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13

Prescribed burning in the European Mediterranean Basin

Paulo M. Fernandes, Carlos G. Rossa, Javier Madrigal, Eric Rigolot, Davide Ascoli, Carmen Hernando, Nuno G. Guiomar and Mercedes Guijarro

A historical introduction

Fire disturbance is an intrinsic and vital ecological process in the Mediterranean Basin wildlands (Pausas and Vallejo 1999). Fire use by humans has a long history and fire has been used in the region at least since approximately 1000–3000 BCE (Pyne 1997; Tinner *et al*. 2009; Gil-Romera *et al*. 2010; Connor *et al.* 2012). Initially used for land reclamation, fire has been key in maintaining ecosystem services related to grazing and agroforestry (Naveh 1975; Keeley *et al*. 2011), as well as a means of rural protest and resistance (Tedim *et al*. 2015; Da Ponte *et al*. 2019). However, depopulation of rural areas in recent decades following socioeconomic changes and fire use restrictions have led to the gradual loss of a 'fire culture' in the region, as well as the traditional knowledge of fire as a management tool (Di Pasquale *et al*. 2004; Ganteaume *et al*. 2013). Fire, in the form of the institutionalised practice of prescribed burning, is now being established as a technology serving fire hazard reduction and ecosystem maintenance and restoration goals (Fernandes *et al*. 2013). Only Portugal, Spain, France and Italy are considered in this chapter, because prescribed burning is not practiced elsewhere in southern Europe, despite the late 1960s pioneering experimentation of Liacos (1974) in Greece.

Early 19th century descriptions reveal burning practices in maritime pine (*Pinus pinaster* Ait.) forests in southern France and Portugal consistent with the concept of prescribed burning (e.g. Alexandrian 1988). In France, burning was legislated and generalised among landowners in the Maures and Esterel regions (Alexandrian 1988). However, the practice was subsequently lost in both countries.

Silva (1987, 1997) gives an account of the inception and early development of prescribed fire in Portugal. The Forest Service trialled prescribed burning in the north-west pine stands between 1976 and 1981 after visits by Edwin Komarek of the Tall Timbers Research Station in Florida in the US. Starting in 1982, a fuel-reduction program with prescribed fire was implemented over 55% of the communal forest area in the region. More than simply being adopted, prescribed underburning was adapted to the local context and its development paralleled that of research. Analysis of data

collected by the Forest Service revealed insufficient planning, but also effective hazard reduction without negative environmental effects (Fernandes and Botelho 2004). Prescribed burning became an occasional and very localised practice from 1994 to 2004. Increased political support following tragic wildfire seasons and improved and more extensive training subsequently revived prescribed fire in Portugal, the use of which has spread from the north-west region to include open vegetation types.

In 1980, foresters from France, Spain and Italy travelled to the US under the auspices of the Direction of Forest Resources of the Food and Agriculture Organization of the United Nations (FAO) and were introduced to prescribed fire as a safe, ecological and cost-effective technique (Alexandrian *et al*. 1980). After this visit to the US, the use of prescribed fire was introduced in France. The initial demonstrations in pine forests were fostered by the contemporary Portuguese experience and were conducted *à la portugaise* (Binggeli 1997). However, insufficient interest from forest managers limited initial initiatives to study the ecological effects of prescribed burning and compare them with the results of other fuel treatment methods (Rigolot 2000). The first prescribed fire programs in France were established in the early 1980s in shrubland in the Eastern Pyrenees and Maritime Alps and subsequently expanded to other regions. Prescribed burning is now actively and officially supported by the Mediterranean French agencies and organisations involved in fire management (Lambert 2010). Fuel reduction was the initial objective, with proven benefits to wildfire control operations (Rigolot 1997; Lambert *et al*. 1999). However, additional objectives were added as burn crews expanded their capacity, including habitat management for pastoral, hunting or nature conservation purposes.

The first prescribed fires in Spain were conducted in Galicia, in the north-west of the country, on small test plots in shrubland and eucalypt plantations in 1978 and, on a greater scale, in 1980 on a pine plantation of *P. pinaster* and *Pinus radiata* within the framework of a fuel management plan (Vélez 1981). This plan resulted from a collaboration between the Spanish National Forest Service (ICONA) and the National Institute of Agricultural Research (INIA), international exchange opportunities provided by the FAO/UNESCO Technical Consultation on Forest Fires and symposia and study trips organised by the US Department of Agriculture's (USDA) Forest Service (Vélez and Vega 1985). Prescribed fire research in pine stands continued throughout the 1980s–2000s (Vega *et al*. 1983, 2000; Rodríguez y Silva 2000), but there was scant translation of the research into the use of prescribed fire by managers.

The Spanish Forest Fire Service undertook two initiatives relevant to further develop prescribed fire. In 1998, it created Integral Wildfire Prevention Teams (EPRIF) to work directly with the rural population in areas where traditional agricultural practices contribute to high wildfire incidence. EPRIF teams work to reduce the impact of wildfires and support the rural economy, and include prescribed burning within their activities. The second initiative was the experimental burning program in forest, started in 2014 and developed by the Reinforcement Brigades against Forest Fire (BRIF) in cooperation with researchers. The main aim of this program was to improve knowledge of the techniques to decrease wildfire risk through fuel reduction and the avoidance of tree damage.

Group of Support to Forest Actions (GRAF) teams, specialised wildland firefighters from Catalonia, north-east Spain, started using fire to train personnel in 1998. This strategy was expanded and Catalonia was the first Spanish territory in which prescribed burning was used as a fire management tool. Other regions, namely Andalucía and Castilla-La-Mancha, are now replicating this model.

In Italy, interest in prescribed fire also arose in the late 1970s (Susmel 1977). The National Forest Service acknowledged the benefits of prescribed burning (Calabri 1981) and, in the 1980s, promoted experiments in pine forests (Toscana) and to maintain fuel breaks (Sardegna) under the supervision of the Istituto Sperimentale di Selvicoltura (Buresti and Sulli 1983). The experiments were abandoned

despite 'promising' results (Calabri 1988). In Italy, unlike in France, Portugal and Spain, the interest in prescribed fire died off. Attention to prescribed fire returned in the early 21st century, and several scientific studies (e.g. Battipaglia *et al*. 2016; Giuditta *et al*. 2020), legislation initiatives, training and burn programs have been conducted throughout the country (Ascoli and Bovio 2013). However, the use of prescribed burning for management purposes is currently restricted to Campania, Piemonte, Toscana and Sardegna.

