E-STAG
European Science & Technology Advisory Group
SENDAI FRAMEWORK
FOR DISASTER RISK REDUCTION 2015-2030

SUSTAINABLE DEVELOPMENT GOALS

Evolving Risk of Wildfires in Europe

The changing nature of wildfire risk calls for a shift in policy focus from suppression to prevention

Abstract

Most of the damage from wildfires is due to extreme events that represent less than 2 per cent of the total number of fires. These events, for which neither ecosystems nor communities are adapted, can have significant socioeconomic and ecological consequences. This is why it is now time to develop appropriate risk reduction strategies and minimize the impacts of large-scale fires. This report demonstrates how climate change, human behaviours and other underlying factors are creating the conditions for more frequent, intense and devastating fires in Europe – now and over the next century. The report also provides authorities with concrete recommendations and examples of good practice. Along with further efforts to combat climate change, this new context requires adapted policies to shift the focus from suppression to prevention, as called by the Sendai Framework for Disaster Risk Reduction 2015-2030, as well as the integration of science into governance, the further use of risk knowledge, and greater awareness among populations of the need for a change in behaviour.

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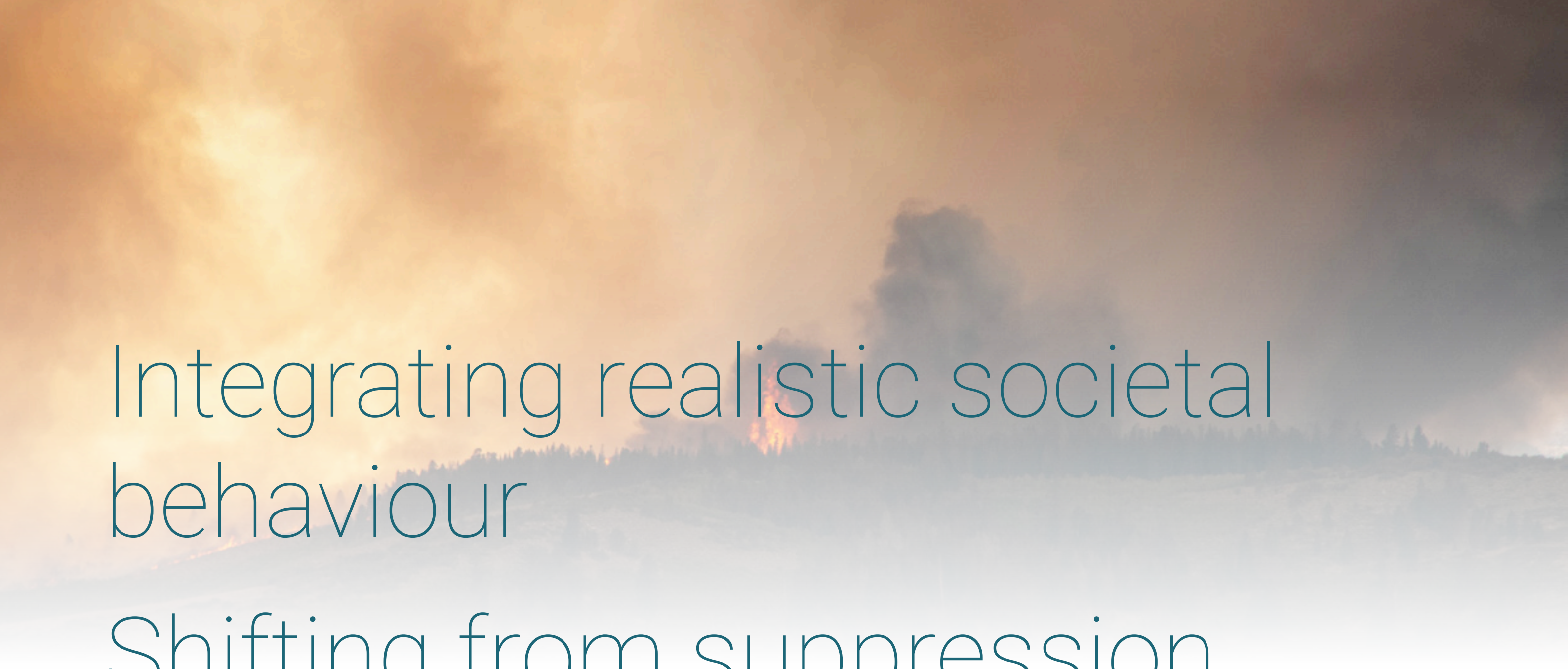

Integrating realistic societal behaviour

Shifting from suppression to prevention

Raising awareness

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Cover picture : Wildfire in abandoned cultivated areas in France.
Credit : Pascal Pochard-Casabianca AFP.

01

Ingredients for disasters

1.1. A changing risk landscape

Changes in climatic and weather conditions are one of the major reasons for the increase in wildfire hazard and risk [1,2]. As global temperatures are expected to be warmer than current levels and severe droughts more frequent, fires season will be prolonged in many ecosystems. Thus, new regions around the globe will potentially be affected by wildfire risk [3].

It is generally recognized that anthropogenic factors have also contributed to increase fire risk worldwide [4]. These include the modification of land use, rural exodus and the abandonment of previously cultivated land – with no alternative strategy for land management. This is exacerbated by rapid, anarchic urbanization in wildland urban interfaces (WUI), fire exclusion policies that contribute to fuel accumulation, and a predominant focus on fire extinction rather than an effective prevention strategy. A combination of all these factors means that the risk of wildfire is likely to increase substantially in the future, and that extreme catastrophic wildfire events (such as the Attica Fire in Greece 2018 – reported in this document) could occur more frequently.

The term 'wildfires' – also known as 'forest fires', 'bushfires' or 'wildland fires' – is commonly used to refer to unwanted fires that burn forests and wildlands [5–7]. Extreme fires that have had significant ecological and socioeconomic impacts occurred in China in 1987; in Portugal in 2003, 2005 and 2017; in Spain in 2006 and 2017; in Greece in 2007 and 2018; in Italy in 2007; in Australia in 2009 and 2020; in the United States in 2013 and 2017; and in Canada and Chile in 2016 (non-exhaustive list). A global reference for the destructive power of these catastrophic fires is the disaster that occurred on the now infamous 'Black Saturday' in the small town of Kinglake in the Australian State of Victoria in 2009. In twelve hours, fire burned through 100,000 ha of land, resulting in the death of 120 people [4].The total annual economic cost of wildfires in Victoria is estimated to be around AUD 180 million and is expected to double over the next 40 years [8]. In Europe, approximately 85 per cent of the total burned area of land in France, Greece, Italy, Portugal and Spain is due to wildfires. Recent studies indicate that **most of the damage caused by forest fires is due to large fire events, which represent less than 2 per cent of the total number of fires** [5]. With the exception of Portugal, there has been a noticeable decrease in the number of fires and the total surface area burned since 1980. In fact, the problem lies in the increase in extreme fires, for which neither ecosystems, communities nor firefighting methods (even aerial) are adapted. Many countries in Europe continue to experience these severe fire events, despite an increase in fire suppression budgets. Recent examples, such as those in the Russian Arctic region, illustrate how forest fires can quickly become out of control [9]: more than 8 million hectares have already gone up in smoke in 2020, following record levels of destruction in 2019. Experts have already noted that "forest fires across eastern Siberia have increased in number and intensity since mid-June in a way that is very similar to the same period last year" [10]. The June heat wave in the Arctic, with temperatures ranging from 12°C to 14°C above the seasonal average – including a record 38°C observed on 20 June in the Arctic city of Verkhoyansk – are among the factors contributing to the rapid spread of fires. Mark Parrington, an expert with the Copernicus Atmosphere Watch Service, declared that "these fires degrade air quality and accelerate climate change".

This changing landscape urgently requires new strategies to reduce the risk of fires and thereby decrease their economic, environmental and social impact. The first aim of this report is to demonstrate how climate change and human behaviours are helping to create the conditions for more frequent, intense and devastating fires in Europe over the next century. The second aim is to provide examples of good practice in Europe. The report also emphasizes that, in addition to the global battle against climate change, this new context requires a fire management policy that includes fuel treatments, prevention measures based of weather forecasts, early warning systems, a stronger focus on population awareness, and strategies and techniques that integrate the use of technical or traditional fires, as well as an institutional **shift in focus from suppression to prevention** [11].

