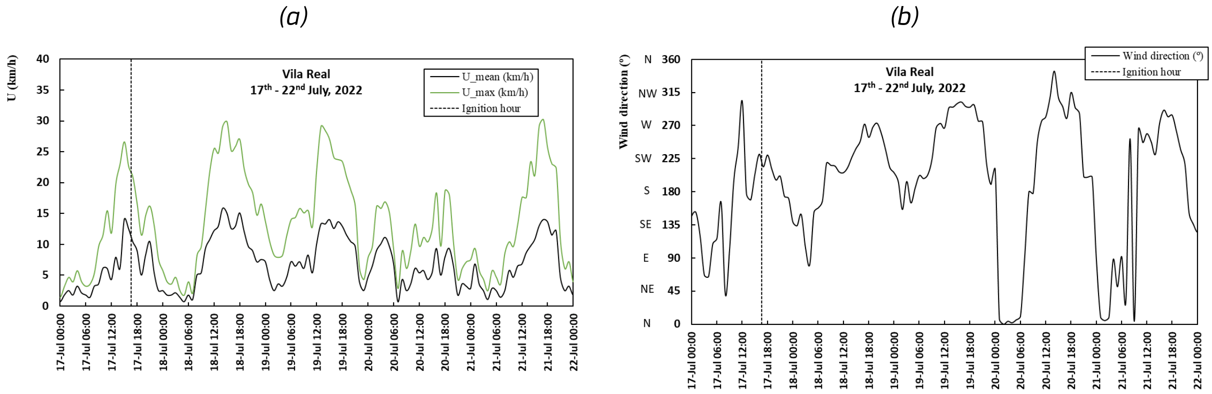

Figure 40. Wind data registered by the meteorological station of Vila Real (ID:567) between 16th and 22nd July: a) Wind speed (U) in km/h, and b) Wind direction in degrees (º).
Data source: IPMA.

As can be seen, from the difference between the average (U_mean) and the maximum (U_max) values, there were periods with gusty winds (U_max), which have a strong effect on fire propagation. On the afternoon of July 17th, at this station, the wind was blowing from the Southwest (SW), turning to the South (S) and then, during the night, to the East (E), with a maximum value of around 13 km/h, gradually decreasing to about 2 km/h at early morning on July 18th. On this day, the wind speed gradually increased to around 16 km/h, at 15:00, and remained at that level of intensity until around 19:00, while its average direction changed from East, at 04:00, to South around 9:00 then to West, at 17:00.

4.3.2 Fuel moisture content of dead fine fuels

Dead fine fuels moisture content were modelled using hourly meteorological data (air temperature and relative humidity) registered by the meteorological station of Vila Real (ID:567), according to the methodology described in Lopes (2013). Figure 41 presents these results for the period from July 17th to July 22nd. Additionally, in the same figure, the fuel moisture content variation for dead needles of *Pinus Pinaster* and dead leaves of *Eucalyptus globulus* measured daily (12:00) in Lousã, a Central region in Portugal, is presented as a reference for observed values.

As can be seen the predicted values of moisture content are higher than the measured values. It must be noted that our model does not consider the effect of solar radiation, therefore the predicted values tend to overestimate the actual values of fuel moisture content.

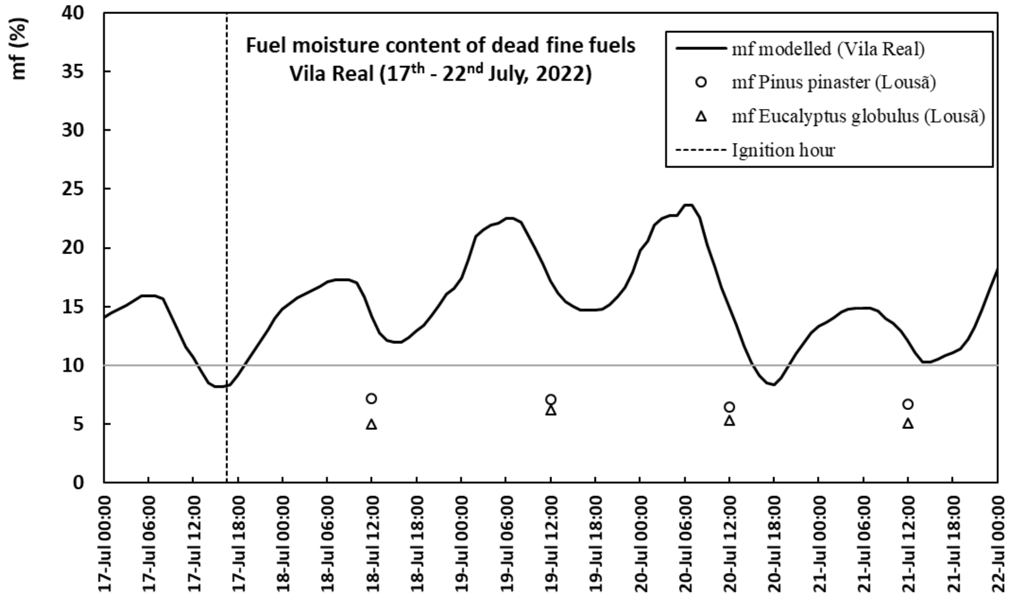

Figure 41. Fuel moisture content of dead fine fuels (mf): modelled variation using the meteorological data from the weather station of Vila Real (ID:567) according to Lopes (2013); and mf of *Pinus pinaster* and *Eucalyptus globulus* measured in Lousã. Data from July 17th to July 22nd.
Data source: IPMA and ADAI/MCFIRE (PCIF/MPG/0108/2017).

The amplitude of the daily cycle of moisture content variation on July 17th was very low, between 7 and 15%. According to our model the moisture content must have reached a maximum of 24% only at the end of July 19th.

Several studies carried out by ADAI indicates that dead fuels *mf* values lower than 10% are associated with highly danger conditions and *mf* values of around 6 to 7% can lead to events of extreme fire behaviour. These were the danger conditions during the wildfire period, especially on July 17th and 20th with *mf* lower than 10%. An indication of the extreme danger conditions in these days in Portugal is given by the *mf* measured in Lousã that reached a very low value on July 18th: 7.2% for *Pinus pinaster* and 4.9% for *Eucalyptus globulus*.

4.3.3 Fire danger

In Portugal, in accordance with current legislation (DL nº 82, of October 13, 2021), the RCM (Conjunctural and Meteorological Risk) is used to define the fire danger level of a region. The RCM is usually called the "Rural fire danger index" and is mainly addressed to the population.

The RCM is calculated daily and results from the combination of two components (IPMA 2020):

- Conjunctural and structural component given by cartography of the land use, slopes and burned areas of the last 10 years (from 2020, the burned areas of the last 3 years are also considered) – updated every year by ICNF.
- Meteorological component given by the Fire Weather Index (FWI) from the Canadian system (Van Wagner, 1987) that represents the intensity of the fire front, defined as energy per unit length of the flame front – updated every day by IPMA;

The integration of the two components is performed by applying a weighting matrix. RCM is rated on a 5-level fire danger scale (Low, Moderate, High, Very High and Maximum) and it is available at municipality and district level.

The interpretation of the FWI value is also made using a danger scale where the increase in FWI corresponds to an increase in fire danger. Table 9 presents the FWI danger level according to two classifications: IPMA 2023 and Viegas *et al.* (2004). The first considers a single scale (limit values of FWI for each level) to define the level of danger for the entire territory of Portugal (IPMA, 2023). The second classification considers a danger scale for each district of the country since the authors consider each of these classes has a relative interpretation, which changes from one district to another (Viegas *et al.*, 2004). Despite this comparison, we highlight that the classification made by IPMA (2023) is the official one used in Portugal.

Table 9. Classes of the Fire Weather Index (FWI) values according with: a) IPMA (2023) for the Portuguese territory and, b) Viegas *et al.* (2004) for the district of Vila Real, and FWI description according with IPMA (2023).

Level	Limit values of FWI		Description according to IPMA (2023)
	IPMA (2023) for Portugal (a)	Viegas *et al.* (2004) for Vila Real (b)	
1	<8.2	<13	Surface fires.
2	17.2	20	
3	24.6	30	High fire intensity with crown fires
4	38.2	50	
5	50.1	>50	Exceptional fire intensity with crown fires active, potential for spot fires and high difficulty of control.
6	64.0	-	Exceptional fire intensity with extreme difficulty of control
7	>64.0	-	

In Table 10 we compare the level of fire danger given by the FWI values and the RCM. This table presents the observed values for July 17th and the predicted values at 24h, 48h, and 72h for July 17th in Vila Real.

Table 10. Fire Weather Index (FWI) and Conjunctural and Meteorological Index (RCM) observed and predicted for July 17thin Vila Real. The red colour in RCM indicates the maximum danger classification.

Day	FWI observed and predicted				RCM observed and predicted			
	Obs.	Predicted			Obs.	Predicted		
		24h	48h	72h		24h	48h	72h
July 17th	42.6	48.5	53.6	49.9	5	5	5	5

On July 17th in Vila Real, the predicted and observed fire danger level according with RCM was classified as *Maximum* (level 5).

The predicted FWI at 48h (53.6) was also classified as *Maximum* according with IPMA (2023) and Viegas *et al.* (2004). For these FWI values the fire is characterized by "exceptional fire intensity with crown fires active, potential for spot fires and high difficulty of control" (IPMA, 2023).

The FWI at 24h (48.5) and the observed FWI (42.6) were classified as Maximum according with IPMA (2023) and Very High according with Viegas *et al.* (2004). According to IPMA (2023), the limit FWI value that defines the change to the Maximum level is 38.2 and, as shown in Table 9, all forecasts (and the observed FWI) were above this value. Although this level corresponds to the serious reality of the day in Vila Real, in general this classification is more penalizing, putting any region of the country with FWI>38.2 at Maximum fire danger. The concept of danger scale must have an interpretation or relative character as proposed by Viegas *et al.* (2004), for example a given value of FWI can mean a Maximum danger level in Vila Real (North region), but not in Faro (South region).

4.4 Fire Behaviour

The evolution of the perimeter of the fire of Murça from its ignition on the 17th of July until its extinction on the 21st is shown in the map of Figure 42. The location of the fire perimeter at given times gives an indication of the fire growth in some periods of the fire which are described below.

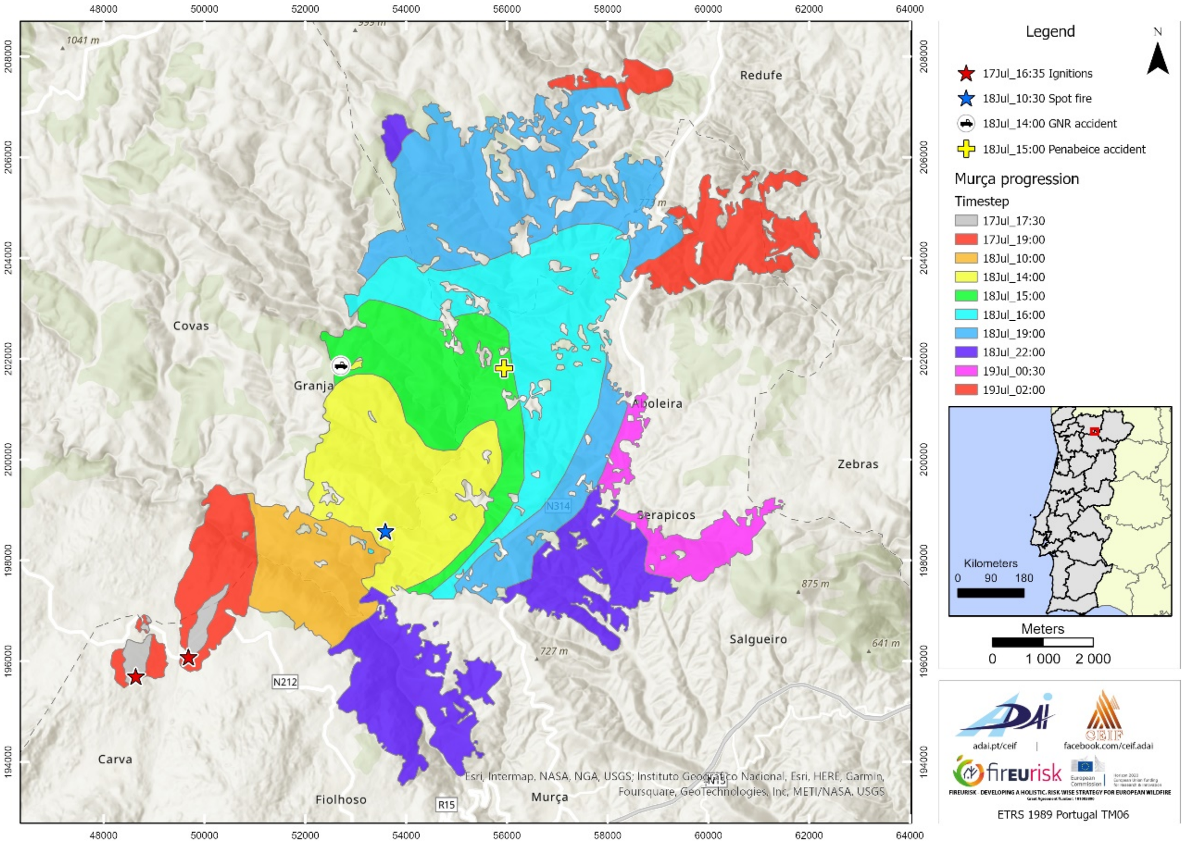

Figure 42. Evolution of the fire perimeter from the ignition on July 17th until the extinction of the fire on July 21st.

4.4.1 Fire ignition and spread on July 17th

The fire of Murça had two ignition points that were detected on July 17th at around 16:25, near an electrical 15kV line (Figure 43). One point was close to the Road N212, and the other one was close to Cortinhas.

Figure 43. View of the location of the East ignition point, close to the electrical post shown in the photo near the road N212.

The initial attack was performed by five Firefighter Corporations. Two helicopters were also dispatched, although one of them did not take off due to mechanical problems.

The ground forces of the initial attack were split into two forces to attack both ignitions. The suppression of the west ignition was achieved after a couple of hours but that was not the case of the eastern ignition. This fire spread towards Vilares and a back burn had to be made near the road N212, to protect this village. Soon afterwards the fire entered the Municipality of Vila Pouca de Aguiar.

Figure 44 presents the location of the two ignition points and the perimeter of the fire in the SW section of the fire perimeter.

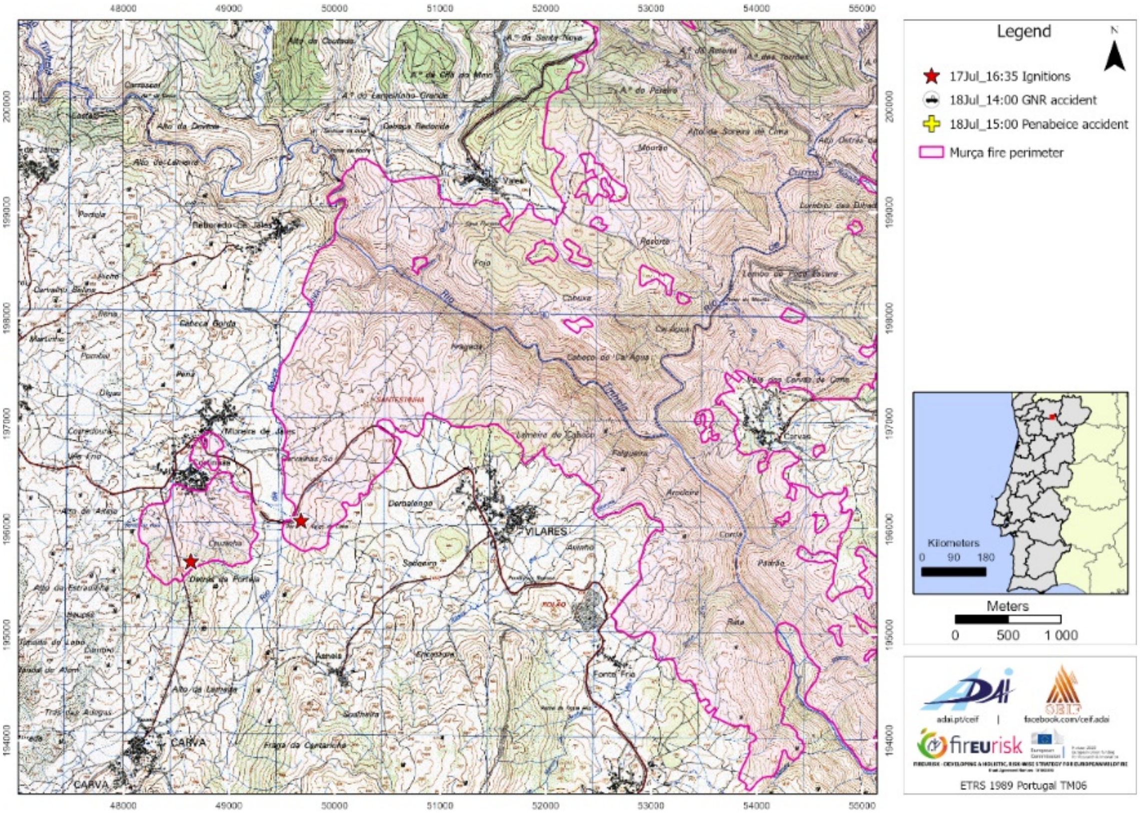

Figure 44. Location of the two ignition points and the perimeter of the fire in the SW section of the fire perimeter.

As can be seen in the images by the reconnaissance aircraft *Óscar 2*, around 17:26 on July 17th that are shown in Figure 45, less than one hour after its start, the two ignitions already had an important development, having covered around 668 m the western ignition and around 1 700 m the eastern ignition, corresponding to ROS of 0.73 km/h and 1.82 km/h, in that period of time. These values are indicative of the difficulty of the initial attack, especially for the east ignition. In Figure 45 there is a set of three spots ahead of the western fire. At a certain stage it was assumed that these were intentional ignitions, but it was realised that they must have been spot fires caused by the main fire, similar to one that can be seen near its head.

Figure 45. IR and video images from the fire of Murça obtained by the observation plane *Óscar 2*, around 17:26 on July 17th.

(a) *(b)*

Data source: ANEPC

There was a great effort by the Fire Brigades of Murça and of V. P de Aguiar, supported by other forces, to contain the fire on the west side of the river Tinhela to avoid that it could endanger the North of the Municipality of Murça. Despite the very difficult conditions of the terrain on the west bank of the river, due to the steep slope and rocky terrain, the fire was actually contained on this side of the river.

4.4.2 Propagation on July 18th

In the dawn and morning of July 18th, with a reduction of the wind velocity the fire evolved to the east along the west bank of River Tinhela and to the south of it.

Around 10:00 some spot fires produced a fire escape on the left flank of the fire containment near the river. As this fire was not contained it spread and around 10:30 produced one or two spot fires on the other bank of the river Tinhela.

As was already remarked, after 7:00 the wind velocity started to increase and its direction veered from east, then to south and southwest, turning to west by 21:00. The wind between 14:00 and 18:00 had velocities around 15 km/h and gusts of 30 km/h. With the increased wind velocity these spot fires spread out of control, towards the north, and the same happened to the fire perimeter in the Municipality of Murça, which also spread out of control in the same direction.

This was the worst phase of the fire in which there were two fire fronts spreading on both sides of the valley of River Curros that merged near Penabeice and Curros, spreading like a junction fire as described by Viegas *et al*., (2012) and Raposo *et al*. (2018). Groups of broken trees were found near Jou. This effect is characteristic of the strong convective processes that occur in these types of fires as had been observed in Pedrógão Grande, in June 2017, as it is reported in Viegas *et al*. (2017) and analysed in Pinto *et al*. (2022) and Viegas *et al*. (2023).

As it is shown in Figure 42 between 12:30 and 16:00 the fire reached and average ROS of 1.37 km/h which corresponded to peak values of the ROS possibly of the order of 3 km/h and fire line intensity (FLI) of the order of 16 to 30 kW/m, that corresponds to a fire completely out of control and of the capacity of suppression by direct attack.

The level of damage grading provided by the Copernicus satellite (Figure 46) is consistent with the observation of a very high intensity fire in this area of the fire.

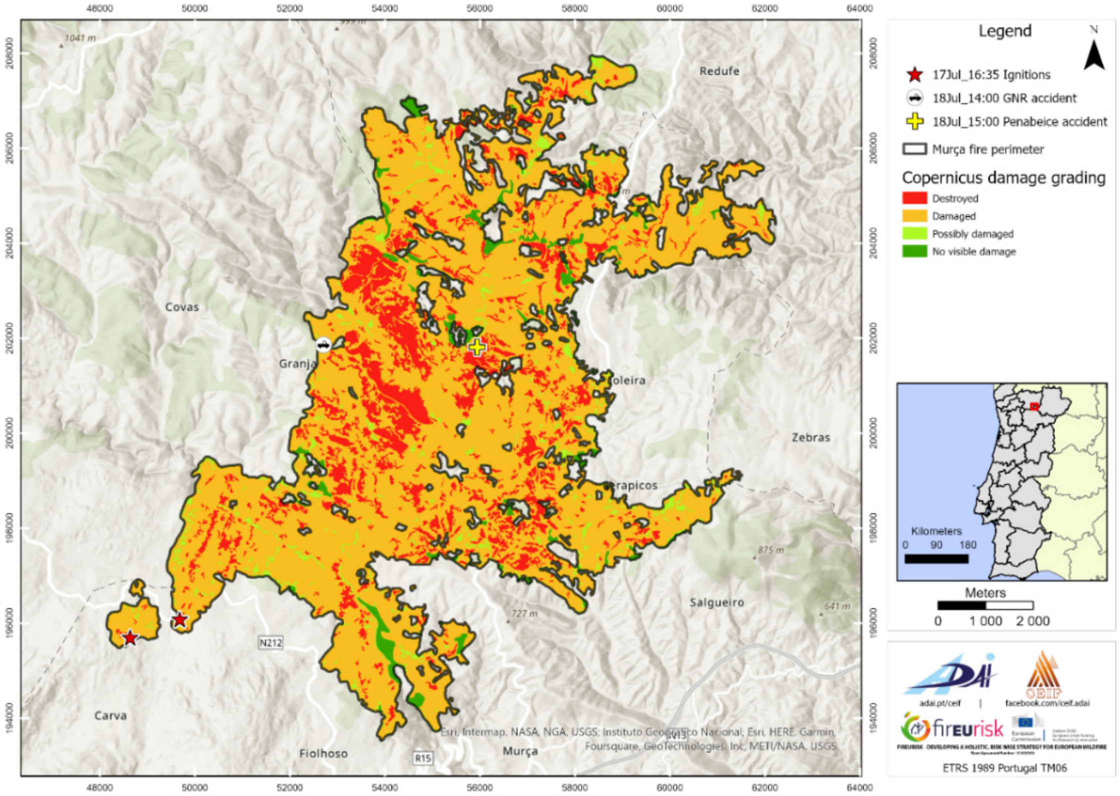

Figure 46. Level of damage grading provided by *Copernicus* satellite.

At the end of July 18th the fire spread along two fingers in the Southeast direction reaching almost its final perimeter.

On July 19th there were many resources to fight the fire that was mostly controlled along its entire perimeter. The difficulty to access some parts of the perimeter led to some rekindling during the night of July 19th and the fire did not spread more after 2:00 of July 20th.

4.4.3 Fire Suppression resources

On July 17th there was another fire in Bustelo, Chaves, district of Vila Real that involved several firefighting resources not only from the district but also from neighbouring districts, including several elements of the District Command, which may have affected the conditions of the initial attack of the fire of Murça.

Based on data provided by the Portuguese Civil Protection Authority (ANEPC), Figure 47 presents the variation of the firefighting resources allocated to the fire of Murça: a) human resources (firefighters and other civil protection agents), and b) ground and aerial resources. The allocation in the fire started on July 17th at the time of the first ignition until the closure of the occurrence report (July 25th). Resources with incomplete information in the occurrence report were excluded (e.g., resources without date of departure).

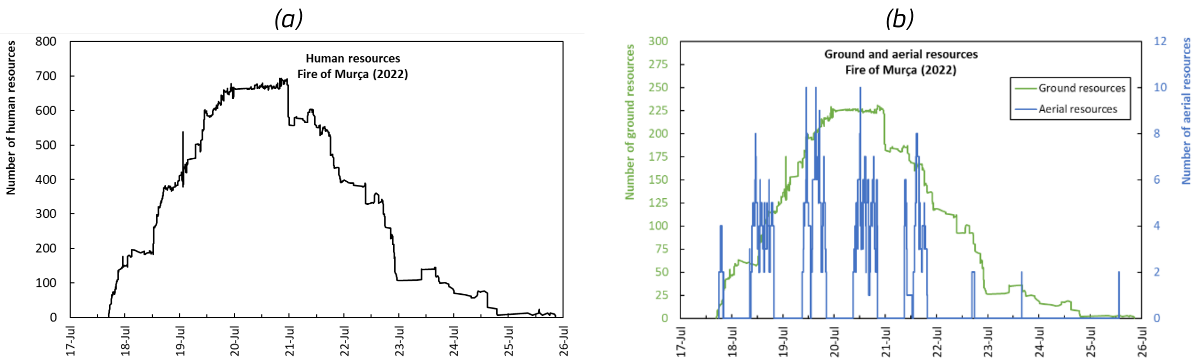

Figure 47. Evolution of the resources in the fire of Murça: a) human resources, b) ground and aerial resources.

Data source: ANEPC

In total, this wildfire had allocated 1 859 human resources complemented by 661 ground vehicles and 134 aerial resources. These aerial resources include the combat aircraft, heli-transported teams and the fire monitoring aircrafts.

4.5 Fire Safety Issues

4.5.1 Operational Agents Safety

Since its start the fire of Murça created an important danger for the safety of the operational agents and for the population, with various personal accidents being registered, plus the loss of vehicles and houses.

On July 17th at around 18:00 two firefighters had to be taken to the Hospital of Vila Real with light injuries. Although we do not know the nature of the injuries it must be remarked that this event happened barely in the first hour of the fire suppression activities. At 22:00 there was another register of a firefighter hurt by inhalation of gases, without indication of the severity of the problem.

On the July 18th after the end of the morning and the beginning of the afternoon the safety conditions aggravated. At 14:05 there was a register of a fire fighter with burns in his feet.

At around 14:00 a fire truck from the National Guard (Guarda Nacional Republicana) was trapped and destroyed by the fire near Tresminas. The vehicle and its crew with other two fire trucks were preparing to attack the fire that was spreading on a gentle slope below them, when this incident occurred. The terrain shape was that of a bowl, causing a fire acceleration that caught the agents by surprise giving them barely the time to escape on foot, abandoning the vehicle that was destroyed by the fire. There were no personal casualties, but this incident gives an indication of the quick spread of the fire from this hour on.

At 16:30 the Command Post was transferred from Vilares to Murça, for safety and to have better access conditions, and remained installed there from 17:30 onwards.

At 16:52 it was registered that the fire was out of the extinction capacity and safety was recommended to all operational agents. At 19:42 another firefighter with light injuries was registered in Ribeirinha.

On July 19th by 10:47 one other firefighter was hurt when he was caught by a falling tree that was downed by a discharge from a Canadair. On this day by 16:40 there was a register of a firefighter hurt by inhalation.

4.5.2 Citizens Safety

Besides the accidents that involved operational personnel that were referred to above, the fire threatened the population from its initial stage, endangering the villages of Carvas, Cortinhas and Vilares. As was said above this situation affected the effectiveness of the initial attack and created problems to the attack of the two starting fires.

Nevertheless, it was on July 18th that this threat became more extensive and dangerous, leading the authorities to promote the evacuation of various villages.

At 11:05 the evacuation of eight houses in Carvas was demanded; at 13:50 the evacuation of Mascanho and Penabeice was requested due to projections. GNR and the Civil Protection of Murça started this operation with the support of a bus. At 14:30 the Municipality of Murça activated the Municipal Emergency plan to allow the mobilization of all available resources, to face the situation.

At 14:39 it was registered that the National Road 314 had been cut off between the crossroad of Carvas and Vale de Égua and between Carrazedo de Montenegro and Murça. This indicates that other roads might be inaccessible to traffic or about to become so.

At 14:42 a GRIF from Guarda was sent to Penabeice to protect this village. Slightly later the help of military forces available in the area was requested to support the evacuation of Penabeice and Mascanho.

At 15:10 there was an indication of residence houses burning in Penabeice. At 15:12 the presence of the Medical Emergency Services (INEM) was requested to support the evacuations and at 15:42 it was reported that in Mascanho there were operational agents and civilians surrounded by the fire.

At 16:03 the presence of the National Guard was requested in Penabeice and at 16:57 also in Mascanho as the fire was spreading towards this village with great intensity.

At 17:11 one civilian informed by phone that the fire was very close to the village of Jou and that there were five aged persons and no firefighting resources.

4.5.3 Fatal Accident

In this fire two fatal victims occurred on the July 18th, around 15:00, near the village of Penabeice (Figure 48).

Figure 48. Map of Penabeice, with the road (CM1176), that goes up from the village to the road ER314, giving access to Murça. The yellow dot indicates the place where the car went off the road on to its left side, falling in the ravine.

The two victims were a couple that lived in a house near the western limit of the village. The house had very good habitability conditions, it was very well built and surrounded by other constructions that provided good safety conditions (Figure 49a). As the house was located above a slope towards the approaching fire the two persons had the perception of its very strong advance and decided to leave the village using their own vehicle.

The municipality of Murça was carrying out an operation of evacuation of some citizens from Penabeice, with the support of the firefighters. A bus was parked in the main square of the village with some citizens but as the fire was approaching it was decided to suspend the evacuation, due to the lack of conditions.

A reinforcement group of around 10 vehicles and more than 40 firefighters that had arrived at the scene of the fire had been mobilized to protect Penabeice. In spite of the relatively small size of the village this force was deployed inside and around the village providing a very effective support and protection to its citizens and to their houses.

It was recommended to all persons to remain in the village but unfortunately this message did not reach the couple that was affected by the fire. Several citizens had left the village during the two hours before the accident, including some persons that lived near the couple.

There are indications that at least one of the members of the couple deployed some hoses in the courtyard behind the house, overviewing the area from where the fire was coming, trying to wet the scarce vegetation that existed in that part of the terrain. At a certain time, possibly slightly before 15:00, the couple went in their car to get out of the village and away from the fire. They went along a lateral street that bypassed the main square and were not spotted by the authorities. They left the village, crossed a small bridge over the river Curros and started to drive along the road CM 1176 that went up along a relatively steep slope on the other side of the valley, opposite to Penabeice.

Going up this road they did not realize that the fire was climbing the slope behind them. After a turn they must have been engulfed by smoke, losing visibility. The vehicle veered to the left side and went off the road, falling on the slope. The car was immobilized with its wheels up and the two occupants did not manage to get out of it before the fire reached the vehicle (Figure 49b).

In this case the two citizens decided to escape from their house very late, with the fire approaching the village of Penabeice in a very violent form. They probably underestimated the rate of spread of the fire, especially going upslope and, above all, they possibly did not consider the effect of the smoke that caused their disorientation and ultimately their death.

Penabeice is a village that participates in the National program of Safe Villages and Safe Citizens, but we do not know to what level this participation impacted in the training of the villagers and in particular of the two victims.

(a) *(b)*

Figure 49. a) A view of the house where the couple lived; b) A view of the place where the vehicle fell.

4.6 Conclusions and Lessons learned

In the fire of Murça several issues were identified. We list here the most relevant ones that can provide lessons to be learned:

- In the initial attack there was possibly a delay in the launching of the alert which was compounded by the existence of another fire in the region, which limited the available resources, namely of aerial means.
- There were two ignition points with very important spread due to the wind, causing multiple spot fires, challenging the fire suppression strategy and the safety of the operational agents.
- There was a lack of coordination between the several agencies in presence, namely with the aerial means during the second and third day of the fire, given the extension of the fire and the intensity of fire propagation.
- Regarding the protection of the people during the fire, namely in the late morning and in the afternoon of July 18th, the authorities took the right measures to protect the citizens. The decisions to evacuate the villages or other places in peril were taken with prudence and in their execution the required agencies were involved.
- It is necessary to intensify the preparation of the populations to deal with fires of great intensity that can surprise them and overcome their predictions based on their past experience with fires in the region. It was found that the populations are now more receptive to the instructions or orders given by the authorities, but they are more in favour of the decision of sheltering in place instead of leaving their homes and villages. It was also found that the population helped the firefighters in all that was requested, including the support of firefighting operations. It was felt that the fuel management operations that were performed by the citizens around their houses after the 2017 fires had declined and that a new effort was needed to increase the motivation.
- It was mentioned that some sectoral meetings of the various commands during the fire could have been made online. The displacements required for the face-to-face meeting at the main command post represented a waste of time that could be avoided. It was mentioned that there was a need to verify the follow up of some orders that were given at the tactical level.
- The lack of water due to the drought at some water sources and scooping areas created some problems to the fire suppression effort, namely for the aerial means, increasing the distance to collect water and the time between drops.

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5 The Fires of Sierra de la Culebra (Zamora, Spain)

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5.1 General description

The Sierra de la Culebra region is a low populated region in the western part of the province of Zamora, in Northwest Spain (Figure 50), one of the areas historically most affected by wildfires. The region is characterised by steep hillsides and wide valleys, with altitude ranging between 747-1 205 m above sea level. The climate is Mediterranean, with mean annual temperature and precipitation of 11ºC and 750 mm, respectively (Ninyerola *et al*. 2005). The conifers are distributed preferentially in the high and sloping areas, while the broadleaves occupy the low and flat areas. Most of the burned area occupied by broadleaves is located in the northern region of the fire.

Two very large fire events occurred in this region in the summer of 2022. The two large fire events occurred one month apart, and they finally merged into a single burned patch, which totals more than 55 000 ha, therefore being one of the largest burned patches in the European historical records (Figure 51).

The first fire event (Ríofrío de Aliste Fire) started on June 15th between the municipalities of Ferreras de Arriba and Sarracín de Aliste, in the western region of the province. The ignition was caused by several lightning strikes produced by an electric storm as 18 lightning strikes were detected in the area, with six of them reporting ignition of fires between 19:00 and 21:00. The fire spread fast due to intense and erratic winds. The alert was given at 22:20 of the same day by the *Castilla y Leon* Forest Firefighting Department. Considering the magnitude of the fire, the regional government requested support from the Military Emergency Unit and reinforcements from several other regional governments. The fire was controlled on June 24th after burning 24 738 ha, although most of the area was burnt during the first three days. Fortunately, there were no human victims to mourn, but among the impacts are some cultural heritage sites and the disturbance of population from 17 localities who had to be evacuated. More than 560 firefighters worked in the extinction event, supported by 22 helicopters and 18 aircraft.

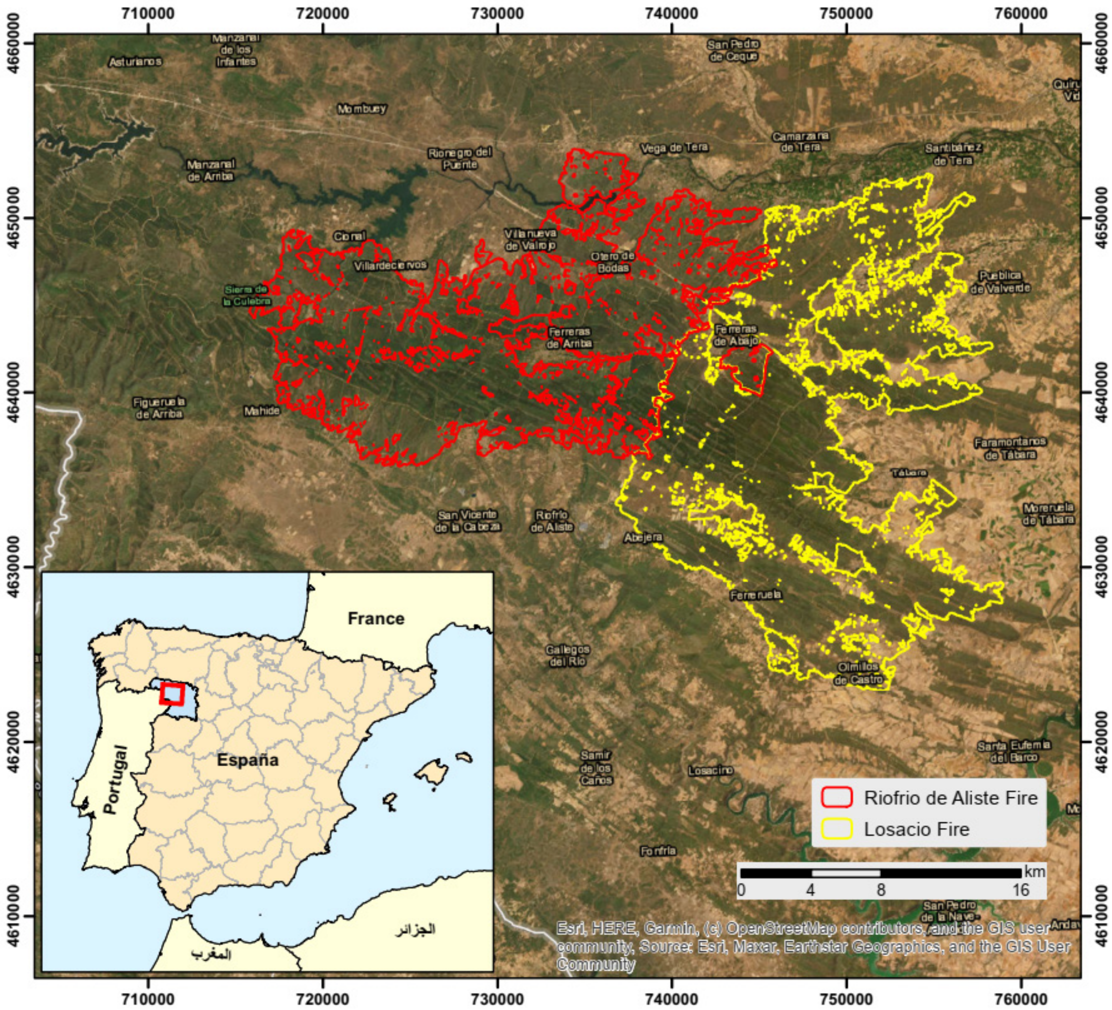

Figure 50. Location of Sierra de la Culebra Fires (Riofrio de Aliste Fire in red and Losacio Fire in yellow).

The second fire (Losacio Fire) occurred about one month later, on July 17th. It was also caused by lightning, and it was active for five days, causing a total burned area of 34 473 ha, with higher spread rate on the July 18th due to strong winds (>35 km/h) and extremely dry fuel. The fire started a few kilometres from the perimeter of the first large fire and finally merged with it. The fire was considered extinguished on August 14th. The propagation of this fire was very intense (10 000 ha were estimated to have burned in just four hours), which recommended the evacuation of 28 villages in the area. One firefighter died during the first day of the fire, and a shepherd perished on the following day, both trapped by the flames. Two more civilians died some weeks later as a result of the wounds caused by these fires. More than 450 firefighters worked in the fire extinction, helped by 15 helicopters and 12 aircraft.

A third fire event occurred on July 24th, called the Losacino Fire, affecting a non-contiguous area of the same province, covering around 1 600 ha. We will not cover this third fire event in here, as only the two large fires firstly mentioned have been analysed.

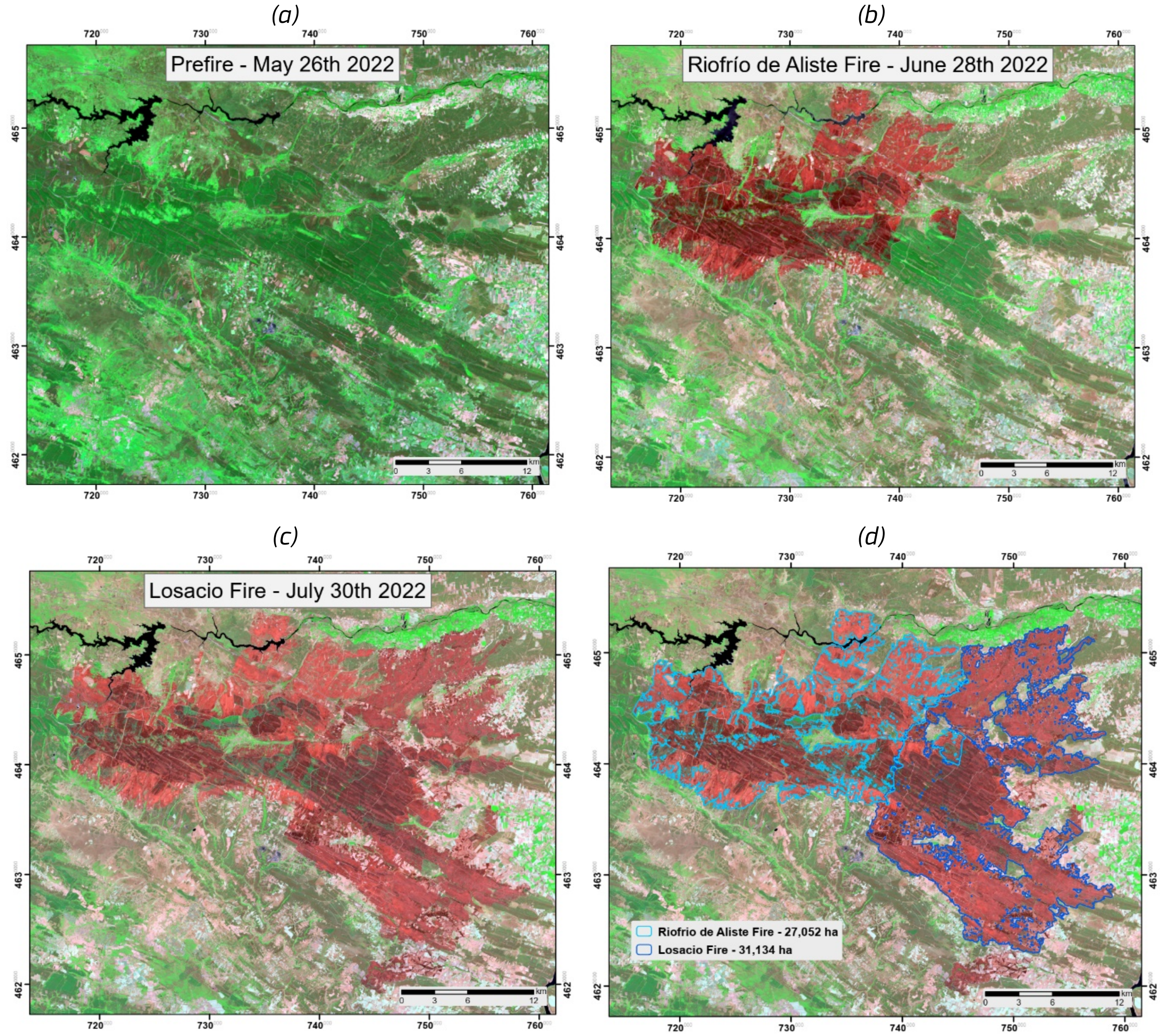

Figure 51. Sentinel 2 images acquired before the fires occurred on May 26th, after the Riofrío de Aliste Fire on June 28th, and after the Losacio Fire on July 30th. The colour composite used (SWIR-NIR-RED) shows the vegetation in green tones, with light greens for growing crops and darker greens for forested areas; the burned areas are shown in magenta tones, areas with sparse or no vegetation are shown in light pink colour. The bottom right image shows the fire perimeters of both fires with the estimated burned area from satellite images.

5.2 Characterization of the affected area

The Riofrío de Aliste Fire implied the evacuation of 18 communities of the region. In terms of land cover (Figure 52), the fire mainly affected forested areas (13 000 ha), followed by shrublands (7 839 ha) and grasslands (742 ha), with a minimal area of agricultural areas (453 ha). The affected forested area includes both natural forests (61.63 %) and plantations (38.37 %) (Figure 52). The main tree species affected were *Pinus pinaster* (maritime pine), *Pinus sylvestris* (Scots pine), *Quercus ilex* (holm oak), *Quercus pyrenaica* (Pyrenean oak) and *Castanea sativa*. The shrublands were dominated by *Cistus ladanifer L.*, *Pterospartum tridentatum* (L.) Willk., *Erica australis L.*, and *Halimium lasianthum subsp. alyssoides* (Lam.). Four protected areas included in the Natura2000 network were inside the perimeter of the fire (Lagunas de Tera y Vidriales, Riberas del Río Aliste y afluentes, Riberas del río Tera y afluentes and Sierra de la Culebra). Also, a part of the biosphere reserve called Transfronteriza Meseta Ibérica was affected by the fire.

The Losacio Fire was even larger than the first one, affecting a total of 31 134 ha across 38 municipalities. The land covers affected were forested areas (14 760 ha), followed by shrublands (4 601 ha) and grasslands (6 820 ha), with a significant share of agricultural areas (4 955 ha) (Figure 52). Two protected natural areas were affected by the fire: Lagunas de Tera y Vidriales and Sierra de la Culebra. Species burned included *Quercus ilex, Quercus suber, Pinus pinaster, Pinus sylvestris, Quercus pyrenaica, Quercus faginea, Pinus nigra, Pinus pinea and Populus x canadensis.*

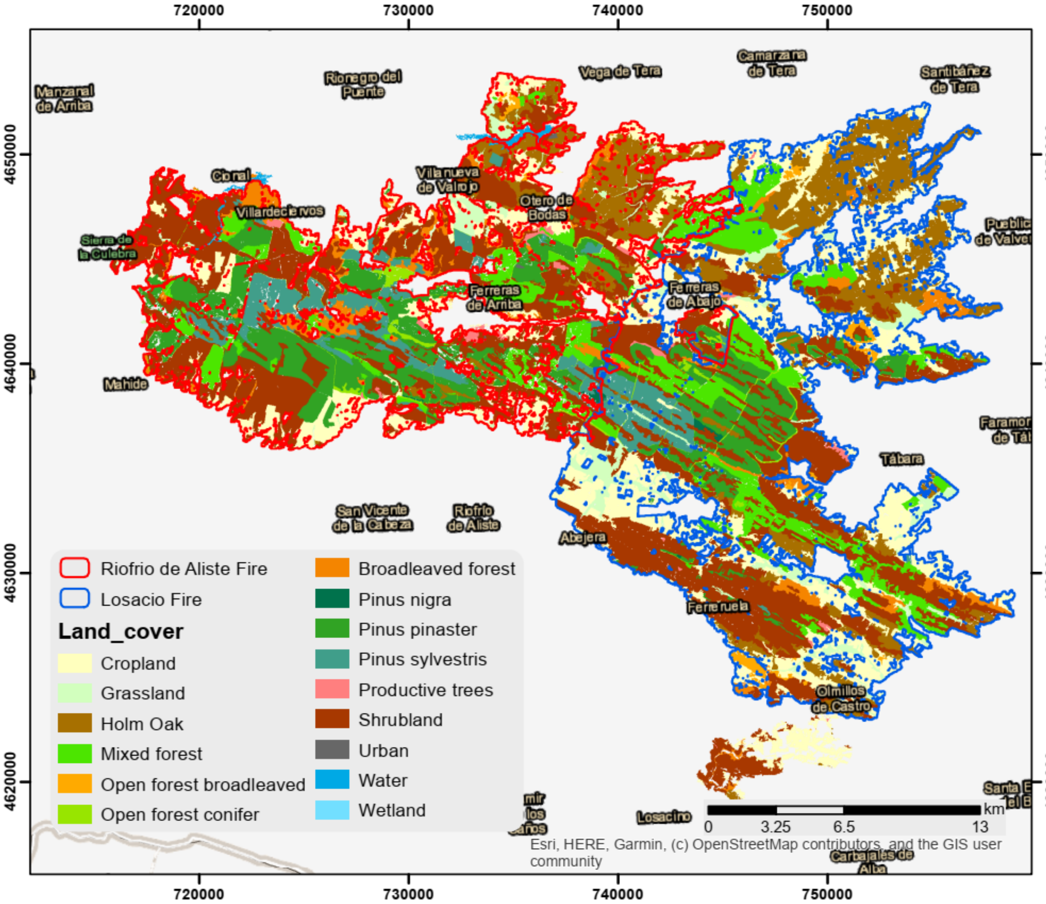

Figure 52. Land covers affected by the Sierra de la Culebra fires (Riofrio de Aliste and Losacio).

5.3 Fire conditions of *Riofrio de Aliste* Fire

Regarding the meteorological conditions, the winter of 2021-2022 was the fourth warmest and second driest winter recorded in Spain. The spring of 2022 was also unusually dry. In particular, the month of May 2022 was the second warmest and second driest on Spanish records.

In June, a heat wave occurred in Europe which in Spain lasted from June 12th to 18th, making it the second earliest heat wave ever recorded. The Spanish weather service's (AEMet) weather station at Villardeciervos (Figure 53) recorded a maximum temperature during the heatwave of 35.8°C on June 15th, while on the night of June 17th- to 18th the minimum temperature was 17.5°C. By comparison, the average minimum temperature for June at that weather station is 11°C. In these circumstances, AEMet warned of an extreme risk of fires from June 14th in most of peninsular Spain and, in particular, in the north-west of the province of Zamora. These weather episodes led to very favourable conditions for the spread of the fire on June 15th.

The high temperatures, both during the day and at night, and very low relative humidity resulted in a situation of marked and progressive hydric stress of the vegetation, resulting in a very high probability of ignition of the fine fuels (Figure 53 and Figure 55).

On June 15th, the day the fire started, a low-pressure centre began to form on the west of the Iberian Peninsula, associated with the DANA (Isolated depression at high elevation of the atmosphere) (Figure 54), with high atmospheric instability, which produced a cold front and dry storms over the west of the community where the fire started. This cold front and the storms produced strong winds that caused the fast spread of the fire during that evening.

In the following days, from June 16th to 20th, the movement of the DANA located to the SW of the Iberian Peninsula towards the NE generated a situation of strong winds of 30 to 35 km/h with gusts of up to 70 km/h, which rotated from E to W during the first days of the fire. The winds conditioned the main directions of fire spread, which together with the conditions of very high temperatures, very low relative humidity and low vegetation moisture content caused the fire to spread quickly, triggering a large burned area.

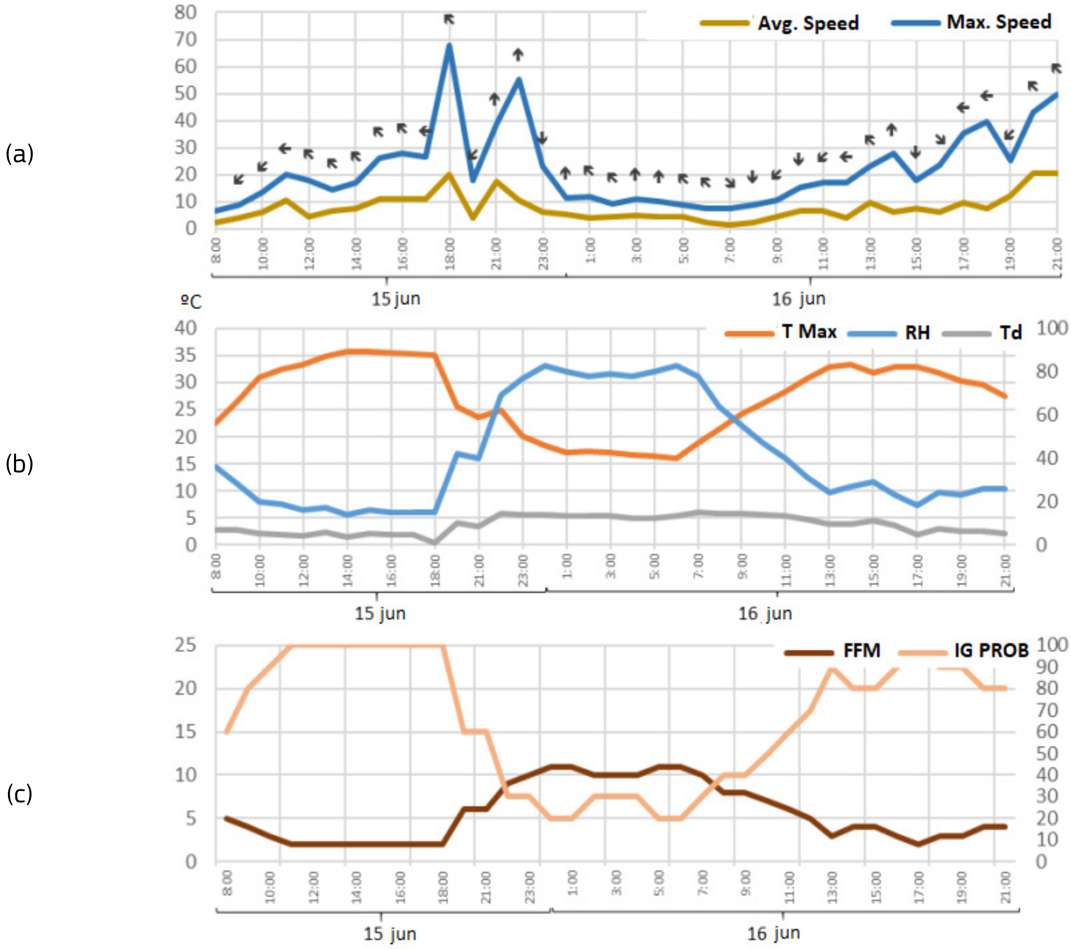

Figure 53. Meteorology station of Villardeciervos – 2775X, at 850 m above sea level. A) Wind speed, B) Temperature and relative humidity, C) Fine Fuel Moisture (FFM) and ignition probability (IG PROB).
Sources: AEMet and Castilla y León Forestry Department.

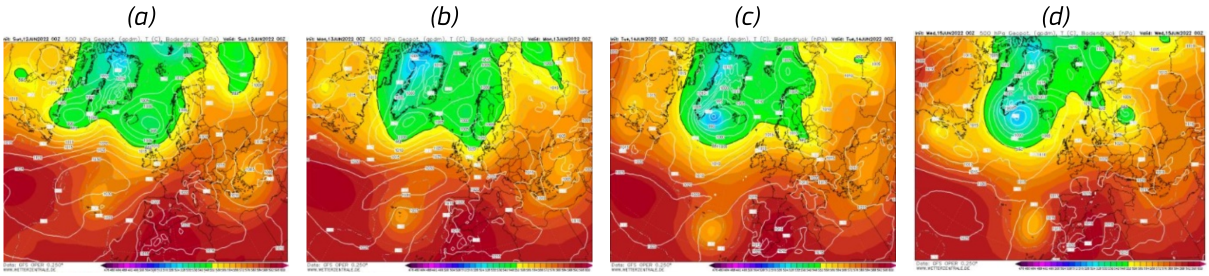

Figure 54. Geopotential pressure at 500hPa at 00z from July 12th to 15th and dominant synoptic situations during the week of June 13th to 19th.
Source Wetterzentrale and AEMet

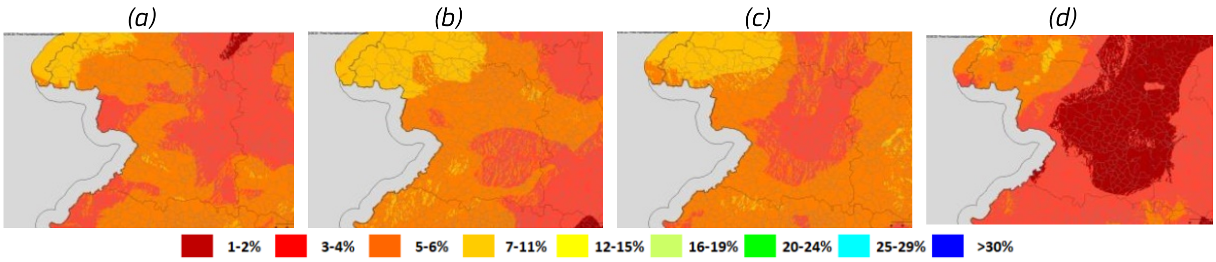

Figure 55. Fuel moisture content of dead fine fuel from June 12th to 15th.
Source: METEOSIG.