Since the 1990s, the Directorate-General for Research and Innovation of the European Commission has funded international cooperation on the use of prescribed burning (Vega *et al*. 1994; Valette *et al*. 1998; Botelho *et al*. 2000; Silva *et al*. 2010). These projects have produced a substantial body of knowledge (Fernandes *et al*. 2011, 2013; Fernandes 2018) from which several burn guidelines and manuals have been produced and helped with the implementation of prescribed burning in southern Europe.

Prescribed burning effort and objectives

As a consequence of its fragmented and intermittent history, prescribed fire activity in southern Europe is essentially local in scope and the area treated is modest (Figure 13.1). Prescribed fire implementation in Spain is limited to national or regional organisations, either forest services or fire management agencies. Users of prescribed fire in France, Portugal and Italy have more diverse backgrounds, and include private forest associations, pastoral associations, volunteer or professional fire brigades and municipalities. Still, the number of active teams is limited in all countries. In France, the number of active prescribed burning teams stabilised at 20–25, after a gradual increase between the 1980s and 2000s. In Portugal, although 150 technicians are currently certified to apply prescribed fire, only 24 have worked as a burn boss in more than 20 burn operations (2006–15). In Spain, there are currently 18 EPRIF distributed throughout the country, mainly in the north; each team consists of two to four technicians.

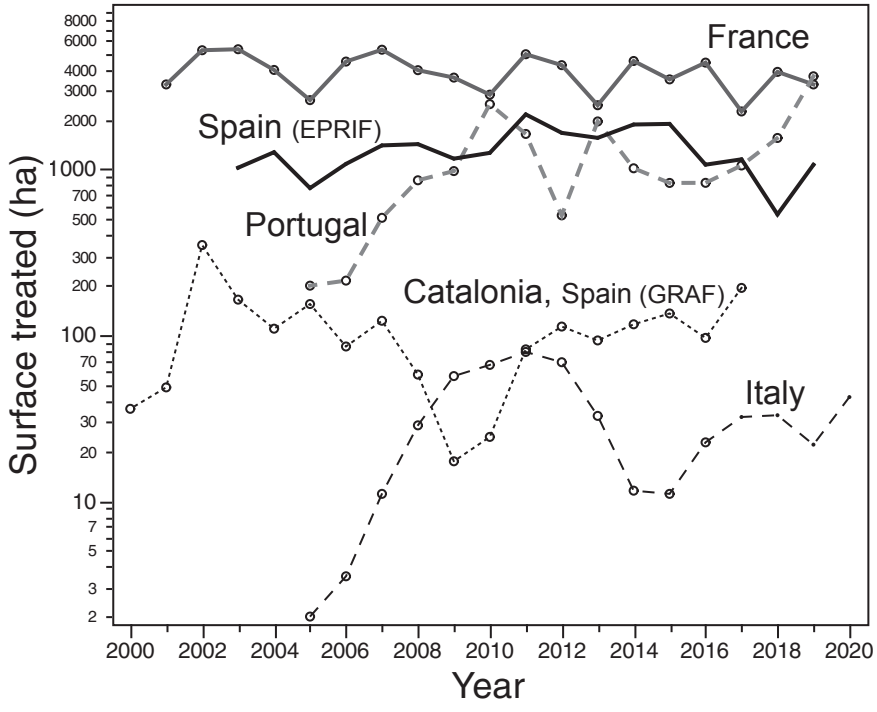

Figure 13.1: Temporal changes in the area treated with prescribed burning in southern Europe.

During 2006–15, a period for which data are available for France, Portugal and Spain, the number of burn operations in Portugal was exceeded by a factor of 1.9 in Spain (EPRIF plus GRAF) and by a factor of 2.4 in France. The leading position of France is confirmed by the amount of area treated, which is 3.6-fold higher than in Portugal and 2.4-fold higher than in Spain. Since 2010, France and Portugal have used prescribed burning on an average of 0.19% and 0.08% of their shrubland area every year respectively. Interannual variation is substantial, but no temporal patterns in the extent of prescribed fire activity are visible in Figure 13.1. Current area targets for Portugal are ambitious, as determined by its national prescribed burning plan, and in 2019 the area treated with prescribed fire in Portugal slightly exceeded that in France. The use of prescribed fire remains very limited in Italy (Ascoli and Bovio 2013), although there are prospects for its expansion, particularly in Toscana. Considering the recent upward trend in Portugal, we estimate that approximately 10 000 ha year^{-1} are now treated with prescribed fire in southern Europe.

More than 90% of prescribed fire activity in France occurs in the south of the country. The Maritime Alps and Eastern Pyrenees are particularly important and account for 31% and 20% of the total area treated respectively; in the Eastern Pyrenees, 14% of the total rangeland area has been treated with prescribed fire from 1987 to 2009 (Lambert 2010). Most burn operations in Portugal take place in the north, especially in the oceanic north-west quadrant (55% of the total area treated), with practically no prescribed fire operations in the south of the country. Coincidentally, 55% of the total area burned by the EPRIF is in north-western Spain; Navarra, in the north-east, accounts for 23% of the total surface treated (Ministerio de Agricultura Pesca y Alimentación 2019).

Prescribed burning objectives in southern Europe are variable, but fuel hazard reduction and pastoral burning prevail. Fuel reduction is particularly (and overwhelmingly) important in Portugal (Table 13.1), where the wildfire problem is considerably more severe.

