CSIRO PUBLISHING

International Journal of Wildland Fire **2019**, *28*, 85–98
https://doi.org/10.1071/WF18004

Analysis of forest fire fatalities in Southern Europe: Spain, Portugal, Greece and Sardinia (Italy)

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Abstract. Wildfire fatalities remain a significant problem in Mediterranean Europe. Although there is a strong inter-annual variability with regard to their number, repeated tragic accidents remind us of this grim occurrence, despite the increasing firefighting capacity aimed to improve human safety. In this paper, we present an analysis of the 865 fatalities caused by wildfires in the 1945–2016 period. Data originating from national databases were merged, contextual and weather factors related to the accidents that caused these deaths were documented and analysed to explore probable relationships with the number and type of fatalities. Results show a major rise of fatalities in late 1970s in the four regions of Greece, Sardinia (Italy), Spain and Portugal. Fatalities present a strong seasonality in summer months, as expected. Overall, Spain has the highest absolute numbers of fatalities; however, normalisations by population, and burned and forest area show that annual number of fatalities is comparatively smaller. Certain other factors showed correlation with mortality. Civilians were the most affected group in Greece (65%) and Sardinia (58%), but not in Spain and Portugal. Findings indicate that an in-depth revision of fire-management policies and practices is required, with emphasis on prevention planning in urban areas, and better training of the firefighting resources.

Additional keywords: Mediterranean Europe, wildfire accidents, wildfire fatalities, wildland–urban interface.

Received 12 January 2018, accepted 5 December 2018, published online 23 January 2019

Introduction

Each year, wildfires exact a dramatic death toll in Mediterranean Europe (Cardil and Molina 2015; Diakakis *et al.* 2016) and elsewhere (Mangan 2007; Blanchi *et al.* 2014). Civilians, firefighters, military personnel, and helicopter and plane pilots, among others, are exposed to the inherent dangers of forest firefighting and the effects of wildfires (Mangan 2007). However, whereas firefighting operations are subject to safety rules, e.g. LACES (Lookout, Anchorage, Communication, Escape Routes and Safety Zones) (Thorburn and Alexander 2001) or Dead Man Zone (Cheney *et al.* 2000), civilians exposed to fire, smoke and embers in the so-called wildland–urban interface (WUI) (Butler 1974) rely mostly on their personal instincts for self-protection and on the available resources to survive. Today, firefighters and members of the public face unprecedented scenarios of fast-growing, intense wildfires showing extreme fire behaviour for which neither the fighting resources nor the protection strategies and suppression operations are adequate, safe and effective (Maditinos and Vassiliadis 2011; Cardil *et al.* 2015, 2016; Jones *et al.* 2016). Additionally, the abundance of WUI areas, and their exposure to such a phenomenal threat, poses a real challenge for civil protection and firefighting personnel (Caballero 2017). Although a wealth of assets have been duly allocated to fire suppression and prevention (Liang *et al.* 2008), recent multiple-fatality events show that there is still a noticeable gap between the observed fire behaviour and the applied firefighting and self-protection capacity. In response to this, Resco de Dios and Molina-Terrén (2017) suggest that new science-based educational programs are necessary to meet the challenge of managing wildfires while at the same time avoiding their negative societal effects. This is clearly needed in southern Europe.

Climate-change trends depict a future in which longer and more intense drought periods, higher temperatures, extreme weather and increased biomass growth set the conditions for large, rapidly growing, intense wildfires (Flannigan *et al.* 2009; Cardil *et al.* 2014; Molina-Terrén and Cardil 2016). Besides, it seems clear that high or extreme temperatures are behind several health incidents affecting firefighters, due to fatigue, exhaustion or dehydration, sometimes ending in serious consequences (Mangan 2007; Cardil and Molina 2015). It is well known that the combination of intense drought periods and high temperatures lead to extreme, unexpected fire behaviour (Werth *et al.* 2016), entailing a higher likelihood of serious entrapments. Lower atmosphere dynamics, and the resulting air movement in such large fires, favour the development of huge plumes, generating rather unpredictable processes that involve the vertical transfer of matter and energy in turbulent movements and fast downbursts (Lareau and Clements. 2016). A massive generation of spot fires, abrupt changes in wind direction or speed, local channelling and acceleration of wind, or the presence of fire whirls are all phenomena associated with extreme fire behaviour (Viegas 2004) and frequently create very risky situations.

In addition to climate change, Europe is experiencing an increase of forest fuel load and continuity in undeveloped lands that further contribute to the intensity of wildfires (Moreira *et al.* 2011). This fuel build-up is primarily due to the decline or abandonment of rural activities in forested areas (Vega-García and Chuvieco 2006).

In addition to fuel build-up, the transformation of forest landscapes is aggravated by the steady growth of urban sprawl towards forested grounds (Xanthopoulos *et al.* 2012). The WUI areas introduce and consolidate new fuel types (gardens, hedges, vegetal remains, etc.) and vegetation structures into the landscape, while very often lacking any type of fuel management. Additionally, the intensive fire suppression operations that take place in case of fire, especially in the surroundings of WUI areas, lead to even higher accumulation of fuel and eventually to the development of very intense and destructive fires. We are labelling this as the 'fire suppression paradox', as inspired by Martin and Sapsis (1992), who stated that 'modern fire control has attempted to remove fire from wildlands; however, the result has been a great distortion in the fire regime, increasing the proportion of large, high severity fires'. Although this concept later became known as the 'fire paradox' (Silva Sande *et al.* 2010), the term 'fire suppression paradox' would be more adequate. According to Silva Sande *et al.* (2010), the WUI population is potentially even more exposed to large wildland fires, which are undoubtedly more difficult and risky to handle (Viegas 2009). This aspect has been particularly observed in the most recent tragic fire seasons (2003–2018) in Southern Europe, in which citizens and firefighters have been involved in several entrapment episodes.

Many catastrophic cases were recorded in recent years in Southern Europe (Viegas *et al.* 2006; Cardil and Molina 2015), some of them very lately (Diakakis *et al.* 2016; Cardil *et al.* 2017). As a reference, some of these remarkable forest fire events are:

- Mati (Greece, 23 July 2018, 99 fatalities)
- Central Region (Portugal, 15 October 2017, 53 fatalities).
- Pedrógão Grande (Portugal, 17 June 2017, 66 fatalities).
- Horta de Sant Joan (Tarragona, Spain, 21 July 2009, 5 fatalities).
- Makistos–Artemida (Peloponnese, Greece, 24 June 2007, 30 fatalities).
- Riba de Saelices (Guadalajara, Spain, 17 July 2005, 11 fatalities).
- Ikaria (Ikaria island, Greece, 30 July 1993, 13 fatalities)
- Curraggia (Sardinia, Italy, 27–28 July 1983, 9 fatalities).
- Águeda (Portugal, 14 June 1986, 16 fatalities).
- Armamar (Portugal, 8 September 1985, 14 fatalities).
- La Gomera (Canary Islands, Spain, 11 September 1984, 20 fatalities).
- Lloret de Mar (Girona, Spain, 7 August 1979, 21 fatalities).
- Sintra Mountains (Portugal, 7 September 1966, 25 fatalities).

