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Drivers and implications of the extreme 2022 wildfire season in Southwest Europe

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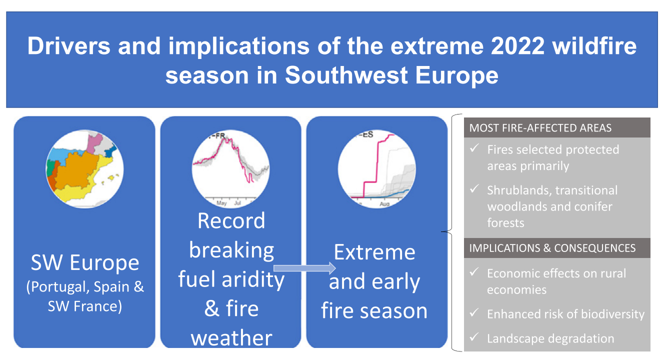
HIGHLIGHTS

- The 2022 fire season in SW Europe reached record burned area in some regions.
- Early fire onset and early occurrence of large fires characterized the season.
- pt?>Record-breaking fuel aridity and pyrometeorology associated with fire activity.
- Nearly half of the area burned in large fires occurred in protected areas.
- 2022 may be a spyglass into the “new normal” for fire activity under global warming.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildfire is a common phenomenon in Mediterranean countries but the 2022 fire season has been extreme in southwest Europe (Portugal, Spain and France). Here we provide a preliminary but comprehensive analysis of 2022's wildfire season in southwest Europe. Burned area has exceeded the 2001–2021 median by a factor of 52 in some regions and large wildfires (>500 ha) started to occur in June–July, earlier than the traditional fire season. These anomalies were associated with record-breaking values of fuel dryness, atmospheric water demand and pyrometeorological conditions. Live fuel moisture content was below the historical minima for almost 50 % of the season in some regions. A few large wildfires were responsible for 82 % of the burned area and, in turn, 47 % of the area burned occurred in protected areas. Shrublands, transitional woodlands and conifer forests (but not eucalypt plantations) were the land cover types most affected by extreme fires. As climate change intensifies, we can expect such fire seasons to become the new normal in large parts of the continent, potentially leading to major negative impacts on rural economies. These results highlight the need for landscape level fuel management also in protected areas, to avoid fire-induced biodiversity

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losses and landscape scale degradation. Our results have important policy implications and indicate that fire prevention should be explicitly addressed within continental forest legislation and strategies.

1. Introduction

Wildfires are a natural phenomenon in Mediterranean countries, playing a key role in the conservation of landscapes and the dynamics of forest communities (Resco de Dios, 2020). When the natural regimes of fire are altered due to increases in fire intensity and severity from global change, fires can threaten both the environment and society (Cochrane and Bowman, 2021; Moreira et al., 2020; Wunder et al., 2021). The confluence of fire exclusion and fuel build-up over the last decades, together with climate change has set the conditions for unprecedented situations, already witnessing earlier and longer wildfire seasons (AghaKouchak et al., 2020; Moreira et al., 2020).

The 2022 fire season in southwest Europe (Portugal, Spain and France) has drawn considerable international attention due to the large extent of burned area, as 469,464 ha have burned at the time of writing (28th September 2022), which is nearly 3 times higher than the 2006–2021 annual mean (173,415 ha; EFFIS dataset, explained below in methods). The season coincided with the chained irruption of several heat waves, which have appeared earlier than usual breaking temperature records in several countries like Spain or France (C3S, 2022), leading to record-breaking wildfire events. This season could thus potentially act as a spyglass into what the "new normal" will look like under climate change in forthcoming years. Understanding the processes and underlying drivers of these unprecedent events is crucial to mitigate and building fire-adapted and resilient landscapes and communities.

The goals of this manuscript were to: 1) understand to which extent was this year's regional variation in burned area in southwest Europe extreme, relative to the 2001–2021 mean; 2) test the associated anomalies in terms of fuel moisture content, pyrometeorology and ignitions as driving forces of the extraordinary wildfire season and; 3) provide an initial assessment of the associated impacts, particularly in protected areas.

