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Analyzing the dynamics of forest fires in Málaga province: assessing the interplay of vegetation and human influence on regional hazard trends over three decades

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Abstract
Wildfires are a global issue, exacerbated by climate change, and are particularly significant in the Mediterranean basin. This study aims to analyze forest fire dynamics in Málaga province (Southern Spain), examine their temporal evolution, evaluate significant hazards such as vegetation and human activities, and assess the effectiveness of measures taken against forest fires. The primary objective is to identify factors that exacerbate fires and suggest mitigation strategies. The study analyzed the frequency, affected area, and casualties of forest fires over the past 30 years using data from the Andalusian Environmental Information Network (REDIAM). Vegetation flammability, generally high in the province, was evaluated by classifying plant species from the Map of Land Use and Land Cover in Andalucía (MUCVA) and comparing burned and unburned areas from 2010 to 2022. Additionally, fuel density and continuity, also notably high, were examined using REDIAM geodata. The study also assessed the implementation of the Forest Fire Fighting Plan in the Autonomous Community of Andalucía (INFOCA Plan), focusing on its spatial distribution and the "protection" provided by public administration for areas with protective designations and public forests. Finally, the effectiveness of prevention and firefighting measures in Málaga province was evaluated through an extensive literature review. The data indicates a high occurrence of fires, with three-quarters caused by human activities, and significant peaks in the affected areas. It was found that protected areas represented three-quarters of the burned area. The findings revealed that certain preventive measures were insufficient, leading to proposed improvements.

Keywords Regional geographical studies · Forest fires evolution · Forest fires hazard factors · Vegetation flammability · Prevention measures

Introduction

It is well-known that the Mediterranean belt is one of the territories most affected by forest fires (Fernandez-Anez et al. 2021). Over the last decades, numerous scholars have confirmed that the reasons may be related to its characteristic climate, human population growth, land abandonment, and the traditional use of fire to burn catch crops (Verkaik et al. 2013). Moreover, other new factors contribute to this multifaceted environmental dynamic: the intensification of urban sprawl and rural depopulation (San-Miguel-Ayanz et al. 2013), and conflicts in the rural interface. Some of these conflicts are caused by the declaration of protected areas that limit local populations, the demand for more agricultural land, the presence of stubble and weeds that complicate replanting, the woody vegetation in pastures, and the fine fuel that develops rapidly with the cessation of rural activities on the land (Vélez 2002).

Nowadays, the number of forest fires and the affected area are decreasing, but the occurrence of large forest fires is of great importance compared to ten years ago (San-Miguel-Ayanz et al. 2013; Araque-Jiménez 2013). The European countries where the situation is most worrying are Spain, Portugal, and Turkey (European Environment Agency 2021). Especially in southern Spain, such as Andalucía and Extremadura, drought periods characterized by high temperatures and elevated evapotranspiration rates are modifying

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the potential fuel accumulation. As forest fires are a serious problem in the Mediterranean area, many studies have been conducted on this issue. For example, Duguy et al. (2007) carried out simulations of different fuel scenarios using remote sensing based on the parameterization of the FARSITE model (which relates meteorological, relief, and fuel variables) and fieldwork. This work was based on a fire that occurred in the Ayora site, in the province of Valencia in 1979, using the same days and times and the same locations of ignition sources. They compared the results obtained with the models with the real fire and established a relationship between fuel and the characteristics of the fire, which clearly exists, also showing the importance of reducing the continuity of dense Mediterranean scrub and creating firebreaks. Another example was demonstrated by Elia et al. (2014), where four fuel models were created for a region of Apulia, located in southeastern Italy. After collecting forest cover data, the fuel load in selected experimental plots was modeled with hierarchical cluster analysis and the FlamMap5 software to simulate different meteorological situations, obtaining, again, a significant relationship between fuel and fire characteristics, in addition to the high hazard of Mediterranean maquis vegetation.

The forest fire hazards in a specific territory can be analyzed through mapping techniques, usually resulting from the combination of environmental factors and related human activities (e.g., Mota et al. 2019; Kanga et al. 2017). Remote sensing is mostly used not only to analyze fire hazard but also to study fuel characteristics, detect active fires, and monitor fire effects and post-fire recovery (Chuvieco et al. 2020). Some of the frequently used satellites include LANDSAT 8 (Flores-Rodríguez et al. 2021), Sentinel-2, and MODIS (Ramo et al. 2021; Bilgiç et al. 2023), as well as others such as NOAA-7-19, PROBA V, SPOT 1–7 and 4–5, and other versions of Sentinel and LANDSAT (Chuvieco et al. 2019). Numerous indices related to forest fires are also extracted from satellite imagery and based on a single image date or bands, such as the Normalized Difference Vegetation Index (NDVI), the Landsat Enhanced Vegetation Index (EVI), the differenced Normalized Burn Ratio (dNBR), or even combined with LiDAR technologies (Flores-Rodríguez et al. 2021; Chuvieco et al. 2019).

Temporal and spatial resolutions also vary, ranging from 1 to 2 days to almost a month, and from 2.5–5 m to 1000–1200 m. Other very modern technologies are also being used in relation to forest fires. These include machine learning, used to predict forest fires based on risk using historical fire data, various hazard factors combined with meteorological data, for example (Mohajane et al. 2021; Rubí et al. 2023), or data mining, which enables accurate analysis based on algorithm models, such as the torque-on-bit (TOB) model, support vector machine (SVM), functional data analysis (FDA), and others (Wood 2021; Eskandari et al. 2020). However, each method naturally has its disadvantages and issues related to subjectivity when using weighted indices (Parajuli et al. 2020), establishing categories by comparing the results to current burned areas (Trucchia et al. 2023; Sharma et al. 2015), different periods depending on the state of vegetation (Vallejo-Villalta et al. 2019), or using grid climate data, which makes it possible to analyze the impact of climate change on the burned area by forest fires (Turco et al. 2018b). This allows for obtaining a climate-fire model focusing on drought and maximum temperatures (Turco et al. 2019, 2017), or predicting the burned area from dynamic seasonal climate predictions (Turco et al. 2018a) but with a resolution of kilometers.

Despite the diversity of existing studies about forest fires, there is a lack of long-term studies dealing with analyzing the historical evolution of fires in recent decades, considering specific aspects such as the vegetation flammability (which has not been analyzed at the regional scale) or the work carried out by public administrations, especially regarding the availability of human resources and prevention measures.

To address these gaps, this research focuses on the Málaga province as a case study, which is highly affected territory by forest fires, many of which are traditionally caused intentionally, often associated with the process of 'agriculturization' (Cruz-Artacho et al. 2000). However, there have been few studies on fires in the region, and none covering the entire province in recent decades. Therefore, this study aims to deepen our understanding of the true significance of forest fires in a Mediterranean territory like the Málaga province, firstly by comprehensively examining the characteristics of the problem within it. Our initial specific objectives were to analyze the dynamics by understanding trends in recent decades (including their frequency, affected area, and causes) to comprehend the origins of the problem and the primary factors contributing to it. However, we subsequently discovered that it was necessary to assess the extent of the impact of human activities on the problem, identifying actions that negatively affect it and exploring efforts to improve the situation and their effectiveness. Additionally, in connection with this, we aimed to evaluate the effectiveness of measures utilization of both firefighting and preventive measures, presuming that the latter would be lacking. Thus, this study also aims to underscore the insufficient research dedicated to preventive measures against forest fires (Riera and Mogas 2004), which are crucial. Finally, based on our analysis, our last and main objective is to propose measures that could be implemented to mitigate the problem.

In relation to these objectives, we established some hypotheses regarding the temporal changes in forest fires in the province: the number of forest fires and the area affected by them might be increasing. We also assumed that the main cause of fires would be human in origin.

We suggested that the type of vegetation would also contribute as a trigger, in addition to the preventive measures being insufficient. To validate or refute these hypotheses, we studied the temporal changes in the number, affected area, and causes of forest fires in the province over the last thirty years. We analyzed the role of vegetation in the danger of forest fires in the province by evaluating its flammability, density and continuity. For this purpose, a classification of the plant species present in the region was made, and this aspect was compared between burned and unburned areas in each period. For the analysis of human influence, we considered the population distribution in the territory, the location of protected areas, the availability of resources, and the extinction and prevention measures of the Forest Fire Fighting Plan of the Autonomous Community of Andalusia (Plan de Lucha contra los Incendios Forestales de la Comunidad Autónoma de Andalucía—INFOCA Plan). To carry out this analysis, cartographic data and bibliographic resources were used.

Our hypotheses have been tested. As a result, we refute the idea that the area and number of fires are increasing, but we validate that fires are predominantly of human origin, the type of vegetation is a determining factor, and preventive measures are insufficient. As a result of our observations, we propose various preventive measures that can be applied to the provincial territory.

Materials and methods

Study area

This study focuses on the Málaga province, situated in the southern region of Andalucía, Spain (Fig. 1). The province comprises 103 municipalities, with 75 falling within the Forest Risk Danger Zone, as designated by Decree 371/2010. The urbanization process in the province has been characterized by late industrialization since the 1980s, along with intensified agriculture, the rise of tourism, and the prominence of the construction and service sectors. These latter factors have led to the proliferation of buildings, often in linear patterns, and the concentration of the population along the coast, resulting in demographic decline in the mountain regions. The decline is largely attributed to the crisis in traditional agriculture, as the economic allure of coastal activities accelerated the abandonment of the primary sector, prompting a migration from inland to the coast (Galacho Jiménez 2002). This rural abandonment has implications for forest fires, contributing to excessive vegetation density and continuity.

The Málaga province encompasses the Mediterranean macro-bioclimate and oceanic pluvial bioclimate, allowing for the distinction of various ombrotypes ranging from dry to hyper-humid, and thermotypes, ranging from thermo-mediterranean to oro-mediterranean. This diversity results in varying temperatures and rainfall across different areas, characterized by a summer drought (Martínez-Murillo et al.

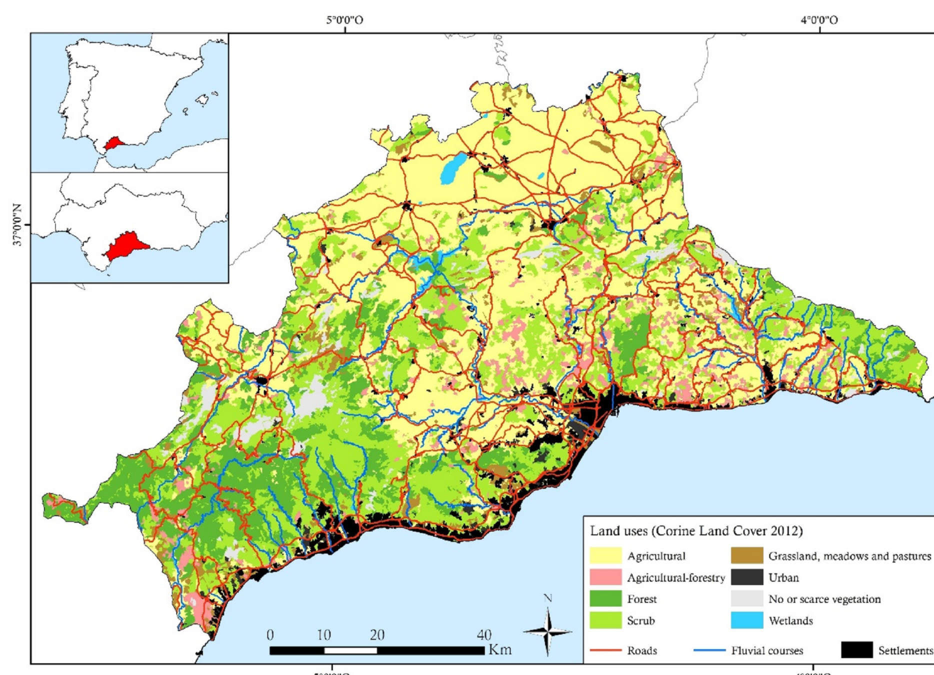

Fig. 1 Localization and main land uses (CORINE Land Cover 2012) of Málaga province

2017; Rivas-Martínez 1996, 2007). Consequently, different types of vegetation including climatophilic, edaphoxerophilic, and edaphohygrophilic species, thrive in the region (Asensi-Marfil and Díez-Garretas 1987; Caldera et al. 1991; Cabezudo 2009; Pérez-Latorre 2009; Pérez-Latorre and Cabezudo-Artero 2003, Pérez-Latorre et al. 2013). The altitudes in the province range from 0 to 2065 m a.s.l. at La Maroma (Fig. 2).

Methods

Historical evolution of forest fires

The evolution of forest fires has been studied based on data from the Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM) (Portal Ambiental de Andalucía, accessed on 01/2024; https://portalrediam.cica.es/descargas), from which graphs have been compiled. To assess the statistical validity of the data represented in the graphs, both the calculation of the coefficient of determination R^2 and the application of the Mann–Kendall test were employed. Mann–Kendall's non-parametric test (Mann 1945; Kendall 1975) deals with the analysis of trends with statistical significance without the need to use a high number of samples and with noise tolerance in the series (Miró et al. 2009). This test was conducted on the complete time series, while the R^2 calculations were performed for the corresponding sub-periods under analysis. This approach allowed for the verification of trends in the data, with values greater than 1.96 indicating an increasing trend and values less than −1.96 indicating a decreasing trend. Furthermore, the statistical significance of the results was ensured by considering the null hypothesis probability "p" value, which needed to be less than 0.05 in the test.