1.2. Underlying risk factors

Studies have shown that in many parts of the world, the nature of wildfires is changing [12,13]. Since the 1980s, there has been a decrease in the total burned area in Europe's most affected countries – with the exception of Portugal [5]. The problem lies more in the significant impact of extreme fires. Despite a rise in fire suppression budgets, fire seasons have become increasingly severe. Deadly and destructive wildfires have become the norm in many regions around the world. This requires a better understanding of the intimate relationships between ecosystems and fire (the 'fire regime') [14].

Recent studies suggest that this increase in catastrophic wildfire events appears to be correlated with a number of factors. For example, Ganteaume and Jappiot [13] report that in the south of France between 1997 and 2010, fires that burned more than 100 ha were responsible for 78 per cent of the total burned area. These wildfires spread predominantly during periods of drought in densely populated areas characterized by high shrubland cover. The researchers conclude that the size of burned areas was largely dependent on wildland vegetation, long periods of dry weather in summer and wet weather between autumn and spring. They also correlate these wildfires with pressure from tourism, rural exodus and land abandonment (as a result of high rates of unemployment) and the expansion of wildland urban interfaces.

Based on a number of analyses, there appears to be three underlying factors that trigger destructive wildfires: climate, fuel and human behaviour. First, recent studies [15] confirm that the effects of climate change, such as heavy loads of dead or extremely dry fuel, are important causes of this increase in extreme wildfire events. Second, while abundant vegetation is climate related, it is also a function of land management practices. For instance, fire exclusion over long periods allows for increased fuel density and creates the conditions for extreme fires. In Europe, traditional burning has ceased in many places [16], creating a paradox around the benefits of managed fires and the impact of wildfires.

The role of **human behaviour goes beyond the question of fire management.** A recent study in southern France [13] demonstrates the links between burned areas, and high rates of unemployment and pressure from tourism. In many places, people are abandoning previously cultivated land, thereby extending fire-prone areas [15]. For instance, in the Western Mediterranean region of Europe, fuel loads are now greater than ever before due to rural abandonment and depopulation resulting from the decline in rural economies [17]. In other places where wildfires have often occurred, there has been an increase in population density. The expansion of WUIs into fire-prone areas exacerbates exposure and vulnerabilities [18]. WUIs are areas where man-made structures are located in or adjacent to fire-prone areas. These densely populated areas do not have proper wildfire protection measures in place, and have an increasing number of citizens who are unaware of the risks [17].

When this complex fire environment receives an ignition, it often has severe ecological and socioeconomic consequences. Therefore, research on the linkages between extreme fire events and human activities is of paramount importance, and requires **closer cooperation between scientists, policymakers, local authorities, fire managers and civil society.** In addition, strategies and techniques that integrate the use of managed fires, management options for restricting the potential spread of fire, and long-term options that include an increase in the rotation and change of tree species should be promoted [19]. **This calls for a strategy for wildfire landscape management [20] to reduce damage and maximize the benefits of fire.**

Wildland Urban Interface (WUI) fire in Portugal - Credit RTE

1.3. Case study of an extreme wildfire in Europe: Greece, 2018

23 July 2018 marked the beginning of the fire season – the first day with a 'very high' danger rating. Across a large part of south-eastern continental Greece strong westerly winds were forecast [21]. A wildfire erupted at 12:03 in the western region of Attica near Kineta, a town about 50 kilometres west of Athens. The fire, fanned by strong winds, spread rapidly, destroying houses and eventually reaching the sea, posing a threat to a large oil refinery. While resources were concentrated on the initial wildfire, a second fire erupted at 16:41 in the north-eastern part of the Attica region. Interestingly, the weather conditions meant that the probability of anticipating the disaster was relatively low and the vegetation was not water-stressed because the season had been much wetter than usual. However, even with this unusually high moisture content, the wind was able to generate a high rate of spread (ROS). This second fire moved eastwards through Mediterranean shrub, olive groves and stands of Aleppo pines. Five minutes after the eruption, the wildfire perimeter was approximately 400 metres in length; within the next 35 minutes the perimeter grew to more than 3,500 metres. The wildfire then formed two fingers: one extending to the southeast and the other to the east. Gale force winds resulted in a high ROS following the first stage of the fire. Twenty minutes later the perimeter was about 6,000 metres long and had reached the settlement of Neos Voutzas. At Neos Voutzas Hill, the fire became a high-intensity, wind-driven crown fire and began to spread rapidly eastward. With flames reaching higher than 20-30 metres, the wildfire crossed the main thoroughfare, Marathon Avenue, and spread towards the coast through homes and pines in the settlement of Mati. It formed several fire fingers with an ROS of up to 4 km/h-1. The fire grew with the intermittent ignition of crowns as hot gases were pushed forward by the wind. The head of the faster fire fingers reached the sea in less than 2 hours after ignition. This catastrophic event was a new record for fire fatalities in Greece. The rapid ROS took the population by surprise, causing widespread panic. Many people tried to escape at the last minute in their cars but were soon caught up in traffic jams. Similar to other Mediterranean countries, the communication networks (roads, streets) on the periphery of cities and in villages are often old and narrow, hindering evacuations. In many areas the traffic jams also delayed the arrival of firefighters. Some people died near their cars while others attempted to reach the sea. Some were eventually trapped behind the crest of a sea cliff. Others jumped into the sea but had to wait hours for lifeboats and some drowned trying to swim away from the coast. During this extreme wildfire, 100 people were killed, 1,650 homes were destroyed and 1,431 ha were burned.

If we draw a straight line between the location of the eruption and the end of the propagation, the wildfire spread over 5.2 km with an average ROS of 2.6 km h-1. While such a ROS is not rare, it was the erratic fire behaviour, with bursts of rapid ROS (exceeding 5 km h-1), that explains the severity of this event. In addition, there was no warning from the authorities of the approaching fire.

In September 2018, the government appointed an independent committee of experts to study the issue of wildfires in Greece and this event in particular. A report was delivered to the Prime Minister in February 2019 and on 20 March, Greek officials were charged with responding to the disaster. The report called for a Landscape Fire Management approach and the development of a holistic, integrated policy that incorporated the various sectoral responsibilities [22].

02

How Climate change could influence wildfire activity in the 21st century

Temperature, precipitation, wind and atmospheric moisture are major drivers of fire activity [23]. The influence of weather and climate – along with variations in terrain and fuel – is therefore key for understanding the scale of fire events [24]. Climate change and exceptional weather conditions (such as heat waves and droughts) recorded in Europe in recent years are likely to have a considerable impact on wildfire risk.

2.1. Climate change in the 20th Century

Several reports demonstrate that climate change is already having an effect on wildfire activity. For instance, Jolly et al. [2,3], using daily data sets, mapped spatiotemporal trends from 1979 to 2013. During this period, the areas burned by wildfires amounted to 350 million ha per year and annual pyrogenic CO2 emissions were equivalent to over 50 per cent of combustion emissions from fossil fuels. The findings also indicate a 18.7 per cent rise in the global average length of fire seasons, as well as an increase in the number of fire-prone areas.

On 8 January 2020, the Copernicus Climate Change Service (C3S) and the Copernicus Atmosphere Monitoring Service (CAMS) provided the first global picture of 2019 temperatures and CO2 levels [25].

Data released by C3S shows that, globally, 2019 was the second warmest year ever recorded and the warmest year on record for Europe. C3S also reported that twelve-month averages for Europe were higher from 2014 to 2016; they then dropped but remained at least 0.5°C above the 1981-2010 average (Fig.1). Twelve-month averages have subsequently risen again. In January 2020, the average temperature was more than 1.5°C above the 1981-2010 norm [26].

The figures indicate that, **in Europe, all seasons were warmer than usual and that most regions were warmer than average, especially in Eastern and Southern Europe.** CAMS also estimated that **concentrations of CO2 in the atmosphere are on the increase.** The figures recorded during winter are particularly interesting because of the potential impact on vegetation. The decrease or absence of colder temperatures in winter impacts many ecosystems, increasing the risk of insect infestations. In **Northern and Southern Europe, ecosystems have become more fragile, the mortality of trees has increased, and higher temperatures have prolonged the fire season later into the year.** Several important fires have been observed in the Mediterranean regions even in December and January. Moreover, hot and dry winters create the conditions for high-risk fire seasons during the summer.

Climate largely determines ecosystem characteristics [27] and fire regimes [28]. Even though the link between wildfire risk and climate change is complex, it is **evident that if these trends are confirmed, and if coupled with ignition sources and the availability of fuel, they could not only have a significant impact on ecosystems and the nature of wildfires but could also disrupt societies and economies**.

