

CHANGING WILDFIRES

POLICY OPTIONS FOR A FIRE-ADAPTED AND FIRE-LITERATE EUROPE

EASAC Policy report 48

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Foreword

Across the globe, wildfires are increasing in intensity and scale. This report focuses on wildfires in Europe, which are also changing in frequency, timing, and intensity. For example, by the end of this century, southern Europe will face more high-intensity wildfires than today, and on the regional scale, such events may occur as frequently as once every two years. Europe will increasingly have to learn to live with fire and adapt society to a new challenging reality. This EASAC report makes, on the basis of the most recent scientific evidence of the effectiveness of suitable proactive approaches, a critical analysis of the state of knowledge intended to reduce increasing wildfire impacts, framed in local and regional contexts.

The climate is changing, and in many parts of Europe, there will be a large increase in multiyear droughts, leading to an increased probability of extreme fires. In addition to climate change, much of the increase in large wildfires is attributed to widespread land use change in Europe, with the conversion of open landscapes to shrub and forest landscapes. Current fire management policies focus mostly on suppression and are clearly inadequate for addressing the impacts of severe fire seasons associated with a changing climate and land use changes.

Europe is a diverse continent where the conditions and drivers of change differ substantially across regions, with the Mediterranean region having the highest probability of very severe wildfires in the future. However, continental, alpine, and boreal regions also need to be prepared for increased fire risk in the future.

The combined effects of socioeconomic, ecological, and climatic trends have led to a shift in regional fire regimes from fuel-limited to weather-driven. Compared with historical patterns, the area burned today has fewer, larger fires, including extreme high-intensity wildfire events, which poses significant environmental and risk management challenges.

This report also highlights the fact that wildfires have more than just negative impacts. Many ecosystems are adapted to fire, and the use of fire by humans has a very long history, especially in Europe. Fire impacts on ecosystems depend on when, where, how, and how often it burns, with some ecosystems even being dependent on fire. The positive impacts of wildfires in the environment never reach the news, whereas wildfire loss and damage do.

EASAC also underlines the utmost need for strengthening institutional capabilities to address effective wildfire risk governance, cooperation and coordination among stakeholders, as well as efforts to increase fire literacy. In addition to increasing budget expenditures for prevention and restoration and adopting a system to allow effective sharing of sufficient suppression resources among EU member countries, this report calls for European policies to recognize fire as an intrinsic process in European landscapes and reinforce investments in land-use planning, agriculture, and environment policies.

The report links to a number of EU policy areas, such as the Common Agricultural Policy, Climate Strategy, Biodiversity Strategy, Farm to Fork Strategy, the Forest Strategy and the new Nature Restoration Law, and proposes policy options that are becoming increasingly urgent to be put in place both at the EU level and at the Member State level. The report also explores

design principles for the planned large-scale EU tree planting program to avoid inappropriately adding substantial amounts of flammable fuel in already vulnerable landscapes across Europe.

The EASAC document concludes by launching a toolbox of three urgent key messages and eight policy options to enable better management of fires today and to prepare and adapt society for fires in the future.

EASAC's work relies on the input and contributions of Europe's leading scientific experts. I would like to thank all the members of the working group who generously gave their time to make this project a success and to write such a comprehensive report.

Wim
EASAC President

van

Saarloos

Summary

Wildfires in Europe are becoming more frequent and intense, even impacting regions that are historically less affected. This report, prepared by the European Academies Science Advisory Council (EASAC) special working group, examines the drivers behind these changes, explores the consequences, and reviews current wildfire management practices. It advocates for an integrated EU framework for fire adaptation and assesses current policies and strategies. Moving beyond fire suppression strategies alone, this report emphasizes addressing root causes and strengthening institutional capacities. It advocates for enhanced cooperation and coordination across stakeholders, increased fire literacy, and improved funding for prevention, restoration, and land-use planning. This EASAC publication also supports a unified European integrated fire management system to enable the interoperability of qualified resource sharing among member states. The report culminates in a set of three urgent key messages and eight policy options designed to improve today's wildfire management and prepare for future challenges. In the future, nearly one-fifth of southern Europe may experience severe wildfires as often as every two years. Europe must learn to coexist with fire and adapt to this evolving landscape.

Understanding

Wildfires

Defined as unplanned fires affecting various landscapes, wildfires are increasingly complex and driven by intertwined factors such as land use changes, climate change, and social and economic dynamics. Policies must shift from predominantly suppression to integrated, adaptive strategies that manage fire as a natural element, recognizing its ecological roles in specific ecosystems. As such, local or regional definitions of acceptable risk would be beneficial, aiming at addressing only those situations that local policies consider to constitute an unacceptable risk to communities and the environment.

Drivers

of

change

With climate change intensifying droughts and reducing summer precipitation, wildfire risk is predicted to more than double by 2100. Urban expansion, urban sprawl, infrastructure development and land-use changes, such as farmland abandonment and the spread of scrublands and forests also significantly increase vulnerability to fire, necessitating investment in proactive measures to reduce risk.

Ecosystems

and

Risk

Fire has both positive and negative effects, depending on the ecosystem type and the fire timing, intensity and frequency. Certain ecosystems depend on fires for biodiversity, while high-intensity or very frequent fires might have major impacts on ecosystem functioning and related services. Policy frameworks should account for this diversity, with a focus on risk reduction, post-fire restoration and balanced fire use.

Regional

differences

Fire risk varies across Europe. The Mediterranean, for example, faces more intense fires due to regional vegetation characteristics and seasonal weather patterns, whereas wildland–urban-interface areas across Europe require targeted risk management due to increasing exposure to fire.

Current

EU

policies

Current EU policies prioritize fire suppression; however, the increasing intensity of wildfires strongly emphasizes the need for increased investment in proactive fire management along with climate change mitigation and adaptation, prioritizing a reduction in damage over simply minimizing the burned area.

Policy Shifts and Integrated Frameworks

A proactive approach focusing on landscape management, restoration and fire literacy is essential. Instead of a suppression focused strategy, an integrated EU landscape fire risk governance framework should prioritize prevention based on stakeholder collaboration, rural development, risk awareness, behavioral change, and effective risk management on the basis of vertical and horizontal policy harmonization.

Three Urgent Key Messages and Eight Policy Options for Long-term Proactive Wildfire Management

This report aims to embed fire resilience into European landscapes, ensuring that wildfires are managed not only as emergencies but also as part of a sustainable, proactive environmental strategy.

Urgent key messages:

1. Prioritize the Implementation of Climate Change Mitigation and Land Use Policies

Swiftly implement existing EU climate change mitigation plans and land use policies to address wildfire risk intensified by climate change, rural depopulation, farmland abandonment and woody encroachment. The new Nature Restoration Law should also be swiftly implemented, with a particular focus on restoring peatlands and managing forests to reduce risk. Peatlands are critical for preventing significant carbon loss and mitigating climate feedback loops, since peatlands, the most carbon-dense ecosystems on Earth, store approximately ten times more carbon per hectare than boreal forests do.

2. Incorporate Assessments of Wildfire Risk into Biodiversity and Tree Planting Initiatives

Ensure that wildfire risk scenarios are thoroughly assessed and integrated before the Kunming–Montreal Global Biodiversity Framework’s 30x30 strategy and the EU tree-planting program are fully implemented. These initiatives must be aligned with fire-wise landscape management to avoid unintended consequences, such as increased fire vulnerability in afforested areas and exposure of large restoration investments to fire hazard.

3. “Living with fire” - enhance Public Health Interventions and Education on Wildfire Risk

Address the severe health risks posed by wildfire smoke, particularly for vulnerable populations, by improving preparedness and public health interventions. Awareness should be increased through comprehensive education programs for all ages, particularly young populations, fostering a fire-literate society equipped to adapt to the growing challenge of “living with fire” in Europe.

Eight Policy Options for Long-term Proactive Wildfire Management

- 1. Invest in Integrated Wildfire Risk Reduction**
Shift from dominant reactive fire suppression to a more balanced approach, combining proactive and reactive strategies.
 - **Actions:** Focus on reducing fuel in high-risk areas, adopting multihazard planning, and aligning wildfire policies with broader disaster risk frameworks.
 - **Benefits:** More effective wildfire management, reduced costs, and fewer gaps in cross-sector policies.
- 2. Implement Nature-based Solutions (NbS)**
The use of suitable NbS to reduce wildfire risk and support postfire recovery.
 - **Actions:** Implement prescribed grazing, prescribed burning, and native species reforestation
 - **Benefits:** Cost-effective biomass control, co-benefits such as water retention, erosion prevention and job creation in rural areas.
- 3. Embrace the role of fire**
Recognizing fire as part of many ecosystems and allowing planned burns to maintain ecological balance.
 - **Actions:** Support prescribed burning and cultural fire practices to reduce fuel loads and benefit biodiversity.
 - **Benefits:** Reduced wildfire intensity, improved ecosystem benefits, and preserved traditional practices.
- 4. Invest in Education and Communication for Wildfire Awareness**
Increased fire literacy and preparedness through education for all ages.
 - **Actions:** Integrate wildfire education in curricula and public awareness campaigns, which focus on fire literacy and management skills.
 - **Benefits:** Greater public understanding and preparedness, more informed land-use decisions, and skilled professionals.
- 5. Invest in Landscape Management to Reduce Vulnerability**
Design and maintain resilient landscapes that reduce wildfire risk.
 - **Actions:** Promote mixed land use, agroforestry, and targeted conservation to create more fire-resilient environments.
 - **Benefits:** Fire-resilient landscapes, diversified rural economies, and sustainable farming practices.
- 6. Harmonize Sectoral Policies**
Align land-use and environmental policies to prevent unintended increased wildfire risk.
 - **Actions:** Review sectoral policies with potential wildfire impacts, especially around afforested areas, ecological corridors, and urban planning and greening.
 - **Benefits:** Fewer cross-policy conflicts, enhanced biodiversity protection, and reduced wildfire vulnerability.
- 7. Promote compact urban development**
Reduce urban sprawl to limit the expansion of the wildland–urban interface (WUI) and associated fire risk.
 - **Actions:** Incentivize compact urban design, use farmland as a buffer, and integrate wildfire risk in urban planning.
 - **Benefits:** Reduced exposure of urban areas to wildfires, lower carbon emissions, and safer peri-urban landscapes.

8. Encourage Sustainable Private Land Management

Support private landowners in adopting fire-resilient practices.

- **Actions:** Promotion of mixed-species forests, closer-to-nature silviculture, extensive grazing, and climate-adapted farming practices.
- **Benefits:** Reduced fire fuel loads, biodiversity preservation, and stronger rural economies.

Preamble

This report addresses the urgent need for updated policies to manage increasing wildfire risk in Europe. Wildfires are increasing in frequency, duration, and intensity, even in regions historically less affected. Society must adapt to the reality of living with fires. Yet current fire management policies are insufficient for addressing high-severity fires and prolonged fire seasons exacerbated by climate change. Recognizing this critical gap, the European Academies of Sciences Advisory Council (EASAC) convened experts from 17 academies across Europe in 2023 and 2024 to analyse the evidence for proactive, holistic wildfire management policies. Based on the latest scientific findings, this report presents an in-depth review of effective approaches to mitigate wildfire impacts across local and regional contexts.