We examined the number of fires, surface area affected, and their causes (including natural, accidental, intentional, unknown, and cases involving negligence and human activities). These aspects have been elucidated through various sources including scientific research (Araque 2013; Gutiérrez-Hernández et al. 2016), documents from the Public Administration, such as those provided by the Ministry of Agriculture, Fisheries, and Food (Ministerio de Agricultura, Pesca y Alimentación 2019), as well as journalistic sources (e.g., Caballero 2017; or Europa Press 2021).

Fire hazard according to the current vegetation

The characteristics of vegetation play a significant role in influencing the risk of forest fires, affecting both their likelihood of occurrence and spread. Among these characteristics, flammability is a key factor examined in this study within the territory of Málaga province, aiming to assess its level of influence. To achieve this, a classification of species in the Map of Land Use and Land Cover in Andalusia (Mapa de Usos y Coberturas Vegetales del Suelo de Andalucía—MUCVA) from 2007 vegetation covers in the province was conducted (Table 1). We reviewed following studies: Elvira-Martín and Hernando-Lara 1989; Valette 1997; Generalitat de Catalunya 1994; Massari and Leopaldi 1998; Dimitrakopoulos and Papaioannou 2001; Hernando-Lara et al. 2004; Liodakis et al. 2011; Mancilla-Leytón et al. 2012; Molina et al. 2017; Rosentreter et al. 2017; Henaoui 2018; to determine average flammability levels for each species, which were subsequently standardized to encompass all species in the classification. The resulting categories were very low, low, moderate, high, and very high flammability.

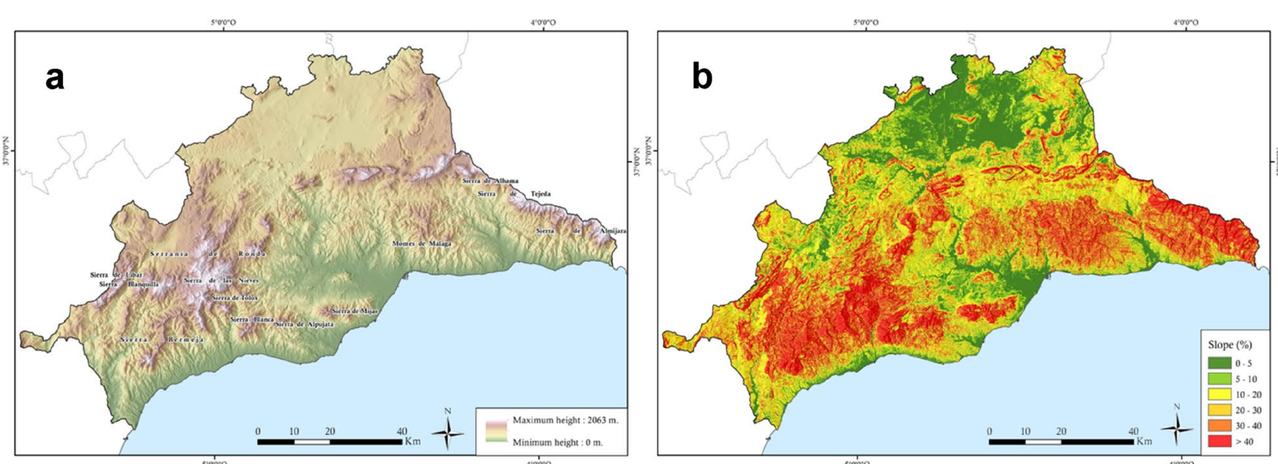

Fig. 2 Altitudes (**a**) and inclination (**b**) of Málaga province

Table 1 Flammability of the plant species present in the 2007 MUCVA forest area in Málaga province

Very low flammability				
Arthrocnemum macrostachyum	*Festuca scariosa*	*Phlomis lychnitis*	*Salix pedicellata*	*Suaeda vera*
Arundo donax	*Flueggea tinctoria*	*Phlomis purpurea*	*Salix pedicellata x Salix atrocinerea*	*Tamarix africana*
Buxus balearica	*Fraxinus angustifolia*	*Phragmites australis*	*Salix purpurea*	*Tamarix canariensis*
Calicotome intermedia	*Fraxinus angustifolia subsp. angustifolia*	*Populus alba*	*Santolina rosmarinifolia*	*Tamarix gallica*
Calicotome villosa	*Juglans regia*	*Populus nigra*	*Sarcocornia perennis subsp. alpini*	*Thymelaea hirsuta*
Coriaria myrtifolia	*Juncus acutus*	*Prunus dulcis*	*Schoenus nigricans*	*Ulmus minor*
Crucianella maritima	*Juncus maritimus*	*Salix alba*	*Scirpus holoschoenus*	*Viburnum tinus*
Daphne gnidium	*Opuntia ficus-indica*	*Salix atrocinerea*		
Low flammability				
Berberis vulgaris subsp. australis	*Crataegus monogyna*	*Helianthemum racemosum var. stoechadifolium*	*Juniperus oxycedrus subsp. oxycedrus*	*Pistacia lentiscus*
Brachypodium sylvaticum	*Halimium atriplicifolium*	*Juniperus communis subsp. hemisphaerica*	*Maytenus senegalensis subsp. europaea*	*Rhamnus alaternus*
Cistus albidus	*Halimium atriplicifolium subsp. atriplicifolium*	*Juniperus oxycedrus*	*Pinus sylvestris*	*Rhus coriaria*
Cistus salvifolius				
Moderate flammability				
Arbutus unedo	*Cistus populifolius subsp. major*	*Myrtus communis*	*Quercus canariensis*	*Rubus ulmifolius*
Astragalus granatensis	*Cupressus sempervirens*	*Nerium oleander*	*Quercus coccifera*	*Teline linifolia*
Bupleurum fruticosum	*Cytisus baeticus*	*Olea europaea var. sylvestris*	*Quercus faginea*	*Ulex baeticus*
Bupleurum gibraltaricum	*Cytisus scoparius*	*Ononis natrix*	*Quercus fruticosa*	*Ulex baeticus subsp. baeticus*
Castanea sativa	*Erinacea anthyllis*	*Ononis reuteri*	*Quercus lusitanica*	*Ulex borgiae*
Cistus clusii	*Genista cinerea*	*Ononis speciosa*	*Retama sphaerocarpa*	*Ulex parviflorus*
Cistus crispus	*Genista longipes*	*Pinus canariensis*	*Rhamnus oleoides*	*Ulex parviflorus subsp. parviflorus*
Cistus laurifolius	*Genista spartioides*	*Pinus pinaster*	*Rhamnus saxatilis*	*Ulex parviflorus subsp. rivasgodayanus*
Cistus populifolius	*Hormathophylla spinosa*			
High flammability				
Abies pinsapo	*Cistus ladanifer*	*Ficus carica*	*Pinus pinea*	*Rosmarinus officinalis*
Anthyllis cytisoides	*Cistus ladanifer subsp. ladanifer*	*Hyparrhenia hirta*	*Pinus radiata*	*Stipa tenacissima*
Ballota hirsuta	*Cistus monspeliensis*	*Lavandula multifida*	*Pistacia terebinthus*	*Thymbra capitata*
Brachypodium retusum	*Dittrichia viscosa*	*Lavandula stoechas*	*Quercus alpestris*	*Thymus mastichina*
Ceratonia siliqua	*Echinospartum boissieri*	*Phillyrea latifolia*	*Quercus suber*	*Thymus zygis*
Chamaerops humilis				
Very high flammability				
Acacia cyanophylla	*Erica arborea*	*Eucalyptus globulus*	*Juniperus phoenicea subsp. phoenicea*	*Quercus ilex subsp. ballota*
Adenocarpus decorticans	*Erica australis*	*Genista hirsuta*	*Juniperus phoenicea subsp. turbinata*	*Ricinus communis*
Adenocarpus telonensis	*Erica scoparia subsp. scoparia*	*Genista tridens*	*Juniperus sabina subsp. humilis*	*Rosa canina*
Asparagus acutifolius	*Erica terminalis*	*Genista umbellata subsp. equisetiformis*	*Pinus halepensis*	*Spartium junceum*
Calluna vulgaris	*Eucalyptus camaldulensis*	*Helichrysum stoechas*		

The next challenge involved classifying the vegetation covers of the MUCVA, which often included multiple species, with the surface area occupied by each species in these covers being unknown. In such cases, the flammability of the species within the cover was averaged. The study aimed to compare the flammability of both burned and non-burned surfaces during a specific period (2010–2022). Secondly, we analyzed the continuity of fuel, identifying categories in the province based on the density and continuity of the scrub and the potential spread by crowns. This categorization was derived from REDIAM geodata from 2016.

Human-induced forest fires hazard and measures to extinguish/prevent forest fires

The human-induced hazard has been assessed through mapping related to the traffic and the presence of infrastructures, which contribute to the risk of forest fires. This evaluation is based on the 2016 REDIAM geodata, integrating the visualized information with a relevant bibliography, particularly focusing on the hot spots of hazard. Additionally, the control measures implemented in the province of Málaga have been analyzed. This includes an examination of the resources of the INFOCA Plan, with geodata from REDIAM; the protection of areas, with geodata from Datos Espaciales de Referencia de Andalucía -DERA- (Portal de Datos Estadísticos y Geoespaciales de Andalucía, accessed on 02/2024; https://www.juntadeandalucia.es/institutodeestadisticaycartografia/dega/datos-espaciales-de-referencia-de-andalucia-dera/descarga-de-informacion) and with an evaluation of their surface area (Piqué 2015; Mazón-García 2016); and the adequacy of extinction and prevention measures (World Wildlife Fund-WWF 2015, 2021, 2022, 2023a; b).

Results

Historical evolution of forest fires

The evolution of forest fires in the autonomous community of Andalucía, where the province of Málaga is located, over the last few decades has been marked by two characteristics. The first of these is the increasing trend, both in number and frequency, of forest fires in the community since the 1960s. This trend is attributed to the rural exodus, resulting in the depopulation of the interior of Andalucía, leading to the abandonment of forests and an excessive increase in plant fuel. Additionally, the concentration of the population on the coast, particularly the Western Costa del Sol in Málaga province, due to the development of touristic activities, has heightened the demand for rural land over forestry use, which is considered less profitable. This shift in land use, coupled with the urban-forest interface, has increased the occurrence of intentional fires and fires caused by negligence.

All this gave rise to the second noted characteristic: the development of the forest fire extinction and prevention policy in Andalucía in the 1990s, highlighted by the creation of the INFOCA Plan in 1995 (Department of Sustainability, Environment, and Blue Economy -Consejería de Sostenibilidad, Medio Ambiente y Economía Azul 2010). The increase in hiring, surveillance, land and aerial extinguishing means, and awareness-raising work, along with the development of new technologies for prediction, observation, location, communication, etc. (Ministry of Environment 2002), is reflected at the beginning of the graph about this (Fig. 3). Therefore, the clearly decreasing trend between 1990 and 1996 is the result of the implementation of these policies. From 1996 onwards, the graph is characterized by stabilization, which seems to indicate the intensity of the measures and the early reaching of their limits. Another aspect highlighted by the graph is the higher number of fires of less than 1 ha compared to fires of more than 1 ha over the whole time series, especially from 1996 onwards, indicating the success of fire suppression policies, above all. The Mann–Kendall test (Table 2) indicates decreasing trends for the entire time series for small fires (<1 ha), fires >1 ha and for the total (M–K $=-1.69$, -3.32, -2.55, respectively; and $p<0.05$ in all cases).

Burned area

Regarding temporal changes in burned area, three trends can be distinguished in Fig. 4. Firstly, the increasing trend between 1988 and 1991 indicates the period preceding the development of prevention and extinguishing measures discussed above. This period not only led to a high number of fire occurrences but also to a large affected surface. Secondly, the decreasing trend between 1991 and 1996 is a result of the implementation of these measures, undoubtedly contributing to reducing the size of fires, with an essential role played by improved extinguishing measures. Finally, a moderately stable trend is observed between 1996 and 2021 with low values of the burned surface compared to the preceding periods due to the previously implemented measures. However, this trend is marked by years of large forest fires, where some significant contributors include the forest fires in Coín in 2012 and Sierra Bermeja in 2021 (Caballero 2017; Europa Press 2021). Additionally, the fire in Parauta in 1991 affected 8225 ha, emphasizing the impact of large forest fires on the overall stability of the trend, in which only this type of fire involves major changes in the affected surface (Caballero 2017).