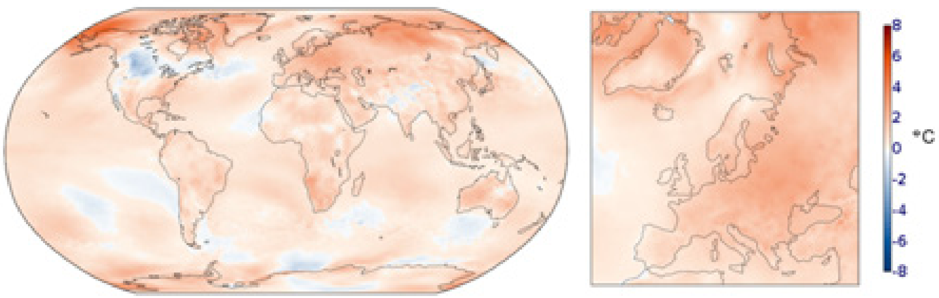


Figure 1. Surface air temperature for February 2019 to January 2020, relative to the average for 1981–2010

Data source: ERA5v / Credit: Copernicus Climate Change Service/ECMWF

As an illustration, experts believe that the catastrophic fire season in New South Wales and Victoria (Australia) in 2019-2020 [29], may have resulted from the severe drought induced by the Indian Ocean Dipole (IOD) – also known as the Indian Ninõ; the IOD was in a positive phase, bringing about more precipitation along the eastern coast of Africa and drier weather conditions in Indonesia and Australia. Preliminary observations seem to indicate changes in the frequency of adverse weather conditions in Australia in recent years, most likely linked to global warming. Similar conditions were observed between 2006 and 2008, just before the 2009 Black Saturday bushfires in Victoria. During the first half of 2019, severe droughts and heat waves affected the Western Mediterranean region of Europe, prolonging the fire season [17]. In Spain, these conditions led, in June 2019 alone, to five large wildfires that burned over 13,000 ha. The first of them, known as La *Torre de l'Espanyol*, affected 6,500 ha in the northeast region and burned for five days through shrubs, forest and abandoned agricultural lands.

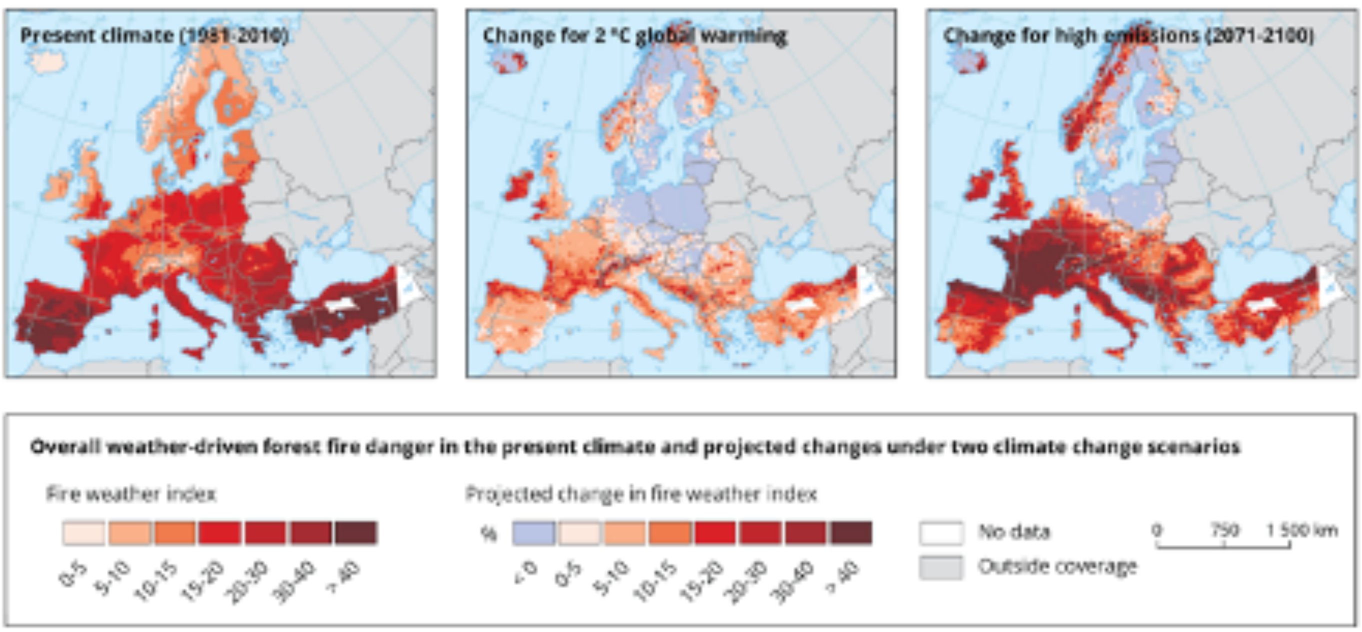
2.2. Projected climate change impacts in Europe

The impact of climate change on wildfire hazards remains a complex issue. Based on the work undertaken by the Joint Research Centre of the European Commission through the PESETA III project [30], the European Environment Agency presented a study on how Europe could be affected by a number of climate risks (including wildfires) during the 21st Century [31]. Figure 2 shows wildfire risk under present climatic conditions and two estimates based on greenhouse gas emissions scenarios and climate change assumptions.

Figure 2 shows notable increases in wildfire risk in several European regions. As expected, these increases are more pronounced under higher emissions scenarios. The figure also depicts a northward expansion of the zones at moderate risk of fire, with a notable increase in wildfire risk in Western and Central Europe.

Experts suggest substantial warming and an increase in the number of heat waves, droughts and dry spells across most of the Mediterranean region provide an important indicator of fire risk. Moreover, climate change could increase the length and severity of fire seasons, as well as the size of the area at risk and the probability of extreme fires. However, it is possible that more frequent fires may lead to ecosystem changes that limit fuel availability and, as a result, have a paradoxical impact on wildfire risk.

Flannigan et al. studied the severity of the global wildfire season during the 21st Century [32]. They used scenarios to examine the potential influence of climate change on global fire season severity for mid-century (2041–2050) and late century (2091–2100) relative to the 1971–2000 baseline. They conclude that changes in the length of fire seasons will be most pronounced at the end of the century and for northern high latitudes where fire seasons would be prolonged by more than 20 days per year. These increases in wildfire risk must be reduced by appropriate measures.



Credit: European Environment Agency

Figure 2. Wildfire risk in the present climate and two estimates using climate change scenarios. Credit: European Environment Agency.

03

Health impact of wildfires – A growing concern for Europe

In current European Environment Agency [33] and IPCC reports [34,35]. the health impact of wildfires is briefly addressed, while the health impacts of climate change associated with other extreme weather events such as floods or storms are given more prominence [36]. This is particularly concerning as projections of more intense fires put many urban communities at greater risk. Pollution and health impacts are also recognized by the Sendai Framework for Disaster Risk Reduction as cascading effects that need to be considered in improving risk reduction and sustainable development. This review summarizes the existing scientific knowledge gaps on the health impacts of wildfires.

Wildfires can have negative impacts on human health across a large range of scales and are likely to contribute to human health impacts across Europe (local, regional, national and EU-wide). Most of the fatalities from fires are as a result of the inhalation of toxic gases [37]. Those directly affected by fire, such as civilians in the immediate vicinity or first responders, can suffer a broad range of physical and mental health impacts related to heat, stress and emissions. Wildfire emissions can also have significant effects on transboundary air quality, and so lead to health impacts regionally and across Europe.

Wildfires can adversely impact human health at four different levels: direct exposure to flames and radiant heat; exposure to materials or substances dispersed through the air; use of land contaminated by chemical substances after a wildfire or other geologically meditated impacts such as exposure to airborne dust; and through water contamination [38]. In addition, indirect effects (such as stress related illnesses) may have a significant impact. These vary in scale and can affect human health over larger and more densely populated urban areas. Estimates of the average number of worldwide deaths per year attributable to air pollution from wildfires alone range from 260,000 to 600,000 [39] – illustrating the magnitude of indirect effects.

