Current Wildland Fire Patterns and Challenges in Europe: A Synthesis of National Perspectives

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ABSTRACT: Changes in climate, land use, and land management impact the occurrence and severity of wildland fires in many parts of the world. This is particularly evident in Europe, where ongoing changes in land use have strongly modified fire patterns over the last decades. Although satellite data by the European Forest Fire Information System provide large-scale wildland fire statistics across European countries, there is still a crucial need to collect and summarize in-depth local analysis and understanding of the wildland fire condition and associated challenges across Europe. This article aims to provide a general overview of the current wildland fire patterns and challenges as perceived by national representatives, supplemented by national fire statistics (2009–2018) across Europe. For each of the 31 countries included, we present a perspective authored by scientists or practitioners from each respective country, representing a wide range of disciplines and cultural backgrounds. The authors were selected from members of the COST Action "Fire and the Earth System: Science & Society" funded by the European Commission with the aim to share knowledge and improve communication about wildland fire. Where relevant, a brief overview of key studies, particular wildland fire challenges a country is facing, and an overview of notable recent fire events are also presented. Key perceived challenges included (1) the lack of consistent and detailed records for wildland fire events, within and across countries, (2) an increase in wildland fires that pose a risk to properties and human life due to high population densities and sprawl into forested regions, and (3) the view that, irrespective of changes in management, climate change is likely to increase the frequency and impact of wildland fires in the coming decades. Addressing challenge (1) will not only be valuable in advancing national and pan-European wildland fire management strategies, but also in evaluating perceptions (2) and (3) against more robust quantitative evidence.

KEYWORDS: wildland fire, society, Europe, perceptions

TYPE: Review

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Introduction

Wildland fires have been an integral part of many of the Earth's ecosystems throughout much of their evolution (Pausas & Keeley, 2019) but are also considered as one of the most dangerous "natural disasters" to human societies (Doerr & Santin, 2016). The occurrence of fire is essential in the continuation of many live cycles and in maintaining the natural diversity of many ecosystems (Pausas & Keeley, 2019). Yet in Europe, millennia of intensive agricultural and silvicultural activity, the use of fire as a land management tool, additional ignitions by other human activities as well as very effective fire suppression, has left its regions with a complex pattern of land-covers and fire occurrence that shows little if any resemblance of a natural fire regime (Santín & Doerr, 2016).

In some regions of Europe, the probability and severity of wildland fire is increasing (European Environment Agency, 2017). This is due to several factors, including a decrease in farming activities, population aging, and the decrease in the exploitation of timber and wood resources (Moreira et al., 2011). In addition climate projections suggest (1) substantial warming and increases in the number of heatwaves and (2) droughts and dry spells across most of southern Europe, increasing both the length and the severity of the fire season (Wu et al., 2015).

Due to their prevalence in southern European countries, the behavior and consequences of wildland fires have been particularly studied in these regions for many decades; in some cases with the direct participation of the stakeholders (Champ et al., 2012). More recently researchers in most of the European countries are joining the effort to understand and support manager on the control of wildland fires. This may have in part been driven by an increase of the spent budget (European Commission, n.d.) and an increasing trend in the area burned observed for Eastern Europe (European Commission & Joint Research Centre, 2014), a trend that is expected to continue to increase due to global warming and land abandonment in agriculture area and in plantations for timber production purposes. In Northern Europe, extensive fires have occurred in recent years (European Environment Agency, 2019; Krikken et al., 2019) accelerating research efforts in its regions.

To evaluate and share information about wildland fires across Europe, many of its countries have collected information on wildland fires since the 1970s. However, the lack of harmonized information has hindered its analysis, evaluation, and a common approach to wildland fire management (San-Miguel-Ayanz et al., 2012). Accurate and reliable comparisons between countries are not possible due to the differences in the information from the European countries concerning: (1) quality of fire-cause investigation; (2) the heterogeneity of national classifications, concerning causes of fire categories, the classification criteria, and the level of detail; (3) length of time of national databases; and (4) a restrictive European wildland fire classification scheme (Tedim et al., 2015).

Apart from reports by the Global Fire Monitoring Center (Fire Ecology Research Group, n.d.), the most comprehensive European effort that has been conducted to date is the European Forest Information System (EFFIS, n.d.), a joint collaboration between the European Commission and the European countries. This is a large repository of information on individual wildland fires in Europe, where 43 contributing countries (26 European Union [EU] member states, 12 European non-EU, and 5 countries from Middle East and North Africa) provide every year a common set of data on wildland fires such as time of the fire, locations of fire, size of the fire, and cause of the fire. However, each country still has its own national rules to report individual fire events, which differ between countries, making direct comparisons, and analyses of fire events difficult.

To facilitate the exchange of information on wildland fire across Europe the COST action FIRElinks (CA18135; https://firelinks.eu) was established in 2018. It is an open, EU-spanning network for researchers, practitioners, policymakers, and stakeholders involved in wildland fire research and land management, facilitating the discussion of diverse experiences and the emergence of new approaches to fire research. The participation of most European countries in this network provided the unique opportunity to collate national data and personal perspectives of the wildland fire situation and associated future challenges from representatives of 31 countries across Europe.

The aim of this article is therefore to provide a general overview of the diverse wildland fire patterns and challenges across Europe. For each of the 31 countries, we present a perspective authored by a scientists or practitioner from each respective country, representing a wide range of disciplines and cultural backgrounds. This is accompanied for each country by a summary of national fire statistics for the period 2009–2018. Where relevant, key studies and notable fire events are also highlighted. This is followed by a synthesis of the diverse characteristics and perceived challenges, and suggestions for future research directions associated with wildland fire among the European countries covered here.

Materials and Methods

Each country representative was tasked with providing (1) an overview of current (as of April 2020) wildland fire patterns and challenges in their country including particularly noteworthy events, and relevant key studies, and (2) data from annual wildland fire statistics collected by the relevant national authority for the years 2009–2018 on the total number of fires and the total area burned (where available; see Supplementary Table 1 for further details). Where not available, annual data from EFFIS for the same period are provided. It should be noted that the national methods for recording fires vary between countries. Where EFFIS data are shown, this will only include fire events exceeding ca. 30 ha in size (San-Miguel-Ayanz et al., 2012). The data provided in the Supplementary Table 1 should therefore be seen as indicative rather than directly comparable. The national perspectives are presented in alphabetical order by country. They follow an overall common format where bio-geographical and climatic country characteristics are present, followed as appropriate, by information on historical as well as currently dominant wildland fire situation, highlighting also particularly noteworthy events and key challenges.

National Data and Perspectives on Wildland Fire

Austria

Austria is a Central European Alpine country with a forest cover primarily dominated by coniferous tree species. It has a total land area of 8.4 m ha, and approximately 4.0 m ha is forested land (47.6%). According to the national forest inventory, Austria has 3.4 billion trees with 65 tree species (Bundesforschungszentrum für Wald, 2020). Austrian forests are currently not considered as particularly fire-prone ecosystems, as wildland fires play no major role compared to the damages and costs caused by other natural disturbances, for example, storm events or bark beetle outbreaks (Müller & Vacik, 2017). Nevertheless, the summer seasons of 2003, 2013, and 2015 have demonstrated that wildland fires can be widespread, indicating that they might become a more important issue in the near future. Although Austria has not been susceptible to widespread wildland fires so far, international studies warn that the area burned will increase in the future under changing climate (Khabarov et al., 2016).

The high population density together with the highly developed infrastructure, the eminent significance of tourism and other human activities play a significant role in wildland fire ignition throughout the country. The major causes of anthropogenic wildland fires range from controlled burns getting out of control, sparks from train brakes, to arson and cigarettes (Vacik et al., 2011). However, natural ignitions caused by lightning are also an important factor. In the summer months, up to 50% of wildland fires can be ignited by lightning strikes. The Austrian wildland fire database includes more than 5000 wildland fire incidents, with almost complete documentation of the last 25 years (Vacik et al., 2011). In recent fire seasons, around 200 wildland fires and a mean area burned of 60 ha were recorded per year. Almost 95% of wildland fires in Austria do not last more than 1 day or exceed an area burned of 5 ha. The quick extinction is possible due to a high settlement density and an early notification of fire brigades in the case of a fire. The legal competence for firefighting lies with individual municipalities. A high number of voluntary firefighters (>340,000) and fire brigades (>4500) in Austria supports a rapid response rate. Also, the high density of forest roads, which are suitable for heavy firefighting trucks, allows the rapid arrival of firefighters at the fire site. If necessary, extinguishing lines are established or helicopters are requested for support, especially in difficult or inaccessible terrain.