Spain shows substantial regional variation in burn objectives. In the northern regions (Galicia, Asturias, Cantabria, Navarra, Aragón) and in Extremadura, prescribed fire is merely used to manage pastures and shrublands for grazing. Here, and in France, prescribed burning is largely a surrogate for traditional burning practices that are declining or are perceived as unsustainable or risky, given the current trends in fuel accumulation and landscape-scale fuel connectivity. In Castilla-La Mancha, Andalucía and the Canary Islands, fire management plans consider the use of fire to reduce fuels, manage habitats and for research and training purposes. Fuel reduction in wildlands and at wildland–urban interfaces and training are

Table 13.1. Distribution (%) of prescribed fire operations by treatment objective in France, Portugal and Spain

Data show the percentage of prescribed burns for each objective/the percentage of area burned. Data for France are mean values for 2002, 2007 and 2014. EPRIF, Integral Wildfire Prevention Teams of the Spanish Forest Fire Service; GRAF, Group of Support to Forest Actions

			Spain	
Burn objective	**France**	**Portugal (2006–16)**	**EPRIF (2006–12)**	**GRAF (1998–2017)**
Fuel reduction	33.0/–	80.9/83.6	23.6/13.1	67.1/39.9[D]
Silviculture	18.7/–[B]	4.5/4.6[C]	2.7/1.8	–
Pastoral	41.3/–	6.0/9.3	65.6/79.5	19.4/46.5
Habitat management[A]	7.0/–	1.5/0.7	8.1/5.6	2.9/5.8
Training		5.1/1.6		8.0/6.7
Research		2.0/0.1		2.5/1.1

[A] Wildlife management (including for hunting), nature conservation.
[B] Includes burning for agricultural purposes and other objectives (silviculture being a minority).
[C] Mostly slash burning after tree harvesting in eucalypt plantations.
[D] Includes silviculture.

evident in Castilla-La Mancha and Andalucía, as well as in Valencia (eastern Spain) and Castilla y León (central Spain).

Catalonia has the most complete set of objectives regarding the use of prescribed burning. There is an equilibrium between hazard reduction, essentially by treating specific areas in strategic locations, and pastoral and habitat management. However, consideration of Departamento de Medio Ambiente burn activity in Catalonian mountains (on average 747 ha year^{-1} from 1996 to 2002; Grillo Delgado 2002) strongly shifts burn objectives towards rangeland management.

In France, management objectives other than hazard reduction prevail. In Italy, prescribed burning is used mostly to reduce fuels and manage rangelands, with examples of habitat restoration programs (Ascoli *et al*. 2013).

Quantitative information on the distribution of prescribed fires by fuel type is scarce and is available for Portugal and Catalonia only (Table 13.2). Various shrubland communities are treated with fire, including: heathlands in the Iberian Peninsula, comprising *Pterospartium tridentatum* and species of the *Erica*, *Ulex* and *Cytisus* genera; mixed shrub–grass stands of *Cytisus oromediterraneus* in the French Pyrenees and *Calluna vulgaris* in Italy; and Mediterranean shrublands dominated by *Cistus* spp. or *Quercus coccifera* at various locations. Prescribed fire in forest is used in pine stands of *P. pinaster*, *Pinus nigra* and *Pinus canariensis* (Canary Islands, Spain), as well as to consume *Eucalyptus globulus* slash after clearfelling; other species (e.g. *Pinus pinea*, *Pinus halepensis*, *Pinus sylvestris*, *Quercus pubescens*) are much less represented. In any case, forest understorey burning is a minor component of burn activity in southern Europe, except in Catalonia; again, consideration of high-elevation rangeland burning in the region would substantially decrease the relative weight of prescribed fire in forest. Although understorey burning has never been a significant component of prescribed burning in France, current figures for Portugal are in stark contrast with earlier (1980s–1990s) practice, which was essentially focused in maritime pine stands (Fernandes and Botelho 2004). Prescribed burning in forest requires more personnel per unit area because the need to maintain fire intensity within limits tolerable by trees implies conservative ignition patterns; this is more time consuming and probably contributes to the contemporary preference for prescribed fire in open vegetation.

Table 13.2. Prescribed fire distribution by fuel type

Data show the percentage of prescribed burns for each fuel type/the percentage of area burned. GRAF, Group of Support to Forest Actions

Fuel type	Portugal	Catalonia (GRAF)
Grassland	0.7/0.1	6.0/13.0
Shrubland	78.6/84.2	26.3/41.0
Forest		
Grass–litter	0.1/0.0	15.2/10.3
Shrub–litter	8.3/3.3	37.9/23.9
Litter	4.9/4.9	–
Slash	7.4/7.5	9.7/6.3
Cereal stubble	0.0/0.0	4.7/5.5

Prescribed burning requirements and barriers

During the past two decades, despite increased studies into and communication regarding prescribed burning in southern Europe, its acceptance remains limited (Montiel and Kraus 2010; Fernandes *et al*. 2013). The policies, legislative framework and practices of prescribed burning in southern Europe and their evolution are well documented (Lázaro and Montiel 2010; Montiel and Kraus 2010), as are existing societal concerns and future perspectives and challenges (Fernandes *et al*. 2013).

Cultural and social issues with fire

Obstacles to prescribed burning expansion are varied and important, including public and institutional acceptance, policies adverse to risk, funding, training and available human resources, administrative constraints, land tenure and conservation status, conflicts with other land management activities and assets and weather or climate constraints (Cleaves *et al*. 2000; Fernandes *et al*. 2013). Cultural barriers to fire use and poor social acceptance have

ancient roots, in some cases dating back to the 16th century (Pyne 1982).

The early 20th century need to increase vegetation cover to reduce soil erosion and desertification in the Mediterranean Basin outlawed traditional fire (Métailié 1981; Seijo and Gray 2012; Ascoli and Bovio 2013; Coughlan 2014). The use of fire, including prescribed burning, was limited and, in most cases, hampered by the increasing demand of forest ecosystem services requiring fire protection (e.g. wood production) and a disregard of fire ecology by classical forestry (Fernandes *et al*. 2013; Marino *et al*. 2014). Consequently, fire bans generated social conflicts throughout the 20th and early 21st centuries (Seijo and Gray 2012). Where rural burns have been prohibited or severely restricted, the surreptitious use of fire for range management on days of high fire danger increased. This contributed to wildfires with negative effects on ecosystem services and large socioeconomic impacts, thus strengthening opposition from environmentalists and the general public to the use of fire.

Laws and regulations governing prescribed burning

The legal framework for prescribed fire in southern Europe is quite variable. In France it first appears in the 1992 forestry law (*Loi n° 92-613 du 6 juillet 1992*), which allows land management agencies to conduct prescribed burning for wildfire prevention purposes. However, legislation considering prescribed fire in its full extent did not appear until 2001, although it was preceded by the definition of formal training processes in 1996 (a burn crew leader, 12 days of training) and 1998 (a burn crew element, 5 days of training). The regulation of training activities was completed in 2004, and these are located in two centres in Gardanne (Bouches-du-Rhône) and Bazas (Gironde) and are monitored and assessed by a national committee. In addition, burn certification requires significant operational experience. In France, the framework for prescribed fire is given by a general law (*Loi d'Orientation Forestière* 2001) and supplementary legal documents that address wildfire prevention and the competencies and training of those involved in prescribed burning; prescribed burning can also be subjected to local regulations.