Wildfire emissions contain a highly complex and dynamic mixture of components that can impact human health over a range of spatiotemporal scales. Many of the emitted components, such as Carbon Monoxide (CO), are an immediate health risk to those in close proximity to the fire [40,41]. Moreover, due to the scale of emissions, the potential dispersal of pollutants over thousands of kilometres and the impacts on atmospheric processes, wildfire emissions can impact air quality and human health across regional or even larger scales. Wildfire emissions, for example, have contributed to increased levels of pollutants including Ozone (O3) and Particulate Matter in regions far from the fire [42,43].

If the fire occurs in an area contaminated by radionuclide (the region of Chernobyl is a good example), the resuspension of radioactive particles in the atmosphere, which can be transported long distances, can have additional impacts on the health of populations [44]. A fire in this region in April 2020, illustrates perfectly that such catastrophic events are not purely hypothetical and should be of concern to other regions, particularly in Russia.

In addition to wildfires, peatland fires resulting from the conversion of tropical (Indonesia) [45] and boreal (Russia) forests for agricultural activities or the domestic use of peat, constitute a huge public health problem, largely because of the enormous quantity of carbon particles emitted into the atmosphere [46] and the exceptional duration (which can be measured in terms of months) of such fire events. **As global warming is likely to have a greater impact on boreal regions, the problem of peatland fires could increase significantly during the coming decades, especially in Russia and Northern Europe.** The 2009 peat fire in Las Tablas de Daimiel National Park (Spain) shows that Mediterranean areas could also be affected, although at a more local scale [47].

A key requirement for assessing air quality and the health impacts related to wildfire smoke is the accurate quantification of the individual constituents in the smoke from each type of fire. Currently, the Joint Research Centre of the European Commission provides an operational fire emission module for the regional/ European scale, which is integrated into the European Forest Fire Information System (EFFIS). The EFFIS fire emission estimation model is one of the finest resolution fuel map-based operational systems; it uses detailed fuel maps and sequential mapping of the evolution of fires based on satellite imagery from across Europe [48]. However, wildfire emissions vary considerably in composition depending on a wide range of factors such as fuel source and combustion mode. The British Columbia Health Board highlights the need to enhance the characterization of emissions across a range of real-world scenarios. Notwithstanding limited data collected during past wildfire events [49], sampling smoke in the direct vicinity of the fire is complicated by the extreme conditions and high spatiotemporal variability of emissions.

A key challenge is the spatial and temporal scales over which wildfires can impact air quality. Current approaches for modelling the impact of wildfires on air quality generally adapt

1. Wildfire smoke in Australia - RICK RYCROFT_AP
2. Prescribed fires conducted for scientific research on fire risk.

readily available air quality models for emissions from wildfires [50–52]. However, for larger and more intense wildfires, there is a need to develop models that adequately describe the injection height of fire emissions and the broader effects of smoke on atmospheric processes. Modelling the transportation of smoke and the atmospheric chemistry helps determine the spatial and temporal distribution of pollutants, which is fundamental for assessing exposure to wildfire-specific pollutants and for quantifying the associated health impacts. There are some exposure studies for firefighters [50] but calculating population exposure to smoke from wildland fires requires further development. **Cascio [53] highlights that the increasing frequency of intense fires, the expansion of the WUI, and a growing and ageing population are increasing the number of people at risk from wildfire smoke.** This highlights the need for population exposure estimations and for broadening stakeholder cooperation to address the health effects of wildfires.

Air pollution from wildfires has been consistently associated with respiratory outcomes [54], with less evidence currently available on cardiovascular effects [55] and other health endpoints (e.g. kidney disease). **Certain population sub-groups, such as the elderly, young children and those with pre-existing illness or disabilities, are likely to be more heavily affected and have less capacity to adapt [52].** Occupational exposures and associated health risks for firefighters and other first responders also need to be characterized in the context of increasing pressures on emergency services due to climate change. A recent review by the International Organization for Migration [56] highlighted that firefighters were at greater risk from a number of cancers.

Human health impacts from exposure to wildfire smoke are often ignored in estimates of monetized damages from wildfires [57]. Cost of illness measures, which are frequently applied in studies of the health cost of disasters, are known to significantly underestimate the true economic cost of health effects from exposure to pollutants – for example, ignoring the costs of defensive actions and disutility [58]. **The lack of health cost data for wildfires in European countries is worrying; pioneering US studies find that smoke health impacts are an important consideration in the overall costs of wildfires** [59].

In addition to the health effects of smoke, forest fires can cause health risks from damage to infrastructure. US studies have identified such ‘ripple effects’ in the form of contaminated water distribution systems. Pipes, meters, valves and fittings show levels of volatile organic compounds and benzene above acute and chronic exposure limits. The removal and replacement of the affected distribution systems following the 2017 Tubbs fire in Sonoma and Napa counties in California cost approximately $44 million [60].

While the multiple health costs from forest fires and the cost of adaptation will rise in the future, a number of adaptation measures (such as wildfire smoke forecasting systems [61]) may also bring multiple health co-benefits. Recent studies demonstrate the importance of estimating the total impact and cost of each adaptation measure to determine if and how the benefits outweigh the costs [51].

04

Recommendations

There is already plenty of scientific evidence of the impact of human activities and climate change on disaster risks – wildfires are no exception. Rapid urbanization and inadequate land-use planning also represent a growing threat. Therefore, in addition to measures to support the global battle against climate change, appropriate risk reduction policies are needed to ensure that the risk of fires is minimized and their potential spread reduced.

4.1. Integrating realistic societal behavior

As well as climatic conditions, anthropogenic factors contribute to an increase in wildfire risk worldwide. However, models used to estimate economic losses from disasters rarely integrate realistic societal behaviour [62]. Researchers often argue that if the perceived risk is below a certain threshold level, then the probability of risk is treated as zero and adequate protection is deemed unnecessary [63]. In January 2020, many countries believed that a COVID-19 pandemic was highly improbable, resulting in a lack of preparedness measures. The same is true for extreme weather events, such as Superstorm Sandy in 2012 and Hurricane Harvey in 2017; estimates show that only 20 per cent of homeowners were insured against flooding [64]. Many of the remaining 80 per cent presumably felt that the probability of flooding was below their threshold level of concern or they expected to receive government compensation following such a disaster. The principle of 'charity hazard' [65] can, unfortunately, act as a disincentive for adopting preventative/protective measures. While experiencing an extreme event like a wildfire or a flood can incite people to change their behaviour to better prevent risks [66], memories tend to fade over time and perceptions of risk once again fall back below threshold levels of concern.

These factors partly explain the increase in population density in fire-prone areas such as WUIs or in places where wildfires have already occurred [15]. The same is true of abandoned land where fuel is no longer managed by agricultural workers, and which then become fire-prone areas.

Neglecting realistic societal behaviour means that policymakers do not have accurate information and maps on which to base their strategies [67]. **Socioeconomic factors and human behaviours need to be further analysed and included in risk assessments.** One way of doing this could be to adapt models applied to floods, such as the agent-based-modelling approach [68].

Policymaking processes, development plans and land-use planning exercises need to more effectively integrate wildfire risk to limit exposure, avoid the creation of new risks and promote sustainable agricultural practices that can help reduce the availability of fuels and improve the management of forests.

Changing human behaviours also requires efforts to disseminate information, raise awareness and educate people about risk. Specific actions such as advocacy campaigns, the use of social media and on-site information are particularly important for reducing risks associated with tourism, outdoor activities or gardening. (See recommendation 4.3. for more on this).

4.2. Shifting from suppression to prevention

Expenditure on fire suppression is on the increase. [69]. However, this reactive approach is often inefficient and ineffective for large fires. This is especially true when the costs of fire suppression are compared to the costs of preventive action. Evidence from National Park Service lands (US) demonstrates that fire suppression costs approximately \$2,100 per hectare, while preventive measures such as prescribed burning cost only \$200 [70]. In 2006, the United Nations Food and Agriculture Organization claimed that "forest fire prevention may be the most cost-effective and efficient mitigation programme an agency or community can implement" [71].