2. Materials and methods

2.1. Fire data

Fire data for the 2000–2022 period were collected from the European Forest Fire Information System (EFFIS dataset; San-Miguel-Ayanz et al., 2012). We used EFFIS data instead of governmental records collected by each country as it represents an updated and harmonized data source at subcontinental scale. We employed data from the EFFIS real-time burned area and GlobFire databases, based on the MODIS Collection 6 (C6) MCD64A1 burned area product (Giglio et al., 2018). We retrieved daily burned area data over the full period, aggregating it at weekly level using the regional divisions by Calheiros et al. (2020) for Portugal, López Santalla & López García (2019) for Spain and Resco de Dios et al. (2021a) for France. When a fire crossed over more than one region, it was assigned to the region where most of the burned area occurred.

2.2. Drivers: fuel moisture content, fire weather and ignitions

We explored several indicators related to fuel moisture content and meteorological danger conditions. We examined trends in live fuel moisture content (LFMC) using a recently developed remotely-sensed product based on MODIS imagery (Cunill Camprubí et al., 2022). We also investigated temporal patterns in vapor pressure deficit (VPD), one of the main drivers of compounded live and dead fuel moisture content (Resco de Dios et al., 2021b), following previous protocols based on thermal imaging derived from MODIS LST MOD11A1 collection 6 (Nolan et al., 2016a) . Regarding fire weather, we explored the dynamics of the Hot-Dry-Windy (HDW) index, which multiplies VPD by wind speed at 925 hPa Srock et al. (2018). The data for HDW calculations was available from Kanamitsu et al. (2002). VPD integrates temperature and relative humidity, and consequently indicates how "hot and dry" atmospheric conditions are.

In addition, we sought to characterize fire weather conditions for fires over 5000 ha, which are the ones we regarded as extreme given their size. To this end we obtained data on the Canadian Fire Weather Index (FWI) and its two main components, Initial Spread Index (ISI, indicative of rate of spread), and Buildup Index (BUI, indicative of fuel consumption), from the data available in the EFFIS dataset (San-Miguel-Ayanz et al., 2012.). We also incorporated the most likely cause of ignition consolidating the preliminary evidence from a variety of sources including official records from national agencies, media and press reports.

2.3. Impacts: Protected areas and land cover

Wildfires are a natural phenomenon and their negative impacts often increase with burned area. We thus examined how dependent was the total burned area of the season on the occurrence of a few large wildfires (those affecting >500 ha). We then quantified to which extent were protected areas (PAs) affected by large wildfires after sourcing data on PAs from The World Database of Protected Areas (UNEP-WCMC and IUCN, 2022). We examined how many PAs had been affected by a large wildfire and what percentage of the burned area occurred in PAs.

For extreme wildfires (those affecting over 5000 ha), we additionally examined the prevailing land cover type from Corinne Land Cover, as available in the EFFIS dataset (2022). A land cover type was considered as prevailing when it accounted for >20 % of the burned area.

2.4. Statistical methods

We performed the interannual comparison of the cumulative distribution of burned area between different regions of southwestern Europe. Weekly data on area burned were aggregated into cumulative records during each year. The annual cumulative distributions were synthesized using 95 % confidence intervals allowing the identification of anomalous seasons. The same procedure was replicated with LFMC, VPD and HDW data, but with non-cumulative data.

We also investigated the links between LFMC, VPD and HDW, and burned area during the summer season (June to August) by fitting linear regression models. We aggregated each index as its period average and summarized the total burned area at yearly level. Individual models were trained for each region, reporting the slope of the regression line, the R^2 and the significant level of the model (Fisher's F test).

