3.10 Climatological risk: wildfires

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3.10.1 Introduction – wildfires in the context of natural and man-made hazards

About 4 % of the global vegetated area is burnt every year by fires (Giglio et al., 2013; Hantson et al., 2015). Wildfires have significant impacts on humans and on the natural environment. They affect human lives and livelihoods (Finlay et al., 2012) and result in high social and economic costs, associated not only with the damages, but also with the prevention and suppression measures put in place every year (Birot, 2009). Fires cause large increases of atmospheric emissions and pollutants (Carvalho et al., 2011), cause soil erosion (González-Pérez et al., 2004), reduce the provision of goods and services by forests (Mavsar et al., 2013), and change land cover patterns and landscape ecosystem dynamics (Moreira et al., 2011; San-Miguel-Ayanz et al., 2012).

Wildfires, which are often caused by humans, have a large impact on human assets and the natural environment, contributing to atmospheric pollution and reducing the provision of goods and services from forests and other ecosystems.

Wildfires are commonly considered natural phenomena for many ecosystems, as wildfire ignition and spread are greatly driven by vegetation and meteorological conditions. However, humans have used fire for land use management and hunting for at least the past 100 000 years (Bowman and Panton, 1993). Nowadays, human-caused wildfires have become a major hazard for the environment and human assets globally. An analysis of fire causality in Europe shows that more than 95 % of the fires in this region are caused by negligence or arson (Ganteaume et al., 2013). Likewise, an analysis of fire causality worldwide shows that most wildfires are caused by humans (Krawchuck and Moritz, 2011).

However, although wildfires are most often initiated by human actions, their intensity and their effects are mainly driven by fuel condition and availability, vegetation structure (Gonzalez-Olabarria and Pukkalaet, 2011) and prevalent meteorological and topographic conditions. In the context of this subchapter, wildfires are considered a natural hazard, regardless of their ignition source.

3.10.2 Wildfires – definitions

Definitions of wildfire vary according to the scientific or operational context in which the issue is discussed. Until recently, in Europe, the most commonly used term to define and discuss wildfires that are not the result of a controlled human activity (these would usually be called 'prescribed fires') was 'forest fire'.

This chapter uses the term 'wildfire', as it is more general than the term 'forest fire' and includes fires that affect other vegetation types such as grasslands, shrublands and other non-forest land covers.

A forest fire, according to EU regulations (EC, 2003) is a fire that starts in any land cover and spreads to affect forest areas, these being forests as defined by the FAO (1998). However, the term 'wildfire' is more general than that of forest fire and includes fires that affect other vegetation types different from forests. This term is thus more applicable to fires that affect grasslands, shrublands and other non-forest land covers.

3.10.3 Wildfire risk

3.10.3.1 Definition

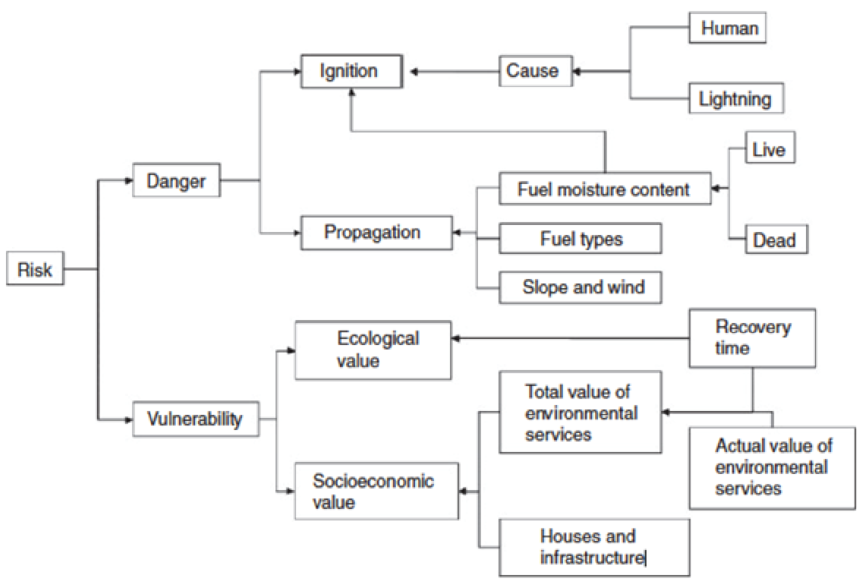
The definition of risk used by the IPCC's special report Managing the risks of extreme events and disasters to advance climate change adaptation (2012) is that risk is a function of hazard, exposure and vulnerability. This subchapter uses these terms as key components of the wildfire risk. In other fields, such as the prediction of droughts or earthquakes, risk is often considered as the conjunction of two factors, namely the hazard, or potential threat to humans and their welfare, and the vulnerability, or exposure and susceptibility to losses.