Belgium

Currently, about 23% of Belgium's territory, or 693,000 ha, is covered by forests. The forested area is distributed unevenly across the country as the Walloon Region, which makes up the southern part of the country, is covered by about 545,000 ha, whereas the Flemish and Brussels Region account for 146,000 ha and 2000 ha, respectively (Tallier et al., 2018). In the southern part of the country, forests typically consist of Norway spruce (*Picea abies*) plantations, and oak (*Quercus sp.*) and beech (*Fagus sylvatica*) stands. The latter two species are also dominating forests in central Belgium, but in the northern part of the country Scots pine (*Pinus sylvestris*) and mixed forests are the most common.

Given its temperate maritime climate, wildland fires are relatively rare in Belgium and are typically smaller than 500 ha, though a wildland fire of more than 1000 ha was recorded in 2011 and altogether more than 2300 ha burned that year. Considering wildland fires between 2008 and 2018, most of them were recorded between April and August during periods of drought and high temperatures. This temporal pattern can be explained because April is the month with the lowest amount of precipitation (Journée et al., 2015), while the consecutive months are characterized by relatively high temperatures. The spatial wildland fire distribution does not match the forest distribution, as most wildland fires have been recorded in the Flemish Region, although the forest area in the Walloon Region is three times larger than in the former. This can be explained by the presence of heathland and Scots pine stands on the poor, sandy soils in the eastern part of the Flemish Region (Provinces of Antwerp and Limburg) (Hermy et al., 2004), which are especially vulnerable to droughts.

In the aftermath of the major wildland fires in 2011, the Federal Public Service Interior (2013) launched a national action plan on wildland fires to evaluate and improve the risk analysis and cartography, materials, procedures and training, emergency planning, and exercises related to the outbreak of wildland fires. Among other things, this national action plan resulted in the compilation of a data-based wildland fire risk map for the entire territory of Belgium (Depicker et al., 2020), based on land-cover, land use, soil, and historical wildland fire data. This map can be used to identify high-risk areas, optimize resource allocation, and increase preparedness for the projected northward expansion of the zones at moderate fire danger in Europe (de Rigo et al., 2017).

Despite the aforementioned national action plan, many issues remain because wildland fires in Belgium are not high on the priority list as they rarely occur. For instance, wildland fires are not always properly recorded, especially in the case of minor events, area burned is typically recorded only for major events, and the exact location is often lacking.

Bosnia Herzegovina

The total area of Bosnia Herzegovina is 5.1 m ha, where the Federation of Bosnia and Herzegovina's (FBiH) total area is 2.6 m ha (51%) and Republika Srpska's RS is 2.5 m ha (49%). The forest cover of FBiH is 1,465,600 ha or 56.2% of FBiH total area, while forest cover of the RS is 1,282,412 ha or 51.7% of RS total area (Ministry of Foreign Affairs and Economic Relations of Bosnia and Herzegovina, 2018). Fire occurrence in BiH is seasonal with maxima in March and secondary peak in August. Both, drought periods over the summer and human influence have increased the number of wildland fires in the last decades. For example rural abandonment contributes to weed expansion, vegetation succession, and conversion of cropland into shrubland, making some areas highly vulnerable to wildland fires (Kapović Solomun et al., 2018). This is a common problem in post-conflict societies such FBiH.

Bulgaria

Forest territories in Bulgaria occupy about 4.150 m ha (37% of the total area), with 71% of deciduous and 29% of coniferous forests. Forests dominated by *Quercus* sp. prevailed (35.5%), followed by *Fagus sylvatica* (16.5%) and *Pinus sylvestris* (14.9%). About 75% of forests in the country are owned by the state from which by State Forestry Agency about 70% and by Ministry of Environment about 4% and for training forestry <1%. The rest (25%) are forest territories owned by municipalities (13%), private and legal entities (11%), religious organizations, and forests on former agricultural lands (Ministry of Agriculture and Foods, 2019).

According to the Executive Forest Agency (Ministry of Agriculture Food and the Forestry, 2019) database in 2018, the number of wildland fires in Bulgaria was 222 with an estimated area burned of 1453 ha, of which 19.7 ha was burned by crown fires. The average size per wildland fire in 2018 was 6.5 ha, while the biggest wildland fire was a ground fire and affected 617.7 ha of area. The largest number and area burned by wildland fires were reported in Regional Forest Directorate (RFD) Lovech with 20 fires and 667.3 ha, RFD Berkovitsa with 12 and 419.1 ha and RFD Blagoevgrad with 36 and 101.2 ha, respectively. Over 80% of all burned forest areas in the country are concentrated in these three RFDs.

By comparison with the average annual burned forest territories in the country of nearly 9000 ha with an average number of 560 wildland fires in the period 2007–2017(San-Miguel-Ayanz et al., 2019), 2018 ranks second after 2014 and is among the years with the most detailed statistics on burned forest areas and the number of wildland fires occurring.

Croatia

Wildland fires in Croatia can occur naturally; however, in recent decades, their occurrence has an obvious human signature, where 95% of fires occur from human cause (Kisić, 2019). Fires occur in all Croatian territory, although the most affected region are the mid-Adriatic coast and islands. From 1998 to 2008, out of all the wildland fires in Croatia, 31.7% were recorded in the Dalmatia region (Croatian Mediterranean area that consists of four Croatian counties). Dalmatia has as much as 64.3% of the areas burned of Croatia, with half (50.2%) of these areas being covered by coppice forests, shrubs, garrigues, and thickets (Mamut, 2011). These fires do not only affect vegetation and soil but also have socioeconomic impacts. The fire seasons of 2000, 2003, 2007, 2011, 2012, and 2017 were particularly impactful, mostly due to extremely high summer temperatures when the Adriatic coast was hit by several consecutive heat waves with strong winds and low relative humidity.

Catastrophic wildland fires in Croatia occur due to several reasons: strong wind types such as *Bura* (NE), *Jugo* (*SE*), and *Maestral* (NW); fuel accumulation (afforestation, land abandonment, including mine-affected land, and invasion of allochthones plant species) and the spread of "imported" wildland fires from neighboring countries. Fires often start in rural areas during April when agricultural activities increase (Kisić, 2019), while the second maximum occurs in the hot and dry summer on Islands and the coastline as a consequence of tourists visiting the densely spaced conifer forests (Stipaničev et al., 2007).

Helicopters are the primary aircraft used to fight wildland fires (Keating et al., 2012). However, a serious problem of fire suppression in Dalmatia is the access to fresh water. Seawater is therefore used for wildland fire suppression which can changes soil chemical properties. However, only a few studies in Croatia have been carried out on wildland fire impacts on the environment (Pavlek et al., 2017) and detailed studies on socioeconomic impacts are currently scarce.

Cyprus

Cyprus is the third largest island in the Mediterranean Sea, with a land area of ~925,000 ha. Its cool, wet winters and hot, dry summers combined with a long history of human influence, favor the occurrence of frequent wildland fires (Agee, 1998; Boustras et al., 2008). Cyprus ranks second among 24 European countries when the total area burned is divided by the countries' surface area (EFFIS, n.d.). Total forested and wooded land in 2015 was reported to be 386,190 ha, 28% of which is state forest, 14% is private forest and 50% is maquis and garigue vegetation (The Food and Agricultural Organization of the United Nations, 2015).

Several government agencies are involved in the suppression of fires, in particular the Fire Service and the Department of Forests and the Civil Defense Force (Boustras et al., 2008). The national institutional framework for wildland fires management, as well as the duties and responsibilities of all bodies involved in firefighting, are specified in the Forest Law and the Fire Fighting Action Plan in Rural Areas (Cyprus Department of Forests, 2019). According to these, the legal, administrative, and technical responsibility for extinguishing wildland fires lies with the Department of Forests of the Ministry of Agriculture, Rural Development, and Environment. Wildland fires are defined as fires starting or spreading inside state forest land, or within two kilometers from state forest boundaries, or fires that upon the judgment of the Director of the Department of Forests may pose danger for state forest land. Despite the importance of wildland fires in Cyprus, limited relevant research has been conducted in Cyprus. A total of 17 scientific papers appear in the Scopus database, which focus on wildland fires in Cyprus (searched words: "Fire" AND "Cyprus"). Remarkably, only five of these papers had the first author affiliated to an organization in Cyprus, indicating a lack of interest or capacity for fire-related research in Cyprus. Nine papers were about fire occurrence, dynamics and prevention and four were about socioeconomic aspects of wildland fires. There were only three papers about wildland fire effects on soil, water, sediment transport, plants or fauna, indicating an even greater need for this type of research in Cyprus.