3. Results

3.1. The season in numbers

Burned area reached abnormally high values in some areas (Fig. 1). In southwest France, burned area between April–August 2022 exceeded the 2001–2021 median for the same period by a factor of 52 (27,228 ha in 2022 relative to 519.5 ha, Fig. 1f). Burned area in northwest (Fig. 1c) and in central Spain (Fig. 1d) also extended beyond historical records and it exceeded the 95th percentile in southeast Spain (Fig. 1e). Burned area in northwest Portugal (Fig. 1a), southeast Portugal (Fig. 1b) and southeast France (Fig. 1g) was higher than the 2001–2021 median by a factor of 4, 2 and 5, respectively.

Another anomalous situation of the 2022's fire season was its early start, especially in southwest and southeast France and in central and northwest

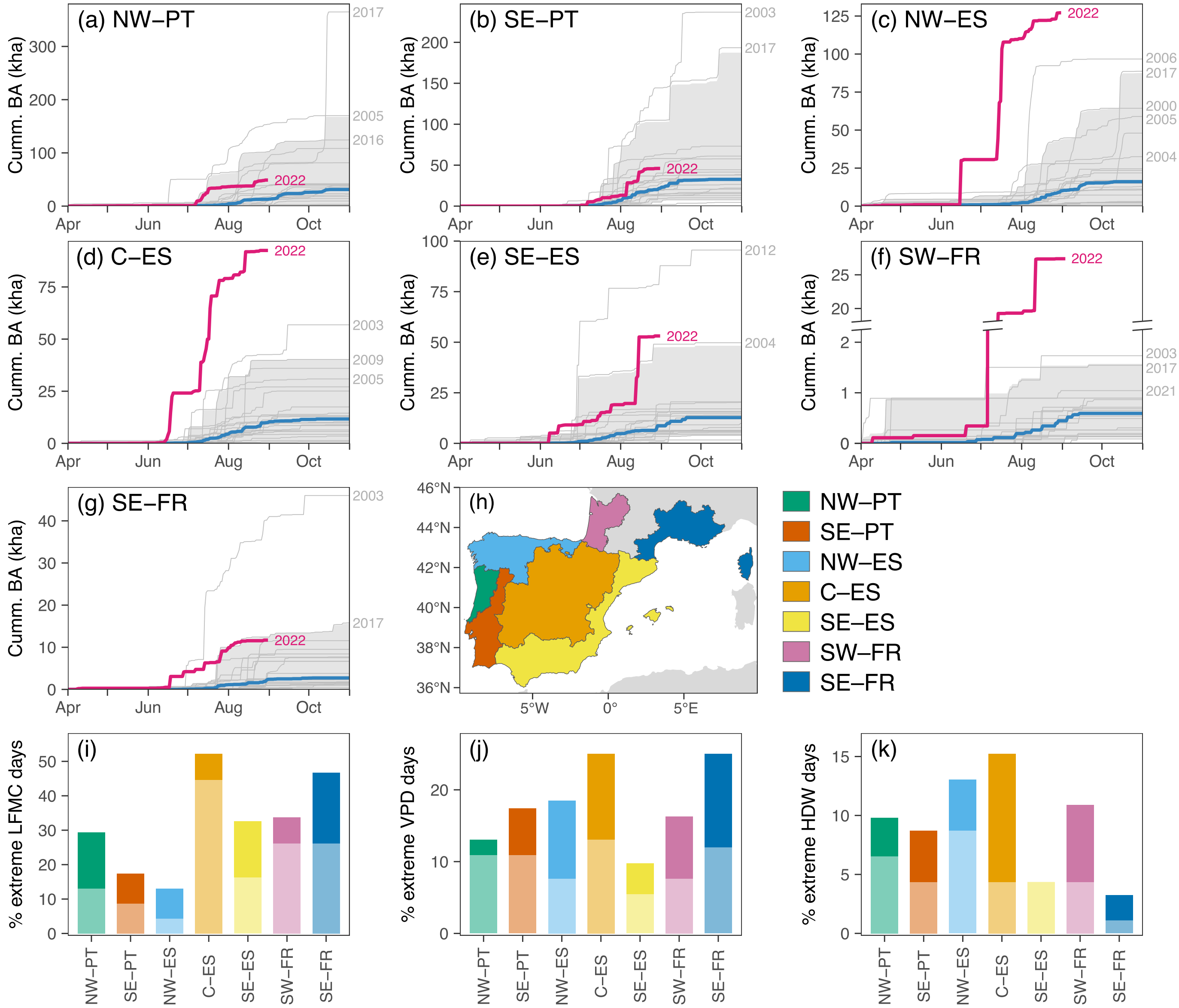

Fig. 1. Cumulative burned area in SW Europe. The shaded area indicates the 95th percentile in the historical records (2001 – 2021) and the blue and pink lines the historical median and current year, respectively. Panel i indicates the % of days between June–August when live fuel moisture content (LFMC) reached either record-breaking levels below the absolute minimum in the 2001–2021 registry (lower part of the bar) or below the driest 95th quantile (upper part of the bar). Panels j and k indicate the % of days between June–August when vapor pressure deficit (VPD) and the hot-dry-weather index (HDW) reached either record-breaking levels above the absolute maximum in the 2001–2021 registry (lower part of the bar) or above the highest 95th quantile (highest part of the bar graph). Data sources for panels i-k are provided in Figs. A1-A3.

Spain. In those regions, large fires (>500 ha) are usually infrequent until mid to late August, whereas this year large fires occurred almost a month in advance (depending on region, Fig. 1). The onset of the season in the Mediterranean Spanish regions situates usually in July, though this year fire activity started in early-to-mid June. In France, the season started in April.