In 2016, a study based on the concept of a 'Fire Smart Territory' argued that wildfire policies in European Union countries do not adequately address the problem and are unlikely to be effective in the future because they focus predominantly on suppression and/or on preparedness for a wildfire event [72]. As a result, and despite increased spending on fire suppression, many countries still face extreme fire events [15,69] and risk prevention remains a key regional issue. In Europe, **a transboundary strategy for wildfire landscape management is required to build on existing national plans and measures, and move beyond a focus on fire suppression.**

The allocation of resources should build on knowledge of risk to develop efficient fire-risk policies [4,5]; these would include elements such as:

- A legal obligation for homeowners to maintain a standard defensible area around their homes, making properties much easier to defend while protecting surrounding fuels from accidental fires.
- Improved regulation of individual prescribed fires and outdoor activities to prevent accidental fires.
- The systematic creation and maintenance of specific roads and tracks with associated fuelbreaks in disaster-prone areas. As seen in Germany and several other countries, this type of action supports prevention, preparedness and response to fires by breaking up the continuity of fuels, improving access for firefighters and providing shelter.
- Promote a strategy for wildfire landscape management to sustainably manage and monitor fuel cover over time, to reduce fire hazard/risk and help decrease intensity in the event of a large fire under extreme conditions.
- Improved and more frequent use of prescribed fires as a management tool.
- Consideration of the long-term adaptation of vegetation to climate change and the potential impact on fire risk.
- Increased use of models to anticipate changes in fire risk and to adapt measures and policies, and develop innovative legislation in fire-prone regions. In particular, there is an interest in institutionalizing the use of accurate fire-risk maps to support land-use planning, and risk-informed public and private investments.
- Systematic alignment between climate change and DRR efforts focusing on fire risk, including the protection of biodiversity, green infrastructure and long-term weather forecast systems.

4.3. Improving awareness and risk information

While wildfires cannot be completely avoided, improved warning systems can significantly limit their impact [73]. Public communication must evolve to adequately reflect the evolving nature of wildfires in Europe. Populations must learn how to live with fire risk, as with other hazards such as storm surges or floods [15]. Effective risk information should take into account differences in education, and social and cultural backgrounds within communities, and develop appropriate channels of communication and messaging accordingly.

In terms of improving awareness, an integrated fire-risk policy could include the following steps:

- Develop more specific information about the causes of fires: reducing risk through education and knowledge, and creating a fire consciousness.
- Increase government knowledge on how extreme wildfires require different resources, skills, appropriate regulations and prevention policies, in addition to emergency management.
- Improve communication between populations and rescue services.
- Prepare communities for a fire event – as is done for floods or earthquakes.

4.4. Tackling the health impacts of wildfires

The growing frequency of large wildfires, the expansion of WUIs and an ageing population are increasing the number of people at risk from wildfire smoke. There is therefore an urgent need to more effectively and consistently address the health effects of wildfires. The following actions to address knowledge gaps on the health impacts of wildfires could be considered:

- Enhance the ability to accurately characterize and monitor emissions from wildfires, and use monitoring techniques to improve atmospheric modelling. This includes the development of chemical transport models to improve the quantification of air quality impacts, and exposure assessments for wildfire smoke exposure-response functions for specific pollutants.
- Develop a better understanding of less widely researched health impacts such as increased cancer risk or mental health effects and other health endpoints related to wildfire smoke.
- Study the toxic impacts of wildfires on public and private water systems.
- Identify populations that are particularly vulnerable and analyse the different impact chains.
- Examine the long-term health consequences of residing in wildfire-prone regions, including the health effects of different types of fuel.
- Use accurate regional predictions to effectively estimate the health impacts and associated costs under a variety of climate and socioeconomic scenarios.
- Develop recommendations for effective and efficient adaptation strategies for public health and forestry sectors in relation to wildfires, including studies of the co-benefits and co-costs of adaptation.

4.5. Giving science and technology a core role in fire-risk reduction

The Sendai Framework for Disaster Risk Reduction 2015-2030 specifically stresses the importance of integrating science and technology into DRR efforts. However, operational management or decision-making mechanisms do not always adopt the innovations developed by fire science. One of the main challenges for the coming decades will be to bridge the gap between the needs of stakeholders and the production of scientific knowledge and tools. Challenges to address include:

- *Fire behaviour,* trends and monitoring – While there is now an abundance of available data, and technology can be acquired for a fraction of the cost, the challenge is to identify the relevant data and use it appropriately. This is particularly important for data and tools used to identify fire-prone areas or to detect the initial signs of a fire and pinpoint its location, as well as to understand fire propagation scenarios [8].
- *Ecosystem behaviour* – Understanding how ecosystems respond to fire is essential for managing landscapes in fire-prone regions [13,73,74]. For instance, innovative studies on how an ecosystem would respond after a fire occurs or how to develop adaptation plans to improve the resilience of the vegetation to climate change could be of primary interest to forest managers [75,76].
- *Climate and weather forecasts for prevention and fire management* – The scale of fire events is often associated with the El Niño-Southern Oscillation and other atmospheric-oceanic patterns. Weather/climate forecasts should therefore be integrated into fire prevention programmes [76, 77]. Even though the relationship between climate change and the changing patterns of forest fires is complex, there is a critical need to more accurately identify the areas where future wildfires are likely to occur [77,78]. As shown in Figure 2 (Section 2.2), a combination of improvements in climate forecasts and the quantification of the effects of annual/inter-annual climate variability on wildfires would significantly improve wildfire planning in the decades ahead [2].
- *Innovative technologies for detection and prevention* – Several areas of further research could be encouraged:
    - o *Video surveillance for fire detection* - there are two main types of wildfire detection surveillance systems:
        - Terrestrial video surveillance systems [79–81].
        - Extraterrestrial surveillance based on analysis of satellite pictures.
    - o AI-based visual recognition technology to analyse satellite and video imagery to determine fuel conditions and vegetation risks in proximity to utility lines [82].
    - o Fire modelling tools to support fire departments and emergency responders [75,83].
    - o Widespread adoption of aerial patrols, LiDAR and advanced imaging for vegetation management and utility infrastructure inspections [84].
- *Virtual reality simulations for training operational staff* – The capacity to respond to an emergency is based not only on pre-existing knowledge or ability, but also the degree of familiarity with potential scenarios staff may have to face [85]. Including these elements in training sessions can be expensive, dangerous and, in some cases, impossible. Virtual reality simulations can approximate real contexts and constraints, while maintaining all the advantages of a controlled simulation environment. In this way it is possible to train staff to respond to stressful real-life conditions, thus improving their ability to make critical decisions in challenging conditions.


Prescribed fires conducted for scientific research on fire risk.

4.6. Examples of good practices

Mitigating the risk of an extreme wildfire is a general conceptualization that can involve a large number of factors. Indeed, the combination of 'when we act', 'what we do', 'how we do it' and 'what tools we use' can generate very different lines of action. Generally, we can classify wildfire-related good practices using a four-dimensional matrix based on the following dimensions:

1. The disaster cycle phase (prevention, preparedness, response, etc.)
2. The domain (technical, social, economic, political, etc.)
3. The approach (study, operational assessment, action, etc.)
4. The technologies involved

This section presents a series of wildfire-related good practices, categorized using the above-mentioned matrix.

1. Early response to fires in Turkey

Disaster cycle phase	Suppression/ Prevention
Domain	Technical/Social
Approach	Research/Action/ Operational assessment
Technologies	Helicopters/fuelbreaks/ silvicultural practices/ fire detection network

Turkey is more than 1,600 kilometres long and 800 kilometres wide, and roughly rectangular in shape. It is surrounded on three sides by water and forms a bridge between Asia and Southern Europe. The country is dominated by rugged mountains and the Anatolian Plateau, and has a wide diversity of climates. Approximately 28 per cent of the country is forested. In recent years, population growth and urbanization have increased the pressure on forests (for recreational use), particularly in the southern and western coastal regions where the Mediterranean climate dominates and where there is the greatest risk of fire. Moreover, 40 million visitors come to Turkey each year. This has significant repercussions for firefighting policy in the country. Fire management in Turkey is managed by the Turkish General Directorate of Forestry; particular attention is paid to the use of research results to inform forest fire policy and anticipate how climate change, human behaviours and other factors create the conditions for devastating fires. Over the past eight years, the number of wildfires has averaged almost 2,500 fires, burning approximately 7,000 ha per year. It is notable that the average area burned per wildfire (2.8 ha) is lower than that of other Mediterranean countries [86]. This is undoubtably due to Turkey's firefighting policy, which aims to initiate a first attack on wildfires within 15 minutes of detection. A total of 42 helicopters are available for the initial attack and the average time from detection to attack fell from 40 minutes in 2003 to 14 in 2018. **These impressive results were due to an effective fire detection network, extensive road networks, and the use of fuelbreaks, water impoundments and silvicultural practices in much of the country – an effective complementarity between prevention, preparedness and early response measures.**