In other parts of the world, several cases of fatal incidents show that similar conditions regarding vegetation structure, weather patterns and social changes fuel a similar conditions to those in the European fires. For example, in the USA, 310 firefighter fatalities were recorded from 1990 to 2006 (Mangan 2007); in Chile, 62 forest firefighters died on duty from 1978 to 2012. Lately, some horrendous events, such as the entrapment the 2017 Portugal fires, where more than 60 civilians died, have raised the attention of the firefighting community, researchers and authorities to the fact that fires occurred under extreme weather conditions that exceed their prediction capacity and response capability.

To understand the factors that affect the vulnerability of individuals, studies have focused either on a single event (Krusel and Petris 1992; Rothermel 1993; Butler *et al.* 1998; CDC 2006) or on a collection of events (Mangan 2007; Haynes *et al.* 2010; Lahaye *et al.* 2018*a*, 2018*b*), and examine specific details of fatal incidents and the demographics of the victims. Fatalities are found to be associated or correlated with a diversity of issues and circumstances (Desmond 2011; Beaver 2002). Examples are exposure to heat, situations of entrapment, physical conditions, traffic accidents, vehicle failures and others that create conditions of high risk. In addition, extremely high-temperature environments create conditions of high risk for personnel on the ground, mostly due to fatigue, exhaustion, dehydration, heat stroke. In particular, in heat-induced exhaustion, the person experiences fatigue (extreme

Table 1. Sources of information on forest fire-related fatalities

Country (region)	Source description	Period covered	References
Greece	Fatalities database for the period 1977–2013, with an update for the years 2014, 2015 and 2016 based on Fire Service and Forest Service official records, the record of the Association of Families of Lost in Action Aviators, scientific publications and detailed descriptions contained in newspaper articles.	1977–2016	Diakakis *et al.* (2016)
Italy (Sardinia)	Historical fire data records from the Sardinian Regional Forest Agency (CFVA, CorpoForestale e di VigilanzaAmbientale).	1945–2016	Cardil *et al.* (2017)
Spain	Data from Spanish EGIF database (General Statistics on Wildland Fires, www.magrama.gob.es), wildfire official yearbooks of the Ministry of Agriculture, Food and Environment. Fatality reports from the Ministry of Interior, Directorate General of Civil Protection and research over historical news or articles in newspapers and magazines. Complemented with face-to-face interviews and in-field testimonies.	1979–2016	Cardil and Molina (2015)
Portugal	Data compiled by the authors in a continuous process since 1986, based on visits to accident sites, personal interviews, media, journal papers and other documents quite often in the preparation of official and unofficial reports.	1963–2016	Viegas *et al.* (2005; 2013). There is not a Portuguese Official Database. It is the only country in this study without an official Government database

tiredness) due to a decrease in blood pressure and volume as a result of the loss of electrolytes (salts and minerals) and body fluids after prolonged exposure to intense heat sources (NHS 2010). Indeed, fatigue is commonly observed in firefighters working at extreme temperatures (Lorber 2006). In Canada and USA, some remarkable analyses of the records of firefighters who were injured or killed have been performed. Among them, Beaver (2002) studied human performance in risky operations and Karter (2012) scrutinised the causes behind firefighter injuries. In light of these findings, it seems clear that the systematic investigation of fatal accidents in wildfires, the recording of lessons learned and the capitalisation of experience are keystones for understanding the underlying conditions and processes in order to reduce the number of victims in future wildfires.

In this paper, an analysis on fatal wildfire accidents in the 1945–2016 period in Mediterranean Europe is presented, aimed at assessing the circumstances under which they occurred. Several contextual factors behind the accidents are considered, endeavouring to identify their relationships with the number and type of fatalities.

Data and methods

A common official database, which systematically gathers all records of fatalities caused by forest fires, has never existed in the European Union (EU) and is currently still missing for Mediterranean countries. In light of this, we took the initiative to design and develop the first version of such a database that eventually may serve as seed for a more elaborate, complete and official one in the EU. To achieve this, several national sources of information have been consulted (Table 1) and a significant number of pieces of data have been gathered from Portugal, Spain, Greece and the region of Sardinia in Italy. We recognised the limitation of compiling this dataset from different countries and diverse purposes. Additionally, some of these data (i.e. Portugal) do not come from an official national database. However, we see this compilation as a valuable effort for our study and a good step to further uses by other researchers as well.

Given the many types and formats of the information handled, a process of screening and quality assurance was first applied to ensure uniformity, completeness and accuracy of the available data.

Based on the collected information, a common database was jointly developed and populated to provide detailed and systematic descriptions of each fatal incident. The structure of the common database was designed based on a selection of significant variables to be included, their meaning and units, and their coding in the case of ordinal variables.

Each entry in the database corresponds to one fatality (record) and consists of several variables, each one stored in a corresponding field (columns as displayed in Table 2), providing a detailed and objective description of each incident. The database consists of five modules, each grouping information in different categories (Table 2).

The first module includes the date, time and location of the incident. The second module contains data on victims, including their name, age, gender, role (i.e. fire professional, volunteer or civilian), organisation (e.g. fire service, forest service, air crew or military), work status (employed or volunteer personnel). However, we do not differentiate between seasonal or permanent workers in our study. This distinction is not straightforward in this fire management module because some permanent workers in forestry move to firefighting during summer only. Additionally, in some regions and countries, seasonal workers are upgraded to permanent positions or close to that (i.e. a 10-month-per-year employment) in some years depending on trade-union strength and finances of the

Table 2. Structure of the joint database

Module 1. Timing and location	Module 2. Victim data	Module 3. Incident details	Module 4. Meteorological conditions	Module 5. Source of information
Date of fatal incident	Gender	Activity being carried out by the victim at the moment of the incident	Temperature (°C)	Sources of data
Time of occurrence	Age	Cause of death	Relative humidity (%)	
Exact location	Role (fire professional or civilian)	Surrounding elements and means of transportation	Wind speed (km h^{-1})	
Region	Work status (permanent fire professional, seasonal fire professional, volunteer). Not applicable in case they are not a fire professional	Location of death (in relation to the location of incident)		
Country	Organisation (i.e. fire service, forest service, air crew or military)	Vegetation type		

organisation. The third module contains details of the incident itself, including:

- a description of what the victim was doing before the incident (activity of the victim),
- the cause of death (e.g. categorised as burns, physical trauma, respiratory problems, heart attack),
- the topography and fire spread interaction (e.g. downslope spread, flat, moderate slope, canyon),
- the type of vegetation (e.g. grassland, phrygana (low shrubs), shrubs, tall forest),
- the means of transportation (e.g. victim on foot in an open space or indoors, inside a land vehicle or an aircraft), and
- the location of death in relation to the location of the incident.

Note that we chose to add 'canyon' as particular situation regardless of steepness. The fourth module concerns information on the meteorological parameters recorded at the time of the incident (e.g. air temperature, air relative humidity and wind speed). We had no solid data to positively correlate drought periods with number of victims. A Drought Code index was not available in all countries to a fine scale of the particular location of any fatality event. The fifth module reports the source of information for each element of the database (Table 1). The database includes all deaths that were immediately and directly attributable to a forest fire. Long-term health effects of forest fire disasters were not examined because of a lack of data.

The pathway of the analysis is shown in Fig. 1. NUTS 2 (in spatial distribution box) refers to the countries subdivision to the second level of the Nomenclature of Territorial Units for Statistics, as defined by European Union (2003).