Czech Republic

An overwhelming majority of recent wildland fires in the Czech Republic (CR) were caused by humans (Adámek et al., 2018; Holusa et al., 2018). Ignition aside, the distribution of wildland fires in the CR is also influenced by environmental factors of both anthropogenic and natural origin. The CR has a fragmented terrain and a dense network of forest roads, which has contributed to minimizing the extent of fires in the past (Niklasson et al., 2010). Nevertheless, fires have affected forestry in the CR (Adámek et al., 2015).

The forested area in the CR represents 32.64% of the total area of the country. The numbers of wildland fires varied between 444 and 1398 per year in the period of 2006–2018, 725 per year on average. The area burned is usually not large, rarely exceeding 0.35 ha, and about 70% of all wildland fires are smaller than 0.05 ha. The incidence of wildland fires is not uniform; in some municipalities, there was no single wildland fire, while in some municipalities, there were more than 10 wildland fires (Holusa et al., 2018). However, an increasing fire risk highlights the need for understanding more about fire including the changes to vegetation dynamics, soils, and water. In the CR, there is no data on post-fire contaminants and little attention has been paid to long-term effects of fire, especially solutes and associated pollutants.

Estonia

Estonia belongs to the hemiboreal vegetation zone (Ahti et al., 1968) where the average annual temperature is +5.2°C. The coldest month is February, and the warmest month is July, with an average temperature of –5.7°C and +16.4°C, respectively. The average precipitation is 550–650 mm (Parro et al., 2009). In Estonia, wildland fire research, mainly focused on the natural recovery of forests, has been carried out mainly in the northwestern part of the country (Vihterpalu and Nõva). The terrain is relatively flat and forest consists largely of pure Scots pine (*Pinus sylvestris L.*) stands. These forests belong to the *Vaccinium uliginosum* and *Calluna vulgaris* site types (Lohmus, 2004), with sandy and dry soils. During the last years, investigations were carried out in Estonia to assess the effect of wildland fire and post-fire management on ground vegetation within 12–14 years after the fire. The main results showed that in the first years after the fire, birch as a pioneer species was the most successful in regeneration. Pine and aspen did not regenerate immediately after the fire, but after a while, pine started to dominate. It was also found that clearing areas burned after fire significantly reduced the abundance of regeneration compared to burned uncleared areas but favored growth of Scots pine in later development (Parro et al., 2015). There are also some studies related to changes in aboveground and belowground biomass and initial recovery of carbon (C) and nitrogen (N) pools and CO_2 efflux considering soil temperature and soil respiration values (Köster et al., 2016), or variations in extracellular activity, litter decomposition, vegetation biomass, and soil physicochemical properties in relation to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions (Ribeiro-Kumara et al., 2020).

Finland

About 23 m ha (75% of the total area) is covered by forests in Finland, belonging to the boreal coniferous forest zone. The most common species are Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) as well as birch (*Betula spp*.). About 61% of the forests are privately owned, 26% is owned by the state, 8% by companies (forestry enterprises), and 5% by others.

The wildland fire season in Finland is rather short, usually starting at the beginning of May and ending in September. Finnish summers are cool and relatively wet. Annually burned area and the average size of a single wildland fire have decreased significantly during the last century in Finland according to statistics of the Finnish Forest Service. The average annual area burned was 5760 ha in the 1950s and decreased to 936 ha by 1970s (Lindberg et al., 2020). In recent decades, the annually burned area has varied between 200 and 700 ha, occasionally exceeding 1000 ha (Peltola, 2014). The average size of a single wildland fire was around 70 ha between years 1871–1900, around 33 ha between years 1901–1920, while today it is around 0.4 ha (Lindberg et al., 2020; Peltola, 2014). The combination of climatic and biogeographic conditions in Finland does not favor the spread of large, catastrophic wildland fires. Fire prevention in Finland is facilitated by several factors. Limited topography, many natural fire breaks (around 188,000 lakes), and a very extensive road network, which all helps to keep wildland fires quite small. In addition, Finland's forests are divided into small compartments and are heavily managed (the clear-cut system is used, and during harvesting, most of the biomass [including branches] are removed from the forest stands). Occurring wildland fires are mostly low-intensity surface fires, which are not able to spread widely, usually not spread beyond a single compartment, with borders created by wide paths or by trees with different heights. This all allows the Finnish wildland fire management system to keep fires relatively small-scaled when compared Southern Europe.

France

France is the fourth most forested European country with 16.9 m ha of forest. The size of its wooded areas makes it vulnerable to the risk of wildland fires, particularly in summer. The regions of the South-West with the Aquitaine massif (New Aquitaine) and the South-East with its Mediterranean forests (Auvergne-Rhône-Alpes, Corsica, Occitanie, Provence-Alpes-Côte d'Azur) are the regions most exposed to this risk. Over the period 2007–2018, there was an annual average of 4040 fires affecting 11,117 ha of forest in France (BDIF and Prometheus databases). The occurrence of large wildland fires is related to long-term droughts, and in the Mediterranean to the usual summer drought, and specifically the soil moisture deficit (Barbero et al., 2019). This highlights the importance of soil factors in addition to weather conditions for large wildland fire occurrence.

The majority of large fires occurred in the Mediterranean area (6698 ha, compared to 4419 ha outside this area), and few large wildland fires in the Southern part of France are responsible for the majority of the national total area burned (Barbero et al., 2019). Therefore, some recent investigations were specifically focused on studying the main driving factors and causes of the large fires in this region. For instance, Ganteaume and Jappiot (2013) investigated the impact of different explanatory variables, that is, climate, land-cover, the density of transportation networks, topography and socioeconomic variables, on the number of large fires, and the extension of the area burned. These authors reported that large wildland fires mainly initiate on areas with high scrubland and pasture covers and a high density of minor roads and occur during the summer (July–August). Otherwise, the incidence of large wildland fires decreases on areas with high forest cover and high topographic heterogeneity.

The main fuel types in the Mediterranean area with limestone-derived soils encompass species like *Pinus halepensis* and mixed pine-oak (*Quercus ilex* and *Q. pubescens*). Shrubs in landscapes called "garrigue" are another dominant fuel type in the Mediterranean area (Ganteaume & Long-Fournel, 2015). The proportion of wildland–urban interface (WUI) was identified as one of the most important factors driving high fire density. The area burned is positively correlated with socioeconomic variables, such as unemployment rate and tourism pressure, which is particularly high in summer on the Mediterranean coast. Other factors affecting fire extent are wildland vegetation, especially scrubland covers, long dryness in summer, and plant water availability between fall and spring. However, according to Ganteaume and Jappiot (2013), the only significant predictors of occurrence and area burned are scrubland cover (positively correlated) and topographic heterogeneity (negatively correlated).

Since the 1990s, fire policy in France has been oriented toward rapid aggressive suppression (Evin et al., 2018; Ganteaume & Long-Fournel, 2015). To predict fire, it was found that the return period of large fires was important (Ganteaume & Long-Fournel, 2015). However, despite an effective fire suppression policy showing a decrease in the average area burned, large wildland fires still occur due to a combination of climate change, fuel accumulation, and increasing human pressure. Fire policies should also consider the potential of fire ignition of garbage dumps and power lines in the dry season.

Germany

Forest covers ca. 33% of Germany's total area and is distributed very irregularly throughout the different landscapes. Wildland fire data are collected since the 1970s. The median annual total

Figure 1. (a) A peri-urban fire on Mt Hymettus, in the outskirts of Athens, on July 17, 2015, with one fatality (Photo: G. Xanthopoulos), (b) a peri-urban fire on Mt Hymettus, in the outskirts of Athens, on July 17, 2015 (detail) (Photo: G Xanthopoulos), and (c) fire in the rural area of Kalamos Attica Greece (summer 2017) (Photo: K. Stampoulidis).

area burned since 1991 was around 447 ha but only 283 ha between 2009 and 2018. Nevertheless, 2018 had the second highest forest area burned since 1991. The average area burned per fire generally around 0.5 ha. The current regional hotspot of wildland fires is in the region of Brandenburg with more than half of the area burned during the largest fires in 2018 (725 ha burnt only in August) and almost three times more than in the dry summer of 2003 when approximately. 600 ha of forest has burnt in this federal state. This region is very prone to wildland fires as it has large proportion of connected forest area (44% of the forest is under protection, LFU Brandenburg), which are formed by pine monocultures on sandy soils, a particularly dry and flammable forest type. Since the industrialization, changes in forest management in several regions of former Prussia have replaced some of the previous and less-flammable forest dominated by deciduous trees (Dietze et al., 2019) by pine monocultures. This deep transformation was only possible by strong intervention into the hydrology, for example, building drainage ditches, which now are increasing drought problems, and thus fire susceptibility, in the mid mountain ranges.