The use of prescribed burning in Portugal preceded formal regulation. Its practice, and the use of fire in fire management operations in general, has been regulated by dedicated legislation since 2006 (*Regulamento do Fogo Técnico*, with the most recent update in 2014), which abides by a 2006 decree (and its subsequent modifications) that established the National System of Forest Protection Against Wildfires.

Prescribed burning legislation and regulation are regional in Spain. Complexity is high, because each region has generated a plethora of legal frameworks and specific fire use and prescribed burning regulations. Some regions (Galicia, Asturias, Castilla y León, Valencia, Andalucía) have forest laws in which the use of fire follows specific annual regulations. Other regions base their regulations on specific ordinances or decrees. In any case, most of these regulations are oriented to control the use of fire and rarely to promote prescribed burning programs.

In Italy, prescribed fire legislation is also a regional responsibility (Bovio and Ascoli 2012). Both regional fire management plans (Italian law on wildfire No. 353/2000) and regional laws provide the legal framework for prescribed burning, mostly in the forestry sector, although some regions regulate prescribed burning in the fire management law. The Campania region enacted a specific prescribed burning law, but it is a unique case. To date, 70% of Italian regions regulate prescribed burning in either a fire management plan or in a regional law. Notably, these regions account for 95% of the area affected by wildfires in the past two decades. However, many regulatory documents still lack clear information on key issues such as liability and detailed authorisation procedures (Bovio and Ascoli 2012).

A positive outlook for prescribed fire development?

Traditional fire use regulation through prescribed burning has lessened conflicts in recent decades. In

central–northern Spain and Portugal, regulations now allow the use of fire under conditions of low fire danger, although the demand for burn permits is higher than the administrative capacity to manage the burns requested by farmers. The traditional use of fire would benefit from rural extension to assist people in their practices, more than from administrative permits and awareness strategies.

The expansion of prescribed fire programs succeeded in changing wildfire regimes into planned burning regimes (e.g. in the French Pyrenees). Increased scientific knowledge (Fernandes 2018), scientific communication on climate change and fire-related issues and recent tragedies caused by fires have increased the acceptance of prescribed burning and pushed for its inclusion on the agenda of European policy makers. Understanding within groups of professionals linked to the forest and nature conservation sectors is evolving in the same direction, albeit slowly. A recent position paper coordinated by the Ministry of Agriculture of Spain (Comité de Lucha contra Incendios Forestales 2019) suggested, for the first time, a role for prescribed burning in forest management and fire hazard mitigation. This is one example of signs of a cultural change that sees prescribed fire as a key element of modern fire management systems throughout southern Europe (Faivre 2018; Moreira *et al*. 2020). However, most national or regional stakeholders in different countries remain far from this understanding, which is visible in the current narratives, particularly in the discourse in relation to actions that enhance or limit pyrodiversity.

Because prescribed burning can be the subject of high levels of controversy and scrutiny (e.g. Davies *et al*. 2016), burn programs should increasingly include systematic, after-the-fact assessment of results and long-term monitoring to document and improve the practice (Van Wagtendonk *et al*. 1982; Pyne *et al*. 1996). Methods and tools for such assessment and long-term monitoring, including from a scientific perspective, include user surveys (Sando 1969; Cleaves *et al*. 2000; Haines *et al*. 2001; Quinn-Davidson and Varner 2012), operational data collection (Czuhai and Cushwa 1968; Fernandes and Botelho 2004), monitoring of permanent plots (Ewell and Nichols 1983; Keifer 1998; Waring *et al*. 2016) and remote sensing (Yallop *et al*. 2006; Allen *et al*. 2016).

Getting fire on the ground

Prescribed burning in southern Europe is a practice that varies substantially among and within countries. People with different backgrounds and from distinct organisations use fire to accomplish variable goals in specific ecosystems. However, the small scale of the operations is shared by all, and is a distinctive feature compared with the relatively large organisations that manage fire on public land and on broader scales in North America and Australia.

Burn seasonality and prescribed weather

Prescribed burning in southern Europe follows the Mediterranean climate seasonality. Thus, most activity takes place between October and May, before the summer wildfire season, when fire use of any kind is banned. However, regional specificities are possible, particularly in mountain regions where a winter fire season can occur. A certain amount of prescribed burning takes place in late spring, with the potential to increase soil heating and litter consumption (and hence soil erosion) in case of a dry spring (Stoof *et al*. 2013).

Prescribed fire operations in Portugal are conducted mostly from October to May, with an emphasis during the February–April period (Figure 13.2). In Catalonia, prescribed burning can be conducted in any month of the year, but February and March are the main months. In the rest of Spain, the prescribed fire season is from late autumn to spring. As in Portugal, burn operations conducted by the EPRIF crews occur mostly (76% of the total number) in February–April. Prescribed fire operations in France occur during winter and spring, but can also occur in the autumn months in the Maritime Alps, Haute-Garonne, Eastern