Data quality and uncertainties

Given the social impact of fire events leading to fatalities, it was fairly easy to find information from several sources, whether they were official reports or news in media. This gave us the opportunity of completing the information gaps (particularly name, age, affiliation, occupation and details of the event) and to cross-check the obtained data, particularly for clarifying the circumstances and factors involved in the fatality.

In spite of the above, uncertainty still exists for some information because of the non-scientific nature of some data sources. Newspaper and periodical libraries have been used before as data sources in the study of natural hazards (Llasat *et al.* 2009; Diakakis *et al.* 2012; Cardil and Molina 2015; Cardil *et al.* 2017), but they potentially add subjective information. To deal with this, the circumstances under which each incident occurred were described through a set of selected variables (shown in Table 2 and Fig. 1), which were specifically chosen to provide an objective account of the conditions. In this way, the description of key elements of each fatal incident would not be subject to the reporter's opinion.

A second source of uncertainty was connected to the medical cause of death. In some cases, available reports did not provide a clear statement about the cause of death, for example, whether a victim was affected by smoke inhalation or was severely injured by burns, or both factors actually contributed to the death. In these cases, the reported causes of death were grouped in a combined category.

Results

Spatial distribution of fatalities

The total number of victims identified in the study area in the period 1945–2016 was 865, with Spain being the most affected country in absolute numbers (346 fatalities) followed by Portugal (232), Greece (211) and Sardinia (76) (Table 3). The spatial distribution of these fatalities in the study area is shown in Fig. 2 and 3. Several spatial patterns can be observed in each country. In Spain, a higher number of the deaths was concentrated along the Mediterranean coast, especially in Catalonia and the Valencian community where 37.5% of the total number of fatalities occurred, whereas these two regions comprise only 16.2% of the surface area burned in the study period. Regarding Portugal, most fatal incidents occurred in areas that are usually most affected by forest fires, the Central and Northern Regions of the country. In Greece, 59.7% of the fire fatalities took place in the southern part of the country, where the climate is warmer and less humid. The major fatal fires of 2007 that occurred in Peloponnese and Euboea in the south of Greece, which faced

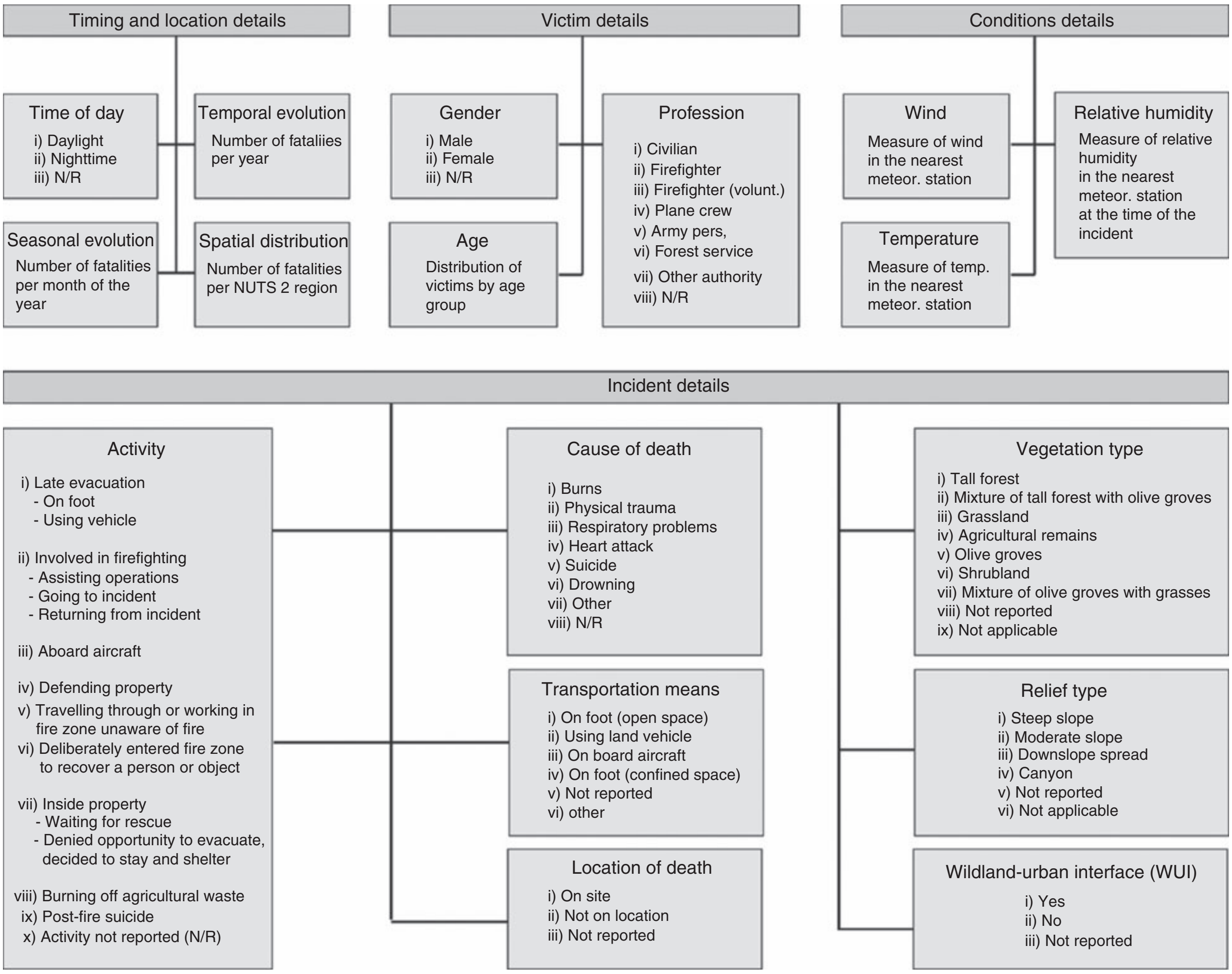

Fig. 1. The pathway of the analysis. (N/R, non responses; NUTS, Nomenclature of Territorial Units for Statistics; WUI, wildland–urban interface.)

Table 3. Total and mean annual (in parentheses) number of fatalities in each country in the study period

Period	Spain	Portugal	Greece	Sardinia	Total
1945–1978	No data available	29 (0.9), data from 1963	3 (0.1), data from 1945	13 (0.4), data from 1945	45 (however, these are very incomplete data)
1979–2016	346 (9.1)	203 (5.3)	208 (5.5)	63 (1.7)	820 (21.6)

extreme drought that year, have clearly influenced this statistic. In the case of Sardinia, more than 85% of fatalities were recorded in the northern part (Sassari and Nuoro provinces).