What are Wildfires?

In this report, *wildfire* refers to all vegetation fires except for prescribed burns and traditional fires regulated by national and regional laws. The UN Office for Disaster Risk Reduction and International Science Council defines wildfires as any unplanned or uncontrolled fires affecting vegetation across natural, cultural, industrial, and residential areas (adapted from FAO 2006) (see also Glossary). Wildfires can be ignited both naturally (e.g., by lightning or volcanic activity) and frequently by human activities.

While related terms exist, such as *wildland fire*—a broad term encompassing any fire occurring in wildland areas regardless of its cause, damage, or benefits (FAO 2006, 2024)—this report primarily uses *wildfire* in line with international standards. *Landscape fire* is another term covering fires in natural and cultural landscapes, such as forests, peatlands, shrublands, grasslands, agricultural lands, and peri-urban areas, regardless of the ignition source or outcome.

Additionally, the term *fire regime* is occasionally used to describe the spatiotemporal patterns, frequency, and intensity of wildfires in a specific area over extended periods (Krebs et al. 2010).

Please refer to the **Glossary** for more details about the terminology used.

Wildfires affect various landscapes, including forests, shrublands, grasslands, peatlands, and urban areas. Wildfires have broad, often severe, impacts on natural ecosystems and socioeconomic systems. The EU climate adaptation strategy, adopted in 2021, aims to make Europe resilient by 2050, including addressing increased wildfire risk. Similarly, the EU Forest Strategy for 2030 acknowledges climate-driven threats, including wildfire risk, facing European forests.

Despite these strategies, resources have been disproportionately allocated to fire suppression over prevention. The United Nations Environment Programme (UNEP) has called for a

fundamental shift in funding, urging the EU and member states to reallocate spending toward prevention and improve monitoring and coordination. Currently, most resources are funnelled into emergency responses, with only a small fraction dedicated to planning and prevention, creating a significant imbalance (UNEP 2002).

Scientific Review of Proactive Approaches

This report provides a comprehensive review of the evidence for proactive approaches to wildfire risk management tailored to the EU context. Effective strategies include fire regime management through land-use planning, fuel management, closer-to-nature forestry, grazing, and prescribed burning. Restoring burned areas and managing vegetation to reduce vulnerability to wildfire impacts are equally critical. The evidence base for the effectiveness of proactive measures is presented in sections A-C, while calls for actions are presented in sections D-F.

Policy Linkages and Recommendations

The report ties into several EU policy areas, including the Common Agricultural Policy, Climate Strategy, Biodiversity Strategy, Farm to Fork Strategy, Forest Strategy, and the new Nature Restoration Law.

Through key messages and recommendations, this report aims to embed fire resilience into European landscapes, ensuring that wildfires are managed not only as emergencies but also as part of a sustainable, proactive environmental strategy.

A. Wildfires, landscapes and people

A landscape approach that views ecosystems as social-ecological systems that deliver vital services has become a central area of research (e.g., MA 2005). It is where people and nature intersect, making landscapes a key arena for addressing sustainability challenges (Plieninger et al., 2018). The landscape approach promotes integrative, transdisciplinary management, bridging divides between diverse land uses, such as forestry, agriculture, livestock, infrastructure, and urban settlements. This approach, if increasingly adopted in policy and practice, would support food production, watershed protection, biodiversity conservation and rural livelihoods as interlinked objectives within the landscape rather than in isolation (Scherr & McNeely, 2008).

Wildfires are increasingly recognized as a landscape issue (e.g., Cochrane and Bowman, 2021; Moreira et al., 2020; Wunder et al., 2021), similarly requiring a shift from isolated, single-focus management strategies to a holistic, adaptive approach that integrates land-use planning, agriculture, forestry, civil protection, and climate and energy policies (Stoof et al. 2025). These interconnected sectors, each of which impacts fire management and broader disaster resilience, call for an integrated, multilevel, multiactor, cross-sectoral governance strategy (Fra Paleo, 2015). This approach prioritizes the reduction of loss and damage over simply minimizing burned areas (Moreira et al., 2020).

In Europe, wildfires are predominantly human-caused (Ganteaume et al. 2013), with outcomes influenced by human-induced landscape alterations and settlement patterns

(Moreira et al. 2011; Bar-Massada et al. 2023). These wildfire-prone landscapes function as social-ecological systems, where resilience is a critical focus (McWethy et al. 2019; Newman Thacker et al. 2023).

Disasters often occur as interconnected hazard events, compounding impacts and creating polycrises that strain resources and intensify vulnerability. This also applies to the small number of global wildfire events that turn into wildfire disasters each year. When hazards occur simultaneously or sequentially, they interact, trigger other hazards and amplify damage in a series of cascading effects. Through “spotting,” fires can spread over long distances, igniting new areas, accelerating the fires and compounding the impact. Fires may be sparked by primary hazards such as lightning or infrastructure failure, and their severity is often fuelled by extreme conditions such as heatwaves or droughts—hazards in themselves that contribute to rapid wildfire spread.

Wildfires can also serve as primary hazards that trigger further hazards, impacting the environment and built infrastructure in two main ways: by altering environmental conditions or directly affecting structures. For example, a wildfire that destroys vegetation can lead to soil erosion and increased runoff during rainfall, resulting in gradual yet significant soil erosion and land degradation. (Swain et al. 2025). These types of cascading impacts, often delayed, require continuous monitoring to be effectively managed.

Natural hazards, including wildfires, frequently set off technological hazards in so-called natech disasters. In wildland–urban interfaces (WUI), fires can cause structural damage to energy infrastructure, disrupt transportation networks, ignite urban and industrial facilities, and lead to further hazards.

Europe's fragmented landscapes create an extensive wildland–urban interface that is highly vulnerable to wildfires (see further in chapter 8). The WUI is especially critical for Europe, where the population density around fire-prone areas is greater than that in regions such as Australia or parts of the Americas (Bar-Massada et al. 2023). The challenge of “living with fire” is therefore especially urgent to address in Europe.

Living with fire: Cultivating cross-disciplinary and cross-border partnerships is key

Living with fire is an aspiration in many regions of Europe, as there is often a need for fire to be integrated into the landscape rather than excluded (Moritz et al. 2014). The acceptance of fire is a key element of resilient fire-prone territories (Newman Thacker et al. 2023). However, for living with fire to become a reality, diversity is imperative (Stoof and Kettridge 2022). The social-cultural context is important (Fig. 1a), as is the diversity that crosses disciplines, risks and borders, as are diverse partnerships, such as those linking academia with practitioners (e.g., Barreiro et al. 2021, Santos et al. 2021) (Fig. 1b).

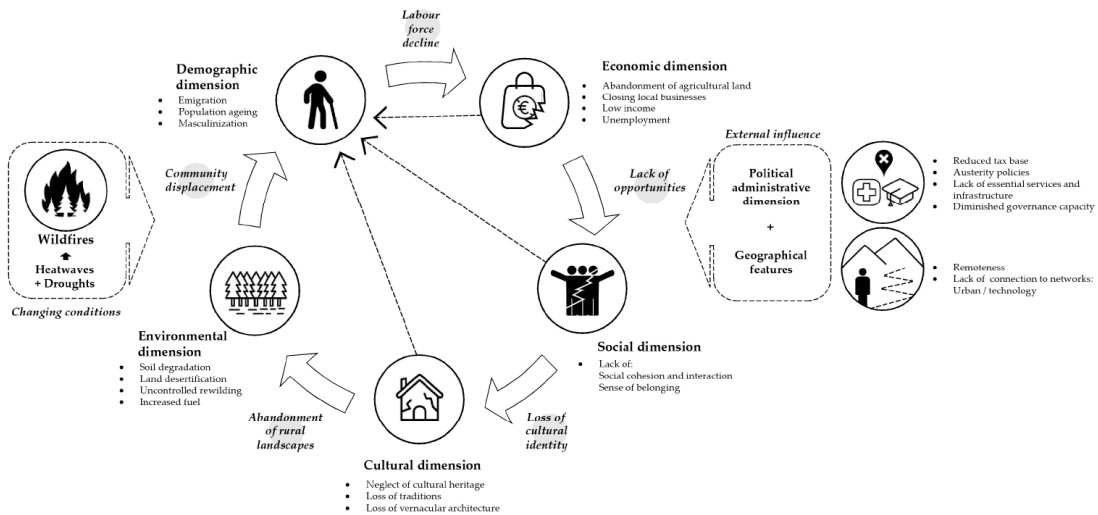


Figure 1.a. The social-cultural context of wildfires. Source: Graus et al. (2024)



Fig. 1.b. An inter- and transdisciplinary perspective on living with fire, the four axes of diversity Source: Stoof and Kettridge (2022).

Engaging inter- and transdisciplinary teams fosters a systems-thinking approach, emphasizing wildfire as a social-ecological process rather than as the isolation of social and environmental aspects. Acknowledging the diversity of wildfire impacts is crucial, as vulnerable and marginalized populations often bear a disproportionate share of the negative effects (Paveglio et al., 2015; Davies et al., 2018; Palaiologou et al., 2018; Ottolini, 2023).

Community preparedness depends on the capacity to integrate wildfire knowledge and actions into daily life, which varies widely across local contexts, highlighting the need for tailored solutions that incorporate traditional and local knowledge (Vigna et al. 2024).

Policy frameworks aiming for coexistence with fire must recognize that response capacities differ across local, national, and international levels and should adapt accordingly. It is equally important to consider the broader disaster risk landscape, as communities at risk of wildfire, as emphasized above, are often exposed to multiple hazards. At the same time, wildfire is just one of many hazards and challenges that local communities face. Investing in general resilience is therefore key (Ottolini et al. 2024).

Summary: Wildfires, landscapes and people

A landscape approach is crucial for addressing Europe's wildfire challenges, viewing wildfires as interconnected social–ecological phenomena requiring adaptive, cross-sectoral governance. Human-induced landscape changes and dense wildland–urban interfaces heighten vulnerability. Emphasizing resilience, *living with fire* integrates fire into landscapes via diverse, interdisciplinary partnerships. Tailored, inclusive policies must address wildfire risk alongside broader cascading hazards to enhance broader disaster resilience and environmental justice

B. Why are Wildfires Changing?

1. Global Wildfire Regimes

Wildfires have been a key ecological process for hundreds of millions of years, shaping biomes and maintaining the structure and function of fire-prone ecosystems (Glasspool et al., 2004; Bond et al., 2005; Archibald et al., 2018) where the scale of both time and space are important (Fig. 2). Over geological timescales, fire occurrence has varied dramatically due to changes in climate, atmospheric oxygen levels, and vegetation patterns. These fires have influenced evolutionary trajectories, with many plant and animal species adapting to specific fire regimes. For example, even high-intensity stand-replacing fires, while often viewed as destructive, may play a crucial role in fostering vegetation succession and creating mosaics of age classes that may increase long-term ecosystem resilience (Bond et al., 2005).