The bulk of the burned area occurred in large wildfires (Table 1). We observed that only 12 % of all fires exceeded 500 ha in size but they accounted for 82 % of the total burned area (Table 1). We additionally observed a total of 21 extreme wildfires (>5000 ha), which were responsible for 58 % of the total burned area. The number of fire events should be interpreted with caution as we discarded fires smaller than 30 ha given the resolution of the MODIS MCD64A1 product, from which the EFFIS dataset is derived (San-Miguel-Ayanz et al., 2012). This does not impact burned area significantly, but it is likely that the actual percentage of fires over 500 ha was much smaller than the 12 % reported here.

3.2. Drivers: anomalies in fuel moisture and fire weather and ignition sources

Fuel dryness is a critical driver of fire ignition and spread in forested landscapes. LFMC reached record-breaking values during the 2022 season (Figs. 1, A1), ranging towards the driest historical conditions (Figs. 1i, A1). The major departure from the 2001–2021 median values (the driest anomaly) occurred in southwest France and central Spain, where 27 % and 45 % of the days between June–August coincided with values below the historical minimum of LFMC (Figs. 1i, A1), respectively. In the same line, we observed that 2022's VPD values were towards the upper end, indicating a more desiccating atmosphere than under average conditions (Figs. 1j, A2). This season also showed record high VPD levels (relative to 2001–2021) during 10 % of the fire season (June–August) across the entire area (Fig. 1j). The HDW index, despite depicting substantial day-to-day variability as expected in weather-related variables, denoted record high values for 5 % of the fire season across southwest Europe (Figs. 1k, A3).

Table 1
Burned area and number of fires and of large fires (>500 ha) overall and in protected areas across southwestern Europe. Data sourced from the European Forest Fire Information System (https://effis.jrc.ec.europa.eu/apps/effis_current_situation/), World Database on Protected Areas (https://www.protectedplanet.net/) and Corinne Land Cover (https://land.copernicus.eu/pan-european/corine-land-cover). Wildlands include all "burnable vegetation": the vegetation classified as "forests and semi-natural areas" in CLC but also pastures, agroforestry and mosaic areas (2.3.1, 2.4.3 and 2.4.3 in CLC).