Temporal and seasonal trends

Examination of the temporal evolution of the number of fatalities showed a strong year-to-year fluctuation with a high annual variability in all countries. A remarkable rise in the number of fatality occurred simultaneously in all regions after 1978. Considering the 1979–2016 period, for which the data are comparable for all countries (Table 3), the average annual number of deaths for the whole study area was calculated at 21.6 (821 fatalities accumulated). The worst years for total fatalities were those including multiple-fatality events, such as: 1966 (Sintra, Portugal, 25 fatalities), 1983 (Curraggia, Sardinia, Italy, 9 fatalities), 1984 (La Gomera, Canary Islands, Spain, 20 fatalities), 1985 (Armamar and Guarda, Portugal, 17 fatalities), 1986 (Águeda, Portugal, 16 fatalities), 1989 (different events between July and August 18 fatalities; Porto S. Paolo, Olbia, Sardinia), 2005 (Riba de Saelices, Guadalajara, Spain, 11 fatalities, all firefighters) or 2007 (in 10 major incidents in Greece, 78 fatalities). The absolutely worst year of the study

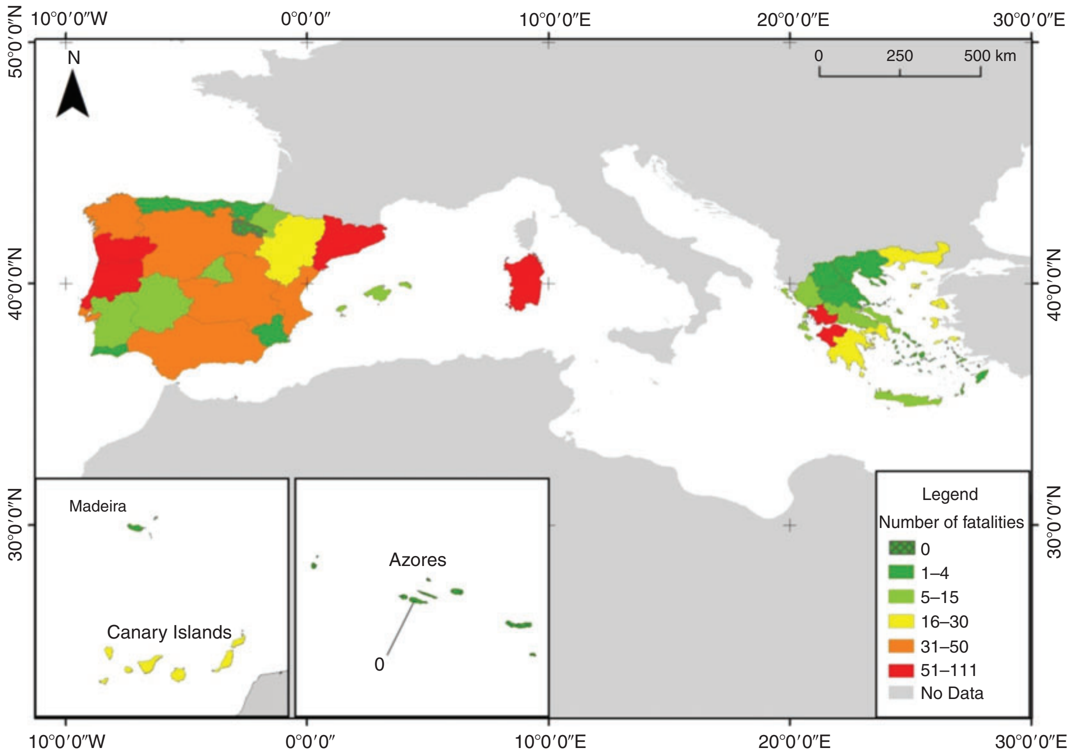

Fig. 2. Spatial distribution of wildfire fatalities in each NUTS2 region in the study area.

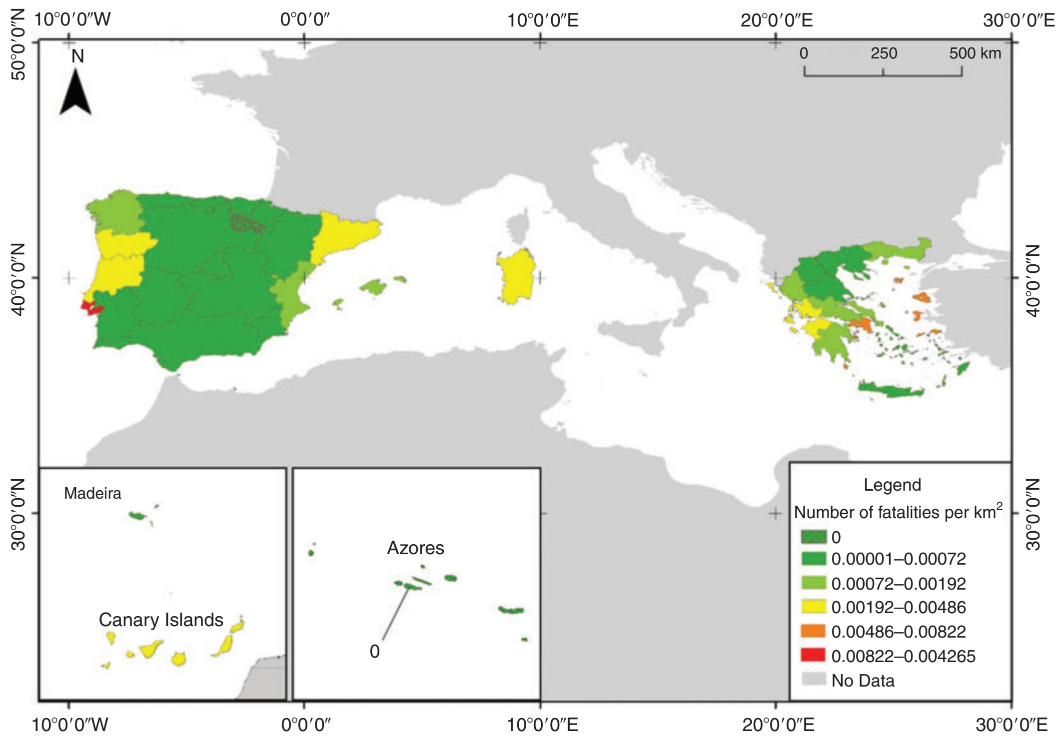

Fig. 3. Spatial distribution of wildfire fatalities per square kilometre in each NUTS 2A region in the study area. NUTS (Nomenclature of Territorial Units for Statistics) is a geocode standard for referencing the divisions of states for statistical uses. This standard is established and regulated by the European Union, and consequently only covers the member states of the EU. In Europe there are 276 NUTS at level 2. NUTS 2 level is approximately equivalent to autonomic regions in Spain.

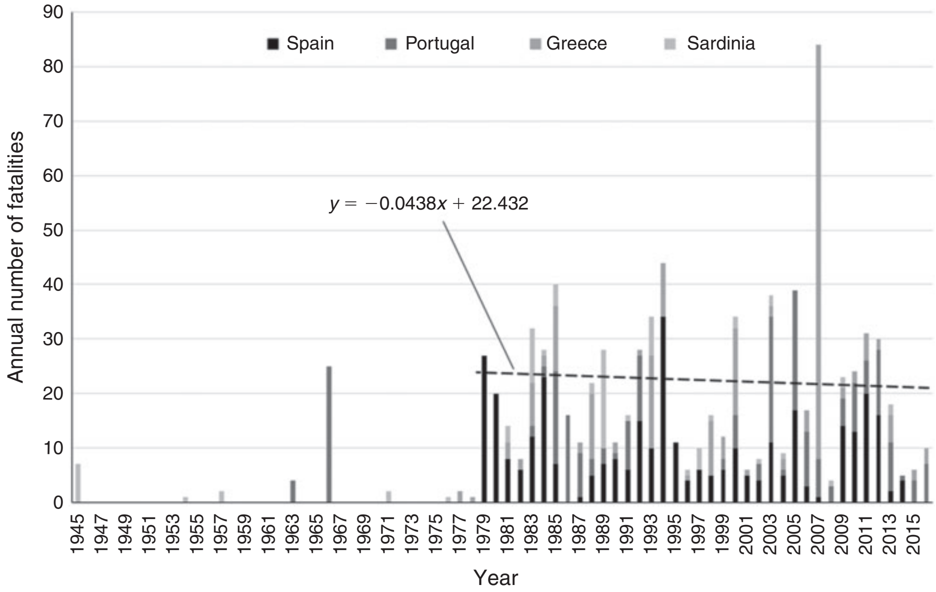

Fig. 4. Annual number of fatalities in the 1945–2016 period for Spain, Portugal, Greece and Sardinia (Italy), including a trend line for the 1979–2016 period.