The Standardized Precipitation-Evapotranspiration Index (SPEI) shows the drought conditions including intensity and duration, over a region. The data were calculated using the meteorological data of the area. Figure 56 shows the drastic descent of the water content starting in December 2021, not modified by the Spring season (which is regularly the wettest in the region). The continued drought conditions produced a sharp decrease of fuel moisture content, increasing fire risk in the area. The fuel moisture content of dead fine fuels is relevant for the analysis of the ignition conditions, the potential of spotting and for the understanding of the initial fire propagation. The values of dead fine fuel moisture stayed below 6% in the region and decreased to 1-2% on the day of the fire, producing very favourable conditions for fire occurrence.

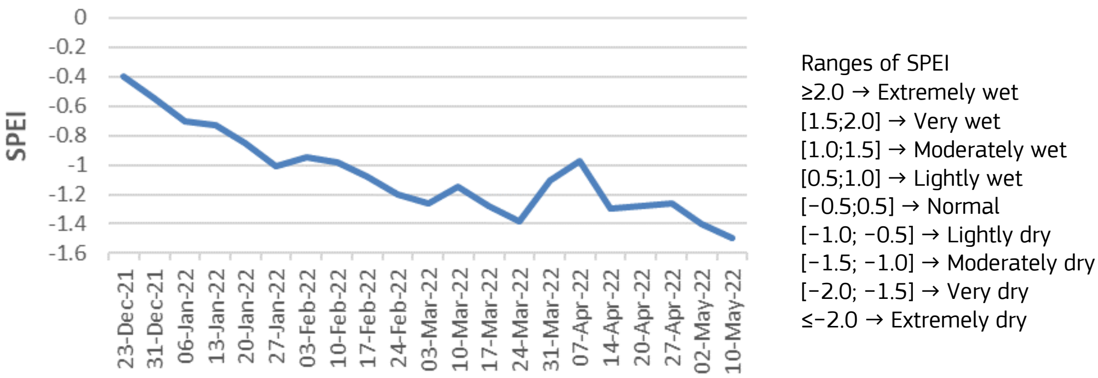

Figure 56. Standardized Precipitation-Evapotranspiration Index (SPEI) in Zamora during the six months prior to the Riofrio de Aliste and Losacio fires occurrence. *Sources: AEMet and Castilla y León Forestry Department.*

5.4 Fire behaviour of Riofrío de Aliste Fire[1]

In the late afternoon on the June 15th, 18 lightning strikes were detected in the Sierra de la Culebra produced by an electric storm. Eleven of these lightings generated ignitions, but only six turned into active fires (Figure 57). The fire was detected at 20:08 of June 15th and was declared extinct at 21:00 of June 21st.

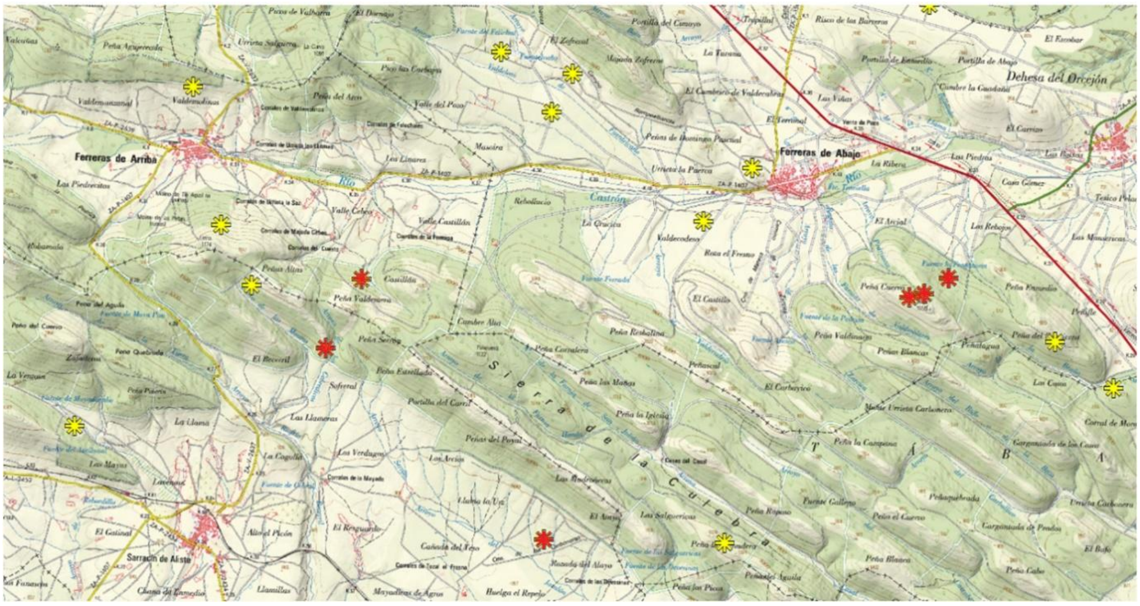

Figure 57. The map shows the lightning strikes occurring in the region on June 15th in yellow and the lightning strikes which turned into active fires in red. *Source: Report of the Forest Firefighting Service of JCyL.*

During the night of the lightning strikes, the fire quickly propagated, influenced by strong winds of more than 50 km/h and burning more than 500 ha. During the following day, the fire stabilized in the early morning. However,

[1] We have used for this section the report prepared by fire authorities of *Junta de Castilla y León*, courtesy of Angel Manuel Sánchez and Francisco Javier Ezquerra.

in the afternoon it started progressing rapidly and intensively again influenced by low humidity and high atmospheric instability, with wind changing direction and gusts of more than 50 km/h, particularly at late afternoon and early night (Figure 58). On June 17th, there were strong winds blowing towards the southeast with an average speed of 25 km/h, and gusts of 40 km/h, were observed. The eastern ignition was stabilized but the western fire flank advanced very quickly and out of control. The wind conditions were constant until 4:00, when the wind rotated to a southern direction, moving toward populated areas such as Cabañas de Aliste, Torres de Aliste and Pobladura de Aliste. Consequently, the protection of the populated areas was prioritized, involving firefighting resources (Figure 59).

By 5:30 the wind changed direction again, turning to the east and threatening the town of Mahide. The population of Mahide was evacuated. In the afternoon, the wind changed again to the South component reactivating the northern fire flank. The towns of Villardeciervos, Villanueva de Valrojo and Otero de Bodas were evacuated as the fire approached the populated areas. Again, the priority was to protect the villages.

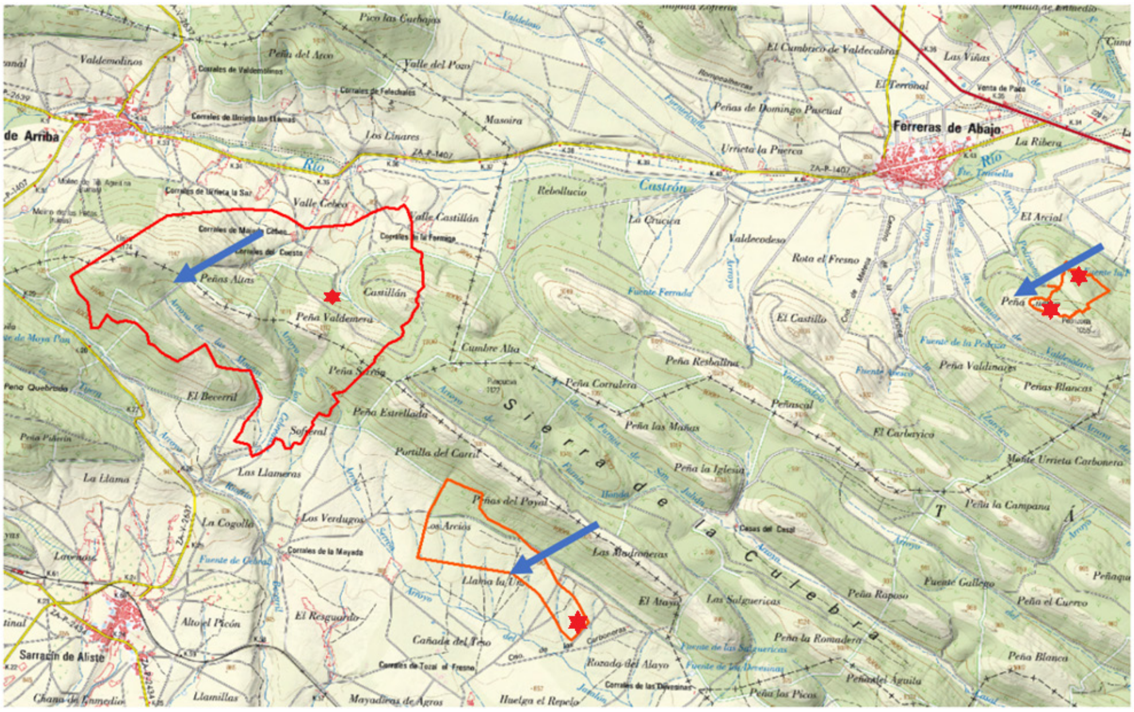

Figure 58. Fire growth and dynamic on June 16th. Red stars mark the location of the ignition, blue arrows indicate the direction of the wind, and the red polygon indicates the size of the affected area.
Source: Report of the Forest Firefighting service of JCyL.

(a)

(b)

(c)

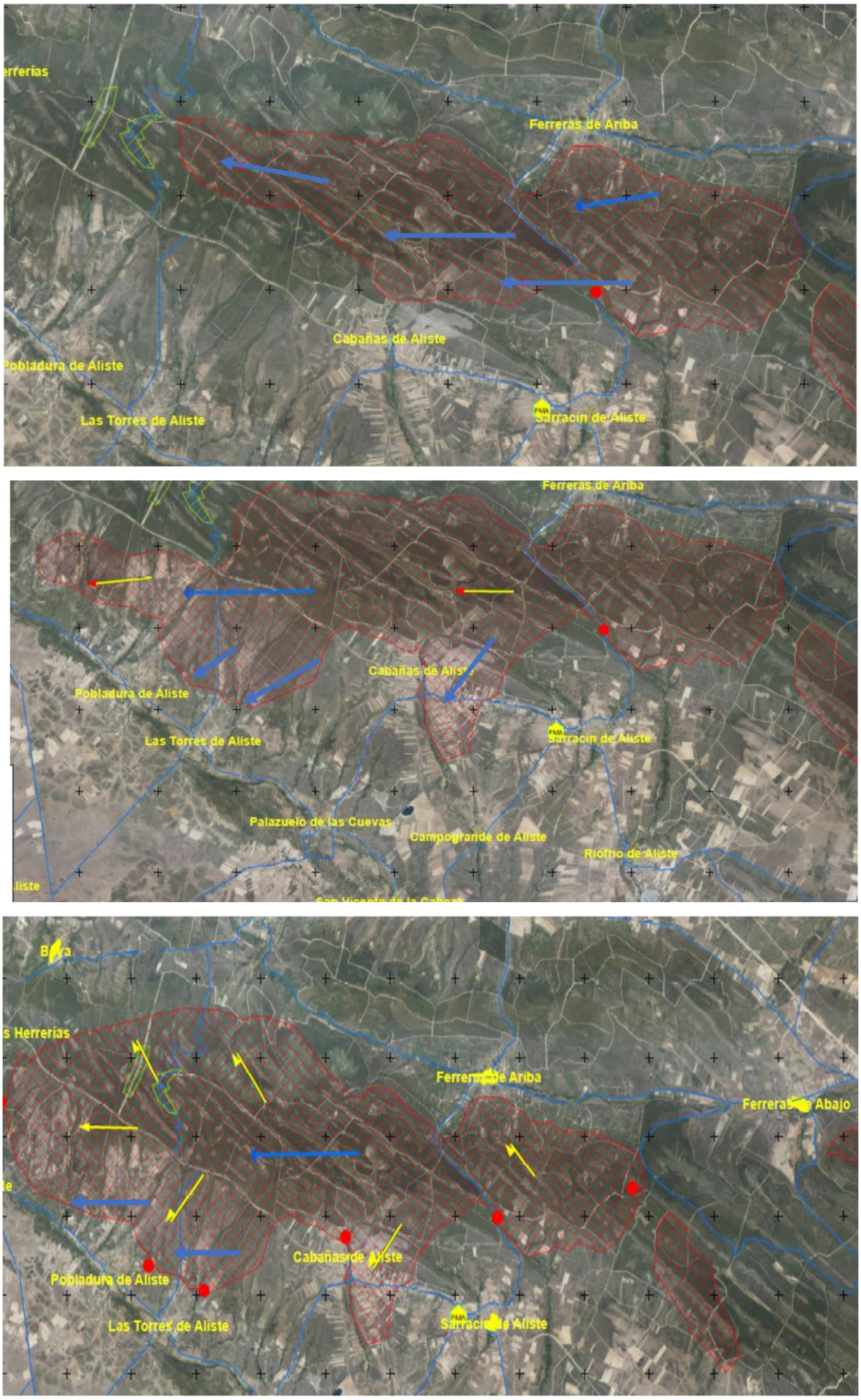

Figure 59. Fire growth and dynamic on June 17th: a) Shows the fire growth at 3:00, b) the fire growth at 5:00, and c) shows the fire growth at 8:00.

Source: Report of the Forest Firefighting Service of JCyL.

On June 18th, the fire crossed the highway N-631 advancing in a southwest direction quickly and out of control (Figure 60). More villages were evacuated: Melgar de Tera, Olleros de Tera, Calzadilla de Tera, Pumarejo de Tera, Junquera de Tera, Milla de Tera, Vega de Tera and Val de Santamaría.

On June 19th, the wind changed direction again towards west-southwest direction moving towards the towns of Villanueva de las Peras and Litos (Figure 61). However, the wind slowed down, and the firefighting brigades could control the fire by the end of the day. The fire continued burning in some areas until the June 24th, but the fire spread was stabilised, and the fire perimeter varied little.

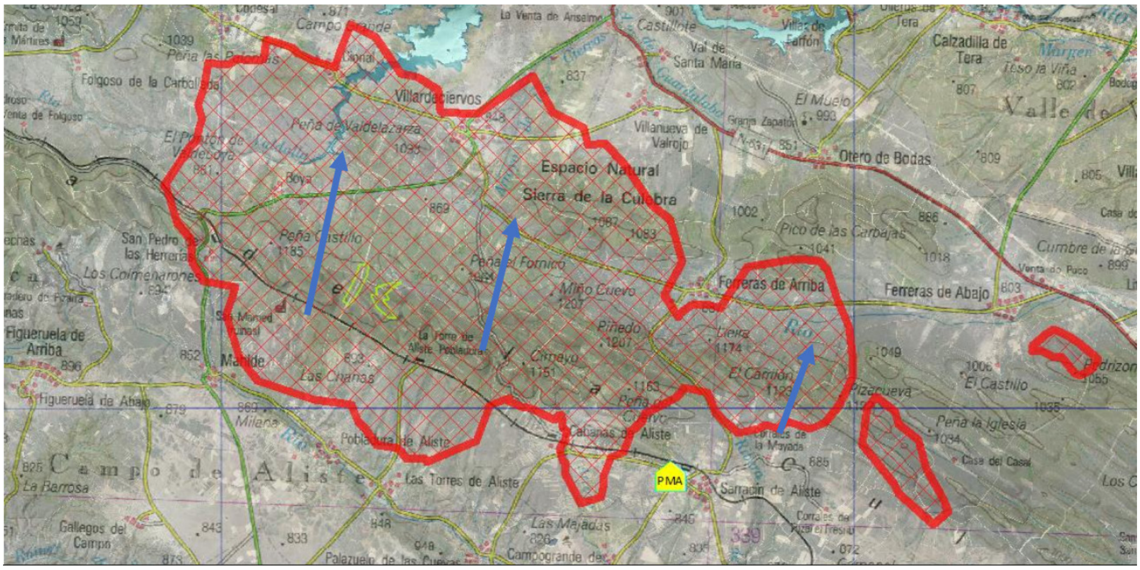

Figure 60. Fire growth and dynamic on June 18th. Blue arrows indicate the direction of the wind, and the red polygons mark the extension of the burned area.

Source: Report of the fire extinction service of JCyL.

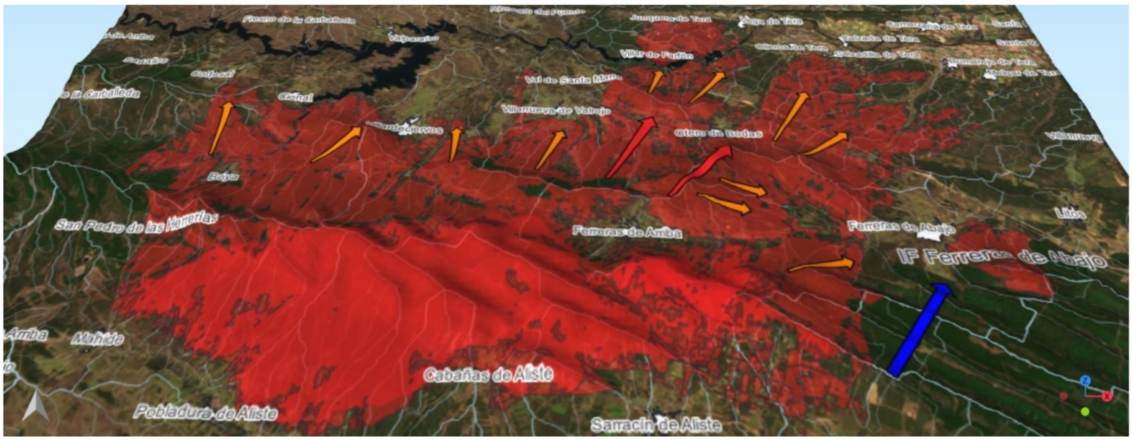

Figure 61. Fire growth and dynamic on June 19th. Blue arrow indicates the direction of the wind, red and orange arrows mark the fire spread.

In summary, during the four days that the fire was active, the atmospheric conditions were very unstable and unfavourable for extinction, with maximum temperatures above 30º C, no rain, low humidity levels and strong winds. However, the local weather conditions were not those measured by the weather stations, but rather those observed at the fire front, which were more extreme, since the fire created its own wind whirls and thermal conditions, exacerbating the difficulty of extinction. During many hours the fire was outside extinction capabilities, with strong convective winds. Propagation was facilitated by those fast winds, with spotting registered up to 500 m.

Table 11. Summary of fire propagation parameters for the Riofrío de Aliste Fire.

Date/time	Time since prev. obs.	Area (ha)	Increase (ha)	Speed (ha/h)	Length (km)	Rate of Spread	
						(km/h)	(m/s)
15/06/2022 20:08	--	0	0				
16/06/2022 12:00	15:52	800	800	50.42	4	0.25	4.2
16/06/2022 20:00	08:00	1195	395	49.38	1	0.13	2.08
17/06/2022 08:00	12:00	7378	6183	515.25	13	1.08	18.06
17/06/2022 22:30	14:30	15702	8324	574.07	7	0.48	8.05
18/06/2022 12:00	13:30	17761	2059	152.52	1	0.07	1.23
18/06/2022 21:00	09:00	29185	11424	1269.33	7	0.78	12.96

Source: Report on the fire by Junta de Castilla y León.

5.5 Fire conditions of *Losacio* Fire

As commented in the previous section, winter and spring were unusually warm and dry inducing the hydric stress of vegetation in peninsular Spain. During the summer of 2022 a continuous condition of heat wave took place from mid-June, with very high temperatures and low relative humidity, which added to the drought conditions occurring since winter. In fact, the average temperature of July in the region was 4.5º higher than the average of the reference period (1981-2010).

This situation was produced by the lifting of a DANA located to the west of the peninsula, producing a cold front and dry storms over the west of the community, affecting to a greater extent the provinces of León, Zamora, Salamanca and Ávila.

One of the most important factors for the high propagation speed of this fire was the intensity of the wind, which during the 17 to 20th of July had an average speed of more than 25 km/h in the central hours of the day, reaching peaks of more than 60 km/h (Figure 62). Moreover, on the afternoon of July 18th, the day of greatest spread of the fire, the average wind speed was over 35 km/h from 15:00 to 19:00 hours, which caused the fire to be very difficult to control by the firefighters.

Figure 63 shows the moisture content of the dead light fuel on the day of the start of the fire and subsequent days. As can be seen, the FFMC varied from 1 to 4%, which are extremely low values that facilitate the ignition of the vegetation.

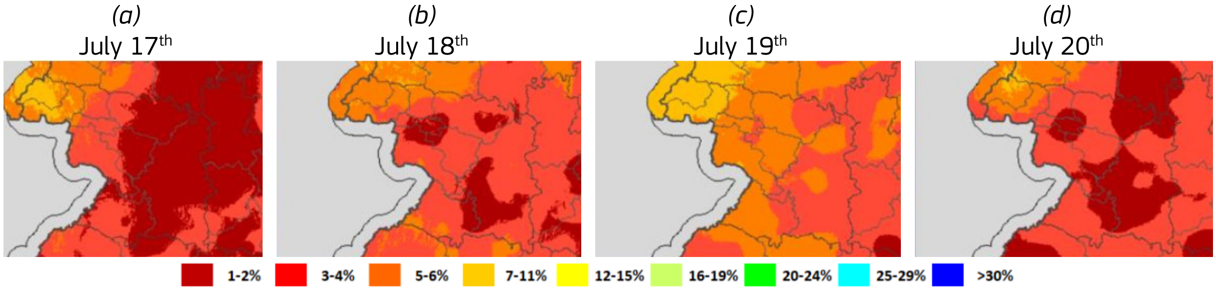

Figure 62. Fuel moisture content of dead fine fuel from July 17th to 20th. Source: METEOSIG.

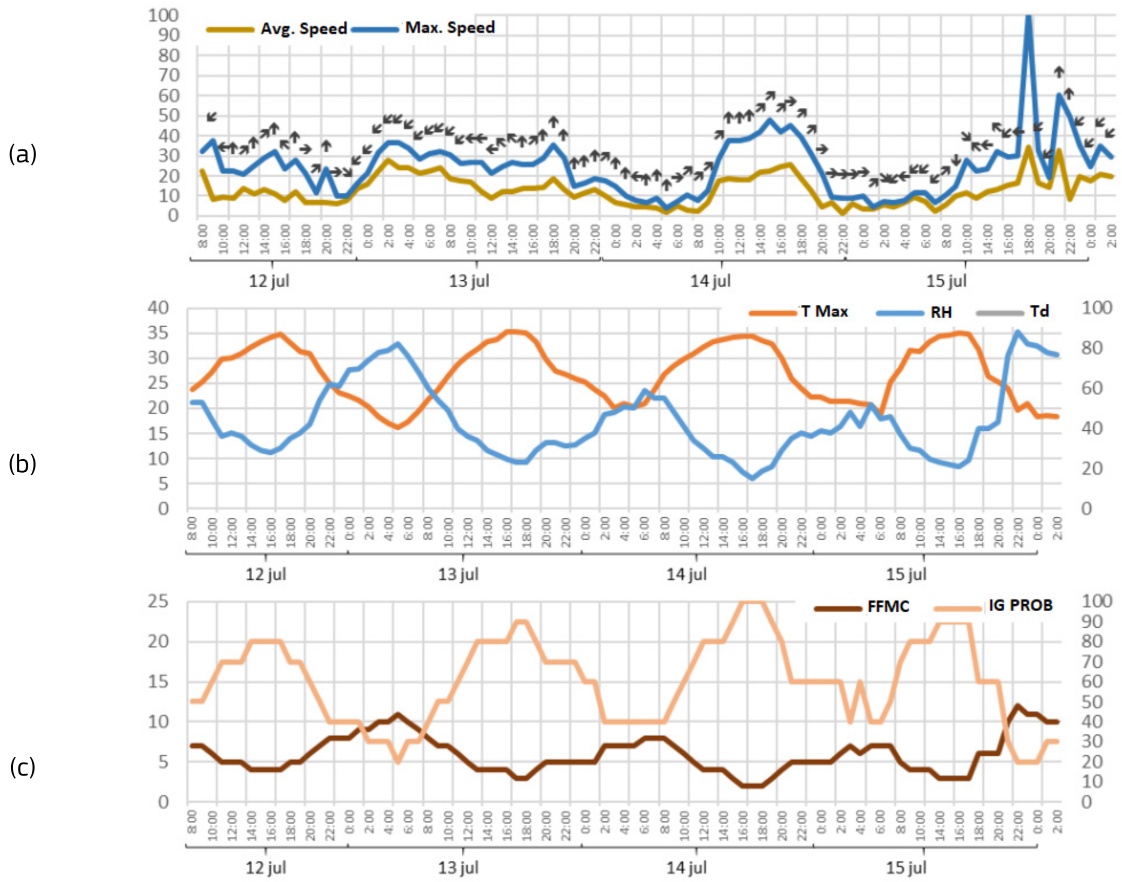

Figure 63. Meteorology station of Alcañices – 2966D, at 840 m above sea level (Right), during the previous days to the Losacio Fire (started on July 17th). A) Wind speed, B) Temperature and relative humidity, C) Fine Fuel Moisture (FFM) and ignition probability (IG PROB).

Sources: AEMet and Castilla y León Forestry Department.

5.6 Fire behaviour of Losacio Fire[2]

Fire propagation analysis was based on images and videos recorded by the coordination aircraft during the fire suppression activities, as well as field information from fire brigades and forest rangers. Estimations of fire rate of spread are approximated, as propagation sometimes was very dispersed. However, a more detailed analysis of the fire propagation conditions, similar to the Riofrío fire, is not available.

It was observed that the fire had a very diverse propagation pattern, with high propagation speed during the first hours of activity (Table 12 and Figure 64). The peak of extreme behaviour was observed on the second day of the fire, particularly between 17:30 and 19:00 of July 18th, when more than 3 300 ha/h were observed. Winds were predominantly from the south, and they changed directions several times during the extinction period.

Table 12. Summary of fire propagation parameters for the Losacio Fire.

1st hour	2nd hour	Area burned				Propagation			
		Total (ha)	Δ	Δ%	Speed (ha/h)	Main axis	Speed (km/h)	Speed (m/min)	Class
17/07/2022 18:00	17/07/2022 20:00	187.27	187.27	100.00	93.64	2151.26	1.08	17.93	High
17/07/2022 20:00	18/07/2022 3:00	8918.65	8731.38	97.90	1247.34	10635.05	1.52	25.32	High
18/07/2022 3:00	18/07/2022 8:00	9852.67	934.02	9.48	186.80	2535.5	0.51	8.45	High
18/07/2022 8:00	18/07/2022 13:30	15982.43	6129.76	38.35	1114.502	4890.74	0.89	14.82	High
18/07/2022 13:30	18/07/2022 17:30	22029.96	6047.53	27.45	1511.88	8561.27	2.14	35.67	Extreme
18/07/2022 17:30	18/07/2022 19:00	27102.1	5072.14	18.71	3381.43	6484.99	4.32	72.06	Extreme
18/07/2022 19:00	18/07/2022 22:00	28317.85	1215.75	4.29	405.25	4527.24	1.51	25.15	High
18/07/2022 22:00	19/07/2022 5:00	40277.11	11959.26	29.69	1708.47	3959.44	0.57	9.43	High
19/07/2022 5:00	19/07/2022 15:00	35941.66	-4335.45	-12.06	-433.55	-2519.15	-0.25	-4.20	Adjusted
19/07/2022 15:00	20/07/2022 15:00	33932.56	-2009.1	-5.92	-83.71	-3237.82	-0.13	-2.25	Adjusted

Source: Report on the fire by Junta de Castilla y León.

[2] We have used for this section the report prepared by fire authorities of *Junta de Castilla y León*, courtesy of Angel Manuel Sánchez and Francisco Javier Ezquerra.

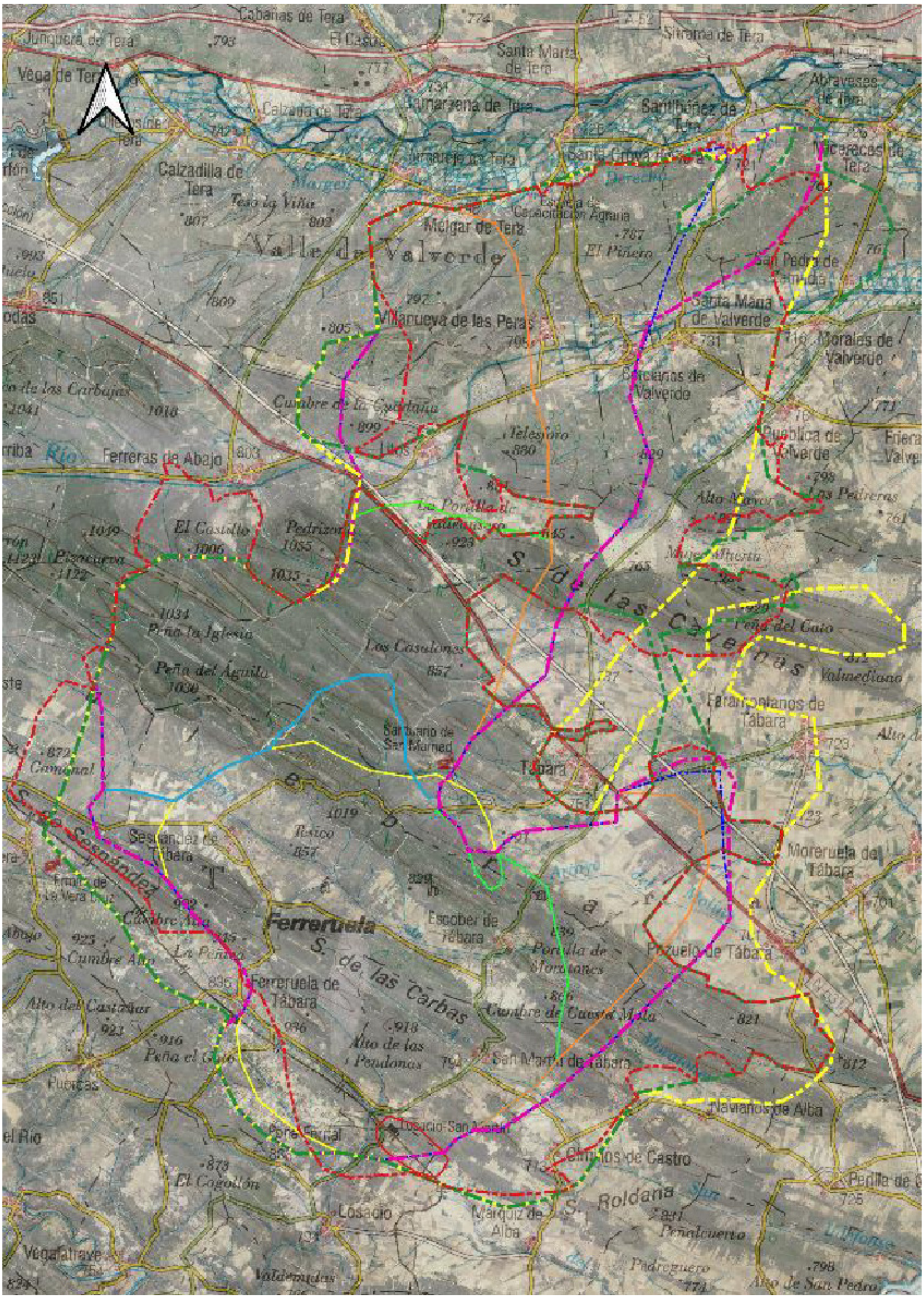

Figure 64. Fire growth of the Losacio fire following aerial photography and field reports. Yellow line: July 17th at 03:00; Light Blue line: July 18th at 08:00; Green line: July 18th at 13:30; Brown line: July 18th at 17:30; Dark Blue line: July 18th at 19:00; Magenta line: July 18th at 22:00; Discontinuous yellow line: July 19th at 05:00; Discontinuous green line: July 19th at 15:00; Discontinuous red line: July 20th at 15:00.

Source: Report of the Forest Firefighting Service of JCyL.

5.7 Fire damage and burn severity

As indicated earlier the two large fires – Riofrío and Losacio Fires - were among the most extreme occurring in Spain, burning more than 25 000 and 34 000 ha, respectively, and creating a continuous immense burned patch. The fires caused four deaths and the evaluation of more than 3 000 persons in around 30 villages.

Our research group has performed field work over the affected area, to estimate combustion completeness (biomass consumed by the fire), mainly focused on the Riofrio de Aliste Fire and post-fire severity measured in both fires. Measures were taken almost one year after the fire, in May and June 2023.

Field measures allowed us to observe a great diversity of burning conditions in the huge area affected by the fire. The most intensively burned areas were located in moderate to high fuel loads and short pine trees, which were almost completely burned (Figure 65). Lower severities were found in those areas where coniferous forest was taller. These areas showed varying understory density, the lower density of understory was found in managed forests with higher tree heights, as the effect of the shadow limits the growth of shrubs. There were also areas where the fire showed lower intensity as indicated by the less affected understory formed mainly by heather (*Calluna vulgaris or Erica L.*) (Figure 65).

Burn severity was measured following the GeoCBI (Composite Burn Index) (De Santis and Chuvieco 2009). The GeoCBI considers a list of variables that are adapted to temperate and Mediterranean forests. It follows the hierarchical structure of CBI (Key and Benson 2006) dividing the vegetation in 5 strata (Soil and litter, vegetation < 1 m, vegetation 1-5 m, vegetation 5-20 m, and vegetation > 20 m), also introducing the consideration of the fraction covered by each stratum inside the plot.

In addition to GeoCBI estimates, we collected inventory measurements over 18 plots distributed across different burn severities, as well as unburnt plots. Field measurements included: diameter at breast height (DBH) of all the trees taller than 2 m, tree height of 10-20% of the trees, identification of species, and visual estimation of the percentage of biomass consumed in different biomass fractions (foliage, trunk, and branches diameter classes of: <2 cm, 2-7 cm, and > 7 cm). Moreover, four subplots of 2×2 m^2 were analysed in each plot to account for understory vegetation. These measurements will be used to estimate above ground biomass before and after the fire. In addition to these inventory field measurements, the plots were scanned using a terrestrial LiDAR system (TLS) and a drone Lidar system, to complement the field measurements for biomass estimations.

(a) *(b)*

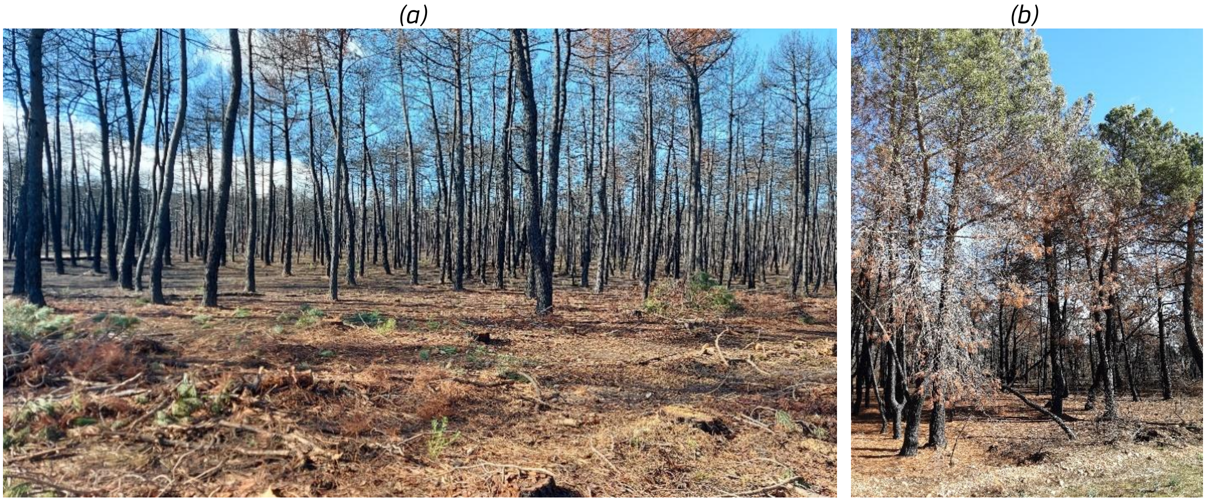

Figure 65. a) Post-fire situation in the central valley of the Riofrío de Aliste fire showing intense severity; b) Post-fire situation in the Southern mild slopes of the Riofrío de Aliste fire showing medium fire severity. (*photos taken by Emilio Chuvieco in November 2022*).

(a) (b)

Figure 66. a) Post-fire situation in the north of Losacio fire showing intense severity; b) Post-fire situation in the North East of Losacio fire showing medium fire severity. (photos taken by Patricia Oliva in June 2023).

Burn severity was computed following a simple approach based on changes in reflectance of two spectral bands after the fire. Following a standard procedure initially proposed by the USGS ((Key and Benson 1999)), we have used the changes in the Normalized Burn Ratio (NBR), which is a spectral index closely related to post-fire effects and defined by:

$$NBR = \frac{\rho_{SWIR} - \rho_{NIR}}{\rho_{SWIR} + \rho_{NIR}} \qquad \text{[Eq. 1]}$$

Where SWIR refers to the reflectance values in the SWIR (2-2 μm) and NIR (0-7-0.9 μm) bands. In this case, we used bands 11 and 8A from Sentinel 2 images, respectively. The burn severity then was computed as the temporal difference of NBR (dNBR) from before (t1) and after (t2) the fire:

$$dNBR = NBR_{t_1} - NBR_{t_2} \qquad \text{[Eq. 2]}$$

Once the difference was computed, the severity levels were classified using intervals adapted to the burn severity measured as CBI in the field based on the standard intervals of USGS (Key *et al.*, 2006) (Table 13 and Figure 67).

Table 13. Burn severity classes derived from dNBR values obtained from Sentinel 2 data.

Severity level	**dNBR range**
Unburned	-0.1 - 0.99
Low severity	0.1 - 0.26
Moderate severity	0.27 - 0.469
High severity	0.47 - 0.66
Extreme severity	> 0.66

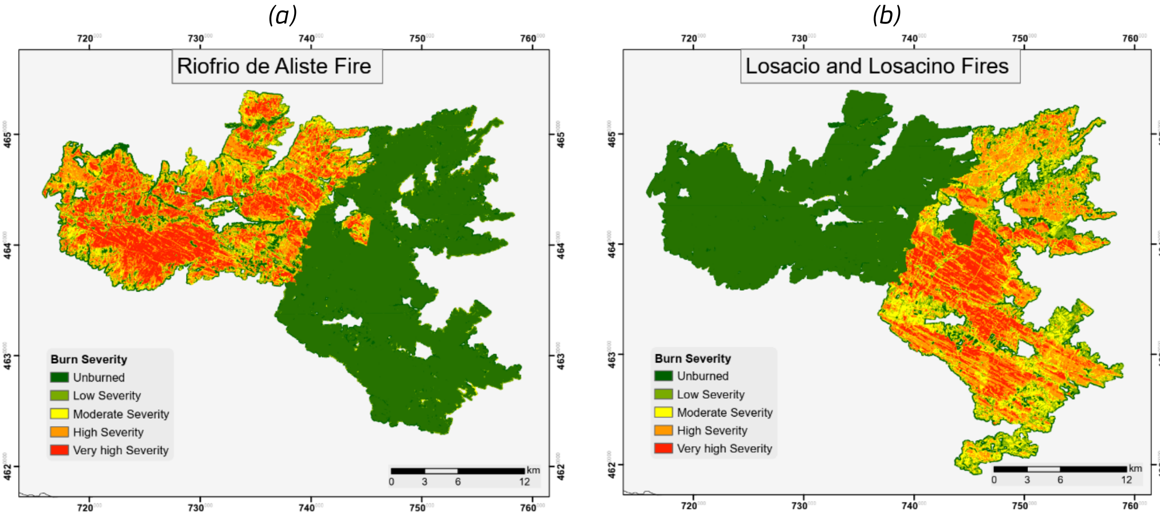

Figure 67. Burn severity estimation based on the difference in NBR for the Riofrío de Aliste fire (left) and Losacio fire (right), based on Sentinel-2 images. The Riofrio de Aliste estimation was computed by the difference between the NBR in the prefire date of May 26th and the postfire date of June 28th. The Losacio burn severity estimation was computed by the difference between the pre-fire image of June 28th and the postfire image of July 30th.

In the Riofrio de Aliste Fire higher severities were found in dense forested areas mainly composed of *Pinus pinaster*, and shrublands. Lower severities were found in deciduous species such as *Quercus faginea* and in conifer forests with trees higher than 20 m. In the Losacio Fire higher severities were also found in dense conifer plantations located in areas with steep slopes. Lower severity values were located in the north of the fire affecting holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) forests and agro-forestry areas (*dehesas*) (Figure 68).

The Riofrio de Aliste Fire affected a considerable area of productive forests in the region, mainly chestnut plantations and mushroom production, which reduced the income of the people living there. We estimated an affected area of 354 ha of chestnut plantations and 2 630 ha of *Pinus pinaster* plantation used for mushroom and wood production.

Figure 68. Affected chestnuts plantations in the Riofrío de Aliste fire were already resprouting in November 2022 on the right. (*photos taken by Patricia Oliva in November 2022*).

1.1 Fire damage to cultural heritage

Even though most of the buildings in the affected area were protected from the fire, there were numerous effects on the cultural heritage present in the region. The Unit for Risk Management and Emergencies in Cultural Heritage (UGRECYL) from the Castilla y León regional government performed a thorough revision of the cultural heritage affected in Zamora by the fires of 2022. The cultural heritage considered are all the categories included in the protection law, which are: ethnographic heritage, architectonic heritage, historic roads, cultural landscapes, industrial heritage, geologic and palaeontologic heritage, and archeologic heritage.

Fires have a direct impact on the cultural heritage, but it can also have an indirect effect due to an increase in the level of erosion over time that make them more susceptible to atmospheric and biological agents, thus increasing their degradation and hampering their conservation (Escudero 2023). On the other hand, some of the damage observed in cultural heritage is due to the operational activities of firefighters. These types of damage are related to the use of heavy machinery and the chemical retardant used to control the fire front.

The UGRECYL reported 73 cultural heritage sites affected in the Riofrio de Aliste fire and 43 in the Losacio fire, including Roman roads, ethnographic and architectonic heritage and archeologic heritage. Figure 69 shows the severity of the damage inflicted upon historic buildings used for cattle.

(a)

(b)

Figure 69. Effect of the fire in architectonical heritage sites in Riofrio de Aliste fire. *Data source: a) UGRECYL; B) Plataforma por la Defensa de la Arquitectura Tradicional de Aliste*

5.8 Lessons learned

Large Fires of “Sierra de la Culebra” occurred in very anomalous atmospheric conditions, with intense heatwaves and long dry periods, weeks before the fires, with one of the historically driest months of May in the region. Fires were fuelled by strong winds and benefited by anomalous high temperatures and night, which further complicated the extinction works.

Civil protection services were efficient. Evacuation was done in an orderly and timely manner, and therefore no major civil causalities occurred. One firefighter died in the extinction activities and 3 civilians died because of severe wounds in trying to protect their own properties.

Post-fire severities observed were very dependent on the management conditions of the forest. Those areas where forest management favoured the cleaning up of heliophilic shrubs, which greatly reduced the understory density, and where pine-trees were more mature, had much less severity than areas with more understory and lower pine trees. Even with a dense cover and drought conditions, deciduous trees were less affected by the fire than pine trees. Within deciduous species, chestnut plantations were generally much less affected, as they are more intensively managed and therefore had much less understory than natural broadleaf forest.

The impacts on cultural heritage must be considered in the analysis of the fire effects since due to the rich historic culture of Europe there are many ethnographic, architectonic, and archeologic heritage sites dispersed in the rural areas. To improve their preservation the fire brigades should be informed of the most vulnerable areas to avoid their destruction.

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6 Fire of Karst (Italy/Slovenia)

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6.1 General Description

6.1.1 Introduction

The Karst wildfire (Carso – Italian, Kras – Slovenian) refers to the set of main wildfires that affected the Karst region, located between Friuli Venezia Giulia (Italy) and Slovenia, in the period from July 15th to the first days of August. The Karst wildfire is in fact the result of different and independent fire events, some of which converged into the same area/burned perimeter in the Slovenian and in the Italian territories. The Karst wildfire affected an area of about 4 450 ha, the majority of which (about 3 600 ha) was in Slovenia: in fact, this wildfire represents one of the worst events ever observed in in the cross-border Karst area and overall, in Slovenia. Moreover, a significant portion of the burnt area by the Karst wildfire is part of Natura2000 sites.

The Karst area is historically known for the violent battles between Italian and Austro-Hungarian troops, during World War I. This explains the presence of unexploded bombs, many of which originated detonations and posed safety issues to the operators who were working to contain the fire spread in both Italian and Slovenian areas. For instance, according to the estimations and data provided by the Slovenian fire management forces, over 500 detonations were detected at the fire sites in Slovenia during the suppression interventions.

The wildfire affected several municipalities in Italy (namely Doberdò del Lago, Savogna d'Isonzo, Monfalcone, and Duino Aurisina) and Slovenia (Renče- Vogrsko, Komen, Miren – Kostanjevica) (Figure 70). The municipality that was mostly affected by the Karst wildfire was Miren – Kostanjevica, with about 3 000 ha of burned area, that is approximately 48% of its municipal area. On the Italian side, the most affected municipality was Doberdò del Lago, with about 589 ha burned (22% of the municipal territory).

6.1.2 Note on the methodology

The present report outlines some of the main features related with the 2022 Karst wildfire. The complexity of this event, due mainly to its cross-border dimension (further described in this report), led to the following methodological choices:

- Use of both qualitative and quantitative data sources.
- Need of validation of the emerging analysis with a representative panel of experts.

Moreover, the data collection and validation were based on the following steps:

- Identification and review of relevant official and technical documents provided by agencies and institutions involved in different ways in the issues at stake (such as Friuli Venezia Giulia Region Forestry Corps, or Slovenian firefighters – Gasilci).
- Organisation of in-depth, semi-structured interviews with Italian and Slovenian emergency operators and validation of the related contents. The interviewees are mentioned in the Acknowledgements at the beginning of the report.
- Organisation of further feedbacks activities involving the above-mentioned interviewed operators, and other relevant actors in the field are foreseen after the publication of the Report.

The above described structure is designed to address the overall complexity and some specificities of the selected case study, namely:

- The complexity and the peculiarities deriving from the cross-border dimension of both the physical and socio-economic context of action, the wildfire dynamic, and the firefighting response envisioned and operationalised in the field. Such complexity encompasses the articulation of the multi-agency emergency response governance structure.
- The novelty of the event in the Karst context, giving the fact that, despite the relatively low impact of the wildfire (no loss of human lives and low impact in terms of destruction of anthropic areas), the area has never witnessed a fire of this magnitude in recent history. This feature oriented the research towards more qualitative findings, rather than quantitative/technical data, focusing for instance on land uses or the reaction of local population to the event.

6.2 Topography, vegetation, and land uses of the affected area

The Karst region is a rocky calcareous plateau extending from north-eastern Italy (Friuli Venezia Giulia) to southwestern Slovenia. The Karst tends to gradually rise in elevation from the southwestern area (Gulf of Trieste area) to the northern and western parts of the plateau. The average elevation of the Karst plateau is approximately 330 m a.s.l., with a large part of the area presenting elevations between 100 and 450 m a.s.l. The highest peak of the Karst is represented by the Trstelj hill, which reaches approximately 640 m a.s.l (Figure 71a).

Due to the high presence of superficial stones and rocks and the reduced presence of soil, these areas tend to dry-out rapidly in the summer months and after the occurrence of heat waves. The dryness conditions of the summer months, the limited land and forest fuel management, and the occasional windiness (in fact, although not a constant nor stable variable, the strong ventilation represented one of the crucial factors contributing to the intensity of the Karst wildfire) make the area one of the most fire-prone in Slovenia and Friuli Venezia Giulia (Italy).

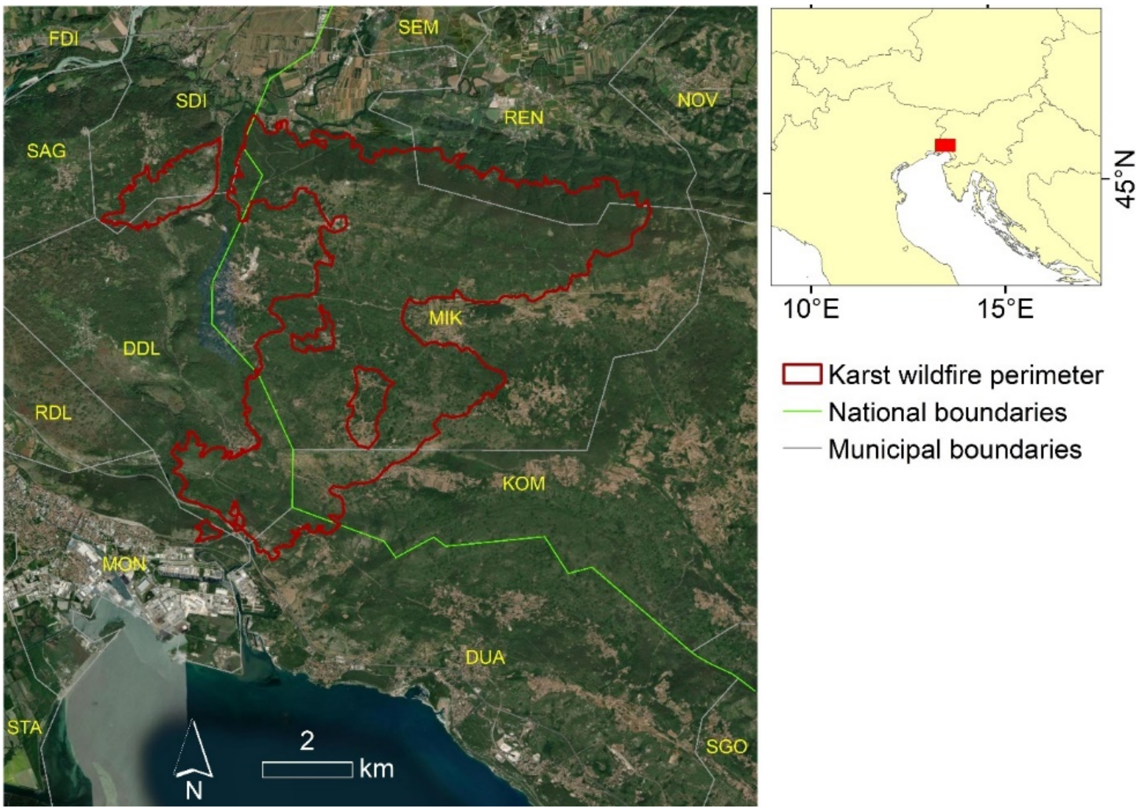

Figure 70. General map of the Karst area, including the 2022 wildfire perimeter and the administrative municipal boundaries. DDL = Doberdò del Lago, FDI = Farra d'Isonzo, MON = Monfalcone, RDL = Ronchi dei Legionari, SAG = Sagrado, SDI = Savogna d'Isonzo, STA = Staranzano, DUA = Duino Aurisina, SGO = Sgonico, SEM = Šempeter- Vrtojba, REN = Renče-Vogrsko, KOM = Komen, MIK = Miren – Kostanjevica, NOV = Nova Gorica.

Data Source: Esri, Maxar, GeoEye, EarthStar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Fire perimeter based on EFFIS Data and Reports of burned areas provided by the FVG Region.

Regarding the vegetation, the Karst region has changed profoundly over the past centuries. Until about a century and a half ago, the Karst was a relatively bare plateau largely covered with herbaceous fuels (dry in the summer months) and a few shrublands. Agriculture was mostly characterised by pastoralism and stable livestock; vineyards and olive groves were confined in the areas that were most fertile and less exposed to winds. Around the mid-19th century, under Austro-Hungarian rule, a process of afforestation with black pine was carried out in some areas of the Karst: this species was able to adapt well to the weather and soil conditions of the stony plateau. The original black pine plantations were regular and covered only a few areas of the Karst region.

As agricultural and pastoral activities in the area decreased over time, with the inherent decrease in herding, wood cutting and fuel control, forests and shrubs progressively occupied the Karst lands and moved closer to urban and anthropic areas. Another recent change to the Karst vegetation is related to Juniperus spp., once very present in the Karst but now less widespread, and often replaced by Rhus spp. (sumac), which presents high potential in promoting spot fires.

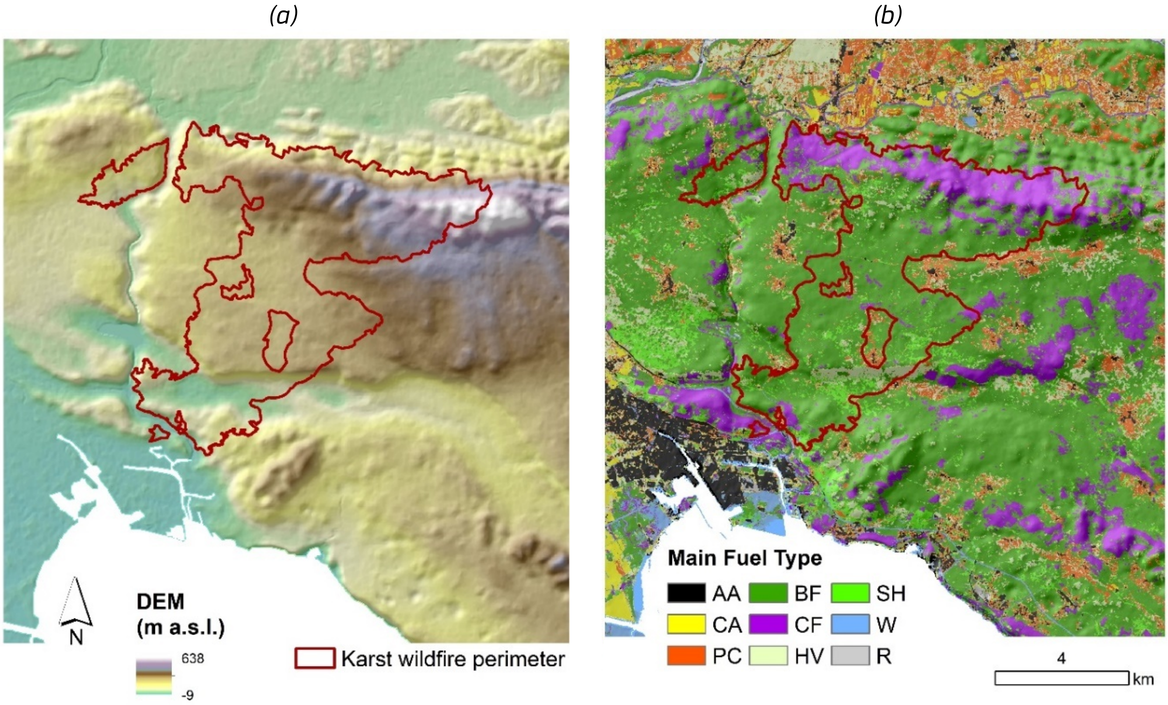

Figure 71. a) Digital elevation model of the Karst area. b) Main fuel types of the area affected by the Karst wildfire. AA = anthropic areas; CA = cultivated areas; PC = permanent crops; BF = broadleaf forests; CF = conifer forests; SH = shrub vegetation; SV = sclerophyllous vegetation; W = wetlands; R= rocks. The map is derived from the Land Use Map of Europe 2017.