Traditionally, wildfire risk has been assessed at national or local scales using individual data sources and methodologies. This has led to local or national indices that are not comparable either across Europe or worldwide. In addition, there are differences of opinion over the definition of fire risk. According to the FAO's terminology (FAO, 1986), forest fire risk is 'the chance of a fire starting as determined by the presence and activity of any causative agent'. The Vocabulary of Forest Fire Terms compiled by the DELFI forum (1999) supports this definition, stating that fire risk is 'the probability of fire initiation'. Other approaches consider wildfire risk as 'the potential number of ignition sources' (Hardy, 2005). It should be noted that fire ignition is not the same as fire initiation, since not every ignition outbreak develops into a fire.

Other authors suggest wildfire risk to be the probability of wildfire occurring at a specified location, and under specific circumstances, together with its expected effects (San-Miguel-Ayanz et al., 2003). Wildfire risk has also been defined as 'the probability of a fire to happen and its conse-

FIGURE 3.47

Proposed framework for an integrated fire risk assessment system
Source: adapted from Chuvieco et al. (2010)



quences' (San-Miguel-Ayanz, 2002), following the general UNISDR terminology of risk (UNISDR, 2009), while other definitions consider that fire risk is 'the union of two components: fire hazard and fire ignition'. In this case, the overall risk depends on the fuel and its susceptibility to burning (i.e. hazard), and on the presence of external causes (both anthropogenic and natural) leading to fire ignition and spread.

Wildfire risk is derived from the combination of fire hazard and fire vulnerability, namely hazards related to the presence of fuels and ignition sources, and vulnerability related to the assets at risk.

The international standard on risk management, ISO 31000, defines risk as the 'effect of uncertainty on objectives'. For this definition of risk, there needs to be a clear objective, for example, avoiding significant human impacts from wildfires. Recent studies at the local and global levels describe wildfire risk as being derived from the interaction of two components, fire danger and vulnerability. In this case, fire danger is equivalent to fire hazard (see Figure 3.47).

3.10.3.2 Components

Considering the most recent definition above, fire hazard can be defined as the combination of the presence of ignition sources, fuel availability and conditions for fire ignition and spread (fire behaviour) (Oliveira et al., 2014). It thus refers to the conditions under which an ignition can result in a wildfire, as a result of the availability of fuels and their condition, and the prevalent meteorological conditions. Vulnerability refers to the susceptibility of suffering damage. This term is often associated with exposure, as vulnerability exists if a series of assets (such as lives or property) are exposed to damage by wildfires (Galiana-Martín and Karlsson, 2012). This approach is consistent with the ISO 31000 standard.

3.10.4 Existing knowledge and the issue of scale in fire risk assessment

Wildfires are a recurrent phenomenon, and their importance in the earth system is widely recognised (Dwyer et al., 1999; Bowman et al., 2009; Flannigan et al., 2009; Scott et al., 2016). Wildfires affect many regions in the world and their impacts are evident in natural systems and human society.

Owing to the many factors that affect fire risk, the issue of scale is highly relevant in the assessment and management of risk. At local to national scales, the assessment of wildfire risk is accompanied by mitigation measures aimed at reducing fire risk by increasing prevention and preparedness. At the supranational and global scales, assessment aims to reduce the negative impacts of wildfire by establishing international guidelines and agreements for best practice among the wildfire management organisations. Organisations such as UNISDR seek to establish common nomenclatures and methods for the assessment of risks. At the European level, an initiative to compile information on National Risk Assessment good practice is currently ongoing. An analysis of the resulting data will provide guidelines on good practices for the assessment of wildfire risk in Europe and, probably, at the global scale.

Although there is a vast knowledge of wildfire risk-related issues, information varies according to the scale at which risk is assessed, varying notably from local to regional or global scales.

Therefore, the involvement of so many organisations in fire management, from national to local level, means that clear definitions of authority, functions, tasks and responsibilities, together with an effective coordination of their inputs is essential. The influence of the multilevel governance structure is a key issue in wildfire management (Aguilar and Montiel, 2011).