There is a differentiation of the affected area according to the vegetation strata of woodland and scrubland. Throughout the time series, it is the second stratum,

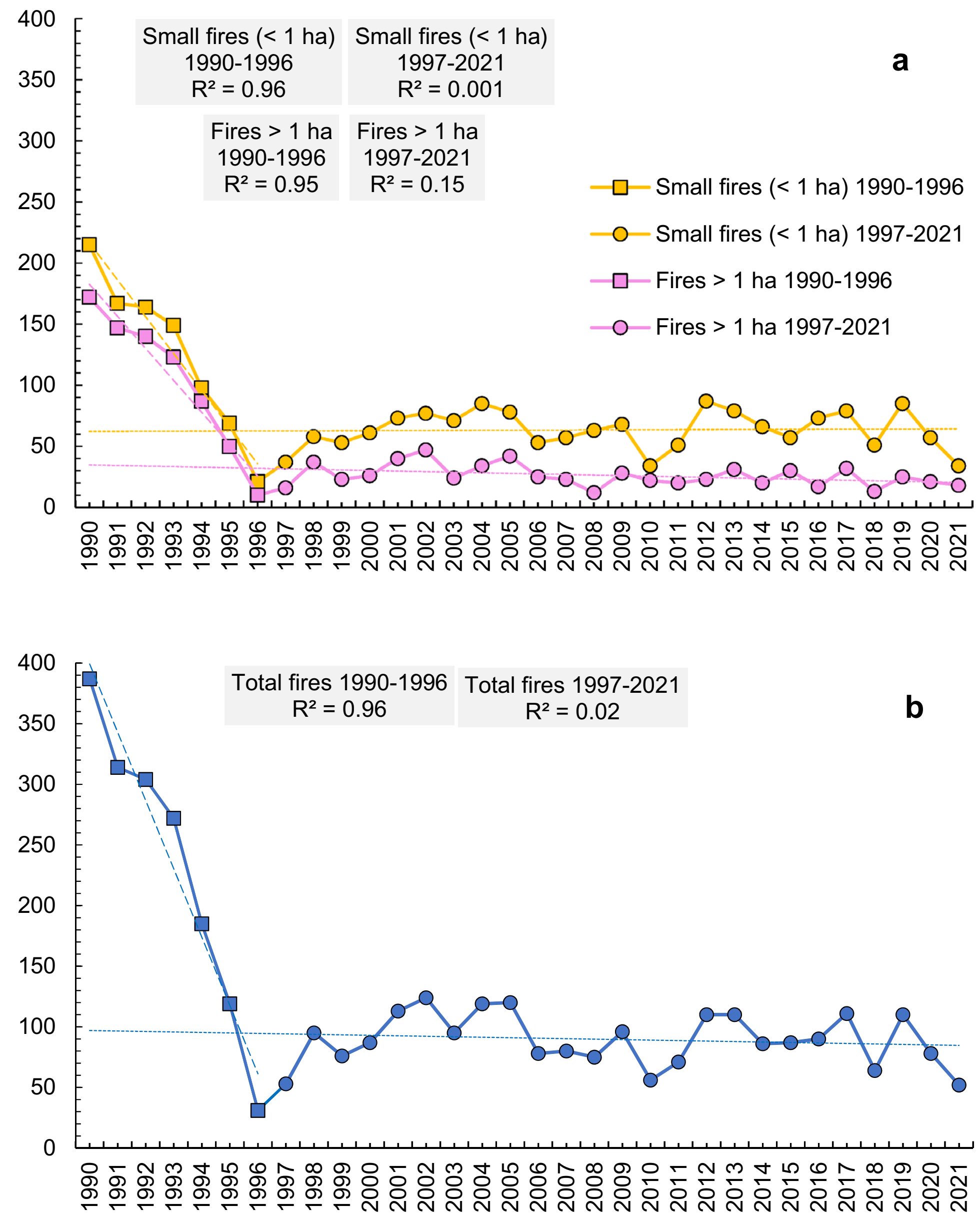

Fig. 3 Evolution of the number of forest fires in Málaga province (1990–2021) per size (**a**) and total number (**b**). *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

Table 2 Analysis of the trend in the number of forest fires in Málaga province

	R^2	M–K	*p*
Small fires (<1 ha)	0.2648	−1.69	<0.05
Fires >1 ha	0.4415	−3.32	<0.05
Total	0.3587	−2.55	<0.05

R^2 coefficient of determination, *M–K* Mann–Kendall test value, *p* null hypothesis probability

scrubland, that burns more extensively (except in two years, 1991 and 1995). This is attributed, on one hand, to the different flammability of the strata, as scrubland tends to burn more frequently, although for shorter durations than woodland. On the other hand, it is influenced by the greater percentage of surface area in the province, 4% more, and 8% more when considering the mixture of scrubland and woodland calculated from data provided by the Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible) (2016). The cover of scrubland continues to increase, with the Sierra de Almijara being a notable example. The Mann–Kendall test (Table 3) indicates, for the whole time series, decreasing trends for the trees surface, the shrubs surface and the total surface (M–K = −2.79, −2.13, −2.40, respectively; and $p < 0.05$ in all cases).

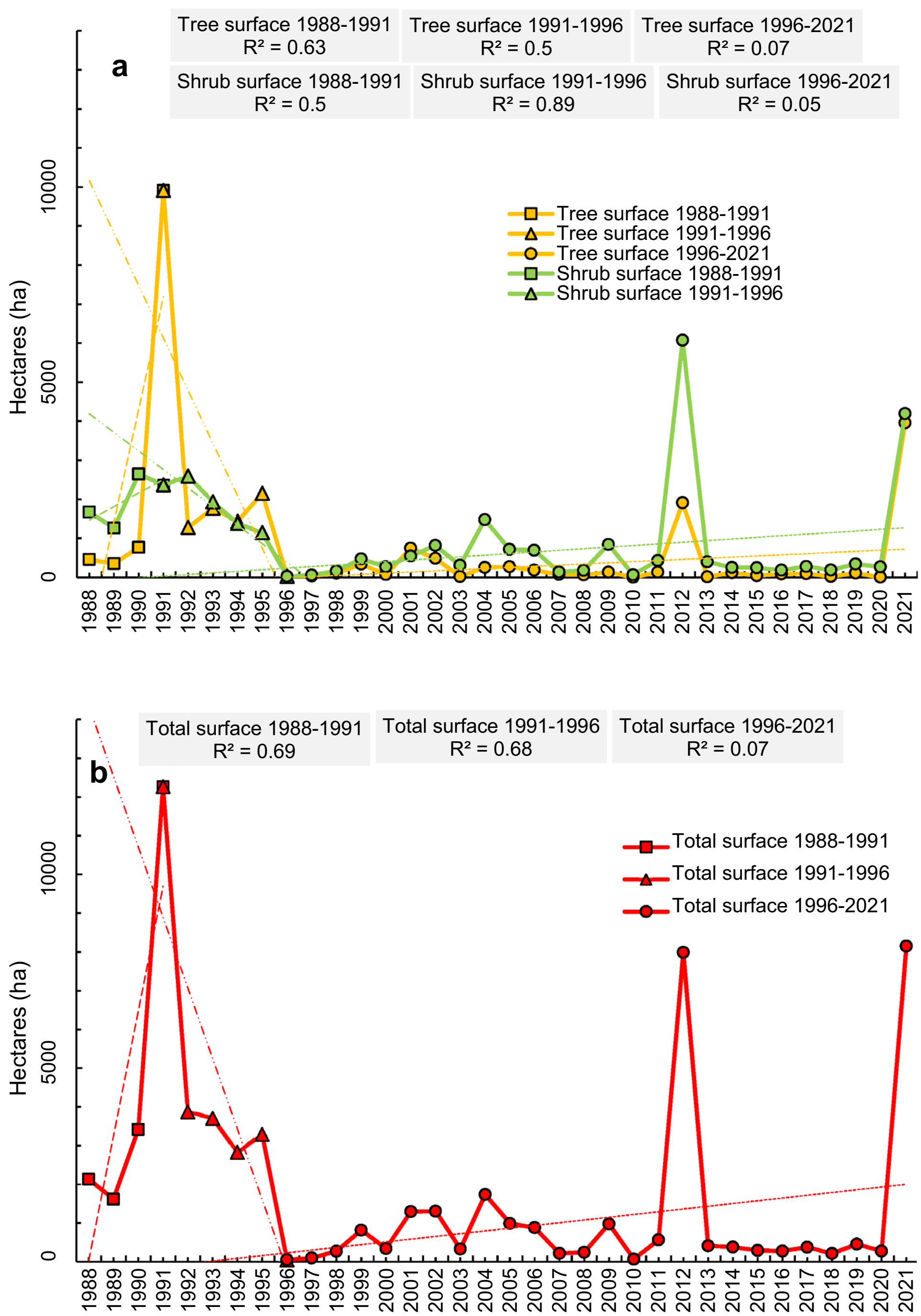

Fig. 4 Evolution of the affected surface by forest fires in Málaga province (1988–2021) per size (**a**) and total surface (**b**). *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

Table 3 Analysis of the trend in the affected surface by forest fires in Málaga province

	R^2	M–K	p
Trees surface	0.0626	−2.79	<0.05
Shrubs surface	0.0187	−2.13	<0.05
Total surface	0.0539	−2.40	<0.05

R^2 coefficient of determination, *M–K* Mann–Kendall test value, *p* null hypothesis probability

Causes of forest fires

To discuss the causes of forest fires, it is necessary to clarify the difference between certain types outlined in the instructions for filling out the forest fire report (Statistical Working Group of the Forest Fire Fighting Committee, Grupo de Trabajo de Estadística del Comité de Lucha contra Incendios Forestales 2021), particularly those related to humans (see Table 4). Analyzing the proportion of each type of cause in the period 1990–2020 in the province of Málaga (Fig. 5), the

Table 4 Difference between causes of forest fires related to humans

Cause of forest fires	Description
Accidental	Occurred despite care, provided that the fire risk of the activity in question has been previously reported, action has been taken to avoid the risk, and the current regulations have been complied with
Caused by negligence	Resulting from activities carried out carelessly or in a 'defective or risky' manner
Intentional	The activity causing the fire occurs with the intention of causing it and with awareness of the offense

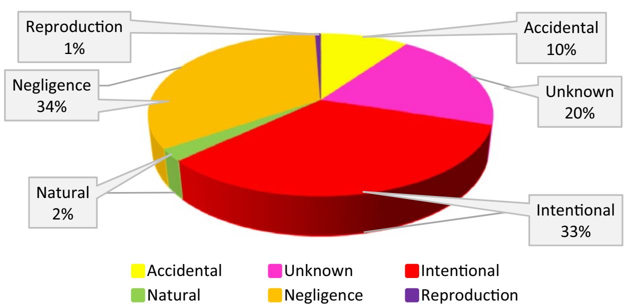

Fig. 5 Mean percentage (1990–2020) of the number of forest fires in Málaga province according to its causes. *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

most common causes are fires caused by negligence (34%) and intentional ones (33%), followed by those with unknown causes (20%), accidental fires (10%), natural fires (2%), and those due to reproduction (1%). It is noteworthy from these percentages that many forest fires are caused by humans, although those that are not, theoretically intentional, outnumber intentional ones. The very low percentage of fires due to natural causes and the high percentage of fires with unknown causes are also striking.

Next, changes in the main causes of fires are assessed, focusing specifically on the number of fires by cause in the period between 1990 and 2020 (Fig. 6). Fires caused by intention, negligence, and unknown causes show a strikingly decreasing trend between 1990 and 1996. The similarity of the trends of fires caused by intention and unknown causes in that period is noteworthy. The trends for these three types of fires stabilized after 1996. However, for accidental fires, a practically inverse trend is observed, with an increase between 1990 and 1996 and a decrease thereafter. The Mann–Kendall test (Table 5) indicates, for the whole time series, decreasing trends for unknown, intentional and negligence causes (M–K = −2.19, −3.11, −1.75, respectively; and $p < 0.05$ in all cases). The tests do not identify significant statistics trends for accidental and natural causes (M–K = 0.83, 1.21, respectively; and $p < 0.05$ in both cases).