Data Source: Malinowski et al. 2020.

Nowadays, the Karst vegetation is dominated by black pine forests, low-height trees, and shrubs, which are expanding rapidly and covering the former grasslands and meadows. Grasslands and meadows are quite fragmented and are not as extensive as in the past. Mature broadleaf forests are primarily represented by *Quercus petraea* and *Carpinus betulus*, even if they cover limited extent of lands; *Quercus pubescens*, *Ostrya carpinifolia* and *Fraxinus ornus* are also present in the Karst region. Another element to highlight is the high anthropization of the territory, evidenced by arson fires as well as fire ignitions due to accidental causes and negligence. For instance, the railway between Monfalcone and Trieste was a source of fire ignitions due to malfunctioning train braking equipment, which can promote multiple ignitions distributed over hundreds of metres.

The Karst wildfire mainly affected forest fuels (Figure 71b): about 2 850 ha of the burned area was covered by broadleaf forests and about 930 ha by coniferous forests. Shrublands accounted for about 7% of the burned area. The remaining fuel types (8% of the burned area) affected by the event were herbaceous vegetation, permanent crops, and cultivated areas.

The Karst territory is highly anthropized: at the same time, relevant changes in the use of forest areas through decades have had an important influence on both the dynamics of fire ignition and its development into actual fires, as well as over the possibility of implementing traditional fire risk management strategies. The abandonment of the territory, and the decrease of traditional economic activities such as herding and wood cutting, does not have a specific influence on the triggering of the fire, but rather on its speed of development and on its intensity, as well as on the difficulty of tackling it and protecting local population from its direct and indirect impacts. In fact, such traditional economic activities, which used to have an important role in controlling local fuel availability, have decreased over time. Nowadays the pastures, which once constituted the most frequent wildland-urban interface, are replaced by highly flammable vegetation, such as shrubs. The abandonment of territory, thus, results in a greater surface area and a greater quantity of fuel available for fires. Furthermore, forest paths and roads which used to be cleaned and maintained for the benefit of local populations, are now less used; this determines less accessibility to high-risk areas, especially for rescue services. Moreover, the abandonment of Karst environment determines a lower awareness of fire risk by the local population, as the natural areas are less experienced.

The presence of the railway line, which runs in Italian territory between Monfalcone and Trieste, is another relevant feature when discussing about Karst land uses. Very often fires are caused by malfunctioning train braking equipment, which generates sparks or leaks of incandescent material in multiple spots along the railway line.

Another statement expressed during the interviews is that, taking into consideration the decrease in caring towards the land by local populations, laws often do not enforce public authorities in implementing practices that used to be traditionally carried on by local inhabitants – such as prescribed burnings – and that would still contribute nowadays to fire risk prevention.

6.3 Fire weather conditions

To better understand the state of dryness of the vegetation in the Karst area, one of the primary factors in this event, a summary of the weather conditions in the months before the Karst event is presented.

In terms of precipitation, the Regional Agency of Environmental Protection of Friuli Venezia Giulia estimated that the cumulative rainfall over the period July 2021-June 2022 was 50% or more lower than the average values observed in the past 10 years.

As far as temperatures are concerned, the months of May, June, and July were approximately 2-2.5°C warmer than the average values recorded in the past 10 years. On July 21st, 22nd, and 23rd, most of the meteorological stations in Friuli Venezia Giulia observed the highest temperatures for the year 2022; for some of them (Pordenone; Cividale; Bicinicco), new historical maximum temperature records were observed in those days.

The largely above-average temperatures are confirmed in Slovenia: July 2022 was the second warmest month since 1961, with average temperatures 2.5°C above the climatological values at the Country level, and peaks of +4°C than the average monthly values in Nova Gorica: in this town, temperatures above 35°C for seven days in a row were observed in the second half of July.

The month of July 2022 started with a strong heat wave, caused by the extension of a North African anti-cyclone to the Alps. In mid-July, synoptic conditions were characterised by strong stability, thanks to the protrusion of the anti-cyclone from the west over the Alps: the thermal zero had risen to over 4 500 m altitude and the sky was basically clear. Very high temperatures were recorded in the lowlands on July 15th, with almost 35°C, but a few thunderstorms were observed in the mountains. From July 17th to 20th, the weather conditions were stable with clear or slightly cloudy skies, maximum temperatures around 35°C in the plains and in the range 30-32°C on the coastal areas. From July 21st to 25th, the North African anti-cyclone reinforced its presence in Italy and neighbouring countries, causing a protracted heat wave, with 20°C at 850 hPA in eastern Friuli Venezia Giulia, and maximum temperatures at the ground in the range 35-40°C in the plains and 30-35°C on the coast. Only on July 23rd, some scattered thunderstorms affected the mountains and partially also lowlands and coastal areas.

To describe the meteorological conditions during the main phases of the Karst wildfire, weather data were gathered from a meteorological network of weather stations of ARPA Friuli Venezia Giulia. The main station used is in the municipality of Gradisca d'Isonzo, in a flat area located about 7 km west of the eastern perimeter of the Karst wildfire; this weather station was considered a good representative of the weather conditions that influenced the Karst wildfire, due to of its proximity to the area affected by event. In addition, data from reanalysis ERA5-LAND referred to the central area of the Karst plateau were used.

On July 15th, during the early stages of the Miren event, the weather conditions provided by the Gradisca station were moderately severe, with maximum temperatures of 32°C and minimum relative air humidity around 26% (Figure 74). Maximum wind intensities recorded were around 4 m/s, with prevailing directions around 240-280° (Figure 75). The second step of the Miren fire (July 19th to 20th) was characterized by more severe weather conditions, particularly those recorded by the Gradisca station, with temperatures around 35-36°C and much lower minimum relative humidity (22-23%) than the previous days (Figure 74). The wind speed was slightly higher, with 5 m/s intensity and prevailing directions fluctuating between 250° and 300° (Figure 75).

The Renče fire, which propagated simultaneously to the to the Miren fire, was characterised by more severe wind intensity conditions on the first day (July 17th), during which the Gradisca weather station detected wind intensities of 6-7 m/s, later decreased to 5 m/s in the afternoon, and prevailing directions from NE-ENE (Figure 75). Due to these conditions and the orography of the Karst plateau, the wildfire in fact spread in a westerly direction, with a sustained spread rate and generating an elongated ellipsoidal burned area. The wind field conditions were also confirmed by the ERA5-LAND reanalysis data, which indicated wind intensities of 6 m/s and prevailing wind directions around 70-100° (Figure 73).

Regarding the Monfalcone fire, which later joined the other fires contributing to the final perimeter of the Karst wildfire, severe temperature conditions were observed on July 20th, 21st and 22nd, with increasing temperatures (above 35°C) and very low minimum relative humidity values (22-24%). Wind conditions, on the other hand, were moderate, with intensities on the order of 4-5 m/s and prevailing directions from the southwest, rotating from the eastern quadrants on July 24th.

The last step, represented by the Brestovec fire (July 27th-29th), took place with initial severe conditions of wind intensities (6-7 m/s) and prevailing directions from the eastern quadrants, which contributed to the prevailing west-south-west propagation of the fire; while on July 29th a wind rotation to southwest, with significantly lower intensities (3-4 m/s), was observed. During this final day, the conditions of maximum temperatures (31-33°C) and relative humidity (32-38 %) were not particularly severe.

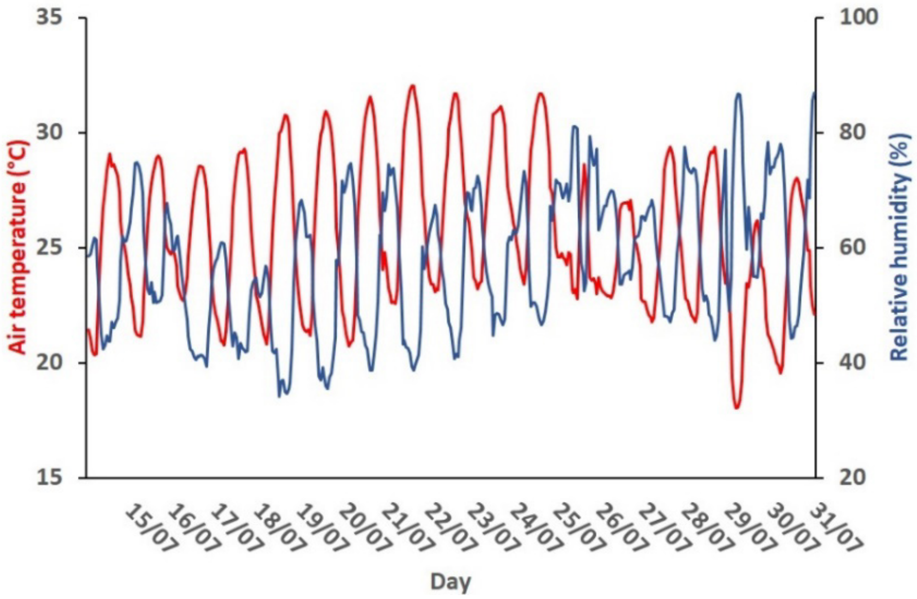

Figure 72. Hourly values of air temperature and air relative humidity provided by the ERA5-LAND Reanalysis for the central sector of the Karst plateau from July 15th to 31st.
Data Source: Copernicus Climate Change Service (C3S) Climate Data Store (CDS).

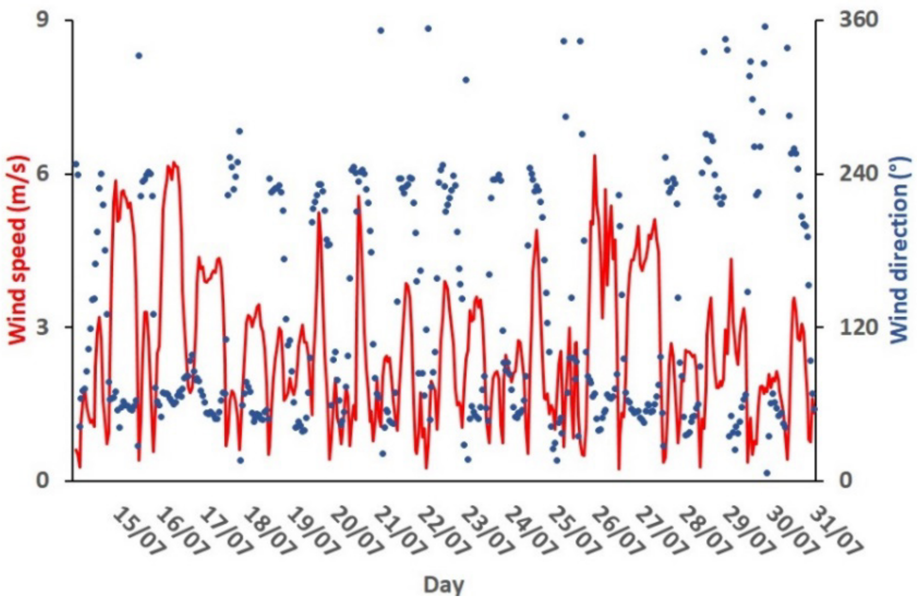

Figure 73. Hourly values of wind intensity and direction provided by the ERA5-LAND Reanalysis for the central sector of the Karst plateau from July 15th to 31st.
Data Source: Copernicus Climate Change Service (C3S) Climate Data Store (CDS).

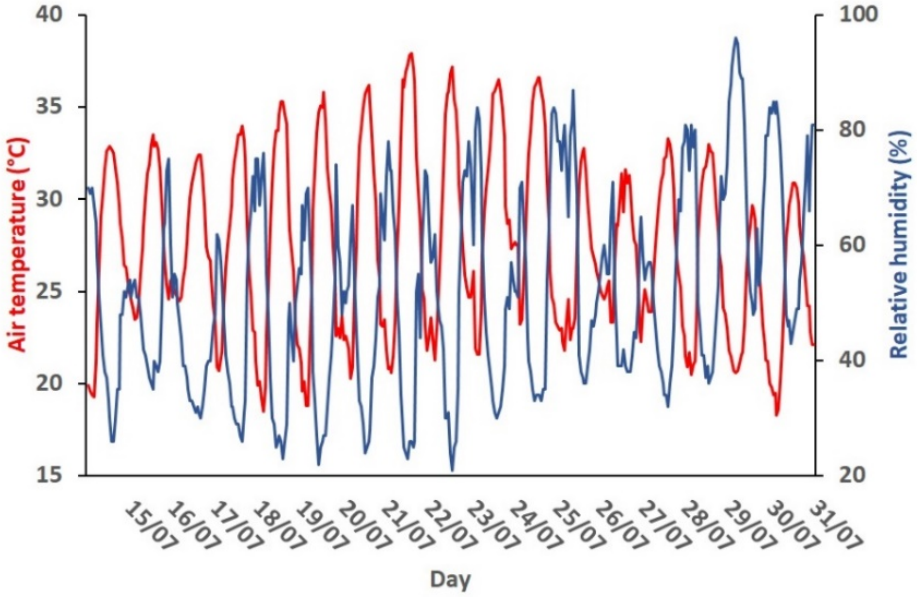

Figure 74. Hourly values of air temperature and air relative humidity measured by the weather station of Gradisca from July 15th to 31st.

Data Source: Regional Meteorological Observatory, Regional Environmental Agency (ARPA) of Friuli Venezia Giulia.

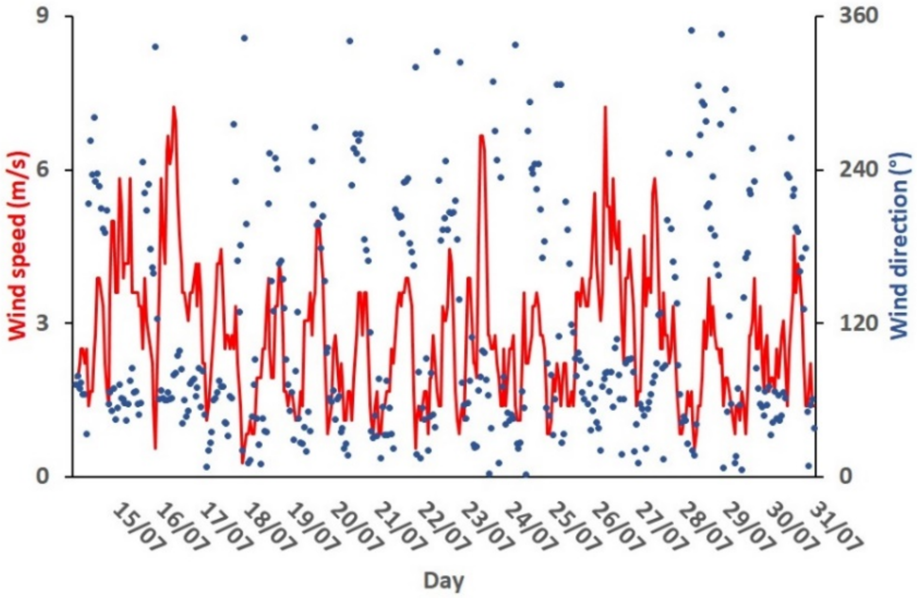

Figure 75. Hourly values of wind intensity and direction measured by the weather station of Gradisca from July 15th to 31st.

Data Source: Regional Meteorological Observatory, Regional Environmental Agency (ARPA) of Friuli Venezia Giulia.

6.4 Fire Development and Operational Response

As anticipated in the introduction, the Karst wildfire indicates several independent but converging fires, which affected a transboundary area between Slovenia and Italy from mid-July to the first days of August, and together contributed to affect a burned area of about 4 450 ha, mainly located in the Slovenian territory. To describe the Karst wildfire development, we will differentiating four main sub-events of the whole wildfire[3]:

1. The first fire that occurred on July 15th in the municipality of Miren-Kostanjevica, in Slovenia, along the road Miren-Opatje Selo (Miren fire, see 6.4.1).
2. The fire that occurred on July 17th along the Renški vrh-Temnica road, in Slovenia (Renče fire, see 6.4.2).
3. The fire that occurred on July 19th along the Trieste Monfalcone railway line, in Italy (Monfalcone-Jamiano fire, see 6.4.3).
4. The fire that occurred on July 27th in the municipality of Doberdò del Lago, close to the Brestovec mountain, in Italy (Brestovec fire, see 6.4.4).

In the following paragraphs, each fire will be presented in more detail, based on the analysis performed by Commander Simon Vendramin (Vendramin, 2022).

It is worth noting that the general setting of the operational response has been structured along the main objectives of protecting human lives (including those of the operators) and secondly protecting, as far as possible, material assets and the environment, keeping in mind the close connection between the former and the latter, especially in a WUI area such as the Karst. Implicitly, another objective has been to avoid the emergence of further emergency scenarios, especially with respect to critical infrastructures.

The strategy for achieving these objectives had to measure itself against four characteristics of the Karst wildfire:

- The emergence of numerous widespread fire triggers, deriving from spotting fires, i.e., sparks which, with the help of the wind, travel even tens of metres away, triggering new outbreaks.
- The strong speed of propagation of the fire determined not only by the weather conditions (temperature, wind), but also by the peculiar conformation of the Karst Plateau.
- The presence of critical infrastructures (highway, state road, railway, power lines, methane pipelines) in the "bottleneck" of the Lisert area, between Monfalcone and Duino.
- The serious risk posed by the presence of unexploded war devices along the war front that ran through the Karst area.

[3] Other wildfire events involved areas close to Trieste, in the Italian Municipalities of Monrupino/Repen, Trieste, Sgonico/Zgonik, and San Dorligo della Valle/Dolina. Between 9th and 12th August, a significant cross-border wildfire hit the area of San Dorligo della Valle/Dolina. Being detached from the other fires described in the following paragraphs, these events were not considered for the purpose of this report, for the sake of brevity.

6.4.1 Miren Fire

The first event, the Miren fire, was ignited in the municipality of Miren-Kostanjevica, near the regional road Miren-Opatje Selo, in Slovenia. The fire started on July 15th at about 16:10 in different points between the intersections of the villages of Cerje and Lokvica, in Slovenia at a very short distance from the border and close to the 400kV high-voltage international transmission line Redipuglia–Divača (Figure 80a). Several firefighting units were rapidly activated by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief – Regional dispatch centre (112), and the fire was contained and was defined under control in the evening hours and supervised during the night and the following day. The burned area during this first event was of about 11 ha, consisting mainly of mixed deciduous and coniferous forests and located entirely in Slovenian territory (Figure 76). Two helicopters of the Slovenian Armed Forces and of Friuli Venezia Giulia Region contributed to successfully limiting this fire. The activation of the intervention of the Friuli Venezia Giulia Region helicopter was possible thanks to the Protocol on Cross-Border Cooperation between the Protection and Rescue Administration of the Ministry of Defence of the Republic of Slovenia and the Civil Protection of the Autonomous Region of Friuli Venezia Giulia.

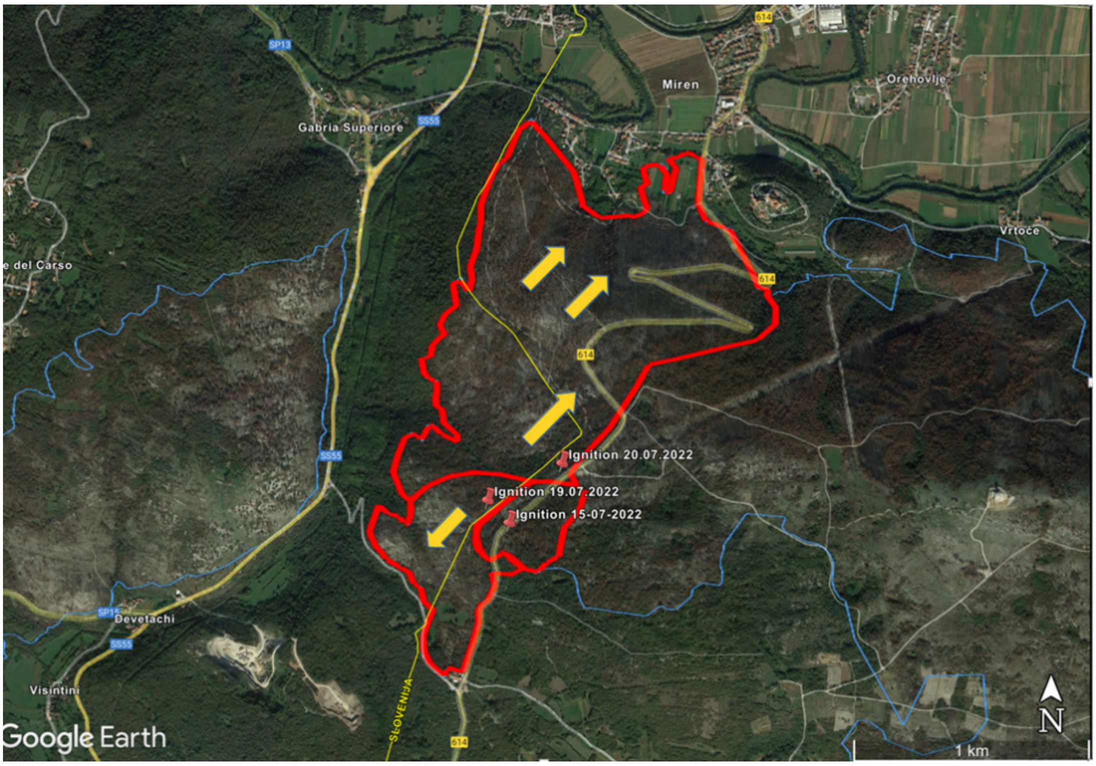

Figure 76. Map of the three main steps of propagation of the Miren fire (in red). The ignition points of the different steps are showed, together with the main directions of propagation. The final perimeter of the Karst wildfire is also showed (in blue). *Data Source: Image elaborated by CNR based on information collected from Vendramin (2022).*

In the morning of July 19th, at about 12:00, there was a re-ignition of the Miren fire, in the proximity of the power line (Figure 76). The fire immediately turned into a crown fire and started spreading towards south-west and crossed the Italy-Slovenia border. Given the extent of the event, and the fact that forces on the ground were previously deployed in firefighting activities in the southern fire front area, it was agreed that the Slovenian forces would take over the fire. The fire extinguishment operation was supported by two helicopters and a PC-6 of the Slovenian Armed Forces and a helicopter of the Slovenian Police, and later by a helicopter and a Canadair from Italy. On the eastern side of the fire area, along the main road Miren–Opatie Selo, a backfire was carried out, all buildings were protected, and the main vehicles were moved to the Lokvica-Devetaki road, where the fire was contained.

A new re-ignition of the Miren fire was observed on July 20th, at around 14:15. The fire crossed the Miren-Opatje Selo Road and propagated at high spread rates in the direction of Miren (Figure 80b). The fire took only 15 minutes to reach the valley from the top of the slope and the village was reached by the flames in the evening. An evacuation order was issued for people staying in the area immediately adjacent to the road Miren-Opatje Selo, nearby Miren. Some tankers arrived on the scene and were deployed to the fire front. On the whole, the Miren fire affected an area close to 185 ha.

6.4.2 Renče fire

The second event, the Renče fire, occurred on July 17th at about 09:50, near the Renški vrh-Temnica road, in Slovenia, 12 km east of the first fire of Miren (Figure 77 and Figure 80c). Immediately after the fire detection, two firefighting units from the Miren-Lokvica fire station were diverted to this fire and based on the assessment of the fire and the smoke column, a request to activate additional forces was made. Due to the windy conditions and the dryness of the fuel, the fire affected the understory of the pine forest with high intensity, and in some parts also spread as a crown fire and started to spread very quickly towards the west. Firefighting units from the nearby Fire Brigades Municipalities (Vipava, Ajdovščina, and Komen) and from the North Primorye Firefighting Region were activated. Air forces were also activated, namely a helicopter of the Slovenian Army and another one from Friuli Venezia Giulia Region, in accordance with the protocol on cross-border cooperation. However, the available activated forces were unable to contain the fire spread. Therefore, at 13:30, the activation of the National Plan for Major Fire in the Natural Environment was requested. In this context, the activation of other Unions Brigades (Postojna and Karst) as well as the firefighting units from the Notranjska Firefighting Region was requested, to replace the forces that were in the field overnight. A request for a Canadair was also made through the EU assistance mechanism. The National Unit for Unexploded Ordnance (NUS) went to the area due to presence of old unexploded weapons in the fire area. Due to the danger posed by these weapons, the complex terrain, the limitations in safely accessing and moving in the area with fire trucks, and the fire spread rates, the firefighting tactics were set to stop the fire near roads. The rate of spread of the fire was approximately 8.5 m/minute and, shortly after 16:00, a Croatian Canadair plane flew over the fire site for the first time. Effective firefighting interventions were carried out in the NE flank of the fire, where (due to favourable weather conditions) the hill ridges were secured with a tactical wildfire of about 1.5 km in length. The fire was successfully contained in the late evening of July 17th.

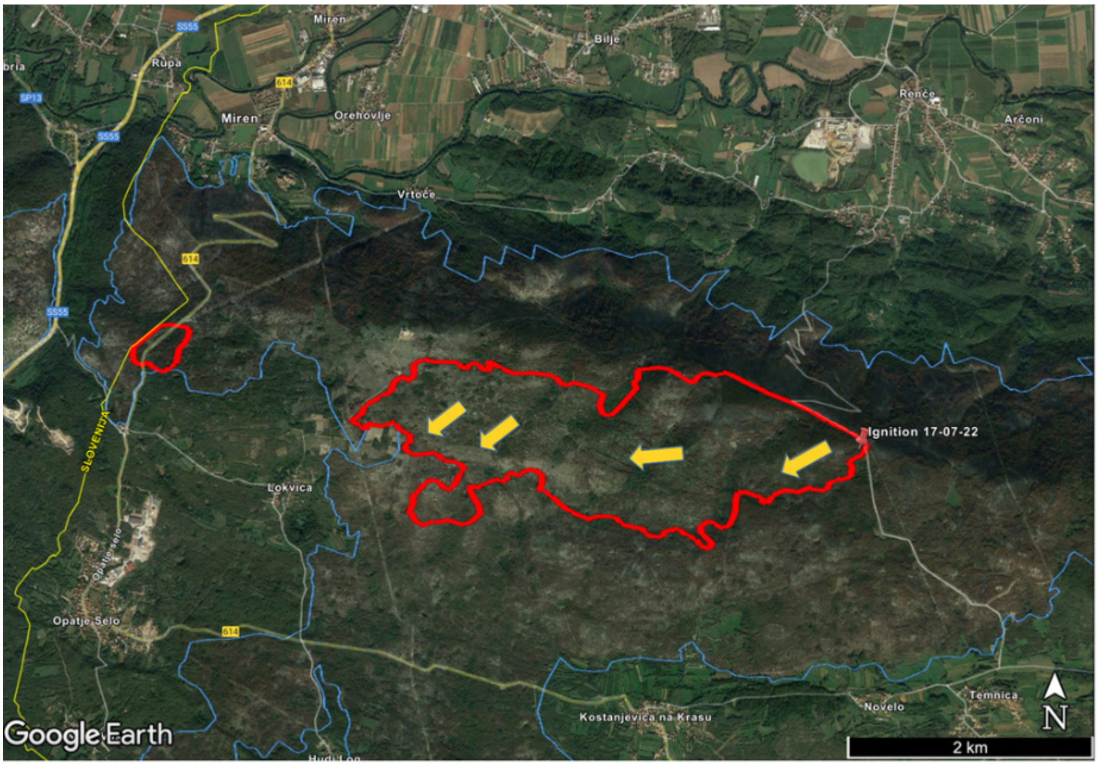

Figure 77. Map of the three main steps of propagation of Renče fire (in red). The ignition point of the fire, together with the main directions of propagation, is also included. The final perimeter of the Karst wildfire is showed in blue. *Data Source: Image elaborated by CNR based on information collected from Vendramin (2022).*

Mop-up of the fire perimeter began in the night, although the fire rekindled in the western front (near the Borojević chair) and spread towards the village of Lokvica. The fire brigades stopped the fire 500 m before the village of Lokvica and along the road Lokvica-Cerje. Further clearing and watering of the fire area were carried out during the next day, with the aerial assistance provided by five helicopters (two from the Slovenian Army, tow from Friuli Venezia Giulia and one from Slovenian Police). In the morning of July 19th, the fire was under control. Overall, the Renče fire burned about 350 ha of land.

6.4.3 Monfalcone-Jamiano fire

On July 19th, at about 10:00, fire ignitions and smoke columns were observed in the eastern side of the Monfalcone municipality, in Italy (Figure 80d). The fires occurred along the Trieste-Monfalcone railway line, in three distinct outbreaks near the villages of Duino, Aurisina, Sistiana, and Medeazza (Figure 78). Italian firefighters from the station of Monfalcone, with the support of aerial forces, extinguished almost all the fires along the railway line where rail traffic was previously suspended. This operation saw the coordinated intervention of many operational forces coordinated by the Gorizia Rescue Coordination Centre. In the area close to Medeazza the fire continued to spread towards north-west (near Sablici, where the advanced command point was established, and where 15 residents were evacuated) and in the evening overcame the Italy-Slovenia border, descended downslope towards the Jamiano-Brestovica road, and threatened homes in Jamiano the following day at 12:00. In more detail, Jamiano, a hamlet of Doberdò del Lago, in Italy, was heavily affected by this fire, with the flames spreading across the local cemetery and menacing several houses and buildings, and necessitated temporary evacuation of houses at risk.

During the same morning, three helicopters started operating to extinguish this fire front in Slovenia. As the fire was approaching the villages on the plateau very quickly, an evacuation order was issued for the villages of Korita na Krasu, Hudi Log and Sela na Krasu. The event venue in Opatje-Selo was designated as an evacuation site. An additional request for air support from foreign countries through the Union's protection and rescue mechanism was made by Slovenian authorities. At around 13:05, the first houses in the village of Sela na Krasu were already threatened by the fire and, due to the high level of smoke in the area, the requests of emergency medical needs among firefighters and citizens increased. Additional units, including medical personnel, were activated. At 14:10, the fire jumped across the road at Brestovica pri Komnu and, at 14:40, the fire also jumped the Sela na Krasu - Vojščica road.

On July 20th, at 14:00, the general situation was particularly critical, mainly for the front originating from the Monfalcone fire, which was advancing rapidly (Figure 78), and for the other active fronts in the Miren and in the Renče fires. Due to the shortage of firefighting units and the reduced water supply, the primary strategic objective of the Slovenian authorities was to protect the people and the villages; so all incoming forces were diverted solely to protect the villages. The tankers arriving on the scene were deployed to the fire sites according to the needs. In cooperation with the Slovenian Forest Service, personnel involved in logging and forestry machinery activities were mobilized to carry out specific forest management measures. At 16:35, the fire also jumped the Opatje selo - Kostanjevica road in Slovenia. Due to the high danger, an evacuation order was issued for the village of Lokvica and the hamlet of Segeti. An order to clear the area around the industrial facilities and to disconnect the Redipuglia-Divača international power line was provided. About 1 000 firefighters were on the ground to fight the fire. At 18:05, 4 Croatian tankers arrived on the scene and were deployed to resupply the helipads. At around 19:15, a Canadair also arrived with the priority to extinguish the fire front, which was approaching the villages of Lokvica, Sela na Krasu, Hudi Log, Korita na Krasu and Kostanjevica na Krasu. Only Lokvica and the hamlet of Segeti remained evacuated, as the fire in this area was still threatening the villages.

Additional interventions were established on July 21st: a backfire was set at Brestovica; the village of Vojščica was evacuated; the cutting of the firebreak on the Kostanjevica - Vojščica road was started. As the fire was approaching the villages of Kostanjevica na Krasu and Temnica, and due to the very high smoke level, an evacuation order was issued at 10:45 for the villages of Temnica, Vojščica and Novelo. At about 17:45, a spot fire allowed the fire to jump the Renški vrh - Temnica road for the first time, but the firefighters were able to contain the fire. Immediately afterwards, a second spot fire occurred a little further south from the first spot fire, but the firefighters could not control it and the fire started to spread towards Trstelj. The fire moved in this area with a tilted smoke column in the direction of the wind for 200-250 m. The forces on the Renški vrh - Temnica road were powerless to stop the fire propagation. The fire front in the direction of the Kostanjevica - Vojščica road was finally under control in the evening.

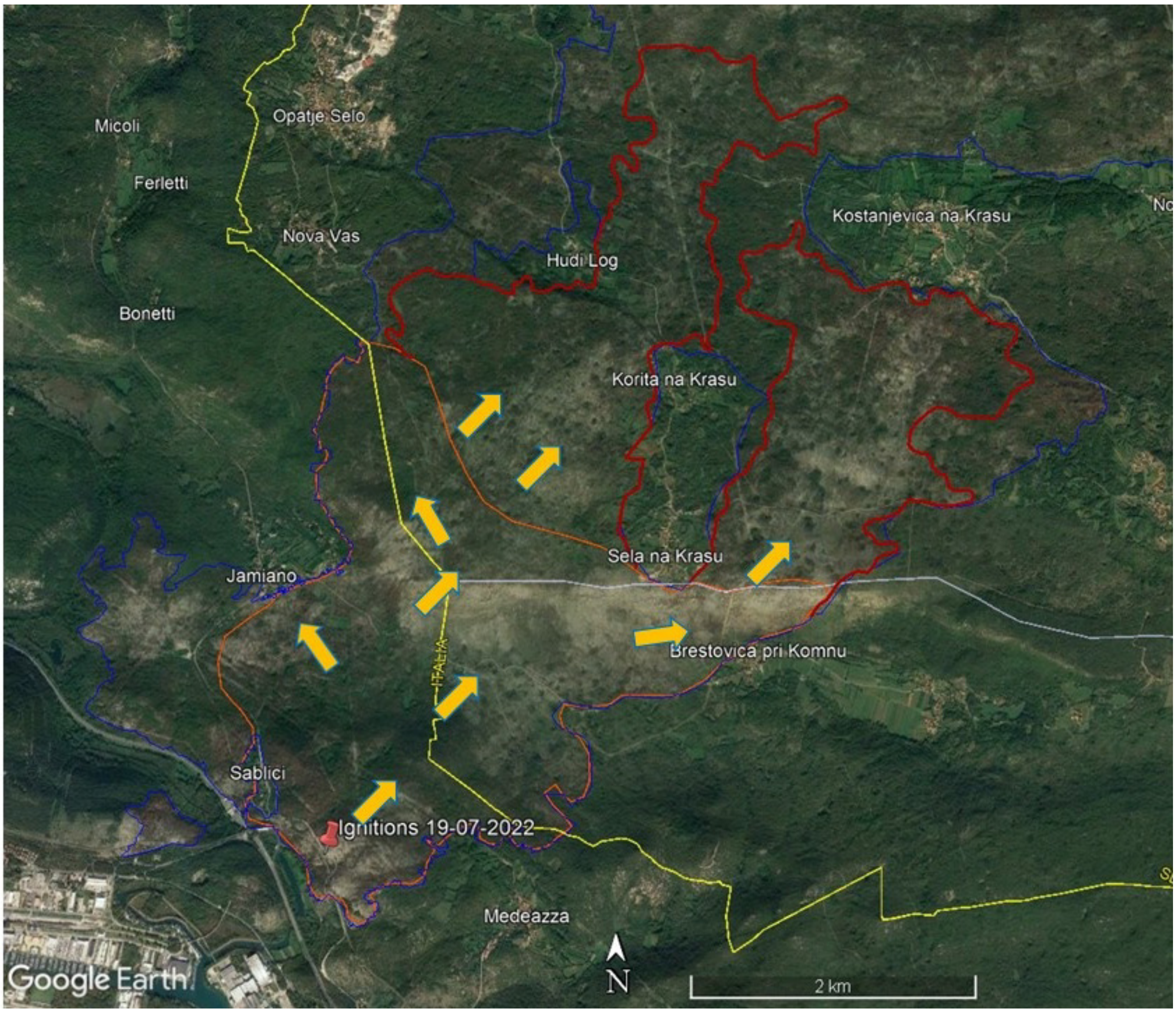

Figure 78. Map of the burned area by the Monfalcone fire on July 20th (in orange) and on Juli 21st (in red). The ignition point, indicating the area where most of the fire ignitions near the railway line were observed, is also showed, together with the main directions of propagation and the Italian-Slovenian border. The final perimeter of the Karst wildfire is showed in blue. *Data Source: Image elaborated by CNR based on information collected from Granata (2022) and Vendramin (2022).*

At nighttime, the fire intensified towards the village of Lokvica and spread further north towards Cerje. Due to the activity under the Redipuglia - Divača power line, a request for disconnection of the power line was made again. During the following morning, on July 22nd, the fire also reappeared at Hudi Log. The close Renče fire spread further south towards Kostanjevica na Krasu. Due to the airborne firefighting in this area, a request was also made to disconnect the Renče - Temnica power line. Later on, additional firefighting units from the Primorje Firefighting Region arrived. As the fire was approaching the villages, Opatje selo, Hudi Log and Nova Vas were evacuated very quickly. Depending on the availability of forces at the time, the firefighting operations were diverted to the protection of the villages; firefighting activities in the area of Cerje were therefore reduced. Assistance was provided by residents with agricultural machinery – tankers. In the afternoon, a new front line began to descend eastwards across Cerje. The fire spread rapidly down the slope. The forces on the ground were limited and the activated forces had not yet arrived on site. Due to the approach of the fire to the hamlets, an order of evacuation was issued for the threatened areas with buildings located in the forest belt (namely Merljaki, Martinuči, Vinišče, and later Mohorini and Oševljek). The lack of visibility for the smoke meant that it was not possible to see the fire area. During the night, the fire spread eastwards down the slope, and merged with the Renče and Miren fires that had crossed the valley, further east at Cerje. Fire watches were established overnight in those hamlets. At Miren Castle, the fire was already in the valley, and by the morning of July 23rd was under supervision. Due to the size of the fire, and consequently the visibility and management of the interventions, a sub-station in front of the village of Lipa was established to manage the fire from the Renški Vrh - Temnica road.

On July 23rd, most of the extinguishing activities were in the eastern part of the fire area, in the hills of Stola and Trstelj. Overnight, there were several spot fires that were successfully contained. During the day, most of the air force was diverted to this area, and an additional helicopter drop-off point was established. By 18:00, the fire in this area was basically blocked. Intensive mopping-up and watering operations in the fire edge were carried out.

On July 24th, in the morning, a short weather front with precipitation passed over the fire area, and this temporarily improved the situation. However, strong winds started to blow and soon dried up the fire area. Smaller hot spots, which were soon extinguished, appeared throughout the fire area during the day. The fire presented some intense conditions only in the area nearby Stol and Trstelj, on the northern side of the hill slope. With extensive air support, the fire was finally extinguished.

Starting from July 25th, the situation on the whole Slovenian burned areas was quite under control. Occasional hot spots or rekindling appeared throughout the fire area and were soon extinguished by aerial and terrestrial forces. Inspections of the burned area to identify hot spots were performed by helicopters equipped with thermal imaging cameras. Small and episodic hot spots and rekindling were still observed in the coming days.

On August 1st, the situation at the fire sites was under full control. The fire was declared extinguished in late afternoon, and at 19:00 the National Fire Plan for major interventions in natural fires was interrupted and all units were dismissed.

6.4.4 Brestovec fire

On July 27th, at about 13:30, a new ignition was observed in the municipality of Doberdò del Lago, in Italy, nearby the Brestovec mountain (Figure 79). The fire was ignited near the National Road no. 55, less than 300 m from the western edge of the Miren fire. From 13:45, the personnel of the Monfalcone forestry station, volunteer firefighters and National fire brigades operated to limit the fire propagation. However, due to the slope conditions, the fire quickly moved upslope, enlarging the front and spreading in several directions. The fire threatened several villages, including San Michele del Carso, which was temporarily evacuated, Marcottini and Gabria Inferiore, all in the Italian territory. Through the cross-border cooperation protocol, firefighter units from Slovenia (Gasilci) were called to provide support in extinguishing the fire fronts and defending anthropic areas and buildings. The advanced command point was established in S. Michele. To allow aerial forces to operate in safe conditions, two electric power lines were disconnected. The fire affected about 239 ha, entirely in the Italian territory, and mainly burned conifer and deciduous forests (172 ha) and herbaceous areas. The fire, which mostly spread on July 27th, was extinguished on July 29th, at 20:00, but mop-up and control of rekindling continued until August 8th.

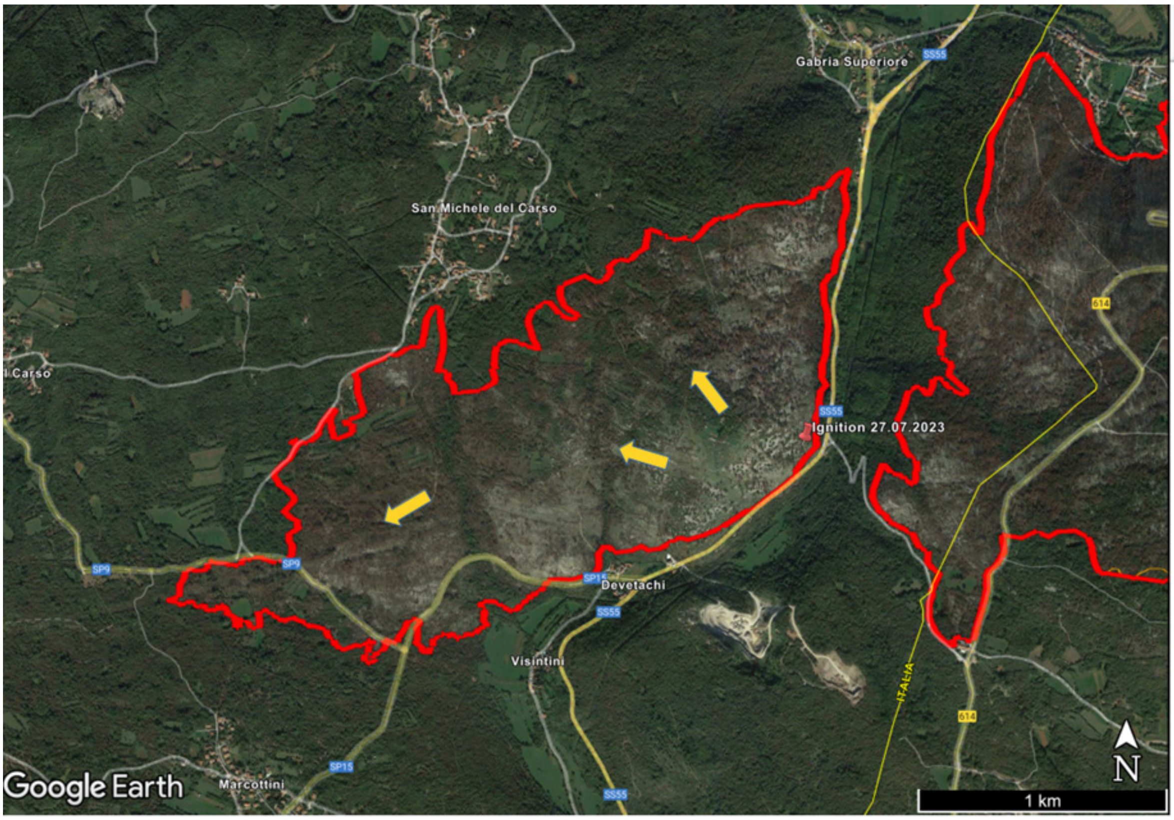

Figure 79. Map of the burned area by the Brestovec fire (left polygon, in red). The ignition point is also showed, together with the main direction of propagation. On the right, the western side of the Miren fire.
Data Source: Image elaborated by CNR based on information collected from Granata (2022) and Vendramin (2022).

(a) (b)


(c) (c)


Figure 80. Pictures of the fires: (a) Initial propagation phase of the Miren wildfire (July 15th); (b) The wildland urban interface threatened by the Miren fire (July 20th); (c) View from north of the initial propagation of the Renče wildfire (July 17th). The are of ignition is located on the left; (d) View from north-east of the initial propagation phase of the Monfalcone fire (July 19th).

Data Source: Vendramin, 2022.

6.5 Cross-Border dimension and related dynamics

6.5.1 Cross-Border Organisational Setting

Cross-border cooperation between Friuli Venezia Giulia Region and the Republic of Slovenia in the field of emergency management is regulated by two main Protocols:

- The Memorandum of Understanding on cross-border cooperation between the Civil Protection of the Ministry of Defence of the Republic of Slovenia and the Civil Protection of the Autonomous Region of Friuli Venezia Giulia, for forecasting, prevention, and mutual assistance in emergency situations. The Memorandum was signed in 2006.
- The Agreement on cooperation between Fire Brigades in the cross-border area between Italy and Slovenia. The Agreement was signed in July 2022, just few days before the Karst wildfire, as a result of the INTERREG Ita-Slo CROSSIT SAFER Project and substitutes the previous Agreements between the Trieste Fire Brigade and the Koper Fire Brigade (2008) and between the Gorizia Fire Brigade and the Nova Gorica Fire Brigade (2009).

The following table summarises the main aspects of the above-mentioned acts.

Table 14. Content of the 2006 Civil Protection MoU and 2022 Fire Brigades Agreement.

Signatories	Civil Protection Services of Slovenia and Friuli Venezia Giulia.	Firefighting Services of Slovenia, Slovenian Municipalities, and Regional Direction of the Firefighting Services.
General scope	Cross-border cooperation for forecasting, prevention, and mutual assistance in emergency situations.	Collaboration in the cross-border border area between Italy and Slovenia.
Objective(s)	Increase and encourage cross-border cooperation in the Civil Protection sector (...) to safeguard the safety of neighbouring populations, animals, assets, cultural heritage, settlements and the natural environment, in the event of emergency situations that occur in neighbouring areas. [art. 1].	Provide mutual assistance for more effective action in the case of urgent relief interventions in border areas. [art. 1].
Area of application	Friuli Venezia Giulia Region (Italy) and Republic of Slovenia.	20km band across the border [art. 2].
Means	- Exchange of information and data via telecommunication channels in real time for the purpose of predicting and preventing disaster events, timely communication of information relating to conditions occurring in the event of an emergency - Mutual assistance in cases of emergency and coordination of relief efforts for affected neighbouring populations [art. 2]	Mutual assistance in firefighting and emergency technical rescue interventions in general, in various operational scenarios [art. 3].
Activation procedure	Mutual commitment to promptly communicate the looming emergency risk or the ongoing emergency [art. 5]. In emergency situations that may involve neighbouring populations, it is possible to request mutual assistance through the reference Operational Centres [art. 7]. The Civil Protection requesting assistance must ensure adequate logistical and linguistic support and is responsible for the direction and coordination of operations [art. 8]. The Civil Protections undertake to provide mutual collaboration in activities aimed at extinguishing forest fires [art. 10]. The Protocol allows aircraft to fly across the border, subject to authorization from the Operations Centre and in compliance with air navigation regulations [art. 9].	After gathering information on the critical event, the territorially competent Fire Brigade Command may ask the corresponding Command in the cross-border area for help in terms of personnel, equipment, and resources [art. 4]. The requested Command can approve or refuse the request for intervention, without any consequences of any kind [art. 5]. Once the request for help has been accepted, the competent Command provides a Liaison Officer to guarantee a contact between the two organisations. The Liaison Officer will go to the agreed border crossing point and accompany the operators mobilised by the Command that accepted the request for help to the place of intervention [art. 6]. Qualified personnel from the country, in which the intervention is carried out, will oversee the intervention. In the event of an incident that affects the territories of both countries or with a cross-border impact, appropriate operational management will be established, including the possible activation of a joint command [art. 7].
Technical means and provisions	Mutual aid may consist, depending on availability, in: - Sending specialized technicians - Sending teams of volunteers and other civil protection units with adequate means and equipment - Dispatch of aircraft - Sending assistance items (food, medicines and others) to the affected population - Any other civil protection activity useful for overcoming emergency situations [art. 8]	Commitment to implement the interoperability of technical means, vehicles, and equipment in case of joint interventions, starting from an exchange of information on the state of the art [art. 11].
Costs	Mutual aid is provided free of charge, the side requesting help covers logistical costs and guarantees insurance coverage [art. 11].	The intervention costs remain under the responsibility of each party, except for any logistical costs which are guaranteed by the host territory [art. 8].
Exchange of information and common training	The Operational Centres are connected to each other in order to exchange relevant information and co-organise training [art. 3]. The collaboration programs are established on an annual basis [art. 6].	Fire brigades undertake to exchange information on hazards and risk of possible cross-border impact, including statistical data, as well as to participate in joint projects in the field of research and planning of emergency mitigation measures [art. 10]. A joint training and education programme on the operational scenarios included in the Protocol can be set up to make cross-border cooperation more effective [art. 9].
Validity	No time limitation [art. 16]	Five years from the signing, with renewal by tacit consent. Possibility to withdraw from the agreement by giving written notice [art. 12].
Previous agreements	The usual collaboration between border municipalities regarding civil protection in cases of emergency remains unchanged [art. 12].	The agreement replaces the previous agreements signed in 2008 (between firefighters of Trieste and Koper) and in 2009 (between firefighters of Nova Gorica and Gorizia) [art. 12].
Controversies	Any disputes must be resolved out of court and through negotiation [art. 13].	N. A.

All the interviewees underlined that in many cases, included the one explored in this Report, the joint commitment informally preceded the activation of the Protocols, and that the most determining factor in the ability to activate a joint response at a cross-border level, beyond formal agreements, is the existence of a common and reciprocal interest in the protection of areas and people affected by fires. It has also been highlighted that there are areas in which informal activation is possible, while for others the operations are inevitably more complex to coordinate on a cross-border level: air interventions, for example, respond to different maps and authorisation, support and check; this complexity was highlighted, during the Karst wildfire, above all when aircraft from third countries (for example, Republic of Serbia) were also present on the field.

The difficulties encountered in implementing the formally reached agreements derive mainly from different operating systems and practices between Italy and Slovenia. The differences relate to the following aspects:

- Organisational scale. In Italy, for instance, operate both national bodies, such as the Fire Brigade, and entities organised on a regional or local scale, such as the Regione Friuli Venezia Giulia Forestry Corps and the Regione Friuli Venezia Giulia Civil Protection. This results in different chains of command, different modalities of operational response, and different access to tangible and intangible resources at the respective level of competence.
- Composition in terms of human resources. Organisations involved in the firefighting response can be exclusively professional (Italian Fire Brigades), or mainly composed by volunteers coordinated by professional personnel (Regione Friuli Venezia Giulia Forestry Corps, Regione Friuli Venezia Giulia Civil Protecion, Slovenian Gasilci). The composition is reflected in the organisational structures, in the degree of “freedom of movement” in relation to (less or more) legal responsibilities, as well as in the kind of knowledge/expertise/experience which can be rely upon during the emergency phase.
- Function within the emergency governance structure. The Civil Protection is focused on providing logistical support to operations. Other actors, such as Fire Brigades, Regional Forestry Corps, or Gasilci, are involved in the direct intervention in relation to fire.

There are also significant differences in the approach to the firefighting operations. In the choice on how to deal with the fire in order to extinguish it, approaches applied between Italy and Slovenia partially differs: some of them – especially in Italy – derive from a tradition of intervention which is focused on the direct aggression of the flame in order to avoid the risk of excessive extension of the fire; others ones – especially in Slovenia – are more defensive, providing for example the use of foaming agents or backfires as a tool for the preventive elimination of the fuel, as well as for orienting the fire route far from sensitive targets.

The interviews highlighted the fact that a high degree of difference in organisational models could account for fragmentation and hinder the capability of a system to properly respond to an emergency, complex systems, if properly coordinated, retain the appropriate degree of internal diversification and redundancy which is highly relevant during emergency scenarios. To positively exploit the features of this complex system, however, it is necessary to have a high awareness of roles and competencies attributed to every actor involved.

In addition to the activation of the bilateral Protocols mentioned above, Slovenia requested international assistance by calling for the Union Civil Protection Mechanism (UCPM), asking for aerial firefighting aircrafts and additional firefighting units, and activated another bilateral military-to-military Protocol with Hungary.

As reported by the Slovenian Gasilci, a total of 9 helicopters (from Italy, Hungary, Croatia, Austria, Slovakia, and Serbia), 5 aircrafts (from Croatia, Romania, and Slovenia) and 1 firefighting unit (4 vehicles and 9 operators, from Croatia and a team of Slovak firefighters to support a Slovak helicopter with a 20 000 liter fire vehicle) operated in Slovenia, both through the UCPM and as a result of bilateral agreements.

6.5.2 Population Response

On both sides of the border, the local population is reported to have been very much cooperative and keen to help emergency operators. However, not much direct participation in the firefighting response activities has been registered.

The impression, from the Italian point of view, is that while for minor fires that occurred in the area in the past there have sometimes been issues related with population low levels or lack of risk awareness, in this situation, despite the unprecedented magnitude of the event, the level of preparation and knowledge of people was higher than before. This impression is confirmed also by Slovenian operators, who recalled that Karst people already know how to move in an emergency, both in terms of individual protection (for example in field cleaning operations carried out with tractors) and in collaboration with evacuation operations.

People's solidarity towards the emergency operators has been shown also in terms of voluntary supply of resources to first line operators.

During the firefighting operations, evacuations, there was necessary not only to put the population in a safe condition, but also to make the firefighting activities more operational, in fact they allowed the operators to concentrate more on the fire, and not on the protection of civilians.

Both in Italy and in Slovenia, even though the official decision is taken by the mayor, evacuation operations are requested by emergency operators:

- In Italy, evacuation operations arise from specific requests from emergency operators, shared in the Prefecture also with the civil authorities and formalised by a municipal ordinance. The sheltering facilities are identified among those that each Municipality surveys as part of the Civil Protection Plan. In this case they were all fixed structures, specifically school gymnasiums, in Monfalcone, Savogna d'Isonzo, and Gradisca d'Isonzo.
- In Slovenia, the Mayor authorizes the evacuation which is then implemented concretely by the Police and the Civil Protection. In this case, the destination of the evacuees was Šempeter, in the Sport Centre Hall, because the entire Karst area was impacted by smoke.

In both cases, the evacuations are not mere formal acts. Beyond the issuance of the formal order there is a dimension of operational implementation through which people must be put in a position to actually be able to evacuate safely (which includes leaving their properties with enough guarantees).

The first evacuation took place in the town of Sablici (Municipality of Doberdò del Lago) already on July 19th, with 15 people evacuated. In the case of San Michele del Carso (Municipality of Savogna d'Isonzo), the sheltering solution organised in the gymnasium was chosen by 20-30 people out of the 250 evacuees; the others found a private solution, for example being hosted by relatives or friends. Different Civil Protection groups took care of different tasks, according to their previous professional experience: sheltering sites, for instance, were monitored by volunteers from the Carabinieri Association (retired police forces), while food was provided on site by the Alpini Association (retired military forces). Support for materials and provisions was organised starting from the centralised warehouses of the Civil Protection. Basically, Civil Protection was primarily concerned with the safety of the population (including safe transportation and availability of sheltering sites) as well as planning issues such as setting the correct time to evacuate based on objective evidence, for example those on the wind forecast.

The reaction of the population to the need to evacuate was on average very cooperative, even if there were some tensions. Obviously, emotional factors also emerge in situations like this, as every individual has their own reaction to emergency events, and someone is inevitably more reluctant to evacuate. More than regret at having to leave one's home, it seemed that the strongest feelings were dedicated to the environment and elements of the landscape (e.g., the tree that "has seen the person who lives nearby grow"). There was also widespread concern about the integrity of properties that needed to be abandoned due to the evacuation. For this reason, for instance, in Italy some volunteers from the technical-logistics sector of the Civil Protection kept a garrison in the emptied towns.