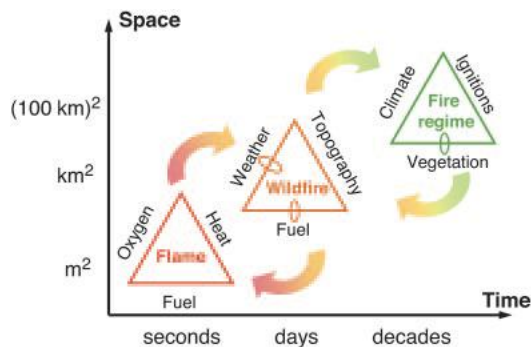


Fig. 2. Controls on fire at different scales. Dominant factors that influence fire at the scale of a flame, a single wildfire, and a fire regime (after Moritz et al. 2005).

From a human perspective, some wildfires may offer critical ecosystem services, e.g., regulating biomass, controlling pests, and maintaining open landscapes for grazing and hunting (Pausas & Keeley, 2019). On the other hand, wildfires often result in the delivery of ecosystem disservices and have negative impacts on human wellbeing, health, and property (Sil et al. 2019). These benefits and harms underscore the importance of understanding and managing fire regimes, particularly in fire-adapted landscapes (Bond et al., 2005, Bond and Keeley, 2005, Pereira et al., 2022).

Fire and Herbivory as Vegetation Consumers

Bond and Keely (2005) considered fire and herbivory as global vegetation consumers, emphasizing their role in maintaining ecosystems that have coexisted with fire and grazing for millennia. Excluding fire from such systems can lead to fuel accumulation, creating a "fire deficit" that results in devastating, uncontrollable fires. This highlights the importance of restoring and managing fire regimes, especially in sparsely populated regions with large continuous habitats, such as parts of Africa, Australia, and the Americas (Fernandes et al., 2013).

Decline in Low-intensity Fires

Globally, approximately 780 million hectares burn annually—equivalent to the size of Australia (Chen et al., 2023). Most of this burned area consists of low-intensity fires in tropical and subtropical savannas. However, these fires decline after agricultural conversion and landscape fragmentation (Andela et al., 2017). In contrast, high-intensity wildfires, which are more destructive and have greater socioeconomic impacts, are on the rise (Cunningham et al., 2024).

A historical example from Australia illustrates this trend. Indigenous Australians have practised fire-stick farming for thousands of years, creating frequent, low-intensity fires that shape the landscape (Steffensen 2020, Bird et al., 2024). The cessation of this practice following European colonization has contributed to the resurgence of high-intensity wildfires (Bird et al., 2024).

A more flammable landscape, driven by climate change, land abandonment, and afforestation, increases the frequency and intensity of wildfires (Cunningham et al., 2024). There is an interplay between climate change and land use changes that intensifies fire dynamics, reshaping fire regimes both globally and regionally (Varela et al., 2020).

High-intensity fires and climate change

Climate change increases wildfire risk by increasing the frequency of extreme weather conditions that promote fuel drying and ignition (IPCC, 2021; Pausas & Keeley, 2021). Many regions are already experiencing larger burned areas and more intense fires. Projections indicate further escalation of fire weather conditions, even under moderate warming scenarios (Cunningham et al., 2024).

While total global greenhouse gas (GHG) emissions due to fires have remained relatively stable—owing to a decline in tropical fires offsetting increases in wildfires in extratropical regions (Zheng et al., 2021)—the regional impacts are profound. Boreal and Arctic regions, for

example, are witnessing rapid changes in fire regimes, as warming accelerates in these high-latitude areas (Kasischke et al., 1995).

In Mediterranean and temperate regions of the world, human activities, such as changes in forest and grassland management, compound the effects of climate change. The result is longer fire seasons, more intense droughts, and sometimes increased lightning occurrences, all of which contribute to greater fire activity (e.g., Hetzer et al. 2024).

2. Changing Wildfires in Europe

Wildfire trends in Europe mirror global patterns, with high-intensity fires increasing and overall burned areas declining (Hetzer et al. 2024). The reduction in burned areas is partly due to the decline in pastoral and agricultural burning, particularly after 2013, due to stricter air quality regulations (Marco and Bo 2013).

European countries report fire data to databases such as the European Forest Fire Information System (EFFIS). Satellite data from the ESA FireCCI project using NASA's MODIS sensor reveal that Europe experiences more than 3 million hectares of burned area annually, with approximately 85% occurring in nonforest habitats (Fig. 3). For example, crop residue burning in Ukraine accounts for more than 60% of the total burned area in Europe (note that since February 2022, war-related fires at a much larger scale have dominated in Ukraine, Matsala et al. 2024, Sergiy Zibtsev pers. comm.).

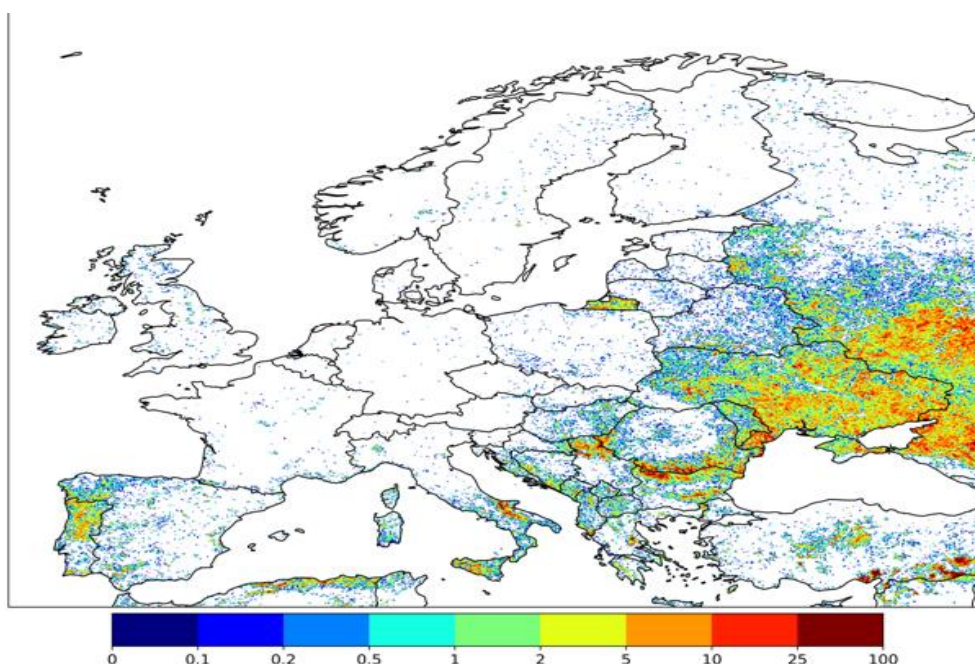


Figure 3. Annual Burned Area in Europe (2001–2019)

The map, which is based on ESA FireCCI51 data, shows significant burned areas in nonforest habitats, with crop residue burning dominating in Ukraine. Mediterranean forest fires are visible at finer scales.

Source: G. van der Werf (unpublished), adapted from Lizundia-Loiola et al. (2020).

In recent years, unprecedented fire events have occurred in Europe. In 2017 and 2018, high-intensity wildfires swept across southern and central Europe, claiming hundreds of lives., Even regions with historically fewer fires, such as Sweden, experienced severe fires driven by extreme droughts and heatwaves. A recent study projected that in Europe, many new areas, such as central Europe and rapidly warming mountainous areas, will likely be exposed to severe fire weather. Fire-prone regions in southern Europe are projected to experience even more extreme conditions (Hetzer et al. 2024).

3. Wildfires and climate change in Europe

Europe's climate has already shifted beyond historical patterns, with 2023 marking the warmest summer in the Northern Hemisphere in more than 2,000 years (Esper et al., 2024). The average global temperature anomaly for the first ten months of 2024 (January--October) was 0.71°C above the 1991--2020 average, representing the highest recorded temperature for this period and a 0.16°C increase compared with the same period in 2023 (Copernicus 2024). Projections under different warming scenarios (SSP1-2.6 to SSP5-8.5) indicate temperature increases of up to 8.5°C by the end of the century, with the Mediterranean region expected to face the most severe impacts (IPCC, 2021).

Projected Changes in Fire Weather

Precipitation patterns are also shifting. While northern and central Europe are projected to experience increased annual precipitation, the Mediterranean could experience decreases of up to 30%. These changes, coupled with rising vapour pressure deficit (VPD)¹ and prolonged heatwaves, further increase fire risk across Europe (IPCC, 2021) (Fig. 4). An increasing atmospheric vapour pressure deficit is a global phenomenon that has clear and usually deleterious impacts on a cascade of plant processes, including carbon sequestration, transpirational water loss, growth, productivity and survival. These impacts are exacerbated by land–atmosphere interactions that link the dynamics of VPD and soil drought (Novick et al. 2024).

Extreme weather events, such as multiyear droughts, are expected to double the probability of extreme fires in Europe by the end of the century (Grünig et al., 2023). Central and southern Europe are expected to experience prolonged fire seasons, with high-intensity fires occurring as frequently as once every two years in some areas (El Garrussi et al., 2024).

¹ The vapour pressure deficit describes the drying capacity of the air, and its exponential rise is one of the most consequential impacts of climate change on terrestrial ecosystems (Novick et al. 2024).

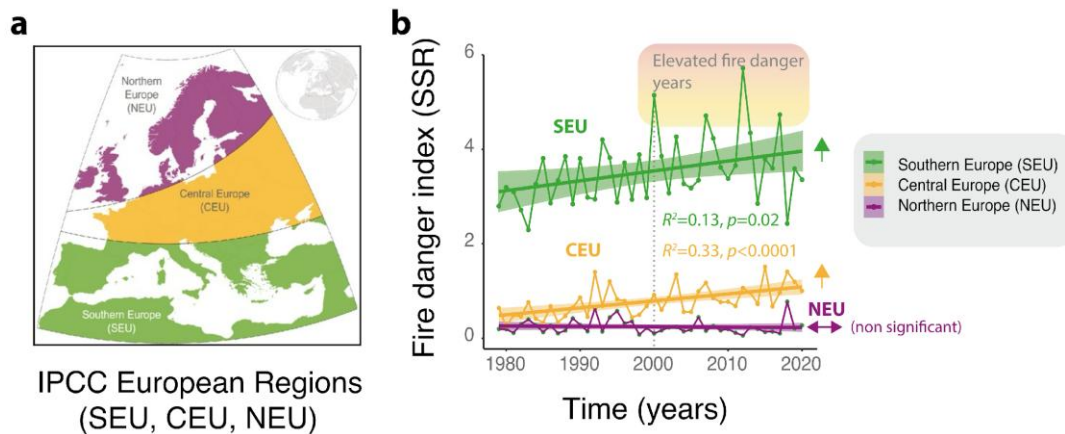


Figure 4. Observed and Projected Fire Weather and Risk Trends

Panel a: IPCC regions in Europe.
Panel b: Seasonal severity rating trends (1980–2019), showing increasing fire severity in southern and central Europe. Source: Carnicer et al. (2022).