	All fires								Fires in protected areas (PAs)					
Region	Total area (ha)	Total wildland area (ha)	Burned area (ha)	Burned area in large fires (ha)	% Burned area in large fires	# fires	# large fires	% large fires	% Total area in PAs	% Total wildland area in PAs	Burned area in large fires in PAs (ha)	% Burned area in large fire in PAs	# large fires in PAs	% large fires in PAs
NW-PT	2,685,272	1,814,479	52,769	34,261	64.9	175	12	6.9	15.3	38.2	7,478	21.8	4	33.3
SE-PT	6,200,068	4,061,651	50,554	43,654	86.4	62	17	27.4	25.6	49.1	26,172	60.0	10	58.8
NW-ES	7,889,491	5,777,455	141,771	120,768	85.2	244	25	10.2	22.2	25.9	56,115	46.5	19	76.0
C-ES	26,040,990	14,529,929	93,588	83,513	89.2	100	23	23.0	27.2	34.5	27,183	32.6	17	73.9
SE-ES	15,936,375	8,682,230	53,674	48,740	90.8	39	12	30.8	31.5	62.1	31,733	65.1	8	66.7
SW-FR	4,172,994	2,408,378	37,087	26,488	71.4	125	3	2.4	25.5	18.3	20,118	76.0	3	100.0
SE-FR	8,049,169	5,710,122	14,974	8348	55.8	81	7	8.6	53.7	27.9	4,838	58.0	6	85.7
TOTAL	**70,974,359**	**42,984,245**	**444,417**	**365,772**	**82.3**	826	**99**	**12.0**	**29.9**	**39.9**	**173,638**	**47.5**	**67**	**67.7**

Altogether, evidence suggests that drier than usual conditions have partly driven the extreme fires of the 2022's season.

We observed significant effects in seasonal burned area of LFMC, VPD and HDW, though with regional differences (Table 2, Figs. A4–6). Northwest Portugal attained the strongest relationships with fuel moisture content (LFMC and VPD; $R^2 = 0.54$ and 0.44, respectively), followed by central and northwest Spain, and southeast Portugal. The fire-HDW relationships were particularly strong in Portugal (northwest $R^2 = 0.61$; southeast $R^2 = 0.37$) and southeast France ($R^2 = 0.35$). As expected, LFMC depicted a negative profile (lower moisture associated with higher burned area; Fig. A4) whereas VPD and HDW showed positive relationships (higher atmospheric drought or HDW associated with higher burned area; Figs. A5-A6). No significant relationship ($p < 0.05$) was apparent for southeast Spain.

For extreme fires, we observed that lightning was the main ignition source (38 % of all extreme wildfires), followed by arson (24 %) and machinery sparks (14 %, Table 3). Live fuel moisture content ranged between 63 % and 107 %, with values around 60–70 % occurring in sites dominated by shrublands and values around 100 % in woodlands or conifer forests. HDW similarly varied between 63 hPa m s^{-1} and 201 hPa m s^{-1} across sites. The reported FWI values ranged from 31 to 104, with most fires burning under very hazardous fire weather conditions. 86 % of the firs occurred under extreme conditions (FWI ≥ 38 which correspond with fireline intensities above 10,000 kw m^{-1} in pine forests; Palheiro et al., 2006). The ISI was consistently above 13.4, the upper limit of the highest interval class according to the EFFIS classification system, whereas BUI was at medium-to-high values, being particularly relevant in those situations of FWI above 70.

3.3. Impacts: Protected areas and land cover

We observed that 69 % of all large fires impacted at least one PA (Table 1). Overall, 173,638 ha of PAs were affected by a large fire, representing 47 % of the total area burned by large fires. The surface of PAs affected by fire this year represent 0.8 % of the total area occupied by PAs.

The most common types of land cover affected by fire were shrublands, transitional woodlands (meaning bushes with scattered trees and naturally regenerating or plantation stands) and conifer forests (Table 3) to different degrees depending on the region. Shrubland fires were most common in Portugal (NW-PT and also SE-PT), followed by transitional woodlands. Fires in NW-ES, where the largest fires occurred (>28,000 ha), burned predominantly over transitional woodlands and, to a minor degree, shrublands. Fires in C-ES occurred primarily over shrublands and secondarily over conifer forests. Forests in SE-ES mostly burned conifer forests and shrublands. Fires in SW-FR predominantly burned conifer (plantation) forests and, to a minor degree shrublands.