2.5.4 Human Resources

On the Italian side, 3 044 man/days of work were recorded between July and August. This effort was performed by around 54 volunteers including firefighting and technical-logistics operators. 1 634 man/days were recorded in Gorizia and 832 in Trieste: essentially 80% of the regional workforce was employed in the two Provinces affected by the Karst wildfire. At the Municipality level, 1 516 man/days were recorded in Doberdò del Lago (Gorizia), 453 in Duino-Aurisina (Trieste). Also, in terms of forest fire fighting vehicles, out of 1 146 missions, 581 were performed in Gorizia, 353 in Trieste. Within two months only (July-August), the average expense of a whole year of fire-fighting helicopters operations was reached. To this must be added the National Civil Protection airplanes, the Fire Brigade Dragon helicopters, and the AB205s helicopters of the Slovenian army.

From the point of view of the voluntary forces available in Italy, at the time of the fire in Friuli Venezia Giulia 121 Civil Protection groups were registered in 111 Municipalities, with around 1 500 volunteers available. With the strength of these numbers, the Civil Protection has provided broad logistical support to every other involved corps, as well as to the local population.

On the Slovenian front, the estimate is that around 1 400 people were involved in the logistical operation which, given the extent of the fire, was unprecedented in the history of the country.

6.6 Fire Impacts

The impact of the Karst wildfire was more substantial in Slovenia in terms of hectares burned, but it was certainly more critical on the Italian side in terms of critical infrastructures involved.

Luckily, on both sides of the border no deaths or serious injuries have been reported by the competent authorities. In Slovenia 48 firefighters were checked for inhalation and one minor injury was recorded. The balance of the impact of the fire is particularly positive especially if considering the 500 explosions caused by the detonations of unexploded war devices.

6.6.1 Infrastructures

Most of the information presented in this paragraph is related to the critical infrastructure which draws a very dense texture in the area between Monfalcone and Trieste, in the Italian territory.

The safety of the three power lines that cross the Karst area (one of which is 380kV) in the Italian territory was guaranteed not only through deactivation, but also by providing discharges to the ground, which are necessary to guarantee the safety of the personnel working under the line. The decommissioning was carried out to allow for the early re-organisation of energy distribution after the emergency, to avoid uncontrolled and unexpected collapses.

The pipeline was also placed under special observation, especially near the control stations. However, the most significant problem relating to gas in the Karst area was found in relation to the presence of numerous private LPG deposits, mainly above ground, in several areas where the methane line does not reach.

The water supply network was put under high stress as well, because of the fire extinguishing activities. Reservoirs realised by the Civil Protection after the very warm summer 2003 were deployed to meet the system's need for water.

In the most complex phases of the fire development, the international civil airport of Ronchi dei Legionari (Trieste Airport, Italy) was first shut down, then downgraded to allow the fire extinguishing means operating on the runway to be used in firefighting operations. The main roads (motorway A4 and National road no. 14, also known as "Costiera" road, both connecting Trieste and Monfalcone), the railway towards Venice, and the National road no. 58 (also known as "Vallone" road, connecting the Lisert area with Gorizia) were temporarily closed as well.

6.6.2 Smoke emissions and dispersion

To analyse the effect of Karst wildfires occurred from July 15th to August 1st on smoke emission, several sources of data were exploited. Satellite images monitoring Fire Radiative Power (FRP) observations from VIIRS instruments onboard the NOAA-20 (https://www.star.nesdis.noaa.gov/) were used to trace fire spread and smoke emissions, while air quality data (PM_{10}) recorded by several measurement stations were downloaded from the Arpa Friuli Venezia Giulia (FVG) network (https://www.arpa.fvg.it/temi/temi/aria/sezioni-principali/). In particular, Arpa FVG, in order to circumscribe the area of actual fire impact, carried out (i) expeditious measurements at various locations of potential fire smoke fallout by means of optical particle counters and (ii) constant hourly monitoring of PM_{10} at the following air quality measurement stations: (a) "Green Area" station in Monfalcone from July 15th (published in the "news" section, https://www.arpa.fvg.it/temi/temi/aria/news/?q=incendi); (b) Trieste-Carpineto, Udine-S.Osvaldo, Tolmezzo stations from July 21st; (c) San Giovanni al Natisone, Trieste - P.zza Carlo Alberto, Trieste - P.zza Volontari Giuliani, Trieste – RFI, Udine - via S. Daniele stations from July 22th.

Satellite images detected a small fire in Slovenia, along the main road Miren – Lokvica, near the Italian borders, on July 17th. However, the closest air quality station, Monfalcone, did not detect any criticality for fine dust on that day. According to Arpa FVG reports, two days later fire smoke affected a large area, evolving vertically in a very dispersed plume shape, but the air quality station in the Monfalcone area did not detect any criticality for fine dust. Indeed, PM_{10} measurements recorded during the morning of July 19th were very low (less than 10 μg/m^3), increasing in the afternoon but still well below the threshold of 50 μg/m^3.

The air quality stations of Monfalcone detected a sudden increase well above the critical threshold during the night of July 19th and the first hours of July 20th, recording a peak of 1 600 μg/m^3. On July 20th, Arpa FVG and satellite images reported the fire plume raising in altitude and dispersing in a west-south-west direction over a wide area.

On July 21st, the change in wind direction (easterly) moved the smoke plume towards Slovenia and the area of eastern Friuli. The four air quality stations in Trieste recorded their peaks at noon (max. 177 μg/m^3, Figure 81). Furthermore, Arpa FVG carried out rapid measurements at various locations using optical particle counters. In this case, Arpa FVG considers more than 1 000 particles with a diameter of less than 1 μm per litre as a reference threshold in the event of a fire. During the night, the values were above the threshold for the cities of Grado, Ronchi dei Legionari, and Gorizia. Indeed, a thermal inversion situation in the low layers was expected, "making the smell of active fires in the Karst perceptible even at considerable distances" (Arpa FVG, 2022a)

On July 22nd, the presence of a weak easterly/northeasterly wind spread the fire smoke towards the area of the Slovenian Karst, while the values measured by the Monfalcone station returned below the critical threshold (from 120 μg/m^3 at midnight to 33 μg/m^3 at 23:00). During the nighttime, the marked thermal inversion that characterized the previous nights reappeared.

The forecast model of Arpa FVG identified the entry of moderate bora in a North - North-East direction during the night of July 23rd: this pushed the smoke generated by the fire over the Slovenian Karst towards the Friulian plain. Smoke was expected to fall on Gorizia (PM_{10} 32 μg/m^3, below the daily mean threshold). Similarly, on July 24th, smoke dispersion from fires in the Slovenian Karst was expected to move towards the Friulian lowlands. On July 25th, the situation regarding fires in Friuli Venezia Giulia was under control and dust levels (PM_{10}) returned to normal values (Figure 81).

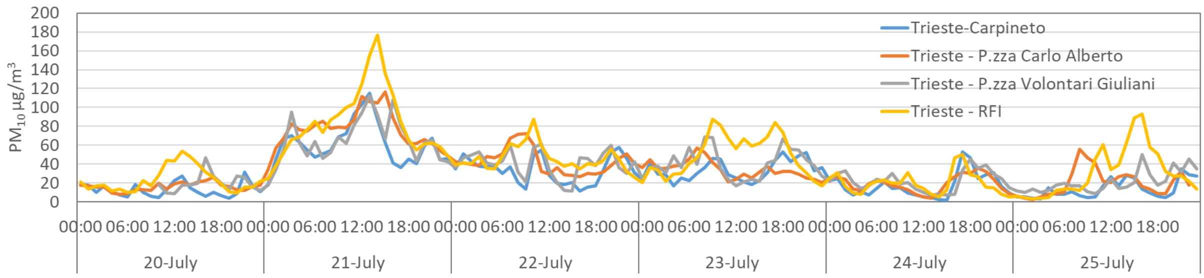

Figure 81. PM_{10} (µg/m³) hourly data collected from the four air quality stations in Trieste (July 20th-25th).
Data Source: Based on data from Arpa Friuli Venezia Giulia (FVG) (2022b).

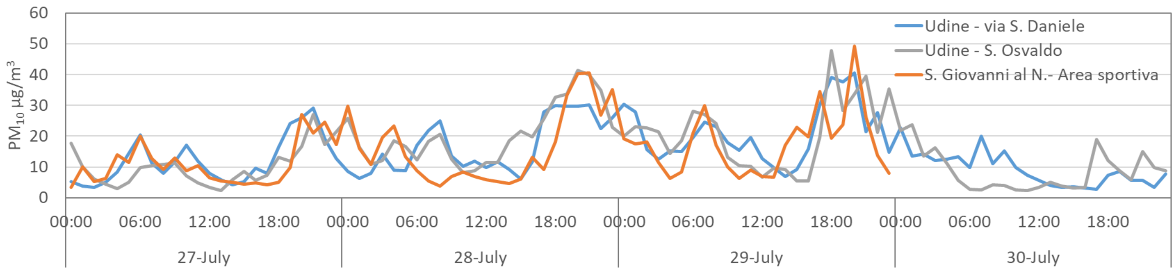

Figure 82. PM_{10} (µg/m³) hourly data collected from the Udine (via S. Daniele and S. Osvaldo) and S. Giovanni al Natisone air quality stations (July 27th-30th).
Data Source: Based on data from Arpa Friuli Venezia Giulia (FVG) (2022b).

Following the new fire that broke out on July 27th in the Dobrevac mountain, during July 28th the fire smoke was dispersed to the west, towards the Friulian lowlands. According to Arpa FVG, the atmospheric turbulence brought the smoke close to the surface, but also diluted its concentrations. On July 29th, Udine (via S. Daniele and S. Osvaldo) and S. Giovanni al Natisone air quality stations detected values near the critical threshold for fine dust after 18:00 (Figure 82).

The fire that broke out on July 27th was declared under control on July 29th. In the morning of July 30th, data from the air quality stations did not show any exceedances of PM_{10} dust particles. Therefore, the extraordinary hourly monitoring and other control measures in the area were suspended.

6.7 Cascading effects

As already anticipated, a significant issue in the case of the Karst wildfire is that of unexploded war ordnance, a presence well known in the territory on both sides of the border that has suffered two World Wars, but perhaps underestimated. The Karst wildfire was characterised by a higher frequency of both the discovery of bombs and their explosions, compared to past episodes. The phenomenon has affected the local population as well as the operators who find themselves in the areas characterised by these explosions.

The Slovenian interviewees report that a similar scenario (in terms of the number of explosions and discoveries) had already occurred in the Montesanto/Sveta Gora fire of 2012. After that episode the Slovenian operating protocol in the event of the presence of unexploded war ordnance was reviewed and partially modified. Up to that moment, indeed, after the first explosion the emergency operators had to move 1 km away, without proceeding with the extinguishing operations, while no specific operational indications were given with respect to the evacuation of people and goods. The regulation currently in force, on the other hand, provides that it is forbidden to proceed immediately with the reclamation operations in the area affected by the explosions for 48 hours, but it is possible to continue with the extinguishing operations. This approach is preferable because it protects operator safety while allowing firefighting activities to proceed.

6.8 Lessons learned and Conclusions

6.8.1 Lessons Learned

6.8.1.1 Organisation of Working and Volunteering Forces

In Italy, following the ex-post assessment of what happened in the Karst wildfire, the 2023/2024 Forest Campaign saw the deployment of an additional Fire Brigade team for each Province, dedicated to fighting forest fires and financed with a regional agreement, operating on shift 08:00 – 20:00. A new Civil Protection Regional air service contract has also been activated in Friuli Venezia Giulia, which includes an automatic detection system with the use of thermal imaging cameras during the flight, therefore in real time. This will facilitate future shutdown operations by sending infrared map and visible map information directly to DOS. In November 2022, a drone which, traveling at lower altitudes, is important for reclamation operations, was purchased.

In Slovenia, at the corps organisation level, the squad activation plan has changed. This will no longer be ordered in relation to the number of people to be mobilised but in relation to the type of intervention to be carried out, according to an organisation in platoons which are supposed to be self-sufficient for the 24h. This setting was already legally defined in 2006 but never implemented. In addition, 5 aircrafts were purchased, 3 of which are still to be delivered, with both firefighting and monitoring and data collection purposes; prior to that decision Slovenia could only rely on military helicopters and aircrafts for air interventions. Finally, the new Slovenian government presented the new National Anti-Forest Fire Plan in December 2022, simplifying the chain of command in the event of a fire, creating a direct channel between DOS in the field and military forces, and integrating the Single Emergency Number into the firefighting system.

6.8.1.2 Accessibility

During the interviews carried out for this study, the issue of improving the accessibility of areas affected by fire risk was often mentioned as a priority. Several secondary roads that serve as fire trails suffer from a poor degree of maintenance, and in some cases the fire easily overrides them, passing from one side of the road to the other. Another critical issue is represented by isolated settlements connected only by dead-end roads.

The first need is therefore to map the current situation, taking into consideration both the areas already affected by the fire (about 1 700 ha) and those that have not been affected by it. Thanks to this mapping carried out on the Italian territory after the Karst wildfire, the 12 settlements most prone to fire risk in the Province of Gorizia have been identified. This information has been shared with the Municipalities as well, which are primarily responsible in terms of risk communication to citizens.

During the interviews, already planned interventions were reported, for instance the creation of secondary roads and escape routes, interventions which, moreover, can be accompanied by other measures such as better accessibility to water (for example the construction of tanks and deposits). It has been observed that the restoration of secondary road networks could also have positive effects from an economic and tourist point of view.

From the Slovenian standpoint, it is believed that it would also be appropriate to intervene on a legislative level, with clearer laws regarding the characteristics that must be guaranteed, for instance in terms of height and width, for forest firebreak roads. Some positive examples from which to draw inspiration exist, for example in France, or the regional law of Tuscany. Such choices could attract criticism from those who express environmental concerns, because their implementation would require the felling or thinning out of some wooded areas.

6.8.1.3 Self-protection and evacuation operations

Other aspects mentioned several times during the interviews concern the strengthening of self-protection measures, in terms of prevention carried out by citizens, for example the pruning of trees and cleaning of the land with respect for the safety distances between buildings and wooded areas. The work of capitalisation of the lessons learned which was structured in the context of *Carso non arso* (see 6.8.2.2) focuses on these aspects in particular.

From the experience in Slovenian territory, it has emerged that, while organising evacuation operations, the request to take care of the livestock often emerges by local inhabitants. The presence of livestock, especially sheep and goats, in the Karst is an element that generates concern and resistance in the population during evacuation procedures. The evacuation of livestock is a complex procedure that should not only be foreseen by the rules but also made operational.

6.8.1.4 LPG deposits and Unexploded war ordnance

A separate mention is needed for the issue of private liquid gas deposits. Very often in the Karst these tanks are installed above ground as the geomorphological characteristics of the territory make the creation of underground deposits very expensive and complex. Although the safety distances for above ground systems are greater than those for underground systems, the regulations in force are probably not sufficient to guarantee an adequate level of safety, according to the interviewees. This is a case that clearly demonstrates how the rules serve to cover 90% of the risks, but at the same time they risk generating a false feeling of security ("I have complied with the rule, so I am safe"). More than interventions on the standard, in this case more common sense and awareness would be needed in the choices of installation and maintenance of these structures.

Regarding the problem of unexploded war ordnance, the Regione Friuli Venezia Giulia Forestry Corps suggests thinking about future action, better if agreed at cross-border level as, for instance: resorting to indirect attack with the use of retardant products, tactical fire, clearing, setting up planned lines of fire to stop the advancing fronts, setting up 'safe' areas. Also, the Regione Friuli Venezia Giulia Civil Protection called for the necessity, to ensure adequate safety for the emergency operators, to plan a new approach to Karst firefighting, no longer aimed at attacking the fire wherever it is found, but at the creation of reclaimed safe routes along which to set up the garrisons to combat the advance of the fire line.

6.8.1.5 Protocols' Revision, Implementation and Extension

The concrete experience of such a wide-ranging joint and cross-border intervention was also fundamental for putting the international protocols in force to the test. The Protocol has proven to be functional in compressing time requested for certain operations, therefore in helping practitioners to operate with a resource that is always scarce in times of emergency.

In fact, the Safety Operating Procedures require guidelines for different scenarios, but it is equally important to have a structure with adequate organisational flexibility at all levels (including the more purely political and institutional one). From the Slovenian point of view, in practice, even more has been done than was written down in the Protocol. Somehow the Protocol was always behind reality: therefore, there is a need for simpler tools to implement.

In general, in the opinion of the operators, coordination skills need to be improved more than the procedural aspects. According to all the interviewees, it would be advisable to multiply the opportunities for meeting also in the preventive phase, as well as in the post-emergency phase, to make the necessary assessments; everyone's story, if shared, can create awareness and generate further knowledge useful to all. Mutual knowledge between operators translates into greater cooperation on all levels: this occurs, for example, with joint exercises. In doing so it is important to be aware of the existence of the language barrier.

Sharing sessions would also be functional for developing innovative and co-created approaches to firefighting operations, for example to shift from a purely offensive approach towards more preventive and defensive approaches. The meetings would make it possible to share strategies, as well as to identify compromise and transition solutions from the old to the new models, including the necessary training in the use of new methods and/or technologies.

The fire also highlighted the need to implement further protocols on other currently less covered fields: an example is the field of risk forecasting, on which interoperability and data exchange between Slovenian and Italian fire susceptibility prediction systems could be evaluated. In other areas, cooperation is currently stronger between Italy and Austria: a few years ago, joint exercises were held at the Carinthian lakes; or in the context of the Single Emergency Number, with a strong relationship between the emergency centres of Palmanova and that of Klagenfurt. Certainly, the recognition of the respective minorities also facilitates cross-border relations.

6.8.2 Capitalising on the Lessons Learned

6.8.2.1 ResiFestGo

In October 2022, right after the Karst fire, Gorizia hosted a series of initiatives within the Italian National Civil Protection Week. One of them was RESIFESTGO, an event which aimed to provide an opportunity for emergency managers and citizens to discuss the issues of resilience and Civil Protection, from a cross-border and European perspective.

The event stemmed from RESILOC - Resilience Europe and Societies by Innovating Local Communities, a Horizon 2020 EU project which started in 2019 and ended in 2022. The project was aimed at improving the resilience of local communities, through research activities and applying a holistic approach to studies, methods and software that combine physical and less tangible aspects associated with human behaviour. The project aimed at improving the level of resilience of local communities, through research activities and by piloting the developed solutions in 4 pilot sites (i.e., Gorizia and Catania in Italy, Tetovo in Bulgaria, West Achaia in Greece).

RESIFESTGO hosted round tables and open debates that provided an opportunity for the exchange of good practices among emergency operators, Civil Protection representatives, and local institutions. The event made it possible to disseminate the principles of self-protection to the local population as well as promoting risk awareness and cooperation. One of the initiatives held within RESIFESTGO was indeed titled “From emergency management to community resilience: European best practices and lessons learnt on the management of wildfires”. This technical workshop targeted emergency experts, professionals, researchers, civil society representatives, and local decision-makers from Slovenia, Italy, and abroad, to share experiences and analyse the impacts of fires in the Italy-Slovenia cross-border area, also in the light of European experiences.

6.8.2.2 Carso non Arso

Carso non arso (literally, “Not burned Karst”) is an initiative promoted by the Fire Brigade and shared with the Prefecture, Region, Forestry Corps, Civil Protection, local administrators of the Gorizia area. It was focused on dissemination activities mainly targeting schools and, in a broader sense, at local communities. The starting point came precisely from the Karst wildfire, from what has been done in the field of firefighting but above all on what must be done in terms of prevention.

Carso non arso’s aim was to spread the culture of forest fire safety in the population. The intention is to develop an annual appointment, which in the first edition mainly involved schools, with the active collaboration of various institutions. In particular, local administrators were involved with the aim of identifying the best interlocutors at the local level. Also due to issues of time and effectiveness of the intervention, it was decided to focus mainly on schools; out of 7 Municipalities involved, in 6 cases the target was identified in the school population of middle and high schools; only in one case (Sagrado) was instead opted for a meeting with the local community, which took place in San Martino del Carso.

Each meeting was structured as follows:

- An illustrative part relating to the risks that are run during a fire, supported by video interviews made after the Karst wildfire with an evacuated person, a local administrator and an official of the Fire Brigade.
- A more specific part on fire risks, introduced with the help of a presentation.
- An informative part with useful information especially for residents of isolated houses.

The presentations were followed by a moment of debate with questions and answers.

- Finally, an exhibition and demonstration section on firefighting operations.

The first initiative of the 2023 cycle was organized in Gorizia in collaboration with the Slovenian firefighters (Gasilci). Furthermore, the leaflet containing the most operational information, in particular those related to the maintenance of isolated buildings, was translated into Slovenian, as were the posters of the events. The intention was to carry out the entire initiative on a cross-border level, but for the first edition some difficulties were encountered relating to the planning of school activities in Slovenia, which has earlier times than in Italian schools.

6.8.3 Conclusions

Events such as the Karst wildfire confront political decision-makers, managers, emergency operators and stakeholders with the question of how to make people's lives safe in the interface areas, given that zero risk does not exist. The Friuli Venezia Giulia Region Forestry Corps has highlighted how, in critically understanding these phenomena, the greatest difficulties are encountered due to widely diffused single-disciplinary views of the subject, for example on the ecological functions performed by trees. If the vegetation, even the bushy one, can in fact on the one hand constitute a risk factor for the spread of a fire, on the other hand it guarantees the stability of the soil and therefore is an important factor in the prevention of landslides. Such nuances need to be taken into consideration when performing risk analyses.

According to the Fire Brigade, the event, unprecedented due to its scope and duration, today would meet a more prepared system, because direct experience of these episodes is always more valuable than any training. In fact, prior to the Karst wildfire an entire generation of operators have had never directly dealt with a fire of this magnitude. This also applies to the local population, although they were quite prepared thanks to the strength and structure of the Civil Protection mechanisms.

In any case, it is the unanimous opinion of the interviewees that, just as the fire had no boundaries in its development, the response to the fire was also organised on the same level, the cross-border one.

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7 Fire of Bohemian and Saxon Switzerland (Germany / Czech Republic)

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7.1 General Description

The fire started on July 24th close to the town of Hřensko in the Bohemian Switzerland National Park, Czech Republic, close to the border with Saxony, in Germany. The location and burnt area can be seen in Figure 83.

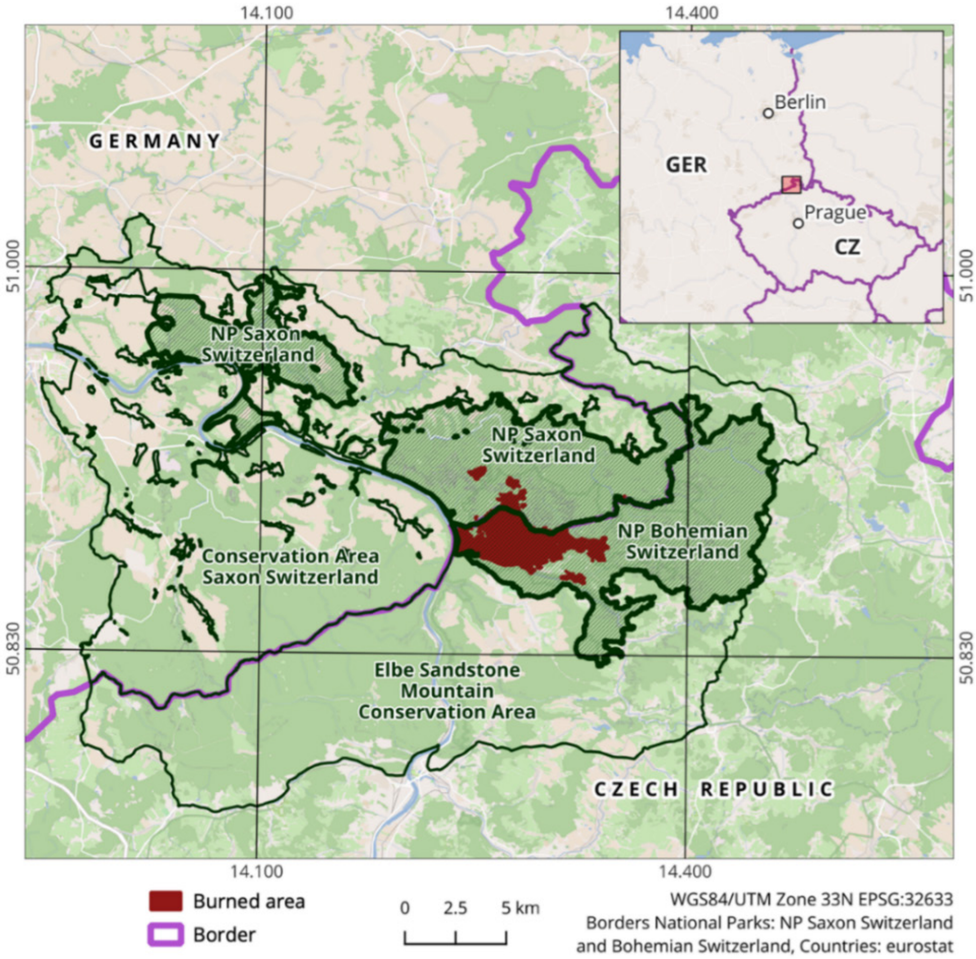

Figure 83. Location of the burned area in the two national parks on the border between Germany and the Czech Republic.

The cause of the ignition is now known to be arson and the fire was first identified in the morning of July 24th by rangers from the Saxon Switzerland National Park patrolling on the German side of the border. By July 25th, the fire was considered to be out of control. In total 1 215 ha of forest was burned, 115 ha or 1.3 % of the Saxon Switzerland National Park was affected, and 1 100 ha or 14 % of the Bohemian Switzerland National Park on the Czech side was impacted. The fire was the largest recorded in the border region and followed a smaller fire just weeks before.

The fire was eventually suppressed on August 12th. Steep terrain, weather conditions, the large amount of standing and lying deadwood, limited accesses, underground fires and distant water sources all played a part in the length of time needed to extinguish the fires. In addition to this, lack of mobile phone reception also reduced the efficiency of the firefighting effort and coordination of resources.

Fortunately, there was no loss of human life during the event, though three firefighters were injured, one seriously. During the fire, around 2 050 emergency service workers were engaged in fighting the fire and 14 aircraft from Germany, Czech Republic, Slovakia, Poland and Italy were deployed. Specialist pilots trained in fighting fires from Sweden also arrived. Around 450 people were evacuated from the nearby settlements of Hřensko Mezná, Janov, and Mezní Louka.

In the small settlement of Mezná (CZ) three houses were lost to the flames; the village was however saved from destruction as a result of the firefighting action of the Czech Fire Brigades, which had to withdraw at one stage to avoid being surrounded by the fire. The village is on a hilltop accessible by only one road. Hřensko nestles in a narrow and high gorge surrounded by forest, much of which contained large amounts of deadwood. The vertical cliffs above the village made for difficult firefighting conditions, though its location on the rivers Elbe and Kamenice ensured that access to water was easily available.

7.2 Characterisation of the affected area

The area affected was predominantly forested land located in the Bohemian and Saxon Switzerland National Parks. As such, the area is sparsely populated within the burnt area, though several settlements are located on its periphery. The area is very popular with tourists, and the international railway between Dresden/Berlin and Prague passes through the area making it accessible to large numbers of people, whether as day visitors or those choosing to stay and hike in the area. Whilst it is difficult to provide an accurate number of tourists visiting the parks, the current estimate is between 3-4 million annually for the German side of the park. The tall and precipitous sandstone stacks are a key attraction for visitors, but in turn proved to be difficult and dangerous conditions in which to fight a fire (Figure 84).

Figure 84. The Richterschlucht, a popular walking trail through the Saxon Switzerland National Park.

The forest itself contains Norway spruce (*Picea abies*) plantations, European beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris)* and European larch (*Larix europea).* Understorey vegetation varies with dominant tree species, but with exception of the beech stands it is for the most part is grasses and bilberry (*Vaccinium myrtillus*). The park and its surroundings are home to wild boar (*Sus Scrofa*), roe deer (*Capreolus capreolus*)*,* red deer (*Cervus elaphus*) and pine marten (*Martes martes*) amongst other fauna. Within the national parks hunting is forbidden and as such relatively high numbers of game species reside within the parks.

Figure 85. Dead standing and lying Norway Spruce (*Picea abies*).

Both Germany and Czechia have a strong and historical commercially based forestry sector; however, within the national parks an absolute bare minimum of tree felling takes place, and only where absolutely necessary such as maintaining access or to reduce hazards for visitors. Large areas of the spruce plantations have succumbed to increasingly damaging infestations of bark beetle since 2017, exacerbated by drought conditions which weaken the tree and reduce their ability to survive the effects of bark beetle infestation.

Once affected by the bark beetle the trees are normally dead within around three years. This has led to large areas of standing deadwood as well deadwood on the ground (Figure 85). The large amount of deadwood in the park and the proximity of settlements to it has become a cause of concern for residents and remains so.

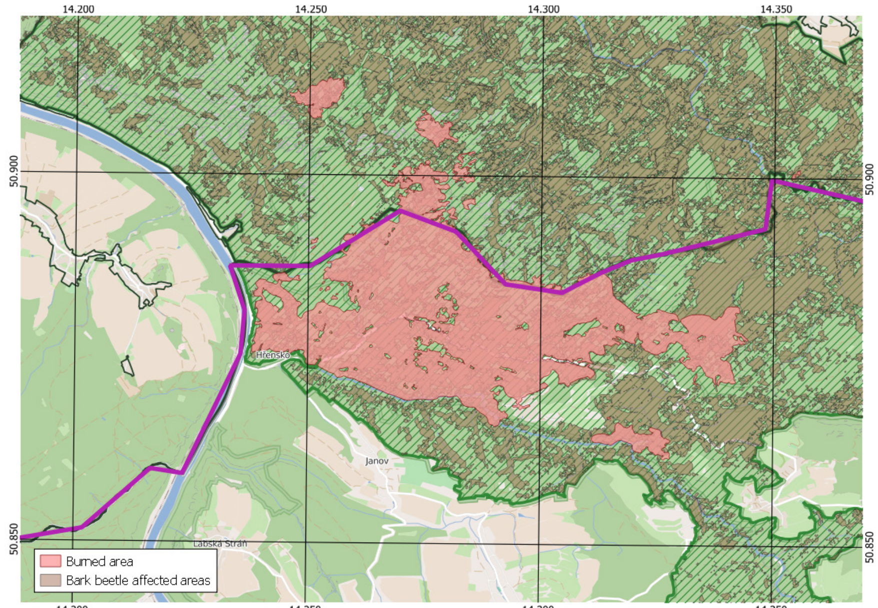

Figure 86. Bark beetle affected areas in the two national parks with overlay of burned area.

7.3 Fire conditions

Like several other countries in Europe, Germany and the Czech Republic experienced a major heatwave in mid-July 2022. Temperatures rose to 40°C in some locations and the number of sunshine hours hit a new monthly record, leading to long periods without cloud cover and very little precipitation. The two national parks were also affected by these dry conditions with very little rainfall being recorded by weather stations in the weeks prior to the fire. Despite these conditions the fire warning level (*Waldbrandgefahrenstufen*) on the day of the fire was set at Level 3, medium risk on a scale of 1 to 5, with 1 being the lowest (Figure 87).

Figure 87. Fire warning levels Saxon Switzerland National Park (according to the German Waldbrandindex) from July 1st to August 31st, i.e., before, during and after the fire. The red column indicates the date of the ignition and the orange box the period of the main fire spread.

The Saxony fire warning level is based on the German National Weather Service (*Deutscher Wetterdienst*) predictions, and the state is split geographically into three regions (high, medium and low forest fire danger). The lowest spatial unit is the *Gemeinde* (a German administrative unit) with a mean average area of 45 km^2, though actual area varies considerably. The high and medium risk areas are in the north of Saxony are monitored by the Automatic Forest Fire Early Detection System (AWFS) which uses cameras, and by employing overlapping fields of view, cover almost all the high and medium risk areas. However, in the south of Saxony where this particular fire occurred there are no cameras monitoring the forests.

The Czech fire warning levels are based upon a combination of the Fire Weather Index (FWI) developed in Canada and the Forest Fire Danger Index (FFDI) developed in Australia.

As mentioned above, the summer of 2022 was hot for sustained periods. However, temperatures of above 30°C are not uncommon during the summer months in Saxony and northern Czechia. In the month leading up to the fire the average daily temperature rose steadily (Figure 88a) and night-time temperatures in the 6 days prior to the fire were on average 15°C. The first days of the fire were characterised by high wind speeds contributing to a fast spread of the fire (Figure 88b). Precipitation in the 10 days leading up to the fire was sporadic and was less than 5 mm in total, leading to very dry conditions for the dead and live fuels (Figure 89).

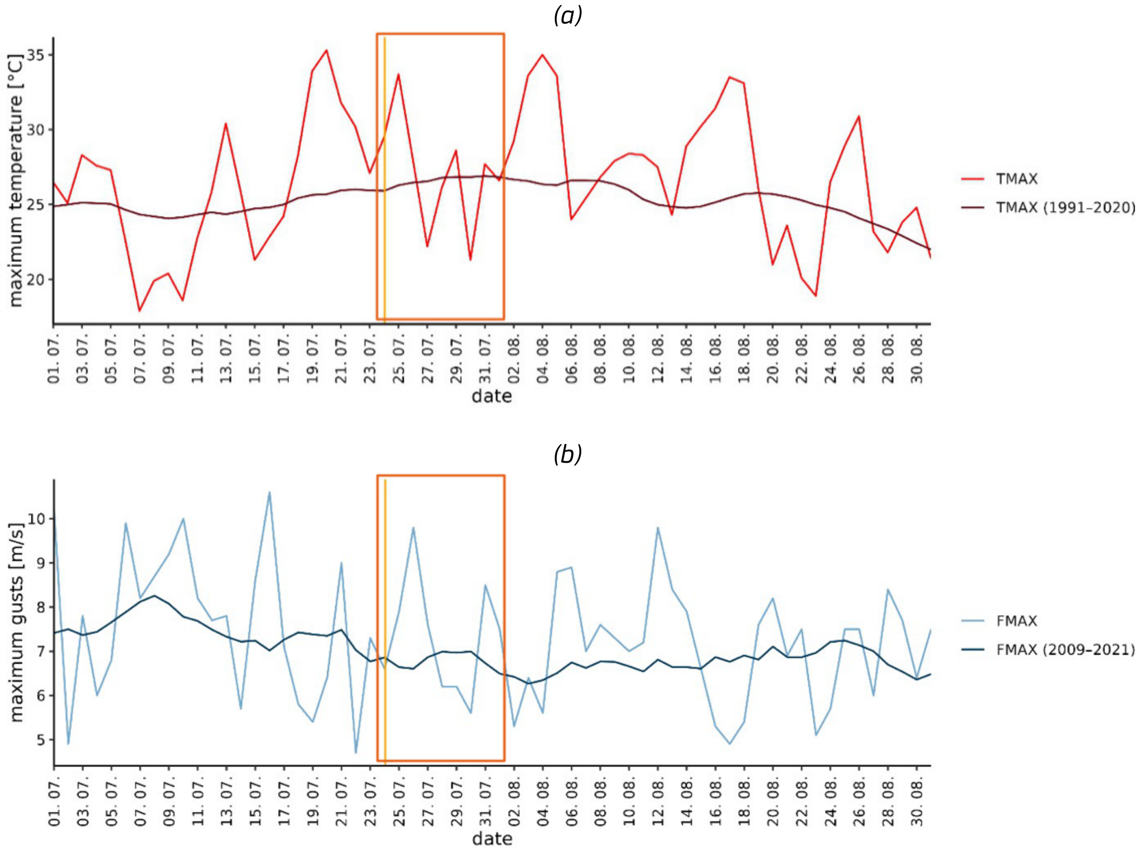

Figure 88. Daily maximum temperature (a) and maximum speed of wind gusts (b) before, during and after the fire.

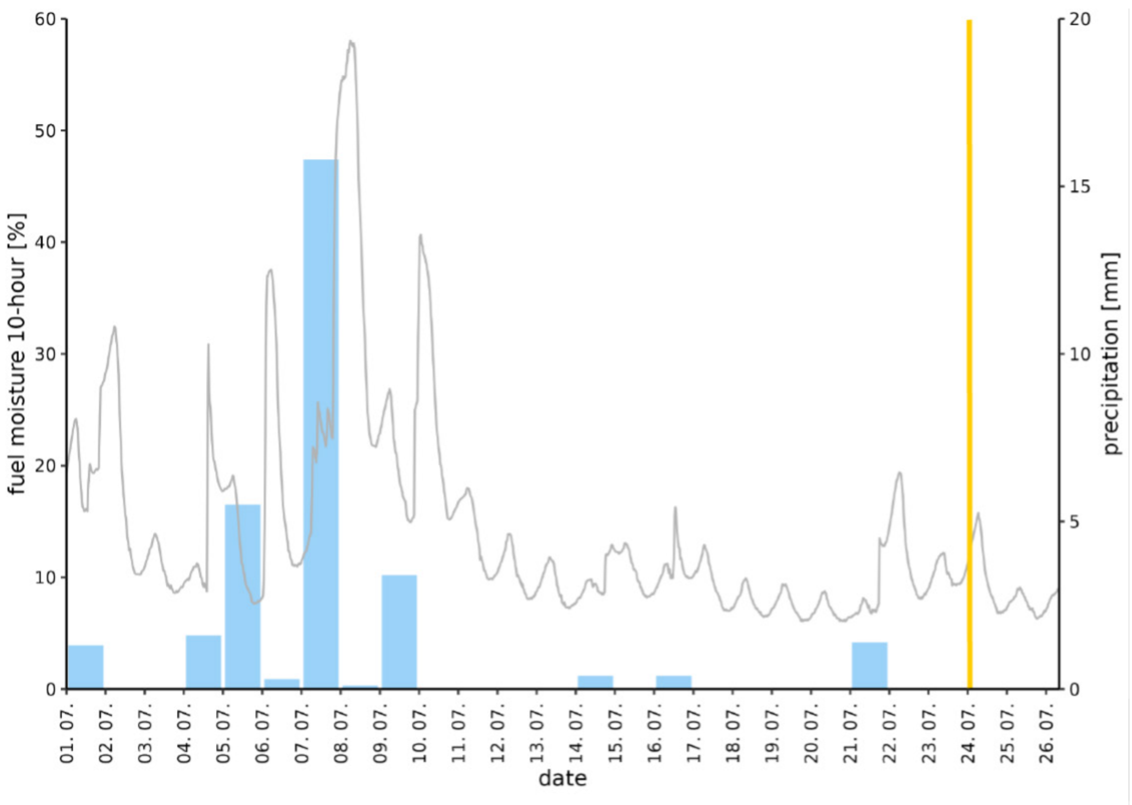

Figure 89. Fuel moisture and precipitation at the fire site. This station was destroyed by the fire on July 26th.

7.4 Fire Behaviour

The fire's relatively small size, compared to larger fires experienced in southern Europe, and the containment efforts of the emergency services, must be taken into account when examining the fire's behaviour. However, research carried out by *Technische Universität Dresden*, revealed a number of key aspects that influenced the fire behaviour.

The stands of dead spruce contained a higher amount of ground-fuels consisting of woody debris (branches, twigs) and fallen needles. This high ground-fuel load was also present in mixed forest where dead spruce could also be found. The spruce remains intact and upright after death until wind or other factors cause the limbs of the tree to fall, at which time they are already dry. The combination of limited rainfall and high fuel loads resulted in these areas burning with more energy and higher flame length than other types of woodland. This meant that adjacent broadleaved woodlands were subjected to a greater exposure to direct flames and flying embers. The dryness of the standing deadwood created the situation where the scorching height or torching was greater. This led to embers being released from a height, travelling further and likely carried upwards as a result of the updraft from the fire. This caused the occurrence of several spot fires that are disconnected from the main burned area.

The high intensity burning of the dead spruce stands combined with slope meant that embers travelled into the broadleaved forest stands and further away causing spot fires, some of which developed into larger fires, causing extensive damage. The beech woodlands have a generally low amount of ground fuel, at least in terms of large branches and twigs. What they do have is a thick layer of dead leaves carpeting the forest floor. This biomass and the low fuel moisture created the perfect conditions for an ember to ignite fires in the beech woods. All the beech trees that were affected by the flames shed their leaves within days of the fire.

The narrow valleys that lead upwards towards the mountaintops were observed to have burned the most ferociously, due in fact to slope effectively increasing the flame length and pre-drying fuels and more than likely aided by the wind. It is in these valleys where the highest loss of forest occurred.

The forest floor except for the beech stands is covered by a mixture of grasses and bilberry (*Vaccinium sp.)*. Images taken from a camera trap (Figure 90) show that despite the relatively green condition of the bilberry before the fire, almost all green vegetation was consumed when the fire occurred. Using the images and the timestamps on the images it was calculated that fire spread at around 1.2 m/min in the bilberry and grasses.

(a) *(b)*

Figure 90. Conditions before and after the fire as captured by camera trap (images courtesy of Saxon Switzerland National Park).

Fire intensity was the highest during the first days of the fire – July 24th – 26th (Figure 91). The highest energy releases in terms of fire radiative power (FRP) were observed in forest stands that were previously affected by bark-beetle infestations with accumulated dead wood. Also, some areas with beech forests had high FRP, which often occurred in beech forest that were in the vicinity of spruce stands. The intensity of the fire was such that large sandstone boulders delaminated and broke apart (Figure 92).

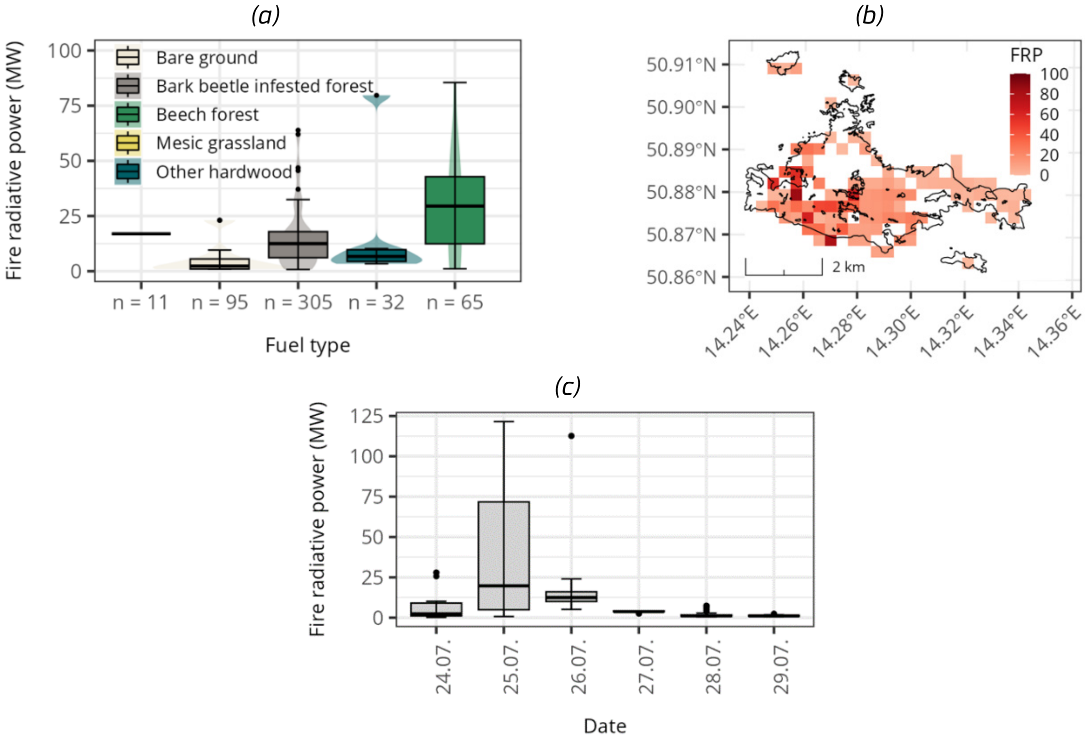

Figure 91. Fire radiative power (FRP) over the burned area as observed by VIIRS satellite sensors between July 24th and 29th. (a) Highest fire energy emissions occurred at forest stands previously affected by bark beetle infestations and in some beech forests; b) FRP over the burned area – July 24th to 29th; c) FRP from July 24th to 29th.

Figure 92. Sandstone affected by high temperatures.

7.5 Fire management at the WUI

The village of Mezná at the border to the Bohemian Switzerland National Park was the only place where three houses were lost to the fire. Other settlements were affected, but firefighting operations meant only Mezná suffered losses. The village sits on a hilltop surrounded on three sides by valley and partly steep gorges which were covered by forests. There is only one road in and out of the village. None of the houses that were destroyed were at the forest/village interface, despite the fact the fire reached the village edge.

There is no pattern to the locations of the destroyed buildings that would lead to any conclusion about the spread of the fire. However, two of the three buildings had a significant amount of vegetation in the gardens surrounding the house, almost all of which burnt. Video footage from the firefighters in Mezná show large firebrands flying at height and along the ground. It is reasonable to assume that the cause of at least two of the house fires could be the result of garden vegetation (coniferous hedgerows) or woodpiles catching fire, as neither were directly affected by flames (Figure 93). Almost every house in the village has a stock of firewood close to the building and during a visit in 2023, it was observed that houses still have large piles of firewood in the gardens and in some places against the sides of the buildings. The visit to the village also revealed that conifer-type bushes were in the garden of one of the destroyed houses.

Figure 93. House destroyed by fire in the centre of Mezná. The house was not located close to the main burned area. The burning was likely caused by flying embers that ignited the coniferous garden hedges (right side).

Figure 94 also reveals several houses directly at the forest edge, indicating that fear of a forest fire was not a concern during construction, nor afterwards judging by the proximity of the vegetation. In the village of Mezná it is difficult to identify any visible or physical measures taken that would lead one to conclude that the risk from a forest fire to the settlement was a concern for the villagers nor planning regulations. Historical images from the early 20th Century and maps from the 18th Century show that villages and individual buildings were built close to the forest in those times. Historically the village was built by foresters for wood and game production and became a tourist destination in the 19th century.

Figure 94. Fires reached the village-forest interface in Mezná. This image was taken in early June 2023. One house to the left of the photograph was completely destroyed, neighbouring houses were untouched.

7.6 After the Fire

Regeneration of the landscape following the fires has been sporadic and in part related to the fire intensity and the effect on the seedbank in the upper soil levels. For the most part regeneration has been limited to ferns and mosses. The depth of the ferns' rhizomes below the highly scorched earth protected the plants and enabled the relatively quick regeneration; ferns were showing less than two months after the fire. In some areas mosses now carpet the burnt areas (Figure 95). In areas that suffered severe burning there are indications from on-going research that the water absorption ability of the soils has been affected, due to the loss of the organic upper layer of the soil. Tracks from game, mostly boar and deer, indicate that the burnt areas do not significantly affect their movement. Indeed, as grasses start to recolonise the area, vigorous growth promoted by the ash and released minerals may actually make these burnt areas a "hotspot" for game.

Figure 95. Regeneration of mosses 8 months after the fire.

The clearing of paths to provide access for firefighters also created some issues. Lack of vegetation means less infiltration of rainfall and increased run-off. The fire was in a core area of the national park: new paths and freed-up access routes enables the public to penetrate the core areas, leading to disturbance for species within them. Measures have been taken to reduce this access but has been considered by some to curtail their perceived entitlement to free access. This discussion about access and the public and the national parks was already an issue before the fires. Resentment amongst locals about newly introduced restriction measures following the fire still requires better communication and understanding between the parks and surrounding communities. In the burnt areas the standing and prone deadwood still remains and to some extent is still an available fuel. However, the small ground-fuels created from fallen branches from the dead trees that helped propagate the fire were consumed. In those areas affected by the bark-beetle but not affected by fire, this ground fuel remains. The effect on the beech stands and their vitality is not yet fully understood. Some trees succumbed to effects of the fires immediately or in the following months. It may be some time before the outlook for the remaining trees is clear and the true losses occurring from the fire are known.

7.7 Conclusions and lessons learned

The forest fire of 2022 was the second fire in the area in that summer. Both fires became the subject of much media coverage, aided in the most part due to the location of the fires in the national parks. Thus, the microscope of public scrutiny became focussed on the actions of all involved in the fire, before, during and after. The National Park administrations have been criticised in some media for allowing the build-up of deadwood stands. The lack of standing deadwood is problem for many forests in Central Europe in terms of biodiversity, and in their defence the park administrations attempted to remedy this by retaining the deadwood stands. However, the amount and location of these stands and the risks associated with such large amounts of fuel in the proximity of more natural woodlands means that this current retention approach is worth reassessment. Since the fire the Czech part of the park has started to thin out and remove stands of deadwood close to the village of Doubice.

The media also covered the efforts of a multinational and inter-sectoral group of professionals to combat the fire, though coverage was done at distance and the real story of what was achieved, and the conditions involved could only be understood after the fire. Information about access in the park, for both vehicles and people on foot was not readily available, resulting in firefighters using tourist maps to navigate, and several local guides coming out of retirement to make up for the deficit in this knowledge. In some places trails and indeed some road access was restricted by fallen logs, causing delays in getting to the fire front.

Communication, even between responders and agencies from the same country, was fraught with problems regarding connectivity in the hilly landscapes and deep gorges, where sunlight can barely reach, let alone a mobile phone signal. Standing deadwood, already weakened and fragile, became extremely dangerous when ablaze, creating serious risks for the firefighters. In many places this danger remains, leading to access to some areas being controlled. This restriction of access is not popular with either visitors or locals, although a completely understandable measure in terms of protecting both the vulnerable soils and the visitors themselves.

The fact that the fire was in two national parks on the border of Czechia and Germany meant that it was featured in the media, and as tragic as the fire was for nature and people who depend upon it for their livelihoods, there is now an increasing realisation that forest fires in Central Europe are a contemporary danger that must be addressed. This needs to be accomplished at a policy, management and community level. Firefighters and other emergency responders are now able to reassess how they deal with large forest fires and where techniques, equipment and preparation need to be improved. Science, whilst already awake to the increasing threat of wildfires in Central Europe, now has a living laboratory where the causes and effects of wildfire on Central European ecosystems can be better understood.

8 Penteli Attica Fire (Greece)

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8.1 General Description

In 2022, Greece experienced a unique pattern of wildfire incidents, both in timing and number. From January 1st to October 31st, 9 245 wildfires were recorded, marking a 3.1% increase from the 15-year average of 8 958 fires (2007-2021). Notably, a significant majority of these fires, numbering 5 922, occurred during the peak fire season, from May to October. The total land area affected by these wildfires in 2022 was 23 838 ha, with 22 322 ha burned during the May-October period. This represents a notable decline of 52.42% in burned acreage compared to the historical average of 50 097 ha for 2007-2021. Of the total burned area, 4 288 ha were forested lands, a reduction from the historical average of 9 532 ha.

The Joint Research Centre's first report of 2022 (JRC, 2022) contrasted this year with 2021, noting a return to average levels of fire activity. A total of 23 942 ha was burned in 230 fires, with 9 778 ha affecting Natura 2000 sites, constituting approximately 41% of the total burned area and 0.014% of Greece's total Natura 2000 area. In Figure 96b is provided the distribution of the mapped burnt area by land. Interestingly, a significant number of fires, approximately 3 323, occurred outside the typical fire season. The 2022 wildfire season posed considerable challenges, with the seven most significant fires, mainly in July, accounting for a large portion of the total burned area.

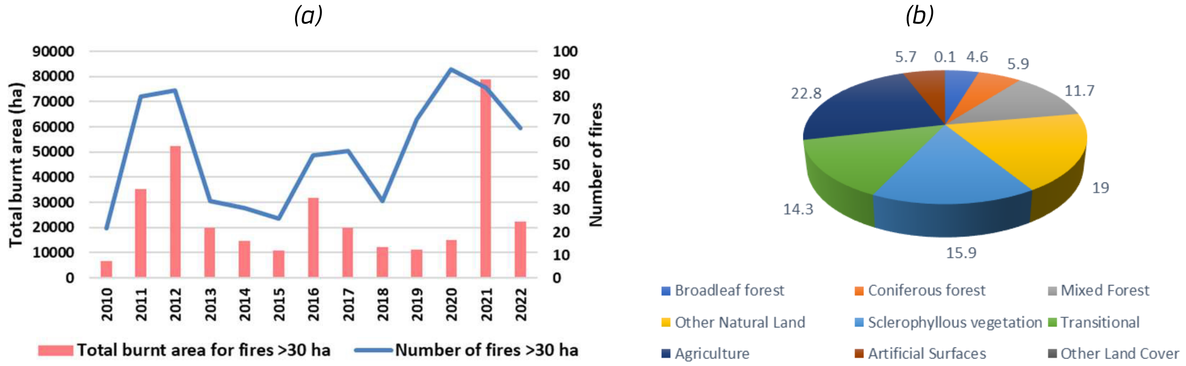

Figure 96. Annual mapped burnt area of fires >=30 ha in Greece (a) and distribution of % total area burnt by land cover types in 2022 (b).
. Source: JRC 2022: Advance report on Forest Fires in Europe, Middle East and North Africa 2022, JRC133215

In terms of regional distribution, the following map (Figure 97) illustrates the burned areas across Greece's thirteen administrative regions. The Dadia Forest Fire in the Natura 2000 network area was one of the most significant incidents, consuming 4 604 ha of a total 42 800 ha area. The fire season also saw the challenging Penteli Fire, covering 2 782 ha and rapidly shifting its perimeter through residential and forested areas. July emerged as a particularly tough month, with the seven largest fires consuming 13 865 ha, which constituted 62% of 2022's total burned area.

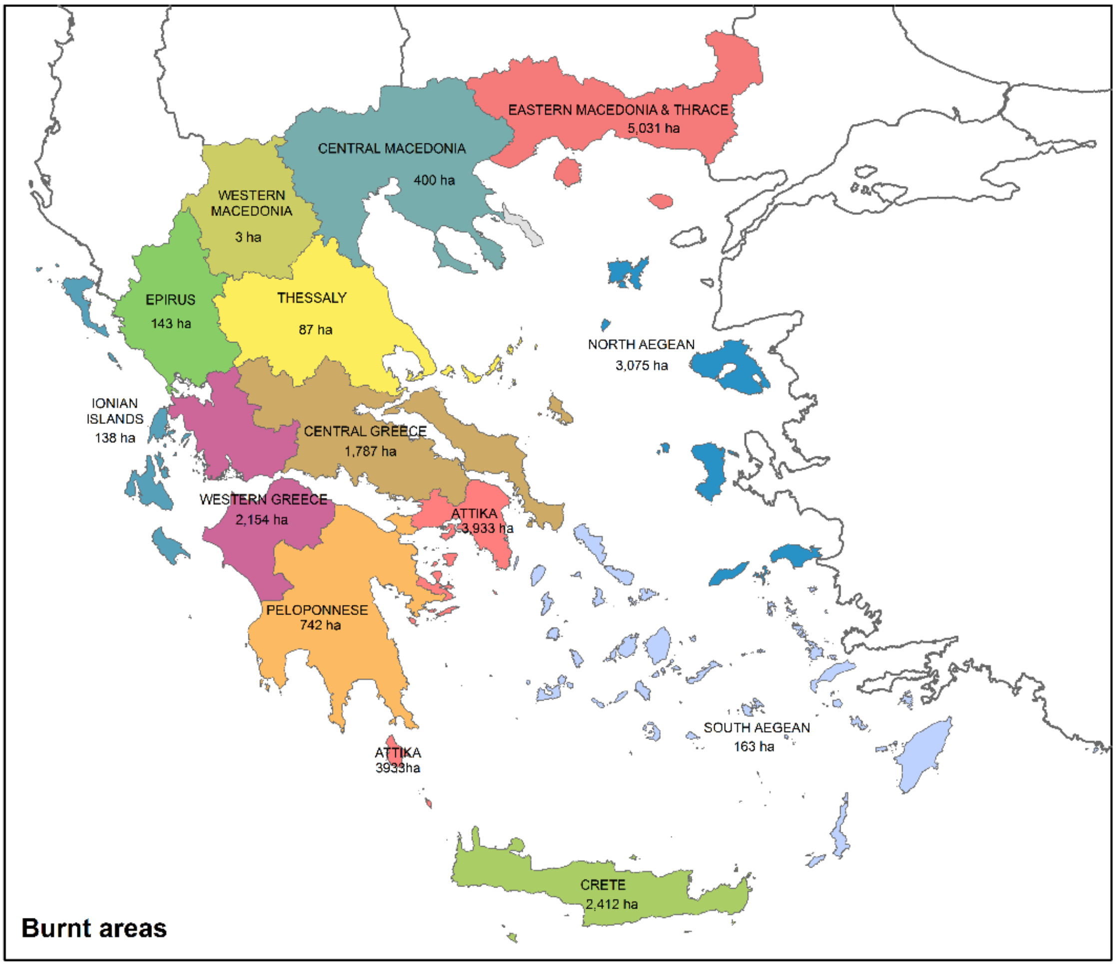

Figure 97. Total number of burnt areas (ha) for each of the country's thirteen region of Greece.
Source: EFFIS

Regarding aerial firefighting resources, Greece deployed an aerial fleet of 83 assets, including 48 fixed-wing aircraft and 35 helicopters. The fleet was a mix of 44 leased and 39 national units. This fleet executed 2 925 air sorties, totalling 7 667 flight hours, with 1 193 hours dedicated to preventive surveillance.