Greece

Greece has an area of 13.2 m ha of which about 50% (6.5 m ha) is characterized as forest land (Eurostat, 2020). Tall forests constitute 2.6 m ha, the rest being evergreen shrublands and partially forested areas (3.4 m ha) or degraded lands with low vegetation of mostly thorny spiny shrubs (*phrygana*) (0.5 m ha) (European Environment Agency et al., 2017). The climate over most of Greece is typically Mediterranean, with relatively mild winters and a hot and dry summer period. Especially in the eastern part, high temperatures and low relative humidity in combination with the prevailing near gale force winds called Meltemi, result in a high level of wildland fire danger during the fire season that peaks between June and September (Keeley et al., 2011). During the period 1980–2018, Greece has suffered a total of 56,043 fire events (1437 events per year) which have led to an annual average of 42,531 ha burned, out of which 20,392 ha y^{-1} are purely forest area and the rest (22,140 hay^{-1}) have a mixed land use (forest and other uses).

In the last few decades, the fire problem is growing mainly due to (1) climate change manifested through periods of extreme fire danger during the fire season, (2) socioeconomic changes in land-use and demographic characteristics of the country; reduction of the rural population has led to horizontal and vertical vegetation continuity as well as forest biomass accumulation, increasing the likelihood of staring fires and making their control more difficult, (3) growth of poorly planned WUI areas where the probability of human-caused fire starts as well as the potential for damage increase steeply. All the above work synergistically, while institutional shortcomings further exaggerate the problem. Besides the social, environmental, and economic impacts of landscape fires—including the loss of public and private assets, destruction of critical infrastructures—wildland fires represent a significant threat to human health and security, mainly as a result of WUI development.

In 1998, the responsibility for wildland firefighting passed from the Forest Service to the Fire Service (Xanthopoulos, 2008). Since then, the Forest Service lost its top-down structure, its personnel were reduced, and funding dropped sharply, with a direct impact on the capacity of forest management. On the other hand, investment in fire suppression more than doubled, mainly due to a steep increase in the employment of powerful and expensive aerial firefighting resources, while fire prevention was almost neglected (Xanthopoulos, 2008). However, the emphasis on firefighting did not solve the problem. Average area burned in the 20 years since 1998 remained essentially the same as in the 20 years before 1998, while damages and fatalities increased steeply with 80 deaths in the 2007 fire season and 102 losses of life in a single WUI fire in East Attica in 2018 (Diakakis et al., 2017). In the aftermath of the latter disaster, which was one of the worst wildland fires in the recent history of Greece, efforts are underway to upgrade the fire management system, improving, among other elements, the level of cooperation between involved agencies (Figure 1).

Hungary

There is no natural fire regime in Hungary, but fires affect approximately 0.01% of the area of the country per year. In

Figure 2. (a) The Myrar wildland fire on 30 March 2006 at 12:55 (image from NASA/MODIS), (b) Myrar 24 July 2006, and (c) edge of a moss fire in June 2007 (Photos: Throstur Thorsteinsson).

lowland coniferous plantations, fire damage can be significant (Szatmári et al., 2016). Human-induced fire, which is generally ignited unintendedly, is the major cause of wildland fires. Arson, for example, affects approximately 10 000 ha of grassland per year (Deak et al., 2014). Prescribed burning is scarcely applied due to legislative constraints, even though in grasslands it may present a feasible solution for several conservation challenges, for example, for increasing landscape-scale diversity, creating habitats for specialist species or for decreasing the amount of accumulated litter (Deak et al., 2014) and also for the protection of the endangered great bustard (Végvári et al., 2016).

In forests, understorey fires (surface fires) are the most common fire type, while crown fires are the most typical in the coniferous plantations. The main wildland fire seasons are spring (especially March, when the increasing temperature leads to the quick-drying out of the leaf litter) and the summer (especially July and August, when the dry conditions allow the ignition of life plant biomass). Spring fires are most typical in Northeast-Hungary, in the hills, while summer wildland fires are most typical in the Central-Hungarian lowland region. Due to the climatic and land-use changes, the size of wildland fires increased almost tenfold in the last decades, and in the recent years, many large-scale wildland fires affected areas larger than 1000 ha.

Studies on wildland fires in Hungary evaluated fire risk in black pine plantations (Csontos & Cseresnyes, 2007; Szatmári et al., 2016), and the regeneration of dolomite rocky grasslands after wildland fire in pine plantations (Tamas & Csontos, 2006). According to Szatmári et al. (2016), wildland fire in lowland contributes considerably to the spreading of invasive plant species. The majority of the studies on the fire effects on Hungarian ecosystems focus on open habitats (Kertész et al., 2017; Ónodi et al., 2008; Valkó et al., 2016, 2018). Ónodi et al. (2008) found that late spring sheep grazing decreased fire spread and might inhibit the burning of large areas of the sandy forest-steppe. Valkó et al. (2016) observed that dormant-season single fire events can support the diversity and the specialist species of alkaline, but regular burning decreases the biodiversity and leads to a decline of specialist plants while favoring the encroachment of weeds in foothill steppe grasslands (Valkó et al., 2018).

Iceland

Iceland is frequently called the land of fire and ice. The term is given by the unique environmental conditions caused predominately by volcanic activities and glaciers, covering about 11% of the total area (Arnalds et al., 2016). Most wildland fires in Iceland are small and limited to the summer months due to extensive snow cover during wintertime (de Niet et al., 2020; López-Moreno et al., 2020); however, there were 20 wildland fires larger than 1 ha in the period 2006–2018 including 12 larger than 10 ha. Most of the fires are due to deliberate or accidental human ignition (Thorsteinsson et al., 2008). The main reason for rare occurrences of wildland fires in Iceland is the lack of connected forest and shrubs, which prevents small campfires from spreading into larger areas. Since the first settlers arrived in Iceland 1000 yr ago, forest and shrubs land-cover was reduced from ~40% to less than 2% (Aradottir & Arnalds, 2001). There is a clear seasonal signal in the occurrence of wildland fires in Iceland in data from 1943 to 2012. They most often occur in spring, with 29% of fires each year occurring in May, followed by 28% in April and 13% in March (Thorsteinsson et al., 2008). Wildland fire occurrence during the summer months is a relatively recent development in Iceland. The recent wildland fires coincide with increased biomass due to global warming and reduced grazing, and denser summerhouse populations increasing the risk of ignitions. Furthermore, the Icelandic government has put forward a Climate Action plan that aims at restoring parts of the original forest cover, and, additionally, primary industries in Iceland plan to offset their carbon footprint by planting trees for carbon assimilation. These plans and the risk of extended periods of drought with global warming could substantially increase the risk of wildland fires in Iceland and exemplify the need for action in developing risk assessments and including wildland fires in planning (Thorsteinsson et al., 2008).

The largest recorded wildland fire in Iceland's history, the Myrar fire (Figure 2), occurred in the sedges and shrubs of a wetland area in western Iceland from 30 March to 1 April 2006. The area affected by the fire was 7300 ha, as measured by mapping on the ground and satellite data; a very extensive fire for Nordic countries (Thorsteinsson et al., 2011).

Italy

Italy is listed as the fourth country in importance on wildland fire events in the Mediterranean region, after Portugal, Spain, and France (San-Miguel-Ayanz et al., 2017). Fire frequency and severity are increasing in the summer season (Carlucci et al., 2019), similarly to many other countries in the Mediterranean area (Keeley et al., 2011). The risk of wildland fire is also correlated with human pressure (e.g., population density), socioeconomic development, and agricultural activity. Fires have frequently an anthropogenic origin and affect society and the local economy significantly.

The total area burned varies strongly from year to year (Carlucci et al., 2019). This is majorly due to the large regional differences in morphological, meteorological, socioeconomic conditions, and biome distribution, which shape the amount and flammability of dry biomass. The effects of climate on fire regimes differ across geographical regions and from those averaged for the whole Italian peninsula (Michetti & Pinar, 2019). Higher number of fires and a large area burned in the forest and non-forest area typically occurs in Southern Italy and on the major islands (Sicily and Sardinia), where fire is more frequent and intense after the summer (www.carabinieri.it). Wildland fires in 2017 were exceptionally severe when compared with the fires in the last three decades with vast fire occurrences during summer, adding to the typical autumn events. The 2017 summer was notably dry, causing exceptionally severe fires all over Italy. Global change, in general, and land-use change, in particular, lead to major changes in the fire regime since they affect the amount of forest fuel accumulation and its dryness (Pausas & Fernández-Muñoz, 2012). Statistical analysis of the temporal properties of fire sequences occurred in Italy showed a clear increase of time-clustering for fires from North to South (Telesca & Lasaponara, 2010).