4. Discussion

The evidence and data already available clearly indicate that the 2022 wildfire season was extreme in many ways. Our findings revealed not only the extraordinary extent of wildfires, but also the early onset of the fire season associated with large fire events (Fig. 1). The implications and consequences of the shift towards extreme fire regimes are manifold, indicating a growing vulnerability of protected areas, and require careful consideration.

4.1. Fuel aridity and fire weather

The Copernicus Climate Service identified 2022 as an unusual year with exceptional heat wave events – in terms of frequency, intensity, and duration – striking the western Mediterranean Basin. This led to sustained high temperatures since May and record-breaking LFMC, VPD and HDW levels over much of the summer (Figs. 1.i,j,k; Table 3; Figs. A1–3). The levels of VPD reported during the brunt of summer (>2 kPa in most regions) are consistent with modelled values of dead fuel moisture content well below 10 % and reaching into the lowest range of possible values (Nolan et al., 2016a). These are values conducive to very fast-spreading fires (Nolan et al., 2016b).

Table 2
Performance (R^2) of the seasonal regression models of burned area during the summer season (June–August) against live fuel moisture content (LFMC), vapor pressure deficit (VPD) and the Hot-Dry-Windy index (HDW). Shading indicates the significance level of the relationships (dark grey, p < 0.05; light grey, $p < 0.10$).

	NW-PT	SE-PT	NW-ES	C-ES	SE-ES	SW-FR	SE-FR
LFMC	0.54	0.25	0.24	0.28	0.01	0.10	0.31
VPD	0.44	0.11	0.32	0.40	0.05	0.19	0.39
HDW	0.61	0.37	0.13	0.08	0.04	0.00	0.35

Table 3
Wildfires larger than 5000 ha in the summer of 2022 in southwestern Europe. Data sourced from the European Forest Fire Information System (https://effis.jrc.ec.europa.eu/apps/effis_current_situation/).

Region	Location	Dates	Burned area (ha)	Ignition source	[a]Prevailing land cover	LFMC (%)	HDW (hPa m s^{-1})	Fire danger		
								ISI	BUI	FWI
NW-ES	Tábara	17–20 July	32,528	Lightning	Shrubland, farmland	75	132	30	175	76
NW-ES	Ferreras de Arriba	16–24 June	28,046	Lightning	Shrubland	98	92	17	141	51
SE-PT	Sameiro	6–21 July	25,260	Arson	Transitional woodland/shrub, shrubland	69	68	18	214	56
SE-ES	Bejis	16–19 August	19,362	Lightning	Conifer forest, shrubland	67	104	18	165	54
C-ES	Ateca	18–20 July	14,159	Agric. machinery	Shrubland	69	75	35	206	84
NW-ES	Folgoso do Courel	14–23 July	13,612	Lightning	Transitional woodland/shrub, conifer forest	95	145	19	88	45
SW-FR	Louchats	7–19 July	13,116	Arson	Conifer forest, shrubland	107	63	25	88	53
NW-ES	Carballeda de Valdeorras	15–22 July	12,735	Lightning	Transitional woodland/shrub	85	201	18	100	46
C-ES	Ladrillar	11–18 July	12,687	Lightning	Shrubland, conifer forest, transitional woodland/shrub	83	117	36	189	85
SE-ES	Vall d'Ebo	13–19 August	12,111	Lightning	Transitional woodland/shrub, shrubland	69	128	18	279	57
C-ES	Borja	14–15 August	9195	Powerline	Shrubland, farmland	63	67	18	136	52
SW-FR	Belin-Béliet	9–11 August	7764	Rekindle	Conifer forest, shrubland	65	84	15	156	47
NW-PT	Tresminas	17–21 July	7641	Arson	Shrubland, transitional woodland/shrub	77	116	21	158	60
C-ES	San Martín de Unx	19–21 June	7144	Arson	Shrubland	90	139	50	207	104
NW-ES	Vilariño de Conso	15–24 July	7090	Lightning	Transitional woodland/shrub	86	201	23	83	49
C-ES	Puente la Reina	18–21 June	6531	Agric. machinery	Conifer forest, farmland, shrubland	94	194	50	231	104
NW-PT	Samardã	21–24 August	5850	Pasture renewal	Transitional woodland/shrub, shrubland	68	76	10	152	37
NW-PT	Vilela Seca	15–20 July	5845	Accidental	Shrubland, farmland	70	96	34	127	72
SW-FR	Teste-de-Buche	12–26 July	5806	Accidental	Conifer forest	104	85	14	60	31
NW-PT	Pousaflores	8–15 July	5342	Arson	Shrubland, conifer forest	83	134	34	127	75
SE-ES	Júzcar	8–11 June	5042	Agric. machinery	Conifer forest, shrubland	108	93	15	137	46