No trend can be identified for fires with natural causes. Changes in percentages of the most important causes is

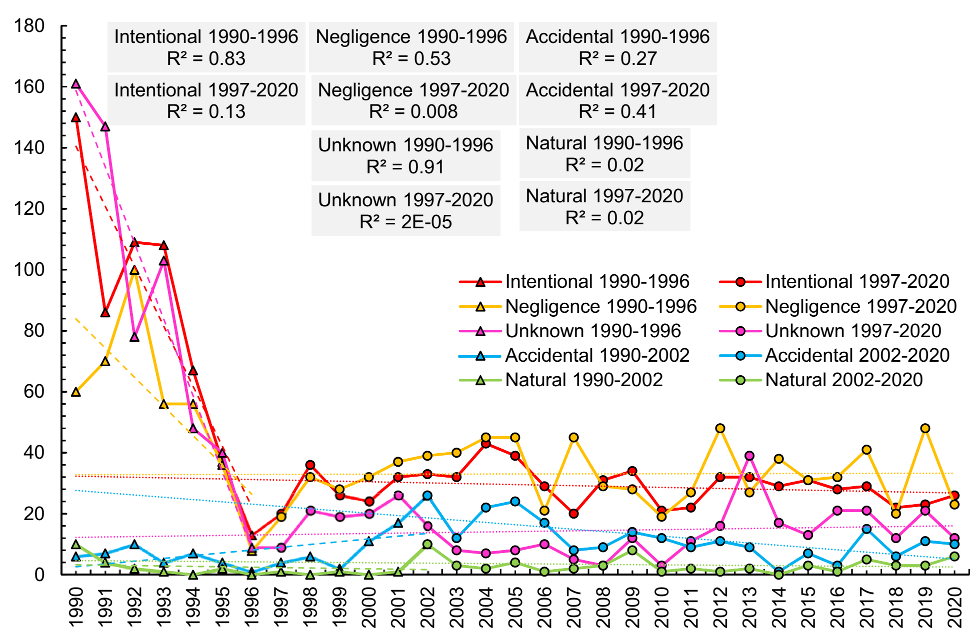

Fig. 6 Evolution of the number of forest fires in Málaga province according to its causes (1990–2020). *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

Table 5 Analysis of the trend in the number of forest fires according to their causes in Málaga province

	R^2	M–K	p
Accidental	0.0173	0.83	<0.05
Unknown	0.3503	−2.19	<0.05
Intentional	0.3743	−3.11	<0.05
Natural	0.0027	1.21	<0.05
Negligence	0.1874	−1.75	<0.05
Total	0.3418	−2.43	<0.05

R^2 coefficient of determination, *M–K* Mann–Kendall test value, *p* null hypothesis probability

analyzed, allowing for comparisons and the identification of trends in a more appropriate way. Two increasing trends can be distinguished for fires with natural causes in two sub-periods, 1990–2009 and 2010–2020. The drop in 2010 breaks the trend in the entire time series (Fig. 7), which is likely related to climate change. Increasing temperatures and decreasing precipitation have impacted the dryness of vegetation, making it more prone to catching fire and spreading sparks across the territory, especially in summer. Regarding the evolution of the percentages of fires with human causes (Fig. 8), two trends can be identified for accidental fires and fires caused by negligence: an increase between 1990 and 2006 and 1990–2007, respectively (more pronounced in the first case), and a stabilization thereafter. Meanwhile, the percentage of intentional fires decreases, especially from 2008

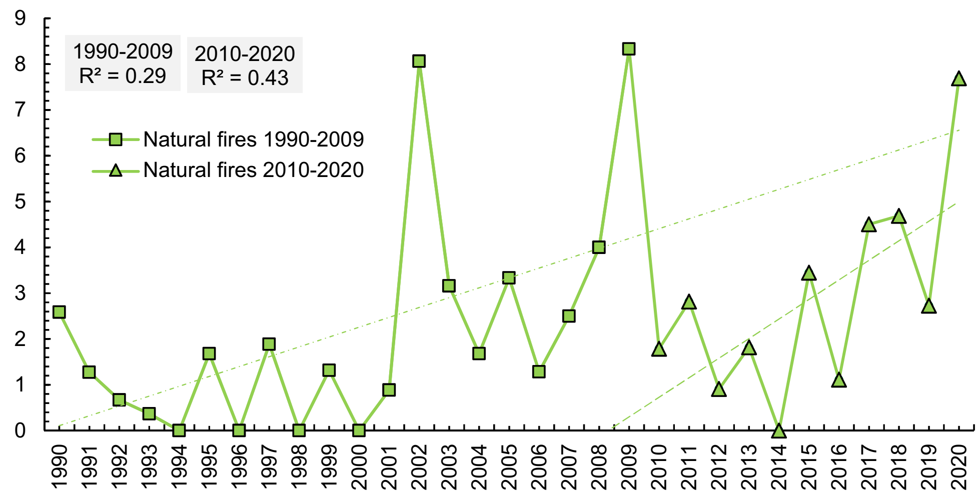

Fig. 7 Evolution of the percentage of the number of forest fires due to natural causes in Málaga province (1990–2020). *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

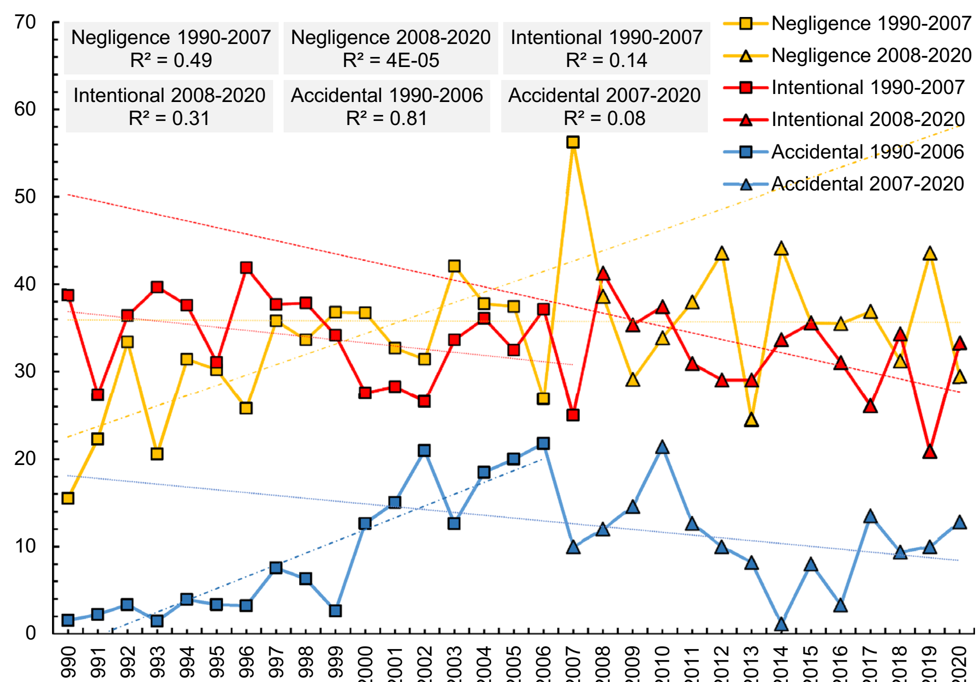

Fig. 8 Evolution of the percentage of the number of forest fires due to human causes in Málaga province (1990–2020). *Data source* Regional Ministry of Agriculture, Livestock, Fisheries, and Sustainable Development (Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible), extracted from the Andalusian Environmental Information Network (Red de Información Ambiental de Andalucía—REDIAM)

onwards. The difference in trends could be attributed to the development of measures that took place, as we know, in the 1990s, influencing the increase in vigilance, public awareness, and prevention, contributing to the improvement of the situation, especially regarding intentional fires.

Fire hazard according to the current vegetation

The incidence of vegetation flammability

Starting with flammability as the first aspect of the vegetation to be assessed, a comparison is made between the burned area between 2010 and 2022 and the non-burned one (Fig. 9). On the one hand, in the non-burned area, vegetation of high, moderate and very high flammability (from largest to smallest surface area) is predominant, representing 40, 29 and 20% of the total not burned area, respectively. On the other hand, low and very low flammability vegetation, representing 6 and 5%, respectively, occupies a very small area, especially the latter, forming small patches scattered throughout the territory (although they are more prominent in the southwest of the province). Moderate flammability vegetation occupies larger areas, especially in the west and in the center of the province. Highly flammable vegetation is concentrated, to a greater extent, in the western part of Sierra Bermeja, Alhama and Almijara mountain ranges and the Montes de Málaga; and it is in this last enclave that the situation is most worrying, as it is here that the most highly flammable vegetation is found, occupying it almost completely. Most of this vegetation is composed of the genera: *Rosmarinus*, *Ulex*, *Stipa*, *Genista* and *Cistus*. However, in the burned area between 2010 and 2022, moderate flammability

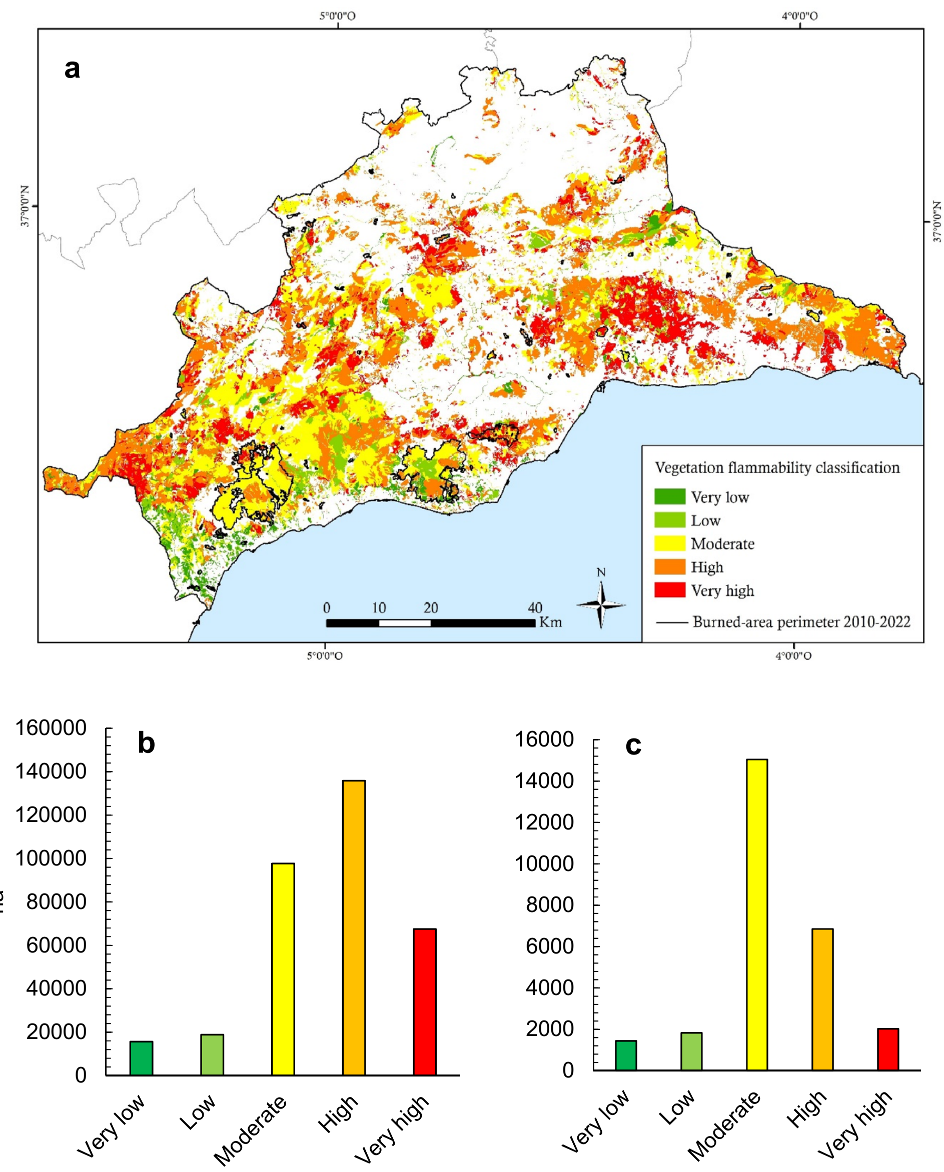

Fig. 9 Map of the vegetation flammability in burned and non-burned area (2010–2022) in Málaga province (**a**). Graphs of the area occupied by vegetation according to its flammability in the non-burned area (**b**) and in the burned area (**c**)

vegetation is overly predominant over high flammability, while low flammability is also in last place and low and very high flammability area a little above. Therefore, the flammability of the vegetation corresponding to the burned area is not higher than that of the non-burned area, as would be expected. It is the opposite. The heterogeneity in the flammability of the vegetation marked by the preponderance of moderately flammable vegetation observed in these areas reinforces this fact. It could be said that the flammability of vegetation covers has not influenced the occurrence of forest fires as expected. To study this phenomenon further, the flammability of the two surfaces was again compared, but this time at the level of plant species instead of vegetation covers (Fig. 10).

There are important differences between the two areas. While plant species of very low and low flammability are found in greater proportions in the non-burned area (being the difference more marked in the first), the species of the other flammability classes are found in greater proportions in the burned area, especially species of high flammability. Therefore, at the species level, the differences in flammability of vegetation between the area affected and not affected by forest fires in the period 2010–2022 are, in this case, as expected, because it seems logical that forest fires affect the most flammable vegetation, which burns easier.

The incidence of the fuel density and continuity

The fuel continuity shown in the map (Fig. 11a) is the result of the consideration of three variables: the fuel load corresponding to the tree strata, the apparent density of their crowns, and the height of the crowns' base of the forest covers of kermes oaks, pines and eucalyptus; resulting in different categories of forest fire hazard linked to the possibility of spread over areas of varying extent. In addition, the possibility of the presence of continuous and dense scrub is considered in all categories.