Lightning as a cause of Fire

Lightning is also an ignition source for wildfires. While global warming is expected to increase lightning-induced fires in many regions (Romps et al., 2014), Europe’s lightning patterns are projected to shift northwards, increasing risk at higher latitudes. Complex terrain and vegetation dynamics further influence the likelihood of lightning occurrences and ignition (Kotroni & Lagouvardos, 2008; Kahraman et al., 2022).

4. Wildfires and land-use change

The increase in large wildfires and their severe impact across Europe over recent decades is intrinsically linked to land-use changes, in addition to the effects of climate change (Oliveira et al., 2017; Cervera et al., 2019; Mantero et al., 2020; Ascoli et al., 2021). These processes are driven by complex interactions in social-ecological systems, leading to landscape transformations that heighten wildfire risk.

Land-use change is shaped by an intricate interplay of socioeconomic, cultural, biophysical, and ecological factors (Pinto-Correia & Kristensen, 201; Plieninger et al., 2016). These dynamics are influenced by agricultural and forestry market trends, urban expansion, rural depopulation, and evolving public policies at the local, national, and EU levels (Hearn & Álvarez-Mozos et al., 2021).

Recurrent fires also drive land-use change by degrading vegetation, altering species composition, and favouring pyrophytic plants with fire-resistant traits, such as *Cistus* spp. in the Mediterranean (Acacio et al. 2007). This creates fire-prone low scrubland areas and exacerbates erosion, leading to permanent shifts in land use (Acacio et al. 2007).

Agricultural policy, land abandonment, and forest expansion

Agricultural intensification in the 20th century triggered significant rural-to-urban migration. Some reforms of the European Common Agricultural Policy (CAP) since the 1990s have led to agricultural deintensification in marginal areas and, subsequently, forest expansion (Jepsen et

al., 2015). While forest and shrubland cover increased and grassland area decreased, these trends also led to the homogenization of landscapes and heightened fire risk through greater fuel continuity (Ascoli et al., 2021; MacDonald et al., 2000).

Studies reveal widespread land-use transformations across Europe. Kuemmerle et al. (2016) used CORINE and MODIS data to report declines in cropland and forest expansion, particularly in Eastern and Southern Europe. Similarly, ESA-CCI-LC data from 1992--2022 highlight significant reductions in cropland across Central Europe, Spain, Greece, and the Balkans, accompanied by forest growth in Eastern Europe and the Balkans (Fig. 5). These processes also have implications for biodiversity and ecosystem services that are mixed, but in southern Europe, they are predominantly negative (Quintas-Soriano et al., 2022).

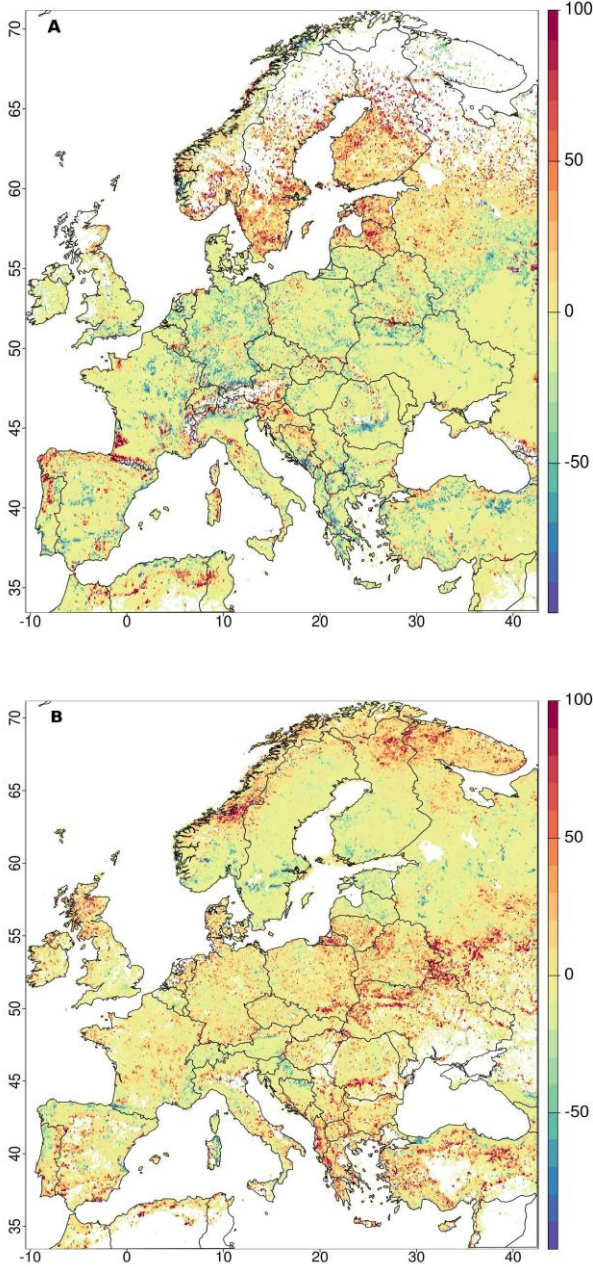


Figure 5

Percentage variation in land use categories, 1992–2022

Panel A: Declines in cropland in Central Europe, Spain, Greece, and the Balkans.

Panel B: Forest growth in Eastern Europe, Greece, and the Balkans. Source: Adapted from ESA-CCI-LC data (Arca, unpubl.)

In Eastern and Central Europe, land abandonment has often led to unmanaged forest regrowth, with many areas dominated by coniferous plantations. These forests are particularly fire prone because of their high flammability (Blumröder & Ibisch 2023). Conifers such as pines produce needle litter and resin-rich cones that are highly combustible (Shafizadeh et al., 1977; Ormeño et al., 2020). Poor forest management and regulatory constraints have further exacerbated fuel accumulation, even in temperate regions historically less affected by wildfires (Maringer et al. 2016)

Future projections indicate continued vulnerability in fire-prone regions such as Spain, Portugal, southern France, Italy, and Greece, where changing land use patterns compound existing challenges (Pawlewicz & Pawlewicz, 2023). Despite all endogenous and exogenous force supporting forest expansion in the 20th century, Oliveira et al (2017) argue that wildfire governance deficits may have been responsible for arresting forest transition and resulted in a loss of afforestation area, since the 1990's.

Hydrological and Climatic Interactions in Fire Risk

Ecosystem productivity is closely tied to water availability, and greater biomass enhances soil water retention, which is crucial for mitigating fire risk (Lal, 2020). Forests and wetlands play a vital role in buffering temperature extremes, stabilizing hydrological cycles, and reducing high levels of vapour pressure deficit, which drive fire risk (Gohr et al., 2021; Miralles et al., 2019).

In regions outside the Mediterranean, where there are no or only short dry seasons, dense uneven-aged forests with diverse understorey vegetation provide a cooler, more humid microclimate and reduce the flammability of combustibles (Pickering et al., 2021). In contrast, even-aged plantations and logged areas lack these buffering properties, leading to drier fuels and prolonged fire seasons (Brown et al., 2023; Blumröder et al., 2021). Soil moisture and temperature dynamics further increase the risk of fire, as drier soils are less resistant to heat and drought (Greiser et al., 2024).

The effects of forest management on fuel moisture often surpass those of climate warming (Brown et al., 2024). In some cases, logging and thinning, while intended to reduce fire risk, can inadvertently increase fire risk by altering structural complexity, desiccating fuels, and changing energy flows (Millikin et al., 2023). Promoting mixed-species forests with diverse age structures is therefore often seen as essential for mitigating these vulnerabilities (Ewald et al., 2023).

Severe wildfires can initiate feedback loops that may lead to ecosystem degradation, increased fire frequency, and shifts in vegetation composition (Landesmann et al., 2020). Recurrent burning may slow recovery, exacerbate erosion, and diminish water retention.

Postfire salvage logging may compound these issues by compacting soils, increasing runoff, and degrading the soil microbiome (Prats et al., 2020; Marcolin et al., 2019).

Summary: Why are Wildfires Changing?

Wildfires are intensifying. Historically integral to many ecosystems, fire regimes are shifting globally and in Europe, with high-intensity fires rising as low-intensity fires decline. Drivers include warming, altered precipitation, inappropriate forest management, and farming decline. These changes heighten fire risk, challenge ecosystem resilience, and demand integrated management to address cascading social-ecological impacts.

5. Wildfires and Carbon

Wildfires release greenhouse gases but may have minimal long-term impacts on carbon balances if vegetation recovers (Mack et al., 2021; Frelich et al., 2024). However, peatland fires typically have more severe impacts on carbon balances. Increased drought and severe fire weather are expected to increase burn rates and carbon losses in peatlands, potentially shifting them from carbon sinks to net sources by 2100, undermining global climate goals (Wilkinson et al., 2023, see Fig. 6 and further below). Forests and other ecosystems can store significant carbon when fire frequency and intensity remain moderate, with recalcitrant pyrogenic carbon from fires potentially buffering CO₂ emissions (Santin et al., 2016; Jones et al., 2019), although the scale of this effect remains uncertain.

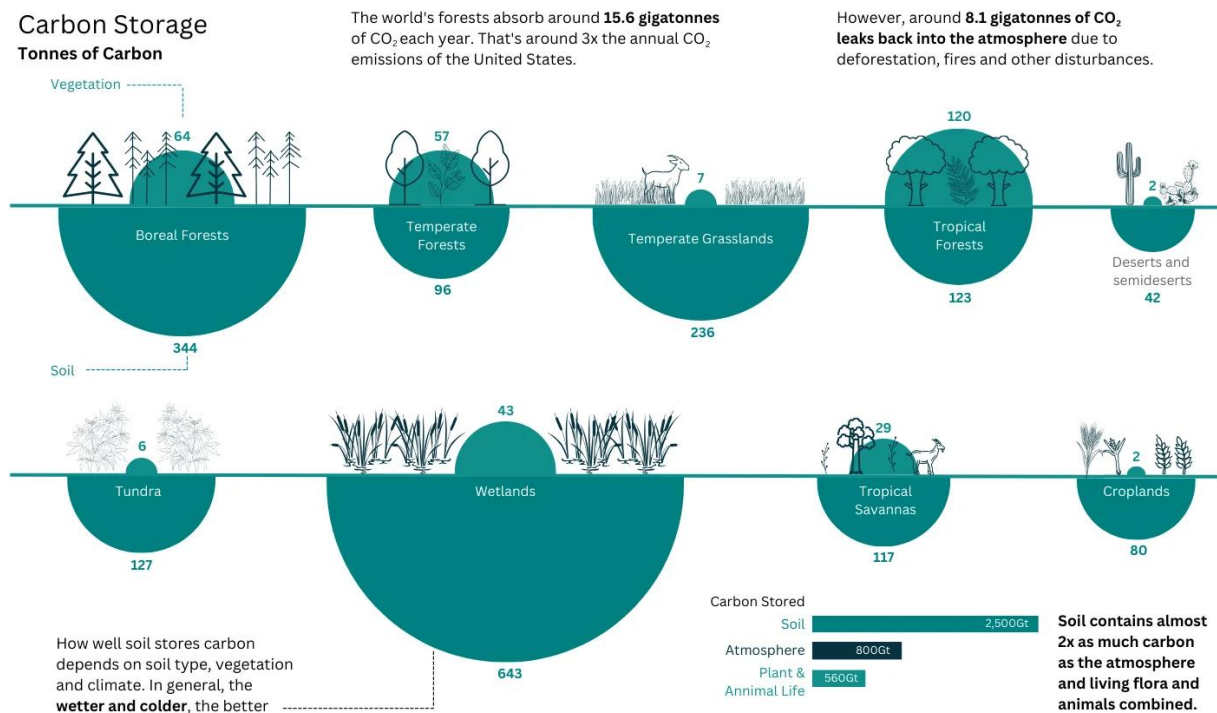


Fig. 6. Distribution of carbon below and above ground in different types of ecosystems. Source: IPCC, NASA, <https://www.visualcapitalist.com/sp/visualizing-carbon-storage-in-earths-ecosystems/>, Miranda Smith