Latvia

Charcoal morphotype-based reconstructions reveal that the mean fire return interval (mFRI) in Latvia was 284 years for the last 11,700 years (Feurdean et al., 2017). It is notable that higher fire activity (mFRI 190 years) occurred during the cool and moist climate characterized by a dominance of boreal forest cover. Low fire activity (mFRI 630 years) was dominant during warm (3°C above the modern-day temperature) and dry climate conditions did coincide with the expansion of temperate deciduous broadleaf forests. This highlights the capability of broadleaf deciduous forests to act as fire-suppressing landscape elements. At the same time, the anthropogenic fire use has surpassed the baseline of natural fire frequency in the hemiboreal/boreal forests (Steinberga & Stivrins, 2021).

During the period 1922–2014, the occurrence and area affected by wildland fires in Latvia have decreased. Over the last 20 years, the majority of wildland fires have occurred near the two largest cities of Riga and Daugavpils, suggesting the prevalence of human-caused ignitions (Donis et al., 2017). Reconstructed wildland fire history based on fire scars in semi-natural Scots pine-dominated forests, showed a large variation of fire activity over the last 250 years, closely linked to the socio-political situation in Latvia (Kitenberga et al., 2019). Fire activity in Latvia has been linked to positive sea surface temperature anomalies in the Baltic and North Seas, suggesting the influence of a high-pressure cell developing during the summertime (Kitenberga et al., 2018, 2019).

In addition to the wildland fires, there are open flame and smoldering type fires in bogs. Peatlands cover nearly 12% (7,514,000 ha) of the territory of Latvia (Tanneberger et al., 2017). However, there is currently very limited knowledge of such fire types.

Lithuania

In Lithuania, wildland fires have been suppressed very effectively during the last century, due to efficient fire prevention and control system. The limited research on wildland fires done in the region included: impacts on vegetation, soil properties after surface fire (Marozas et al., 2011); the impact of wildland fires on fungi species and their distribution (Kutorga et al., 2012; Lygis et al., 2010; Menkis et al., 2012). Several papers discussed wildland fires importance in the management of protected areas (Martín & Lapelė, 2015), policy and legislative framework, and stakeholders' perceptions about fire impacts in Lithuania.

According to Lithuanian forest statistics, the total forest land area in 2018 was 2,196,000 ha, covering 33.6% of the country's territory. Since 2000, the forest land area has increased by 218,000 ha corresponding to 3.3% of the total forest cover.

Wildland fire average number in the period of 2000–2018 was 423 and ranged from 80 in 2017 to 1556 in 2002. Average area burned in the period of 2000–2018 was 231.4 ha and ranged from 20 ha in 2012 to 1199 ha in 2006. Average fire size in the period of 2000–2018 was 0.527 ha and ranged from 0.15 ha in 2007 to 2.06 ha in 2011.

Moldova

According to the Land Cadastre, as of January 1, 2010, the total forest area of the Republic of Moldova amounted to 462.7 thousand hectares, or 13.7% of the country's territory, and the forest fund—410.2 thousand hectares (12.1%); area covered by forest—365,900 ha (10.8%); Forest vegetation—52.5 thousand hectares (30.9 thousand hectares of forest belts and 21.6 thousand hectares of plantations of trees and shrubs). The State Forestry Agency—"Moldsilva" Agency is responsible for 336.6 thousand hectares (9.9%), of which 302.2 thousand hectares (8.9%) are forests. The 44.1 thousand hectares of forest resources (1.3%) are under the jurisdiction of local self-government, and 3.2 thousand hectares (0.1%) is private property; the 26.3 thousand hectares of forest area is located on the territory of Transnistria.

Approximately 95% of Moldova's forests consist of deciduous trees that are not particularly susceptible to fires, but in some cases grass, forest litter and down wood can fuel surface fires.

Montenegro

Forests are one of the most important natural ecosystems that provide the basis for the sustainable development of Montenegro. According to the First National Forest Inventory, forests cover 59% of Montenegro's territory. Due to its geographical position and the increasing impact of climate change, Montenegrin forests are particularly at risk. In particular, the forests in the coastal and central parts of Montenegro, where high summer temperatures and vegetation characteristics including the presence of maquis favor the occurrence of fires (Čurović et al., 2019). Fire occurrence peaks in July and August, when rainfall is very low, as well as February and March—during dry and warmer winters. Fires are often caused by human negligence. Relief features and a poor road network are factors that complicate firefighting. Due to the depopulation of the villages, it is also increasingly difficult to organize a quick response to fires.

The Forest Administration and the Statistical Office of Montenegro hold fire data which differ between those two institutions. The number of fires decreased from 2003 (130 recorded fires) to 2006 (16 recorded fires), while in 2007 the number increased dramatically (210 recorded fires), which was contributed by drought and high temperatures in the summer when the highest number of fires occurred in the northern region. During 2012, we registered 215 wildland fires in state forests, which burned a record of 6663 ha. The associated damage to forests was estimated at around € 4,268,000 (Uprava za sume Crne Gore, 2019). Major damage from wildland fires was also recorded in 2015 as well as in 2017.

The Netherlands

The Netherlands is a relatively small country in Europe of approximately 4.1 m ha. With a population of over 17 million in 2020, it has a high population density of approximately 420 inhabitants per km^2. The high population density is also reflected in the strong human influence on land use. Most of the land is used for agricultural, industrial, and residential purposes. Approximately 8% of the Dutch territory is designated as Natura 2000 area (Ministry of Agriculture Nature and Food Quality, 2005). These areas include a wide diversity of ecosystems including forests, heathlands, coastal dunes, and peat bogs. The Netherlands has a maritime temperate climate with mild winters and cool summers, and rain throughout the year.

Wildland fires have traditionally not been a large concern in the Netherlands due to few natural areas in a highly fragmented landscape combined with a temperate climate. Conversely, high population density and easy access to natural areas result in high human ignition potential. Humans cause almost all fires. Between 2014 and 2018, Statistics Netherlands, the Dutch governmental institute responsible for statistical data, reported on average 504 (standard deviation = 256) wildland fires per year. 29% of these fires occurred in forest, 29% in heathlands, 7% in dune areas, and 1% in peat bogs. The land-cover class of the remaining 34% of the fires was unknown. About 42% of these wildland fires occur in the months April, May, and June, 37% in July, August, and September, 15% in January, February, and March, and 6% in October, November, and December.

Most fires remain small (smaller than 1 ha) and Statistics Netherlands does not report area burned. The number of fires reported by Statistics Netherlands is much higher than by the European Forest Fire Information System (San-Miguel-Ayanz, Schulte, et al., 2013), which only includes data on some of the larger fires in the Netherlands. Sizable fires are rare but occur in the Netherlands, as the recent fire of 800 ha in the natural area of the Deurnese Peel in the spring of 2020. The highest fire risk is in spring when fuel moisture of litter, grasses, and heathers is low. The public and government are increasingly aware of the risk climate change pose to fire occurrence in the Netherlands (Oswald et al., 2019). In 2016, Brandweer Nederland, the government agency responsible for fire prevention and suppression, and the Institute for Safety introduced a vision on wildland fires in the Netherlands (Brandweer Nederland, 2016). The vision focuses on resource management for wildland fire prevention and suppression based on the knowledge of fire in Dutch ecosystems. As part of this effort, a fire risk map and fire spread model calibrated to Dutch ecosystems have been developed (Donkers, 2019).

Norway

Norway is a 38.5 m ha country with just over 5 million inhabitants. The vegetation along the country varies along three gradients: from south to north, from the lowlands to the mountains, and inland from the coast, with seven vegetational regions (Moen, 1987). In the west coast with its oceanic climate, heathlands are the predominant vegetation. Until 50 years ago, many farmers were actively utilizing the heathlands, in cyclical management including prescribed fires. But during the past 20 years, nearly all such activity ceased, and the landscape has become increasingly overgrown by shrubs and trees, and this process is still accelerating today (Kvamme & Kaland Peter, 2009). These heathlands are the main fire risk on the west coast.