3.10.5 Wildfire information systems: regional, national, global

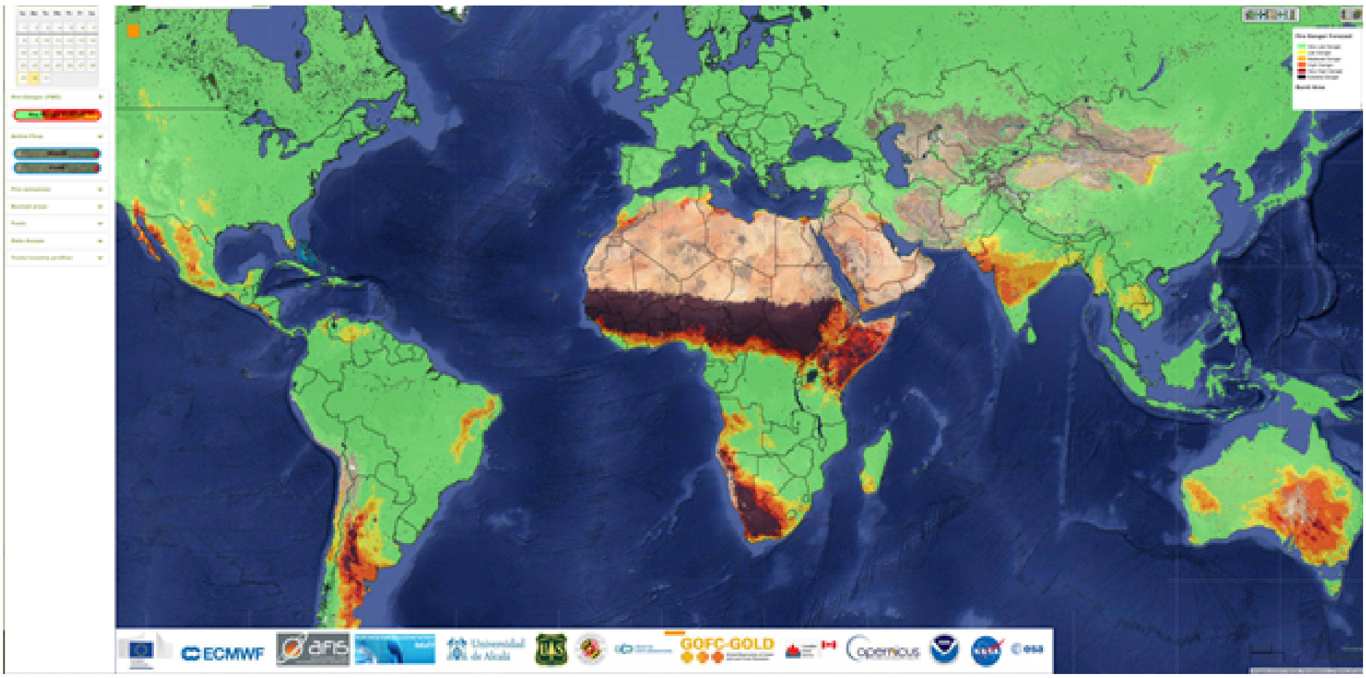
Often, fire management is the responsibility of local to regional agencies within a country, although these operations are commonly supported by national governments. In developed countries, the increase in the number of human-caused fires and the large economic losses caused by them have triggered forest fire prevention and, in particular, firefighting programmes.

A range of infrastructural components including hard infrastructure (e.g. control centres), plus education and awareness raising (strategic as well as tactical or responsive) are part of permanent programmes. Moreover, expenditure in firefighting equipment and operations has escalated in recent decades, especially with the increasing use of aerial firefighting.

As technology has evolved in the last decade, modern methods for the analysis of fire risk components and the evaluation of fire effects have found their place in national, regional and global organisations. Accordingly, wildfire information systems often include modules for the dynamic evaluation of fire danger and the frequent update of fire risk components such as fuel distribution, structure and moisture content. Satellite technology and Geographic Information Systems permit the integration of spatial layers of information to analyse spatial patterns of fire occurrence and to derive fire risk at different scales. National fire information systems to assess and quantify fire risk exist in nearly all European countries, although they differ in approach. Regional initiatives of wildfire information systems are the European Commission's European Forest Fire Information System (EFFIS) and the recent Group on Earth Observations (GEO) initiative to establish a Global Wildfire Information System (GWIS) (see Figure 3.48).

FIGURE 3.48

Global Wildfire Information System (GWIS) initiative of the GEO and Copernicus programmes
Source: GWIS (2017)



Both initiatives are currently under the umbrella of the EU Copernicus Regulation. These systems benefit from other initiatives aimed at deriving relevant information, such as the Climate Change Initiative of the European Space Agency (ESA).

3.10.6 Wildfire management: prevention, preparedness, impact assessment, restoration

The wildfire policies adopted by most European countries over the last century have been based on fire exclusion regardless of their specific context. Nowadays, this approach is widely recognised as being neither ecologically desirable nor economically feasible. Total fire exclusion policies have significant consequences for the magnitude and frequency of wildfires, through an increase of fuel accumulation, the loss of resilience to fire and the alteration of fire regimes. New approaches to wildfire defence are required to improve the strategies of prevention and suppression (Montiel and San-Miguel, 2009). A further step is given by the concept of integrated fire management (Sande Silva et al., 2010). It involves the consideration of the various aspects of fire in suppression and prevention as well as the use of fire as a tool for management practices.