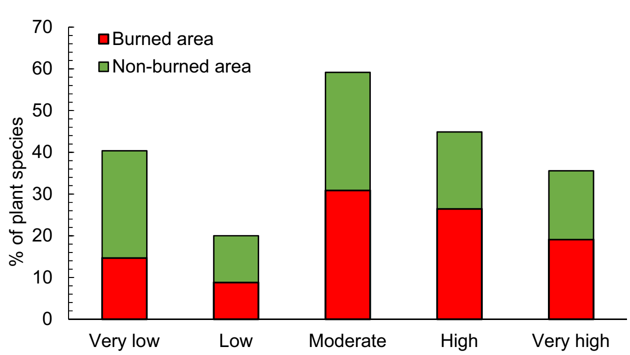

Fig. 10 Percentage of plant species according to their flammability in the burned and non-burned area of Málaga province

The extreme hazard of forest fires due to this cause can be clearly seen in the south-western mountain ranges of the province: Sierra Bermeja, Sierra de las Nieves, Sierra Blanca and Sierra de Alpujata; as well as in the south-eastern ones: Tejeda and Almijara. Very high hazard is found in the western part of the province (for example, in the western part of the Serranía de Ronda shire) and in some areas of the Antequera Mountains, in the northeast. High hazard is in the western half of the province and in the south-central area, being an example the Sierra de Mijas. Moderate and low hazard is found forming patches really scattered throughout the province, with the latter standing out especially in the Montes de Málaga and the Antequera Mountains.

Fire hazard according to human activity

Human-induced forest fires hazard

Humans impact the risk of forest fires, both directly and indirectly. Directly, their impact is evident through traffic, the presence of infrastructure, communication routes, and settlements, as well as the implementation of resources under the INFOCA Plan, space protection measures, and firefighting and prevention efforts. In terms of the hazard directly caused by human activities such as traffic and the existence of infrastructure, communication routes, and settlements (Fig. 11b), the majority of areas with very high and extreme hazards are concentrated in the southern half of the province. This is particularly pronounced in regions close to the coast, aligning with most settlements in the province and the main roads: Mediterranean Highway and Toll Highway (A-7 and AP-7). Noteworthy are the elevated hazard levels in Sierra Bermeja and Sierra Blanca due to the impact of municipalities in the Western Costa del Sol, as well as in Sierra de Mijas and the Montes de Málaga. Extreme hazard is also observed around some inland settlements and at road junctions. Communication routes often contribute to high and very high-hazard areas. As one moves away from the coast, hazard levels decrease, with moderate hazard becoming more prevalent and lower hazard observed in small, scattered areas, primarily in the south and distant from settlements and communication routes.

Availability of INFOCA resources

To see what this problem of forest fires is being faced in the province, both in terms of extinction and prevention, the sufficiency of the INFOCA Plan's resources is evaluated (Fig. 12a). Firstly, regarding extinguishing resources, it is notable that water points are by far the most numerous in the province, although there are deficiencies in the Antequera Mountains and in Sierra Bermeja (in the south-eastern area). There is, however, a greater lack of extinguishing vehicles,

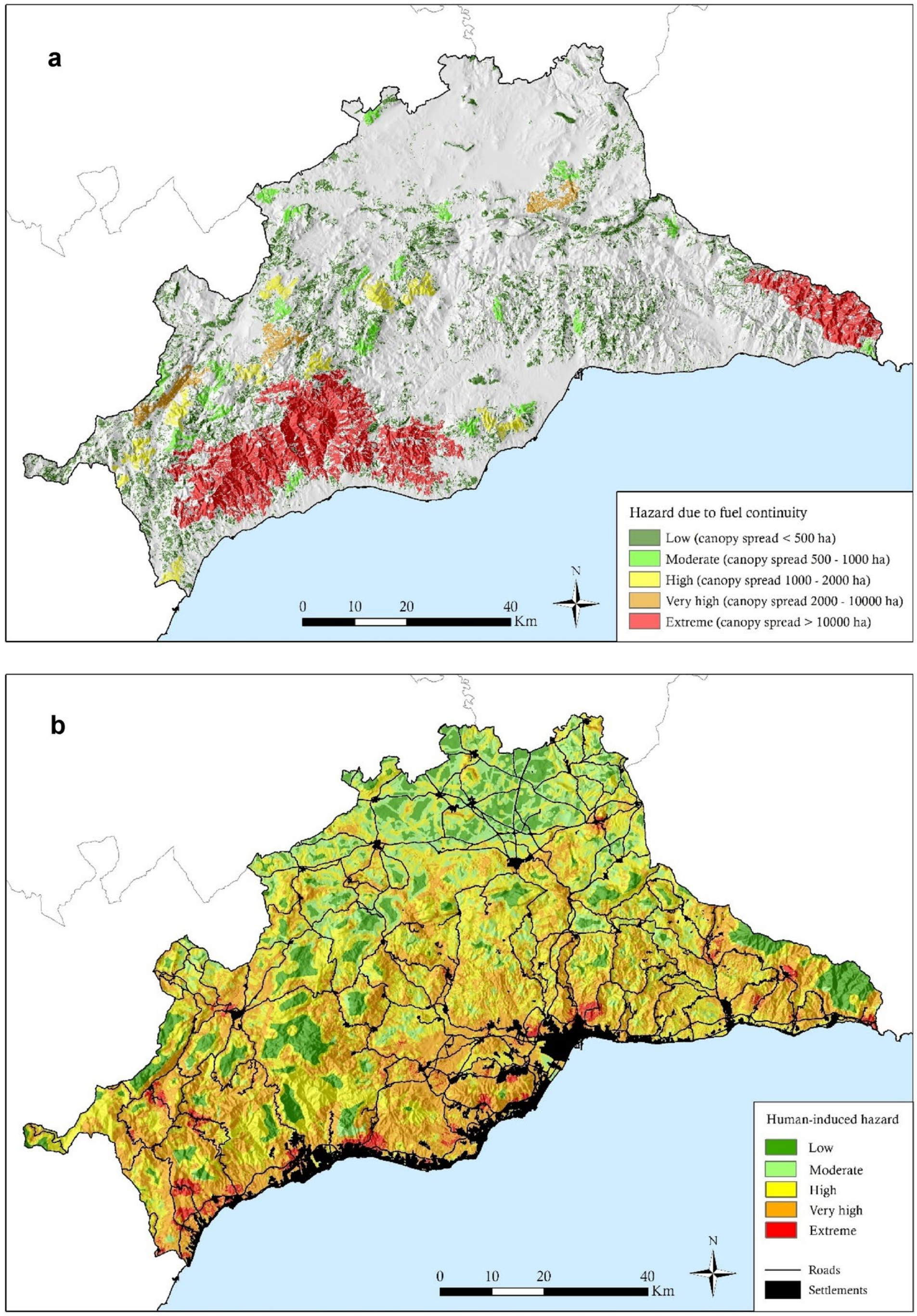

Fig. 11 Maps of forest fires hazard by fuel continuity associated with extreme behavior/large forest fires (**a**) and human-induced hazard of forest fires in Málaga province (**b**)

as in the case of Sierra Bermeja, the Montes de Málaga and the southern and south-eastern mountain ranges.

In terms of prevention resources, there is a clear lack of surveillance points, as they do not exist in the Sierra de Mijas, and there is an insufficiency in other forest areas because of their extent. It is the case of the Montes de Málaga, the south-eastern mountain ranges of Axarquía and the Antequera Mountains, as well as other western areas such as Sierra Bermeja, which should be well monitored due to the recurrence of forest fires there. The network of firebreaks only partially covers the forest areas, with a high density in Sierra Bermeja, in the eastern part of Serranía de Ronda shire and Sierra de las Nieves, and in the western part of Montes de Málaga. However, in these last two forest areas, they appear to be insufficient, as well as in the Blanca, Alpujata and Mijas southern mountain ranges and the south-eastern mountain ranges (where they only exist in Sierra Tejeda). In the Líbar and Blanquilla western mountain ranges they are even non-existent. Other

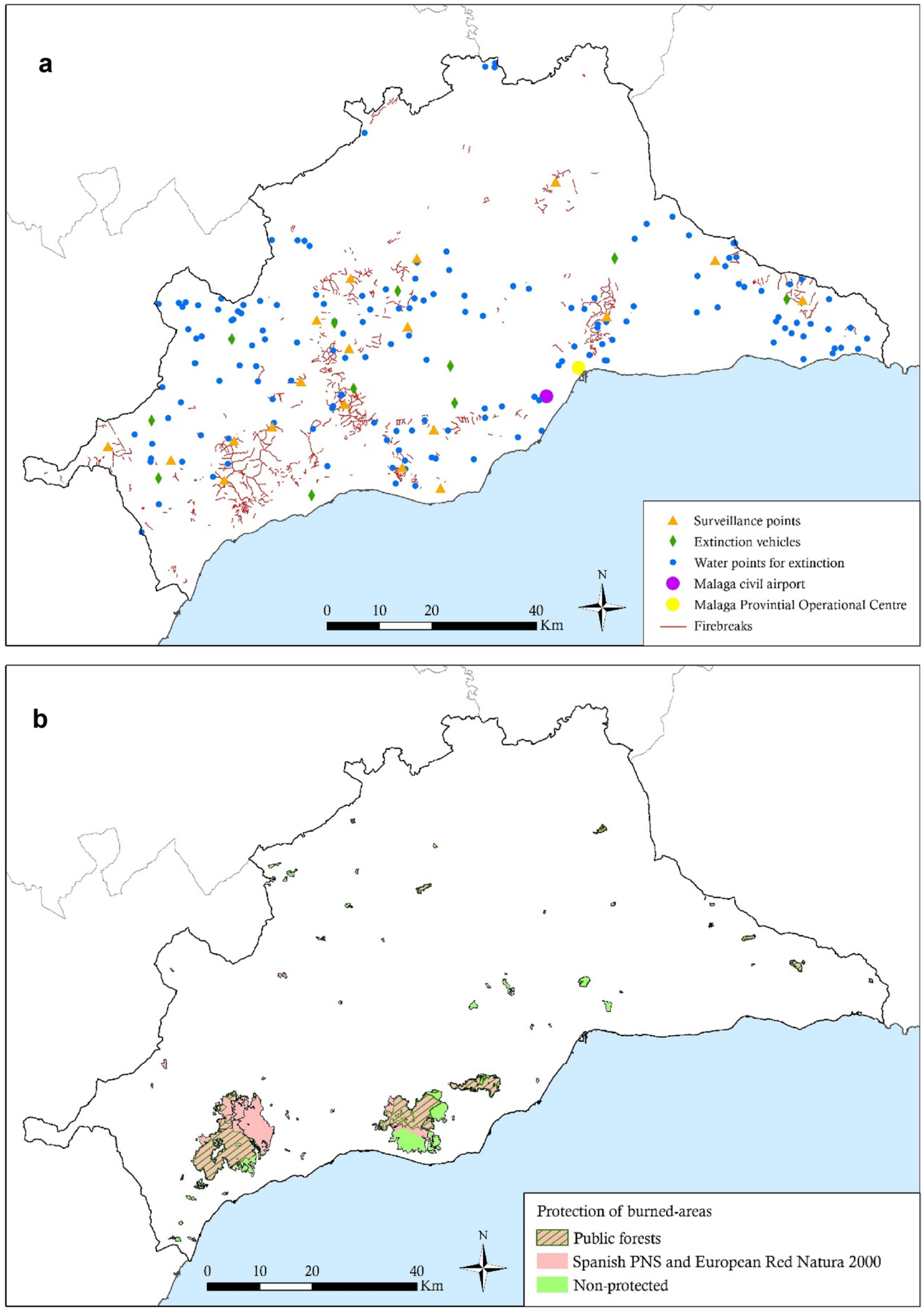

Fig. 12 Maps of INFOCA resources (**a**) and public administration "protection" of the burned area between 2010 and 2022 in Málaga province (**b**)

elements visible on the map are the civil airport of Málaga and the Provincial Operational Center.

Protected areas in relation to forest fires

There are areas protected by the public administration: Natura 2000 Network sites at the European level, Protected Natural Spaces—PNS—at the state and regional level, and public forests, generally at the regional or local level. The "protected" burned areas (Fig. 12b) include, to the southwest, the Special Areas of Conservation—SACs—of Genal Valley, Bermeja and Real mountain ranges and Los Reales de Sierra Bermeja, which is also a Natural Site and a Special Protection Area—SPA; and to the south, the southeast corner of the protection zone of the Sierra de las Nieves National Park, also coinciding with public forests, and the public forests of Sierra de Mijas. There are also small, burned areas in the Natural Park and SPA Tejeda, Almijara and Alhama mountain ranges, in the south-east of the province.

The area affected by forest fires in the period 2010–2022, which is not managed by the public administration, is only 24%, while the remaining 76% is or should be, as 49% corresponds to public forests and 27% to Protected Natural Spaces (PNS) and Red Natura 2000 (Table 6).

Discussion

The temporal analysis of the number, affected area, and causes of forest fires provides a comprehensive context for the situation in the Málaga province regarding this issue. It is evident that the situation in the province has improved since the 1990s, thanks to the development of measures, mainly in extinction, which has reduced the number of fires and their affected area. However, the number of cases remains high, and the fact that this area experiences a peak every few years due to the occurrence of large forest fires is a serious problem, as their consequences are devastating as was demonstrated in other areas (Senande-Rivera et al. 2022; Juang et al. 2022; Shao et al. 2023). The situation becomes even more worrying when we examine the causes of the fires because human responsibility is enormous, as the figures clearly show, almost completely eclipsing natural causes (Yuan et al. 2022; Fusco et al. 2022).