On the other hand, the interior, with a higher topography, is populated by tall trees of different types, including Scots pine and Norway spruce, which provides a completely different fire behavior and fire risk than other regions. Moreover, the variation of vegetation over the years has modified the fire behavior from fire-prone pine-dominated forests to fire-free spruce-dominated forests (Tryterud, 2003). Finally, fires north of the Arctic Circle are attracting a lot of attention and are believed to become more frequent in the coming years (Cockburn, 2020; Vaughan, 2020). These fires do not have many precedents, making it difficult to determine their expected behavior.

The annual number of fires and the area burned depends on the weather conditions. Wet, cool summers were frequent in the past, with a low number of wildland fires occurring and of low intensity. However, recent years have been warmer and drier, producing an increase in both the number and the extent of wildland fires in Norway. In 2018, there were a total of 2079 wildland fires in Norway, twice as many as in 2017 and 2016 (San-Miguel-Ayanz et al., 2019).

Poland

The most recent official data on wildland fires in Poland dates to 2017 (Statistics Poland, 2018). According to the records of the last 10 years, in 2017, wildland fires were least frequent. There were 3592 fires recorded, 1694 less than in the previous year, and the area burned was 1023 ha, that is, 428 ha less than in 2016. The main causes of fires were arson and negligence, or the fires were caused unintentionally by human activity. In 2017, in total there were three extensive wildland fires. However, none of them exceeded an area of 100 ha. In comparison in 2016, there were six large fires and only one of them covering more than 100 ha area. The average area of total wildland fires reached ca. 0.28 ha. Within the entire area of forests in Poland, 44.9% of fires were arson caused, 27.7% due to negligence, 3.6% of them were caused accidentally, 0.9% due to natural reasons, and 22.9% of fires causes were not officially established.

The fire risk of wildland fires in Poland is mainly driven by weather conditions. 2017 was relatively moist when compared to 2011–2016 or even post 2001. The average moisture content of the litter was very much higher than in previous years. It was 35.2% in the morning periods and 29.8% in the afternoon. For the decade of 2001–2010, the moisture was 31% and 26%, respectively. The fire risk level in 2017 within a scale of 4 was recognized at the level of 0.8–0.9, which shows the low fire risk potential (Zajączkowski et al., 2018).

When analyzing the statistical data on wildland fires in post-war Poland, however, there is a growing trend, both in numbers and area burned (Szczygieł et al., 2007). The mean number occurring fires per year in forest had doubled within the decade in the 1980's. It became three times larger than in the 1950s. The number of wildland fires in Poland contributed to 6%–16% to the total number of wildland fires in the whole of Europe (Piwnicki et al., 2008; Tedim et al., 2015). The highest wildland fire risk is usually observed in the central and south region, what was confirmed by fires recorded in 2001–2017, and the lowest risk is considered in northern regions, where atmospheric conditions are milder (lower average temperatures and wetter). Potentially, about 83% of the total forest resources in Poland are subjected to fire risk, which compared with Europe's fire risk overall, is rather high (Grajewski, 2017; Ubysz, 2003).

Portugal

Portugal has the highest number of fires in the Mediterranean region (Nunes et al., 2016; Figure 3). More than 2.5 m ha burned between 2000 and 2018, with special incidence in 2003, 2005, and 2017 (San-Miguel-Ayanz et al., 2018), of which about half were natural shrublands and pastures. The fire regime results from the interplay of diverse factors such as (1) meteorological conditions with rainy and mild winters promoting vegetation growth followed by warm and dry summers (Pereira et al., 2014) and the occurrence of extreme fire weather events during droughts and heatwaves (Parente et al., 2019), (2) landscape characteristics, such as large areas of continuous forest and natural areas (Nunes, 2012), (3) specific topographic characteristics which hinders fire suppression activities and increases fire spread (Nunes et al., 2016); and anthropogenic characteristics, such as land abandonment which is being increasing in the last decades (Nunes et al., 2016; Pereira et al., 2014). As elsewhere, fires have complex impacts on Portuguese biophysical systems (Shakesby, 2011). In the short term, fires have been shown to affect soils, vegetation, fauna, water resources, and aquatic habitats (Figure 4). There are also indications of long-term implications of recurrent fires for soil productivity and the hydrological services provided by forested watersheds.

Climate change is expected to increase the area burned in the future (Tedim et al., 2018), posing strong constraints on the forestry sector and natural and social systems if the problem is not addressed. There has been a strong government response, especially in the wake of the 2017 fires, including the creation of a dedicated agency to coordinate actions on rural fires, and research funding explicitly dedicated to applied wildland fire research. This research effort has led to more information and tools being available for fire managers to assess and understand fire regime, dynamics, and post-fire recovery, helping to mitigate the impacts of severe fire events. Examples include research to understand fire behavior, linkages between weather and wildland fire activity, the role of humans for fire ignitions and driver of land-use dynamics (Moreira et al., 2011; Nunes et al., 2016), fire severity, and vegetation recovery patterns using methods such as remote sensing, statistical analysis, or numerical modeling. There has also been researched on post-fire soil protection and rehabilitation (Keizer et al., 2018), and decision support methodologies for fire-prone landscapes (Silva et al., 2019).

Romania

Romania's land area is 23,839,100 ha. Romania has 14,856,800 ha of agricultural land which represents 62.3% of the total surface; 0.65 ha per capita. In 2017, Romania's forest covers an area of 6,565,000 ha, representing 27.5% of the total area obtained by the reports published by the National Institute of Statistics in 2017. In 2017, there was an alarming increase in the number and area affected by fires, compared to previous years, except for 2012, when the historical maximum in the records was recorded.

The main cause of forest fires is the spread of fire from the agricultural lands bordering the forests, by (1) burning of pastures, mainly before entering the vegetation, on sunny days and

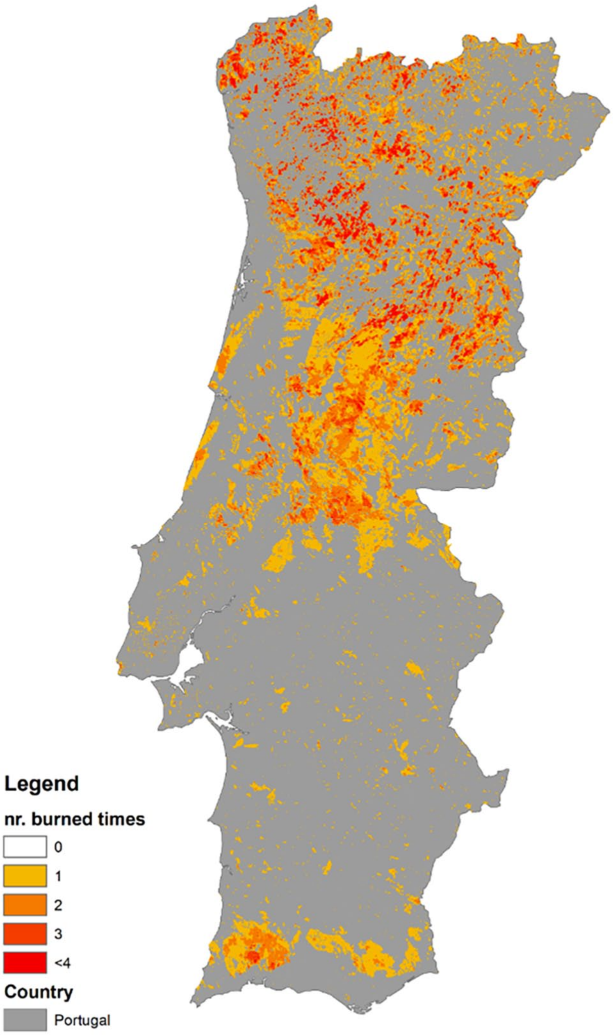

Figure 3. Portuguese area burned and fire recurrence (number of times burned) in the period 1990–2018 (Instituto de Conservacao da Natureza e das Florestas, 2020).

without precipitation; these fires are either unattended or are out of control due to local wind intensifications and usually occur in spring; (2) the burning of the stubble after the harvest of agricultural products, from July to August.