An integrated system for wildfire management must consider the different phases of the fire cycle. According to the definition of fire risk in the sections above, wildfire management requires the monitoring of all the factors that affect fire ignition, spread and impact. It also requires action to prevent and mitigate fire impacts. Fire prevention must target the reduction of fire ignitions as well as the management of fuels, as these are the only factors affecting fire propagation upon which we can act. Whenever the fire exclusion policy is predominant, this fuel management is commonly restricted to reducing fuel spatial continuity, by fuel breaks, or fuel amount using grazing or mechanical means. Those fuel reduction operations can be eventually used for the generation of biomass energy. In many regions, the result of the fire exclusion policy is often the continuous accumulation of fuel, which, when ignited, can result in uncontrollable wildfires (San-Miguel-Ayanz et al., 2013; Viegas et al., 2009). However, prescribed burning is not widely accepted in many countries, particularly because of potential accidents and negative public perception. Policy conflict between different government departments occurs in other areas, for example in the conversion of land for certain forms of wildlife habitat such as heathland, and housing development on land surrounded by vegetation at significant risk of ignition. It is important that these conflicts are worked through and resolved.

Since most fires are caused by humans, fire prevention activities require measures to prevent these ignitions, which can be the result of negligent behaviour or criminal actions. This implies the implementation of education programmes in rural areas where the fires take place. In many places, it is necessary for these to be dynamic and recurrent. Fire is a common tool in agricultural management and the elimination of these practices can be difficult to achieve without significant trade-offs. In some countries, government strategies tend to focus on cooperation with rural populations in the safe implementation of prescribed fires (Montiel and Kraus, 2010). In other countries, fire is still used as the main tool to convert forested areas to agricultural or pasture land. Regarding criminal actions in relation to the widespread deliberate burning to clear rain forest, for example in Indonesia and Brazil, strategies for cooperation with the local population and legal actions must be put in place.

Wildfire management comprises the totality of the fire cycle, before the events in the prevention and preparedness phases and the post-fire assessments that lead to the implementation of restoration measures.

Preparedness refers specifically to activities in the period immediately before fire initiation, notably at times of the year when fire hazard is greatest. Modern technologies for the assessment of vegetation dynamics and meteorological weather prediction systems allow forecasting of fire danger conditions, resulting in enhanced preparation for firefighting. The use of remote sensing techniques has become common among forestry and civil protection organisations. Remote sensing permits the near-real-time assessment of fire spread, which can be used in decision-making for the deployment of firefighting crews and equipment during large wildfire events. Remote sensed information is also used to assess fire effects at a very low cost, which complements necessary field campaigns for the in situ assessment of damage and the planning of restoration measures.

3.10.7 Other hazards such as windstorms and pests and their relationship to wildfire risk

Other natural hazards that worsen the conditions for wildfire management often result in an increase in the levels of fire risk.

Prolonged droughts (see Chapter 3.9) and heatwaves (see Chapter 3.8) dry out fuels and help to create the conditions for uncontrollable wildfires (Gower et al., 2015). Examples of these are the fires that occurred in 2003 in Portugal and southern France, and in 2007 in Greece. Windstorms can result in the sudden accumulation of large amounts of fuel, which are often difficult to manage or extract. Furthermore, the difficult arrangement of fuels on the ground hinders the effective implementation of fire prevention measures and hampers firefighting operations. Examples of these situations occurred in the areas affected by Storm Gudrum in Denmark and Sweden (2004), which resulted in the world's largest stockpile of wood (de Rigo et al., 2016), and Storm Klaus (2012) in France.

In Europe, heavy attacks by insects and phytopathogens can have major impacts on forests, resulting in reduced forest health and, sometimes, widespread tree death (FOREST EUROPE, 2015). Standing dead timber poses an increased risk of wildfire. The loss of economic value may induce lack of fuel management and increase the fire risk. The accumulation of dead and fallen woody fuel following windstorms (see Chapter 3.7) also makes these forest areas more prone to attacks by insect pests and further increases their vulnerability to wildfire.

Other hazards, such as pest outbreaks or windstorms, may increase wildfire risk and hamper wildfire prevention measures.

However, wildfires can also influence other hazards. They are particularly shaping the flood scenarios in the fragile Mediterranean-type ecosystems, where the peak flood and the suspended material load of water streams increase significantly in post-fire conditions, inducing soil erosion, floods and landslides.