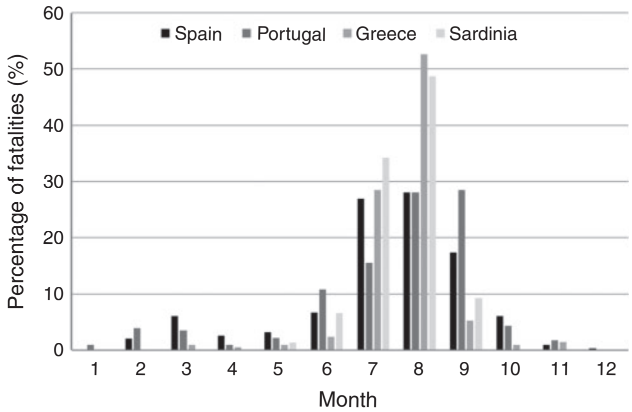

Fig. 5. Monthly distribution of fatalities, in percent, in the 1945–2016 period for Spain, Portugal, Greece and Sardinia (Italy).

period was 2007 with 84 fatalities for the whole study area (Fig. 4).

The number of fatalities exhibits strong seasonality with most of them occurring during the typical Mediterranean fire season, from the beginning of June to the end of September. The distribution is unbalanced even within this period, with the majority in August (35.8%), followed by July (24.8%), September (16.6%) and June (6.7%). Noteworthy differences were found between countries (Fig. 5). In both Sardinia and Greece, more than 80% of the fatalities occurred in July and August.

Across the study area, the examination of the time of the incidents revealed that most occurred in daytime (83.9%). Night-time fatalities represent only 16.1% of the cases. These figures are based on 49% of the cases, for which time was reported. Portugal had the lowest percentage of fatalities in daytime (70%) whereas the rest of the countries had values higher than 88%.

In raw numbers, Spain has the most reported fatalities per year (Table 3). However, to obtain a proper contrast between the different regions, the data were normalised by area and population. There were no substantial differences in population growth among these countries in the study period. Normalising the number of fatalities by the most recent population count of each country (Table 4), it becomes evident that Spain had the lowest fatality rate (0.196 fatalities per million inhabitants per year) and Sardinia the highest (1.001). The mean for the four areas grouped together is 0.286 fatalities per million inhabitants per year. It is true that in summer there are more people in Mediterranean countries than are reported in the census because of the large number of tourists they receive. However, for the purposes of this study, the summer population increase can be considered similar, as all countries have a strong tourist development.

When normalising by country (or region) area, estimating the number of fatalities per 10^6 km^2 per year, Spain has the lowest fatality rate (1.80) and Sardinia the highest (6.88). Portugal with 5.56 and Greece with 4.15 fatalities per 100 000 km^2 per year are closer to the fatality rate of Sardinia. The mean for the four areas as a whole is 2.85 fatalities per 100 000 km^2 per year.

When normalising by wildland area burned in the period 1979–2016, it is Greece that showed the highest rate (annual number of fatalities per 100 000 ha of burned forests and wildlands): 11.81 fatalities per 100 000 ha burned per year. The other three countries had a similar rate of ~5.0. More specifically, Spain had 5.63, Portugal 5.05 and Sardinia 4.82 fatalities per 100 000 ha (of burned area) per year. The mean for the four areas, as a whole, was 6.20 fatalities per 100 000 ha burned per year.

Table 4. Mortality numbers per country or region

Period	Spain	Portugal	Greece	Sardinia	Total
Average annual number of fatalities					
1979–2016	9.1	5.3	5.5	1.7	21.6
Average annual number of fatalities per million of inhabitants (population number from the latest census shown in line below)					
Inhabitants (latest data available)	46468102	10345210	10955000	1656003	75424315
1979–2016	1.96	3.27	5.00	10.01	2861
Average annual number of fatalities per 10^6 km^2 area (total country area (km^2) shown in line below)					
Area (km^2)	50 5370	96 090	131 957	24 090	757 507
1979–2016	1.80	5.56	4.15	6.88	2849
Average annual number of fatalities per 10^6 km^2 of forest and woodland area (total forest and woodland area ($\times 10^6$ km^2) shown in line below)					
Total forest and woodland area ($\times 10^6$ km^2)	2.7627	0.4907	0.6539	0.1213	4.0286
1979–2016	3.30	10.89	8.37	13.67	5.36
Population density, i.e. population km^{-2}	92	114	82	69	

Table 5. Cause of death by profession (or role) in the study area (1945–2016)
N/R, non responses

	Aerial accident	Health problems	Burns and suffocation	Other causes	Terrestrial accident	N/R	Total	%
Army personnel	0	3	25	0	0	2	30	3.5
Authority	0	3	3	0	0	0	6	0.7
Citizen	3	25	229	2	2	105	366	42.3
Firefighter	0	49	157	2	36	22	266	30.8
Plane crew	68	28	0	0	0	0	96	11.1
Volunteer firefighter	0	5	5	0	3	1	14	1.6
Forest service official	1	8	6	0	0	2	17	2.0
N/R	0	2	21	0	0	47	70	8.1
Total	72	123	446	4	41	179	865	100

A fourth normalising attempt was performed by calculating the fatality rate per 10^6 km^2 of forest and woodlands, based on the area of forest and other wooded land in 2015. The forest and woodland area increased similarly in these countries; the most obvious change was land abandonment (i.e. agriculture and forests with less management). This result was consistent with the previous attempts: Spain has the lowest number of fatalities per 10^6 km^2 per year (3.30), whereas Sardinia has the highest rate (13.67), followed by Portugal (10.89) and Greece (8.37). The average for the four areas was 5.36 fatalities 10^6 km^{-2} per year. In summary, Spain was ~35% below the average (of the value for the four regions together) in these three normalising attempts (31.5, 36.8 and 38.5% when normalising by inhabitants, country area and country forest area respectively). However, Sardinia was way above the mean (~182%), whereas Portugal and Greece were also above the mean with 71 and 59% respectively.

Profession, cause of death and last activity of victims

With regard to the professional status of the victims, results show that civilians record the higher percentage (366 or 42.3%), followed by firefighters (266 or 30.8%), aircraft crew (96 or 11.1%), army personnel (30 or 3.5%) and other categories (Table 5). In 8.1% of the total number of cases, profession was not reported.