Serbia

The forest area in Serbia is estimated at 2,373,740 ha (approx. 30% of the state territory) (data obtained from CORINE Land Cover database 2012). Out of the total forest area, the greatest percentage is made of broadleaved forests, particularly beech forests, oak forests, elm forests, and lime forests. Coniferous forests are represented by pine, spruce, and fir, and mixed forests mostly consist of beech, maple, birch, and fir. Among all factors which affect the forest health and sustainable development, wildland fires cause the majority of economic and ecologic damages. Wildland fires in Serbia are considered as a natural hazard (without distinction between a wildland fire hazard and general fire hazard), and there are several documents aimed to the regulation of fire prevention, mitigation, protection, rescue, and rehabilitation from these events (relevant laws listed below). The data on wildland fires (number of fires, area burned, and wood mass destroyed) can be obtained from the Statistical Office of the Republic of Serbia (yearly reports), which are being updated from the Ministry of Interior Affairs—Sector for Emergency Management and the Ministry of Agriculture, Forestry and Water Economy—Forest Directorate. A significant risk for wildland fires in Serbia comes from stubble burning. About 70% of the Serbian territory is under agriculture (Đorđević et al., 2020) and most farmers are burning crop residues in autumn. In previous research, we identified a very high concentration of K in atmospheric aerosol during autumn as a tracer for biomass burning including stubble burning (Đuričić-Milanković et al., 2018a, 2018b). These open fires present a high risk for wildland fires because they are more likely to be spread from fields to forests.

There are many issues related to fire prevention and protection system in Serbia: inappropriate application and outdated legal directives related to the protection of wildland fires, lack of appropriate open forest roads, firebreak tracks and the communication network, lack of human resources for prevention and suppression of fire, inappropriate material and equipment for fire protection, lack of education and training for firefighters and headquarters, and lack of an efficient way of information distribution and poor public information. On the contrary, there are notable attempts for international connections and knowledge exchange, which have already resulted in collaboration, equipment procurement, and training of professionals. For example, an interactive wildland fire hazard GIS web map has been developed for publicly owned forest land in Bosilegrad Municipality, Serbia as a pilot area (see http://ipacbc-bgrs-forest-fire-hazard-map.eu).

Slovakia

The Slovak Republic (area: 49,035 km^2, population: 5,450,421) is a landlocked country in Central Europe with temperate-continental climate. However, the Carpathian Mountains act as a barrier for moist oceanic air masses causing rainfall deficiency and droughts in some regions of Slovakia. Other factors which contribute to the frequency of wildland fires and associated impacts are steep terrains characterized by low opening-up level deploy to deploy the specialized trucks to fight the fire as well as the human factor (particularly also socioeconomical factor in poorer regions in Eastern Slovakia). Wildland fires occur most often in April, May, and October. A relatively stable frequency of wildland fires in recent years (except years 2011 and 2012 during which long drought seasons appeared) was probably reached as a result of measures adopted after a tragic wildland fire in the Slovak Paradise National Park in October 2000. During that well investigated fire, six fatalities occurred, and two people were injured. This tragic fire stimulated extensive research in the field of vegetation fuel mapping and study fire behavior using advanced fire simulation tools for Slovak

Figure 4. To the left, the recently area burned near S. Pedro de Alva village following the 15 October 2017's wildland fires in Portugal. To the right, view of the wildland fire, July 15, 2018. The Iberian Peninsula shows a long history of wildland fire, which in the last 60 years resulted in recurrent wildland fire in the north of Portugal and the Galicia region (NW) region of Spain.

conditions (Glasa et al., 2010). However, the most important changes in wildland fire prevention were adopted after the wind disaster disturbance in Southern part of the High and Low Tatras in November 2004 where about 120 km^2 of forest were destroyed. New requirements for landowners and land users were introduced for mapping the spatial distribution of water bodies, road network, and warehouses with tools for fire-fighting and building fire prevention measures. Research on the impact of fire on soil hydraulic properties (Novák et al., 2009), the effect of vegetation on hydro physical properties of soils, evaluation of fire weather indices, forest vegetation and duff moisture content indices, and wildland fire risk assessment (Šurda et al., 2015), and impact of wildland fire on the formation of bio indicative forest beetle communities (Šustek et al., 2017) was conducted as well. The applied measures include not only technical and technological modernization of fire suppression means but also substantial improvement of preparedness of firefighters and rescue workers, regional, national, and cross-border training and cooperation as well as the development of methodologies for wildland fire risk assessment, design of progressive fire protection measures, implementation of early stage warning systems based on the CCTV smoke detection (ForestWatch, later also FireWatch) and others (Majlingova et al., 2018).

Slovenia

Wildland fires in Slovenia are especially prevalent in the south-western, that is, the Mediterranean part of the country. In Slovenia in the period 2004–2018, an average of 87 wildland fires occurred per year, which burned an average of 190 ha of forest land. Every year the Slovenian Forest Service issues a report on the state of the forest, which also includes a chapter on "Fires and fire protection" (Zavod za gozdove, n.d.). This includes data on the number of fires and area burned, as well as the causes for wildland fires and fire protection works carried out.

In 2016, Ministry of Agriculture, Forestry, and Food issued an extensive report "Risk Assessment for Great Fire in the Natural Environment" (Ministrstvo za kmetijstvo gozdarstvo in prehrano, 2006) with some analyses on wildland fires in the period 2000–2014. Wildland fires analysis for earlier periods, for example, for 1983–1992 was written by Zupančič and Preskar (1994) and 1991–1996 by Jakša (1997). The Slovenian Forest Service has made a map of "Wildland fire risk," which is available in shape format. According to this map, the Slovenian Forest Service provides data on wildland fire risk by municipalities and cadastral municipalities. The scientific literature on wildland fires in Slovenia is scarce. Some handbooks on the topic were written already before and just after WWII. General reviews on wildland fires were written by Jakša.

As south-western Slovenia (i.e., the Mediterranean part of the country) has the highest wildland fire risk, most articles connected with wildland fires are usually focused on this area (Urbančič, 2002, 2003; Veble & Brečko Grubar, 2016).

Spain

The fire activity in Spain during the last decade has moved from fuel limited to become strongly driven by its Mediterranean climate (Pausas & Fernández-Muñoz, 2012) and socioeconomic factors (Chergui et al., 2018). The annual and inter-annual droughts during the summer period are frequent, and thus, the vegetation is available to burn in a large part of the territory. The trend of wildland fires in Spain during the decade 2009–2018 shows a progressive reduction in fires and area burned (Spanish National Forest Fire Statistics). This evolution can be explained, at least in part, by two main factors. First, the progressive improvement and efficiency of the emergency response (Castellnou et al., 2019). Second, the success of risk prevention in certain areas that have invested in reducing the number of ignitions and fuel management (Turco et al., 2016).

Despite the negative trend in fire activity for the last decade, the risk of having large and intense wildland fires in Spain has increased (Urbieta et al., 2019). Factors such as climate change and fuel build-up as a consequence of social changes (i.e., rural abandonment, land-use change, a vulnerability in the rural–urban interface) are increasing wildland fire risk and the likelihood of

Figure 5. Wildland fires induce a sudden removal of the plant cover, but soon plant cover recovers and changes in plant composition as a consequence of the fire takes place. Carcaixent, Eastern Iberian Peninsula. To the left June 22, 2016, to the right September 8, 2016.

having larger, more intense, and severe wildland fires (San-Miguel-Ayanz, Moreno, & Camia, 2013; Figure 5).

Sweden

Sweden is dominated by forests, which are a vital component of Swedish natural ecosystems, supporting biodiversity and species composition, and contributing to the national economy. Due to its relatively wet and cold climate, along with a relatively low population density, the risks of wildland fires are lower in Sweden than in many other EU countries, but when fires occur they can be severe. They usually take the form of surface and ground fires, burning deep roots, peat, and other woody fuels lying beneath the surface (Doerr & Santin, 2016). Although the cause of any specific fire is difficult to detect, analyses have shown that only about 7% of fires that occurred in Sweden during the period 1998-–2014 were ignited by lightning, while over 50% were ignited by human activities, such as barbeques, camping, smoking, and traffic. Wildland fires in Sweden are thus strongly affected by human activities, in combination with prevailing weather conditions, and risks may be enhanced by climate warming. Enhanced drought conditions on daily to annual scales, which may be an expected effect of warming, affect the frequency and size (forest area burned) of fire events.

A major fire in Västmanland county in central Sweden, which is regarded as Sweden's largest wildland fire in modern times, affected an area of 13,100 ha and was started by sparks from a soil tillage machine, during to the hot, dry summer of 2014 (Hagelin & Cluzel, 2016). More recently, in the summer of 2018, high fire risk and multiple fires were occurring in many areas (covering in total 21,602 ha) of forest throughout Sweden. The fires occurred after a period of prolonged drought and sustained high temperatures extending across Europe. In general, severe drought years are associated with a larger area burned, and climate warming can further cause the wildland fire season to start earlier and end later. Although many forest professionals in Sweden do not regard climate change as the main cause of wildland fires so far (at least not in comparison with severe storms) (Lidskog & Sjödin, 2016), the global and regional warming has become a more prominent issue in Swedish media after the major 2014 fire event in Västmanland (Berglez & Lidskog, 2019).