3.10.8 Harmful effects of wildfires on human population and health

The effects of wildfires include damage to land cover, which encompasses the loss or degradation of natural values and the decrease or failure of provision of ecosystem services in the affected areas, which can be temporary or permanent. These include, among other things, soil protection, water purification, recreation, tourism, etc.

In addition, wildfires emit large volumes of gases that affect the human populations in the areas affected by them. Wildfire emissions contribute considerably to the total global atmospheric carbon emissions and are a concern from local to global scales. At the global scale, assessment of emissions is compiled in the Global Fire Emissions Database - GFED (Randerson et al., 2015).

In addition to economic and environmental damage, wildfires pose a serious threat to human populations, producing negative effects on human health and increasing death tolls.

At the local scale, wildfire emissions can have harmful effects on the local population (Finlay et al., 2012; Bowman and Johnston, 2005). The effects of atmospheric pollution by wildfires include the aggravation of respiratory problems in the population and can result in the deaths of more susceptible individuals. Serious problems to human health were recorded in many critical fires during the last decade; possibly the most noted events were those in Indonesia and Russia in 2010 and Indonesia in 2015. The Indonesian fire event in 1997 resulted in an estimated 45 000 km^2 of forest and land being burnt on the islands of Sumatra and Kalimantan, releasing between 0.81 and 2.57 Gt of carbon to the atmosphere, equivalent to 13–40 % of the mean annual global carbon emissions from fossil fuels. As a result of this fire, an estimated 20 million people in Indonesia suffered from respiratory problems, with 19 800-48 100 premature mortalities (IFFN, 2000). Russia reported a death toll of about 700 people daily in connection with the smoke problems caused by peat fires in the Moscow region in 2010 (The Guardian, 2010). Less well known is the significant psychological effect that some people can experience after close contact with wildfire (Eisenman et al., 2015).

3.10.9 Contextual factors affecting wildfire risk

3.10.9.1 Climate change

Currently, an average of 400 million ha of natural areas are burnt annually at the global level (FAO, 2015: 245). Many organisations, including the IPCC (2014) contribute to the assessment of the relationship between climate change and fire occurrence, supporting wildfire prevention in the context of global change. A number of researchers have highlighted the potential changes in fire climate regimes in different parts of the world, which may result in increased fire risk and exacerbation of the effects of wildfires, especially in the Boreal and Mediterranean climatic regions (Barbero et al., 2015). Climate studies in Sweden show that more fires, especially in south-east Sweden, with a fire season that is about two times longer than the current fire season, is expected, with attendant climate change scenarios (Sandahl, 2016).

The effect of climate change in the United States (Westerling et al., 2006) has already led to an increase in large-fire activity in the western United States, with longer wildfire duration and longer wildfire seasons. Likewise, climate change is associated with an increased fire danger and consequent larger burnt areas in the EU Mediterranean region by the end of the century (Amatulli et al., 2013; Khabarov, et al., 2014). The increase in fire activity and burnt areas will consequently lead to an increase in fire emissions in Europe and globally (Jolly et al., 2015). The economic impact of climate change, including the effects of wildfires, has recently been assessed in the context of the Peseta II project of the JRC (Ciscar et al., 2013).

3.10.9.2 Socio-spatial factors of wildfires: population, land cover and land use change, and landscape dynamics

Socio-spatial factors have a major role in the management of wildfire risk. As noted in the literature, there is a proven relationship between ignitions and human populations (Bowman et al., 2011). Furthermore, the increase in the intensity of wildfires results every year in a number of human casualties and large economic losses due to the destruction of human assets (San-Miguel-Ayanz et al., 2013; Viegas, et al., 2009; EM-DAT, 2009). The expansion of the so-called Wildland Urban Interface (WUI) leads to an increase in wildfire risk and to the much more difficult management of wildfires. Often, fire-fighting crews must protect human assets and disregard the fighting of wildfires, limiting their intervention to the protection of human lives and properties.

Wildfire risk is affected by contextual factors. The main factors are climate change and socio-spatial factors such as population, land cover and land use change, and landscape dynamics.

The changes in land cover and land use patterns due to the movement of population from rural areas to urban centres in many parts of the world, and the consequent decline in fuel management in these areas, leads to an increase in fire risk and higher intensity of wildfires (San-Miguel-Ayanz et al., 2012).

Wildfires are a complex socio-spatial

issue. However, both systemic components – space and society – have usually been dealt with separately. The spatial patterns of wildfires have been analysed at the regional scale, using the available data and employing methods of comparative analysis for producing an overview of fire occurrence in Europe (Chas-Amil et al., 2015; Montiel and Herrero, 2010; Salis et al., 2014). Interesting literature on the spatial distribution of fire occurrence has also been developed at the municipal level (Fernandes, 2016; Martínez-Fernández et al., 2013). The social aspects, which are basically related to community-based fire management and community wildfire relations beyond wildland fire causes and wildland fire defence organisation, are less well known.