The season's most impactful fires included those in Dadia, Evros (4 604 ha), and Penteli, Attica (2 781 ha), among others. These fires underscored the critical role of proactive measures and the importance of a coordinated response in wildfire management. The Ministry of Climate Crisis and Civil Protection's activation of the "112" service 43 times for forest fire warnings, coupled with preventive evacuations and increased volunteer firefighter numbers, were key strategies in this response.

Overall, the 2022 wildfire season in Greece underscores the necessity for robust fire management strategies, enhanced preventive measures, and coordinated efforts to protect both natural and human resources against wildfire threats.

According to the Fire Service Department, the Penteli Attica Fire, due to the proximity to residential areas, sensitive structures, hospitals, industries, propane and natural gas facilities, was an extremely difficult fire to manage, as very strong winds were blowing in the area. The fire burned mostly through shrub vegetation, pine trees and parts of agricultural land, leading also to impacts on the environment. Therefore, in this report, this fire was selected for further analysis.

More specifically, a forest fire broke out on the slopes of Mount Penteli, closed to Ntaou Penteli area, in the northern suburbs of Athens on July 19th (17:19). Due to strong north winds (13.9-20.7 m/s), the fire moved southwards to lower altitudes and spread to the surrounding areas towards Anthousa, Ntrafi, Dioni and Pallini towns, as well as Penteli residential area (Palaia and Nea Penteli) to the west. As the fire was moving southwards, residents of those towns were receiving notification to their cell phones (through the activation of 112 emergency number) to evacuate the affected areas, as the flames approached their houses and as the fire fighting forces were operating in the area with land and aerial units (example of these messages in Figure 98). The fire was extinguished on July 20th.

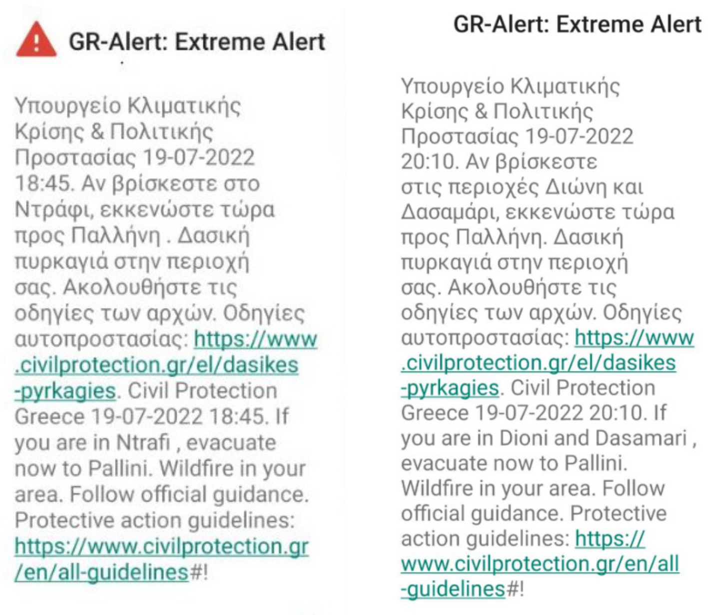

Figure 98. Examples of the received notifications to geotargeted population to evacuate as the fire approaches to residential areas.
Source: https://www.cnn.gr/ellada/story/321335/fotia-penteli-neo-minyma-ekkenosis-gia-dioni-dasamari-ekkenoste-tora-pros-pallini

8.2 Characterization of the affected area

Mount Pentelicus or Penteli is a mountain in Attica, Greece, situated northeast of Athens and southwest of Marathon. Its highest point is the Peak Pyrgari, with an elevation of 1 109 m. This mountain is covered in large part with forest (about 60 or 70%). Habitations surround the mountain, especially in Vrilissia, Penteli, Kifisia, Ekali, Dionysos and north of Pallini-Gerakas, housing around 169 862 inhabitants according to Census 2021 (https://elstat-outsourcers.statistics.gr/Census2022_GR.pdf).

The latest study of the World Wide Fund for Nature (WWF) (Tzamtzis *et al*., 2022) for the area affected by this fire event indicates::

- *Pinus halepensis* forests were burned;
- Fire spread in sparsely vegetated areas, that concern rocky places and slopes, where a little vegetation cover of grasses and small shrubs dominates;
- There are no burned forest ecosystems not adapted to fire;
- Most of the burnt area is double-burnt stands (reburned within the last 20 years and specifically in 2009), which have either *Pinus halepensis* forests or sparsely vegetated areas;
- There are a few burnt stands of *Pinus halepensis* some of which are double burnt, on deep slopes between 50-100%, in which natural regeneration is difficult. There is a notable increase in the number of halepensis pine stands that have experienced double burning and are situated on slopes with a gradient below 50%.

Unfortunately, in Penteli several fire events have occurred in the last 30 years. The most important event, which is extensively described in the study of Xanthopoulos (2002), involved the severe fire in early July 1995 (July 21st to 24th, 1995) that had severe impacts on the mountain forest – total burned area reached 6 200 ha; about 105 buildings of various types were heavily damaged or fully destroyed. Xanthopoulos (2002) indicated that the smoke emissions were tremendous, nearly covering the entire northeastern area of Athens. The blaze lasted about five days. It burnt three quarters of the Mount Pentelicus, and was the worst wildfire registered in Athens and Greece in the 20th century. Some of the buildings were high quality houses built with reinforced concrete frame, clay-tile roofs etc., whereas most of them were out-houses, mobile homes, small temporary buildings, farm-barns etc. made of flammable materials. Fortunately, and despite the adverse conditions, there were no fatalities registered.

Several other fires occurred from1998 (burnt area exceeded 7 500 ha and 1 fatality) to 2018 (Neos Voutzas) by destroying the forest that had remained on the mountain of Penteli after the fire of 1995, and reburned most of the previously burned area reducing the capability for natural regeneration of pine due to lack of seed (Xanthopoulos, 2002). In the following years, housing development occurred in the eastern part of the mountain, resulting in the depletion of its remaining natural elements. The streets in this area are designed in a grid and circular pattern. The northern half remains heavily forested.

8.3 Fire conditions

8.3.1 Fire Danger

The fire season report (May 1st –October 31st) which was presented by the Minister of Civil Protection (https://www.kathimerini.gr/society/562144600/5-922-pyrkagies-antimetopistikan-to-22/) in November, citing statistics for high-risk days of meteorological conditions (a combination of high temperatures and wind), mentioned 20 high risk days in July and 12 days in August. It should be noted that Etesian northerly winds (also known as Meltemi wind) are prevailing during summer in the eastern part of Greece and usually playing an important role in fire behaviour. They result from a high-pressure system over the Balkans area and a relatively low-pressure system over Turkey, affecting mainly the Aegean Sea and its islands.

The wildfire danger conditions for July 19th and July 20th were analysed using the fire behaviour indexes of the Canadian Fire Weather Index System (ISI – Initial Spread Index, Buildup Index – BUI, FWI – Fire Weather Index), as well as the moisture code sub-indexes, provided by EFFIS and depicted in Table 16. These indices can be interpreted on a danger scale where an increase in the index corresponds to an increase in fire danger based on the classification included in the following Table 16 associated with the colour's legend.

Table 15. Fire Danger classes for the FWI and its sub-components by EFFIS

Fire Danger Classes	FWI	FFMC	DMC	DC	ISI	BUI
Low	<11.2	< 86.1	< 27.9	< 334.1	< 5.0	< 40.7
Moderate	11.2 - 21.3	86.1 - 89.2	27.9 - 53.1	334.1 - 450.6	5.0 - 7.5	40.7 - 73.3
High	21.3 - 38.0	89.2 - 93.0	53.1 - 140.7	450.6 - 749.4	7.5 - 13.4	73.3 - 178.1
Very High	38.0 - 50	>=93.0	>=140.7	>=749.4	>=13.4	>=178.1
Extreme	>= 50					

Table 16. Fire Danger behaviour indicators.

Fire Weather Index (FWI)	67.7 – Extreme danger	Low Danger Moderate Danger High Danger Very High Danger Extreme Danger Very Extreme Danger
Fine Fuel Moisture Code (FFMC)	92 – High danger	Very Low Danger Low Danger Moderate Danger High Danger Very High Danger Extreme Danger
Duff Moisture Code (DMC)	94.8 - High danger	
Drought Code (DC)	535.3 High danger	
Initial Spread Index (ISI)	19.9 – Very High danger	
Build Up Index (BUI)	131.4 – High danger	
Anomaly	1	
Ranking	92.4	

Source: EFFIS application, https://effis.jrc.ec.europa.eu/apps/effis_current_situation/index.html

The following graphs in Figure 99, downloaded by EFFIS, provided the fire behaviour indices evolution, two days before the fire-starting date, and during the period that the fire broke out. The indexes assumed extremely high values, as well as the day before of the fire-starting date by yielding extremely high FWI values between 76 and 68. This magnitude of FWI means that any eventual wildfire would be expected to have an exceptional intensity with extreme difficulty of control.

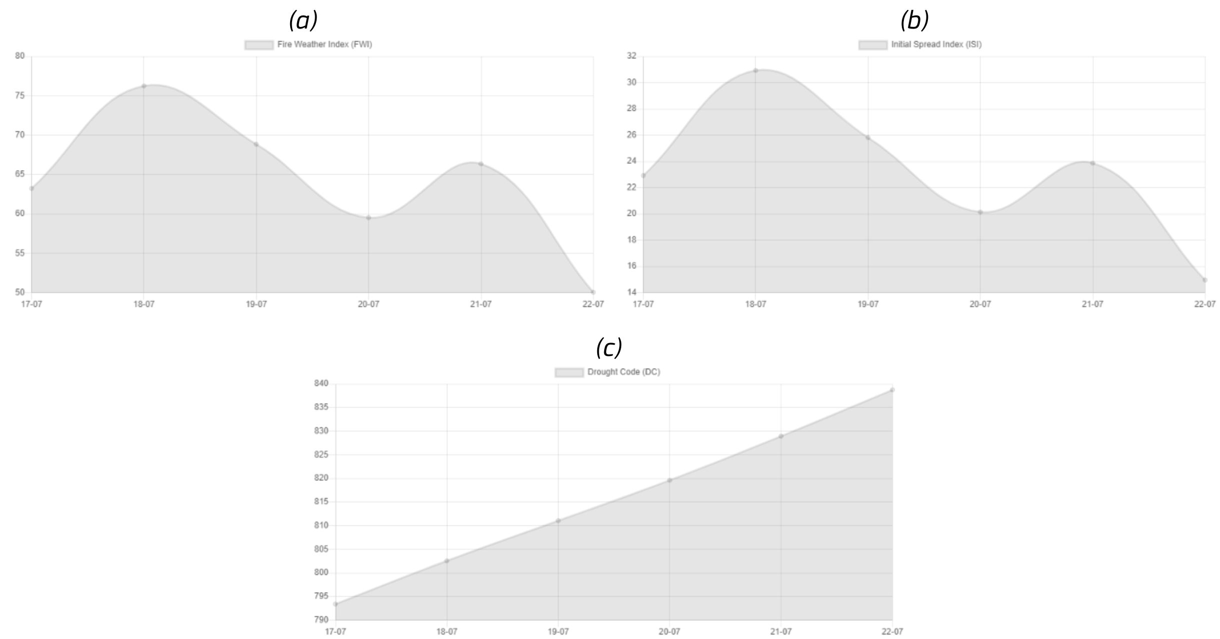

Figure 99. Daily evolution of a) Fire weather index, b) initial spread index an c) drought code provided by EFFIS before and after the fire occurred in the burnt area of Penteli.
Source: EFFIS application, https://effis.jrc.ec.europa.eu/apps/effis_current_situation/index.html

In addition, in Figure 100 is pointing out spatially the total burnt area (in green color) of Penteli Attica fire by MODIS/SENTINEL2 (supervised) and MODIS & VIIRS NRT, in the area of Mount Penteli along with the FWI background in the day (extreme value) that the fire has started.

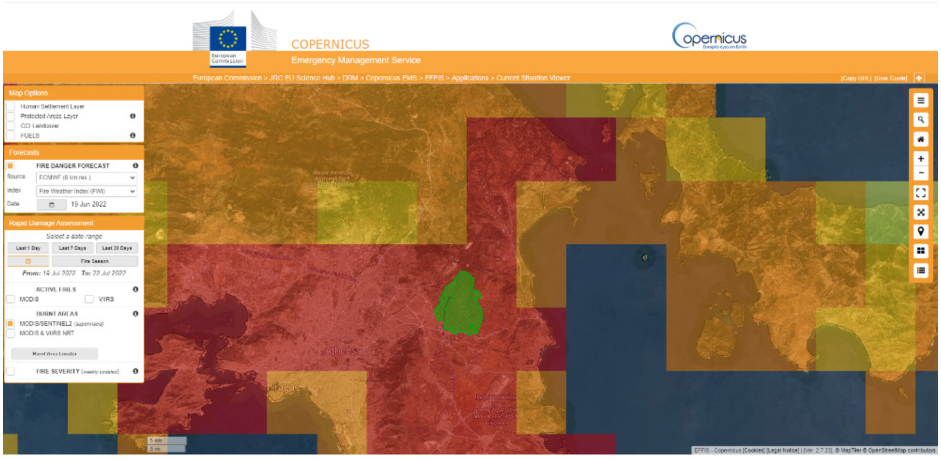

Figure 100. Spatial depiction of FWI index and Total burnt area by MODIS/SENTINEL2 (supervised) and MODIS & VIIRS NRT in the affected area (in green) of Mount Penteli.
(Source: https://effis.jrc.ec.europa.eu/apps/effis_current_situation/)

Moreover, according to the Fire Risk Prediction Map (Figure 101) for Tuesday July 19th, provided by the General Secretariat of Civil Protection of the Ministry of Climate Crisis & Civil Protection (https://civilprotection.gov.gr/), a very high risk of fire (category number 4 in the map, orange colour) was predicted for the whole Attica Region. This map was issued on July 18th at 12:30.

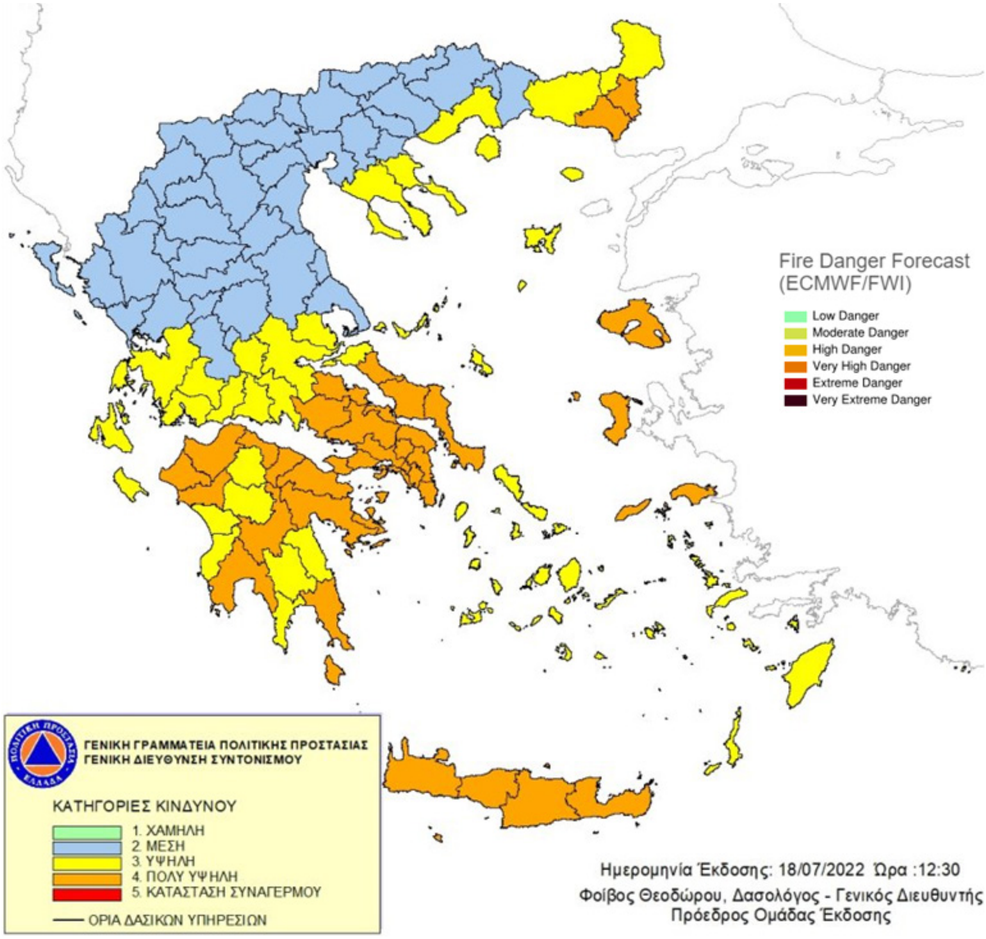

Figure 101. Fire Risk Prediction Map for Tuesday, July 19th. The legend on the bottom left corner classifies by colour the fire risk in 5 categories, as (1.low, 2. moderate, 3. high, 4. very high and 5. alert situation). The black lines show the boundaries of local forest services).

Source: https://civilprotection.gov.gr/arxeio-imerision-xartwn

8.3.2 Resources allocation

Overall, during the fire season, 2 925 aerial vehicle sorties were made, and a total of 7 667 flight hours were carried out, of which 1 193 hours were for surveillance in the framework of strengthening prevention. In what concerns the actions towards the Penteli Attica fire, the elements provided by the Fire Service Department (https://www.fireservice.gr/el_GR/synola-dedomenon), reported that this wildfire event had allocated in total 2 485 firefighters, assisted by 28 ground teams and several volunteers, as well as by 120 fire engines, five CL-425 water-dropping planes, three CL-215 aircraft and thirteen helicopters.

8.4 Fire management at the WUI

The burnt area provided by MODIS is estimated of 2 836 ha as depicted in Table 17 which also includes the percentage of the estimated affected land cover.

Table 17. MODIS burnt area detailed layer information for Penteli Attica Fire.

Start Date	July 19th
Last Update	July 20th
Country	Greece
Province (NUTS3)	Regional Unit of North Athens (Northern Sector of Attica Prefecture)
Location	Local Municipality of Penteli
Total Burnt Area (ha)	2 836
Forest: broadLeaves (%)	0
Forest: coniferous (%)	0
Forest: mixed (%)	0
Sclerophyllous Vegetation (%)	13.8
Transitional Woodland-shrubland (%)	35.5
Other Natural Areas (%)	1.6
Agricultural Areas (%)	3.4
Artificial Surfaces (%)	45.7
Natura 2K (%)	0
Other Land Cover (%)	0

Source: EFFIS application, https://effis.jrc.ec.europa.eu/apps/effis_current_situation/index.html

In these two days, the emergency Copernicus system (https://emergency.copernicus.eu/mapping/list-of-components/EMSR598) and EMS Mapping products were used mainly by local authorities (Forest Service, Region of Western Greece, municipalities) for recovery and restoration planning of the affected area. Furthermore, local authorities are expected to use the mapping products for future flood protection measures, the Greek Agricultural Insurance Organization is expected to use the maps for damage assessment of farming activities, the Ministry of Infrastructure and Transport is expected to use the maps for damage assessment in roads, houses and buildings, among other infrastructures.

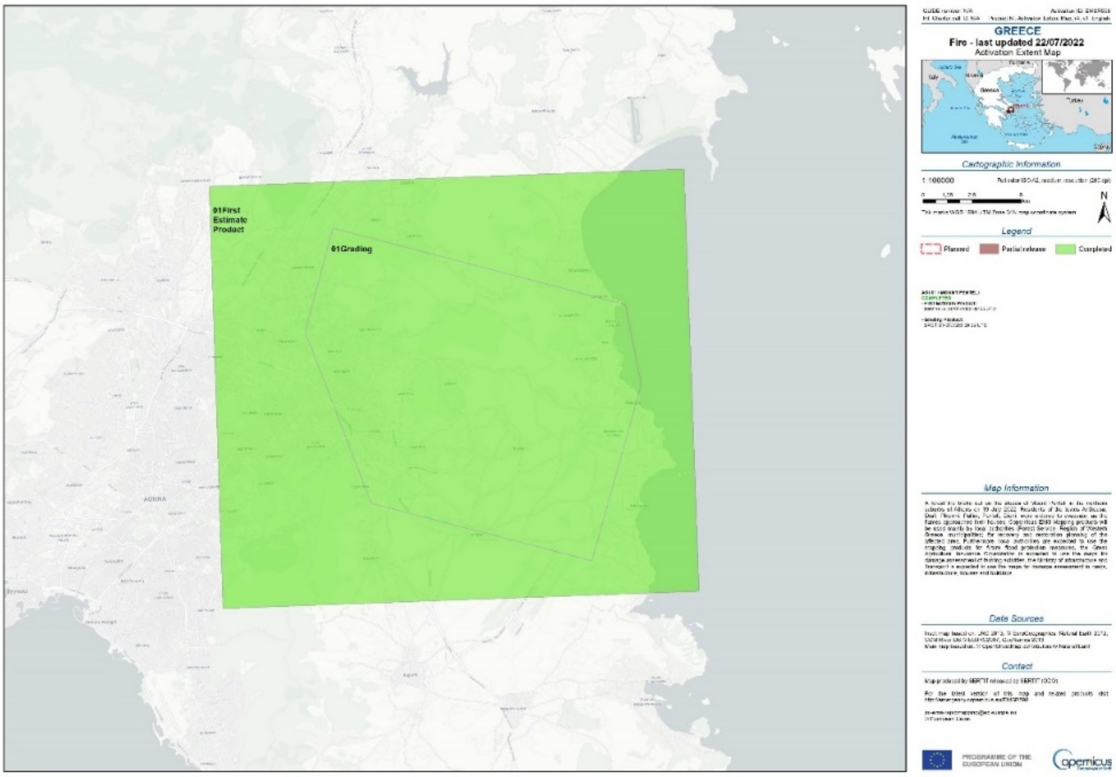

Figure 102. First estimate product from the activation of emergency Copernicus focusing on Mount Penteli.
Source: EFFIS

The following two maps in Figure 103 and Figure 104 show the fire delineation in the area of Mount Penteli and presented the situation on July 21st at 12:06 after the fire event. The thematic layer has been derived from post-event satellite image by means of visual interpretation. The scale analysis is 1:10 000. The second map is focused on a sub-area of the previous map to depict the potential damage in residential areas in more detail.

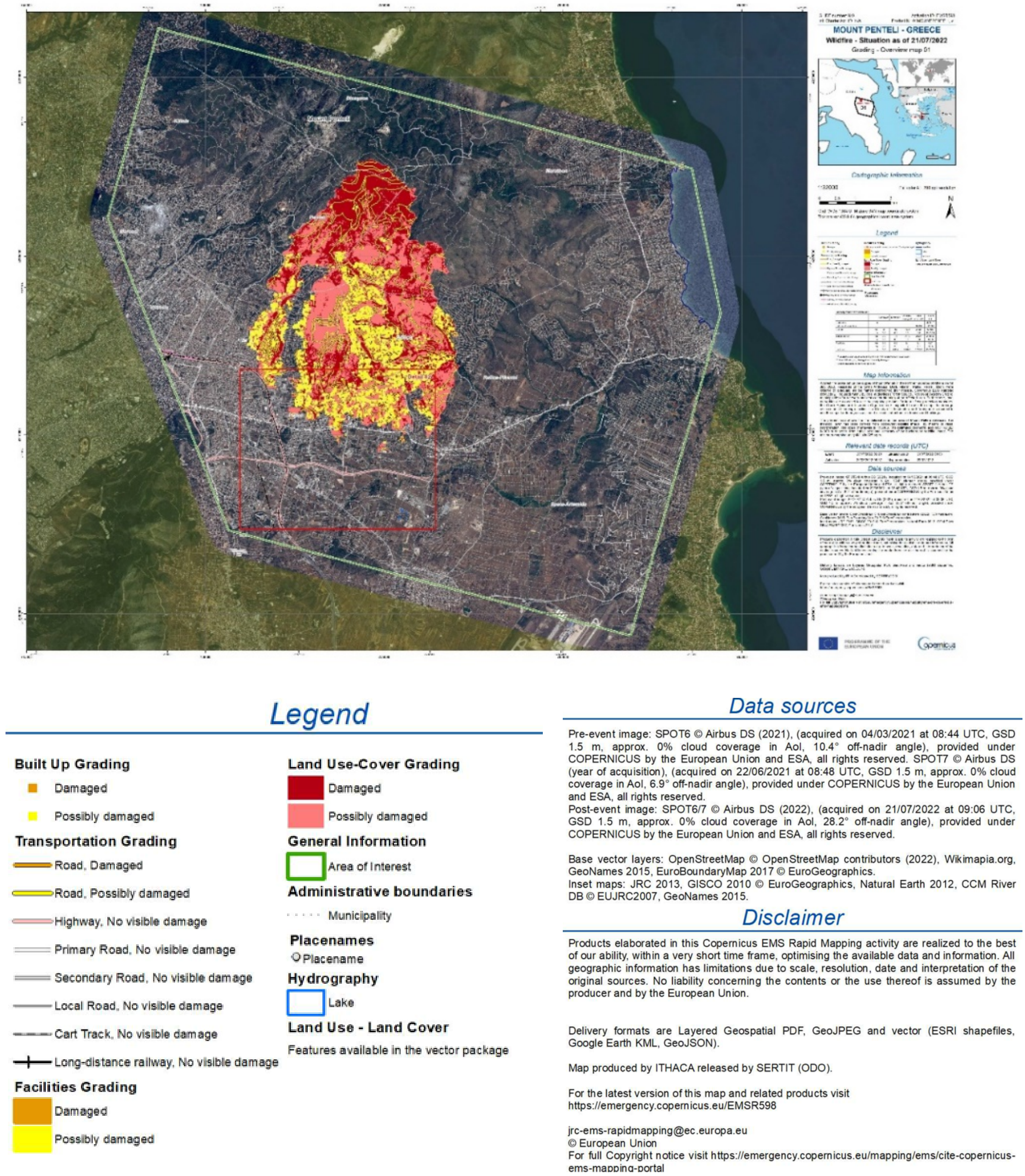

Figure 103. Fire delimitation in the area of Mount Penteli provided under Copernicus by the European Union and ESA *(Source:EFFIS)*

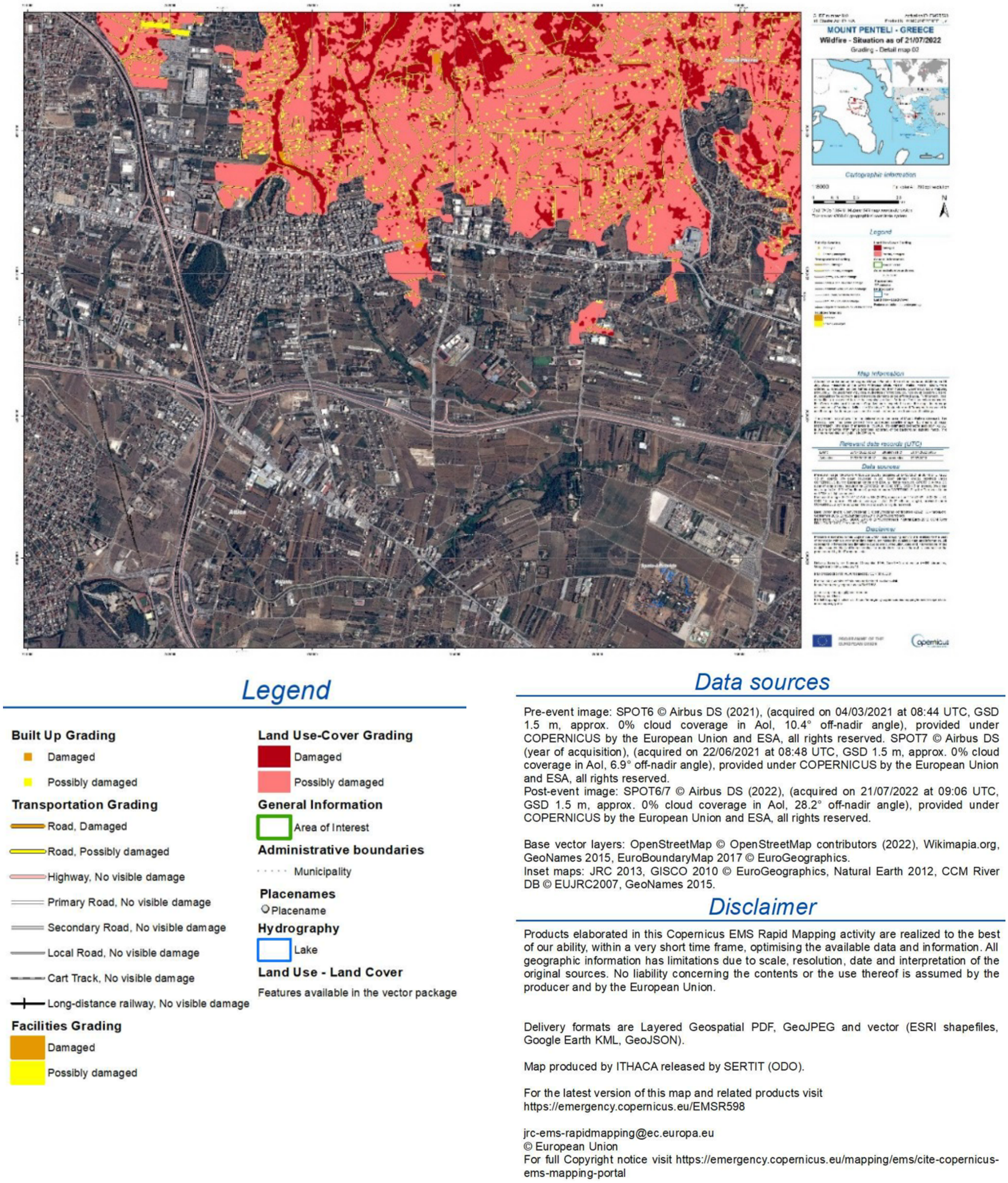

Figure 104. Fire delination in the area of Mount Penteli provided under Copernicus by the European Union and ESA.
(Source: EFFIS)

The wildfire also severely scorched 54 houses, five businesses, seventeen warehouses and one religious structure, according to the Ministry of Infrastructure and Transport (https://www.yme.gr/2013-01-31-06-37-23/2013-01-31-07-00-49/item/10388-aftopsies-apo-mixanikoys-tou-ypourgeiou-ypodomon-kai-metaforon-se-ktiria-ton-pligenton-dimon-pentelis-pallinis-pallini-gerakas-anthoysa-kai-rafinas-pikermiou-logo-tis-pyrkagias-tis-19is-iouliou). An 84-year-old man, from Penteli, decided to end his life after seeing his house destroyed by the fire (Lekkas *et al.*, 2022). Thirty people were taken to the hospital, three of whom with skin burns. Most of the people suffered respiratory problems and minor injuries, including three firefighters from the Pallini, Gerakas, Anthousa and Penteli regions (https://www.euronews.com/video/2022/07/20/wildfire-rages-in-athenss-northeastern-suburbs-for-a-second-day). The two following photos exemplify how this fire impacted ethe residential areas.

(a)

(b)

Figure 105. Houses (a) and a car (b) are engulfed by flames during the Penteli Attica Fire – in Pallini, near Athens, Greece July 20th. REUTERS/Costas Baltas.
Source: Reuters

8.5 Conclusions and lessons learned

- The Penteli Attica Fire of July 19th was one of the most severe and dangerous fire events because of its proximity to the residential network, with significant impacts on the environment, vegetation, infrastructures and one indirect fatal victim.
- Due to strong north winds, the fire front moved southwards and later westwards with high velocity in low-vegetation areas to the towns of Anthousa, Gerakas, Pallini, Dioni and Palaia Penteli.
- Difficulties were observed on fire suppression because of the geomorphological conditions of the area and the strong north winds especially during the night.
- Increased risk of landslides and flood risk are expected due the geomorphological characteristics of the burnt area along with runoff and erosion conditions, which will worsen in the south and southeast slopes of Penteli Mt (Lekkas *et al.*, 2022). This risk must be taken into consideration, since it can be reinforced, due to the already burdened landscape affected by past fires during the last 25 years in the same area.
- Reinforcement of psychological support to those who lost the house, so avoiding dramatic situations that can lead to suicides.
- Geotargeted citizen information: The timely information of citizens about the risk they face due to an upcoming forest fire cannot, in any case, be solely based on the sending of emergency messages 112, but on a series of measures and actions that will have been defined in advance in the particular plans of the Municipality and the Region, to be launched, if there are reasons, by the competent institution at the local level.
- It should be emphasized that the measure of the total organized preventive evacuation of citizens can be applied only when the time of approach of an upcoming fire in a residential area provides scope for timely information and evacuation.
- Education for increased awareness and preparedness of populations living in fire-prone regions is very important as part of the prevention activities.

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9 Dadia National Park-Evros Region Fire (Greece)

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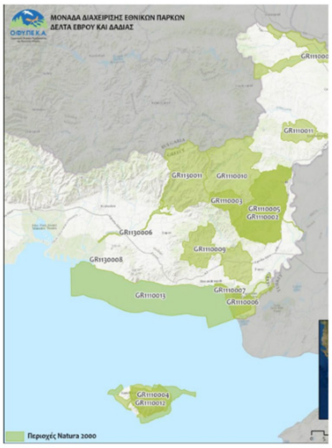


Copernicus Sentinel-2 image (ESA)

9.1 General description

In July 2022, a severe wildfire erupted in the northeastern section of Dadia National Park, situated within Greece's largest Natura2000 site, which also harbours a significant colony of black vultures. This incident marked one of the park's most devastating fires, particularly alarming due to the area's ecological sensitivity and history of wildfires.

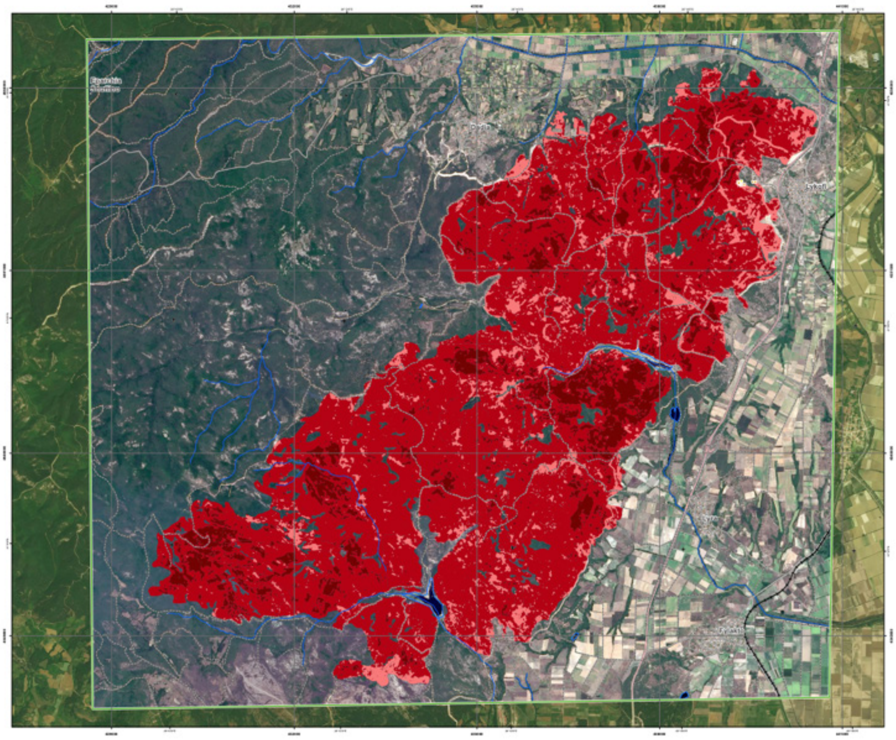


Figure 106 Copernicus EMS Mapping product depicting Dadia's 2022 fire extend and damage.
Data source: AUTH, NOFFi | National Observatory of Forest Fires.

The incident started at approximately 14:30 pm local time near the Lyra Dam, located within the Evros and Dadia Delta National Parks Management Unit. Between July 21st and 27th the fire burned approximately 4 600 ha of the park's extensive 42 800 ha area within the Natura network. According to data from the Natural Environment & Climate Change Agency (N.E.C.C.A./OFYPECA), only half (2 219 ha) of the total affected area (4 541 ha) has been completely burned. The type of destruction, combined with the absence of human activity in the forest, raises hopes that nature will recover quickly.

Initial investigations point to a lightning strike as the likely cause of ignition. This wildfire posed a critical threat to the park's biodiversity, particularly affecting its population of over 200 endangered black vultures. Since 2016, black vultures in the park have been fitted with tracking transmitters for ongoing monitoring. This monitoring has provided valuable data, showing that these vultures have started to resettle in park areas, hopefully not affected by the fire.

During the wildfire, the behaviour of the fire was quite unusual and extreme in certain places. In some areas, the pine forest was completely burned, while in others, the fire moved along the ground burning only low vegetation, leaving the trees mostly unaffected. In some of these cases, the thick fuel bed on the ground, along with its high bulk density, caused a prolonged and creeping burn that lasted for days, leading to problems due to rekindling caused by changes in the wind speed and direction. The fire's paths in the National Park were serpentine, creating a mosaic of burned and unburned areas.

Fortunately, the larger of the two cores of the national park (zone A1) was not affected by the recent fire and remains intact. However, the second core of the park (zone A2) has suffered significant damage, with almost half of the southern region burned. The total burnt area is less than 10% of the national park. Despite the damage, there are still some patches of unburned vegetation that are expected to aid in the natural recovery of the area.

The Hellenic Fire Brigade, EMAK (Hellenic Fire Service's Special Disaster Response Unit), Forest Service, Forest cooperatives, locals, villagers, volunteers, conservationists, and other involved units, both aerial and ground-based, made a concerted effort to contain the fire. They all joined forces to save the threatened villages and the core of the National Park. Their hard work was instrumental in achieving this goal.

9.2 Incident Progression

The fire broke out on July 21st at around 14:30 pm local time, near the Lyra Dam in the Evros region. Within a short time, a secondary fire front emerged south of the Lyra Dam, which required a reallocation of firefighting resources. This development made the situation more complex and raised concerns about the potential magnitude of the fire. Despite the combined efforts of multiple agencies, including the Fire Brigade, forest services, military units, civil protection of the Region, the municipality of Soufli, and local volunteers, the fire continued to spread. Initial attempts to contain the fire were unsuccessful, and the perimeter extended several kilometres.

The figure below shows the active hotspots recorded by MODIS/VIIRS during the fire duration.

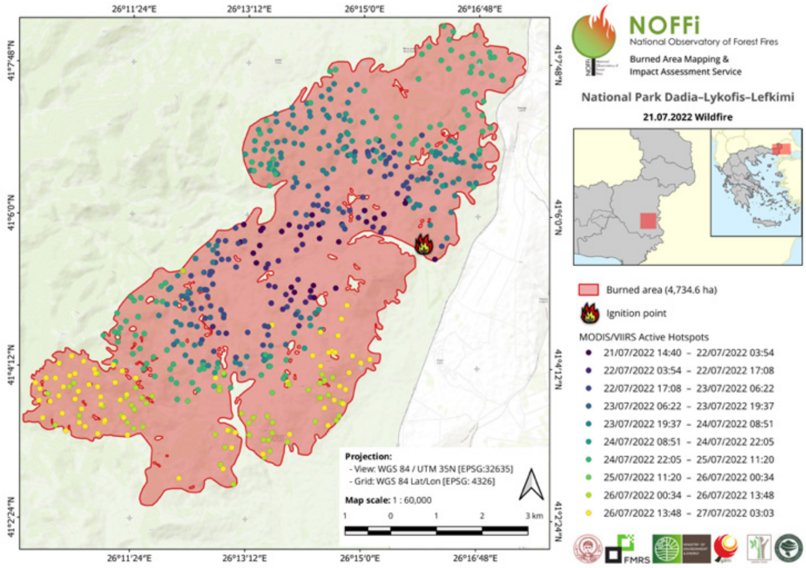


Figure 107. Dadia fire active hotspots – July 21st to 27th.
Source: MODIS/VIIRSA: NOFFi | National Observatory of Forest Fires.

The Hellenic Fire Service acted promptly to the Dadia wildfire by deploying a significant number of resources. The operation involved 102 firefighters, 4 groups of ground forces, 29 vehicles, 6 water-bombing aircraft, 5 helicopters, and municipal water tanks. Despite this strategic deployment, the wildfire could not be adequately suppressed and managed.

The progression of the Dadia fire over seven days is shown and analysed next. The fire initially spread towards the southwest, in the direction of the prevailing winds that blew from the north and northeast (ePADAP). However, it is essential to note that the fire's path changed during the seven days due to alterations in wind direction and speed. Figure 108 provides a series of daily fire propagation patterns, accompanied by a wind rose diagram for each day, which depicts these changes.

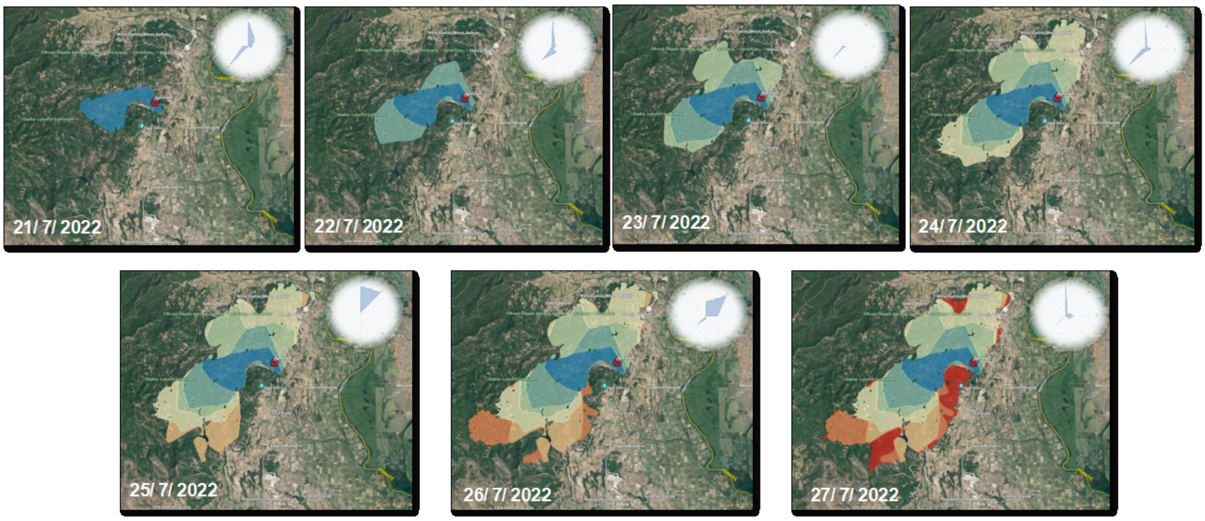
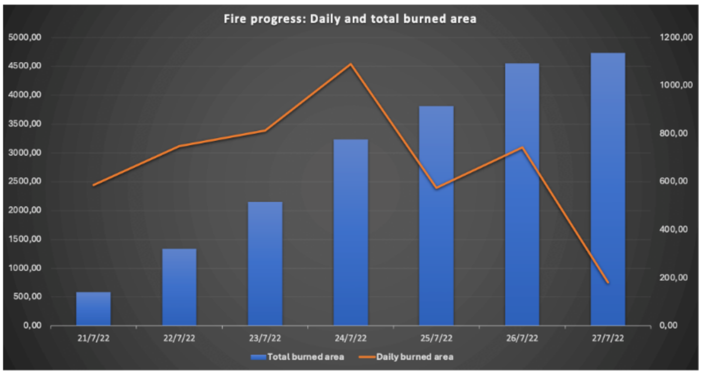


Figure 108. Daily progress of the Dadia fire – July 21st to 27th.
Source: AUTH, NOFFi | National Observatory of Forest Fires.

Presented below are the daily and total burned areas between July 21st and July 27th, in both graphical and tabular formats.



	Total burned area (ha)	Daily burned area (ha)
21/7/22	586,74	586,74
22/7/22	1333,62	746,88
23/7/22	2147,12	813,50
24/7/22	3236,00	1088,88
25/7/22	3809,89	573,89
26/7/22	4553,11	743,22
27/7/22	4734,59	181,48

Figure 109 Daily burned areas in Dadia fire – July 21st to 27th.
Data source: AUTH, NOFFi | National Observatory of Forest Fires.

Analyzing wildfire data from Dadia National Park provides insights on daily fire behaviour and growth (ePADAP).

Day 1: July 21st

- Fire growth: 586.74 ha burned.
- Meteorological conditions: Average temperature of 29.4°C and peak wind speed of 20.5 km/h from 240°.
- Impact: The rapid spread of the fire on the first day was likely due to high temperatures and strong winds from the north and south-southwest, which made firefighting challenging due to increased fire intensity and spread rate.

Day 2: July 22nd

- Fire growth: 160.14 ha more than the first day burned (total burn for the day 746.88 ha).
- Meteorological conditions: Slightly cooler with average temperatures around 30°C, wind speeds up to 16.6 km/h, winds shifting from south-southwest to west-southwest (240° to 250°).
- Impact: Despite a slight decrease in temperature, the persistent strong winds caused a significant increase in the burned area due to abundant fuel.

Day 3: July 23rd

- Fire growth: 66.62 ha more than the previous (second) day burned (total burn for the day 813.50 ha).
- Meteorological conditions: Temperatures peaked at 34.6°C with 18.4 km/h winds from the southwest (240°).
- Impact: The fire's behaviour was likely worsened by high temperatures and gusty winds, causing it to spread further and making containment more challenging.

Day 4: July 24th

- Fire growth: Significant increase, with 275.38 ha burned more than the previous day (total burn for the day 1 088.88 ha).
- Meteorological conditions: Temperatures reached 34°C with variable wind speeds up to 20.5 km/h.
- Impact: This day saw the largest daily increase in burned area, possibly due to shifting winds that exposed new fuel and flanks of the fire to combustion.

Day 5: July 25 th

- Fire growth: The fire's daily spread was reduced by almost 50% from the previous day, with a total burn of 573.89 ha for Day 5.
- Meteorological conditions: Slightly cooler temperatures around 30°C with wind speeds up to 18.4 km/h from varying directions.
- Impact: The slight improvement in weather conditions enabled firefighters to slow the rate of spread.

Day 6: July 26 th

- Fire growth: There has been a 169.33 ha increase in the daily burned area compared to the previous day, bringing the cumulative total from Day 1 to 4 553.11 ha.
- Meteorological conditions: Temperatures peaked at 33°C with south-southwest winds at speeds up to 22.3 km/h.
- Impact: The wind's persistence and strength, in combination with high temperatures, likely caused the fire to continue spreading, especially in areas with a large amount of fuel.

Day 7: July 27 th

- Fire growth: A decrease in wind speed and change in direction reduced fire spread to only 181.48 ha burned while extinguishing active fire fronts.
- Meteorological conditions: High temperatures reached 35°C with 20.5 km/h south-westerly winds.
- Impact: Despite the hot weather, the reduced wind speed may have contributed to a smaller increase in burned areas. This could be due to effective firefighting efforts or the fire reaching natural barriers or areas with less fuel.

The most challenging days for firefighting during the Dadia National Park wildfire were July 21st and July 24th. On July 21st, the fire spread rapidly due to high wind speeds and temperatures, making it difficult to control. The situation continued to worsen, and on July 24th, the fire burned the greatest area in a single day. This was made worse due to a significant change in wind direction, complicating containment efforts. Both days were marked by weather conditions that significantly influenced the fire's behaviour and posed substantial challenges to firefighting strategies.

9.3 Operational Challenges and Strategy Shifts

The firefighting efforts in Dadia National Park were compounded by the stringent restrictions imposed by the park's protected status, which posed additional challenges to the wildfire containment strategies. The National Park's designation meant that any firefighting measures had to be carefully balanced to prevent ecological damage, complicating efforts to manage the wildfire while preserving the habitat of species such as the rare black vulture.

The deep beds of forest fuel, typical of untouched natural reserves like Dadia, offered abundant combustible material, exacerbating the fire's intensity and persistence. The topography of the park, characterized by rugged terrain and dense underbrush, further hindered the effectiveness of traditional firefighting methods and equipment. To mitigate this, heavy earthmoving machinery was utilized to carve out firebreaks, a critical action in containing the spread of the fire from Zone A2 to the more sensitive Zone A1, where the core of the forest and the black vulture colonies reside.

The operation was a testament to coordination and collaboration, bringing together 320 firefighters, 13 hiker teams, 75 water trucks, 5 aircraft, and 9 helicopters. These forces worked in unison, supported by the robust assistance of the Hellenic National Defence General Staff (HNDGS) and the Regional Unit of Evros, which provided additional machinery and water trucks. The integral efforts of local foresters and volunteers were pivotal; their in-depth knowledge of the terrain allowed for strategic firebreak placements and fuel thinning while maintaining the ecological balance.

Despite the coordinated response, the unpredictable nature of wildfires, fuelled by dry conditions and variable winds, led to a prolonged engagement with the fire. The operation was further challenged by the need to ensure that the actions taken to control the fire were in line with the conservation goals of the national park, avoiding unnecessary harm to the protected environment. The firefighting forces were hampered by the direction and not so much the speed of the wind, as well as the area's topography.

The firefighting teams' commitment to safety and conservation was evident in their adaptive strategies, which were responsive to the dual imperatives of combating wildfire and preserving the park's natural heritage. They demonstrated an unwavering dedication to the task, even as they faced the continuous threat of re-ignition and the logistical complexities of managing an extended operation in a sensitive and protected landscape.

In conclusion, the firefighting operation in Dadia National Park highlighted the critical importance of integrating conservation principles into wildfire management. It underscored the effectiveness of collaborative efforts and the value of local expertise in protecting natural ecosystems and human interests. The experience from Dadia provides valuable insights for future wildfire management in protected areas, where the balance between immediate threat mitigation and long-term ecological preservation is of paramount concern.

9.3.1 Objectives and Defensive Measures

The Dadia National Park wildfire required a strategic approach that included both offensive and defensive measures due to the challenging conditions presented by the limited water supply from the Lyra Dam. Unfortunately, the dam's compromised capacity, caused by unresolved leakage issues, severely impacted water availability for firefighting. This underscored a critical gap in disaster preparedness and preventive measures. Despite prior knowledge of the dam's state and a previous incident at the neighbouring Provatonas Dam, the necessary maintenance to ensure water availability had not been prioritized. This demonstrated a shortfall in proactive management and risk assessment.

The operational strategy had two main protection goals. The first goal was to defend Dadia village, which was located dangerously close to the northern front of the fire. A comprehensive fire defence perimeter was quickly established, involving a coalition of regional fire units, military personnel and expert local forestry workers. Although residents were evacuated as a precaution, they played an active role in the firefighting efforts. This collaborative defence effort culminated on the evening of July 23rd, with the village emerging unscathed from the immediate threat.

A robust defence line for Zone A1, a biodiversity hotspot and sanctuary for numerous predatory species, was a top priority. A meticulous and labour-intensive operation established an extensive firebreak that spanned two kilometres, effectively linking the Airport area to the Lefkimi fire station. The tireless work of the crews over 24 hours resulted in a formidable barrier that halted the fire's progression toward this ecologically critical area. Preserving the predator nests was a significant victory in the face of the blaze, epitomizing the success of the defensive strategy.

The offensive measures, although hindered by the water shortage, were augmented by alternative firefighting techniques and adaptive strategies. These included deploying specialized ground and aerial equipment adapted to the rugged terrain and the need for precision in sensitive ecological zones.

The Dadia National Park firefighting operation serves as a case study of the complexities of wildfire management within protected areas, highlighting the delicate balance between aggressive fire suppression tactics and the imperatives of environmental conservation. The experience underscores the necessity for thorough preparedness, the integration of local expertise, and the importance of maintaining critical infrastructure to ensure readiness for emergency responses.

9.4 Characterization of the affected area

The Dadia-Lefkimi-Soufli Forest National Park (DNP), located in the Evros Prefecture of northeastern Greece, is ecologically significant nationally and internationally. Covering 42 800 ha, this park is part of the Eastern Rhodope Mountains' southeastern hills. The ecological diversity of DNP is remarkable, featuring a blend of pine and oak forests, open clearings, pastures and agricultural fields. This varied habitat supports a wide range of species, notably raptors, and is home to three of Europe's four vulture species, including the Balkans' only breeding population of Black Vultures. The park's extensive biodiversity includes around 360-400 plant species, 104 butterfly species, numerous amphibians, reptiles, mammals, and over 200 bird species, including 36 European raptor species.

The low-altitude Dadia forest, with its mix of xerophilous deciduous oaks and Calabrian pines, underwent significant changes in the 1970s. Recognized for its high conservation value, especially for birds of prey, the forest saw development projects, including infrastructure improvements and reforestation. Conservation concerns led to the designation of the Dadia Forest as a Special Protection Area or Nature Reserve in 1980, categorized into a buffer zone and two core protection zones, each with distinct management practices focused on protecting threatened bird species.

Since the 1970s, the Dadia-Lefkimi-Soufli forest complex has been managed for timber production, game and livestock support. However, stricter protection measures implemented since the 1980s, especially in the core zones, led to denser woodlands. In the early 1990s, a shift in management philosophy emphasized a balance between conservation and sustainable use, leading to the park's designation as a National Park and implementing a Forest Management Plan. A monitoring system established in 2000 ensures regular assessment of the forest's health and interventions.