Turkey

According to the latest official data, the total forest land is 22,621,935 ha (28%) in Turkey. The average number of wildland fires per year is 2360 occurs and an average 8763 ha of forest lands are damaged due to the wildland fires (Republic of Turkey General Directorate of Forestry, 2019b).

Forest lands are monitored continuously with 776 watchtowers and 230 thermal cameras. In addition, 3041 water reservoirs were constructed to be able to intervene more quickly in response to wildland fires. The initial response time to wildland fires is now less than 15 min. Damaged lands after wildland fires are cleared from burning trees and afforested within a year (legal obligation) after rehabilitated if it required (Figure 6). There are many causes for wildland fires in Turkey; 47% of wildland fires are unknown, 12% deliberately, 3% lightning strike, 38% are the result of neglect and carelessness. The human-caused wildland fire rate is 97% in Turkey (Republic of Turkey General Directorate of Forestry, 2019a).

United Kingdom

Fire activity in the United Kingdom, which includes England, Northern-Ireland, Scotland, Wales, has been episodic during the past decade, with notable national wildland fire episodes occurring in 2011, 2018, and 2019. Most wildland fires occur in the spring or summer, with episode years characterized by long periods of fire-conducive weather, associated with anticyclonic conditions (Albertson et al., 2010). Aside from satellite-derived products, national-level wildland fire occurrence, and area-burned statistics are not available for the United Kingdom. An Incident Recording System was established in 2009, although summary statistics are only available for England (54% of the land area of the United Kingdom). According to these wildland fire statistics from 2009 to 2017 for England, only 4.9% of the area burned (1721 ha) occurred in forest land-cover classes, with the majority of area burned occurring in other classes (35203 ha) including arable, grassland, and heath land-covers.

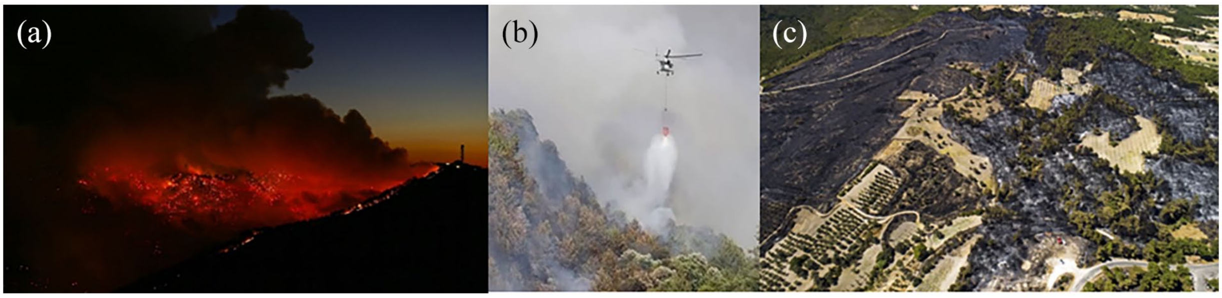

Figure 6. (a) The wildland fire rage, (b) response to fire, and (c) destroyed area in the Karabaglar, Izmir province (August 19, 2019).

Without reliable long-term records, it is not possible to discern past trends in the UK wildland fire activity. However, significant lengthening of the duration of UK heatwaves from an average of 6.1 days in 1961–1990 to 18.3 days for 2008–2017 (Met Office Hadley Center, 2018), as well as predictions of future increases in wildland fire probability for the United Kingdom through this century (Krawchuk et al., 2009), suggest that wildland fire episodes may become more frequent, or annual events in the near future. Efforts are being made to improve UK fire resilience, focussing on a multi-agency approach to preparedness, prevention (including efforts to address fuel loading and ignitions), and suppression (Gazzard et al., 2016).

Synthesis and Required Actions

The national summaries provided in the previous section provide a contemporary perspective of the national wildland fire situation across Europe. The data and insights provided by the COST Action FIRElinks National representatives highlight that there remains an alarming lack of consistent wildland fire data collected by the national or even regional government bodies. Although coarse-scale country statistics based on satellite data as provided by EFFIS (San-Miguel-Ayanz et al., 2012; Tedim et al., 2015) provide valuable insights on larger fire events, this lack of data and consistency remains a major detriment to allowing in depth analysis and understanding of the wildland fire situation and associated challenges across Europe. The lack of consistent records for, and evaluation of particularly smaller-scale, wildland fire events is a common feature in many of the national perspectives presented above. This leads to an important lack of information that would allow not only detecting emerging trends, but also in designing more effective prevention and protection measures.

The national-level information gathered here for each country (see also Supplementary Table 1) does highlight that wildland fires occur in most regions and countries across Europe. Apart from notable exceptions as exemplified by Finland, a common view in many European countries is the increased threat they pose to societies and the natural environment. This view emerged already in the 1880s in the Mediterranean region after two decades of agricultural land abandonment. Although Spain for example has seen a decrease in the number and size of fires during the last years, the common view in the Mediterranean region is that the frequency of large and destructive wildland fires is growing, with ongoing land use changes and climate change promoting larger fires. A contrasting situation is present in some of the northern regions such as Scandinavia where the widespread establishment of intensely management plantation forests has led to very effective suppression of fire recent decades. Despite this, however, the drought period in 2018 followed by extensive fires occurring over much of Sweden suggest that climate warming may trigger a new situation where severe wildland fires become more frequent, affecting the sustainability of some of the northern European forests. In Eastern Europe, a shift of forest and plantation management from focusing largely on timber production to a more intense recreational use is a notable trend in this region that could lead to more fuel accumulation and more ignitions, which together with climate change effects is likely to increase fire occurrence. In most countries in Central and Western Europe, there is also concern about an increase in wildland fires that pose a risk to properties and human life due to the high population densities here and the urban sprawl into forested regions. Recent wildland fire events proved also quite well that wildland fires are an urgent issue in the Alpine region which can damage forests, increase the vulnerability to natural hazards and result in costs up to millions of euros for one single fire event. In addition, across many regions in Europe, there is concern about fires in shrublands, heathland, and peatland. While these typically pose a lower threat to communities compared to fires in forested regions, they are also seeing increasing attention regarding their role in the sustainability of the ecology and carbon storage of their habitats.

The national summaries presented here, and the issues highlighted above, clearly demonstrate not only a large and changing diversity of the wildland fire situation and their management in Europe but also the widely perceived increase in wildland fire threat. Policies relevant to wildland fires and tactics to control fires often change following large events in some countries, contributing to an evolving diversity in perceived threat and response between nations. However, a common view that seems to emerge in most countries is that, irrespective of changes in management, climate change is likely to increase the frequency and impact of wildland fires in the coming decades. At least for Scandinavia, Atlantic, and Southern Europe, this view is supported by a range of recent model predictions

(Bowman et al., 2020; Jones et al., 2020; Met Office Hadley Center, 2018; Turco et al., 2016).

There is clearly a need not only for more detailed and consistent reporting of wildland fires across Europe, but also for more research and collaboration between the different countries and between the different actors involved in wildland fires events, their prediction, control, and protection. The perspectives presented here also highlight the need for developing new policies at EU level that enable more effective and sustainable management of wildland fires and the associated risk to its citizens. To this end, the EU has identified the need for "Developing synergies between EU and national policies to improve wildland fires risk management (Cardoso Castro Rego et al., 2018)" in its recent report on wildland fires in Europe.

Conclusion

The general overview of the current national wildland fire patterns and challenges as perceived by scientists or practitioners from 31 countries across Europe, supplemented by national fire statistics (2009–2018) presented here provide a much greater diversity of insights than could be collated from examining only the published English-language literature. While there is an enormous diversity in patterns and challenges perceived across Europe, there are some key recurring themes:

(1) The lack of consistent and detailed records for wildland fire events, which hampers evaluation of events and detection of trends within and across countries.
(2) An increase in wildland fires that pose a risk to properties and human life due to the high population densities and sprawl into forested regions.
(3) Irrespective of changes in management, the view that climate change is likely to increase the frequency and impact of wildland fires in the coming decades.

Progress across Europe in improvement and standardization of wildland fire recording and assessment systems will not only help in advancing national and pan-European wildland fire management strategies but also in enabling the perceptions about the increases in wildland fire risk associated with population and climatic trends to be evaluated against more robust quantitative evidence.

We hope that what is presented here provides a useful contribution toward understanding the diversity of wildland fire issues across Europe and also serves as an example and catalyst for closer collaboration in this topic between diverse countries, cultures, and the different actors involved in managing, reporting, and investigating wildland fire events.

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Supplemental Material

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