2. Fire legislation in Portugal

Disaster cycle phase	Prevention/Preparedness
Domain	Technical/Social/Political
Approach	Study
Technologies	Fuel management bands / prescribed fires

Portugal is frequently threatened by forest fires. During the 2017 fire season, an extreme wildfire occurred in Pedrógão Grande, burning a record 45,328 ha, destroying 458 structures, killing 65 people and injuring more than 200 [7]. Thirty people were killed in their cars while trying to flee. Following this catastrophic event, the Portuguese Government decided to introduce more effective preparedness measures. To this end, the country's fuel management laws have been amended. The aim of these amendments is to provide guidance on the **creation of fuel management bands and to increase the penalties for non-compliance**. For example, legislation was enacted to clear trees and brush on the sides of the roads. This ten-metre buffer zone creates a safe passage for people who need to escape. When landowners or communities cannot manage the land, the rural fire service, AGIF, can intervene. The Portuguese Government is also investigating other innovative solutions. For example**, a pilot programme was launched to enlist shepherds in fire-prone areas and use goats to clear low-lying fuel**. Prescribed fires in winter are also used to create fuelbreaks to prevent the spread of wildfires in the summer [87]. **A key element is the need to further anticipate fire seasons with rigorous prevention and preparation measures to forecast the conditions expected during the driest periods.**

3. Video surveillance for monitoring and preventing forest fires in Croatia

Disaster cycle phase	Prevention/Response
Domain	Technical/Social
Approach	Study
Technologies	Video surveillance

Located in Southeast Europe, Croatia is geographically diverse. The crescent-shaped country features low mountains and highlands near the Adriatic coastline, flat plains that hug the Hungarian border, and a multitude of islands. The country's coastal areas have a Mediterranean climate; during the summers temperatures reach as high as 39°C and the area receives only 25-50 mm of precipitation per month (according to the Croatian Meteorological and Hydrological Service) [88]. Over a thousand islands are found off the coastline. Many are major tourist areas including those along the Dalmatian coast. Due to current conditions, climate change and the high population density in coastal areas during the tourist season, Croatian forests are extremely vulnerable to fires. According to Jurjević et al. [89], the country experiences between 200 and 500 fires every year. A report by the Croatian Ministry of the Interior states that 82 per cent of the fires in coastal areas are a result of human behaviour or a lack of care [90]. In comparison, only 2-3 per cent of forest fires are the result of natural phenomenon.

In recent years firefighters have actively increased the use of video surveillance as a preventive and operational tool for forest fire control. Video surveillance offers multiple benefits. Besides the expected increase in fire detection and more timely interventions, it acts as a psychological deterrent as potential fire offenders are now aware that their actions are being monitored and will be sanctioned.

The use of video surveillance to prevent forest fires was started in 2003 by the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture at the University of Split after an extremely demanding fire season. The initiative was initiated through an EU scientific research project entitled HOLISTIC. Initially only a few video surveillance cameras were connected to the research centre, which then raised the alarm at nearby fire stations. The system is now almost fully developed with dozens of cameras set up in strategic locations; these can automatically detect smoke and fires within a radius of 10 km. The cameras are connected to two operational centres in Zagreb and Split. These are equipped with image processing systems and fire propagation prediction software, which enables the coordination centre to quickly organize, disperse troops and geo-reference fires according to the data received and analysed by the system [91].

The installation has already shown positive results with a reduction in deliberate fires and the successful identification of offenders. The number of fires has drastically reduced from 1,167 in 2017 to 165 in 2018 [91]. An extended and more systematic use of such systems will help to demonstrate their efficiency.

4. Fuel load reduction through the use of prescribed fires

Disaster cycle phase	Prevention
Domain	Technical
Approach	Study
Technologies	Prescribed fires

Wildfire behaviour is predominantly driven by three main factors: topography of the terrain, weather conditions and fuel. These form what is known as the fire environment triangle [92]. Among those three factors, the only one that can be manipulated to reduce fire risk is the amount and distribution of fuel. This explains why **many countries have developed biomass reduction programmes to reduce wildfire hazard and risk.** Prescribed burning represents one of the most efficient large-scale tools for land management [93–95]. This type of fire is used in several ways [96–99]. For instance, it can be employed in the construction and maintenance of fuelbreaks in advance of suppression action or in the removal of excessive fuel load and forest debris at ground level. Most prescribed burnings try to avoid killing terminal buds and are of low intensity to reduce the impact on the soil and trees as well as minimize the risk of fire escape. These types of low intensity fires have to be managed in order to minimize smoke production and maintain air quality, to limit the impact on personnel and the surrounding population [100,101].

Different burning techniques [95] can be used depending on the weather, topography and fuel conditions to prevent harmful impacts on the forest. Based on the different angles of exposure of unburned fuels to the flames, backfire, flank-fire and head-fire techniques can be used [102]. The exposure angle is determined by the geometry of the slope, the arrangement of fuels and air movement. Most prescribed burns are started by a backing fire. These are deemed safe because variations in wind speed have little effect on the rate of fire spread [103,104]. They also produce minimum scorch and can be used for heavy fuel loads. However, the slow rate of spread means that this technique takes longer and is more expensive [100]. This can be compensated for by the use of the flank-fire burn technique, which reduces the amount of time needed to complete the burn and improves combustion conditions. The head fire burn technique consists of setting lines of fire to spread upwind or upslope. It can be used to reduce the amount of time needed to perform a complete burn or in low fuel loads and high fuel moisture areas. Another technique is the area grid method. It was developed in Australia and applied to large inaccessible areas [94,105]. The simultaneous or area ignition method consists of inducing a strong convective force to create a convective column. It is used in heavy dead and live fuel load areas. A point ignition aims to create a convective column in the centre of the burn area and is commonly employed on flat ground or on slopes of up to 20 per cent, with backfire used as a fire-control measure. Finally, the edge burning technique consists of running fires around the perimeter of a small area and letting them run towards the centre.

The optimal technique for a specific area depends on weather, wind and topography, as well as vegetation type, properties and cover. A combination of techniques can be used for a prescribed fire but the backing fire technique is the most common.

Prescribed burning is one of the most effective and sustainable techniques for creating a safe and habitable environment. Moreover, such a technique has an immediate impact on the ability to safely and effectively achieve natural resource objectives and ecosystem resilience [95].

5. Wildfires in Slovenia: the example of the Mediterranean Plateau (Kras/Karst)

Disaster cycle phase	Prevention/Suppression
Domain	Technical/Social
Approach	Operational assessment
Technologies	Land management/risk forecast system

The Kras Plateau region in southwest Slovenia comprises 6.8 per cent of Slovenian forests but is responsible for as much as 50 per cent of reported forest fires. On average, there are 50 forest fires a year burning more than 600 ha.

The natural forest is a combination of littoral oak and hornbeam [107]. Deforestation began after the Middle Ages, but the traditional cultural landscape of pastures with sporadic trees was preserved until the 19th Century when the landscape was transformed into a bare rocky surface. Over the last two centuries, the process has been reversed. Afforestation was introduced to prevent the strong gusts of the bora wind, commonly reaching 150 km/h, from eroding the soil and accumulating snowdrifts. Following the afforestation laws, 10,842 ha were afforested between 1859 and 1914 [108], mainly using black pine (Pinus nigra). Consequently, most of the traditional pastures were abandoned and over the following decades the landscape reverted back to forest.

In the karstic region, the limestone reduces the risk of fire. Compared to other rocks limestone is extremely permeable. As it is comprised of almost pure CaCO3 it can only be weathered chemically and does not provide enough material for building soil. The soil in this area is therefore thin or completely absent. The strong bora wind dries, drains and removes what little soil there is, contributing to droughts. The introduction of black pine to these areas has altered the natural processes, resulting in a reduction in biodiversity, a deterioration in soil quality due to increased acidity in the coniferous forests, and higher levels of erosion. The introduction of pine trees has also increased the risk of fire because of the accumulation of fuel in the form of pine needles that can form layers more than 10 cm thick. Over the centuries, the area burned by forest fires has increased by a factor of 100.

During the last few decades, this region has experienced a large number of extensive forest fires, causing a great deal of damage. (Fig. 3). For example, a forest fire in 1994 caused more than 4 million euros-worth of damage, instigating discussions on whether to allow further natural afforestation of pasture areas. One of the largest forest fires (1,049 ha) occurred during the extremely hot summer (29 July) of 2003 on the Slovenia-Italy border (Sela na Krasu). The fire was extinguished under extremely difficult conditions with the risk of explosions from unexploded ordnance (UXO) from World War I. In 2006, a 950 ha forest fire caused a further 884,000 euros-worth of damage [109,110].