There has been a lack of research at the regional scale in the last decades, as presented in this article. The results extracted from the complete time series did not accurately reflect the reality shown in the graphs. Consequently, very specific subperiods had to be selected to identify the correct trends. The analysis conducted allowed us for the evaluation of the hazard factors of forest fires, with a specific focus on vegetation and human factors. Special emphasis should be placed on flammability, a section that encountered numerous obstacles as other studies remarked (Coskuner 2022). This began with the usual challenge of a scarcity of studies, particularly regarding the flammability of specific plant species. Additionally, the analysis often involved different methodologies for both the instruments used and their management. This variability led to diverse assessments of the flammability of the same species. These problems were solved by averaging and standardizing the data and using references found of species of the same genus based on their similarity when we did not find information about specific species. The subsequent ignorance of the area corresponding to the plant species of the MUCVA vegetation covers meant the same superficial consideration of all species. However, the biggest problem was found later because the results of the flammability analysis using vegetation coverings were not as expected, and the opposite happened later when using plant species. But then, what is the reason for the difference in results obtained from both methodologies? The answer seems to be in the species combinations that make up the vegetation covers, as they contain plant species with different levels of flammability. Based on this hypothesis, it seems reasonable that the occurrence and spread of forest fires according to this flammability criterion does not depend on large areas being covered by highly flammable plant species, but that their mere existence already has an influence, and that forest fires can spread from these to areas covered by less flammable plant species.

However, this criterion must be accompanied by other criteria when analyzing forest fire hazard in a territory. For example, the density of vegetation covers together with forest management, as high densities of vegetation (often caused by the abandonment of the forest) favour the spread of forest fires and the proliferation of highly flammable species; as well as other factors such as the amount of dead biomass and microclimatic or topographic conditions (Pausas 2017). The other vegetation characteristic analyzed was the continuity of the fuel, on which problems were also found in some areas (Shaik et al. 2022; Briones-Herrera et al. 2022). However, this hazard factor was evaluated for the tree surface, without considering the different possible influences of the shrub vegetation, as the geodata does not identify them. Differentiation of distinct categories according to the density or continuity of the scrub could be very useful information to include in future studies.

In evaluating the hazard of forest fires due to human factors, the direct influence was assessed first, revealing a greater hazard along the coast. In line with this, Gutiérrez-Hernández et al. (2015) identified ‘hot spots’ in both the Western Costa del Sol mountain ranges and the eastern part of Málaga, specifically Sierra de Almijara. The latter is of particular concern due to substantial urban growth associated with tourism, leading to residential establishments in forested areas. This has increased the risk to both houses and forested areas, given the frequent occurrence of forest fires in the region (Martínez-Murillo and Ruiz-Sinoga 2014; Romero-Padilla and Martínez-Murillo 2019). Furthermore, the tourism activity in this region results in a significant population surge during the summer—a period coinciding with the highest meteorological hazard for forest fires (Martínez-Murillo and Ruiz-Sinoga 2014).

Table 6 Burned area between 2010 and 2022 according to its protection by the public administration in Málaga province

Protection of the burned area	Surface area (ha)	Percentage (%)
Spanish PNS and European Red Natura 2000	7969.7	27.2
Public forests	14,262.2	48.6
Non-protected	7115.3	24.2
Complete surface	29,347.2	100

Subsequently, the action taken by the public administration related to forest fires was analyzed. First, attention was given to the availability of INFOCA resources, and secondly, the focus shifted to the situation in protected areas. In this context, the analysis highlighted a scarcity of resources, particularly in prevention measures. This scarcity explains the high fire hazard, attributed to the density and continuity of vegetation resulting from forest abandonment, and the significant number of fires caused by human activities, as depicted in the graphs.

Regarding the information derived from the analysis of protected areas, the data reflect the consideration of non-management of these areas as a conventional measure for nature preservation (Pradeep et al. 2022; Amrutha et al. 2022; Sikuzani et al. 2023). Traditional issues with the local population, especially farmers, arise due to the perceived lack of profitability of these protected areas. These problems contribute to forest fires caused by abandonment (once again) and intentional burning (once again too). It is concerning that much of Málaga's privately owned forest surface (Yus Ramos et al. 2022) ends up burned, while publicly owned areas face challenges. Therefore, there is a need to develop 'multifunctional planning' with dual objectives of conserving the natural environment and economically utilizing the forest (Piqué-Nicolau 2015). Additionally, state-level fire prevention in these areas is imperative, given the current scarcity and inefficacy of existing measures (Mazón-García 2016). So, the great influence of humans on the occurrence and the spread of forest fires has been demonstrated, as well as the great development of extinguishing measures in recent decades, which can no longer improve the situation (Ruiz-Mirazo et al. 2007). Extinction measures are already insufficient in the face of rural depopulation and climate change, but investments in this type of measures are much higher than in prevention measures (WWF, n.d.a.; WWF, n.d.b.), which are not sufficiently developed. In this context, numerous authors have evaluated and proposed various prevention measures, many of which are probably applicable to Málaga province.

Some of the measures are related to the creation of discontinuities in the fuel to reduce the spread speed of forest fires, with firebreaks being a common measure. They can also be of great importance to the local population, who can benefit if they are fairly rewarded economically (WWF 2022), which could be used as a way of reducing intentional forest fires. This is the case of the introduction of livestock farming, which gave rise to the Andalusian Network of Pasture-Firebreak Areas (Red de Áreas Pasto-Cortafuegos de Andalucía—RAPCA). This measure used controlled grazing and benefited the province. However, the need for infrastructure, the conflicts that can arise between livestock farmers, the control to which the activity should be subjected, as well as the little hope of generational replacement, do not bring promising prospects (Ruiz et al. 2007). Livestock can also be combined with crops to create "firebreak landscapes" (WWF 2021), and biomass could also be extracted from shrublands (Madrigal et al. 2016), which could be profitable in the medium to short term from large quantities of biomass of medium to high energy quality according to the European project "Enerbioscrub" (Barrero 2017). Another strategy carried out in Portugal in relation to livestock farming is "restocking", which consists of the introduction of free-wild livestock (Rewilding Europe 2020).

Other measures are framed in the context of preventive forestry, such as the elimination of scrub and plant debris (especially undergrowth and pyrophytes), the reduction of plant density or the promotion of species heterogeneity (Alejano and Martínez 2003). For this purpose, prescribed burning is sometimes used, which can also provide information on the possible behavior that would occur in a specific forest mass in the event of a fire (Julio and Giroz 1975). In addition, it would be advisable to take into account the flammability of the vegetation, eliminating or reducing the most flammable species and replanting (when necessary) with low flammable species, avoiding cases such as reforestation with eucalyptus in Huelva (Márquez-Fernández 1985) or with pine in the Montes de Málaga (Garrido et al. 2013). An example to follow could be the work of Anaheim Fire & Rescue (2018), which consists of creating lists of recommended and non-recommended species according to their flammability, calling the technique "fire landscaping".

Finally, other measures are directly related to human behavior, such as limiting traffic in forest and semi-forest areas during times of extreme meteorological hazard (high temperatures, low relative humidity, strong winds, dry thunderstorms, etc.), and discouraging construction in the forest-urban interface through land rezoning or "pyrotaxes" (Almarcha 2022; Pausas 2021). Other useful measures could involve efforts to slow down climate change, such as reducing fossil fuel consumption to mitigate the increase of atmospheric CO_2 and decrease the frequency of heat waves and the pace of climate change, thereby reducing the meteorological hazard of forest fires (Pausas 2021). Investing in initiatives such as environmental education or social intervention programmes, as proposed by WWF (2015) through the use of the European Agricultural Fund for Rural Development, could also be beneficial.

However, as already mentioned, Spain is not the only country where the problem of forest fires is serious, and the issue is also prevalent in many other areas of Spain. Therefore, it is highly likely that the specific problems identified in the province of Málaga are present elsewhere, and that the measures proposed to alleviate them may also be useful in those areas. The general steps to be followed to understand the situation in the province of Málaga and to find possible solutions could also be applied in other regions:

firstly, a study of the territory, in terms of its land uses and the evolution of the trend of forest fires in recent decades, paying special attention to the current situation in terms of the number of fires and the area affected, and their causes, relating these to land uses. Subsequently, a review of the measures implemented to address the problem in terms of extinction and prevention, as the same issue of insufficient prevention could arise, which could also be reflected in the state of the vegetation. Thus, if similar problems are identified, perhaps some of the measures proposed in this study could be applied, such as those aimed at the diversification of activities and landscapes or those related to vegetation limitations. However, it will always be necessary to bear in mind the importance of involving the local population in the measures to be implemented and raising their awareness to address the problem.

Conclusions

Forest fires pose a significant problem today across various scales. The study area, the province of Málaga, is profoundly affected due to several converging factors, including climatic characteristics, high coastal population concentrations, inland depopulation, and a lack of preventive measures. Consequently, the number of forest fires and the affected area has not seen a consistent decrease, with large forest fires burning thousands of hectares every few years. Additionally, three-quarters of forest fire causes are human-related, highlighting the need for increased awareness. Regarding vegetation, flammability is a significant concern, with Málaga facing challenges due to the prevalence of highly flammable vegetation, followed by moderate and very high flammability, while low and very low flammability occupy the bottom positions. Examining human-induced hazard, “hot spots” are located around Western Costa del Sol, Sierra de Mijas, and Montes de Málaga, primarily due to their proximity to the coast (with concentrated houses) and the main roads. However, the primary issue in the province of Málaga concerning this matter is insufficient management, especially in fire prevention. This is evident in the distribution of INFOCA resources, particularly the lack of firebreaks and surveillance points in certain areas, and the absence of protection in supposedly ‘protected’ areas and public forests, accounting for three-quarters of the burned surface between 2010 and 2022, alongside the vegetation-related problems mentioned earlier. Improving the forest fire situation in the province of Málaga requires considering all influencing factors, which, although partially addressed in this study, should be fully explored, including climate, vegetation characteristics, and human settlement locations. This necessitates a genuine commitment from the public administration, involving increased investment in prevention measures (acknowledging the insufficiency of extinction measures) and heightened public awareness—an imperative aspect when analyzing the root causes of fires.

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Data availability The data will be available upon due request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Agencia Europea de Medio Ambiente (2021) Forest fires in Europe, 18 de noviembre de 2021. https://www.eea.europa.eu/ims/forest-fires-in-europe

Alejano R, Martínez E (2003) La selvicultura mediterránea en Andalucía. Respuestas técnicas ante los objetivos actuales. Ecosistemas 12(3). https://revistaecosistemas.net/index.php/ecosistemas/article/view/232

Almarcha M (2022) Riesgo de incendios extremo por calor. Eltiempo.es, 27 de julio de 2022. https://www.eltiempo.es/noticias/que-condiciones-meteorologicas-aumentan-el-riesgo-de-incendios-forestales

Amrutha K, Danumah JH, Nikhil S, Saha S, Rajaneesh A, Mammen PC, Ajin RS, Kuriakose SL (2022) Demarcation of forest fire risk zones in Silent Valley National Park and the effectiveness of forest management regime. J Geovisual Spatial Anal 6(1):8. https://doi.org/10.1007/s41651-022-00103-3

Anaheim Fire & Rescue (2018) Recommended acceptable fire resistive plant species (Archivo PDF). https://www.anaheim.net/DocumentCenter/View/26964/Fire-Resistive-Plant-Species

Araque-Jiménez E (2013) Medio siglo de grandes incendios forestales en Andalucia (1961–2011). Méditerranée Revue Géographique Des Pays Méditerranéens/j Mediterranean Geogr 121:41–52. https://doi.org/10.4000/mediterranee.6840

Asensi-Marfil A, Díez-Garretas B (1987) El Parque de Málaga. Ayuntamiento, Málaga (**ISBN 84-505-5007-6**)

Barrero A (2017) Se le puede sacar provecho a los matorrales? Energías renovables, 25 de septiembre de 2017. https://www.energias-renovables.com/bioenergia/se-le-puede-sacar-provecho-a-20170925

Bilgiç E, Tuygun GT, Gündüz O (2023) Development of an emission estimation method with satellite observations for significant forest fires and comparison with global fire emission inventories: application to catastrophic fires of summer 2021 over the Eastern Mediterranean. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2023.119871

Briones-Herrera CI, Vega-Nieva DJ, Briseño-Reyes J, Monjarás-Vega NA, López-Serrano PM, Corral-Rivas JJ, Alvarado E, Arellano-Pérez S, Jardel-Peláez EJ, Salicrup DRP, Jolly WM (2022) Fuel-specific aggregation of active fire detections for rapid mapping of forest fire perimeters in Mexico. Forests 13(1):124. https://doi.org/10.3390/f13010124

Caballero JF (2017). Moguer: El tercer mayor incendio de los últimos 25 años en Andalucía. Diario de Huelva, 3 de julio de 2017. https://www.diariodehuelva.es/articulo/provincia/huelva-registra-historicamente-los-mayores-incendios-andalucia/20170703002736162584.html