The main causes of death based in 686 fatalities (i.e. 865 minus 179 non-reported cases) were burns and suffocation 446 (65%), health problems 123 (18%) and aerial accidents 72 (10%).

Civilians were the most affected group in Greece (65%) and Sardinia (58%), whereas firefighters were the most affected group in Spain (35.5%) and Portugal (43.5%). Firefighters accounted for 22.4% of the fatalities in Sardinia and 11.8% in Greece. Aircraft crew fatalities (and some N/R (non responses)) were major contributors to the rest not covered by civilian and firefighters.

When the incidents occurred, there were various causes of death and diverse activities of victims (Table 5). ‘Burns and suffocation’ was the most common cause of death with 446 cases (229 civilians and 157 firefighters) out of a total of 865 (51.5%) of all the fatalities. Health problems, including heart attacks, physical trauma, respiratory problems and exhaustion, affected all victims causing 123 fatalities or 14.2% of the total (Table 2). Aerial and terrestrial accidents contributed with smaller, but still noteworthy, percentages of fatalities (10.5 and 6.0% respectively).

In the case of aircraft crew, all of the causes of death were reported, showing that most of the victims were due to fatal aviation accidents, followed by medical causes as second most recurrent cause. As for civilians, the main causes of death were burns and suffocation, totalling 229 cases (63%), followed by health problems with just 25 cases (7%). However, in a significant number of cases the cause was not reported (105 or 29%). In terms of firefighters, the main causes of death were also burns and suffocation, adding up to a total of 157 cases (59%), followed by medical issues with 49 cases (18%) and ground-vehicle accidents with 22 cases (14%). There were only 22 (8%) unreported causes of death for firefighters. However, unreported causes of death for civilians were much higher (105 or 29%), indicating that there is insufficient attention paid to this in reporting, pointing to a strong need for improvement.

With regard to the activity being performed by victims at the time of the incident, as listed in Fig. 1, most frequent was firefighting (41.6%) followed by evacuation (13%), agricultural activities (10.3%), being aboard an aircraft (10%) and protecting property (8.3%).

Surrounding environment

The exact location of death was reported in 491 (56.8%) of the total number of cases. Data show that most of the victims 423 (86.2%) died at the location of the incident, whereas the remaining 68 (13.8%) died in hospital, while being transferred to the hospital or at home after returning from wildfire incidents.

With regard to the surroundings, 438 fatalities (50.6%) occurred in open space, whereas only 47 (5.4%) happened indoors (in a confined space). In a significant number of cases (380) the exact type of surroundings were not recorded. The database shows that 121 of the victims were using a ground vehicle at the time of the incident, 26 were aboard of an aircraft and 316 were on foot.

Regarding the incident-location topography, the obtained 309 registers show that a high percentage of the victims died on moderate (>20%) to steep (>50%) slopes (23.3 and 28.8% of cases respectively), whereas 26.2% of the fatalities occurred in canyons. In case of canyon locations, this study does not reflect the steepness as it was considered as a particular situation regardless of steepness, given that a canyon by itself can induce a dramatic change in fire behaviour. Flat areas recorded a smaller, but noteworthy, number of cases (17.5%), whereas settings favouring the downslope spread of fire accounted for only 4.2% of the known cases. Concerning the vegetation type present in the vicinity of the accident, similarities were found across the considered regions. In most of the cases (432 out of 471, which represents 92%), vegetation type was tall forest, shrubs or grasses. In particular, tall forest type was present in 251 out of 471 cases (representing 53%). Some other vegetation types that are frequently found in specific countries, such as olive groves in Greece, which were found in 24 out of 127 cases (a remarkable 19%), were not reported in other regions. Besides, in many cases (394) no vegetation type was specified at all, particularly in Spain and Portugal.

Presence of WUI

WUI can be defined as the space where structures and vegetation coexist in a fire-prone environment (BRP 2008), adding the human component (Ribeiro 2016), as people are affected as well. The original WUI concept was suggested in 1974 by an American physicist, C. P. Butler, who stated that 'In its simplest terms, the fire interface is any point where the fuel feeding a wildfire changes from natural (wildland) fuel to man-made (urban) fuel. For this to happen, wildland fire must be close enough for its flying brands or flames to contact the flammable parts of the structure' (Butler 1974).

There was a limitation in the number and quality of records about the involvement of WUI areas in accidents in the study area. Even with this limitation in mind, some interesting results were still found. A total of 193 deaths (22.3% of total) occurred in WUI areas, in contrast to 375 fatalities (41.3%) that happened in the wildland. In 315 cases (36.4% of total), the environment around WUI area was not reported. The complete set of numbers is presented in the Table 6.

Table 6. Number of fatalities and percentage (in parentheses) occurring in wildland–urban interface (WUI) or wildland areas

Country	WUI	Wildland	Not reported
Spain	37 (10.7%)	111 (32.1%)	198 (57.2%)
Portugal	25 (10.8%)	132 (56.9%)	75 (32.3%)
Greece	100 (47.4%)	69 (32.7%)	42 (19.9%)
Sardinia	31 (40.8%)	45 (59.2%)	0

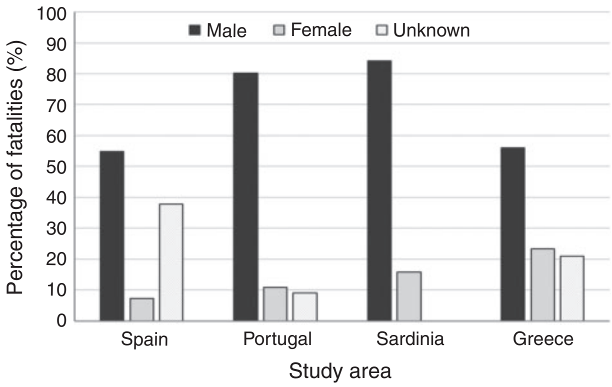

Fig. 6. Percentage of fatalities in each country considering the gender of victims in the 1945–2016 period.

Victim demographics

With regard to gender, the majority of fatalities were male (558 of the 865 cases or 64.5%), whereas female victims were recorded in 111 cases (or 12.8% of total). The gender was not reported in 196 cases (22.7% of the cases). Numbers by country are shown in Fig. 6. The percentage of male fatalities (excluding unknown cases) was 86% with values ranging between 70.6% in Greece to 88.4% in Spain. Approximately two-thirds of civilian fatalities were male, with values ranging from 42.7% in Spain to 73.3% in Greece, using only data where gender was reported.

Regarding age groups, both Greece and Portugal had nearly 30% of fatalities in the older than 65 years age group, whereas in Spain and Sardinia this accounted just for a merely 10% (Fig. 7). In sum, the percentage of victims in this age group, considering

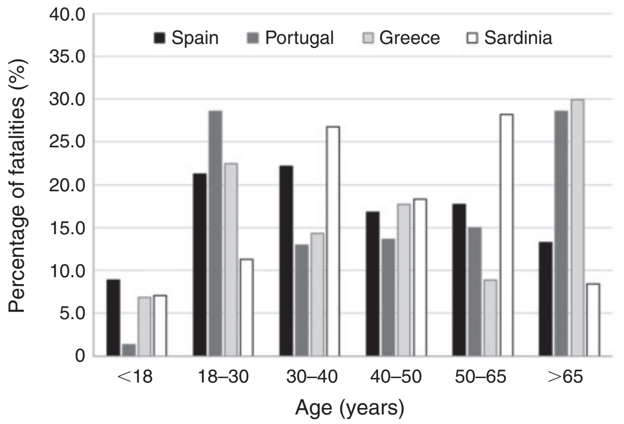

Fig. 7. Percentage of fatalities in each country considering the age segment of victims in the 1945–2016 period.

just the civilians, ranged from 13.6% in Sardinia to 62.8% in Portugal, with an overall mean of 40.7% across all studied countries.