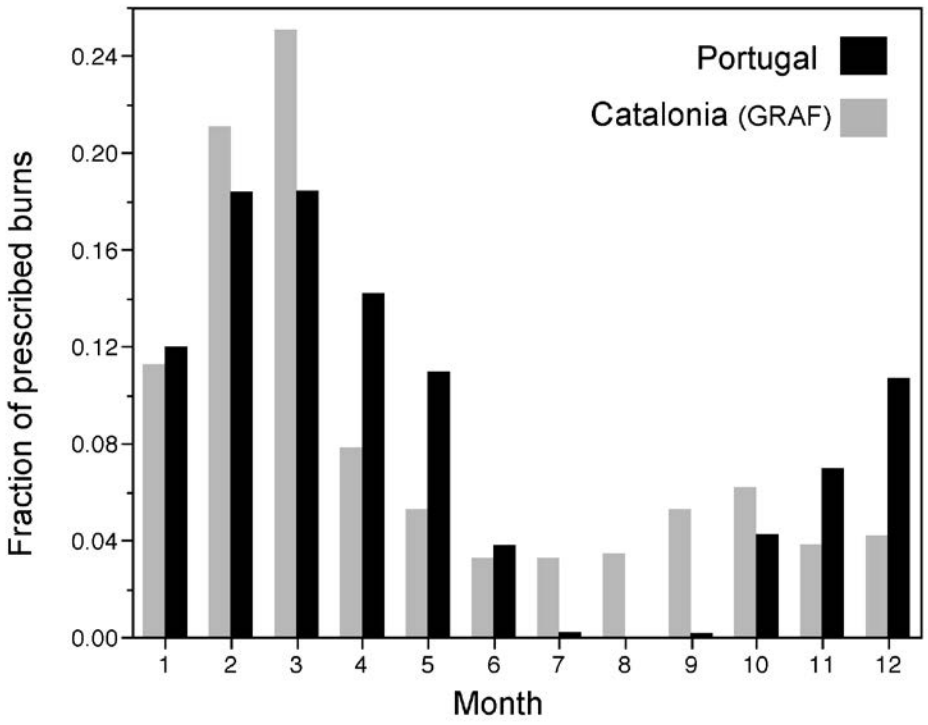

Figure 13.2: Monthly distribution of prescribed burning operations in Portugal (2006–19) and Catalonia (1998–2017).

Pyrenees, Corse and Landes de Gascogne. Finally, prescribed fire in Italy occurs from autumn to spring, except in Piemont (autumn–winter).

Burn prescriptions in Europe are variable, ranging from generic windows for broad objectives to site-specific windows for specific objectives. More often than not, prescribed fire users monitor local weather conditions, the fire danger rating and larger-scale forecasts and their effects on fuel moisture content to comply with generic burning windows.

A set of burn prescriptions for European ecosystems has been developed based on an analysis and compilation of existing burning guides and best practices, prescriptions from the agencies and individuals involved in burn management or research in Europe and the use of fire behaviour and effects models to help attain specific treatment goals (Fernandes and Loureiro 2010). Prescription windows vary markedly according to management goals and vegetation structure, but only approximately 10% of the prescriptions are lower or higher than 25 (km h^{-1} [wind speed], °C [ambient temperature], % [relative humidity] or the duff moisture code of the Canadian Fire Weather Index or FWI]; Figure 13.3). Thus, prescribed fire in Europe proceeds under mild weather conditions and, in general, shortly (up to 2–4 weeks) after rain. Optimum burn conditions typically combine an air temperature of 8–16°C and a relative humidity of 40–65% under steady surface wind speeds of 4–12 km h^{-1}.

Burn size and spatial patterns

Burn operations are relatively small and spatially scattered in the Mediterranean Basin. Approximately half the burns in both Portugal and Spain are smaller than 5 ha. In Spain (EPRIF), only 19% of burns exceed 10 ha; in Portugal, 10% of burns exceed 20 ha; and in Catalonia 10% of burns exceed 10 ha. Similarly, treatment units in Italy are <5 ha (Piemonte, Toscana) and <10 ha (Campania, Sardegna). Maximum recorded sizes of individual burn operations are 146 ha in Portugal, 128 ha in Spain (EPRIF) and 67 ha in Catalonia (GRAF), with

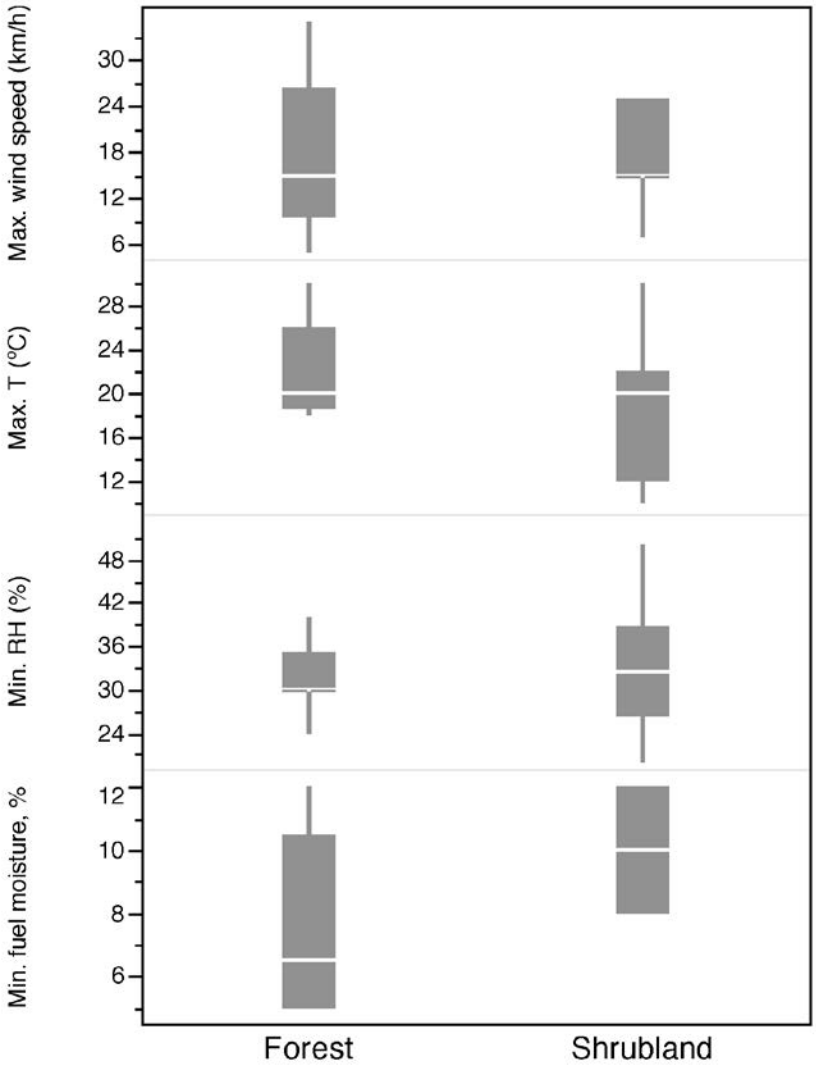

Figure 13.3: Box plots for weather-related variables in the compilation of European burning prescriptions of Fernandes and Loureiro (2010). Whiskers indicate the 10th and 90th percentiles, boxes indicate the 25th–75th percentiles and white horizontal lines indicate the 50th percentile. RH, relative humidity; T, temperature.

a maximum size of 179 ha mentioned by Lambert (2010) for the Eastern Pyrenees in France.