The park administration is shared among several municipalities, with most of the land being public. Only cultivated fields are privately owned. The Forest Service, particularly its Soufli Office, manages the forest. The park was initially designated as a Nature Reserve in 1980, covering about 42 400 ha. By 2006, it had expanded to 42 800 ha and was officially designated as the Dadia-Lefkimi-Soufli Forest National Park (Natura 2000, GR1110005). The park has a zoning structure established before its official designation as a national park. The zoning structure includes a strict protection zone of 7 800 ha and a buffer zone subdivided for various uses such as forest exploitation, agriculture and grazing. The figure below shows the current zones of the Dadia National Park with the fire perimeter overlay for each day between July 21st and July 27th.

(a) *(b)*

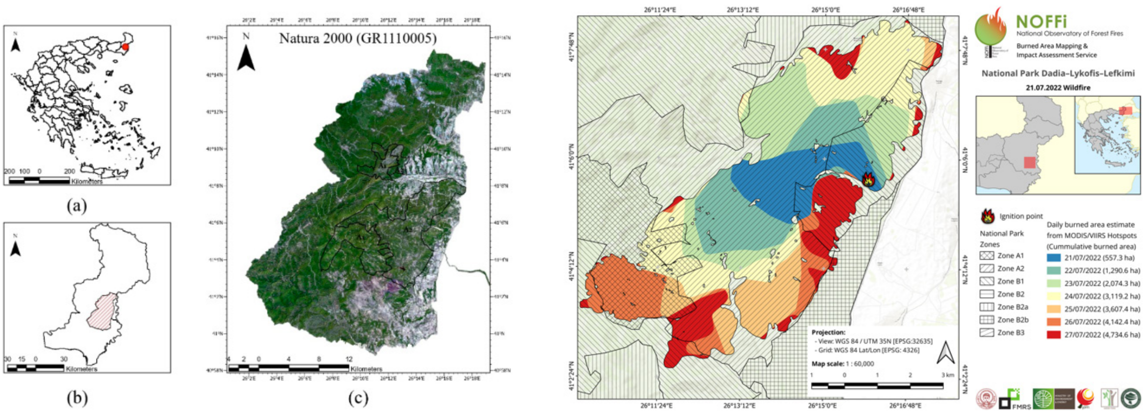


Figure 110 Dadia National area and Park Zones with the daily burned areas during the 2022 fire.
Data source: AUTH, NOFFi | National Observatory of Forest Fires.

Geographically and geologically diverse, DNP is located 36 km from the coast, near the Evros Delta, and at a varied altitude between 10 and 654 m above sea level. Tertiary ophiolite complexes characterize the northern part of the park, while the southern part comprises Paleogene volcanic and sedimentary rocks. The park experiences a modified Mediterranean climate, with northern winds influencing the weather patterns. Historical data from 1964 to 1998 indicates an average annual precipitation of 732 mm, with the dominant vegetation consisting of thermophilous sub-continental deciduous oaks and pine forests (N.E.C.C.A).

The next figures display slope (Figure 111a) and elevation (Figure 111b) maps of the wider park area.

(a) *(b)*

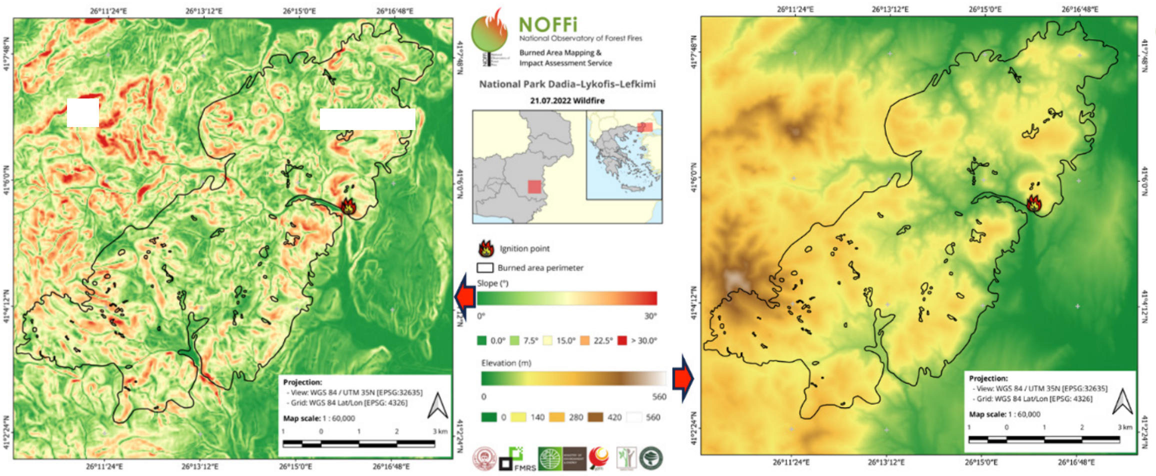


Figure 111 Slope and elevation of the Dadia National Park area.
Data source: AUTH, NOFFi | National Observatory of Forest Fires.

The area of the National Park most affected by the fire was predominantly forested, with a vegetation composition primarily of black pine (*Pinus nigra*) and Calabrian pine (*Pinus brutia*), interspersed with oak species (*Quercus spp.*) and various deciduous trees, alongside areas of maquis shrubland. The vegetation in the two protected zones, A1 and A2, covers an area of 7 350 ha. Oak and pine trees make up most of the forested areas. The spatial distribution of the different types of trees in the National Park can be divided into two areas. The centre is covered with pine trees, whereas the north and southwest are mostly oak. The distribution of these fuel types within the impacted zone is illustrated in Figure 112a. Furthermore, the area experienced in the past multiple smaller-scale wildfires in the region, with the subsequent figure detailing incidents from 2018 to 2022 (Figure 112b). During 2019 and 2021, two major fires occurred within the National Park, both in the southern region and the northern part of the village of Lefkimi. The first burst-fire occurred on October 1st, 2020, burning approximately 694 ha, and the second on July 9th, 2021, burning approximately 242 ha (Maniatis *et al.*, 2022).

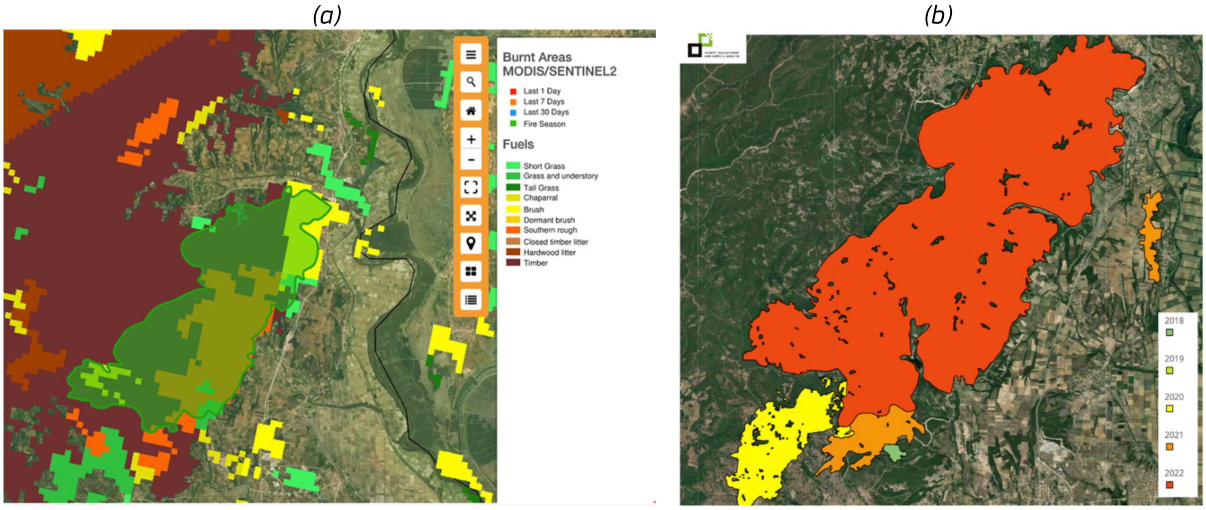


Figure 112. Recent fire history (a) in the area and fuel types (b).
Data source: AUTH, NOFFi | National Observatory of Forest Fires.

9.5 Fire conditions

By the end of July 2022, the cold air masses that had been present over the eastern parts of Europe for the past few days will gradually be replaced by warmer ones. The temperature is expected to rise to 10 degrees above the average climate value of the season. According to the forecast data shared by NoA, the temperature will start to rise on Thursday, July 21st, and high temperatures are expected to persist until the end of July.

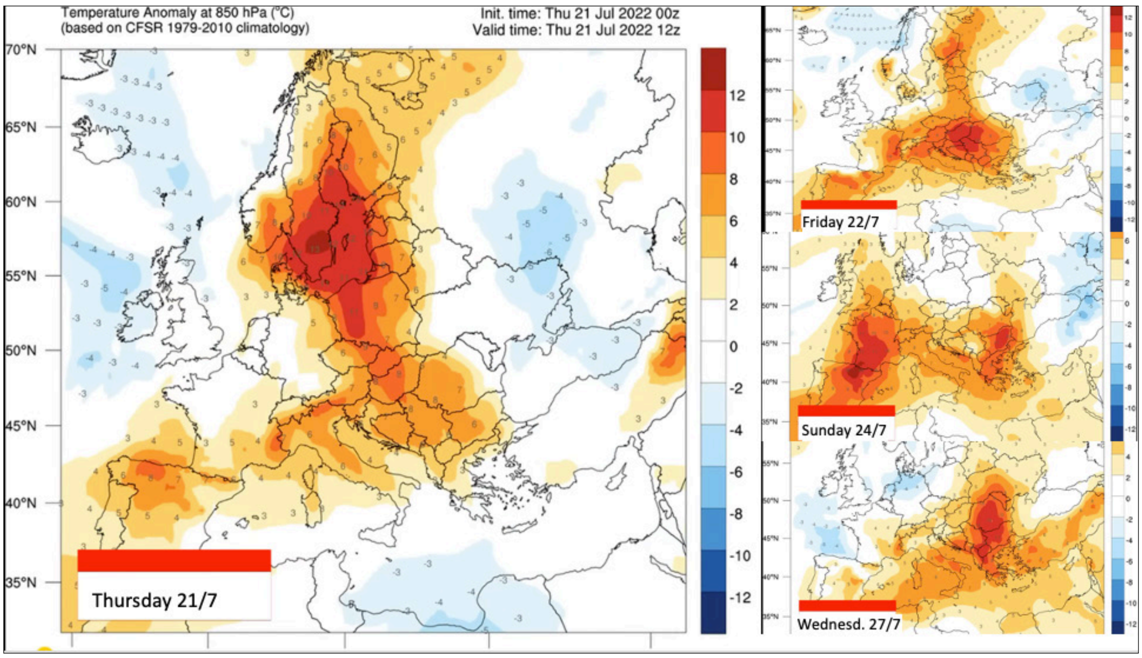


Figure 113. Temperature anomaly over Europe at 1 500m – July 21st to 27th.
Source: National Observatory of Athens.

Below are charts presenting the temperature and wind speed data recorded during the period of the fire event.

(a) *(b)*

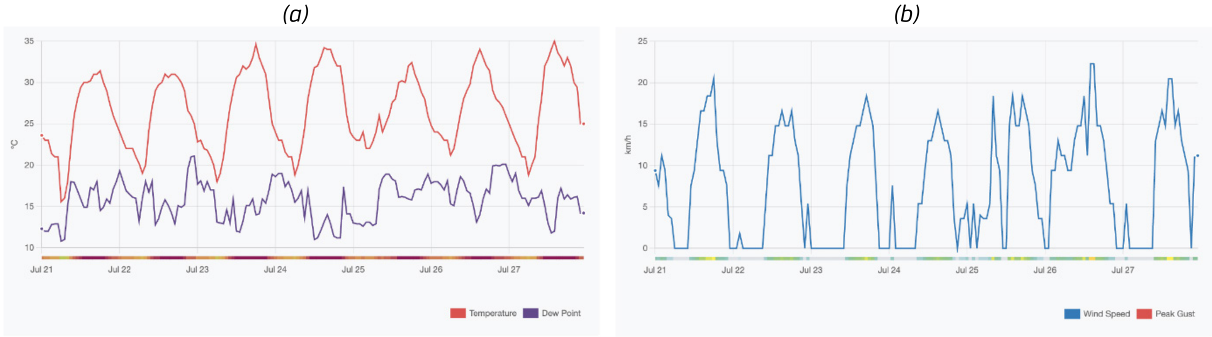


Figure 114. Temperature and wind speed data between July 21st and 27th.
Source: meteostat.net

Based on the data presented, it is clear that the winds were not particularly strong throughout the entire fire incident. The graph below shows the wind gusts during the days of the fire. From the graph, it is evident that the gusts were at their maximum during the morning hours and were more pronounced on the first and fifth day. However, the maximum fire growth occurred on the other five days when the gusts were not as significant. This suggests that the growth of the fire was not heavily influenced by the wind gusts.

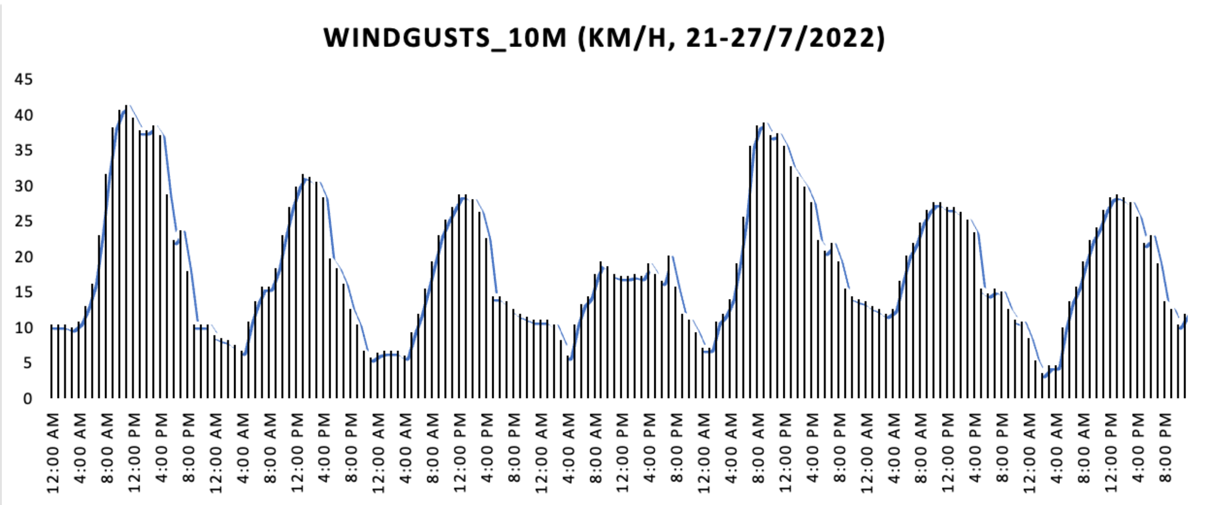


Figure 115. Wind gusts graph in Dadia region between July 21st and 27th.
Source: meteostat.net

The fire risk maps issued by the Greek General Secretariat of Civil Protection indicate that the conditions during the Dadia fire were not associated with high fire risk. However, the difficulties in containing and extinguishing the fire suggest that the excessive fuel load and fuel status were contributing factors to the duration of the fire.

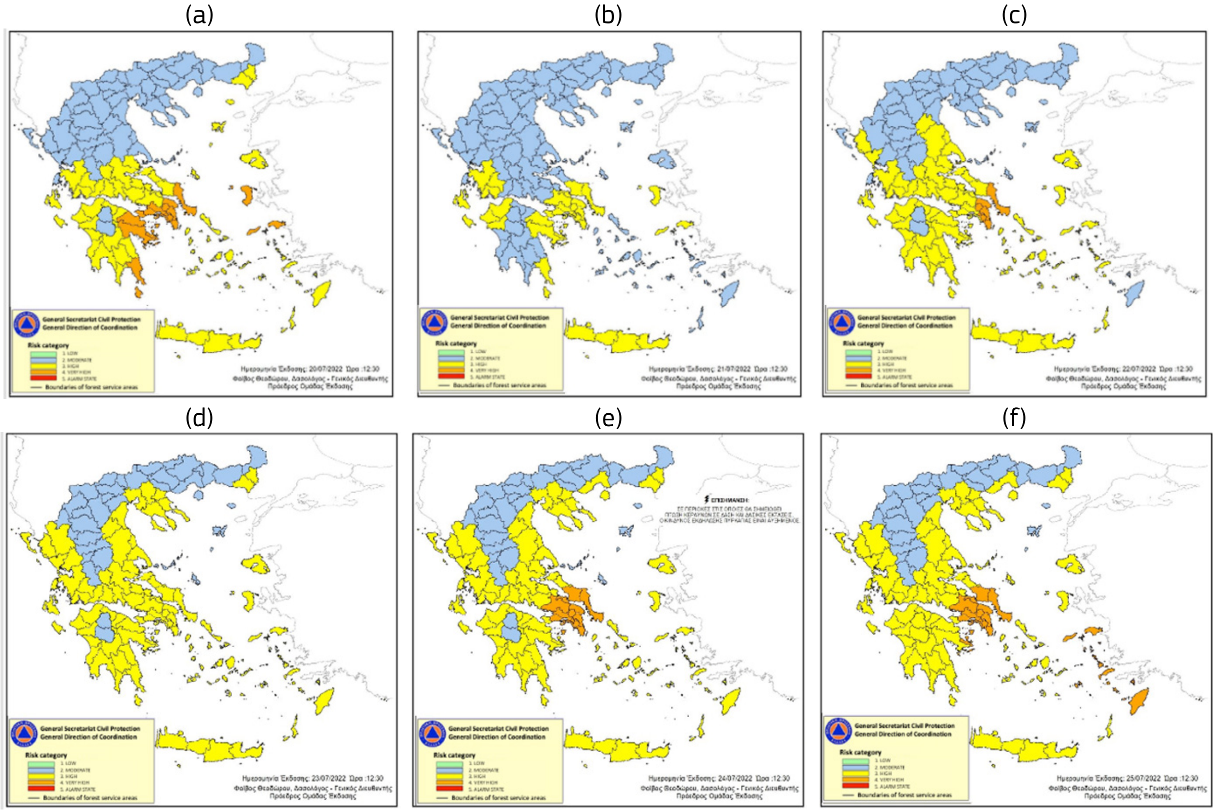


Figure 116. Fire risk map: a) July 21st; b) July 22nd, c) July 23rd, d) July 24th, e) July 25th,) July 26th.
Source: Greek General Secretariat of Civil Protection (GSCP).

9.5.1 Pyrometeorological Dynamics of the Dadia Wildfire

The wildfire spreading in Dadia National Park has become a major concern in the Northeastern part of Greece. The fire has exhibited complex pyrometeorological phenomena that require careful scientific analysis. The FLAME team of the National Observatory of Athens (NOA) has released a Pyrometeorological Index of Fire Propagation Potential based on hot, dry and windy weather conditions (as shown in Figure 117). This index provided more accurate fire potential estimations compared to the risk map of the GSCP, based on relevant meteorological conditions.

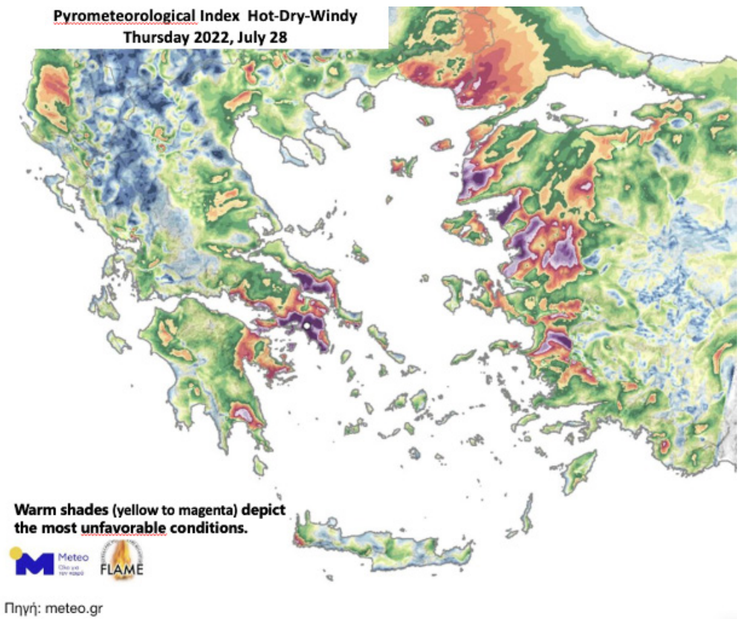


Figure 117. Pyrometeorological index (hot-dry-windy) for July 28th.
Data source: FLAME project, National Observatory of Athens.

Based on meteorological data, the region of Dadia experienced mainly northeastern winds blowing at a speed of 12-19 km/h during the fire. The temperature reached 34-35°C, while the fine fuel moisture content remained below 10% for most days. These conditions led to the formation of 'shallow' pyrocumulus clouds (pyroCus), indicating the potential of the fire intensity. The presence of pyrocumulus clouds formed due to strong updrafts caused by the heat released from the fire indicates instability in the atmosphere. It also suggests that a circulation system of air has been created due to the fire. This system had the potential to greatly increase wind speeds in the vicinity of the fire, which could cause the fire to spread more rapidly.

Figure 118. Transient "shallow" pyroclouds over the induction column of the southwestern front of the forest fire in Dadia, Evros – July 26th.
Source: Weather News of Thrace.

Observations indicate that a wildfire can develop an induction column, causing the fire to behave in a 'self-guided' manner. This phenomenon leads to a more complex fire behaviour as it indicates a significant amount of energy release that can affect local wind patterns and weather conditions. The Dadia wildfire is a result of the intricate combination of fire behaviour and local weather conditions, which create a feedback loop that speeds up the spread of the fire.

9.5.2 Land Cover within the Fire Perimeter:

The vegetation types that covered the burned areas included:

- Mixed Forest: The dominant land cover type was mixed forest, comprising 61.8% of the burned area.
- Transitional Woodland and Shrublands: This type of vegetation form covered 30.4% of the affected area.
- Other Cover Types: The fire also impacted agricultural areas (2.1%), coniferous forest (1.9%), natural pastures (1.5%), and sclerophyll vegetation (2.4%). No significant impact was recorded on artificial surfaces, broadleaf forests, shrubs, and heaths, open spaces with little or no vegetation, wetlands, or water surfaces.

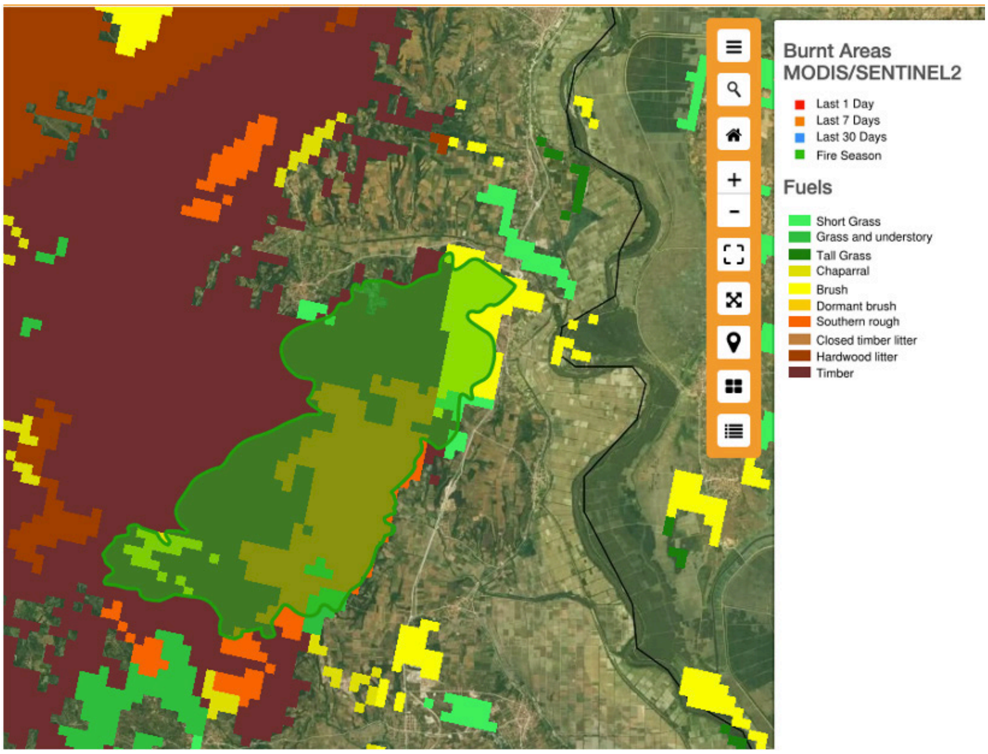


Figure 119. Fuel types of Dadia area.
Data source: AUTH, NOFFi | National Observatory of Forest Fires (MODIS/SENTINEL2).

The 2022 Dadia Forest Fire was a significant event that affected a large area with varying degrees of severity. The fire's behaviour and spread were influenced by meteorological conditions, particularly high temperatures, low humidity and wind patterns. The varying impact on different vegetation types highlights the complexity of forest fire dynamics and emphasizes the need for detailed analysis in post-fire recovery and management strategies (Pleniou, 2022).

9.6 Fire behaviour and smoke dispersion

The wildfire's behaviour was unpredictable due to the thermal-induced wind systems it generated. These winds created a localized inversion layer that trapped smoke close to the ground, reducing visibility and affecting air quality over a vast area. The limited water supply from the Lyra Dam hampered the suppression efforts, allowing the fire to maintain its intensity for an extended period.

As the fire grew, it created a convective column that drew in fresh air from the surroundings, feeding the fire's intensity and enabling the vertical growth of smoke plumes. This self-sustaining system contributed to the long-range transport of smoke particles, impacting not only the immediate area but also regions downwind of the fire. The fire's behaviour showed a marked escalation in the afternoon, aligning with peak temperatures and lower relative humidity, leading to greater fire spread rates and increased smoke production.

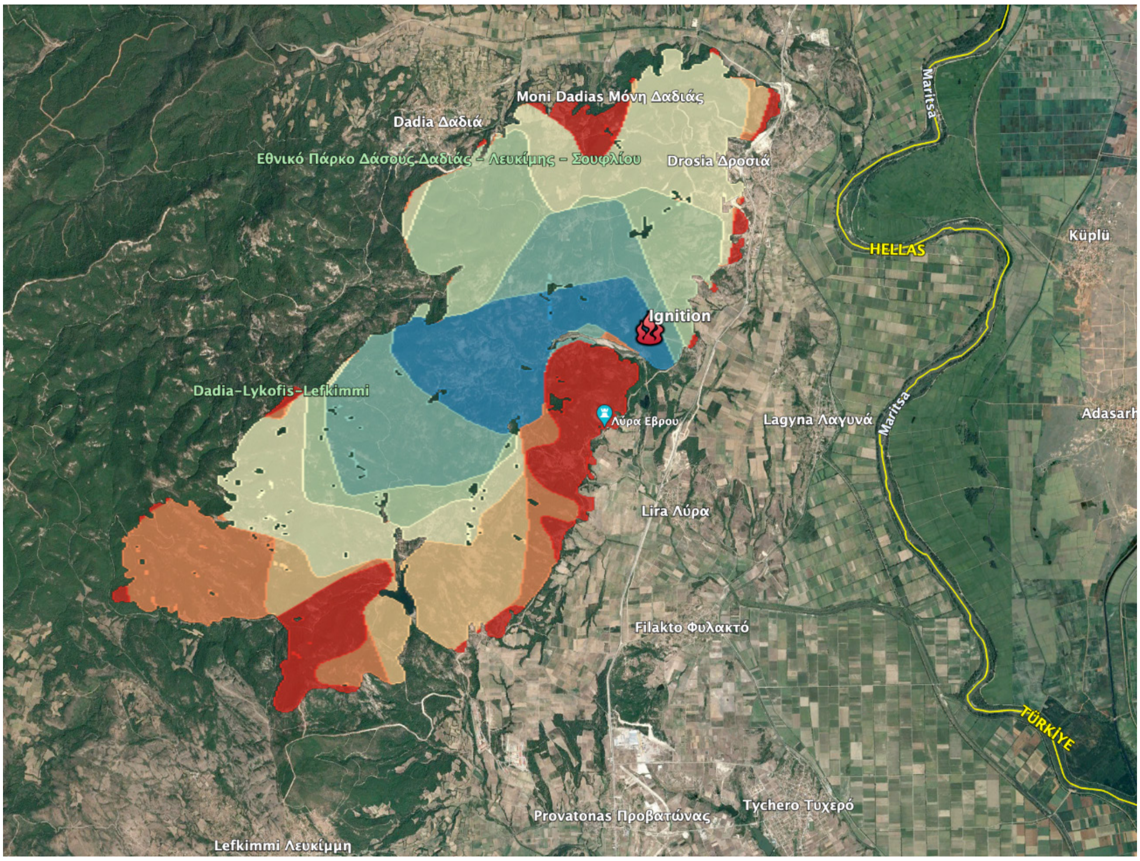


Figure 120. Patches of area burned during the seven days Dadia fire.
Data source: AUTH, NOFFi | National Observatory of Forest Fires

Satellite imagery from the Copernicus service on July 23rd, 24th, and 26th provided evidence of how smoke from the Dadia National Park fire was dispersed by the wind. The images showed that the direction of the smoke changed as the wind changed. On July 23rd, the smoke was blown southwest by the north wind. On July 24th, the smoke was redirected northwest by the southern wind. Two days later, on July 26th, the smoke was again blown in a different direction by the northeastern wind. These observations show that smoke dispersion is influenced by local wind patterns and can change quickly. The satellite data provides direct visual evidence of how wind affects smoke behaviour, which can help decision-makers manage air quality and public health advisories during wildfires.

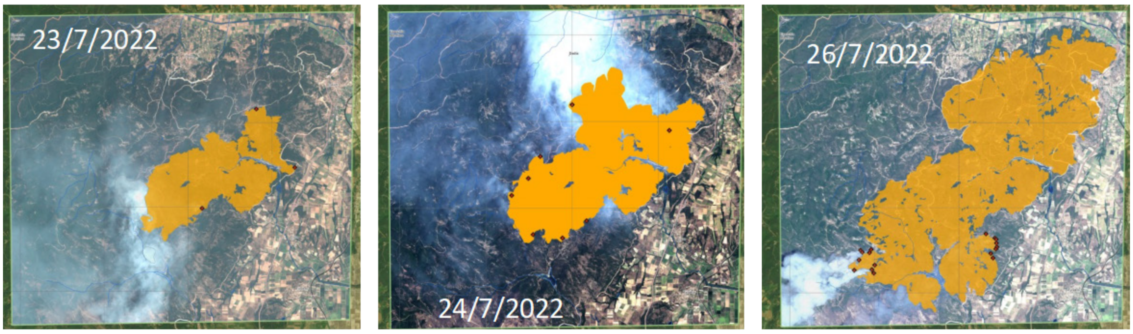


Figure 121. Wind-driven smoke dispersion pattern of Dadia fire on July 23rd, 24th and 26th.
Source: Copernicus EMS.

The Dadia National Park fire's behaviour underscores the importance of understanding the multifaceted nature of wildfires and the necessity for integrated fire management and air quality monitoring systems, particularly in areas of ecological significance.

9.7 Direct fire impacts

The wildfire in Dadia, which raged from July 21st to 27th, has left deep ecological scars (Vasilopoulos & Survas, 2022). The persistent flames over such an extended period resulted in severe ecological degradation, affecting plant life, wildlife habitats, and the soil microbiome. This has had several critical consequences:

- The forest's natural regenerative capabilities have been impaired, making it likely that human intervention will be necessary to assist in ecological restoration.
- The demand for prolonged firefighting efforts drained the resources and taxed the capacity of the responding agencies, both in terms of logistics and human capital.
- The area's biodiversity suffered, with the potential loss of endemic and endangered species due to the long-term exposure to high heat and destruction of habitat.
- The fire has also likely led to soil sterilization and disruptions in the hydrological patterns of the region, heightening the risk of erosion and landslides.
- The carbon sequestration function of the forest stands compromised which may have implications for climate change mitigation strategies.
- Finally, the extended duration of the fire could have set off a series of cascading ecological effects, disrupting predator-prey dynamics, nutrient cycling, and overall ecosystem services. Figure 122 offers a detailed mapping that delineates the wildfire's impact on vegetation and natural assets within the Dadia National Park, utilizing color coding to signify varying degrees of severity. This color-coded system used by the Greek Natural Environment & Climate Change Agency (N.E.C.C.A.) of the Ministry of Environment and Energy aids in understanding the extent of damage and facilitates targeted rehabilitation efforts.

(a) *(b)*

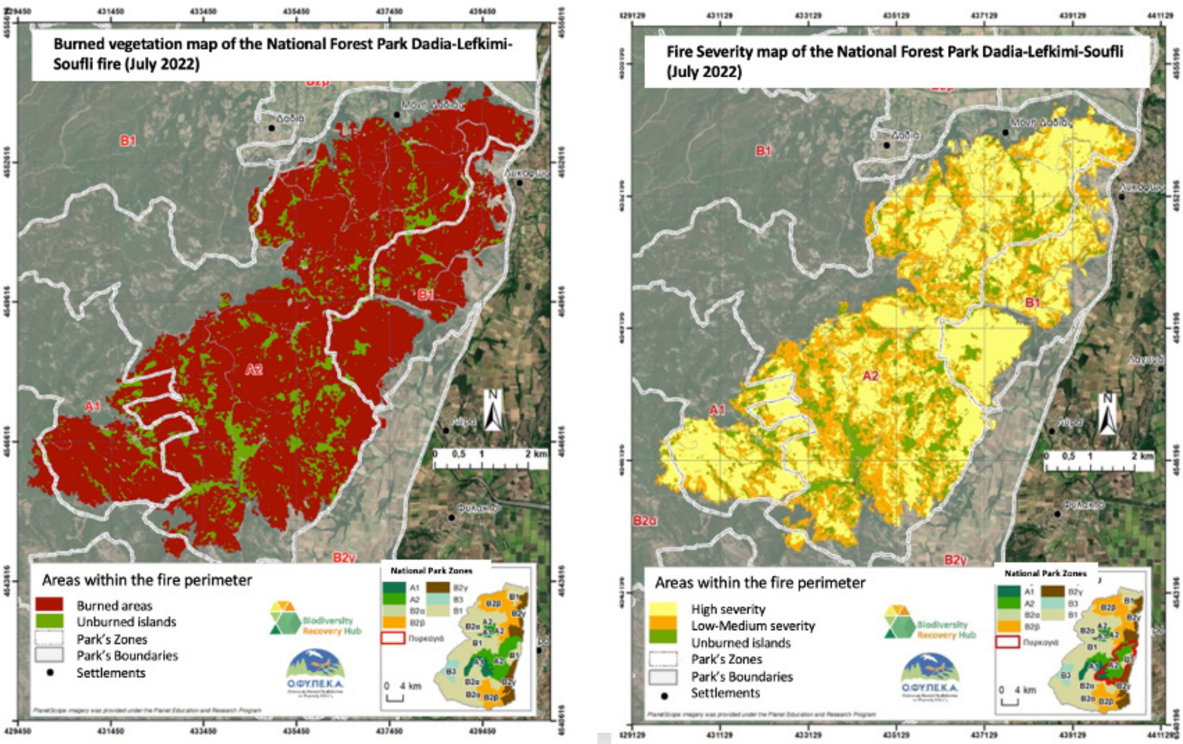


Figure 122. a) Map of the fire-affected area, encompassing 45 412 ha; b) Map detailing the fire's severity and impact on vegetation.

Data source: Greek Natural Environment & Climate Change Agency (N.E.C.C.A.).

The orange-coloured areas covering 1 607 ha experienced a fire impact primarily at the ground surface level. The fire here consumed forest fuel directly contacting the ground, including dry leaves, needles, small branches, grasses and low-lying shrubs. Notably, in these areas, the tree canopy largely remained intact or suffered only minimal damage. This suggests that while ground-level vegetation was affected, the overarching forest structure and canopy were preserved to a considerable extent.

Areas coloured in yellow, encompassing 2 210 ha, witnessed a more intense level of fire impact. The fire in these zones was severe enough to consume almost all available vegetation, ranging from the subfloor to the tree canopy, in some cases leading to the complete annihilation of vegetation. This level of intensity indicates extensive damage to both the understory and the canopy, significantly altering the ecological balance and necessitating more intensive restoration efforts.

Finally, 615.3 ha coloured green depict patches that remained entirely unburned. The presence of these untouched areas within the impacted zone is crucial for ecological recovery, serving as refuges for wildlife and seed sources for natural regeneration.

The fire notably impacted the park's A2 zone, where 2 637 ha were scorched. This area is significant due to its biodiversity and ecological value. More critically, the A1 zone, known for its high density of Black Vulture nesting sites, experienced fire impact over 459 ha. The damage to this zone is particularly concerning given the conservation status of the Black Vulture.

The existence of approximately 50% of the area remaining unburned or subjected to low to moderate fire severity provides a hopeful perspective for biodiversity conservation. These areas could be pivotal in the park's ecological resilience, benefiting rare predatory and scavenger species. Additionally, many regions experienced low fire severity, warranting further study to identify surviving plants that could contribute to natural reseeding processes. The fire's effect on vital bird habitats necessitates evaluations by specialists knowledgeable about local species to ensure the implementation of effective conservation measures.

In response to these findings, N.E.C.C.A, the relevant authority of the Ministry of Environment, developed a comprehensive post-fire rehabilitation plan for the region, informed by the mapping results. Additionally, these results will be further refined and verified through extensive fieldwork, enhancing the accuracy and relevance of the thematic information. This fieldwork is essential for confirming the initial assessments and adapting the rehabilitation strategies to the specific needs and conditions of the affected areas.

The General Secretariat of Forests, under the aegis of the Ministry of Environment and Energy, has officially designated an expansive forested region encompassing 46 330 240 m^2 at the Dadia site in Evros for immediate reforestation. This decision comes in the wake of a catastrophic fire event that could have profound ecological ramifications.

The primary forest types impacted include Mediterranean pine forests with native species and oak woodlands with *Quercus cerris* and *Quercus petraea*, both exhibiting high resilience and regenerative capacity following fires. However, the fire also partially affected the priority habitat Pseudosteppe with grasses and annual Thero-Brachypodietea plants, thus requiring targeted restoration efforts.

Reforestation initiatives should be reserved for areas where the topography hinders natural regrowth or those previously affected by fires within the last ten years to avoid obstructing the ecosystem's intrinsic recovery mechanisms.

(a) *(b)*

Figure 123. The 'feeding rock', a boulder in the heart of the national park where food is left for the area's endangered prey birds (a) and prey birds required care (b).

Source: a) kathimerini.gr

(a) *(b)*

Figure 124. Complete burning of the pine forest in the smaller of the two cores of the National Park.
Source: kathimerini.gr

(a) *(b)*

Figure 125. Prey bird observatory (before & after fire).
Data source: kathimerini.gr

9.8 Cascading effects

The Dadia-Lefkimi-Soufli Forest National Park, a bastion of biodiversity in NE Greece, was engulfed by a catastrophic wildfire during the summer, scorching over 22 000 ha. Amidst the flames, vulture colonies faced dire threats during their breeding season, prompting swift conservation action. Months on, assessments unveil the breadth of ecological damage and implications for the vulture populations.

The park's international significance is underscored by its rich mosaic of species, providing sanctuary to a plethora of European and Asian wildlife, including endangered vulture species. The park's role as a vital haven for raptors, particularly the Cinereous Vulture, the Egyptian Vulture, and the Griffon Vulture, is critical. The Dadia colony is particularly noteworthy as the last natural breeding ground for Cinereous Vultures in the Balkans, making its preservation imperative.

During the blaze's peak, conservation efforts intensified to protect the vulture nests from the encroaching flames. The fire, striking at a critical juncture of the breeding cycle, posed an immediate risk to the nearly fledged vulture chicks. Remarkable coordination between governmental bodies, NGOs, and volunteers, including supplementary feeding and habitat protection strategies like new firebreaks, was instrumental in shielding the vulture habitats from destruction.

Despite the devastation surrounding them, all active Cinereous Vulture nests saw their chicks fledge, an outcome mirroring resilience amidst adversity. The immediate threat to vulture colonies was averted, but the path to recovery mandates vigilant monitoring and increased conservation efforts to mitigate the loss of nesting grounds for other key species.

9.9 Conclusions and lessons learned

The Dadia National Park wildfire has underscored the importance of robust fire management frameworks in protected areas. The post-fire scenario has emphasized the criticality of real-time monitoring, rapid response systems, and the reinforcement of park infrastructure against future environmental challenges. The fire has also necessitated a revaluation of conservation strategies, focusing on restoration and prevention while highlighting the vital role of community engagement in preserving natural resources. Furthermore, the event has reaffirmed the ecological significance of the park as a sanctuary for diverse wildlife, and exceptionally various raptor species, thus necessitating focused conservation measures.

The Dadia wildfire experience has imparted key lessons in emergency management. Firstly, the indispensability of dynamic and adaptable management plans to effectively respond to crises. The collaborative efforts of local authorities, conservation groups, and volunteers have demonstrated the power of united action in crisis management. Moreover, integrating advanced technological tools for ecosystem monitoring and damage evaluation is pivotal. These lessons lay the groundwork for post-fire recovery and future strategies to fortify the park's resilience against similar events.

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10 Fires in Romania

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10.1 General Description

The fire 2022 season in Romania does not contain a few significantly large or notably high impact fires. Instead, it was characterized by a larger than normal number of fires, which in combination burnt unusually large areas and brought consequences in terms of several lives lost and many injured together with record-high burnt area.

10.2 Second largest burnt vegetation area in Europe

While the 2022 fire season was very focused on large forest fires in France, Portugal and Spain, a quick glance at the numbers of burnt area in Europe put Romania in the spotlight. With 719 EFFIS-detected fires (the highest number in the EU) an area of over 150 000 ha was burnt, Romania appears just second after Spain among the worst hit European countries. Much of this affected open areas but also the closed canopy forests were affected with an area of >13 141 ha, the largest area of forest burned since 1965 (Popa, 2023e). For parts of the country (South-West), this followed the also exceptional 2021 with locally (but not nationally) large areas burnt (Lorenț *et al.*, 2022; Lorenț *et al.*, 2023). As for large parts of Europe, the 2022 season also stands out from the typical seasons since EFFIS started tracing fire areas in 2006 (although Romania is covered only since 2011). Clearly, the spring fires are completely dominating the tally and over 70% of the fires occurred in March (Figure 126). This is apparently the common seasonal trend in Romania where 85% of the area is burnt outside of the characteristic forest fire seasons for Europe (beginning of April to end of September) (Lorenț *et al.*, 2018; Mallinis *et al.*, 2018). Although assessed over a very limited time-period, the total annual burnt area exhibits an increasing trend during the last decade.

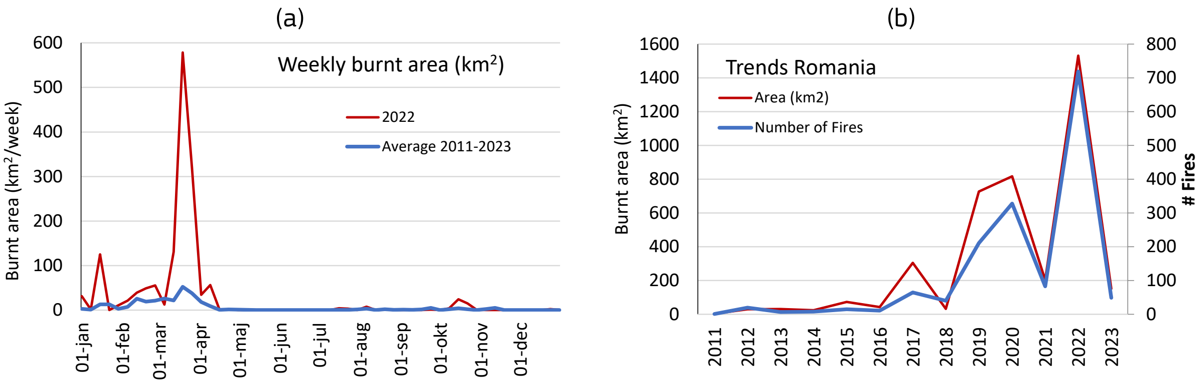

Figure 126. a) Weekly burnt area in Romania for 2022 and the 2011 – 2023 average; b) The trend in number of EFFIS-detected fires and total burnt area in Romania since 2011.

Source: https://effis.jrc.ec.europa.eu

10.3 Only a fraction of the area on forested land

Assessing the incident reports on forested land from Romanian Ministry of Environment, Water and Forests (MMAP, 2023) shows the same seasonal trend. Over 80% of all burnt forest areas occurred in the second half of March but the total area for 2022 is less than 9% of that reported by EFFIS (Figure 127).

(a) *(b)*

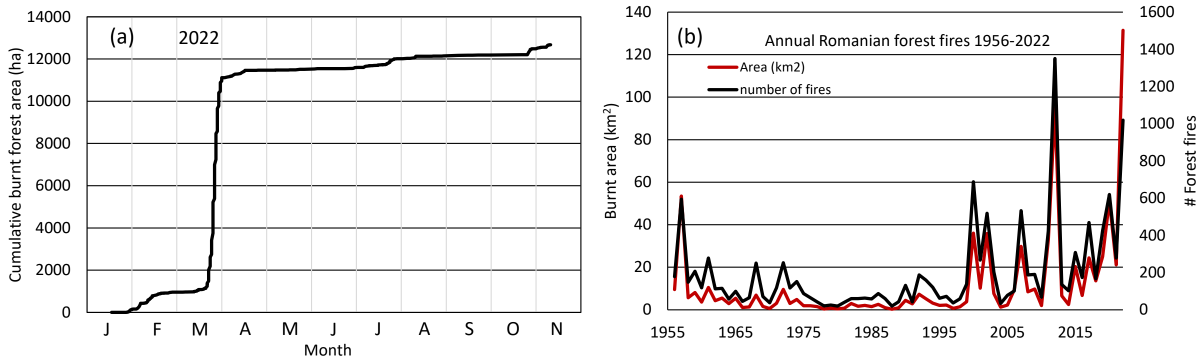

Figure 127. a) Cumulative burnt area on forested land during 2022 until November; b) Annual burnt area on forested land and the number of forest fires between 1956 and 2022. *Source: a) MMAP, 2023; b) MMAP and RNP-ROMSILVA, 2023.*

Thus, the main burnt area reported by EFFIS is not on forest fires but open area fires, mainly in the Danube Delta, the large wetland biosphere reserve at the mouth of the Danube into the Black Sea. It is a UNESCO world heritage site and comprises many Natura2000 areas. On and along the many watercourses, vegetation is dominated by reed of many species such as the common reed (*Phragmites communis*) or cattail (*Typha latifolia*). The reed has been used for generations as construction material (such as roofing), for fuel pellets or food for livestock. Often, last season's litter is burnt during spring as soon as weather allows, which speeds up the succession of green vegetation and helps during harvesting, since old dead reed will be intermixed with the live material for at least a season or two. On solid ground within the landscape, grasses and reed are also burnt in spring enabling earlier possibility for grazing. Conflicts of access to and use of commercial areas for grazing, harvesting, and fishing lead to large areas being burnt also in the Danube Delta Biosphere Reserve. Agricultural burning is prohibited in Romania but not often considered a big problem by local authorities due to its long tradition (Popa, 2023a, 2023b). However, the legal aspect reduces the potential for large arrays of crews and planning a controlled event, thereby increasing the risks of uncontrolled spread.

Some of the fires during March became large. Examples include the burnt area polygons from MODIS in part of Gorj county and the Danube delta (where several fires are almost 1 000 ha) from the week March 28th to April 3rd (Figure 128). In the Gorj county, one can see how the fire perimeters border arable land and how the fires have climbed the forested hills between cultivated valleys, sometime covering several hundreds of hectares. The Gorj fires shown here all occurred between March 28th and 30th.

(a) (b)

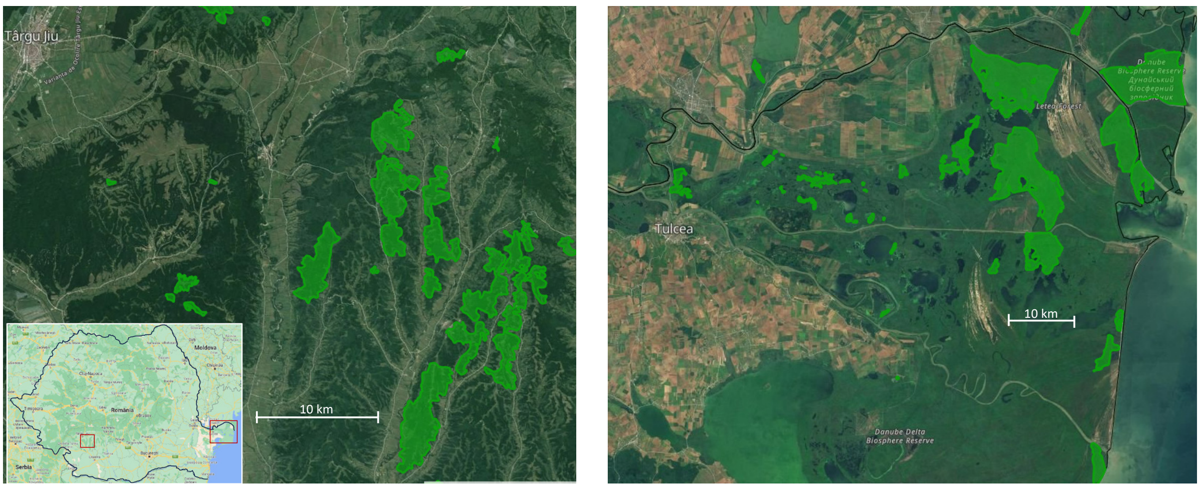

Figure 128. MODIS polygons during March 28th to April 3rd in part of Gorj (a) and Tulcea (b) counties. The numbers indicate the date (in March if not stated otherwise) at which the fire was detected.
Source: Reuters

Figure 129. Photos of forest fires in Romania: a-b) Someșul Rece Forest District, Cluj, July 28th; c-d) Apuseni Natural Park, Cluj, July 21st. *Source: Photo credit: RNP-ROMSILVA*

Figure 130. Photos with reed fires in the Danube Delta Biosphere Reserve.
Source: Photo credit: Danube Delta National Research-Development Institute – INCDDD.

10.4 Vegetation management, the dominant ignition cause

Since most forested areas also burn in March, there is a strong indication that these too are connected to agricultural burning and management of debris from last season. The records of forest fire ignition causes from national authorities (MMAP, 2023; IGSU, 2023) also confirm that over 90 % of the fires in forests are caused by these activities (Figure 131).

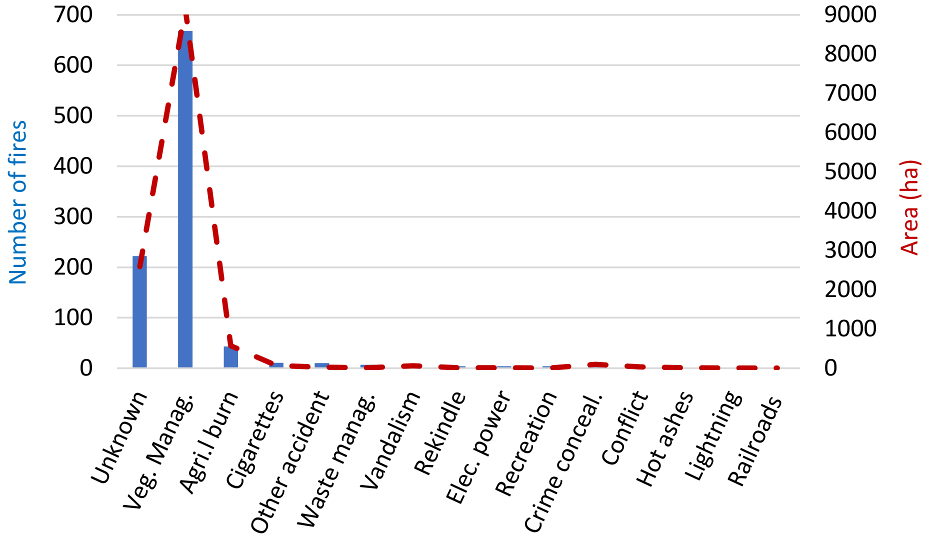

Figure 131. Number of forest fires and burnt area broken down to cause of ignition (Data source MMAP, 2023).

The largest forested burnt areas and frequencies are in rural areas between the west and south-west Oltenia regions (counties of Gorj, Caraș-Severin, Mehedinți and Sibiu). The fires mostly originate in agricultural or grazing areas but can rapidly spread to adjacent forested regions, where they primarily consume readily available fuel such as litter, grass, and other lightweight dead vegetation from the previous growth season. Anecdotal examples of this can be seen from the photos (Figure 129).

The largest forest fire was just over 330 ha, but the area distribution is more uniform than for typical European countries. 20 fires burned almost 100 ha or more; these were all strictly surface fires, occurred in March and were either caused by vegetation management or had an unknown cause.

Reports on several deaths have also been found (IGSU, 2023; Popa, 2023b, 2023d). These occur in separate fires and involve mostly elderly people who have been burning the same land for many years (Popa, 2023d, 2023f). Just one single event caused two casualties, one death and one injured, all the other fire incidents having just one victim each. We find reports of 18 deaths in 18 different fires, 3 in forest fires and 15 in open vegetation fires. These are high numbers for Romania, considering previous experience (0 cases in 2018, 1 case in 2019, 8 cases in 2020 and 5 cases in 2021). The number of injured people in 2022 is also higher, with 43 victims, more than the combined number for the preceding four years. The burnt area and estimated value of the damage are also the highest in the report for the year 2022 (IGSU, 2023).

The apparent increase in burnt area shown above (Figure 126b and Figure 127) is not easily explained. High spread rates in the flammable vegetation in March will be determined by periods of dry air, sunlight and high wind gusts, even if the duration of these is only a day or two. An earlier snow melt will only shift the fire season to earlier in spring and not contribute to larger areas as it would for pure forest fires. The increase is likely much related to human behaviour, conflicts of land use and traditional ways of making a living from the land. Romania, like most parts of Europe, has seen an increase in urbanisation, leaving rural areas depreciated of young people and with and increasing portion of non-attended and uncultivated land (Mallinis *et al.*, 2018).

10.5 Applying a grassland fire danger model to 2022

As March passes the new live light vegetation grows, which clearly hinders the fire spread propensity and intensity of fires (Sjöström & Granström, 2023). This is probably the reason the fire season almost came to a complete arrest during the summer months (Figure 127). For herbaceous dead fuels, only a few hours of low relative humidity can make fuel highly flammable and there is no need for long droughts, especially if exposed to wind and sunlight. Having said that, the winter of 2022 was unusually dry, which must facilitate the spread of fires from open into forested land.

We calculated the spread rates on a model grassland from the RING model (Rate of Spread in Northern Grasslands) used operationally for fire danger in grasslands in Sweden since 2021. This model accounts for the growth of new grass, the wind speed and the moisture of the fuel based on past hourly data of temperature, RH, precipitation, wind and solar irradiation. The danger indicator for grassland fires is related to spread rates and not to intensity as for forest fires. The weather data used here is hourly data from Bucharest and thus only represent one location of the country and not the danger indices for each fire. The Bucharest data however displays that danger indices were low in the first half of March, after which they peaked in the second half and thereafter decreased again (due to the continued growth of fresh grass) in April (Figure 132). This coincides well with the peak of fire occurrence although the model is not calibrated to Romanian conditions. The model predicts that grassland fire season is practically over by April 20th, coinciding well with what is seen from the forest fire record. It should however be noted that reed can probably burn later in the season due to its tall structure, but the model more resembles light fuels typical for borders between open and forested land.