Weather conditions

Analysis of weather conditions in the incidents showed a higher frequency of fires in lower relative humidity (particularly in the range from 10 to 30%) and higher temperatures (particularly in the range from 25 to 35°C) (Fig. 8). In terms of air temperature, 58% of fatalities occurred with temperatures higher than 30°C. However, for Spain and Portugal temperatures under 30°C are also significant. Most incidents (60% of the cases) occurred under relative humidity below 30%. Regarding wind speed, most of the accidents (75%) occurred with wind speeds between 0 and 20 km h^{-1}. Similar percentages were observed across all considered countries, except in Greece, which showed higher values for adverse episodes of relative humidity and temperature (Fig. 8). For this study, data availability was not even; indeed, just 52% of cases had records for temperature, 44% for relative humidity and 49% for wind speed.

Note that the database included several cases with air relative humidity higher than 70%. Although this may seem surprising, this was mostly attributed to a single case with 21 fatalities, in Lloret de Mar (Girona, Spain, 7 August 1979), for which relative humidity was at 71% during the accident.

Discussion

Analysis of the fatal incidents offered insights and understanding about the conditions under which forest fire fatalities are more likely to occur, and highlighted some of the factors that influence their occurrence in a large area of Mediterranean Europe. Regarding the spatial distribution of fatalities, results show that highest number of fatalities occurred in the most fire-prone regions.

Analysis of the temporal evolution of fatalities shows a clear jump in the yearly number of deaths since 1979 in all four regions examined almost simultaneously. This jump is likely to reflect the results of depopulation of rural areas and subsequent land-use changes (e.g. fuel build-up, vegetation continuity, age distribution changes) that took place in the 1960s and 1970s

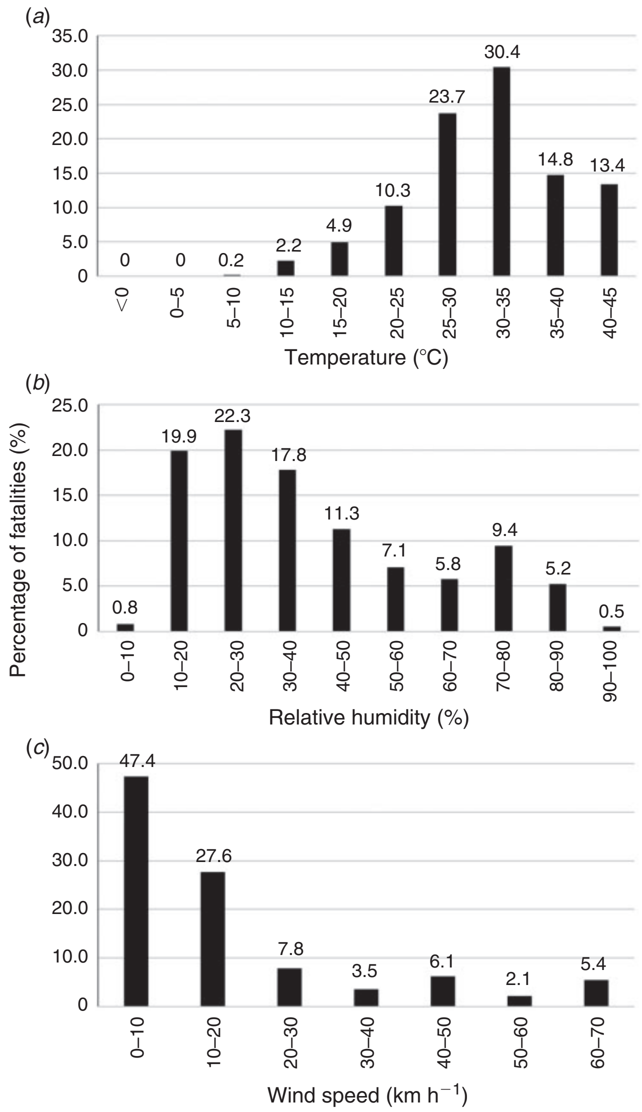

Fig. 8. Total number of fatalities considering (*a*) temperature (°C), (*b*) relative humidity (%) and (*c*) wind speed (km h^{-1}) in the 1945–2016 period.

(Velez Munoz 2007), as well social changes on population composition interacting with wooded lands (increase of tourists, urban and seasonal residents, etc.) and a higher exposure of people in the WUIs (Viegas 2009). In addition, more frequent extreme-weather conditions in Southern Europe (Cardil *et al.* 2014, 2015) could have also played a role.

Examining the trend of the yearly number of fatalities in the 1979–2016 period, there is a marginally decreasing trend (a near flat slope in Fig. 4), indicating a fairly stable regime. The trend line reflects the perpetuation of the adverse conditions that developed and led to the increase in the number of fatalities after 1979. However, the trend is fairly sensitive to fluctuations of the annual fatalities (especially to extreme values; i.e. the worst years) and therefore should be considered with caution and revised periodically.

Regarding the seasonal distribution of fatalities, as expected, the data reflected the strong seasonality of fire occurrence in the four regions as a result of the characteristics of the Mediterranean climate (hot, dry and often windy summer). Variability between the four regions (i.e. Greece and Sardinia present a stronger seasonality) is attributed to broad, climatic weather patterns that affect local weather conditions, such as specific well-known winds (Etisies or Meltemi in Greece, Mistral in southern France, etc.).

Examination of the timing of the incidents revealed that most occurred in daytime (83.9%), a pattern that is attributed to the typically calmer fire behaviour (Beck *et al.* 2001) and to the decreased mobility of people in the forest during night-time.

Analysis of fatalities in terms of profession, shows that, although the majority of victims (49.6% in total) are professionally related to forest fires (including firefighters, military, local authorities, plane crew), the percentage of civilians among the victims is also high (42.3%). This highlights the increased risk for people who are in the path of the fires, even when they are not involved in fire suppression. The high number of firefighter fatalities is alarming and indicates a need to improve training on safety protocols and procedures (Molina *et al.* 2010), such as LCES (Lookout, Communication, Escape Routes and Safety Zones) (Gleason 1991), LACES (Thorburn and Alexander 2001) or Dead Man Zone (Cheney *et al.* 2000). This could be done by revisiting previous accidents (and lessons learned) in the very suppression agency.

As soon as the number of victims of a wildland fire passes one or more it automatically escalates to a higher level of emergency stress (Molina *et al.* 2010), as social pressure increases quickly (Xanthopoulos 2008). Although additional resources are dispatched immediately as a reaction, they are usually less efficient in such situations of panic and strong emotions (i.e. thinking about affected teammates, suffering uncertainty).