In Spain (EPRIF), the annual mean burn size is 6.8 ha with little interannual variation. In France, the annual mean burn size decreased by almost half within the period 2001–19, reaching approximately 10 ha, which is viewed as a refinement of prescribed fire implementation. Burn operations increase in size from Catalonia to Portugal and from Portugal to France, and those conducted in shrubland and grassland are twice the size of the fires conducted for forest underburning (Table 13.3). Mean treatment size in Portugal is similar in shrubland, pine forest without an understorey (an hence lower potential fire intensity) and post-harvest slash fuels.

By way of comparison, the mean prescribed burn size on US federal land is 34.5 ha (Barnett *et al*. 2016), which is three- to sevenfold greater than that in the European Mediterranean Basin. In

Table 13.3. Mean prescribed fire size (ha) by fuel type

Fuel type	Portugal	Catalonia (GRAF)	France
Grassland	1.27	7.17	–
Shrubland	8.48	5.19	11.54
Forest	4.93	2.13	5.23
Grass–litter	–	2.25	
Shrub–litter	3.59	2.09	
Litter	9.18	–	
Slash	7.56	2.15	
Cereal stubble	–	3.92	

south-western Australia, the annual prescribed burning rate in public forest is 6.6% of the total area (vs 1.1% burned by wildfire; Burrows and McCaw 2013), exceeding that in the Eastern Pyrenees by a factor of 10. The small scale of prescribed burning in southern Europe, in terms of both the size of the treatment units and the treatment effort, implies that most burn units are dispersed in the landscape and account for a small fraction of the potentially treatable area. However, at subregional to local scales, the landscape imprint of prescribed fire history is noticeable. Such is the case of the Eastern Pyrenees in southern France, where prescribed burning is mostly used to maintain or restore rangelands. Long-term use of prescribed fire in the region produced a small-grained mosaic of vegetation patches, which is generally viewed as beneficial for both wildfire hazard reduction and biodiversity (Lambert 2010).

In Catalonia (GRAF), 47% of the total number of prescribed fires are designed as 'strategic management points' (i.e. the treatment is applied to specific locations that are expected to block or delay the spread of a subsequent wildfire; Madrigal *et al*. 2019). Most patches shown in Figure 13.4 reflect this strategy. In Portugal, burn units vary in shape in forests, but tend to be more linear in shrubland, corresponding to fuel breaks (up to 200 m wide).

Burn planning and evaluation

Management of prescribed fire activity varies widely across southern Europe. Managers can use different tools to help with decisions regarding where, when and how to burn. In particular, plot-, stand- or landscape-level fire behaviour simulators are available, including those developed by the USDA Forest Service, based on Rothermel's fire spread model and the assignment of fuel models to typify fuel conditions (Finney 2006; Andrews 2014). Empirically based burning guides and applications developed in Europe, such as PiroPinus (Fernandes *et al*. 2012) and FireGlobulus (Pinto *et al*. 2014), allow site-specific development of prescriptions and simulation of fire behaviour and effects, unlike tools requiring fuel models. Prescribed fire planning in most of Spain makes use of fire behaviour modelling tools, and training on the use of such tools is standard in Portugal; however, French users of prescribed fire do not rely on fire behaviour simulation (Rigolot 1993). In Portugal, an online platform (CeaseFire) is available that maps whether or not, and to what extent, generic prescriptions are met over subsequent days and the whole country based on forecasts of the Canadian FWI (Fernandes 2018).

Spatial planning of prescribed burning based on fire modelling is useful for optimising treatment locations when the objective is fire hazard reduction. For example, FlamMap (Finney 2007) identifies major wildfire travel routes using a minimum travel time algorithm and proposes treatments for the locations that disrupt fire spread the most. This approach is customary in Catalonia (GRAF), but only occasionally used elsewhere in Europe.

Prescribed fire planning in the landscape occurs on an annual (France, Spain, Italy) to multi-annual (Portugal) scale. As in other countries around the world, an operational burn plan includes a map, the firing pattern, holding strategy, a contingency plan and a notification checklist; it may also include a complexity analysis. The degree to which these elements are developed depends on organisational structure, burn size and complexity and perceived risk.

Portugal and France have implemented systems to collect burn data and monitor practitioners' activity respectively through the Instituto da Conservação da Natureza e das Florestas (ICNF;