[a] All the cover types accounting for >20 % of the burned area, presented by decreasing order of importance.

Similarly, the values of LFMC associated with extreme fires ranged between 60 % for shrublands to 100 % in conifer forests. Although it is physiologically possible to observe leaf-level values of LFMC down to 40 % in some Mediterranean shrubs (Pellizzaro et al., 2007), the remotely sensed values reported here with 500-m resolution are below historical records and they are well below critical thresholds of occurrence for large wildfires in the area (Jurdao and Chuvieco, 2012; Resco de Dios et al., 2021a).

The variability in HDW, from 63 to 201 hPa m s^{-1} likely represents the different types of extreme fires that occurred this summer. Plume-driven fires do not require strong winds (and may consequently show low HDW values). However, wind-driven fires are necessarily associated with high HDW values. It is worth noting that, while high HDW values are not incompatible with plume-driven fires, low HDW values do indicate that fires were not wind driven. This result indicates that HDW does not depict fire danger in its entirety, and should be supplemented by indicators of atmospheric instability and of fuel moisture content, both of live and of slow-drying dead fuels.

It is worth noting that there was also regional variation in terms of the roles played by average values of LFMC, VPD and HDW on cumulative burned area. Relationships were generally significant, but they varied from strong in NW-PT, to non-significant in SE-ES. The variation in the strength of the relationship was apparently mediated by a gradient in productivity, since NW-PT is the most productive region while SE-ES is the least productive one (Fernández-Guisuraga et al., 2022). The relative role of fuel limitation to fire activity is thus higher in SE-ES (Boer et al., 2021), which explains the lower impact of LFMC, VPD and HDW over longer-term averages. Additionally, a higher degree of spatial connectivity in NW-PT may explain the higher coupling with atmospheric and fuel drivers.

Regarding FWI, high and extreme values were observed, especially in fires larger than 10,000 ha. The ISI component, which was consistently high in all extreme fire events, suggested a relevant role of wind and fine dead fuel moisture in the spread potential. Most fires burned mainly shrub-type land covers, which were readily available for burning posing an additional layer of difficulty to containment and suppression.

It is currently being discussed whether this year's exceptional summer was the result of global warming. At any rate, these rare meteorological events fall inside the expected trend under climate warming projections (C3S, 2017, 2022) and may even amplify over the next decades (Ruffault et al., 2020), potentially becoming average by 2035 (CCAG, 2022).

4.2. An increased role of lightning-caused ignitions?

We observed that lightning was the most important ignition source for extreme wildfires. Lightning is associated with more extreme fires as they occur under higher atmospheric instability (Fernandes et al., 2021). Over the Iberian Peninsula, lightning fires are known to be linked to dry thunderstorm episodes, particularly frequent in certain enclaves in the northwest of the Iberian Peninsula (Dijkstra et al., 2022). Summer thunderstorms are usually linked to thermal lows eventually developing after sustained anticyclonic conditions driving abnormally high temperatures (Fernandes et al., 2016a; Rodrigues et al., 2019).