It should also be noted that, despite having better-trained firefighters and better Civil Protection departments (Miralles *et al.* 2010; and Molina *et al.* 2010), there is no significant reduction of firefighter deaths in the 2009–2016 period compared with the 1979–2008 period. This could be understood as a clear indicator of the need to focus as much as possible on training on fire-safety subjects, particularly under the current trend of global climate change under which forest fires are and will be more intense, difficult to predict and hard to contain. As part of the training and education based on lessons learned, it is advisable to improve and continue the systematic research and reporting of the accidents leading to fatalities, underlining the factors, context and unfolding events that took place. A common, normalised guideline set for this purpose could be of a great help in Europe. Besides, a complete survey on the existing media records on forest-fire-related fatalities should be completed, under the scrutiny of expert personnel ensuring the quality of the obtained data.

According to the data, most of the victims died on the location of the accident. This is attributed to the nature of these events that commonly involve some form of entrapment, offering little escape opportunity to the victims (Xanthopoulos *et al.* 2009).

Examination of topography showed that the majority of victims died on steep morphology environments (either steep slopes, canyon-like topography or moderate slopes). Less than one-fifth of the victims died in flat areas.

Examination of the environment surrounding the fatalities showed large differences regarding representation of WUI environments in the database. In Greece, 47.4% of the fatalities for which location were reported was in WUI areas. In Sardinia, the percentage was quite similar (40.8%). However, in Portugal and Spain the percentages of WUI fatalities were markedly different (10.8 and 10.7% respectively). An obvious explanation could not be established. Reasons for the difference could be due to differences in reporting (e.g. the meaning of WUI within each reporting organisation and the extent of area around the WUI for considering an incident as a WUI fatality) or could reflect different conditions (e.g. relative extent of WUI areas, different quality of planning WUI areas).

It is also remarkable that most of the reported victims related to accidents in the WUI happened in large numbers and often in the course of unplanned and panicked evacuation, such as in Lloret de Mar 1979 (Spain), Ikaria 1993 (Greece), Artemida 2007 (Greece) or Pedrógão Grande 2017 (Portugal). Additionally, as reflected in the data on surroundings, victims were found inside their houses only in a few occasions. It should be noted that, despite the existence of houses and other infrastructure, which may eventually serve as a last-resource shelter, the presence of dense smoke complicates the survival chances in an entrapment episode, particularly for civilians without any training nor any appropriate equipment (such as autonomous breathing systems). Houses that have not been prepared appropriately may not serve as shelter in cases of dense smoke or a high intensity fire. These lessons learned indicate the need of an adequate design and assessment of houses as shelters in advance. Some of the houses, or even whole residential areas, may not offer adequate probability of survival and should be excluded. Such areas should be identified in the prevention planning phase.

Concerning gender, the majority of victims were male for all age classes. Examining all the cases for which gender of victims was registered, 83.4% were male and just 16.6% were female, rendering a five-to-one ratio, which is consistent with what is found in literature (Blanchi *et al.* 2014). This might be expected to some extent because of the over-representation of males in the firefighting community, aircraft crew and volunteers. However, even when considering only civilians, the corresponding percentages are 66.7% male and 33.3% female, indicating that males are statistically more exposed to fire risks.

With regard to weather conditions, most of deaths occurred in the middle of the summer under very adverse fire-danger factors (relative humidity below 30% and temperature $>30°C$), indicating that lives are more at risk under such weather conditions. This is especially true for firefighters working close to the fireline (e.g. performing hard physical work under stressing temperature conditions) and sometimes using personal protecting clothing (PPC) with a fabric composition that might compromise sweat evaporation (Carballo-Leyenda *et al.* 2017). A high quantity of moisture retained in PPC could raise the risk of scalding and this could compromise the safety during a direct attack on the fire line. Scalding is a form of thermal burn resulting from overheated fluids. Additionally, researchers have related thermal stress to fatal heart attacks (Kales *et al.* 2007).

Aircraft-crew fatalities are not negligible, particularly in Spain, where 72 out of the total 96 fatalities reported occurred.

This is alarming, although it can be explained to some extent by the heavy use of aerial-firefighting resources in Spain when compared, for example, to Portugal. Aerial firefighting is also heavily applied in Greece, although fatalities in this country are not just the result of the number of flying hours, but also of a host of other parameters still to be investigated and described by specialists. Indeed, an evaluation and a comparison between countries of these other parameters and operational protocols are needed.

It is also worth noting that in several incidents in the database, with many of these happening in the WUI, senior citizens (65 or older) were involved in an entrapment episode. Frequently, in these types of entrapments the whole group had perished, whether they were children (typically grandchildren), teenagers or young adults. This observation confirms the notion that physical impairment or mobility limitations of older members of a group can determine the mobility of the group overall. This presents a paradox, the more fire-suppression resources are available decade to decade does not relate to fewer fatalities due to wildfires.

Conclusions

This study assembled and examined a database of civilian and firefighter forest-fire fatalities in four regions in Mediterranean Europe in an effort to build a better understanding of the circumstances under which these fatalities occurred. The database covered the period 1945–2016 and included a total of 865 fatalities and 821 for the shorter period 1979–2016 (a sharp increase since 1979).

According to the data, forest-fire fatalities of fire professionals and civilians occur on a yearly basis (21.6 deaths per year on the average; for the shorter period 1979–2016).

Even though there are significant fluctuations, no significant increasing or decreasing trend was identified. Spain has the largest numbers in absolute terms, but the lowest in relative normalised figures. Similarly to previous works, males and older individuals were represented in much higher percentages among the victims.

Fatalities happen mostly in the peak months of the fire season under adverse weather conditions. Many fatalities are associated with WUI areas. The need for better fire preparedness of homes in WUI areas and of their inhabitants is highlighted. Civilians and authorities should not consider living in WUI areas safe. Most victims die in open spaces, often during late evacuation, a finding in agreement with other similar studies (Diakakis *et al.* 2016; Prior and Paton 2008).

The analysis also demonstrated the risk that firefighting presents for professionals in the field. The need for improved safety has been highlighted. This can be achieved through better training with emphasis on safety issues. Additionally, it was found that the number of fatalities related to aerial resources in Spain seems to be disproportionally large in comparison to the other regions, a finding that calls for a deeper investigation by professionals who have the necessary expertise.

As a final, general remark, it can be concluded that a major revision of policies and practices is required to mitigate the number of fatalities in Mediterranean Europe. We strongly suggest that this be done with emphasis on prevention planning, preparation of WUI areas (both structurally and risk awareness and participation of population), and better organisation and training of firefighting resources. Lessons learned have to be systematically recorded, particularly from incidents affecting the WUI where many fatalities are originated. It is desirable to implement suitable designs and assessments of houses that will eventually serve as shelters in European countries, following examples as developed in Australia (Australian Standard, AS 3959's building requirements, http://www.as3959.com.au/as-3959-download/, accessed 2 January 2019) and US (Ordinance 2017–01, Rancho Santa Fe Fire Protection District, which adopts The 2016 California Fire Code, https://www.citymb.info/Home/ShowDocument?id=28089, accessed 2 January 2019, and the 2015 International Fire Code, https://codes.iccsafe.org/content/IFC2015, accessed 2 January 2019). In sum, we suggest that a better understanding of the fire-suppression paradox will help to properly address it.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Declaration of funding

This research did not receive any specific funding.

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