The temporal patterns and the evolution of the spatial patterns through history have also been less studied, owing to data limitations. The temporal dimension of wildland fires has been mainly explored in the short term, considering the different periods of the existing statistical series, although some studies have analysed fire history on the basis of lake charcoal deposits from the last 12 000 years (Whitlock and Larsen, 2012). The interactions between environment factors, the social context and the fire regime over the long term, as well as changing fire behaviour spatial patterns, resulting in the creation of new territories at risk, are still largely unknown. Furthermore, it is essential to take into account the territorial contextual factors (land cover and land use, meteorological factors, land tenure, cultural and organisational aspects, public policies) that interact and influence fire occurrence to better understand wildland fire causes (Beilin and Reid, 2015; Montiel and Galiana-Martín, 2016).

The interactive evolution of spatial and human issues is defining different land-type fire scenarios at various scales. The concept of fire scenario (Montiel and Galiana-Martín, 2016) has provided an important conceptual foundation by which to understand connections between landscape patterns and dynamics and fire behaviour (propagation patterns). The use of fire scenarios is thus useful to establish fire-design management strategies at the landscape level (Costa et al., 2011; Moreira et al., 2011) that increase social and ecological resilience and reduce territorial vulnerability to fire risk. Figure 3.49 shows a fire-resilient Mediterranean landscape in Sierra de Gata (Spain), in which diversified land management and fuel discontinuity prevent high-intensity wildfires.

FIGURE 3.49

Wildfire- resilient Mediterranean landscape in Sierra de Gata, Spain. Source: photo courtesy of C. Montiel

3.10.10 Innovation for better understanding and wildfire management

Innovation in wildfire management comes from two main sources: (1) operational experience, in a lessons learning process, and (2) scientific research. Such knowledge and innovations are incorporated in the management activities through, for example, the advancement in methods to quantify and map fire risk components and the incorporation of human factors in the management of wildfires through education campaigns, rural programmes and a better consciousness of human society on the impacts of wildfires. However, there remains a lack of agreement with national and regional fire administrations on the implementation of a common wildfire risk assessment at the European or global levels.

Relevant progress has been made in the implementation of common methodologies to assess fire danger at the European level in the context of EFFIS. At the global level, there are initiatives to promote the production of information that forms the basis of wildfire risk assessment (GWIS, FIREGLOBE, 2008), such as global fuel maps (Pettinari and Chuvieco, 2016), global fire ignition sources datasets, global fire vulnerability (Chuvieco et al., 2014), as well as global burnt area maps (Chuvieco et al., 2016). In addition, global data on fire ignitions and burnt areas are provided by the National Aeronautics and Space Administration FIRMS activity and fed into regional and global systems (e.g. AFIS, INPE, GWIS).

Innovation in wildfire management involves the adoption of new technologies for the assessment of wildfire risk and the incorporation of the human component in the implementation of prevention measures.

Some of the areas in which innovation can be further developed are as follows:

- Increased use of fire spread models, coupled with portable, handheld devices to make decisions on site during firefighting (SCION, 2009).
- Increased use of digital technologies and social media to reach relevant stakeholders and lay communities at times of heightened fire risk; use of these platforms to get early warnings of wildfire outbreaks (two-way knowledge exchange).
- Increased synergy between different agencies and departments with responsibility for disaster management. Economies of scale and greater effectiveness in bringing relevant parties/actors together when it matters. This is important for countries such as the United Kingdom, where the risk of storm and flood damage is currently much greater than the risk of wildfires. Working together is likely to engender a better understanding of the impending wildfire problems that climate change is already bringing about — a significant form of preparedness.
- A better integration of the four 'R's (risk reduction, readiness, response, recovery) with shared responsibilities between land managers/owners and the civil contingency community.
- A better understanding that prevention is better than cure (e.g. Firewise (NFPA, 2016)), especially in times of recession when government agencies are being cut back. Hence, land managers are being brought into the risk management process via wildfire fora, projects and other forms of communication. Government financial incentives for forest management (grants) are also manipulated to ensure that applicants understand the need to embrace wildfire risk-reduction policy and practice (GOV.UK, n.d.).
- Increased rooting of government policy in a risk-based framework (HM Tresaury, 2013), driven by climate change and other national risks (e.g. in a National Risk Register (Cabinet Office, 2015)). Better understanding that poor handling of a disaster can be politically damaging in a digital environment when blame can be ascribed with some confidence (Gasper and Reeves, 2011).
- Increased use of the ecosystem framework (e.g. Millennium Ecosystem Assessment - MEA, Mapping and Assessment of Ecosystems and their Services - MAES) to contextualise ecosystems, their goods and services and their values (e.g. via Natural Capital Accounting (BISE, n.d.)), and thus the potential loss from wildfire; e.g. the ecosystem approach has been used to evaluate potential loss from wildfire in a study in the United Kingdom (KWFW, 2014).
- Disaster Management degree (BSc, MSc) courses will help to embed risk analysis in the mainstream.