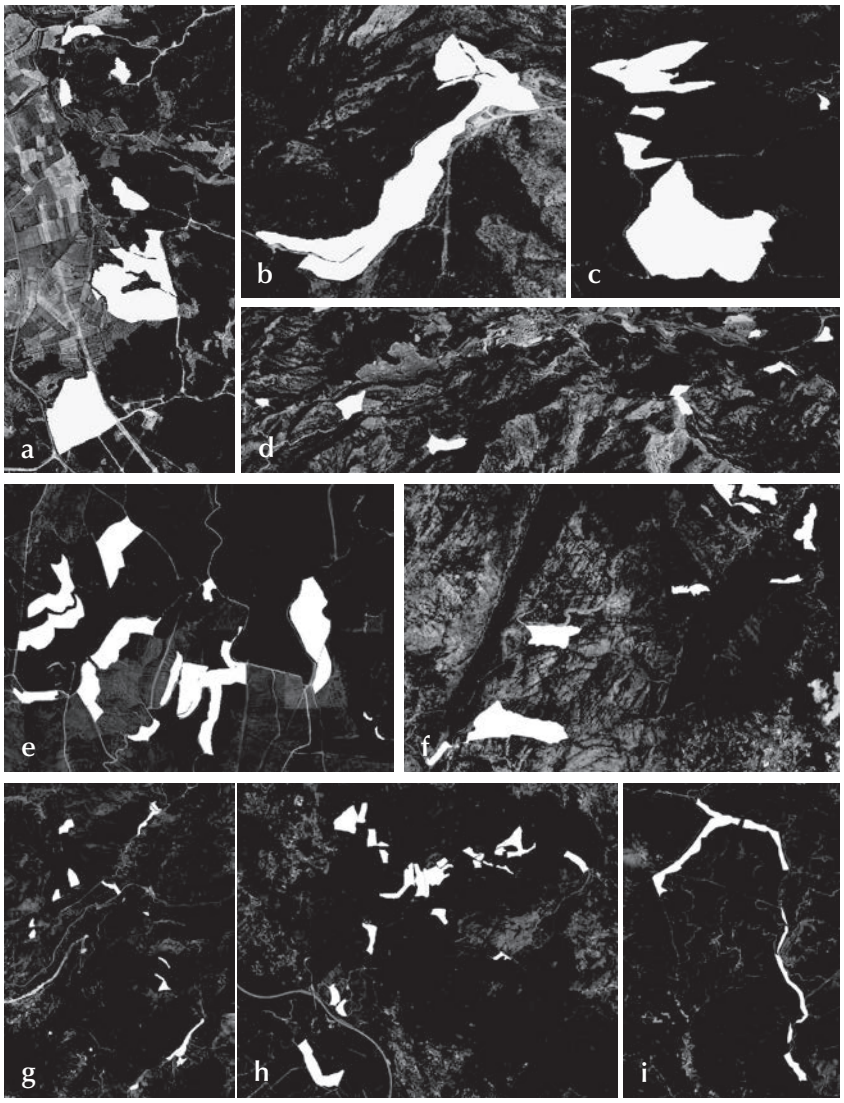

Figure 13.4: Examples of spatial patterns of prescribed fire in (a–d) Catalonia and (e–i) Portugal. The scale is variable and treatment units are overlaid on Google Earth imagery as white patches. Data were obtained from official databases (http://interior.gencat.cat/ca/arees_dactuacio/bombers/ for Catalonia; supplied by the Instituto da Conservação da Natureza e das Florestas [Forest Service] for Portugal).

Forest Service) and a national prescribed burning network that periodically gathers to share experiences. A knowledge-based system and a relational database are used in France to collect and organise information (Rigolot *et al*. 1998). The major challenge of meeting annual planning targets relates to the constraints imposed by scarce resources and weather opportunities. Statistics for France (2001–15) are illustrative of the existing difficulties, where the estimated number of annual burn days for each burn team, based on normal climatology, varied between 20 and 83. However, on average, burn operations took place on just 58% of those days, with the mean annual number of burn days per team varying between 7 and 18 (averaging 10) and only half the target area burned (range 33–72%).

In Portugal, prescribed fire reporting includes an assessment of whether treatment objectives were met and, if so, to what extent. For the 2006–15

period, the accomplishment of burn objectives was overwhelmingly (93%) classified as very good or good. This is a far more optimistic assessment than previously found for the 1980s–1990s (Fernandes and Botelho 2004), and it should reflect improved procedures but probably suffers from self-assessment bias.

Costs are an important component of the evaluation of prescribed burning. In France, an important cost factor is whether the burn is a first entry or a maintenance operation, the former being costlier. Portuguese surrogate data for costs (personnel and equipment used; data on file at Universidade de Trás-os-Montes e Alto Douro [UTAD] from ICNF records) offer some insights into what drives burn costs. The amount of human resources and vehicles used in burn operations in Portugal is poorly correlated with burn size. This implies that increasingly larger burn units will be increasingly less costly to treat.

Burn operations

Burn units are delimited as much as possible by existing natural or man-made barriers to fire spread (e.g. rock outcrops, non-flammable vegetation, snow [common in the Pyrenees], fuel breaks, roads and tracks). However, additional work has to be undertaken to establish control lines, which is done manually or mechanically or by creating wet lines or blacklines. In Spain, preparation costs associated with control lines accounts for 41% of the total operational cost, followed by ignition costs (36%) and extinction costs (23%; González-Pan 2012). Control lines are at least 1 m wide and are wider in shrubland than in forest, often following a rule of thumb that the width of the control line should be at least twice the height of the vegetation.

The areas selected for treatment can be divided in small plots of 1–5 ha that are burned on different days according to the prescription window. The burn crew includes a burn boss and one or more people igniting the fire using drip torches, depending on burn size and subdivision. However, the overall organisation and the amount and type of equipment used vary and can be minimal. In Spain, all people involved in prescribed burns are professional specialised wildland firefighters following the Incident Command System and equipped with international standard individual security equipment; logistic and suppression sections are established to contain possible fire escape and at least one fire engine is available for possible contingencies.

In Portugal, different organisations often cooperate in a given burn, which allows scaling-up and provides learning and training opportunities. A complete burn team is composed of a burn boss, a holding boss and the corresponding holding crew(s), a lookout and several drip torch operators. However, in low-complexity operations and when available resources are scarce, a burn can be conducted with just one burn boss and a holding crew; in these situations, the burn boss performs all tasks other than holding the fire, although sometimes members of the holding crew operate the drip torches.

Figure 13.5 shows examples of prescribed burn operations in southern Europe. The firing patterns used in prescribed burning in Europe are very much a function of vegetation type and safety concerns. Conservative ignition techniques are used in forest (i.e. downslope and against the wind or strip-head firing at short distances between consecutive ignition lines). The same methods are used in open vegetation, but often are extended to include more aggressive ignition patterns, namely head firing and ring ignition, provided that the likelihood of fire escape is minimal. Fire behaviour characteristics follow these options and the inherent environmental conditions of wind speed, fuel moisture, fuel load and structure and slope. Although flame lengths of 0.2–1.2 m and spread rates of 20–60 m h^{-1} are preferred in pine stands, these variables can be higher by one order of magnitude in shrubland (Fernandes and Loureiro 2010). Lower fire intensities than in pine forest are advised for thin-barked broadleaved trees (e.g. in short-rotation eucalypt plantations; Pinto *et al.* 2014), but the routine use of prescribed fire in those

Figure 13.5: Examples of prescribed burning in Europe: (a) in a *Pinus pinaster* stand in Soria (Northern Plateau), Spain, conducted by the Lubia BRIF (Reinforcement Brigade against Forest Fire) to reduce fuels; (b) in *Cytisus oromediterraneus* shrubland in the Eastern Pyrenees for habitat management, and where the presence of snow often implies fire patchiness and circumvents the need to prepare firebreaks; (c) in grass–heather in the Apennine Mountains of Italy to preserve *Vaccinium myrtillus* for fruit production; (d) in a young *Pinus nigra* plantation in northern Portugal with dense dry heathland to establish a fuel break and where high tree mortality is expected due to stand age; and (e) *Pinus canariensis* after underburning in Gran Canaria, Spain. This species is highly resistant to fire due to its thick bark and resprouting traits. (f) Prescribed fire can be challenging in Mediterranean shrubland types, such as *Cistus ladanifer* in southern Portugal, given the lack of elevated dead fuel. Back burning was used in all cases shown, except in the *P. pinaster* stand in Soria (a), where strip headfiring was used. Photographs taken by the authors: J. Madrigal (a), P. M. Fernandes (b, d, e), D. Ascoli (c) and N. G. Guiomar (f).

settings and the recommended procedures are still emerging.