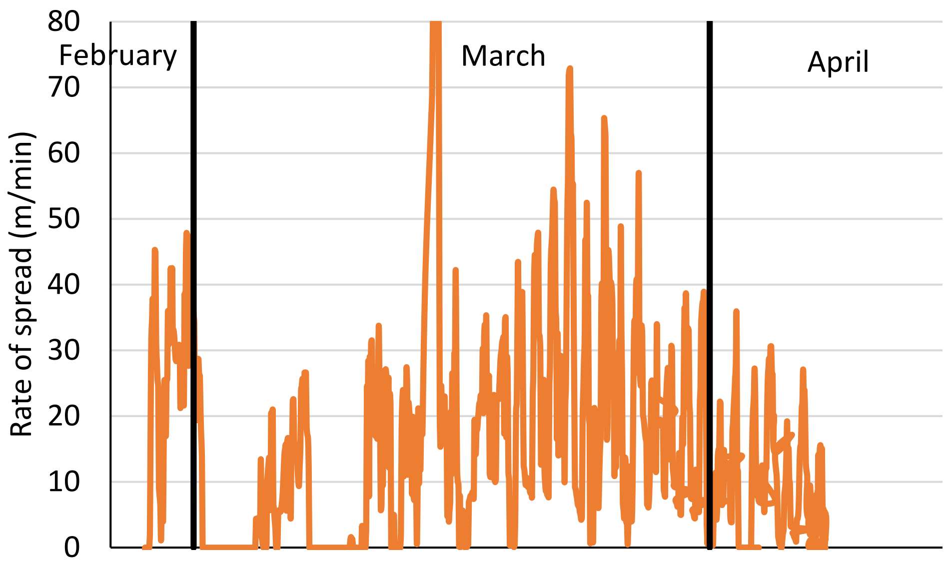

Figure 132. Danger index (Rate of spread for a model grassland) based on the weather during spring 2022 in Bucharest and calculated according to [3] (Weather data source: https://www.visualcrossing.com/weather-history/bucharest, assessed 2023-10-12).

Source: https://www.visualcrossing.com/weather-history/bucharest (assessed 2023-10-12).

10.6 Summary

The very large wildfire areas reported for Romania 2022 were over 90% dominated by fires on open land in the second half of March. Vegetation management on reed areas in the Danube delta comprised an overwhelming majority of these fires. The tradition of burning past seasons' light litter can be found all over Europe, especially in those of colder climate. However, even if concerning only fires in forests, this year also marked the most severe season known by records with 13 141 ha of forest in a total of 1 019 fire incidents. Also, the forest fires were mostly concentrated in March. They mostly show the same pattern of vegetation management fires escaping to surrounding forested land, burning mostly light litter from the past season in low intensity, but sometimes rapidly spreading, fires. Many of these events had consequences and 18 people died in total, mainly older people igniting the initially controlled fire. The areas and numbers of spring fires appear to increase. The reason behind this increase is not fully investigated but is likely driven by human activity. For mitigation, a grassland fire warning model could be a helpful tool to focus public engagement during periods with the highest likelihood of escaping fires.

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11 Fire of Razdel (Bulgaria)

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Nadya Tsvetkova	IICT
Yanko Boyanov	FSPP - Yambol
Ilian Gospodinov	NIMH

11.1 General Description

The Fire of Razdel started 2 km south-east of Razdel village, in the municipality of Elhovo, District of Yambol in the South-Eastern Region in Bulgaria. The ignition occurred on the morning of August 10th. The alert was given at 11:00 of the same day, and the fire was detected by the passage of the Terra MODIS at 11:26. The final total burned area was 797 ha, where 560 ha were forest areas, and 237 ha were grasslands and pastures. The size of the burned forest territory makes that fire the largest forest fire in Bulgaria in the year 2022 (another fire with 1 023 ha total burned area was also recorded during 2022 in another part of the country, but with a smaller part of affected forest zones - 460 ha). Although the fire of Razdel village did not have an impact on residential zones, it affected considerable areas of Natura2000 and there was the risk of the fire crossing the Bulgarian - Turkish border.

The Razdel Fire was active for five days, spreading in two villages: the village of Razdel (affected territory is 667 ha) and the village of Malko Kirilovo (affected territory is 130 ha). Both villages are located under the same municipal territory of Elhovo (Figure 133a). 95% of the burnt area was reached during the first 60 hours of the fire, approximately around 12:00 on August 12th. The monitoring of the burned area continued until August 14th, several days after the major fire perimeter was suppressed. Smaller fires were active on August 15th and 17th but were considered as separate events. The description of this report focuses mainly on the period between August 10th and 14th. As shown in Figure 133b, the area where the fire was propagating was evaluated as a maximum fire danger zone with a red code probability for fire occurrence at the fire ignition date. The red code is the highest degree of fire danger in Bulgaria calculated on a daily basis by the National Institute for Meteorology and Hydrology (NIMH).

(a) (b)

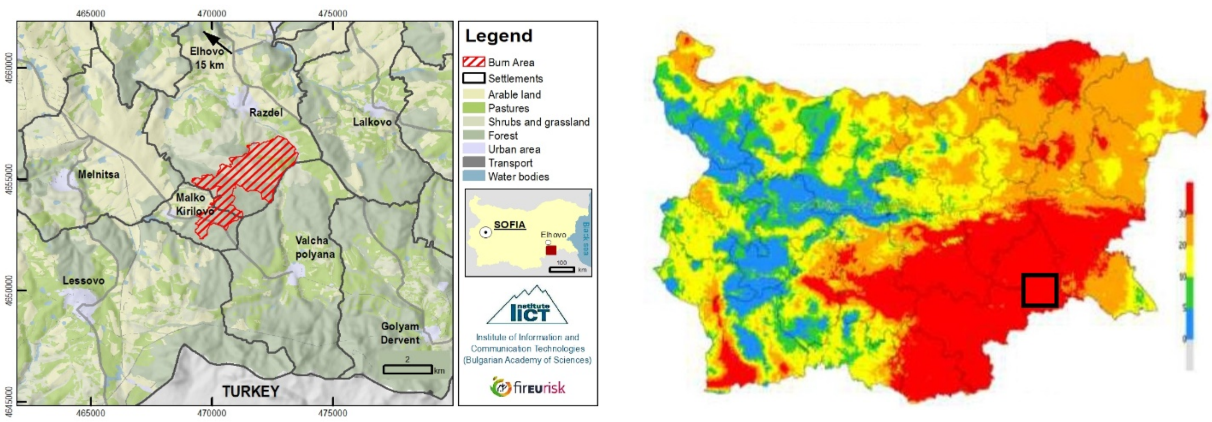


Figure 133. a) Geographical representation of the Razdel Fire (IICT - BAS); b) Fire hazard for August 10th.
Source: NIMH

In March 2023, a team from the Institute of Information and Communication Technologies – Bulgarian Academy of Sciences (IICT-BAS) visited the area affected by the fire nearby Razdel village. The report is based on the collected data. The IICT-BAS team visited the locations described in the report and interviewed the local authorities, who took part in the suppression measures. Explanations were collected from both civil protection team members and foresters who were directly involved in the event suppression measures.

11.2 Characterization of the affected area

The Razdel Wildland Fire occurred within the municipality of Elhovo (LAU1), Yambol district (NUTS3), Bulgaria. The municipality is in the southeastern part of the country. This municipality is situated on the south end of the border between Bulgaria and Turkey. The burnt area covers the southern half of the municipality, on a territory characterized by a hilly relief with a predominance of forest and shrub vegetation. Agriculture is the main economic sector developed in the municipality (Figure 134a). The southern half of the municipality is entirely occupied by Natura2000 protected sites under the Habitats Directive (BG0000218 Derventski vazvishenia 1) and the Birds Directive (BG0002026 Derventski vazvishenia) (Figure 134b). The existence of these two large protected zones is of high value to the biodiversity of the area. That is why specific rules for land management are applied in this municipality, which has an impact on fire response actions. This will be described in detail further in the report.

(a) (b)

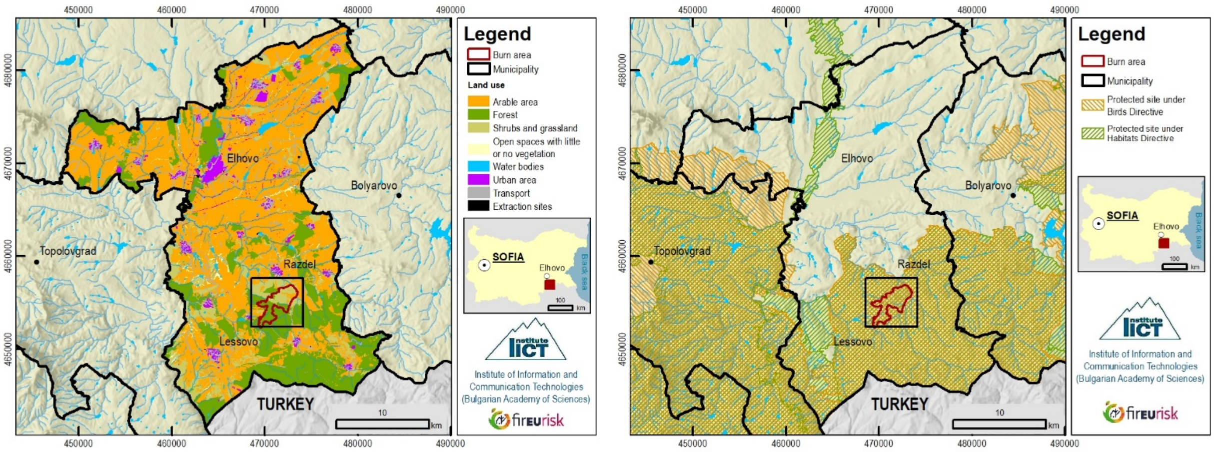


Figure 134. a) Land use map of Elhovo municipality (IICT - BAS); b) Natura 2000 protected sites under birds and habitats Directives.
Source: IICT - BAS

The total population in Elhovo municipality is 16 219 people (NSI, 2021). 65% of them live in the municipal headquarter in the town of Elhovo. The remaining settlements are villages, with no additional towns, and the respective population there is less than 700 people in total. The villages in the southern half of the municipal area have a population of about 100 people, except for those in the western end, located along the main road No 7, which connects to the Bulgarian -Turkish border.

The population is characterized by a deteriorated age structure, except for the town of Elhovo and four other nearby settlements. For the rest of the villages in the municipality, the share of the population over 65 years is above 40%. The elderly population is predominantly found in the settlements in the southern part of the municipal territories. The population reduction is constant since 2011. The lack of young people puts at risk, not only the economic development of the area, but in addition in cases of natural hazards suppression measures are impossible to be maintained by the locals.

Regarding the migration of the population, the statistics are negative – since 2010. Based on the National Statistics Institute's (NSI) regular population reports from 2010 (-226), 2015 (-148), 2017 (-140), and 2021 (-70), the municipality of Elhovo has a constant decrease in its citizens.

Unemployment in the municipality of Elhovo is 14.1%, significantly higher than the average for the country (5.2%). The number of people employed in agriculture in the Yambol district is low – 8 455 (18%), due to the predominance of cereal crops and the high degree of mechanization in the sector. In particular, for the municipality of Elhovo, permanent employees in the agriculture sector are 91%, and seasonal employees are 9% (*Census 2011, 2021; ** Census 2011 (NSI, Bulgaria).

Elhovo municipality is an agricultural territory (34 955 ha) (Agricultural Census 2020, Information system for agro-statistics). The largest share is arable land (71%), followed by permanent grassland (27%). Smaller areas are permanent crops (1%). The arable land is 24 953 ha, where mostly cereals (48%) and industrial plants (39%) are farmed.

The terrain is lowland (in the northern half of the municipality) and hilly - in the southern part, where the fire occurred (Figure 135a). The average altitude in the north is about 160 m, but it increases to 295 m in the south. Hills in the south have a greater degree of roughness than the lowland (Figure 135b). The landscape is characterized by round-top hills cut by a relatively dense river network (Figure 136). Most of the rivers started from the Sakar Mountain and the Dervent Highlands located south of the border between Bulgaria and Turkey. The rivers have a small flow rate, which decreases further during the hot half of the year. There are a few dams located in the northern part of the Elhovo municipality. There are almost none in the south. This, combined with the higher degree of terrain roughness, is a prerequisite for the difficulties in finding water for firefighting needs. The main river is the Tundzha River, located west along the municipal end border. Although it is one of the biggest rivers in the country (the area of the Tundzha River watershed before entering the municipality is about 540 000 ha), there have been cases of fires that have crossed it and spread to the other side.

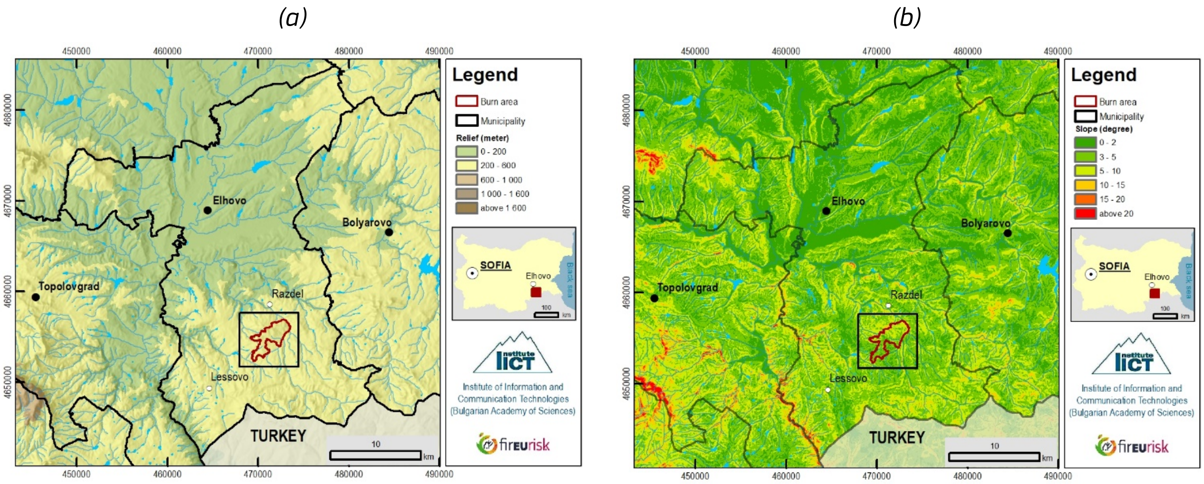


Figure 135. Characterization of the topography in the region: a) orographic map; b) slope map; c) Google Earth image showing the typical orographic pattern.

Data source: IICT-BAS (Aero-orthophoto base map).

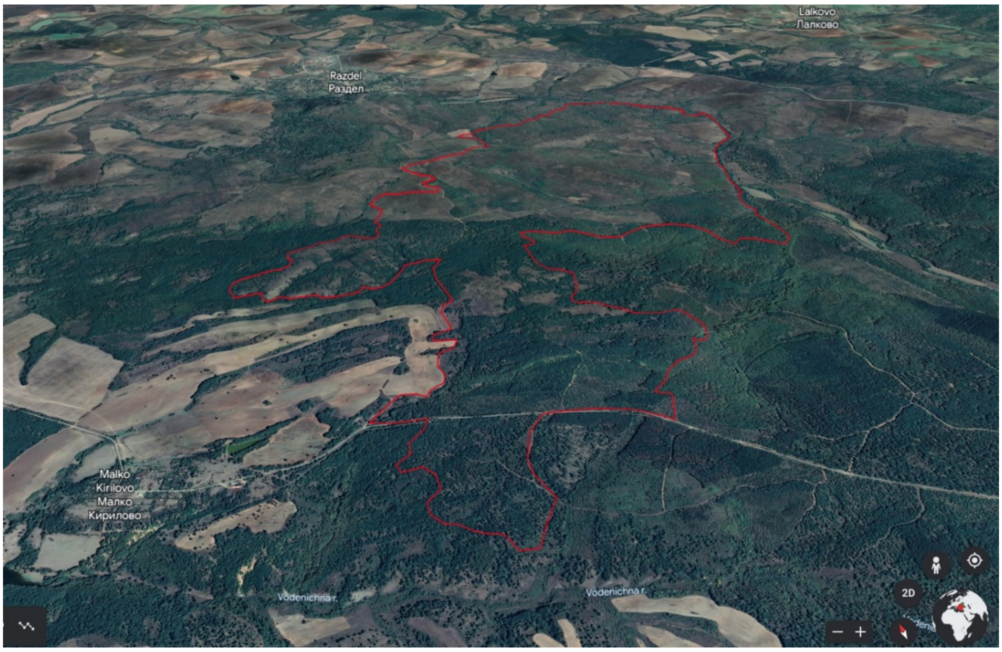


Figure 136. Google Earth image showing the typical orographic pattern.
Data source: IICT-BAS (Aero-orthophoto base map).

The area of Elhovo municipality is affected regularly by small or large wildland fires. Since 2000, more than 35 wildland fires have been recorded within the municipal territory, which led to 5 640 ha burned area in total throughout the years. The three villages that were affected by the fire of 2022 had seven other wildland fires, in the period from 2000 to 2021, with a total burned area in the past of 2 200 ha.

Figure 137 shows the final perimeters of the two largest fires that occurred in this region for the last 10 years. Fire behaviour in the larger and smaller fires follows the same behaviour pattern from North to South. In the southern parts, there are differences in the distribution, because the fire suppression measures can be done easily due to the existence of the asphalt road between the villages Malko Kirilovo and Valcha Polyana. The surrounding area along the asphalt road is regularly maintained with clear-cut techniques that helped a lot during the suppression measures of the Razdel fire in 2022, by stopping the fire propagation at that location.

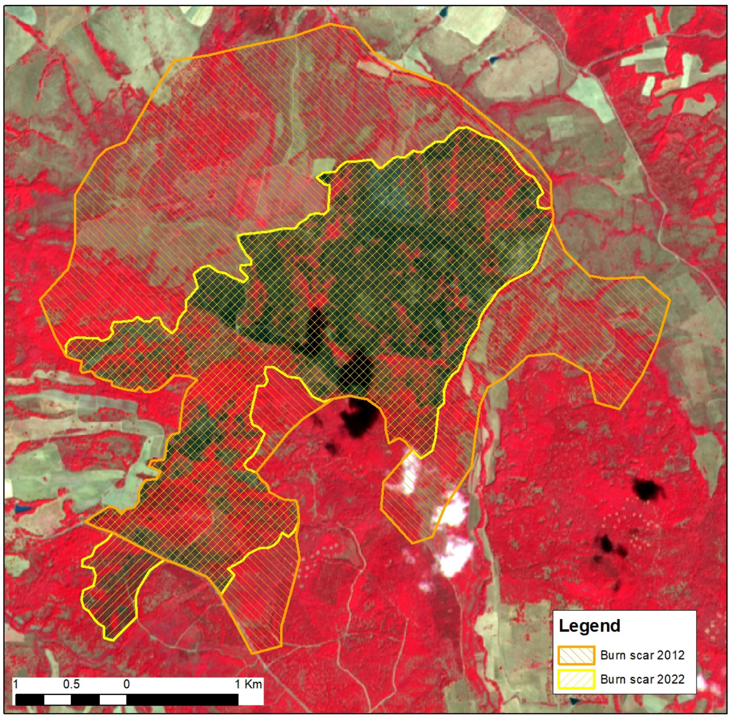


Figure 137. Burned scars of the two largest fires in the area in the last 10 years, 2012 and 2022.
Data source: Copernicus EU, Sentinel 2.

11.3 Fire conditions

Typically, in Bulgaria, the hottest month of the year is August. This is especially true for the southeast regions of the country. During August 2022, 92 fires were registered in the country which is almost one quarter of all the fires in Bulgaria for that year. The total area burned in this month was more than 50% of the total area burned in 2022. 65% of the area burned in August was in the southeast region of Bulgaria in 2022.

11.3.1 Meteorological data

The forecast for August 10th, provided by the National Institute for Meteorology and Hydrology (NIMH), was for sunny weather with a clear sky (Figure 138, and Figure 139), accompanied by strong winds from north-northeast with a speed of 6 to 9 m/s reaching up to 15 m/s. The forecast for the daily max temperatures was 32ºC to 34ºC for the region, where the Razdel Fire occurred.

(a) (b)

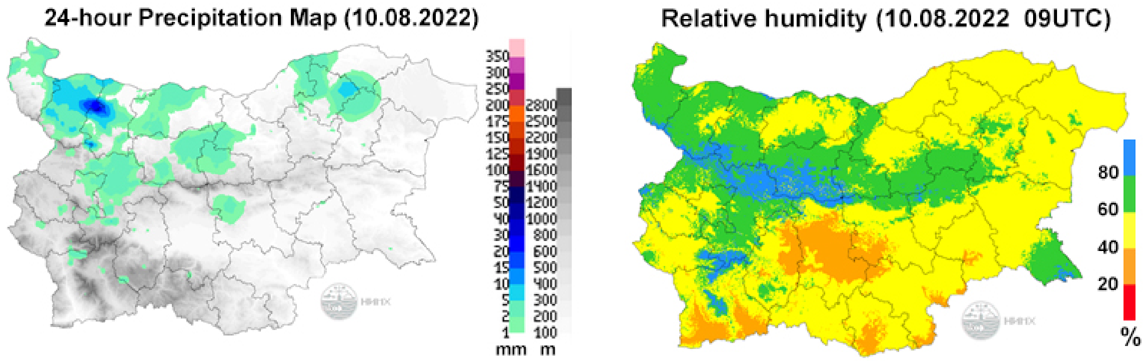


Figure 138. Meteorological parameters for August 10th, 2022: (a) 24-hour precipitation (mm); (b) Relative humidity (%).
Data source: NIMH.

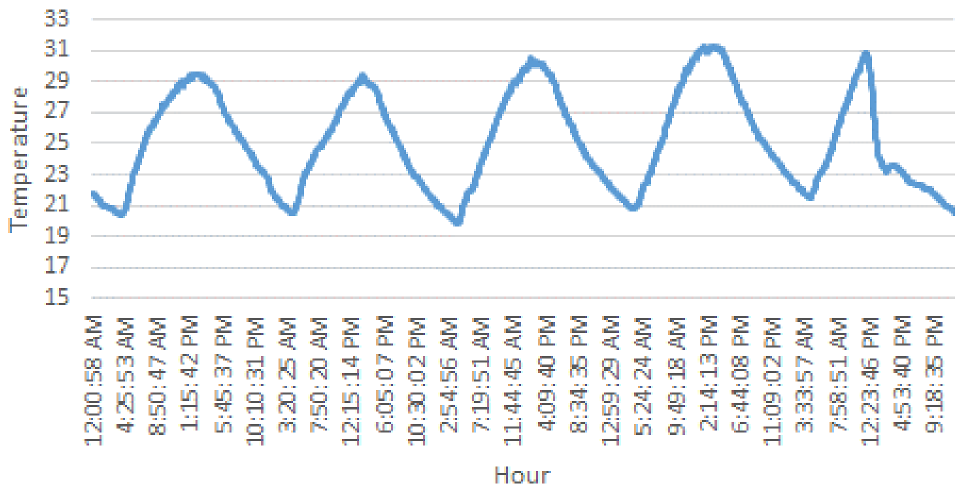


Figure 139. Hourly meteorological conditions (temperature in ºC) registered by the metre. ac from August 10th to 14th in a station located in Elhovo.
Data source: NIMH.

The wind had an important role in the fast fire perimeter spread of the Razdel Fire. As shown in Figure 140a, on August 10th, the wind was expected to be from the northwest reaching in the afternoon 10-15 m/s. This led to the fast spread of the fire in the southwest direction, but stopping the fire after reaching the top of the hill where it turns to the north (close to the village of Razdel). This could be seen in Figure 140b, which is the satellite image from Sentinel 2 from 10:55 on August 10th, taken just a few minutes after the fire started.

(a) (b)

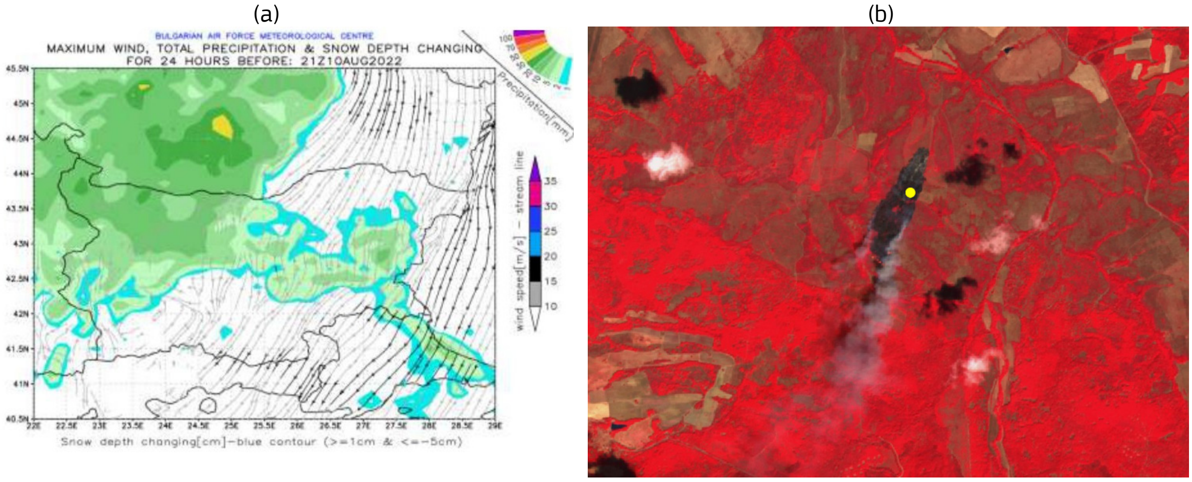


Figure 140. Wind influence on fire on August 10th: (a) Wind forecast for August 10th from NIMH; (b) Fire distribution on August 10th at 10:55, with a yellow dot, is presented the assumed start of the fire and the smoke shows the direction of the wind.

Source: (a) Copernicus EU.

11.3.2 Fuel Moisture Content of dead fine fuels

The fuel moisture content of dead fine fuels in Bulgaria has no specific measurements performed. Bulgarian territory monitoring models are not developed for fuel moisture content estimations. The only regular data sets which are provided are the outcomes from the fire danger forecast from the NIMH system, which is based on a simplified Canadian Fire Weather Index (FWI). The Bulgarian FWI has three sub-indices that indicate the "dryness" of different "fuel" types. Each of these sub-indices is a complex function of the weather elements, but land cover datasets are not taken into consideration.

Each day, the system of NIMH generates FWI forecasts for the current day and the next 48 hours (a daily fire danger map of NIMH used by the Bulgarian fire brigades). The system outcomes are maps of the country giving information on fuels classified as follows:

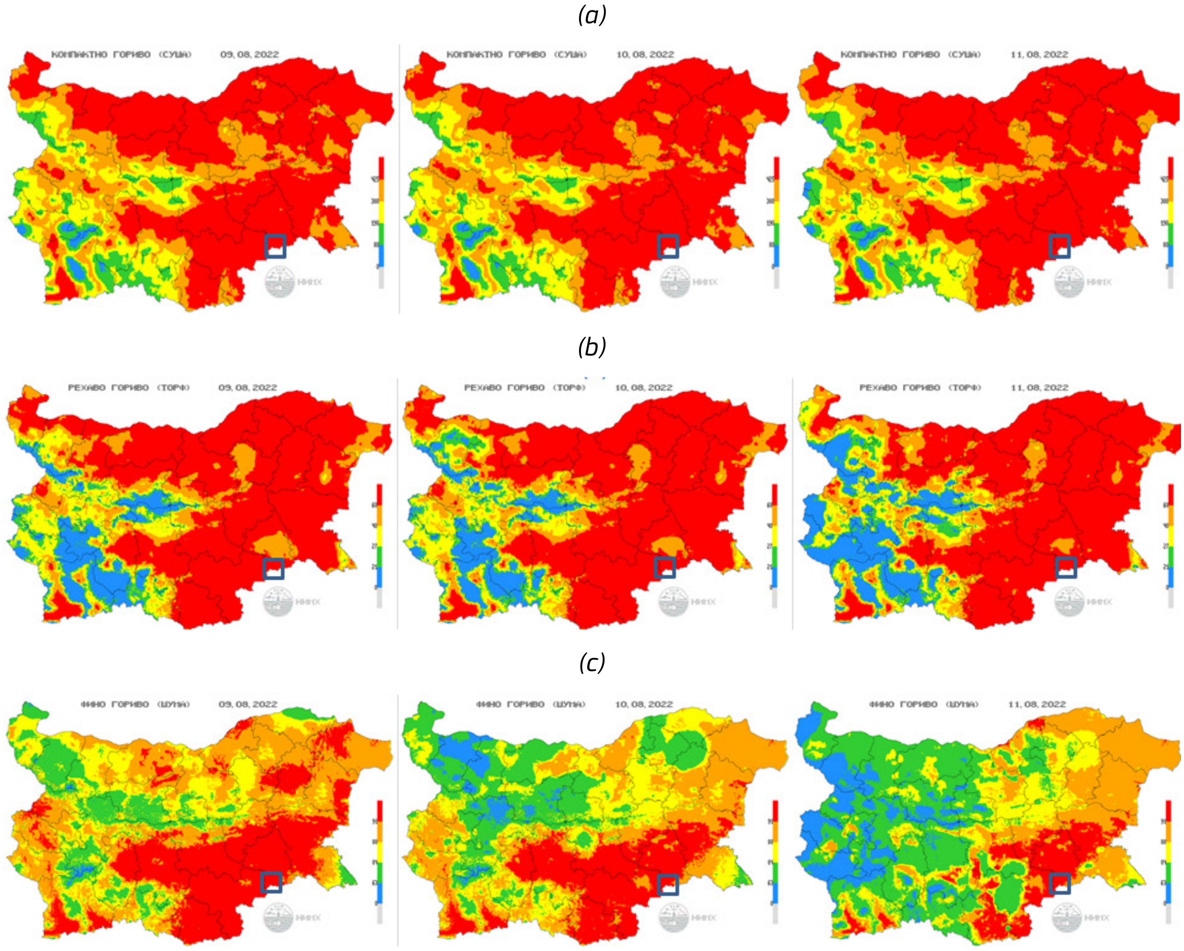
- dry compact fuel;
- loose fuel (herbaceous vegetation);
- fine fuel (leaf litter).

The system is working every year, since April 2008, in the period from April until October (usually this corresponds to the Bulgarian Fire Season). The Bulgarian simplified FWI model uses the typical parameters for FWI calculation: precipitation for the previous 24 hours; and air temperature, relative air humidity, and wind speed at noon; added by the presence of snow cover and duration of the day. The colours used in the NIMH maps are presented in Table 18.

Table 18. Fire danger classes according to NIMH and used in the Bulgarian FWI.

Degree of risk	Description
Low	Existing fires are self-extinguishing and new ones are unlikely to start. Live fires are possible only as smouldering in deep dry layers.
Moderate	Light and slow-growing fires are possible. Existing fires are easily extinguished by ground crews with pumps and hand tools.
High	Moderate to severe fires with entrainment of tree crowns are possible only locally. Fires are difficult for ground crews to control. It is often necessary to use heavy equipment to control fires (bulldozers, tanker trucks, airplanes).
Very high	Very strong fires with partial or complete involvement of tree crowns are possible. The front lines of the fires are impossible to contain by ground crews. Air attacks with a retardant are required to successfully attack the front lines of the fires.
Extreme	Fast-spreading, very intense fires with the involvement of tree crowns are possible. Fires are difficult to control. Extinguishing operations are limited to the flanks of the fire only. Only indirect actions directed against the front lines of the fires are possible.
Not calculated (snow)	No calculations are performed for this area. (Availability of snow cover).

The fuel condition maps calculated by NIMH for the day before, during, and after the Razdel Fire was for extremely dry weather (Figure 141a-c). The dry conditions were constant status for the area of Razdel Fire (red colour) from the beginning of August 2022, based on the NIMH archive maps. The dryness decreases for the fine fuels and herbaceous fuel after August 15th when rain started in the area. On August 15th, the fire was already under control, and only isolated outbreaks were left to be monitored and responded to (the last blazes were declared completely suppressed on August 17th).



Very wet	*Wet*	*Dry*	*Very dry*	*Dangerously dry*	*Not calculated (snow cover)*

Figure 141. Maps of the fuel conditions for August 9th, 10th, and 11th provided by NIMH a) Dry compact fuel, b) loose fuel (herbaceous vegetation), c) fine fuel (leaf litter).
Data source: NIMH.

11.3.3 Fire danger

An analysis of the FWI shows that, for the day before, the day after, as well as on the day of the fire, the territory of the region was in an extreme degree of fire danger (Figure 142). The fire danger bulletin as colour maps, together with additional meteorological data sets, are sent regularly from NIMH to the corresponding firefighting administrations, alerting them to plan preparedness actions. On August 9th, the Governor of Haskovo District (neighboring the Razdel fire area), announced an emergency. During emergency conditions, actions on cutting grass in pastures are prohibited by Bulgarian legislation. The reason was the high fire danger alert issued by the daily bulletin of NIMH. On August 9th three large wildfires started 30 km to 50 km southwest of the Razdel Fire ignition zone.

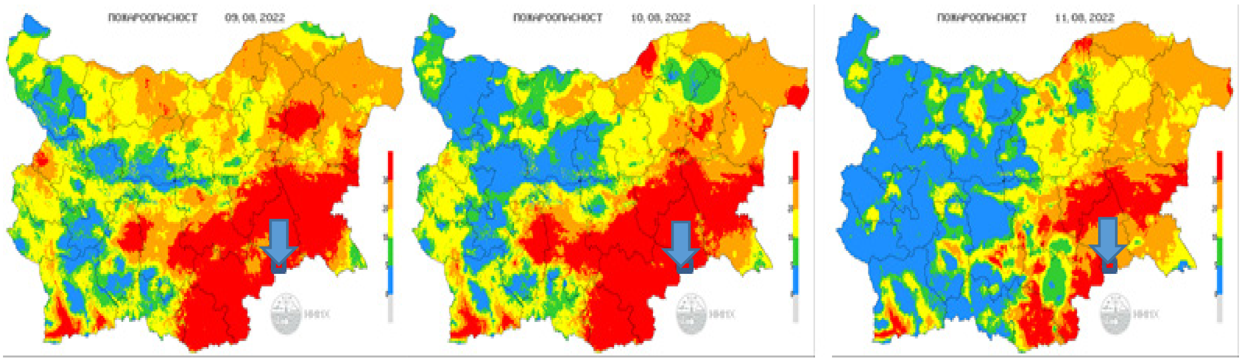


Figure 142. Fire danger maps from NIMH for August 9th, 10th, and 11th (the burned area is represented with a dark rectangle).
Data source: NIMH.

11.3.4 Fire Behaviour

In Bulgaria, fire evolution is not regularly monitored, because several datasets are missing to perform such analysis. In Figure 143, the level of destruction, calculated using the NBR-RAW (Normalized Burn Ratio), is presented. It was calculated by the IICT-BAS team for report visualization purposes. A detailed analysis of some relevant periods will be presented further in this report.

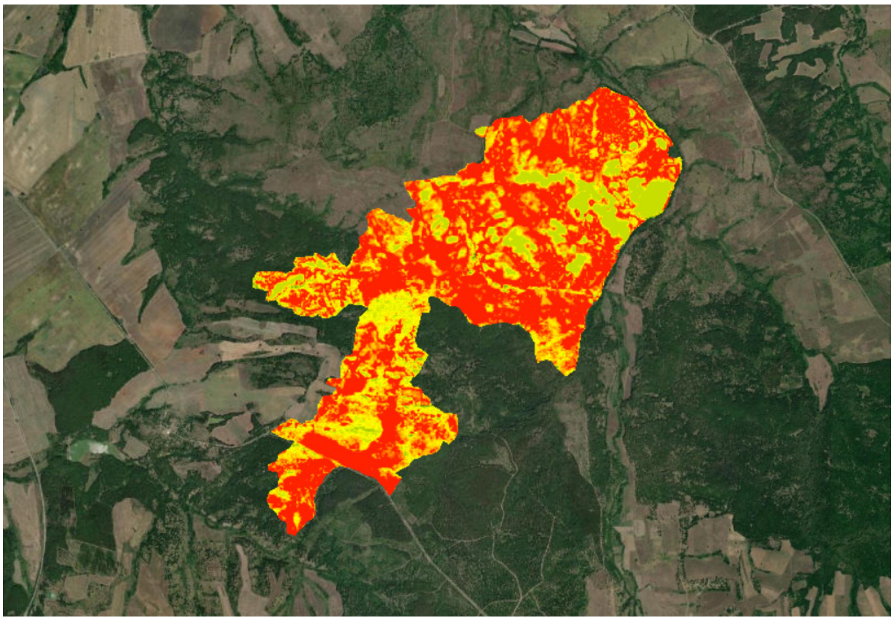


Figure 143. Degree of damage of the burned area difference between NBR-RAW (Normalized Burn Ratio) of the pre-and post-fire images / blue dot is approx. the ignition point of the Razdel Fire.
Data source: IICT-BAS (Burn severity map: red - high, green - low severity).

11.3.5 Resources allocation

The fire started close to the Razdel village, in a remote area 2.5 km from the settlement (coordinates: 42.054700°, 26.662987°). The closest firefighting station and professionals on duty are in the town of Elhovo, about 18 km from the ignition point. This station sent the first firefighting brigade to arrive by truck at the event scene, which happened shortly after the alert of the ignition was received. When the first brigade arrived, it was estimated that the fire perimeter was covering a 20 ha area. 50 minutes after the alert, two more fire trucks were sent from Elhovo and Yambol – located 56 km away from the fire. On the same day (August 10th) teams from the State Forestry Service, from Elhovo, as well as two more fire trucks from the Regional Fire Directorate and Citizen's Protection, from Yambol, were also sent to fight the fire.

Until the evening of August 10th, the fire covered an approximate area of 80 ha, spreading in a south-southeast (SSE) direction pushed by the predominant wind. The fire stopped its propagation to the north. This was possibly because the blazes reached the top of the hill where the fire started. The spread was only 800 m in this direction. During the evening, one fire truck remained on duty at the scene of the Razdel fire, following the regulations for wildland fire suppression of the Bulgarian disaster risks legislative framework.

On August 11th, the active firefighting operations continued. The western and eastern fronts of the fire were extinguished, leaving active only the southern front of the fire (Arapliyska River was used as a natural barrier to stop the fire propagation at this zone). On the satellite images it is confirmed that the eastern fire front stops when reaching the river. Due to the rise in temperatures and the appearance of strong wind in the afternoon hours, at 23:00 on August 11th, the burned area reached about 400 ha, increasing 50% from the previously burned area.

The forces engaged on August 11th were: 6 fire trucks from the Regional Fire Directorate and Citizen's Protection - Elhovo with 14 firefighters; 1 fire truck from the Regional Fire Directorate and Citizen's Protection - Yambol with 2 firefighters; State Forestry-Elhovo – 15 foresters and 1 fire truck.

On August 12th, the fire spread mainly in a southern direction towards the road from the national network III-7902. In the afternoon, at around 15:00, the fire crossed the road in one place. By order No: RD-518/12.08.2022 of the Mayor of Elhovo municipality, the municipal disaster protection plan was activated.

By 17:00 on August 12th, a firefighting helicopter from Airbase Krumovo was activated to support the ground firefighting in the suppression activities. The helicopter was used for suppression measures for the crown fires that were active in some areas and air support in surface fire spread. In general, the helicopter was not evaluated as effective as was thought when it was called on duty, because it was only one and could not help with vegetation cover as the Razdel Fire had. By the evening of August 12th, the fire in the south sector of road III-7902 was extinguished.

On August 13th the fire commander together with the local authority representatives decided to involve heavy chain machinery to participate in the suppression measures. The risk that day for the fire to continue South, approaching the Bulgarian – Turkish border, located less than 5 km, was very probable. On this day, the fire spread mainly in the southeast (SE) direction from Malko Kirilovo village to Valcha Polyana, where road III-7902 was used as a fire barrier (Figure 144).

Figure 144. Razdel Fire spread direction from the village of Malko Kirilovo to the village of Valcha Polyana, where road III-7902 was used as a fire barrier.
Data source: Google Earth Pro.

The help of heavy chain equipment to cut fuel breaks through the dense vegetation was used parallel to the road (on its northern side). In addition, a clearcut was performed perpendicular to the road in the north direction next to the existing forest road. Extra fuel management strips were performed on the south side of the road, in the section where the fire crossed the road the day before (these were protective measures for prevention of fire reoccurrence). The created strips of clear cuts and the backfire used in this zone were enough to stop the fire propagation.

The fire was surrounded by firefighters and heavy machinery, with no option to continue spreading, at 17:00 on August 13th and announced as extinguished at 22:30 on August 13th.

In Razdel Fire suppression measures were used: 11 firefighting trucks and 28 firefighters from the "Specialized operational activities" sector of the Regional Fire Directorate and Citizen's Protection located nearby the Razdel village zone. One bulldozer from "Mini Maritsa-East" EAD (coal powerplant), an MI-17 helicopter from Airbase Krumovo, and one tow truck. 38 foresters with 10 offroad cars, participated from the State Forestry Elhovo and the neighbouring State Forestry Tundzha.

The estimations done by the firefighting brigades show that the fire covers a total area of over 797 ha. According to data from the State Forestry Elhovo 580 ha of forest territories were burned, divided as follows: 392 ha of deciduous forest (90 ha - crown fire and 302 ha surface fire), 4.3 ha of coniferous forest (surface fire) and 184 ha of areas not suitable for forestry. Young crops - 58.3 ha, up to 10 year old deciduous forests, artificially created were also burned.

To establish the causes of the fire, pre-trial investigations have been initiated. According to its findings and the Regional Office "Police" – Elhovo pieces of evidence collection, it was assumed that a spark released from a bush cutter during pasture cleaning was the most probable fire ignition cause.

11.4 Fire management at the WUI

The Razdel Fire occurred and spread mostly in a rural area, with only 3 villages in close vicinity (Figure 145) – Razdel, Malko Kirilovo, and Valcha Polyana. The main impact of the fire propagation was on forests, as the firefighting brigades were focused on the fire not reaching the road from the national network II-7902 leading to the Bulgarian – Turkish border (the road was only 2.5 km away from the fire perimeter). The other main concern of the local authorities was not reaching the Turkish territory – only 5 km in the South. During the field trip of the IICT-BAS team, together with the chief inspector from the Regional Directorate "Regional Fire Directorate and Citizen's Protection"- Yambol, were visited the main points where specific actions to stop the fire spread were performed. All the forest types affected during the fire spread were also registered.

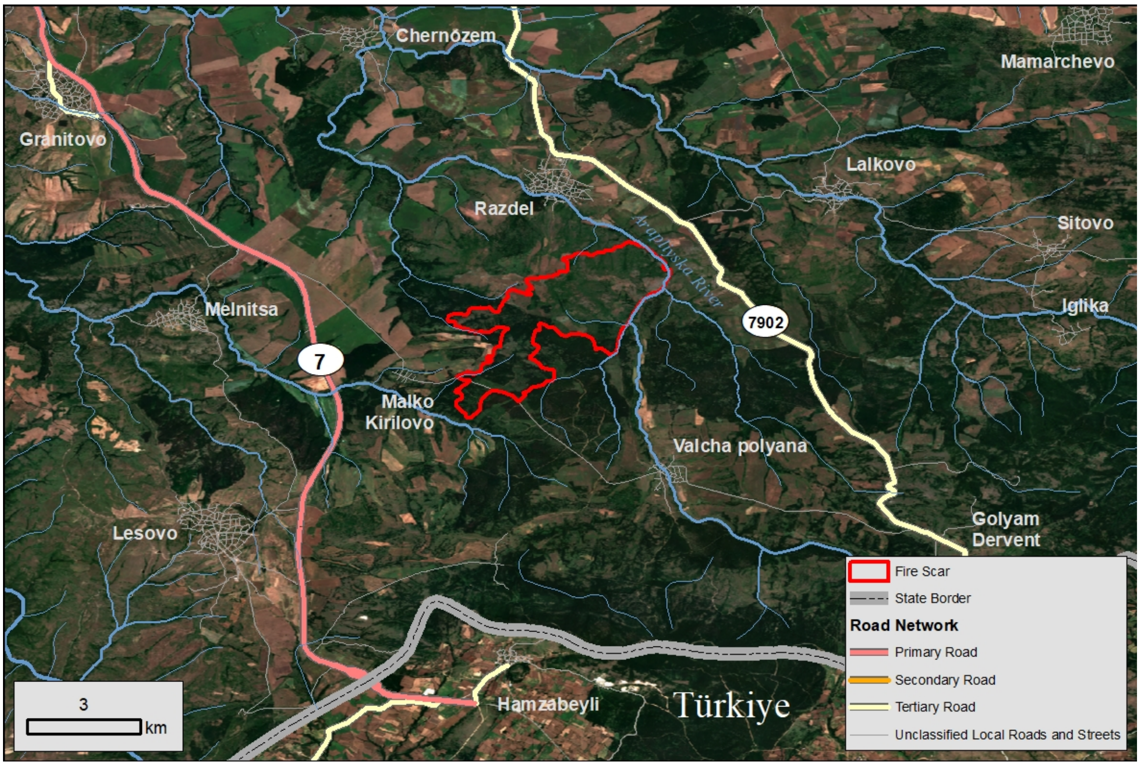


Figure 145. Location of the Razdel Fire burned scar and vicinity to urban, and road infrastructure.
Data source: IICT-BAS.

11.4.1 Damage to buildings and other infrastructures

Three villages – Razdel, Malko Kirilovo, and Valcha Polyana – were directly affected by the fire. The number of inhabitants of the villages is Razdel (161), Malko Kirilovo (5), and Valcha Polyana (14). Casualties from Razdel Fire were not registered.

The two closest villages to the Razdel Fire were Razdel village and Malko Kirilovo village. Razdel village is located north of the fire. Due to the wind coming from the northeast, this community was in no direct danger for its infrastructure and population. The fire spread 800 m during the first hour, reaching the top of the hill in the north direction due to the local topography and wind. The efforts of the firefighters stopped the fire front propagation before heading to the village of Razdel.

On the second day (August 11th), the fire reached 1.5 km from Malko Kirilovo village. The existing secondary road on the west boundary of the fire was enlarged. This together with the fact that the western part of the fire perimeter was agricultural fields, stopped the fire progression in this direction, and it continued towards South, reaching the asphalt road between Malko Kirilovo and Valcha Polyana. This was one of the firefighting opportunities which was used by the firefighters to stop the fire spread in the South.

The only infrastructure damaged was part of a secondary road caused by a heavy bulldozer brought to this location to build a fuel break (Figure 146). The bulldozer broke an electric supply line and stopped the electricity to the nearby villages.

Figure 146. The road which was used as a border to stop the fire going south direction between Malko Kirilovo and Valcha Polyana and fire prevention measures next to the road before the pine forest.

The strategy used by the firefighters to protect the Valcha Polyana village from the Razdel Fire blazes was efficient. The road presence gave the fire brigades a useful fuel break that was enough to stop the fire from reaching Valcha Polyana village. The local authorities face regular wildland fires in this area, thus prevention measures such as buffer zones along the villages can be a good solution for future events. Clearcuts around the villages preventing future fire events from approaching houses, could be another good preventive measure for human and infrastructure safety.

11.5 Cascading effects

The main damages in the Razdel Fire were in the forest areas. The area is a mix of pastures (some of them unmanaged), shrub areas (almost exclusively from *Paliurus spina-christi*), artificially planted coniferous forests, and broadleaf coppice forests. As the area is in NATURA 2000 protected zone all three vegetation has understory and undergrowth, which is a big disadvantage in fire suppression measures.

11.5.1 Fire ignition area (shrubland – Area 01 and Area 02)

The starting point of the fire was in a pasture with the presence of *Paliurus spina-christi*. According to the investigation carried out, the most probable ignition cause was mowing pasture work to remove Paliurus, which produced a spark in a dry vegetation, igniting the Razdel Fire. The bushes of Paliurus are distributed 1 km south of the starting point of the fire which causes the spreading of the fire at a very high speed combined with the wind coming from north. A total area of 1.5 km^2 was burned after 2.5 hours. A landscape view of the most probable ignition point of the Razdel Fire is presented in Figure 147.

(a) *(b)*

Figure 147. Area 01 and 02. The pasture (a) of the ignition area with the neighbouring hill with burned bushes from Paliurus (b).

11.5.2 Area 03 Young coniferous forest

On the west and southwest of the shrubs of Area 02, young plantations of *Pinus sylvestris, Pinus nigra,* and cedar are located. Some of them were separated by the shrub area with a forest secondary road which acted as a fuel break, thus the fire did not spread there. Most of the fire brigade forces were focused on the south side of the perimeter and consequently, the fire spread towards the west causing a complete burning of a small area of *Pinus sylvestris*. After that zone, the fire did not continue to the west. Figure 148 represents a landscape view of the fire break, the forest secondary road.

(a) *(b)*

Figure 148. Area 03 Burned young coniferous forest: cedar (a) and pine (b).

11.5.3 Area 04 and 05 – Acacia area and pasture before the deciduous forest

When the fire reached the top of the hill with Paliurus, due to the wind and because it was difficult to protect this area (relief specificity, strong wind), the fire continued south and reached young (~5 years) acacia forest Figure 149a. This forest burned completely very fast as it was quite dense. The secondary forest road in the direction of the east-west was not enough to stop the fire due to its high intensity, so it spread on the pasture (with small bushes Figure 149b) just close to the deciduous forest with *Quercus Cerris* and *Quercus frainetto*.

(a) *(b)*

Figure 149. Area 04 and 05 Forest with acacia (a) and pastures with bushes (b) between the hill and the deciduous forest.

11.5.4 Area 06 and 07 – Mixed Forest of *Quercus Cerris* and *Quercus Frainetto*

Areas 06 and 07 are mixed forests of *Quercus Cerris* and *Quercus Frainetto*. The forest is around 50 years old with moderate crown density and understory. Here the fire spread was a surface fire and the main firefighting resources were focused on the road passing in the west border of the forest, preventing the fire from crossing it and reaching the neighbouring hill. Unfortunately, in one stretch of the road, the fire crossed and continued west. The interviewed firefighters mentioned that about 1 km west, another second fire started. This new ignition was unlikely to result from spotting caused by the main Razdel fire front. The most probable assumption was that a fire camp of refugees passing in that area was the reason for the second fire occurrence. The spreading in the west was stopped and the fire continued only in the southern direction as a surface fire. Figure 150a represents the Quercus Forest, and Figure 150b represents the fire break that helped the firefighters to stop the fire spread.

(a) *(b)*

Figure 150. Area 06 and 07. The Quercus Forest (a) and the road on the west (b) used as a fire break.

11.5.5 Area 08 and 09 - Mixed Forest of *Pinus Nigra* and *Pinus Sylvestris* with deciduous species

The area between the forest of *Quercus Cerris* and the asphalt road between Malko Kirilovo and Valcha Polyana is covered with various types of mixed forest - mixed deciduous forest, and mixed coniferous (Figure 151) with deciduous species. The firefighting was focused mainly in the areas around the existing roads – the asphalt road on the south (which was assumed as a final opportunity where the fire should be stopped), and the secondary forestry road enlarged with heavy machinery to stop the fire spreading in an eastern direction. Coniferous trees affected during the Razdel Fire were cut later in the autumn of 2022. The fire in this area spread as a surface fire mostly, as can be seen in Figure 151b. The tree trunks were severely damaged, but the crowns were intact.

(a)

(b)

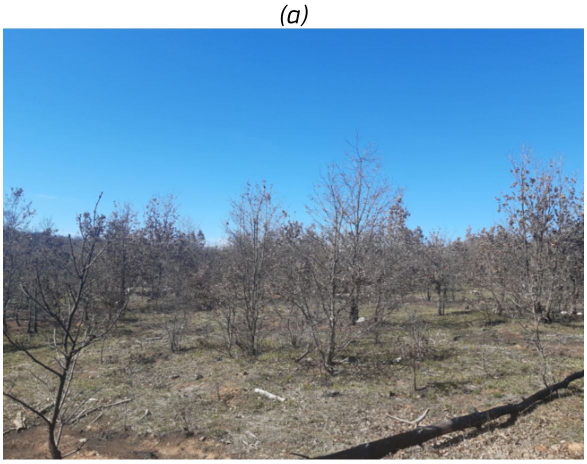
Figure 151. Area 08 and 09 Mixed forests of *Pinus Sylvestris* (a) and *Pinus Nigra* (b) with deciduous species.

11.5.6 Area 10 - Area with young *Quercus Cerris* and mixed forest

The forest before the asphalt road between Malko Kirilovo and Valcha Polyana is a mixed forest with a predominance of *Quercus Cerris*, *Quercus Frainetto,* and *Pinus Sylvestris* (Figure 152). It is a mixed forest of 25 to 45 year old trees. All the trees were no taller than 3-5 m, especially in the area with a predominance of coniferous forest. The active crown fire was present in this zone of the Razdel Fire.

The area between Malko Kirilovo and Valcha Polyana villages was the zone where the helicopter and all extra firefighting forces were called on duty to stop the fire propagation in the south direction. That was crucial because the Bulgarian-Turkish border was only 5 km away and the weather conditions were favourable for the fire to spread into North Turkey if not stopped in this zone in Bulgaria.

(a)



(b)

Figure 152. a) Area 10 mixed deciduous forest b) just before the asphalt road between Malko Kirilovo and Valcha Polyana.

11.5.7 Area 11 and 12 – Area south of the road and artificial clearing to stop the fire

Despite all the firefighting efforts, the fire crossed the asphalt road in one place and continued in a southerly direction. Here the forest was denser with a heavy understory (more than the forest in the north). The last big fire that consumed the fuels in this zone was in 2012. Secondary forest roads were built to separate deciduous from the coniferous forest and were enlarged with heavy machinery to stop the fire in the eastern direction.

Since the international Bulgarian - Turkish border was only 5 km away from this location, it was decided to use a specialized and more efficient bulldozer from the coal mines "Mini Maritsa-East" EAD which made a new wide clear cut around the fire from the south. This measure stopped the fire spread, which was extinguished in the following couple of days.

(a) *(b)*

Figure 153. Area 11 Mixed deciduous forest with understory.

(a) *(b)*

Figure 154. The secondary forest road west of Area 11 (a) and the new extended one (b).

11.6 Conclusions and Lessons Learned

The Radel Fire started at a relatively close distance to the firefighting brigades and the first response was within an hour. The dry vegetation in the area – small bushes and a forest with an understory – was the main reason for the difficulties in fire extinguishing.

The affected area is protected by the Natura2000 sites. According to the national legislation, in such areas the mowing of meadows and pastures is forbidden until July 1st. Farmers can clean their pastures from that date onward and receive national support for agricultural work. The mowing is done with mulchers mounted on tractors. When the mulcher passes through stone or rock, sparks are produced, which may cause an ignition in the surrounding dry vegetation. Probably, this was the ignition cause of the Razdel Fire - two tractors burned by the fire were found on the closest road after the fire was extinguished and local authorities did their first evaluations on the fire perimeter. An investigation into the fire causes was still being conducted by 31st July 2023, when this report was finalized, but this is the most probable reason for the Razdel fire start. Other similar wildland fire events were activated during the mowing of meadows in previous years. It is common also for farmers from this zone to burn pastures eliminating bushes, even if it is illegal based on the Bulgarian law for prescribed burning and open fires. Yambol District, together with Haskovo District are the two administrative units with the highest number of fires and pasture burns in Bulgaria. The characteristics of vegetation along with very favourable weather conditions during summer and agricultural maintenance of pastures after July 1st make the southeast part of Bulgaria the most fire-prone zone in the country. Just the day before the fire (August 9th, 2022), several other small fires started in the closest municipalities (Copernicus image of parallel smaller fires Figure 155).