3.10.11 Research gap

Although innovation provides a better assessment of fire risk components, and research demonstrates the applicability of research methods in pilot projects, there is still a lack of proof-of-concept at an operational level.

Few of the research advances in projects are adopted or implemented by regional or national administrations. This is often due to the complexity in the use of new tools and the inertia of these administrations to change the use of long-established methods, which are well known by staff.

Basic research on the social aspects of wildland fire is very limited. The existing literature is mainly applied research, in particular case-studies of certain aspects of the social dimensions of wildland fires (wildfire human causes and influencing factors; fire laws/policies/regulations; fire management; socioeconomic impacts of wildfire risk; social awareness/vulnerability/resilience to wildfire risk, etc.).

Although progress has been made in the assessment of fire risk components, there is still a need for research on, inter alia, fire risk and behaviour models as well as policy, social and economic aspects.

In general, these scientific publications are analytical descriptions used to assess a specific issue of wildland fire factors or impacts at the local or regional level, instead of the community one which is closer to the social approach because this is the scale at which people organise and interact.

Research is needed in both technical and social spheres. It is easy to predict that developments in wildfire risk management will follow the increase in sophistication and use of digital technologies. These largely support the readiness, response and recovery phases in disaster management. However, it is less easy to be sure that reduction via a decrease in ignition events can take place without significant changes in human behaviour for which social research will be valuable.

The following are a few areas of research that could be prioritised (not in order of importance):

- Refinement of risk models (continual process), based on developments in fire science and better parameterisation, for example based on increased knowledge of vegetation, its phenology and flammability. This will be achieved through basic experimental research, monitoring and modelling.
- Modelling of wildfire risk in the context of predicted land-use change, which is affected by a range of social, economic and environmental (e.g. climate change) drivers. Foresight analysis is very important.
- Gaining a better understanding of wildfire behaviour to support fire prevention and fire suppression activities and to improve fire safety. The development of more advanced fire suppression methods to cope with very high-intensity fires that are becoming more common.
- Economic analysis of wildfire consequences, including all elements of risk management (reduction, readiness, response, recovery) at a regional or national scale in order to evaluate cost-effectiveness of investment in each of these elements. This must include the value of loss of the full range of ecosystem goods and services.
- Land use/cover analysis (both current and future projections) that would better characterise the impacts of landscape structure in fire propagation.
- Policy analysis to understand at national/international levels how wildfire policy can work synergistically with existing agricultural, forestry, urban and habitats/biodiversity policies instead of conflicting with them. Use of ecosystems frameworks to explore trade-offs and provide possible ways forward.
- Social research to understand the perceptions of wildfire risk in the different land management sectors and the constraints to adopting a more realistic approach to it. In other words, why do we still experience so much negligent behaviour? Research to find ways to overcome such obstacles should be undertaken.
- More social research to understand why people commit intentional fires, and how to reduce these motivations and to have a larger involvement of the population in the fire prevention and risk-reduction activities. A better understanding of the interactions between physical and human factors affecting fire ignition is needed.

3.10.12 Partnerships and networks, international collaboration in wildfire management

International collaboration in wildfire management exists in different fora. There are networks that have collaborated to establish common wildfire management practices among countries. For instance, the Voluntary Guidelines: Principles and Strategic Actions of the FAO provide a series of recommended practices for wildfire management (FAO, 2006). These have been adopted by many countries, including most EU Member States.

There are bilateral agreements among many EU Member States for fire prevention and, in particular, for firefighting. In addition, at the European level a general agreement for collaboration exist between countries to share firefighting resources during fire campaigns. This agreement is established under the so-called Union Civil Protection Mechanism (UCPM) and is coordinated by the European Commission's ERCC.

At the global level, one of the most long-lasting initiatives aimed at building and retrieving information on wildfires is that of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) Fire Implementation Team. This brings together researchers and regional networks to generate and analyse information on wildfires at different spatial scales, as well as to develop new methods for wildfire monitoring, management and policy decision-making. The synergies between this network and the GEO Global Initiative on establishing a GWIS may result in improved access to wildfire management information globally.

Regarding community-based cooperation, organised groups of local stakeholders are emerging, especially in Mediterranean countries. These groups contribute to fire management as a result of instrumental motivation, or self-interest (Aguilar and Montiel, 2011).