Forests as Carbon Reservoirs

Forests are critical carbon sinks, storing approximately 861 gigatons of carbon globally, with 44% soil organic carbon (SOC), 42% live biomass, and smaller portions of deadwood and litter (Pan et al., 2011, Pan et al. 2024). While tropical forests store the majority of the carbon in aboveground biomass, boreal forests hold most of the carbon in their soils, highlighting biome-specific carbon dynamics. Wildfires, especially intense fires, release large amounts of CO₂, methane (CH₄), and nitrous oxide (N₂O), directly impacting the global carbon cycle by reducing the capacity of forests to sequester carbon (Körner, 2003).

Severe fires convert soil carbon and nitrogen to greenhouse gases, altering SOC dynamics for years. Postfire areas initially act as carbon sources, transitioning to carbon sinks as vegetation recovers. Recovery times vary, with estimates ranging from 2–14 years (Dore et al., 2008). Additionally, fires transform carbon into more stable forms, such as charcoal, which resist decomposition and contribute to long-term soil carbon storage (Pellegrini et al., 2022).

Fire behaviour influences carbon emissions, with ground, surface, and crown fires producing varying impacts. Ground fires, which burn organic material below the surface, can destroy root systems and deplete soil fauna, whereas surface fires primarily affect aboveground vegetation, allowing root-based regrowth. Crown fires, which reach treetops, emit the most carbon. Mixed crown and surface fires have the most severe carbon impacts because of their ability to reach the entire forest structure. (Ribeiro-Kumara et al. 2022)

Long-term Impacts and Postfire Management

The long-term effects of wildfires on forest carbon balances are complex. Factors such as fire frequency, intensity, postfire management—such as salvage logging, soil ploughing — and succession with deciduous trees may affect ecosystem recovery and carbon storage. Some studies even suggest that C-storage can increase after fires, if a fire in a conifer-dominated forest results in a transition to a less fire-prone landscape dominated by deciduous trees (Mack et al 2021). Poorly managed postfire interventions can hinder regeneration and reduce carbon sequestration capacity (Blumröder et al., 2022). Shifts in vegetation composition, such as transitions to early successional or non-forest species, may, on the other hand, increase surface albedo but diminish overall carbon storage potential (Duveiller et al. 2018).

Grasslands and Carbon Storage

Grasslands cover approximately 17.4% of the EU's land area, with most carbon stored in their soils (European Environment Agency, 2020, Schils et al., 2022). Fires and grazing regulate carbon and nitrogen cycles in grassland ecosystems. While fires release CO₂ in the short term, they can stimulate regrowth and enhance carbon sequestration over time. Wildfire and postfire recovery processes may result in more carbon being stored in the long term than initially released (Bowring et al., 2022). Charcoal formation and other soil changes can stabilize soil organic matter, contributing to carbon retention and also promotes the stabilization of new organic carbon inputs (Leal et al. 2019).

Integrating firewise management practices, such as controlled burning and grazing, can increase the role of grasslands as carbon sinks. These practices maintain ecosystem stability and resilience, helping offset carbon emissions. The inclusion of postfire recovery processes

in carbon cycle models is essential for accurately assessing the long-term impacts of wildfires on grassland ecosystems (Pellegrini et al., 2022).

Peatlands: Critical Carbon Reservoirs Under Threat

Peatlands, the most carbon-dense ecosystems on Earth, store approximately ten times more carbon per hectare than boreal forests do (Fig. 5). Peatlands accumulate carbon over millennia through waterlogged conditions that slow plant decay. However, when peat burns, it releases ancient carbon stores, making these ecosystems a significant concern for climate feedback loops (Witze, 2020).

Peatlands are particularly vulnerable, as they dry out due to warming climates. Lowered water tables from drainage (often for agriculture or forestry) exacerbate this risk, increasing peat susceptibility to combustion. The Arctic wildfires of 2019 and 2020 highlighted the growing vulnerability of these carbon-rich systems, which burned millions of hectares and released significant carbon emissions (Hugelius et al., 2020). Unlike forests, peatlands recover slowly after fires, with carbon losses often becoming permanent.

Rewetting and restoring degraded peatlands are crucial strategies for mitigating carbon loss. Restoration increases their resilience to wildfires and enhances their carbon sequestration capacity. Fewer human-impacted peatlands may continue to act as net carbon sinks despite fire events, emphasizing the importance of minimizing anthropogenic disturbances (Gray et al., 2021). Restoring peatlands offers dual benefits for biodiversity conservation and climate change mitigation (Wilkinson, 2023).

Summary: Wildfires and Carbon

Wildfires significantly affect carbon dynamics, releasing greenhouse gases, particularly in forests and peatlands. Forests can recover carbon storage postfire, whereas peatlands, the most carbon-dense ecosystems, often face permanent carbon loss when burned. More research is needed to fully understand fire-related changes in forest carbon dynamics and develop effective mitigation strategies that increase ecosystem recovery while balancing carbon emissions.

6. Wildfires and Biodiversity

The effects of wildfires on biodiversity depend on both fire regime characteristics and biotic factors, including habitat traits and species-specific responses (Pyke et al., 2011; Valkó & Deák, 2021). The key fire regime variables include frequency, severity, intensity, timing, and extent. Biotic factors include species fire tolerance, regeneration capacity, interspecific interactions, and dispersal ability. Fire impacts are highly context dependent: immediate effects, such as organ injuries or mortality, are typically detrimental, but secondary effects can improve habitat conditions for recolonization and reestablishment. As a result, fire impacts vary at the individual, population, and ecosystem levels.

Wildfires: Positive and negative impacts on biodiversity

The "pyrodiversity hypothesis" posits that variability in fire intensity and frequency fosters landscape-level biodiversity (Steel et al., 2024; Bond et al., 2005). Evidence supports this in fire-adapted ecosystems, where moderate fire regimes benefit species such as birds and pollinators (Kelly & Brotons, 2017). However, a meta-analysis by Jones & Tingley (2021) reported mixed results, suggesting that the hypothesis applies primarily to ecosystems with anthropogenic fire regimes. Wildfires are more likely to support biodiversity in fire-adapted systems, where moderate fires may increase habitat heterogeneity (Figure 7).

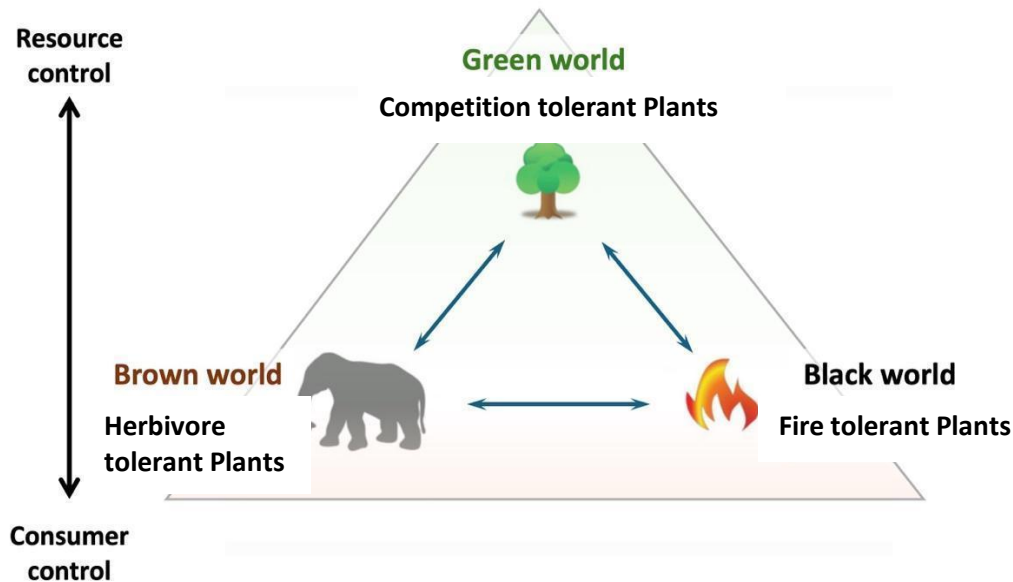


Figure 7: Effects of fire on Ecosystem Drivers

Fire, herbivory, and competition among plants are the three major factors controlling plant biomass globally. In fire-adapted "blacker" worlds where fire is a main biomass consumer, fire tends to benefit biodiversity, whereas in "green" and "brown" worlds, fire effects are more likely to be negative. Excessive fire intensity, similar to overgrazing, can harm biodiversity across all systems. Adapted from Bowman et al. (2016) and based on Bond et al. (2005).

Boreal Forests: Fire Impacts and Species Adaptations

In boreal forests, the effects of fire on biodiversity vary widely depending on the species and fire regime. Low-intensity fires often benefit biodiversity by creating habitats for species that thrive in postfire conditions, such as certain beetles (Muona & Rutanen, 1994), fungi (Tikkanen et al., 2006; Ramberg et al., 2023), and vascular plants, such as some *Geranium* species, which rely on heat for seed germination. Conversely, intense fires harm soil biodiversity by burning humus and litter layers, severely impacting soil organisms (Malmström, 2010; Pérez-Izquierdo et al., 2023).

In Fennoscandia, *Pinus sylvestris* (Scots pine) has greater fire resistance than *Picea abies* (Norway spruce) because of its thicker bark and tolerance for dry soils (Spalt and Reifsnyder, 1962). Deciduous species such as birch and aspen, while poorly fire resistant, regenerate rapidly by sprouting or seed dispersal. In boreal forests, mixed-species forests often reduce fire risk, support biodiversity, and improve ecosystem resilience after fires (e.g., Jonsson et al. 2019; Johnstone et al. 2020; Mack et al. 2021; Jaffe et al. 2023).