Cabezudo B (2009) Diversidad de la flora vascular en la provincia de Málaga. Jábega 101:19–27. https://www.researchgate.net/profile/Baltasar-Cabezudo/publication/277276845_Diversidad_de_la_flora_vascular_en_la_provincia_de_Malaga/links/5694b52e08ae820ff0730ea3/Diversidad-de-la-flora-vascular-en-la-provincia-de-Malaga.pdf

Caldera JMN, Latorre AVP, Cabezudo B (1991) Biogeografía y series de vegatación de la provincia de Málaga (España). Acta Bot Malacitana 16:417–436. https://doi.org/10.24310/abm.v16i.9199

Chuvieco E, Mouillot F, Van der Werf GR, San Miguel J, Tanase M, Koutsias N, García M, Yebra M, Padilla M, Gitas I, Heil A, Hawbaker TJ, Giglio L (2019) Historical background and current developments for mapping burned area from satellite Earth observation. Remote Sens Environ 225:45–64. https://doi.org/10.1016/j.rse.2019.02.013

Consejería de Sostenibilidad, Medio Ambiente y Economía Azul (2010) Plan INFOCA. Marco de referencia frente a incendios forestales en Andalucía. https://www.juntadeandalucia.es/medioambiente/portal/areas-tematicas/incendios-forestales/plan-infoca-marco-referencia-frente-incendios-forestales

Chuvieco E, Aguado I, Salas J, García M, Yebra M, Oliva P (2020) Satellite remote sensing contributions to wildland fire science and management. Curr Forest Rep 6:81–96. https://doi.org/10.1007/s40725-020-00116-5

Coskuner KA (2022) Land use/land cover change as a major driver of current landscape flammability in Eastern Mediterranean region: a case study in Southwestern Turkey. Bosque 43(2):157–167. https://doi.org/10.4067/S0717-92002022000200157

Cruz-Artacho S, Gonzales-de-Molina M, Núñez-Delgado M, Ortega A (2000) Social and environmental determining factors of forest fire history: the case of eastern Andalucía, 1840–1890. In: Forest history: international studies on socio-economic and forest ecosystem change. Report No. 2 of the IUFRO Task Force on Environmental Change, pp 211–222. CABI Publishing, Wallingford. http://sherekashmir.informaticspublishing.com/368/1/9780851994192.pdf#page=225

Decreto 371 de 2010. Por el que se aprueba el Plan de Emergencia por Incendios Forestales de Andalucía y se modifica el Reglamento de Prevención y Lucha contra los Incendios Forestales aprobado por el Decreto 247/2001, de 13 de noviembre. 30 de septiembre de 2010. D.O. No. 192. https://www.juntadeandalucia.es/boja/2010/192/1

Dimitrakopoulos AP, Papaioannou KK (2001) Flammability assessment of mediterranean forest fuels. Fire Technol 37:143–152. https://doi.org/10.1023/A:1011641601076

Duguy B, Alloza JA, Röder A, Vallejo R, Pastor F (2007) Modelling the effects of landscape fuel treatments on fire growth and behaviour in a Mediterranean landscape (eastern Spain). Int J Wildland Fire 16(5):619–632. https://d1wqtxts1xzle7.cloudfront.net/51277817/Duguy2007-libre.pdf?1484040612=&response-content-disposition=inline%3B+filename%3DModelling_the_effects_of_landscape_fuel.pdf&Expires=1699490347&Signature=VOK4CIxN5~NVo2bWiRz1~b42oG1YEJSJiSJFtdmZa6gpORFIqEYIG7Wt8bQ0c1sUnWAs6iHHS3F3d7B9J8x9a3CSyeDnjAt3okd8jgxdHorUi9pDpQ4OLzSBJuhfnIKbGU1BjsdvSj1whlhbBLcK0Zx0rX1DMqyur5M3cL9AcE2v5vSmUtHgM1jhSZT1BOhl55qKm~JJCaScsQygd6nlRvjNsSDoRmy-SXaMa~nMDSAaOMpFdB7~9E413Y6PeHTFY-32z-vvE2WG2zpI26dBAVWmZ4ZbskmZGFyBgqox9UQaP89cq3oZIVQ3M4i-87y1lu1hb25P8QHUupccPGpZ9w__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA

Elia M, Lafortezza R, Lovreglio R, Sanesi G (2014) Fuel models for mediterranean wildland-urban interfaces in Southern Italy. In: Proceedings of the Second International Congress of Silviculture, Florence, 26–29 Nov 2014. https://www.aisf.it/wp-content/uploads/2016/02/416-425-elia.pdf

Elvira-Martín LM, Hernando-Lara C (1989) Inflamabilidad y energía de las especies de sotobosque. Instituto Nacional de Investigaciones Agrarias

Eskandari S, Pourghasemi HR, Tiefenbacher JP (2020) Relations of land cover, topography, and climate to fire occurrence in natural regions of Iran: applying new data mining techniques for modeling and mapping fire danger. Forest Ecol Manag. https://doi.org/10.1016/j.foreco.2020.118338

European Environment Agency (2021) Forest fires in Europe, 18 Nov 2021. https://www.eea.europa.eu/en/analysis/indicators/forest-fires-in-europe

Fernandez-Anez N, Krasovskiy A, Müller M, Vacik H, Baetens J, Hukić E, Cerda A (2021) Current wildland fire patterns and challenges in Europe: A synthesis of national perspectives. Air Soil Water Res. https://doi.org/10.1177/11786221211028185

Flores-Rodríguez AG, Flores-Garnica JG, González-Eguiarte DR, Gallegos-Rodríguez A, Zarazúa-Villaseñor P, Mena-Munguía S (2021) Análisis comparativo de índices espectrales para ubicar y dimensionar niveles de severidad de incendios forestales. Investigaciones Geográficas. https://doi.org/10.14350/rig.60396

Fusco EJ, Balch JK, Mahood AL, Nagy RC, Syphard AD, Bradley BA (2022) The human–grass–fire cycle: how people and invasives co-occur to drive fire regimes. Front Ecol Environ 20(2):117–126. https://doi.org/10.1002/fee.2432

Galacho-Jiménez FB (2002) Los usos del suelo en el espacio costero de la provincia de Málaga basados en un modelo de desarrollo urbano-turístico con importantes consecuencias ambientales. Baética: Estudios de Historia Moderna y Contemporánea 24:21–62. https://doi.org/10.24310/BAETICA.2002.v0i24.397

Garrido A, Gómez A, Díaz A (2013) Montes de Málaga. Diario Sur, 8 de agosto de 2013. https://www.diariosur.es/20130808/mas-actualidad/cultura/montes-Málaga-201308081053.html

Generalitat de Catalunya (1994) Mapes de models d'inflamabilitat. Resum (Archivo PDF). http://www.gencat.cat/mediamb/ModelsInflamabilitatWeb.pdf

Grupo de trabajo de estadística del Comité de Lucha contra Incendios Forestales (2021) Parte de Incendio Forestal (9ª actualización). Instrucciones de relleno v 3.6. https://www.miteco.gob.es/es/biodiversidad/temas/incendios-forestales/instrucciones_parte_incendio_tcm30-512355.pdf

Gutiérrez-Hernández O, Senciales-González JM, García-Fernández LV (2016) Evolución de la superficie forestal en Andalucía (1956–2007). Procesos y factores. Revista De Estudios Andaluces 33(1):111–148. https://doi.org/10.12795/rea.2016.i33.0

Gutiérrez-Hernández O, Senciales-González JM, García LV (2015) Los incendios forestales en Andalucía: investigación exploratoria y modelos explicativos. FLAMMA 6(3):144–148. https://www.academia.edu/26652060/Los_incendios_forestales_en_Andaluc%C3%ADa_investigaci%C3%B3n_exploratoria_y_modelos_explicativos_Wildfires_in_Andalucía_Spain_from_exploratory_research_to_explanatory_models?email_work_card=title

Henaoui SEA (2018) Flammability and Combustibility of Cistus-Plant Groups in Tlemcen Region (Algeria). Int J Ecol Environ Sci 44(4):383–393. https://www.researchgate.net/profile/Smail-Henaoui/publication/362303196_Flammability_and_Combustibility_of_Cistus_Plant_Groups_in_Tlemcen_Region_Algeria/links/62e245107782323cf180fa4d/Flammability-and-Combustibility-of-Cistus-Plant-Groups-in-Tlemcen-Region-Algeria.pdf

Hernando-Lara C, Guijarro-Guzmán M, Díez-Galilea C, Madrigal-Olmo J, San-Martín J (2004) Laboratorio de incendios forestales CIFOR-INIA (Archivo PDF). https://rabida.uhu.es/dspace/bitstream/handle/10272/3555/Laboratorio_de_incendios_forestales.pdf?sequence=1

Juang CS, Williams AP, Abatzoglou JT, Balch JK, Hurteau MD, Moritz MA (2022) Rapid growth of large forest fires drives the exponential response of annual forest-fire area to aridity in the western United States. Geophys Res Lett 49(5):GL097131. https://doi.org/10.1029/2021GL097131

Julio G, Giroz G (1975) Notas Sobre el Comportamiento del Fuego y su Aplicación en el Control de Incendios Forestales. Universidad Austral De Chile. https://doi.org/10.4206/bosque.1975.v1n1-04

Kanga S, Tripathi G, Singh SK (2017) Forest fire hazards vulnerability and risk assessment in Bhajji forest range of Himachal Pradesh (India): a geospatial approach. J Remote Sens GIS 8(1):1–16. https://www.researchgate.net/profile/Suraj-Singh-8/publication/325848531_Forest_Fire_Hazards_Vulnerability_and_Risk_Assessment_in_Bhajji_Forest_Range_of_Himachal_Pradesh_India_A_Geospatial_Approach/links/5b28eb2d0f7e9b1d0034aff4/Forest-Fire-Hazards-Vulnerability-and-Risk-Assessment-in-Bhajji-Forest-Range-of-Himachal-Pradesh-India-A-Geospatial-Approach.pdf

Kendall MG (1975) Rank correlation methods, 4th edn. Charles Griffin, Londres

Liodakis S, Agiovlasitis IP, Kakardakis T, Tzamtzis N, Vorisis D, Lois E (2011) Determining hazard risk indices for Mediterranean forest species based on particle flammability properties. Fire Saf J 46(3):116–124. https://doi.org/10.1016/j.firesaf.2010.11.005

Madrigal J, Fernández-Migueláñez I, Hernando C, Guijarro M, Vega-Nieva DJ, Tolosana E (2016) Does forest biomass harvesting for energy reduce fire hazard in the Mediterranean basin? A case study in the Caroig Massif (Eastern Spain). Eur J Forest Res 136:13–26. https://doi.org/10.1007/s10342-016-1004-5

Mancilla-Leytón JM, Pino-Mejías R, Martín-Vicente A (2012) Do goats preserve the forest? Evaluating the effects of grazing goats on combustible Mediterranean scrub. Appl Veg Sci 16(1):63–73. https://doi.org/10.1111/j.1654-109X.2012.01214.x

Mann HB (1945) Non parametric test against trend. Econometrica 13:245–249

Márquez-Fernández D (1985) Las repoblaciones de eucaliptos y su impacto en la última década 1973–83. Revista De Estudios Andaluces 5:135–142. https://doi.org/10.12795/rea.1985.i05.07

Martínez-Murillo JF, Ruiz-Sinoga JD (2014) Dinámica espacio-temporal reciente de los incendios forestales en un área turística del sur de España (Costa del Sol), 11–14 de noviembre de 2014. XIV Coloquio Ibérico de Geografía, Departamento de Geografia, Universidade do Minho

Martínez-Murillo JF, Galacho-Jiménez FB, Ruiz-Sinoga JD (2017) Itinerarios geográficos por la provincia de Málaga: homenaje al profesor D. Emilio Ferre Bueno. Servicio de Publicaciones y Divulgación Científica de la Universidad de Málaga. https://elibro--net.uma.debiblio.com/es/lc/uma/titulos/60726

Massari G, Leopaldi A (1998) Leaf flammability in Mediterranean species. Plant Biosyst 132(1):29–38. https://doi.org/10.1080/11263504.1998.10654189

Mazón-García N (2016) La incidencia de los incendios forestales en las áreas naturales protegidas españolas (Trabajo de Fin de Grado, Universidad de Cantabria). https://repositorio.unican.es/xmlui/bitstream/handle/10902/8493/MazonGarciaNestor.pdf?sequence=1

Ministerio de Agricultura, Pesca y Alimentación (2019) Los Incendios Forestales en España Decenio 2006–2015. https://www.miteco.gob.es/es/biodiversidad/temas/incendios-forestales/incendios-decenio-2006-2015_tcm30-521617.pdf

Ministerio de Medio Ambiente (2002) Los Incendios Forestales en España Decenio 1991–2000. https://www.miteco.gob.es/es/biodiversidad/temas/incendios-forestales/decenio_1991_2000_tcm30-132584.pdf

Miró et al (2009) Análisis comparativo de tendencias en la precipitación, por distintos inputs, entre los dominios hidrológicos del Segura y del Júcar (1958–2008). Investigaciones Geográficas 49(2009):129–157