In recent years, there have been new opportunities to introduce or expand the use of fire to forest and fire management agencies in Spain and Portugal. As wildland fire fighting systems evolve, the ability to use fire in fire suppression settings becomes manifest, as does the need to train people for such purposes. This has the potential of increasing the acceptance of prescribed burning, and Catalonia is a good example of such a process. In Portugal, where certified burn personnel are being trained (since 2014) to support both prescribed fire and suppression fire technicians, there has been a rising trend in the use of burn operations to exercise the use of fire as a suppression tool. The introduction in Europe of Prescribed Fire Training Exchanges (TREX) training camps (in 2017 in Portugal and in 2019 in Spain), plus other international cooperation initiatives, has allowed for the exchange of experiences and facilitated the accreditation of professionals and organisations in the use of fire.

Future of prescribed burning in Mediterranean Europe

The fact that proper, 'complete' regulation frameworks for prescribed burning exist only in France and Portugal indicates that prescribed burning is better established in these countries and mirrors the current state of development and acceptance of the practice in southern Europe. The degree of implementation of prescribed burning is limited, as indicated by the size of the treatment units and, in particular, the extent of the areas treated. Nonetheless, prescribed burning in south-western Europe is a relevant practice at subregional to local scales.

If traditional burning (Figure 13.6) is accepted as a legitimate practice (i.e. complying with an acceptable prescription), then its effects could be

Figure 13.6: Fires larger than 20 ha in Portugal, northern Spain and the French Pyrenees during the autumn–winter of 2019–20 (from 1 October 2019 to 31 March 2020), mapped by the COPERNICUS Emergency Management System for the European Forest Fire Information System (EFFIS; https://effis.jrc.ec.europa.eu). Most fires correspond to pastoral burning, but prescribed fires are also shown.

assumed equivalent to formal prescribed burning practices and thus contribute to treated area statistics. For example, approximately 4000 ha of shrubland burns, on average, in Portugal every year under weather conditions consistent with prescribed burning (data on file at UTAD based on ICNF records). Portuguese legislation now allows unplanned fires to be treated as management fires if they occur under prescribed conditions. However, this requires more than a change in doctrine or legislation: it requires time for a change in defining the priorities established for fire fighters and to internalise that change, as well as training to support conscious decisions. In the Pyrenees, prescribed burning teams increasingly support traditional burning practices and limit their own activity to the most difficult burn operations (Fernandes *et al*. 2013). Integration of conventional prescribed fire technology with traditional ecological knowledge has the potential to decrease conflicts between local communities and resource managers (Ray *et al*. 2012).

Open vegetation types are the main burn targets in southern Europe due to the existing barriers to applying fire in forests, as well as because of the land cover and land management context. And yet, in fire-prone regions where hazard reduction is an important concern, forests are generally more valued than shrubland, and prescribed burning is expected to be more effective in the former (Fernandes 2015). More awareness and knowledge transfer are needed regarding prescribed burning in forest (Fernandes 2018).

The spatial features of prescribed burning indicate how the practice affects landscape structure and the potential for the spread of large fires. Where the prescribed burning effort is large enough to create a consistent fuel age mosaic (e.g. Eastern Pyrenees), wildfire spread should be substantially constrained. Otherwise, current spatial patterns of prescribed burning in Europe are not likely to be effective at disrupting the growth of large fires (Davim *et al*. 2021), even if fire behaviour and fire severity are mitigated (Fernandes 2015; Espinosa *et al*. 2019), because prescribed burning projects are very localised and the effect of treatments in blocking or delaying wildfire spread is seldom replicated or supplemented by nearby treatments (Finney 2007). The Catalonian practice of treating 'strategic points' is suggestive of a low cost-to-benefit ratio, but this warrants further research, including determination of the leverage effect of prescribed burning on wildfire extent (Price *et al*. 2015).

Current management of prescribed burning operations is quite heterogeneous across Europe, but the procedures seem poorly developed compared with overseas practices. The need for better prescribed burning management will only increase if the practice expands, but further progress is desirable under the current situation, specifically through the increased use of decision-support tools. There is room for improvement in spatial planning, weather monitoring and forecasting, exploitation of burning opportunities, compliance with burn prescriptions and optimisation of costs. Costs are determined mostly by human resources management and would strongly benefit from larger prescribed burning units, which, in turn, would increase the effect on wildfire extent. The current inability to attain treatment area targets is a flagrant example of the need to improve planning: given the limited work force available for prescribed burning, it is crucial that burning opportunities (as defined by the prescribed weather conditions) are fully taken advantage of through close monitoring of forecasts and fire danger ratings, combined with flexibility (i.e. prescribed burning should be a top priority activity on suitable days).

Prescribed burning has attracted increased interest during the current decade, but so far this has not translated into substantially more area being treated. Such an increase in burn effort is unlikely as long as fire management policies are reactive and dominated by activities in the realm of pre-suppression and suppression (Moreira *et al*. 2020). Until then, societal concerns with smoke production and burn impacts on ecosystem services, namely biodiversity, carbon and water, will be minimal, with the potential side effect of

neglecting improved planning and evaluation procedures. If prescribed fire monitoring is inadequate, then its shortcomings and opportunities for improvement will not be identified, and adaptive management informed by sound scientific evidence (Fernandes *et al*. 2013; Davies *et al*. 2016) will not be implemented. Wildfire threats under climate change are increasingly recognised in Europe, particularly after the marked effects of wildfires in Portugal in 2017 and in Greece in 2018, and unprecedented fire seasons in Siberia, South America, south-eastern Australia and California in 2019 and 2020. Media attention and public opinion on fire issues will increase attention on and expectations of prescribed burning, creating opportunities and challenges for its future development in Mediterranean Europe.

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