Grasslands: Fire as a Disturbance and Conservation Tool

Globally, fire is a vital management tool in fire-prone ecosystems, such as savannas, grasslands, and shrublands in the Americas, Australia, and South Africa. In Europe, the potential for fire as a conservation tool remains underexplored. Grasslands in Europe, including seminatural grasslands, rely on disturbances such as fires to sustain biodiversity and prevent woody encroachment (Halada et al., 2011). Fire has played a pivotal role in shaping grassland ecosystems since the Neolithic period (Feurdean et al., 2020). However, traditional fire practices have declined due to socioeconomic shifts (Valkó et al., 2014).

Low-intensity fires during dormant seasons benefit grassland specialists by reducing dominant species, creating open landscapes, and promoting thermophilic taxa such as early spring geophytes (Valkó et al., 2014). However, high-intensity or frequent fires during growth or breeding seasons can harm plants and animals in vulnerable life stages. Prescribed burns offer a valuable tool for managing abandoned grasslands, controlling invasive species, and supporting threatened taxa, but further research is needed to optimize their application in Europe (Valkó & Deák, 2021).

Summary: Wildfires and Biodiversity

Globally, fire is a vital management tool for biodiversity conservation in fire-prone ecosystems, such as savannas, grasslands, and shrublands in the Americas, Australia, and South Africa. In Europe, the potential for fire as a conservation tool remains underexplored. Prescribed burning can play a key role in restoring grasslands, controlling invasive species, and enhancing habitats for fire-adapted species. Managing production forests to include diverse species is essential for enhancing postfire recovery and maintaining biodiversity.

7. Wildfires in Europe – Regional Overview of Trends

Europe is a diverse continent where the drivers and conditions influencing wildfire dynamics differ significantly across regions. Future projections indicate a near-doubling probability of very large fires in most regions by 2100, with the Mediterranean region having the highest risk (Fig. 8). This chapter outlines regional characteristics that must be considered when developing strategies to manage wildfires effectively. We selected three contrasting regions for detailed analysis: Mediterranean Europe, Continental and Alpine Europe, and Northern Europe. (Fig. 8). These regions exemplify well the main fire regime characteristics and trends in Europe. However, it should be noted that not all parts of Europe are covered by these regions

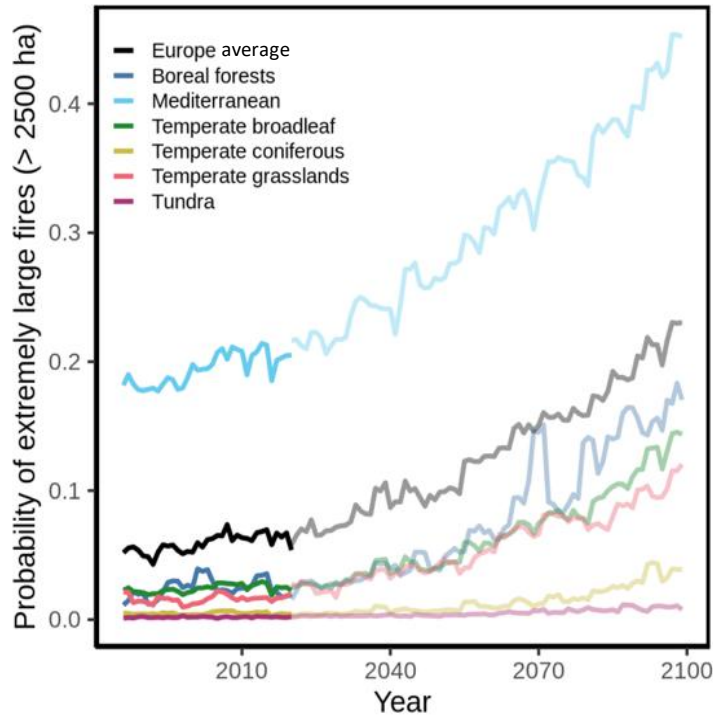


Fig. 8. Probability of large fires (>2500 ha) in different European biomes from 1990--2100. (Source: Grunig et al. 2023)

Mediterranean Europe

The Mediterranean region is particularly susceptible to wildfires because of its unique climate and social–ecological dynamics. The long, hot, and dry summers, coupled with short, mild winters, create ideal conditions for vegetation growth, fire ignition and spread. During the summer, specific synoptic weather patterns, including intrusions of Saharan air masses, exacerbate the situation and favour the occurrence of severe fire outbursts.

Historically, fires have been an integral component of Mediterranean ecosystems since at least the Miocene, with their influence intensifying during the Pliocene as Mediterranean seasonality developed (Rundel et al., 2016). Fires have shaped the region’s vegetation and ecosystems, contributing to its high biodiversity.

Since the middle of the 20th century, rural depopulation and agricultural land abandonment have profoundly altered Mediterranean landscapes (Newsham & Rowe, 2023). Vast areas of cropland have been replaced by shrubland or forest, increasing fuel loads and continuity at the landscape scale (San-Miguel-Ayanz et al., 2012; Oliveira et al., 2017).

Recent climatic trends, including warming and drying, have intensified droughts and heatwaves (Bednar-Friedl et al., 2022; Vogel et al., 2021), contributing to more severe fire seasons (Ruffault et al., 2020). These changes have shifted the region’s fire regime from fuel-limited to weather-driven (Pausas & Fernández-Muñoz, 2012) (see also Table 1).

Despite these challenges, in recent decades, both the number of fires and the total area burned have decreased, which is attributed to reduced fire use in rural management and improved suppression capacity (Turco et al., 2016; Rodrigues et al., 2020) (Fig. 9). However, burned areas are now **concentrated in fewer but larger fires**, including extreme high-intensity events (Royé et al., 2020), which poses significant environmental and civil protection challenges.

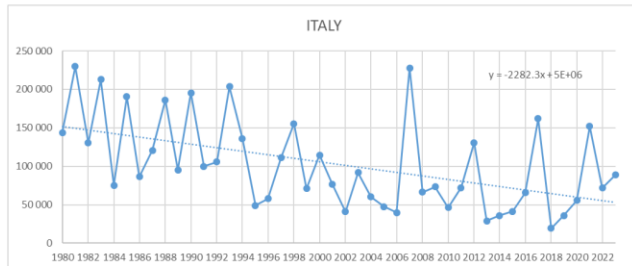
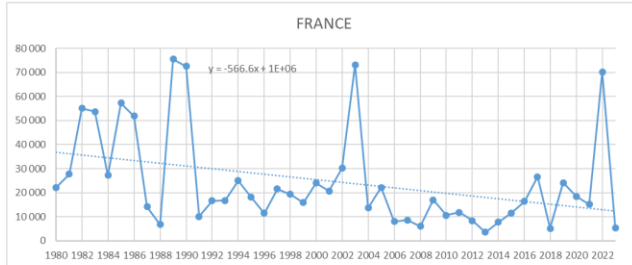
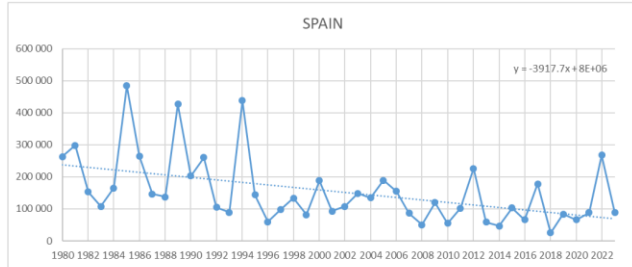
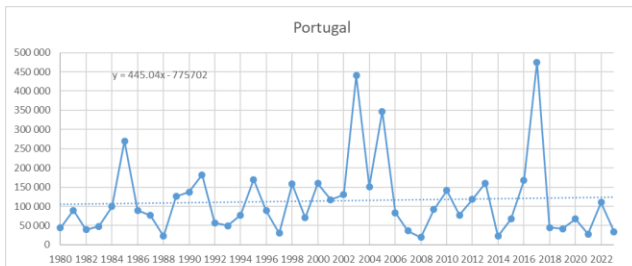
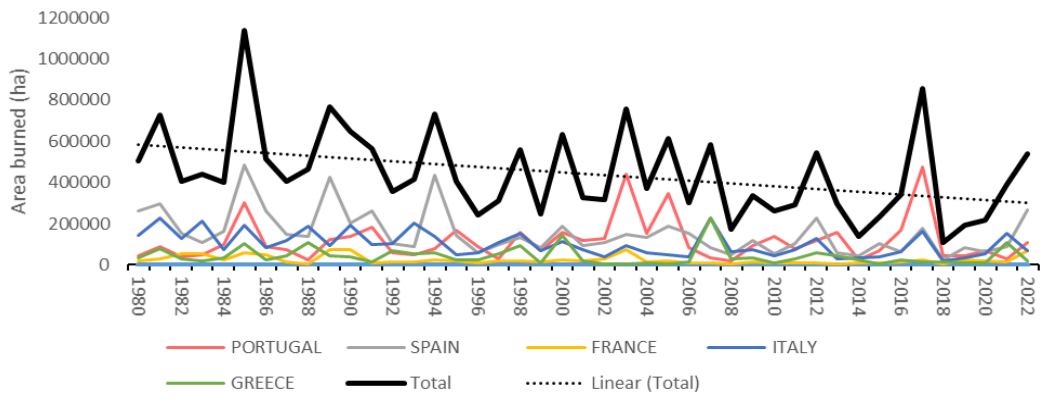


Figure 9. Areas burned in different parts of Mediterranean Europe
(Data Source: San-Miguel-Ayanz et al. 2022)

While the decline in the burned area was notable but variable, peak years such as 1985 and 2017 demonstrated the region’s vulnerability during severe fire seasons. In the 1980s and 1990s, Spain dominated the burned area statistics, but in the 21st century, Portugal took this position, with notable exceptions such as Greece's devastating fires in 2007.

In Portugal, high-intensity fires have risen sharply (Parente & Pereira, 2016), and Greece has seen similarly notable increases in wildfire intensity, extent, and frequency, with projections suggesting up to 40 additional high-fire danger days annually in southern and eastern regions by the late 21st century (Rovithakis et al., 2022).

Continental and Alpine Europe

Central and Alpine Europe exhibit highly altered fire regimes. Fire has been integral to temperate and alpine ecosystems, shaping landscapes since the last glaciation (Tinner et al., 2005; Robin & Nelle, 2014). During the Bronze Age, human use of fire expanded agro-pastoral landscapes, further altering fire regimes (Feurdean et al., 2013; Morales-Molino et al., 2015).

In the plains of Central Europe, increased landscape fragmentation and less flammable vegetation have made fire a marginal disturbance. Fire suppression strategies have further reduced the occurrence of large fires, particularly in productive forests and near settlements (Müller et al., 2020). In contrast, mountainous regions face significant challenges due to population decline and the abandonment of agro-silvopastoral activities. These trends have increased landscape flammability and, combined with extreme fire weather events, have led to large fires with substantial impacts. In some alpine areas, fires now affect vegetation historically less exposed to fire, such as beech forests (Maringer et al., 2016) (see also Table 1).

Continental inner valleys are particularly vulnerable due to their dry climates, flammable vegetation, and steep slopes. Lightning ignitions are more common in these areas, contributing to extensive fires that threaten ecosystem services such as protection against rockfalls and avalanches (Moser et al., 2010; Valse et al., 2014).