Mohajane M, Costache R, Karimi F, Pham QB, Essahlaoui A, Nguyen H, Laneve G, Oudija F (2021) Application of remote sensing and machine learning algorithms for forest fire mapping in a Mediterranean area. Ecol Indicat. https://doi.org/10.1016/j.ecolind.2021.107869

Molina JR, Martín T, Silva FRY, Herrera MÁ (2017) The ignition index based on flammability of vegetation improves planning in the wildland-urban interface: a case study in Southern Spain. Landsc Urban Plan 158:129–138. https://doi.org/10.1016/j.landurbplan.2016.11.003

Mota PHS, da Rocha SJSS, de Castro NLM, Marcatti GE, de Jesus França LC, Schettini BLS, Villanova PH, dos Santos HT, dos Santos AR (2019) Forest fire hazard zoning in Mato Grosso state. Brazil Land Use Policy 88:104206. https://doi.org/10.1016/j.landusepol.2019.104206

Parajuli A, Gautam AP, Sharma SP, Bhujel KB, Sharma G, Thapa PB, Bist BS, Poudel S (2020) Forest fire risk mapping using GIS and remote sensing in two major landscapes of Nepal. Geomat Nat Haz Risk 11(1):2569–2586. https://doi.org/10.1080/19475705.2020.1853251

Pausas JG (2017) Por qué se quema antes una sabana que un bosque? Cinco cuestiones sobre inflamabilidad e incendios. 20minutos, 2 de noviembre de 2017. https://blogs.20minutos.es/ciencia-para-llevar-csic/2017/11/02/cinco-cuestiones-sobre-inflamabilidad-e-incendios/

Pausas JG (2021) Incendios forestales: no todo es cambio climático. The conversation, 18 de agosto de 2021. https://theconversation.com/incendios-forestales-no-todo-es-cambio-climatico-165826

Pérez-Latorre AV, Cabezudo-Artero B (2003) Notas sobre la vegetación de Andalucía. V. Acta Botanica Malacitana 28:258–260. https://revistas.uma.es/index.php/abm/article/view/7300

Pérez-Latorre AV, Hidalgo-Triana N, Cabezudo-Artero B (2013) Composition, ecology and conservation of the south-Iberian serpentine flora in the context of the Mediterranean basin. Anales del Jardín Botánico de Madrid 70(1):62–71. https://www.redalyc.org/pdf/556/55628039007.pdf

Pérez-Latorre AV (2009) Vegetación terrestre de la provincia de Málaga. Jábega, 101 (Ejemplar dedicado a: Biodiversidad en la provincia de Málaga / coord. Por Saturnino Moreno Borrell, Jacinto

Segura Moreno), pp 28–44. https://www.researchgate.net/profile/Andres-V-Latorre/publication/266461298_VEGETACION_TERRESTRE_DE_LA_PROVINCIA_DE_MALAGA_Terrestrial_vegetation_of_the_province_of_Malaga/links/56c8b6f808ae11063707861e/VEGETACION-TERRESTRE-DE-LA-PROVINCIA-DE-MALAGA-Terrestrial-vegetation-of-the-province-of-Malaga.pdf

Piqué-Nicolau M (2015) Planificación forestal en espacios naturales protegidos: herramientas integradoras en un contexto de cambio. Cuadernos de la Sociedad Española de Ciencias Forestales 39:299–312. https://dialnet.unirioja.es/servlet/articulo?codigo=7346741

Portal de Datos Estadísticos y Geoespaciales de Andalucía (accessed on 02/2024). Descarga de la información de los Datos Espaciales de Referencia de Andalucía (DERA). https://www.juntadeandalucia.es/institutodeestadisticaycartografia/dega/datos-espaciales-de-referencia-de-andalucia-dera/descarga-de-informacion

Portal Ambiental de Andalucía (accessed on 01/2024). Descargas Rediam. https://portalrediam.cica.es/descargas

Pradeep GS, Danumah JH, Nikhil S, Prasad MK, Patel N, Mammen PC, Ambujendran R, Oniga E, Ajin RS, Kuriakose SL (2022) Forest fire risk zone mapping of Eravikulam National Park in India: A comparison between frequency ratio and analytic hierarchy process methods. Croat J for Eng 43(1):199–217. https://doi.org/10.5552/crojfe.2022.1137

Ramo R, Roteta E, Bistinas I, Van-Wees D, Bastarrika A, Chuvieco E, Van-der-Werf GR (2021) African burned area and fire carbon emissions are strongly impacted by small fires undetected by coarse resolution satellite data. Proc Natl Acad Sci 118(9):160118. https://doi.org/10.1073/pnas.2011160118

Rewilding Europe (2020) Rewilding – the natural way to minimise wildfire risk, 24 de agosto de 2020. https://rewildingeurope.com/blog/rewilding-the-natural-way-to-minimise-wildfire-risk/

Riera P, Mogas J (2004) Evaluation of a risk reduction in forest fires in a Mediterranean region. Forest Policy Econ 6(6):521–528. https://doi.org/10.1016/S1389-9341(02)00119-3

Rivas-Martínez S (1996) La fitosociología en España. Avances en fitosociología = Advances in phytosociology / coord. por Javier José Loidi Arregui, pp 149–174. https://dialnet.unirioja.es/servlet/libro?codigo=4966

Rivas-Martínez S (2007) Mapa de series, geoseries y geopermaseries de vegetación de España: (Memoria del mapa de vegetación potencial de España). Parte I. Itinera geobotanica 17:5–436. https://www.researchgate.net/publication/234025662_Mapa_de_series_geoseries_y_geopermaseries_de_vegetacion_de_Espana_memoria_del_mapa_de_vegetacion_potencial_de_Espana_Parte_I

Romero-Padilla J, Martínez-Murillo JF (2019) Análisis cartográfico del nivel de afectación de los incendios forestales sobre áreas urbanizadas en la Costa del Sol occidental (1991–2013). Papeles De Geografía 65:49–66. https://doi.org/10.6018/geografia.357061

Rosentreter R, Van Paepeghem B, DeBolt A (2017) Fire resistance of plants master database & placement of species within firewise landscape zones for Southern Idaho (Archivo PDF). https://idahofirewise.org/wp-content/uploads/2017/04/FireXResistanceXofXPlantsXMasterXDatabase.pdf

Rubí JN, de-Carvalho PH, Gondim PR (2023) Application of machine learning models in the behavioral study of forest fires in the Brazilian Federal District region. Eng Appl Artif Intell. https://doi.org/10.1016/j.engappai.2022.105649

Ruiz-Mirazo J, Robles-Cruz AB, Jiménez R, Martínez JL, López-Quintanilla J, González-Rebollar JL (2007) La prevención de incendios forestales mediante pastoreo controlado: el estado del arte en Andalucía. IV Conferencia Internacional de Incendios Forestales Wildfire 2007 (Sevilla, España). https://digital.csic.es/handle/10261/42910

San-Miguel-Ayanz J, Moreno JM, Camia A (2013) Analysis of large fires in European Mediterranean landscapes: Lessons learned and perspectives. For Ecol Manage 294:11–22. https://doi.org/10.1016/j.foreco.2012.10.050

Se cumple un año del incendio forestal de Almonaster la Real (Huelva), que arrasó más de 12.000 hectáreas, 26 de agosto de 2021. Europa Press. https://www.europapress.es/andalucia/huelva-00354/noticia-jueves-cumple-ano-55incendio-forestal-almonaster-real-huelva-arraso-mas-12000-hectareas-20210826180707.html

Senande-Rivera M, Insua-Costa D, Miguez-Macho G (2022) Spatial and temporal expansion of global wildland fire activity in response to climate change. Nat Commun 13(1):1208. https://doi.org/10.1038/s41467-022-28835-2

Shaik RU, Laneve G, Fusilli L (2022) An automatic procedure for forest fire fuel mapping using hyperspectral (PRISMA) imagery: a semi-supervised classification approach. Remote Sensing 14(5):1264. https://doi.org/10.3390/rs14051264

Shao Y, Wang Z, Feng Z, Sun L, Yang X, Zheng J, Ma T (2023) Assessment of China's forest fire occurrence with deep learning, geographic information and multisource data. J for Res 34(4):963–976. https://doi.org/10.1007/s11676-022-01559-1

Sharma NR, Fernandes PJF, Pokharel JR (2015) Methodological development for forest fire hazard mapping in Nepal. Revista Brasileira de Cartografia 66(7):1551–1566. https://dpnet.org.np/public/uploads/files/document%202021-09-28%2008-52-50.pdf

Sikuzani YU, Mukenza MM, Malaisse F, Kaseya PK, Bogaert J (2023) The spatiotemporal changing dynamics of miombo deforestation and illegal human activities for forest fire in Kundelungu National Park, Democratic Republic of Congo. Fire 6(5):174. https://doi.org/10.3390/fire6050174

Trucchia A, Meschi G, Fiorucci P, Provenzale A, Tonini M, Pernice U (2023) Wildfire hazard mapping in the eastern Mediterranean landscape. Int J Wildland Fire 32(3):417–434. https://doi.org/10.1071/WF22138

Turco M, von-Hardenberg J, AghaKouchak A, Llasat MC, Provenzale A, Trigo RM (2017) On the key role of droughts in the dynamics of summer fires in Mediterranean Europe. Nat Sci Rep 7(1):81. https://doi.org/10.1038/s41598-017-00116-9

Turco M, Jerez S, Doblas-Reyes FJ, AghaKouchak A, Llasat MC, Provenzale A (2018a) Skilful forecasting of global fire activity using seasonal climate predictions. Nat Commun 9(1):1–9. https://doi.org/10.1038/s41467-018-05250-0

Turco M, Rosa-Cánovas JJ, Bedia J, Jerez S, Montávez JP, Llasat MC, Provenzale A (2018b) Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. Nat Commun 9(1):3821. https://doi.org/10.1038/s41467-018-06358-z

Turco M, Jerez S, Augusto S, Tarín-Carrasco P, Ratola N, Jiménez-Guerrero P, Trigo RM (2019) Climate drivers of the 2017 devastating fires in Portugal. Nat Sci Rep 9(1):13886. https://doi.org/10.1038/s41598-019-50281-2

Valette JC (1997) Inflammabilities of Mediterranean species. Forest Fire Risk Manage EUR 16719:51–64. http://www.marioloureiro.net/ciencia/ignicao_vegt/9208.pdf

Vallejo-Villalta I, Rodríguez-Navas E, Márquez-Pérez J (2019) Mapping forest fire risk at a local scale—a case study in Andalucía (Spain). Environments 6(3):30. https://doi.org/10.3390/environments6030030

Vélez R (2002) Causes of forest fires in the Mediterranean Basin. In *Risk management and sustainable forestry. EFI Proceedings*, vol 42, pp 35–42. https://efi.int/sites/default/files/files/publication-bank/2018/proc45_net.pdf#page=35

Verkaik I, Rieradevall M, Cooper SD, Melack JM, Dudley TL, Prat N (2013) Fire as a disturbance in mediterranean climate streams. Hydrobiologia 719:353–382. https://doi.org/10.1007/s10750-013-1463-3

Wood DA (2021) Prediction and data mining of burned areas of forest fires: Optimized data matching and mining algorithm provides valuable insight. Artif Intell Agri 5:24–42. https://doi.org/10.1016/j.aiia.2021.01.004

WWF (2015) Incendios en España. Bosques listos para arder. Fondo Mundial para la Naturaleza. https://wwfes.awsassets.panda.org/downloads/bosques_listos_para_arder_wwf.pdf

WWF (2021) Informe sobre incendios forestales 2021 Paisajes Cortafuegos. Fondo Mundial para la Naturaleza. https://www.wwf.es/informate/biblioteca_wwf/?57700/Informe-sobre-incendios-forestales-2021-Paisajes-Cortafuegos

WWF (2022) Informe sobre incendios forestales 2022: Pastoreo contra incendios. Fondo Mundial para la Naturaleza. https://www.wwf.es/informate/actualidad/?61221/Pastoreo-contra-incendios

WWF (2023a) Restaurar ecosistemas es prevenir los incendios forestales del futuro. Fondo Mundial para la Naturaleza. https://www.wwf.es/nuestro_trabajo/bosques/incendios_forestales_/politicas_para_la_prevencion_de_incendios/

WWF (2023b) Bosques: incendios forestales. Fondo Mundial para la Naturaleza. https://www.wwf.es/nuestro_trabajo/bosques/incendios_forestales_/

Yuan Z, Wu D, Wang T, Ma X, Li Y, Shao S, Zhang Y, Zhou A (2022) Holocene fire history in southwestern China linked to climate change and human activities. Quatern Sci Rev 289:107615. https://doi.org/10.1016/j.quascirev.2022.107615

Yus-Ramos R, Senciales-González JM, Gutiérrez-Hernández O, Rodrigo-Comino J, García-Díaz P (2022) Riesgos geológicos (en: Yus Ramos, R. y Senciales González, J.M. (Coord.) *Riesgos y desastres naturales en la Axarquía* (Tomo 2). Ed. Gabinete de Estudios de la Naturaleza de la Axarquía, Vélez-Málaga)