Forest fires usually start in dry grassland and are blown into the forest by strong winds; one-third of the fires occurred in windy conditions and the majority (87 per cent) in dry weather. A large number of fires relate to the traditional practice of prescribed fires: clearing and burning dry grass and grazing land in the early spring.

The number of forest fires is closely related to low levels of precipitation and extreme temperatures. The three years with the highest number of extremely hot days (temperature above 35 °C) experienced an above-average number of forest fires: 2003 (43 fires), 2006 (29 fires) and 2013 (8 fires) [112]. Forest fires were also more common in younger, newly-establish forests (accounting for 41% of fires) and in forests with a greater share of coniferous trees, particularly Pinus nigra.

The prevention measures in the area range from (re)building traditional dry-stone walls along boundaries between pastures and forests, to establishing large tree-free corridors alongside communication networks, re-introducing sheep and goats, and introducing deciduous tree varieties. However, the question remains of how to lower the quantity of accumulated dry grass and pine needles. One possibility would be to re-introduce the traditional cultural landscape of pastures and sporadic deciduous trees (forest pasture). The use of prescribed fires is based on the idea of extinguishing small fires before they become very large [92].

Automated daily wildfire risk forecast system in Slovenia

In Slovenia, an automated daily forest fire-risk forecast system with a free web application was developed using the Canadian Meteorological Fire Hazard Indicator [98,113,114]. The system uses the ALADIN and INCA meteorological models to provide fire hazard forecasts three days in advance. The Canadian Meteorological Fire Hazard Indicator uses four meteorological variables – air temperature (°C), relative humidity (%), wind speed (km/h) and precipitation (mm) – to calculate three fuel humidity indicators.

(1) Fine Fuel Moisture Code, which represents the moisture content of the fine fuel on the forest soil surface, such as foliage, needles and other plant residues.

(2) Medium Moisture Code, which represents the moisture content of the soil horizon from partially decomposed plant residues.

(3) Drought Code humidity indicator, which represents the moisture content of deep soil layers [115].

The Canadian Forest Fire Weather Index System was tested in southwest Slovenia and achieved an adequate degree of accuracy in predicting fire risk [116–118].

The new approaches will include existing machine learning methods [120] **and the integration of the models into the Geographic Information Systems of the fire protection agencies** [118]. The results from the model are publicly available on the Slovenia Forest Institute website [121]. The model is used by different stakeholders to (1) calculate fire risk and support fire management; (2) develop firefighting exercises; and (3) support planning during a fire.

6. Landscape fires in Germany

Disaster cycle phase	Integrated Fire Management
Domain	Technical and political
Approach	Research and development in conservation and wildfire DRR on UXO-contaminated lands
Technologies	Prescribed fires, armoured prescribed burning and firefighting technologies

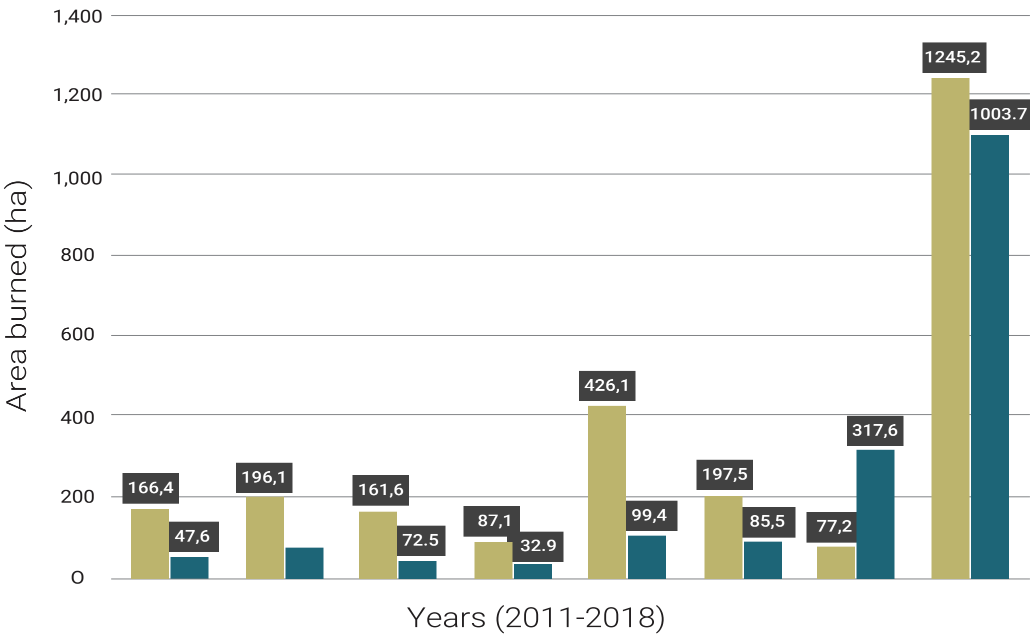
Wildfires in Germany burn across a mixture of cultural and natural landscapes, including forests, agricultural lands and conservation areas. Statistical data on landscape fires, however, are available only for lands classified as forests. These statistics reveal that since the mid-1970s the average total forest area affected by fire in Germany ranged between 200 and 500 ha a year, with an average size per fire event of around 0.5 ha (Fig. 4). **The limited occurrence and impact of forest fires are attributed to the temperate climate characterized by a balanced distribution of precipitation, the healthy conditions of intensively managed forests, the high density of forest road networks (which provide access for large log trucks as well as for fire service vehicles), the array of rural volunteer fire and rescue services, and public adherence to legal restrictions and prohibitions on the use of fire in forests, agricultural lands and disposal of vegetation residues** [122,123].

Until 2017 wildfires mainly affected coniferous forests. The increase in the share of deciduous forests affected by wildfires from 2017 reflects the prolonged dry spells during this period.

With the onset of extreme droughts in 2018 (as a consequence of climate change), the number of wildfires and the size of the area burned increased significantly. One of the reasons for the increase in scale since 2018 is that many of the fires where in forests and open landscapes contaminated by unexploded ordnance (UXO). In Germany, there are more than 630 active and decommissioned military training areas covering around 685,000 ha – approximately 0.2 per cent of German territory. Most of the training ranges are open-land ecosystems with a high conservation value; more than half of them are registered under the Natura 2000 Network. About 250,000 ha of these areas are contaminated by UXO. In addition, conflict sites from WW II – like

Thick smoke spreading over the hill during forest fire. (Europe)

Figure 2. Forest fire statistics for Germany 2011-2018; area burned (ha)