Table 1. Summary of regional differences and similarities in some dominant regions of Europe in the distribution and drivers of wildfires. For details, see the text.

	Mediterranean Europe	Continental and Alpine Europe	Northern Europe
Fire size distribution	<ul style="list-style-type: none"> • most fires are small (up to 10 ha) • fires >100 ha account for more than 80% of the total burned area 	<ul style="list-style-type: none"> • most fires are small (up to 10 ha) • fires > 100 ha account for the 80% of the total burned area 	<ul style="list-style-type: none"> • > 80% of fires are small (up to 0.5 ha)
Fire season conditions	<ul style="list-style-type: none"> • peak fire season from July to September, but official fire season from May to October 	<ul style="list-style-type: none"> • fire season typically from May to September 	<ul style="list-style-type: none"> • fire season typically from May to September

	<ul style="list-style-type: none"> • average number of high-danger days ranging between 50-60 	<ul style="list-style-type: none"> • average number of high-danger days ranges between 20 and 35 	<ul style="list-style-type: none"> • average number of high-danger days ranges between 20 and 35
Prevailing fire-prone vegetation types	<ul style="list-style-type: none"> • sclerophyllous vegetation (>25%); • deciduous forests (20%); • coniferous forests (15%), • agroforestry areas (10%); • pastures (>15%) 	<ul style="list-style-type: none"> • dry conifer forests (50% in eastern Alps, <30% western Alps) • conifer plantations • temperate broadleaf forests with porous litter (e.g. chestnut and beech in western Alps) 	<ul style="list-style-type: none"> • conifer forests (60%) • peatlands • heathlands
Societal conditions and major trends affecting the fire regimes	<ul style="list-style-type: none"> • rural depopulation • abandonment of agricultural land • afforestation of farmland • population ageing • increase of absentee landowners • urban sprawl, suburbanization • loss of cultural practices • reduction and simplification of woodland uses 	<ul style="list-style-type: none"> • rural depopulation, • abandonment of agricultural land • suburbanization, urban sprawl 	<ul style="list-style-type: none"> • rural depopulation, • increase of absentee landowners

Northern Europe

Northern Europe, including the boreal regions of Fennoscandia, is characterized by vast conifer-dominated forests. Although these regions are similar to boreal North America and Asia, the annual area affected by high-intensity wildfires in northern Europe remains relatively small. Fire intensity and severity are also typically lower than those elsewhere in the boreal zone (Wooster & Zhang, 2004; Rogers et al., 2015) (see also Table 1).

Historically, Fennoscandia has experienced frequent fires due to cultural practices such as slash-and-burn agriculture and the use of fires to improve grazing lands. These practices maintained a balanced fire regime until the late 19th century, when industrial forestry and changes in land tenure reduced fire frequency (Niklasson & Granström, 2000; Wallenius, 2011).

Coastal heathlands, maintained for approximately 5,000 years through regular burning, exemplify how traditional practices shaped fire-prone landscapes (Kaland et al., 1986). However, the abandonment of these practices has led to fire-safe vegetation dominated by old heather deciduous species and young conifers (Gjedrem and Metallinou, 2023).

Today, the area burned annually in Fennoscandia is lower than historical levels, but the number of wildfires remains high. Owing to the dense network of forestry roads, initial fire responses are swift, and most fires are controlled at an early stage. For example, the average forest fire size in Finland in recent decades was only 0.4 ha (Lindberg et al. 2020).

However, severe fire events, such as those during the 2018 heatwave, revealed the region’s vulnerability under extreme weather conditions. These events underscore the need for strategies to address the increasing risk of large fires.

Summary: Wildfires in Europe – Regional Overview of Trends

Wildfires in Europe are increasingly influenced by regional dynamics, with the Mediterranean experiencing the highest risk due to hot, dry climates and land abandonment, leading to large, high-intensity fires. Continental and alpine regions are experiencing increasing wildfire threats from landscape changes and extreme weather, necessitating tailored strategies for diverse conditions. Northern Europe benefits from effective fire suppression but faces rising risk due to climate change.

8. Wildfires in the Wildland–Urban Interface (WUI) in Europe

The wildland–urban interface (WUI) encompasses areas where human development meets wild land, including settlements, infrastructure, and cultivated land (Bénichou et al., 2021). These zones face various challenges, such as wildfire hazards; habitat loss; landscape fragmentation; water, air and soil pollution; and zoonotic disease spread. The encroachment of residential areas and infrastructure into high fuel density landscapes has increased the degree of fire risk to people and property (Figure 10). However, detailed analyses of the global extent and impacts of the WUI remain limited (Schug et al., 2023; Tang et al., 2024).

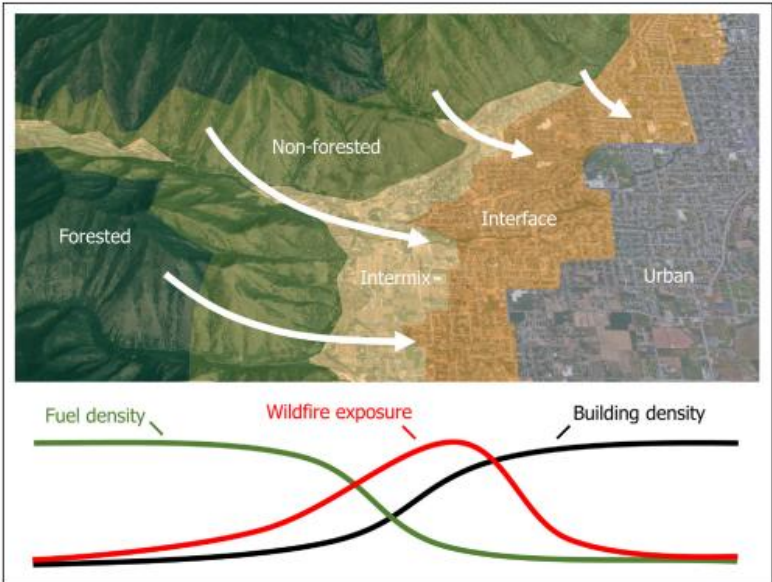


Figure 10: Simplified relationship between wildfire exposure, building density and fuel density gradients in the WUI (after Ager et al. 2021).

WUI Expansion and Fire Risk

Bar-Massada et al. (2023) mapped Europe’s WUI, revealing that it covers approximately 7% of the continent (363,000 km²) (Figure 11).

In Europe, WUI expansion is driven by suburbanization, urban sprawl, and private vehicle-dominant use. “Pull factors”, such as proximity to nature, and “push factors”, such as high housing costs in urban centers, accelerate this trend. Suburban abandoned agropastoral lands often transition into shrubland and forestland, creating vegetation corridors that facilitate fire spread (see chapter 4). These dynamics increase wildfire risk, particularly in Mediterranean regions where summer pyro-meteorological conditions are severe.

Human activities in the WUI contribute to a high ignition frequency, compounding these risks. Efforts to assess WUI wildfire exposure are emerging. Ager et al. (2021) reported that the impacts of some wildfire events, such as the 2018 Paradise fire in California, are predictable on the basis of building-fuel density gradients, with maximum wildfire exposure at building densities of 1,400–1,500 structures/km².

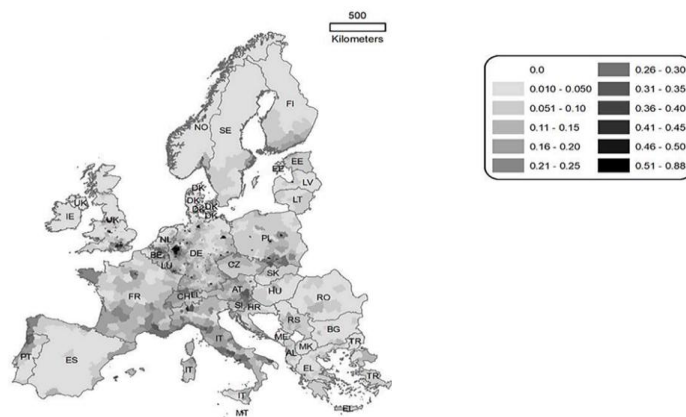


Figure 11: Percentage of total WUI per European region (NUTS-3), from Bar-Massada et al. (2023).

However, although such research calculates the worst-case building density, the lowest safe limit has yet to be estimated, which is likely affected by a landscape’s relative location, land use, and community’s level of awareness and preparedness for wildfires.

The 2025 Los Angeles Wildfires: Implications for Europe

As has become dramatically apparent recently, the Los Angeles area faces a growing wildfire threat due to climate change, land use change, and extreme weather conditions. Although the fire-prone conditions in California may be rather specific, the events that played out in January 2025 can provide relevant lessons and warnings also for urban areas in Europe. The fires occurred in high-risk zones where regulation require vegetation management, yet the fire severity was exacerbated by prolonged drought, and seasonal strong and dry Santa Ana winds, which created extremely fire-prone conditions. Studies show that human-induced climate change has significantly increased fire weather risk in the area, with extreme conditions now 35% more likely and fire seasons extending by over three weeks (Barnes et al. 2025). Vulnerable communities, particularly homeless and marginalized groups, faced disproportionate impacts, while infrastructure weaknesses exposed critical vulnerabilities.

Proposed Policy Responses and Urban Planning Strategies

To build fire-resilient cities, experts in the region advocate for strategic urban planning, including fire buffer zones, fire-resistant materials, and reduction of flammable exotic vegetation. Inspired by Kobe's earthquake recovery and Texas' flood management, Los Angeles is considering relocation incentives and urban densification in safer areas rather than rebuilding in high-risk zones. European cities should similarly integrate fire risk reduction into urban and wider land-use planning by limiting development in fire-prone areas, strengthen emergency preparedness, invest in resilient infrastructure and support collaborative fire-wise governance of the wider urban-rural area.

Wildfires and Tourism

Tourism in the WUI is particularly vulnerable to wildfires, as peak tourism coincides with the fire season. Tourists often lack awareness of fire risk and evacuation routes at visited sites, as seen in recent wildfires in Madeira (2016), Maui (2023), Rhodes (2023), and Montblanc, Spain (2024). Fires threaten local economies, disrupt livelihoods, and endanger tourists and residents, underscoring the need for preparedness.

Improving Preparedness and Evacuation Strategies

Evacuation is the primary strategy for reducing wildfire risk to tourists. Tourists who lack property attachment generally accept early evacuation, whereas locals may prefer alternatives such as sheltering-in-place (Strahan et al., 2018; Rochi et al., 2024). For example, in Cadiz (2016), tourists were evacuated while locals sheltered in place. In Rhodes (2023), thousands were evacuated by land and sea.

Effective tourist evacuation plans must address individuals with reduced mobility and include multilingual early warnings. Although disruptive, evacuations can improve preparedness and risk awareness for future local events.

Cross-border cooperation and heritage protection

In transboundary tourist regions, collaboration between countries is essential but often insufficient. It is clear that harmonized fire risk assessment, preparedness measures, and communication strategies are often lacking. Efforts to protect natural and cultural heritage sites from wildfires are particularly urgent, and hazard modelling can guide fuel management to prevent fires from threatening heritage sites and settlements (Bachantourian et al., 2023; Menemenlis et al., 2023).