4.3. Protected areas have been largely affected by fire and other impacts

We observed that 47 % of the area burned in the 2022 summer fire season occurred in protected areas, while they only occupied 40 % of the wildlands. Consequently, the proportion of burned area in PAs is larger than the area they occupy. This indicates that PAs are thus primary "victims" of forest fires and it also suggests that lack of fuel management within PAs may play an important role on unabated fire spread. The main structural factor enhancing fire spread over large scales is a high degree of spatial fuel connectivity (Fernandes et al., 2016b). This pattern has been traditionally associated to agricultural abandonment and forest plantations (Moreira et al., 2020). Our results indicate that we should additionally consider whether current management in PAs, which often neglects fuel treatments as they may conflict with conservation values, is also contributing to unabated increases in fire spread. This hypothesis is not incompatible with the notion that agricultural abandonment or plantations are the major drivers of large-scale fuel connectivity. In fact, many of the current PAs do include plantations and transitional woodlands (González-Doncel and González, 2017). Future research efforts should clarify whether fires disproportionately select for PAs, and also on how to manage them to mitigate the wildfire problem while preserving the conservation and touristic values typical of PAs.

Wildfire impacts are primarily social and economical in these fire-prone landscapes. That is, fire affects rural economies, and may favour further land abandonment as small-scale farming and forestry become less profitable. This may create a feedback loop, where fire enhances land abandonment, which then increases fuel connectivity and fuel loads and consequently further increases wildfire activity.

However, an increasing impact of fire in PAs may seriously compromise biodiversity conservation and lead to large-scale landscape degradation (Karavani et al., 2018). Shrublands, transitional woodlands and conifer forests were the vegetation types most affected, so this is where fuel management actions should be prioritised. It is worth mentioning that eucalypt plantations were not a relevant component in any of the extreme fires this year. This is consistent with previous work indicating that eucalypt expansion did not affect burned area or fire regimes regionally (Fernandes et al., 2019).

Earlier - and therefore potentially longer - seasons may have profound implications for forest and wildfire management as well. For instance, early onsets are likely to find the fire suppression system at insufficient preparedness levels for a safe and efficient response, while preventive and management activities must also be scheduled sufficiently in advance.

Considering that this year's meteorological conditions may become average by 2035 (CCAG, 2022), it is tempting (albeit speculative) to hypothesize that the year 2022 could be a turning point where, after decades of suppression-driven declining burned area, extreme wildfire seasons may increase due to interactions between an increasingly warming climate and massive fuel accumulations. Although it is too early to test this, it is clear that only landscape-scale fuel management can mitigate wildfire risk and break this reinforcing loop (Cochrane and Bowman, 2021; Moreira et al., 2020; Wunder et al., 2021).

4.4. Policy implications

The European Union is now at a crucial stage in its development of forest strategies and legislation. As part of the Green Deal, a new Biodiversity strategy has been developed and the proposal for a Nature Restoration Law was approved earlier in June (European Commission, 2022). So far, wildfires are simply added as a tag line in EU's forest strategies and legislation. Our results indicate how the wildfire problem is on the rise, exerting major impacts on PAs. We thus recommend for a stronger role of wildfire prevention within forest policies at continental scale.

CRediT authorship contribution statement

Marcos Rodrigues: Conceptualization, Writing – original draft. **Àngel Cunill Camprubí:** Formal analysis. **Rodrigo Balaguer-Romano:** Conceptualization, Writing – review & editing. **Celso J. Coco Megía:** Formal analysis. **Francisco Castañares:** Conceptualization. **Julien Ruffault:** Conceptualization, Writing – review & editing. **Paulo M. Fernandes:** Conceptualization, Writing – review & editing. **Víctor Resco de Dios:** Conceptualization, Formal analysis, Writing – original draft.

Data availability

Data used in this manuscript is available from original data providers indicated in the text

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.160320.

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