3.10.13 Conclusions and key messages

There is a vast amount of information on wildfires at local, regional and global scales. However, problems remain at different scales in terms of harmonising or standardising practices for the assessment and management of wildfire risk.

Resilience theory is providing a suitable framework by which to explain abrupt changes in socioecological systems. The importance of community participation and building social capital through collective learning and governance mechanisms has been highlighted as a required basis for building disaster resilience (Aldunce et al., 2015; Aldunce et al., 2016; Montiel and Kraus, 2010; O'Brien et al., 2010). Another relevant contribution of the resilience theory to fire risk mitigation is the capacity to anticipate, prepare and plan (Aldunce et al., 2015), which is one of the theoretical foundations of the concept of fire scenarios. In fact, understanding the role of fire on the landscape and the influence of landscape on fire regime is crucial for the resilience of territories to wildfire risk.

Cognitive hierarchy theory is also a strong theoretical foundation of social learning processes that may enable a reduction in ecological and social vulnerability to wildfire, particularly at the WUI (Galiana-Martín and Karlsson, 2012; O'Brien et al., 2010). Nowadays, one of the most important factors that affect wildfire impacts (and adds risk to humans) is the expansion of the WUI. Considering that the developments in fire policy, in terms of environmental politics, depend on the social construction of fire problems (Hajer, 2000), the social perception of fire risk and fire culture are crucial components by which to understand and enhance support for specific management strategies (Czaja and Cottrell, 2014). This is one of the bases of social prevention programmes for reducing unwanted ignitions, including the promotion of good practices of fire use (Montiel and Kraus, 2010).

The following recommendations would help to enhance fire risk management from local to global scales in relation to three aspects, namely partnership, knowledge and innovation.

Partnership

Engaging the wildfire community with other involved groups in other areas of disaster management or emergency response in order to build on synergies and best practice methodologies.

Engage the lay public and land management sectors, as a unified and non-contradictory 'voice' is vital — confusion always leads to disinterest and failure of communication.

The exchange of research outputs, models, best practice and experience between countries should be encouraged through the continuation of existing international forums and other mechanisms (e.g. Marie Curie and Erasmus programmes in the EU); this is especially important for countries with less experience of wildfires to learn from those with more experience, particularly in the context of climate change.

Wildfire governance schemes are urgently needed in order to obtain consensus between the different stakeholders to create collective willingness and favour the effectiveness of wildfire management systems. It is important to identify the institutions/administrations that are relevant for the implementation of actions related to wildfire risk assessment/mitigation.

Cooperation between the competent authorities and rural communities for wildfire preparedness and damage mitigation should be enhanced through organisation assistance, equipment supply and training sessions for locals. Good governance in wildland fire management requires the conscious regulation of fire use practices and the establishment of an action protocol to arrange cooperation for pre-extinction measures and emergency responses between the different stakeholders.

The wildfire community should engage with world-changing agencies such as the IPCC to ensure that its voice is heard, and that planning for the future takes wildfire risk fully into account. It may be that there are currently too many competing international wildfire bodies, which need to find ways of integrating together as individually they are too small. The IPCC is an example of what can be achieved using a good platform.

Knowledge

Harmonisation or standardisation of practices for the assessment and management of wildfire risk across Europe or at global scale has merit. However, it is more important to reach a common scientific understanding and to facilitate individual countries to deploy such knowledge/wisdom in the best way for the particular needs of the country.

It is necessary to identify if harmonisation is possible for all European countries, or if this would be appropriate only for countries with similar climatic conditions. The same approach should be considered worldwide.

When dealing with harmonisation/standardisation, it is important to identify what needs to be harmonised. This is possible for example for the definition of wildfire and wildfire risk, information systems, actions to take for wildfire management, capacitation of resources, education and information messages during fire campaigns.

Social education and prevention programmes, which aim to increase knowledge of wildfires and to reduce unwanted ignitions, are essential where fire is a traditional land use and resource management tool.

Innovation

Technical research is important but, using current knowledge to the fullest effect, effort must be put into engagement with politicians and senior decision-makers in order to ensure that wildfire management is given strategic support and is resourced appropriately.

Integrated fire management is an innovative concept to reduce damage and maximise the benefits of fire. It includes a combination of prevention and suppression strategies and techniques that integrate the use of technical fire and regulate traditional burning.

Fire scenarios are a new tool for integrating fire management and land use planning to reduce the vulnerability of territories and societies to wildfires. The concept of a fire scenario is useful when confronted with the need to coexist with fire but this requires an understanding of societal discourses and risk constructs at the landscape scale. This innovative approach to fire management provides arguments for adapting land use and forestry practices to the changing fire hazard.

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3.7 Meteorological risk: extratropical storms, tropical cyclones

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3.9 Climatological risk: droughts

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