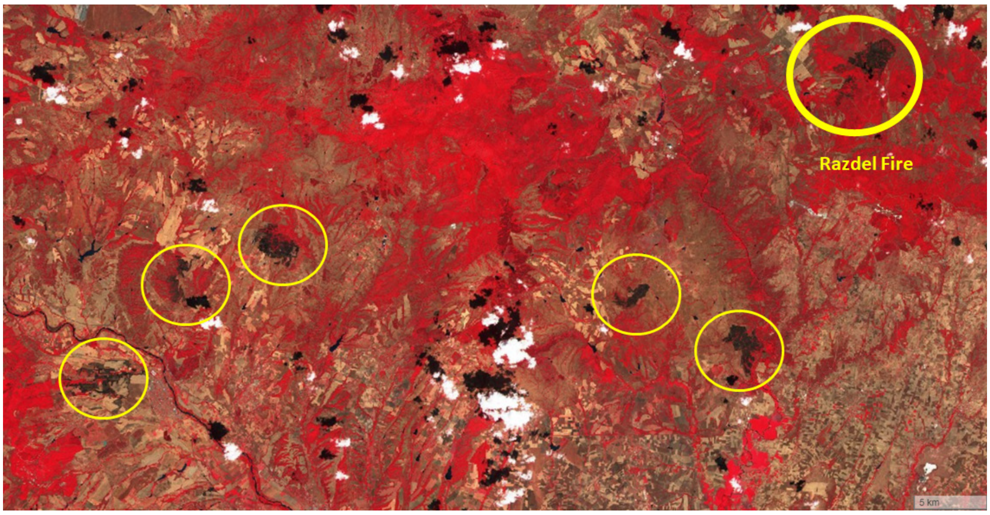


Figure 155. Burnt area in July-August 2022 in the vicinity of Razdel fire.
Data source: Sentinel 2 (Copernicus EU).

Although the local governor announced an emergency for August 9th, 2022, it was violated by the local farmers. A year after this event there are still fires that happen due to the same reason – pasture burns or pasture mulching. Local authorities are looking for a sustainable solution for the years to come trying to prevent more fires of such size.

Another lesson learned by the local authorities was that the decisions to deal with wildland fires require expensive measures and timely activities, which cannot be taken by the local fire commanders. Decisions can be made, by legislation, at the regional or national level for fires above a certain size and fire spread rate. The waiting time is the time during which the fire is growing and putting at risk all suppression measures. For vulnerable areas close to the national borders the suppression measures should be more time efficient, and recommendations were sent to the Bulgarian Ministry of Interior for improvements in the response algorithms.

The territory of the Razdel fire is located at the foot of the westernmost low slopes of Strandzha Mountain. The rivers passing through it are small and dry up in the summer. The larger dams that can be used to fill the firefighting trucks with water are located to the north but are far away from the hazard area. Small dams which were near the fire location, were used from the helicopter and smaller cars to bring water for the fire suppression measures. The roads used by the cars were secondary small forestry roads. A lesson learned from the Razdel Fire is that in the zones regularly affected by wildland fires, there must be well-maintained secondary forest roads for both fuel/fire break and water supply measures. Due to logging, heavy trucks are damaging these secondary forest roads making them useless for smaller cars or firefighting trucks to pass in cases of emergency. Regular maintenance of such roads was accepted to be performed by the local authorities.

Finally, the Razdel fire zone has a large presence of refugees. The Bulgarian - Turkish border is only 10 km away. These people use the forest areas to cross the border unnoticed and move into the inner parts of the country. During the site visit, clothes, backpacks, and other belongings of refugees were observed throughout the area. Very often the refugees light a fire to keep warm or for other reasons that can lead to a fire. On the national level is decided that a more active solution for refugee control must be taken and such open fires to be eliminated.

References

Census 2011, 2021; ** Census 2011 (NSI, Bulgaria)

Agricultural Census 2020, Information system for agro statistics

Daily fire danger map of NIMH is available at: https://weather.bg/0index.php?koiFail=modelsFire&lng=0

NATIONAL SECURITY DEFENSE SYSTEM MANAGEMENT AND OPERATIONAL RESPONSE (in force since 01.11.2015): https://lex.bg/en/laws/ldoc/2136588572

URL:

http://www.weather.bg/pojaroopasnostPlus/index.php A daily fire danger map of Bulgaria provided as online service in NIMH. Link accessed on 15 July 2023

12 Wildfires in Ukraine in times of war

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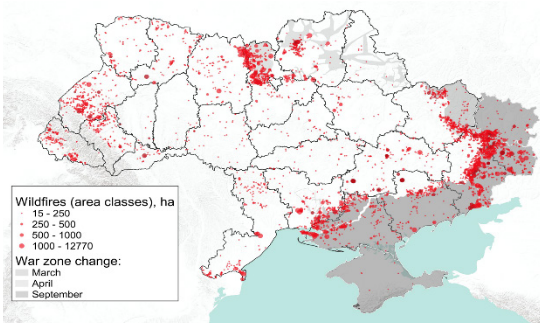

12.1 Introduction

From 1990 to 2020, farmers and rural populations in Ukraine extensively employed controlled burns as a tool for pre-harvest or post-harvest clearance of vegetation residues on croplands, vegetable gardens, pastures and other land categories. This practice stemmed from the privatization of agricultural lands coupled with a lack of technical, technological and financial support for farmers and small landowners from the government. Periodically, during severe dry spells, which commonly occur in spring (April) and summer (July-August), uncontrolled agricultural burnings spread beyond croplands into forests, desiccated wetlands and protected areas, resulting in large wildfires that cause severe damage to the natural and cultural landscapes, including society living therein. Before 2020, wildfires were generally well-managed, and the average annual area of forest fires did not exceed 5 000 to 7 000 ha.

Over the past decade, climate change has heightened the risk of large fires by creating conditions for an increasing recurrence of heatwaves, droughts and windy weather. On the one hand, the high amount of combustible materials in the landscapes resulted in a high wildfire potential. On the other hand, weakness of performance and coordination of responsibilities between public agencies, notably the State Agency of Forest Resources of Ukraine and the State Emergency Service of Ukraine (SESU), which are responsible for prevention and suppression of wildfires, as well as a lack of experience in controlling large fires, have contributed to the catastrophic fires of 2020. Between April and October 2020, three major fires in the Chornobyl Exclusion Zone (CEZ), Zhytomyr oblast (i.e., region) and Luhansk oblast destroyed at least 170 000 ha of mainly pure pine forest land and the surrounding areas. For the first time in Ukraine's history, 22 villages were directly affected by forest fires, leading to fatalities and significant damages of residential areas and critical infrastructure.

On February 24th, 2022, the Russian Federation's military forces invaded Ukraine. The war of aggression spanned vast territories from Belarus to the Azov/Black Sea. Russian military operations involving the movement of hundreds of thousands of soldiers, armoured equipment, tanks, rockets and artillery shelling, aerial bombing, including phosphorous bombs, resulted in extensive collateral damage including wildfires in ecosystems that civilian fire brigades found impossible to tackle. The most intense shelling and burning damage was observed in shelterbelts and pine forests, as these areas were used by military forces to evade detection by drones and satellites. After more than 500 days of rigorous military operations along the Belarusian and Russian border with Ukraine, the contamination of over 1.6 million hectares of land by unexploded ordnance (UXO) and landmines became the most pressing challenge in fire management.

12.2 Fire management on territories contaminated by UXO and landmines

Specialists of mine action teams of the State Emergency Service of Ukraine (SESU) identified at least 70 types of UXO, including anti-tank mines, various types of ground force-targeting mines, and remnants from shelling. These were found across occupied territories, in places like villages, shelterbelts, agricultural fields, vegetable gardens, pastures, forests and roadsides. Periodic fires in these areas often led to UXO detonations, which frequently resulted in injuries and deaths. Land mines have impacted the lives and health of hundreds of Ukrainian citizens. Over 700 agricultural and forestry tractors, used for regular land and forest management practices, were severely damaged by mines. Foresters and firefighters are among the most vulnerable groups residing in liberated areas that remain affected by UXO contamination.

The contamination of forests by UXO has placed significant constraints on routine fire management, necessitating special measures to safeguard the lives and security of personnel. The implementation of Martial Law by the Ukrainian Parliament in February makes it almost impossible to prevent and control large fires. Restrictions now prohibit activities like the use of fire aviation, fire detection cameras, publishing maps, patrolling territories off hard roads, radio station usage, the establishment of firebreaks, and many other standard fire management procedures. SESU, which actively participated in combating large forest fires before the war, had to shift its focus towards protecting citizens from rocket and drone attacks and supporting their daily needs like supply of water, electricity and other essentials. Many forest firefighters have enlisted in the Ukrainian Armed Forces, and key elements of fire management infrastructure like fire lookout towers, fire detection cameras, fire engines, and other special equipment were removed or destroyed during the occupation of Zhytomyr, Kyiv, Chernihiv, Sumy, Kharkiv, Luhansk, Donetsk, Kherson, and other oblasts.

Contamination of forests by UXO and landmines is a widespread aftermath of wars, seen more recently in regions like the Balkans, Afghanistan, Iraq, and various countries across Africa, South America, and Asia (Goldammer, 2013). This was highlighted recently in Germany's Brandenburg region where fires in former Soviet military test areas detonated hidden WWII-era UXO. Specialized international NGOs such as Fondation Suisse de Déminage (FSD), Hazardous Area Life-support Organization **(**HALO Trust), the Geneva International Centre for Humanitarian Demining, Danish Demining Group, the Croatian Centre for Anti-Mine Activities, and others, have over the years developed various methodologies to clear forests of UXO and landmines. However, these mine clearance operations are often costly.

At present, the Ukrainian Government is focusing on clearing settlements, agricultural lands and roads in territories yet to be liberated from unexploded ordnance and landmines. A Special State Mine Action Centre has been established to coordinate the efforts of various agencies, NGOs, and international donors. Forest clearance is projected to commence in 2030, once all other areas have been deemed safe. The demining process in forests is very slow, season-dependent, and involves several stages: personnel training, planning, public risk awareness campaigns, and the work of technical and non-technical survey teams. It requires significant financial and technical support, amounting to millions of dollars.

12.3 Number and area of landscape fires during 2022 in Ukraine

Over the past decade, climate change and land use modifications have led to an increased frequency of large fires, reaching an unprecedented level. The fire season in 2020 was the most severe in modern Ukrainian history, with an extraordinary extent of forest fires. In the Luhansk oblast, forest fires spread to villages, destroying over 730 homes, resulting in 17 fatalities and injuring 861 people (SESU, 2021; Soshenskyi *et al*., 2022). In 2020, forest fires affected seven villages and damaged 82 homes in the Zhytomyr oblast, destroyed 22 private residences in the Kharkiv oblast, and caused an estimated 8.5 billion UAH in damages to natural landscapes within the CEZ (Soshenskyi *et al*., 2021).

The large fires of 2020 exposed various shortcomings in the operations of the agencies responsible for landscape fire management and civil protection. These included a lack of interagency coordination during fire prevention and suppression efforts, poor preparedness levels, and insufficient use of scientific data for risk assessment and fire weather forecasting. Presently, official data on the area affected by fires, which is based on reports from various agencies, does not accurately reflect the reality. For instance, the State Statistics Committee of Ukraine reported 28 056 ha of forest dieback from fires in 2020 and only 6 310 ha in 2022. However, the total area of landscape fires, encompassing fires in forests, cropland fires, degraded land fires, and others across different landscape types is not officially accounted for in Ukraine.

Following the outbreak of war on February 24th, the Regional Eastern Europe Fire Monitoring Centre (REEFMC), with the support of ZOÏ Environment Network, began tracking every landscape fire using remote sensing techniques. Fire perimeters were mapped using time series of surface reflectance from Sentinel-2 images (level 2A), based on the locations and dates of the fires. These fire perimeters were manually delineated from the images. According to SESU, around 30% of Ukraine's territory – equating to 17.4 million hectares of land – is mined. This significantly increases the risk of large and catastrophic fires in the future due to limitations in access.

Within the delineated fire perimeters, the area of each fire was classified by land cover type using the latest published Copernicus land cover map with a 100 m resolution for 2019 (Buchhorn *et al*., 2020). Daily frontline coordinates, provided by ZOÏ, were also utilized to categorize each detected fire into one of three zones: government-controlled, battle zone (extending 30 km on both sides of the frontline), and occupied zone (cf. Table 19, Figure 157).

In 2022, fires affected a total of 754 941 ha in Ukraine. Most of the affected areas were agricultural lands, accounting for 419 112 ha, and abandoned non-forested lands, amounting to 273 674 ha. Forest fires consumed 56 595 ha. Altogether, around 19 930 fires were detected in 2022. A significant proportion of these fires occurred within a 60 km buffer zone along the frontline, comprising 69% of the total fire-affected area, and 43% of all fires took place in occupied territories.

Table 19. Monthly distribution of fires by landscape type in Ukraine in 2022.

Month Category	Number of fires	Area of fires (ha)	Distribution of fire area by types of landscapes (ha)				
			Forests	Thereof coniferous	Agricultural lands	Other natural landscapes	Settlements
January	17	1 881	1	0	206	1 269	405
February	241	11 350	194	33	6 257	4 621	278
March	7 513	301 727	19 318	6 361	136 254	144 116	2 039
April	1 111	26 461	2 790	573	8 722	14 716	233
May	1 854	46 985	18 187	14 105	6 311	21 974	513
June	1 116	20 852	1 605	984	9 918	9 118	211
July	5 418	213 189	6 424	4 097	163 616	42 335	814
August	2 398	114 313	4 180	2 008	84 035	25 496	602
September	161	10 781	3 206	2 328	2 913	4 621	41
October	53	4 663	385	346	230	3 953	95
November	41	2 363	303	275	420	1311	329
December	7	376	2	0	230	144	0
Total	19 930	754 941	56 595	31 110	419 112	273 674	5 560
Military Combat Zone[4]	12 734	520 376	46 522	30 055	300 627	169 319	3 908
Occupied Territories	7 095	321 056	22 787	13 918	186 259	109 732	2 278
Conservation Areas (Emerald Network)	803	88 427	25 358	17 426	10 767	52 243	59

The territories most affected by fires are those where active military operations were ongoing in the eastern, southern and northern parts of Ukraine. Specifically, the most significantly impacted oblasts were Donetsk (146 300 ha), Kherson (84 100 ha), Kyiv (70 900 ha), Zaporizhia (65 600 ha), Luhansk (65 600 ha), Mykolaiv (47 700 ha), and Kharkiv (42 600 ha).

In 2022, landscape fires across Ukraine resulted in the prompt release of over 1.4 million tons of carbon, averaging about 4 ton/ha. The greatest contributors to these carbon emissions were fires on croplands (62.8%), abandoned lands (25.5%), and forests (11.7%). Almost half of the carbon emissions, 48%, were caused by fires in the occupied territories of Ukraine (Zibtsev *et al*., 2023). The net release and thus the long-term impacts of the carbon emissions on the composition of the atmosphere and thus climate change will be determined by the recovery of fire-damages ecosystems and the subsequent sequestration of atmospheric carbon.

[4] *Military Combat Zone: This term refers to a permanent corridor extending 30 km on either side of the Line of Contact (LoC). This corridor is established at the onset of active military combat and continues to be a part of the monitoring areas, even after active military combat operations cease. The reason behind this is the presence of unexploded ordnance in the area, which continue to pose a significant ignition threat.*

12.4 Impact of war on fires within ecosystems

While most fires affect vegetation across all types of land cover, the most extensive and rapidly spreading fires predominantly occur on croplands. These fires often damage agricultural crops like wheat, rye, corn and sunflowers at varying growth stages. Several fields that were not seeded in spring of 2022 and which had been subjected to ecological succession, were affected by wildfires. Uncontrolled fires on croplands often spread to other types of land cover, igniting pine forests, sparse vegetation, wetlands, reeds, pastures etc.

Fires adversely affect large areas, primarily through the intense heat (300-500°C) they generate, which devastates black soil by destroying organic humus and available nutrients, particularly nitrogen, which results in diminished crop yields post-war. Small animals and soil microbiota, unable to escape the fires, are also significantly impacted. Furthermore, fires on agricultural lands are responsible for most carbon emissions, particularly emission of black carbon, which is transported airborne over long distances and deposited, among other, on highly vulnerable ecosystems including the Arctic.

The most diverse and enduring negative effects are observed in the shelterbelts and extensive pine forests in the East and South of Ukraine. Situated at the edge of their natural water and nutrient zones, these pine forests are highly vulnerable to even moderate disturbances. The traditional approach of dense planting, about 5 000 to 6 000 seedlings per hectare, coupled with infrequent or absent thinning, leaves individual trees nearly incapable of survival. At the same time, such dense pine forests create ideal conditions for crown fires, as exemplified by the Luhansk fires in 2020. When these fires reach high intensities, they become difficult and sometimes impossible to control. Wind can carry burning particles over 500 m ahead of the fire's frontline, igniting various land covers, villages, and infrastructure. The presence of UXO and landmines in these forests complicates fire control efforts, making them almost unmanageable unless trained and specially protected professional firefighters are setting backfires (counter firing / suppression firing).

Severe fires can inflict high-temperature damage to tree bark up to 8-10 m in height, leading to their immediate or gradual decline and dieback. Even fire-adapted species, such as Scots pine over 50 years old with thick bark, can be weakened and deteriorate (Sydorenko *et al.*, 2021). When these trees fall due to snow, wind, or other natural disturbances, they add to the fuel loads that will create a higher wildfire hazard and make suppression of future fires more difficult. In war and UXO contaminated zones, forest fires typically go unaddressed due to the risk they pose to human safety. As a result, these fires often persist for weeks or even months until they are stopped by fire breaks (roads, rivers, hardwoods etc.), weather events, or until all ground litter is consumed.

Depending on the drought level and wind speed, fires in these UXO zones can be either fast – burning only the surface litter, or slow – consuming all surface fuels, damaging the topsoil layer and tree roots within the upper 5-10 cm of soil. Regardless of the fire type (slow/fast, surface/deep, ground/crown), all other elements of forest ecosystems, such as grass layers, brushes, and undergrowth, are usually destroyed.

A war-specific type of forest fire is one ignited by phosphorus bombs and shelling under any weather condition, typically short-lived unless the Fire Weather Index (FWI) is high. Most forest animals, birds, and other organisms try to escape the fires or perish if unable to do so, leading to fatal consequences for forest ecosystems.

12.5 Fire conditions

12.5.1 Meteorological conditions in 2022

In the 2022 fire season, cold and rainy weather in regions most vulnerable due to active combat mitigated fire risks. These regions include Chernihiv, Sumy, Kharkiv, Poltava, Dnipro and Luhansk.

Government-controlled weather stations in war-affected regions (Zhytomyr, Kyiv, Sumy, Kharkiv, Luhansk, Donetsk, Zaporizhia, Kherson, Mykolaiv) recorded significant precipitation, particularly in the spring and autumn. April and May saw 21.2 and 16.3 mm more rainfall than the long-term average. In contrast, June and July experienced a precipitation deficit (10.9 and 0.2 mm respectively) and relatively high temperatures (25°C), creating hazardous fire conditions, especially in pine forests. Despite this, wildfire spread was limited in open landscapes due to high moisture content in grasslands and some agricultural landscapes. From August to the end of the fire season, significant rainfall occurred, with levels 100 mm higher than the regions' average long-term rate.

Another critical element of fire weather that significantly influenced fire behaviour during the 2022 fire season was high wind speed, especially at the start of the fire season in early spring. In April, maximum wind speeds reached up to 37.2 km/h. This, combined with the availability of fuel in open landscapes (dry grass) and the collapse of the fire management system in regions with active combat, led to large wildfires. Midway through the fire season, maximum wind speeds rarely exceeded 21.2 km/h, only picking up again towards the end of the season, with wind speeds reaching a maximum of 26.7 km/h in October.

12.5.2 Fire danger

Given the difference in fire weather conditions in 2022 compared to other years, we conducted an analysis comparing the average Fire Weather Index (FWI) during the Russian invasion in 2022 and the period from 1988 to 2021. The FWI, a commonly used index that indicates fire danger based on weather conditions, was chosen for this analysis. The choice of FWI was also informed by the fact that a new fire danger methodology was only implemented in Ukraine in 2018, and there is no official historical fire danger archive for years prior to 2018. FWI index calculations for the territory of Ukraine were performed on the Climate Data Store platform provided by Copernicus (https://cds.climate.copernicus.eu/) using custom Python scripts. The "cells-fire-historical" database, containing daily FWI values, was used as input data. After preprocessing the data, we calculated the combined average FWI values for each year from 1988 to 2022 (Figure 156). In 2022, a relatively low level of fire danger was observed – one of the lowest in the past 18 years.

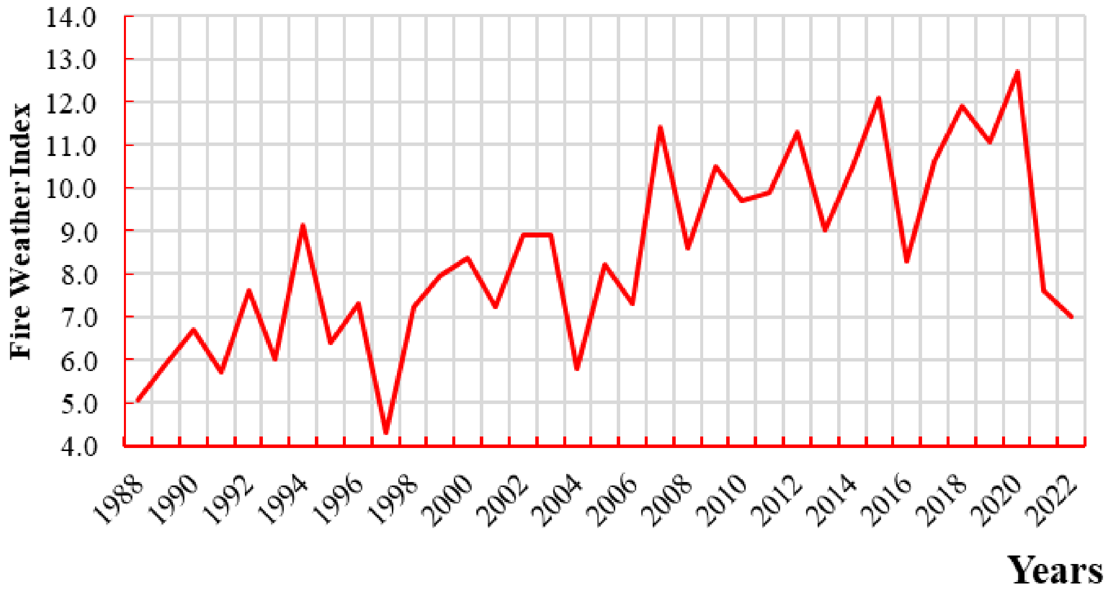

Figure 156. Annual average Fire Weather Index dynamic in Ukraine 1988-2022.

Thus, it becomes apparent that the severity of Ukraine's 2022 fire season was mainly due to war impacts, not extreme weather conditions.

12.5.3 Typical fire behaviour during war

Although the weather conditions in 2022 were relatively unfavourable for fire propagation, a substantial number of wildfires and burnt areas were still recorded. Most instances of wildfires occurred in areas directly or indirectly affected by active combat, particularly in the occupied territories (Figure 157 and Figure 158).

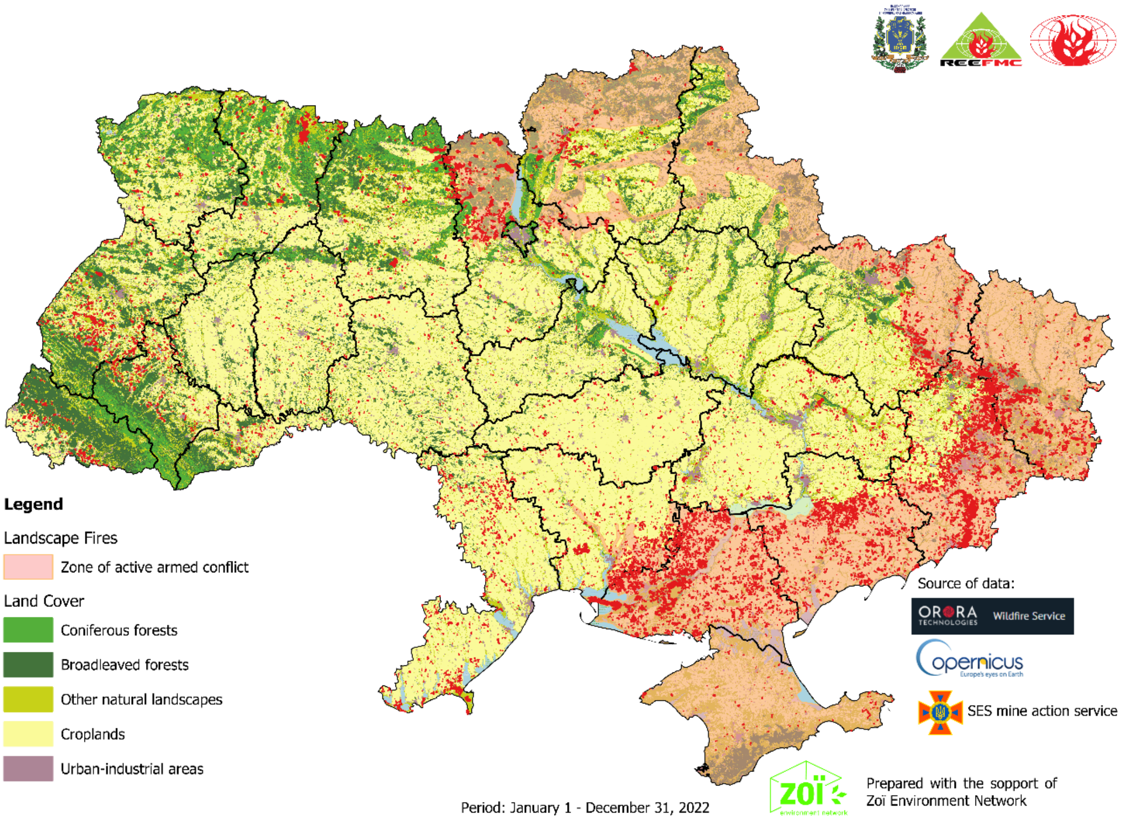

Figure 157. Spatial distribution of wildfires during the 2022 fire season and relation to land cover.
Data Source: Fires mapped by the REEFMC on a land cover background (REEFMC, 2022).

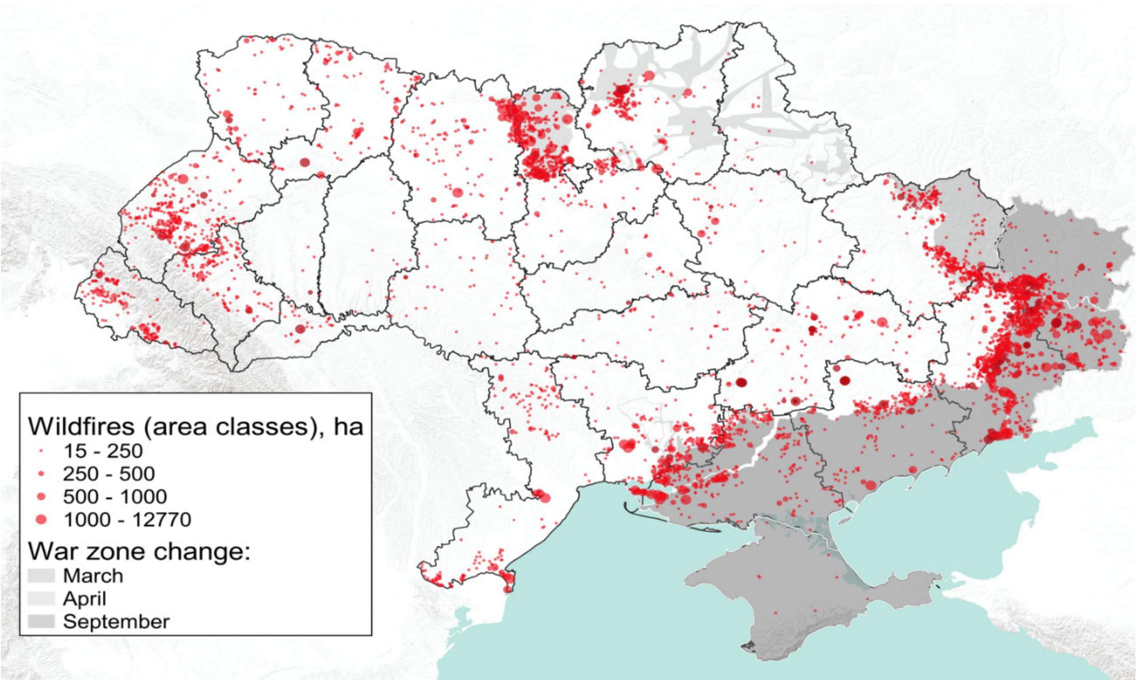

Figure 158. Spatial distribution of wildfires during the 2022 fire season and relation to the war zone.
Data Source: Based on European Forest Fire Information System (EFFIS) data. The frontline zone data provided by ZOÏ.

The largest forest fires predominantly took place in the Eastern and Southern regions, and the Chornobyl Exclusion Zone, largely due to the unfeasibility of implementing fire suppression actions near frontlines or within occupied territories. Consequently, minor surface fires rapidly evolved into unmanageable crown fires within these areas. Fires in such territories were often allowed to run their natural course, occasionally self-extinguishing. However, fire prevention and suppression activities within the liberated territories were greatly hindered by the presence of UXO, with vast expanses of forested landscapes mined by Russian forces.

A notable aspect of the 2022 fire season was the imposition of Martial Law across the entirety of Ukraine, as declared by the Presidential Decree No. 64/2022 (February 24th) "On the introduction of martial law in Ukraine". This led to the restriction of public access to forests and other natural landscapes, subsequently lowering the fire risks in territories not involved in active combat. Consequently, within regions controlled by Ukraine, the spatial density ranged between 0.007-0.009 ha of burnt area per 1000 ha of landscapes, while the fire density hovered around 0.098-0.116 fires per 1000 ha of landscapes. Spatial density, defined as the burnt area per 1000 ha of landscape, was observed to be 2.29-3.85 times higher in the war zone compared to the rest of Ukraine's territory. This difference in average combustibility within the war zone is statistically significant. Concurrently, fire density was found to be 1.75-4.3 times greater in the war zone. Both combustibility and fire density show an increase as the width of the buffer zone reduces, reaching a maximum at a buffer width of 5 km, which accounted for 0.45 wildfires per 1000 ha.

12.6 Characterization of the affected area

12.6.1 Large fires in Chornobyl Exclusion Zone (CEZ)

Despite the restricted access, wildfires occur annually in the CEZ. While their frequency varies, these fires typically cover a small area. However, due to climate change, the incidence of large fires has increased over the last decade. Particularly severe fire situations were observed in 2015 and 2020. Due to the Russian military aggression, 2022 has now joined the ranks of these challenging years.

The Russian military invasion had a significant impact on the incidence and proliferation of fires within the CEZ in 2022. Generally, the timing of fires in this territory can be divided into two stages: those that broke out while the area was under Russian occupation, and those that occurred following the liberation of the CEZ.

In total, fires affected approximately 31 758 ha within the CEZ, with 13 380 ha of that area burned during the occupation of the territory (Figure 159). Contamination of the territory by unexploded ordnance and reduction of capacity of fire service in the CEZ were the reasons of large areas burned after deliberation.

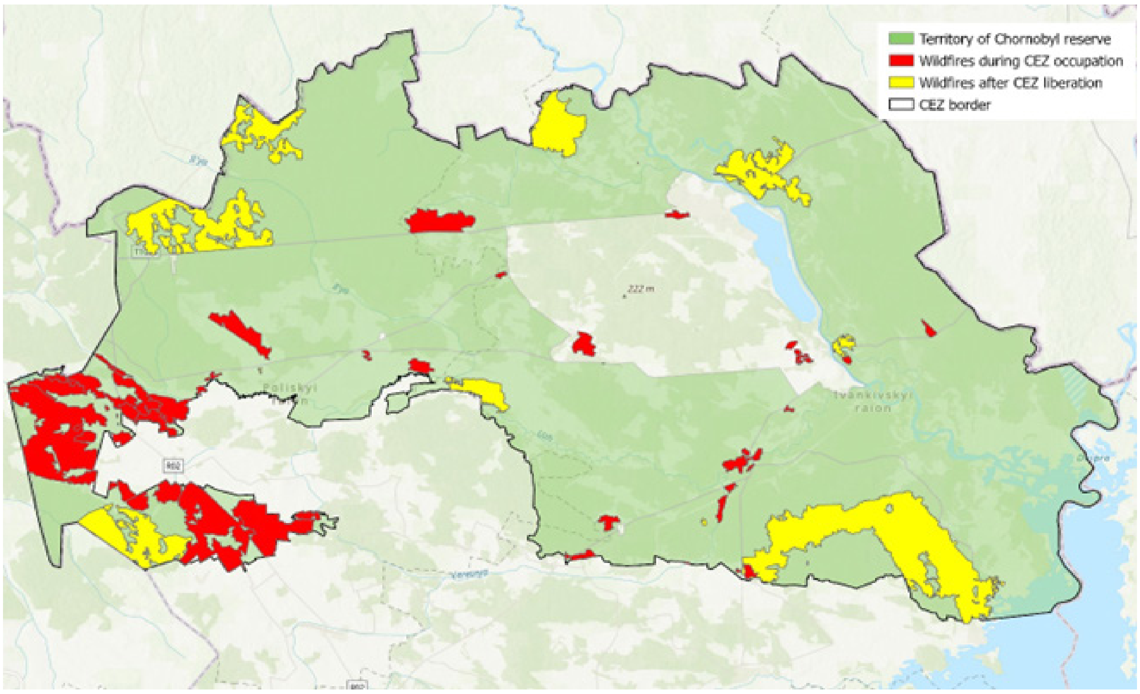

Figure 159. Representation of fires in the CEZ during 2022. Fires that occurred during the occupation are highlighted in red, while those following the territory's liberation are highlighted in yellow.

Determining the precise causes of these fires is extremely difficult, yet it is plausible to attribute them primarily to military activities and the territory's contamination with unexploded ordnance and landmines. Despite the inherent risks fires pose in radioactively contaminated regions, that occurred after the disaster at the Unit 4 of the Chornobyl Nuclear Power Plant in 1986, their potential repercussions, and the consensus that any fire in these territories is unacceptable, we feel that it is worth detailing the most considerable incidents. Table 20 provides a summary of the largest fires (those exceeding 1000 ha) in Ukraine.

Table 20. Characteristics of large fires within the Chornobyl Exclusion Zone

№	Location	Wildfire duration	Affected area by land cover (%)						Total area, ha
			Pine forests	Deciduous forests	Dead forest	Grasslands	Swamp	Abandoned villages	
1	Southwestern CEZ	March 08th – 11th	1.4	11.6		79.6		7.4	2 210
2	Southwestern CEZ	March 18th – 24th	24	14.7		56.6		4.7	3 224
3	Southwestern CEZ	March 23d – 24th	3.2	15.6		79.6		1.6	1 552
4	Dytiatky village	May 04th – 24th	74.2	16.9	0.4	4	4.5		7 836
5	Yasen and Shevchenkove	March 08th – May 30th	84.4	11.2	2	0.5	1.6		2 110
6	Vilcha village	July 01st – September 10th	79.8	16.4	1.3	0.5	2		3 052
7	Denysovychi village	August 10th – September 10th	84.9	14.1		0.2	0.8		1 316
8	Zymovyshce village	August 23d – September 10th	32.7	21.5	1.2	16.5	24.7		1 715
9	Benivka village	September 02nd – 10th	75.6	20.8	1.8	0.5	1.3		1 466

Beginning with the onset of a full-scale war, the CEZ fell under occupation by Russian military until its liberation on April 1st. Throughout this period, only essential personnel involved in the safe operation of the nuclear plant, radioactive waste storage facilities, and other CEZ enterprises remained within the territory. Additionally, a unit from the state emergency service was present. In the early days of occupation, this unit could battle fires around Chornobyl, but their actions were increasingly restricted, and eventually firefighting efforts ceased. Consequently, fires in the exclusion zone could neither be extinguished, nor was their spread controlled. Fire monitoring during this period was only possible via satellite data (Figure 160).

The defining characteristic of fires during the occupation was their initiation and propagation under weather conditions typically non-conducive to fires in the CEZ. Fires during this time expanded uncontrollably, their spread governed primarily by fuel dryness and meteorological conditions. Given the high litter humidity, fires ceased their advance upon reaching forests, as substantiated by the traits of the scorched areas. Even the slightest rainfall played a role in extinguishing these fires.

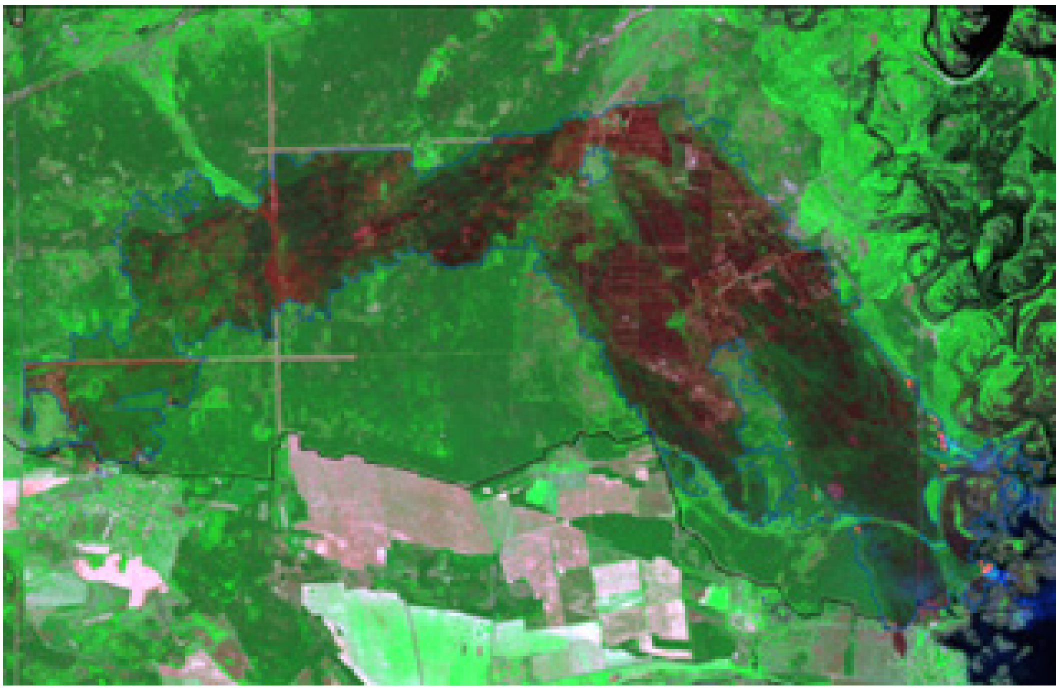

Figure 160. Sentinel-2 satellite images illustrating the situation during the largest wildfire in the CEZ, near Dytiatky village, on May 19th.
Data Source: Borsuk, 2022

After the liberation of the CEZ territory, it was discovered that the occupying forces had stolen or destroyed much of the fire management equipment, including fire trucks. The issue of UXO and landmines contaminating the territory remains unresolved. As the Russian troops retreated, they mined not only the premises of institutions and organizations but also the roads and ecosystems within the CEZ. All these factors significantly complicated the detection and suppression of fires.

In 2022, approximately 18 720 ha of forests, 8 945 ha of grasslands, 1 610 ha of swamps, other habitats, and deserted villages were burnt. The contamination of the territory with unexploded ordnance and landmines poses a high risk to firefighters, thereby necessitating access restrictions to many areas in the future. Given these conditions, the occurrence of large fires in the upcoming years can be anticipated.

12.7 Wildfires in the war impact zone (60 km around front line)

According to the results of spatiotemporal analysis of fires, a significant increase in landscape fires within the combat zone, specifically within a daily 60 km range along the front line, was observed.

To identify the fires that occurred in the area of direct impact of military operations (Military Combat Zone – MCZ) we used the dynamic coordinates of the front line provided by ZOÏ. In this report, the MCZ means permanent corridor spanning 30 km on each side of the Line of Contact (LoC). The corridor is determined at the beginning of active military combat and continues to be included in the monitoring areas even after the ending of active military combat operations. Reason: UXO remains in this area and continues to pose a threat of ignition.

Out of the total area of 754 900 ha affected by landscape fires in Ukraine in 2022, 69% (520 400 ha) occurred in the war-impacted zone. Furthermore, the occupied territories accounted for 321 100 ha, which corresponds to 43% of all fires (cf. Figure 157 and Table 21). The primary reasons for these fires were the absence of fire department response, military-related ignition sources, hazardous weather conditions for fires, and low fuel humidity. The peak months for fires within the war-impacted zone were July (with 4 600 fires), March (2 900), May (1 400), and August (1 400). This is a distinct deviation from typical years, when the maximum number of fires usually occur in April and August.

Table 21. Breakdown of landscape fires in 2022 within the military engagement zone (30 km each side of front line), by land cover type and month, measured in hectares.

Month	Area of fires (ha)	Distribution of fire area by types of landscapes (ha)				
		Forests	Thereof coniferous	Agricultural lands	Other natural landscapes	Settlements
February	8 497	173	33	4 470	3 623	231
March	156 869	10 737	5 838	72 481	72 189	1 462
April	18 433	2 483	553	4 331	11 441	178
May	39 838	17 660	13 879	3 772	17 917	489
June	19 738	1 519	915	9 649	8 427	143
July	171 770	6 184	4 045	134 555	30 259	772
August	94 276	4 092	2 008	68 322	21 288	574
September	9 496	3 157	2 301	2 420	3 878	41
October	443	333	327	8	84	18
November	640	182	156	389	69	0
December	376	2	0	230	144	0
Total	520 376	46 522	30 055	300 627	169 319	3 908

In terms of distribution of areas burned within the MCZ by administrative regions, the worst impact of the war was observed in Donetsk (128 915 ha), Kherson (78 605 ha), Kyiv (69 549 ha), Kharkiv (40 266 ha), Zaporizhia (64 130 ha), Luhansk (51 432 ha), and Mykolaiv (44 343 ha). Since the MCZ is a relatively narrow 60 km strip, such extents suggest that nearly all territories within the MCZ (70-80%) were burned once, and in some cases, twice during the war period, heavily impacting soils, vegetation and wildlife.

Monoculture pine forests, characterized by high fire risk and susceptibility to rapid fire spread, are prevalent in the southern and eastern regions of Ukraine. These regions ended up within the military operations zone. In these areas, the fire response system is practically non-existent, so forests are subjected to the maximum possible damage that can be caused by fires and explosions (Figure 161).

Figure 161. Direct military operations causing extensive damage to forests (Luhansk oblast).
Data Source: tribun.com.ua

Between the beginning of the war in February 2022 and July 1st, 2023, many large fires occurred in Ukraine even though there were not drought periods as there were in 2020 (Table 22).

Table 22. List of largest landscape fires that occurred in Ukraine (whole country) during the war period of February 24th and July 1st (note: LC = Land-use Classes).

Date	Oblast	Area							
		Total (ha)	Forest (ha)			Other natural vegetation (ha)	Cropland (ha)	Urban (ha)	Other land covers (ha)
			Total forest	Incl. coniferous	Other types				
Mar 11th	Kyiv-Chornobyl	4 983	1 109	756	353	2 651	1 221	1	1
Mar 11th	Kyiv-Chornobyl	4 564	270	24	246	1 265	3 029	0	0
Mar 12th	Zhytomyr	4 513	147	14	133	3 106	1 258	0	2
Mar 12th	Lviv	3 241	200	0	200	2 231	785	25	0
Mar 14th	Rivne	4 866	711	63	648	3 885	270	0	0
Mar 14th	Rivne	3 749	638	33	605	2 595	487	0	29
Mar 14th	Rivne	2 850	359	0	359	2 396	88	0	7
Mar 19th	Zhytomyr	5 554	3 072	2 556	516	2 285	191	2	4
Mar 20th	Donetsk	3 064	31	0	31	333	2 698	0	2
Mar 21st	Donetsk	4 686	0	0	0	451	4 174	59	2
Mar 21st	Luhansk	3 115	98	0	98	1 262	1 738	17	0
Mar 22nd	Donetsk	3 515	18	0	18	1 810	1 685	2	0
Mar 23rd	Donetsk	4 115	10	0	10	590	3 505	10	0
May 4th	Kharkiv	5 628	4 018	3 432	586	1 583	0	27	0
May 11th	Kyiv	7 552	5 302	4 392	910	2 241	0	0	9
Jul 27th	Kherson	3 569	970	184	786	2 527	21	0	51
Aug 1st	Kherson	4 152	397	22	375	3 753	2	0	0
Sep 1st	Kyiv	4 694	2 163	1 563	600	2 372	56	0	103
Oct 4th	Odesa	3 559	0	0	0	3 523	0	0	36

Collateral impacts of the war were directly or indirectly responsible for fires in Kyiv, Zhytomyr, Chernihiv, Sumy, Kharkiv, Luhansk, Kherson and Donetsk oblasts near the frontline, while fires in Western Ukraine were related with reduced capacity of fire management due to limitations for fire management during the war (prohibition of deployment of fire aviation), and transfer of part of fire personnel and fire engines to the Ukrainian army.

12.8 Fires in conservation areas

Utilizing the Emerald Network, a system of significant European nature conservation areas established under the Council of Europe's Bern Convention for the Protection of European Wild Flora and Fauna and their Natural Habitats (http://emerald.net.ua/), it was determined that valuable natural landscapes were also devastated by the fires. The conflict directly affected approximately 25% of Ukraine's nature conservation areas in the form of extensive, uncontrolled fires, the destruction of biological and landscape diversity, soil chemical contamination, and territory contamination with UXO and land mines. Fires within the Emerald Network covered an area of 88 400 ha, comprising 25 400 ha of forests, 10 800 ha of agricultural lands, and 52 200 ha of other natural landscapes. Some protected areas reported forest fires exceeding 1 000 ha – for example, the Chornobyl Radiation-Ecological Biosphere Reserve experienced nine major forest fires, with areas ranging from 1 200 to 7 800 ha.

12.9 Constraints on fire management due to wartime conditions

A crucial factor impacting both forests and biodiversity, with immediate and far-reaching implications for forestry, is the contamination of terrain with UXO and landmines. Their detonation can initiate fires and inflict direct harm to trees, in addition to causing fatalities among wildlife and humans. Conventional forestry practices become perilous and challenging, and frequently, the harvested timber is littered with projectile fragments rendering it unusable.

In addition, extinguishing forest fires becomes significantly more challenging in contaminated areas where it is impossible to use conventional equipment and carrying out forest management activities becomes virtually impossible due to the inherent risk to personnel. Forest wildfires ignited by mine detonations have often led to casualties, creating reluctance among staff to confront these fires, or leading to directives instructing firefighters to avoid such hazardous zones.

Territories that were occupied and later liberated and controlled by the Government of Ukraine, are also substantially impacted by the war. This includes the loss of fire management capacity and threats from UXO, as demonstrated by the large areas burned.

Over 690 000 ha of land are contaminated with UXO. Consequently, the forests in these areas, with their valuable timber and non-timber resources, are excluded from forest management. This not only escalates the risk of fires but also has a negative impact on the economic condition of local communities and the state as a whole.

Another significant issue is the destruction and damage of forestry infrastructure. In cases where enterprises in de-occupied zones are not completely destroyed, Russian forces often seize all equipment and vehicles. This leads to a significant decrease in the capacity for fire suppression.

12.10 Conclusions and lessons identified

The full-scale military invasion of Ukraine by the Russian Federation in 2022, along with over 500 days of military conflict across vast territories in eastern and southern Ukraine, have presented an unprecedented challenge for fire management in the country. This necessitates the development of a new national strategy for the post-war recovery period. To mitigate the impacts of climate change, the adoption of new technologies and methods is required. This includes utilizing modern remote sensing tools for daily fire monitoring, establishing firefighter training programs, and creating awareness programs for the forest-fire-threatened rural populace. Moreover, effective fire management strategies with limited resources in safe zones and protected networks must be devised, with special attention given to fire control in UXO-contaminated areas, safeguarding personnel. The national strategy should be based on advanced interagency cooperation and scientific tools for fire risk assessment. This national strategy should be founded on advanced interagency cooperation methods and scientific tools for fire risk assessment.

Wildfires are inevitable consequences of military activity, and, during war, their prevention or control is hampered due to destroyed fire management infrastructures, and risks to the life and health of firefighters. Following the liberation of territories, novel approaches must be developed that factor in the risks posed by UXO contamination, as well as the necessity to safeguard rural populations and their assets, as well as fire brigades. The escalating fire risks associated with climate change and the necessity of integrating research models and tools for predicting these risks must be considered as a mandatory component of this strategy.

The absence of an implemented national strategy for integrated landscape fire management in Ukraine, combined with the shortage of well-trained, organized, and equipped firefighters, diminishes the effectiveness of landscape fire control efforts in the western region of Ukraine, which is under government control. Despite the war, rural populations and farmers continue to utilize fire for agricultural purposes in safe conditions, largely due to the cost-effectiveness of this measure. As such, any new national strategy must consider the interests and needs of all stakeholders, including SESU, rural and volunteer fire brigades, local authorities, and the population. This strategy should encompass legislative initiatives, a new financing system for fire management, and training programs.

The primary objectives of post-war national fire management efforts should be the development of fire resilient landscapes and communities, and the management and reduction of fuel and ignition sources. A thorough evaluation of the war's influence on fire regimes and the environment, grounded in advanced and proven scientific methodologies, will not only elucidate the scale and nature of immediate impacts, but also shed light on long-term, regional, and global impacts including the loss of ecosystems related to the war.

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13 Conclusions

In this document, several of the major wildfires that occurred in Europe in the year 2022 across various countries have been presented and described. The situation of wildfires in Ukraine was also analysed, particularly in relation to the wartime situation experienced during this period. The primary objective of this study is centred around learning lessons, both for national benefit and for the improvement of the European civil protection system. It is crucial to emphasize that this study does not seek to assign responsibilities or evaluate decisions, assuming beforehand that all civil protection stakeholders aimed to do their best in situations where decisions must be made rapidly, with attention dispersed across various aspects and dynamic information. Nevertheless, the survey and analysis of events enable the enhancement of the wildfire management system by continuing or reinforcing positive aspects and eliminating or modifying decisions or actions that performed adversely. This improvement aims to enhance the fire management efficiency in future situations with similar conditions.

As reported, the year 2022 experienced highly conducive meteorological conditions for the occurrence of wildfires. Countries and regions with a limited history of wildfires faced some of the worst fires in their records. While the size and intensity of these fires are common in Mediterranean countries, the lesser responsiveness of countries less susceptible to fires made these incidents exceptional, sometimes requiring support from other nations. The European territory exhibits two distinct realities regarding the susceptibility and preparedness of countries or regions to face wildfires. It is crucial for countries and regions with a limited history in these matters to prepare for more frequent and severe wildfires, through allocating more resources for prevention and response, as well as establishing plans for support from other regions or countries, coordinated with the Union Civil Protection Mechanism (rescEU).

This report also describes wildfires that crossed borders, becoming international events within the European space. The relations between civil protection entities on both sides of the border were found to be good, but differences in working methodologies and the tendency to look at own countries individually led to less integrated cooperation in events that should be seen in an integrated perspective. Occasionally, even with shared information, the management of these incidents is divided along the transboundary line, creating two (semi)independent fire scenes. Given that fire knows no borders, it is essential for increased response efficiency that these events be treated in a harmonized manner, involving shared data, strategies, methods, and cooperative operations, considering the incident as a single fire scene.

Additionally, this document analyses aftermath events caused by wildfires, known as cascade effects. The higher intensity of wildfires increases the likelihood of these subsequent occurrences, sometimes with impacts greater than those directly caused by the fire itself. Cascade effects have different characteristics and importance depending on severity, period, or location. A greater knowledge and preparation for cascade effects are necessary, as these mechanisms do not always receive the anticipated attention they should have had.

Considering the insights gained from the study of past wildfires and to maintain a historical record of these events, it is important for the European Union to adopt the practice of regularly documenting the main fire events that have affected its territory. The authors of this report believe that this study has made a good contribution in that direction.

List of abbreviations and definitions

ADAI	Associação para o Desenvolvimento da Aerodinâmica Industrial [Association for the Development of Industrial Aerodynamics]
AEMet	Spanish Meteorological Agency [Portuguese Civil Protection Authority]
ANEPC	Autoridade Nacional de Emergência e Proteção Civil
AUTH	Aristotle University of Thessaloniki
BUI	Buildup Index
CMA	Air Resources Center
CNR-IBE	Consiglio Nazionale delle Ricerche - Istituto per la BioEconomia
CzechGlobe	Global Change Research Institute, Czechia
DNP	Dadia National Park (full name is Dadia-Lefkimi-Soufli National Pak)
EFFIS	European Forest Fire Information System
EMAK	Hellenic Fire Service's Special Disaster Response Unit
EMS	(Copernicus) Emergency Management Services
EPADAP	National Observatory of Forest Fire information (Greek initials)
FMI	Finnish Meteorological Institute
FSPP-Yambol	Fire Safety and Protection of the Population - Yambol
FWI	Fire Weather Index
GeoCBI	Composite Burn Index
GFMC	Global Fire Monitoring Centre, Freiburg, Germany
GSCP	General Secretariat of Civil Protection
ICS	Command System
IICT	Institute of Information and Communication Technologies – Bulgarian Academy of Sciences
INCDS	The National Institute for Research and Development in Forestry
IPMA	Instituto Português do Mar e da Atmosfera [Portuguese Institute for Sea and Atmosphere]
ISI	Initial Spread Index
ISIG	Istituto di Sociologia Internazionale di Gorizia
MMAP	Romanian Ministry of Environment, Water and Forests
NCSRD	National Centre for Scientific Research Demokritos
NECCA/OFYPECA	Natural Environment & Climate Change Agency
NIMH	National Institute of Meteorology and Hydrology
NOA	National Observatory of Athens
NOFFi	National Observatory of Forest Fire information
RCM	Conjunctural and Meteorological Risk
REEFMC	Regional Eastern Europe Fire Monitoring Center, Kyiv, Ukraine
RH	Relative humidity
RISE	Research institutes of Sweden
RNP-Romsilva	Regia Națională a Pădurilor Romsilva
SENP	Serra da Estrela Natural Park
SGIF	Forest Fire Information Management System
SIRESP	Integrated System for Portugal's Security and Emergency Networks
SPEI	Standardized Precipitation-Evapotranspiration Index
T	Temperature
TUD	Technische Universität Dresden [Dresden University of Technology]
U	Wind velocity
UAH	Universidad de Alcalá [University of Alcalá]
UIAR NUBiP	Ukrainian Institute of Agriculture Radiology of the National University of Life and Environmental Sciences of Ukraine, Chabany, Ukraine
URIFFM	Ukrainian Research Institute of Forestry and Forest Melioration, Kharkiv, Ukraine
VCI	Forest Fire Fighting Vehicle
VTT	Tactical Tank Vehicle
VTGC	Large Capacity Tank Vehicle
WIU	Wildland Urban Interface
WWF	World Wide Fund for Nature
ZCAP	Concentration Zone to Population Support

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