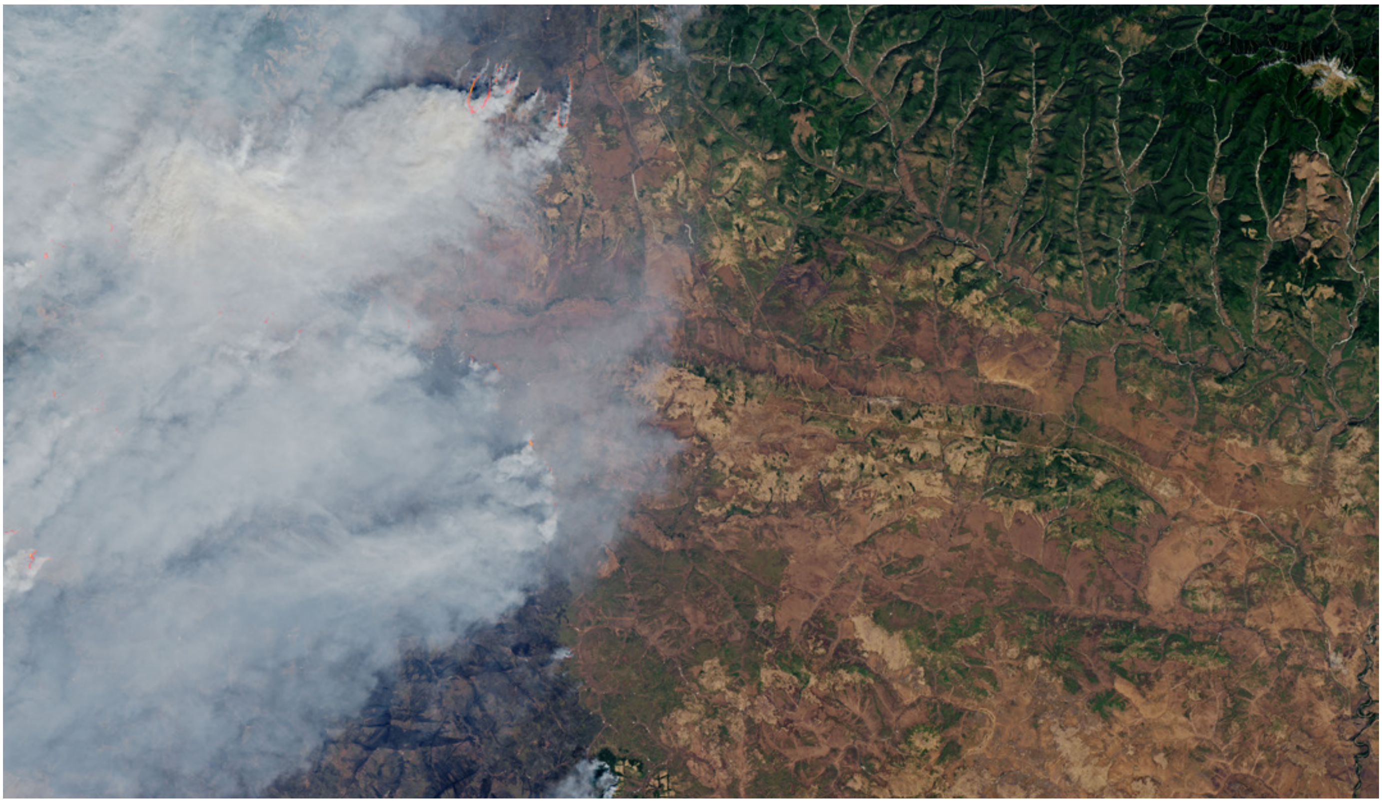


Note: Green – coniferous forests; Orange – deciduous forests. Credit: German Federal Agency for Agriculture and Food.

those around Berlin (ca. 400,000 ha) – are suspected of being contaminated by UXO [124,125]. According to the safety rules for fire and rescue services and explosive ordnance disposal services, firefighting units must maintain a safe distance of 1,000 metres from a fire burning on UXO-contaminated terrain. This means that none of these dangerous fires can be directly suppressed by conventional ground and aerial means. The wildfires that affected UXO-contaminated sites near Berlin in 2018 and in Lübtheen in Mecklenburg-Vorpommern State in 2019 illustrate these extraordinary conditions [123].

In anticipation of the increasing threat of wildfires in Germany – as predicted by global and regional climate change models – two research and development projects were established to develop tools specifically tailored for decision makers and practitioners. The German Natural Disasters Research Network focused on the development of landscape fire prediction and fire behaviour models [126]. Methods for the use of prescribed fire in conservation, landscape fire management and the development of safe technologies for prescribed burning and fire suppression on UXO-contaminated lands were developed as part of an R&D project entitled 'Development and tests of methods for health management on UXO-contaminated sites by prescribed burning' [124]. Subsequently, concepts for the design of fuelbreaks to separate UXO-contaminated areas from residential areas and other valuable sites at risk were developed; these integrate conservation and forestry approaches, including the application of prescribed fires and grazing.

However, there is a major impediment to the systematic application of these tools. According to the Basic Law of the Federal Republic of Germany (the Constitution) the responsibilities for fire prevention and suppression lie with the states, and are decentralized to local and county levels. An intervention by the federal government – such as the deployment of the armed forces – is possible only in a declared emergency. This is one of the reasons for the lack of a coherent and cohesive national landscape fire management strategy. In addition, none of the state fire academies in the 16 states offer training on landscape fire management – a consequence of the low wildfire risk over the last half century. The Global Fire Monitoring Centre (GFMC), an international institution working at the science–policy interface, provides services to the German authorities and scientific institutions in landscape fire research, technology development and fire management [127]. GFMC was Germany's contribution to the UN Decade for Natural Hazard Reduction and its successor arrangements – the UNISDR and UNDRR – and has been hosted since 1998 by the Max Planck Institute for Chemistry. During a



Fire smoke in Siberia - Nasa Earth Observatory thematic conference, 'Impacts of climate change on landscape fires: challenges and solutions for Germany and the European Union', held in the German Parliament (Bundestag) in October 2019, discussions were held on initiating a dialogue to review the Basic Law in regard to crisis preparedness and mitigation at the national level. The recent COVID-19 pandemic has also helped to highlight the limitations of decentralized governance in crisis prevention and management, prompting calls for reform.

7. The RESCULT project: development of a European mechanism to support risk assessment for cultural assets and heritage

Disaster cycle phase	Prevention
Domain	Technical/Social/Economic
Approach	Study
Technologies	None

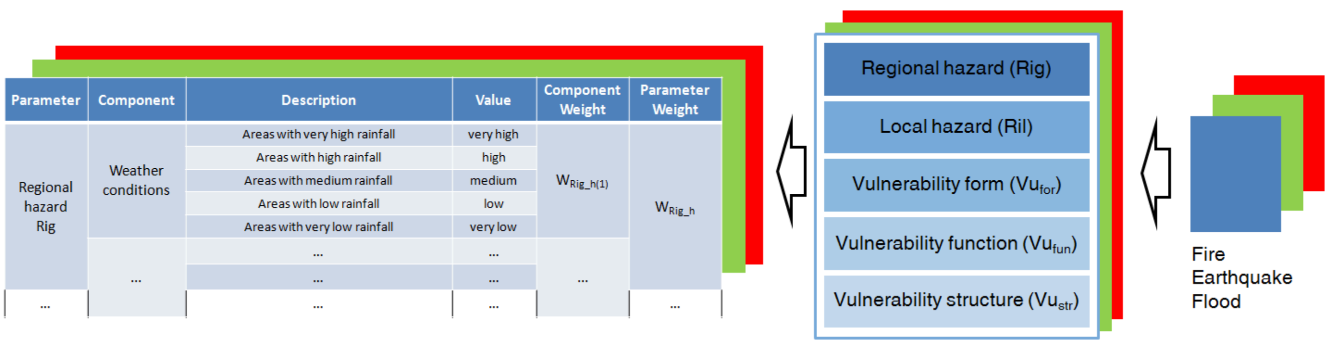
The RESCULT project (2017-2019) is a European project coordinated by the LINKS Foundation, a non-profit research institute. The project developed a European Integrated Database to support disaster responders in the complex task of protecting cultural heritage. It provides reliable, useful and usable data, increasing interoperability among relevant stakeholders (municipalities, firefighters, police, cultural heritage managers) and improving risk and impact assessment processes.

With regards to risk assessment, the project developed a methodology – Asset Risk Evaluation Cards (AREC) – to provide a cultural heritage risk certification against fires, floods and earthquakes (Fig. 5). Using a set of input parameters, including cultural heritage characterization indicators (type, dimension, issues, location, position, etc.), hazard characterization indicators (type, extension, magnitude, time-lapse, etc.) and vulnerability related parameters, the methodology assigns risk rankings for each cultural asset. The aim is to identify the risk level against specific threats (fires, floods and earthquakes) or from a multi-hazard perspective. The weighting of hazard and vulnerability parameters (Fig. 6) is calculated through the SMARTER statistical method (Simple Multi-Attribute Rating Technique Extended to Ranking).

One of the key strengths of the methodology is that it has the potential to support all disaster cycle phases. Prevention and preparedness are addressed through the identification of vulnerabilities, triggering possible preventive measures. During the response phase, the system assists first responders in prioritizing specific actions and intervention procedures. During the recovery phase, the system provides information to local authorities to inform reconstruction strategies.

The methodology was successfully applied in Venice (Italy) to assess a number of churches and historic buildings located near San Marco Square. It was also tested in other European countries, supporting efforts against floods and wildfires that threaten archaeological sites or cultural assets.

Figure 3. Sample of AREC Indicators.



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François Joseph CHATELON is an assistant professor at the University of Corsica, France, where he got his PhD (1996). Prior to entering the field of wildland fire he worked in the areas of fluid mechanics and physical oceanography, solving the Navier-Stokes and shallow water equations. His three main areas of research interests are: 1) Development of a physical simplified surface fire spread model. 2) Development of sub-models which take the convective effects into account. 3) Investigations on fire eruption's occurring.

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