Figures 12 and 13 illustrate examples from Tuscany, Italy, where landscape management integrates tourism, agriculture, and forestry. These coordinated efforts reduce fire risk while enhancing regional appeal. Mapping pyro-boundaries and fuel clusters can further delineate high-risk areas, supporting reforestation and protective measures in postfire zones (Palaiologou et al., 2022; Tzamtzis et al., 2023).



Figure 12: Examples of forestry work at the landscape scale in Tuscany, Italy. Source: WUITIPS, 2024.



Figure 13: The Tuscan landscape mosaic harmonizes land uses, reducing wildfire risk (Agnoletti and Santoro, 2018).

Summary: Wildfires in the Wildland–Urban Interface (WUI) in Europe

The wildland–urban interface (WUI) in Europe poses significant wildfire risk because of expanding settlements near high-fuel landscapes, driven by suburbanization and land abandonment. Tourism amplifies vulnerability, with peak seasons coinciding with fires. Effective evacuation plans, cross-border cooperation, and integrated landscape management are essential for reducing risk while preserving natural and cultural heritage.

9. Wildfires and Health

Wildfires have significant health impacts, ranging from immediate injuries to long-term chronic conditions (EASAC 2019). These include excess mortality, respiratory and cardiovascular diseases, mental health problems, and posttraumatic disorders, particularly in more vulnerable populations. While the short-term health effects caused by flames, heat, and

smoke have been extensively studied, interest in longer-term consequences, including those from smoke exposure and psychological distress, is increasing. Research on wildfire-related health impacts has been conducted predominantly in the USA, Canada, Australia, and mainland Europe, with limited evidence available from the UK (Pashley et al., 2023).

Short-term health impacts: Flames, heat, and smoke

The immediate health effects of wildfires primarily include burns, injuries, and deaths caused by direct exposure to flames and radiant heat. Fire response teams and residents in wildfire areas are at the highest risk (Stokes et al., 2021). Short-term respiratory effects are particularly concerning because of the large amounts of particulate matter and toxic gases released into the air. Wildfire smoke contains carbon dioxide, carbon monoxide, and fine particulate matter, which can also contaminate soil, water, crops and food resources (Finlay et al., 2012).

Particulate matter (PM) is a primary pollutant of concern in wildfire smoke. PM₁₀ particles can affect the upper respiratory system, whereas PM_{2.5} particles (less than 2.5 microns in diameter) penetrate deeper into the lungs, where they reach the bronchioles and alveoli. These fine particles are associated with worsened respiratory symptoms, including asthma exacerbation, bronchitis, and chronic obstructive pulmonary disease (COPD), resulting in increased emergency visits, hospitalizations, and outpatient visits during wildfire events (Finlay et al., 2012; Reid et al., 2016).

Studies have also highlighted the potential for increased respiratory infections during wildfire seasons, and elevated emergency visits for upper respiratory infections have been reported in some studies (Reid et al., 2016). Immediate exposure to wildfire smoke has also been linked to an increased incidence of all-cause mortality, further underscoring the severity of these short-term impacts.

Premature Mortality Linked to Smoke Exposure

Wildfire smoke is a major contributor to premature deaths, largely due to PM_{2.5} exposure. A study in California estimated that wildfire-related PM_{2.5} caused between 52,480 and 55,710 premature deaths from 2008–2018 (Connolly, 2024). Across the United States, wildfire smoke now accounts for 25–50% of PM_{2.5} emissions. While overall air quality has improved in recent decades, regions affected by wildfires, particularly the western and northwestern USA, have experienced worsening summer PM_{2.5} levels due to increased fire activity (Connolly, 2024).

Wildfire smoke also contains carcinogenic compounds, such as polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs). These substances adhere to particulate matter and persist in the environment, posing long-term health risks, and even low-level exposure to such toxins remains a concern, particularly for vulnerable populations (Finlay et al., 2012).

Cardiovascular and neurological health impacts

The impact of wildfire smoke on cardiovascular health is complex and less well understood than its respiratory effects are. Some studies report significant increases in hospital admissions for circulatory diseases, including a 21% increase during wildfire waves in the North Region of Brazil (Requia et al., 2021). However, evidence of a clear association between

wildfire smoke exposure and cardiovascular morbidity and mortality remains unclear, with conflicting findings across studies (Gould et al., 2024; Reid et al., 2016).

Emerging evidence suggests that wildfire smoke and heat stress may affect brain health. Fine and ultrafine particulate matter in wildfire smoke can enter the brain through the olfactory system and bloodstream, bypassing the blood–brain barrier (BBB). Once in the brain, these particles can induce neuroinflammatory and cerebrovascular effects, potentially contributing to cognitive impairment, accelerated cognitive decline, and dementia, including Alzheimer’s disease (White, 2024).

Immune system impacts and chronic conditions

Wildfire smoke exposure also affects immune system function, exacerbating asthma, allergic airway sensitization, and chronic obstructive pulmonary disease (COPD) (Skevaki, 2024). The immunoregulatory impacts of prolonged smoke exposure remain an active area of research. Understanding these effects, along with the broader interplay between climate change and immunology, is crucial for mitigating the health impacts of wildfire (Skevaki et al., 2024; Bowman et al., 2024).

Chronic health impacts, though less frequently studied, are significant. For example, long-term exposure to PM2.5 from wildfires has been linked to increased mortality in Portugal, where between 31 and 189 deaths were attributed to wildfire smoke between 2015 and 2018 (Barbosa et al., 2024). Additionally, the psychological impact of wildfires is increasingly recognized. Posttraumatic stress disorder (PTSD), depression, and anxiety have been documented in both adult and pediatric populations following wildfire events, with effects persisting for years (To et al. 2021).

Vulnerable populations and health inequalities

The health impacts of wildfires are not distributed evenly, with certain populations being more vulnerable to adverse effects. Pregnant women face heightened risks of preterm birth and low birth weight when exposed to wildfire smoke, similar to other forms of air pollution (Bansal et al., 2023). Children, elderly individuals, and individuals with preexisting respiratory or cardiovascular conditions are also disproportionately affected (Pashley et al., 2023; Wilgus and Merchant, 2024; Reid et al., 2016).

The health impacts of wildfires also seem to be unequal in their geographical distribution and particularly affect some ethnic groups (Davies et al, 2018). Southern and Eastern European countries, where wildfire risk is more prevalent, bear a heavier burden of health impacts. The evidence suggests that individuals living in highly deprived areas (e.g., certain NUTS2 regions) are more vulnerable to wildfires than those living in less deprived areas are (van Daalen et al., 2024). However, gaps remain in understanding the sociodemographic factors that drive these inequalities (Grant and Runkle, 2022).

Adapting to and mitigating health impacts

Effective adaptation strategies are critical for mitigating the health impacts of wildfires. These include improved public health surveillance, targeted health management for vulnerable populations, and long-term research into the physiological and psychological effects of wildfires. Strengthening public awareness through tailored risk communication campaigns can

also help communities better prepare for and respond to wildfire events (InterAcademy Partnership- IAP, 2022).

Community-level training programs that educate individuals on wildfire risk and promote preparedness measures, such as maintaining home-ignition zones, are essential for building resilience. Such programs should be complemented by policies that enhance multihazard early warning systems, emergency preparedness, civil protection infrastructure, and healthcare resources in high-risk areas.

Summary: Wildfires and Health

Wildfires pose a multifaceted threat to public health, with impacts ranging from acute injuries and respiratory distress to long-term cardiovascular, neurological, and mental health issues. Vulnerable populations and socially disadvantaged groups are disproportionately affected, highlighting the need for targeted interventions. Effective adaptation strategies are critical for mitigating the health impacts of wildfires. These include improved public health surveillance, targeted health management for vulnerable populations, and long-term research into the physiological and psychological effects of wildfires.

C. How can we manage changing wildfires?

10. Challenges to today's wildfire management strategy

Traditional fire management strategies in Europe have focused predominantly on emergency response, aiming to minimize wildfire impacts during years with average fire weather conditions. While this approach has had some success, it falls short in addressing the impact of increasingly severe fire seasons driven by climate change. Two major issues have emerged from this narrow focus: (i) the accumulation of flammable vegetation and (ii) disproportionate investment in suppression efforts at the expense of proactive landscape fuel management programs.

Although the EU has taken substantial steps to enhance its coordination capacity for emergency response, more efforts are urgently needed to adopt a proactive approach that reduces the prevalence and severity of wildfires. Policies that focus solely or predominantly on mitigating short-term fire damage by emphasizing suppression, inadvertently led to increased fuel loads, ultimately resulting in fewer but far more intense and destructive fires. This "firefighting trap" has been extensively documented in Europe and the USA (Collins et al., 2013; Fernandes et al., 2020; Moreira et al., 2020). Suppression-focused approaches reduce the role of fire as a natural biomass regulator, allowing unburned vegetation to accumulate and fuel subsequent extreme wildfires. This cycle intensifies risk to society, including loss of life, destruction of homes, and disruption of ecosystem services (Spadoni et al., 2023).

Since wildfire risk often stems from multiple interacting factors, including continuous stretches of flammable vegetation and periodic extreme weather events, suppression is

insufficient, as some fires exceed the response capacities of even well-equipped countries, particularly when events are synchronous across regions (Podschwit & Cullen, 2020).

11. Wildfire Risk Reduction: Proactive Approaches

Prescribed Burning and Its Benefits and Challenges

Prescribed burning, the application of fire under planned conditions by trained professionals, faces significant challenges in Europe, particularly in densely populated areas where air quality concerns, the risk of fire escape, and limited suitable weather conditions often restrict its use (Ascoli & Bovio, 2013). Meanwhile, there is a long history of the use of fire as a tool, which has proven effective in managing vegetation and mitigating fire risk (Weir & Scasta, 2022). Additionally, field experience across a range of countries shows the benefit of controlled burns for training purposes and bringing diverse stakeholders together, benefiting safety and efficacy of fire management during unplanned wildfires. Given the values and challenges of prescribed burning, trade-offs between the benefits and costs of prescribed burning must be carefully considered (Fernandes et al., 2013).

Alternative Fuel Management Techniques

Where prescribed burning is not feasible, alternative methods such as mechanical vegetation removal, prescribed grazing, and pyrosilviculture can help manage fuel loads (Fernandes, 2013). Strategic forest fuel management techniques, such as fuel breaks and strategic prevention points, have been shown to effectively disrupt fuel continuity, reduce fire intensity, and improve fire suppression personnel safety (Castellnou et al., 2019; Aparicio et al., 2022).

Strategic Prioritization of Forest Management

Advanced technologies, including stochastic fire simulations and spatial planning tools, enable the prioritization of fuel management in high-risk areas (Palaiologou et al., 2021). Strategic planning focuses on multiple objectives, such as protecting residential zones, economic assets, and biodiversity hotspots. The results often highlight trade-offs between priorities, as demonstrated in Figure 13.

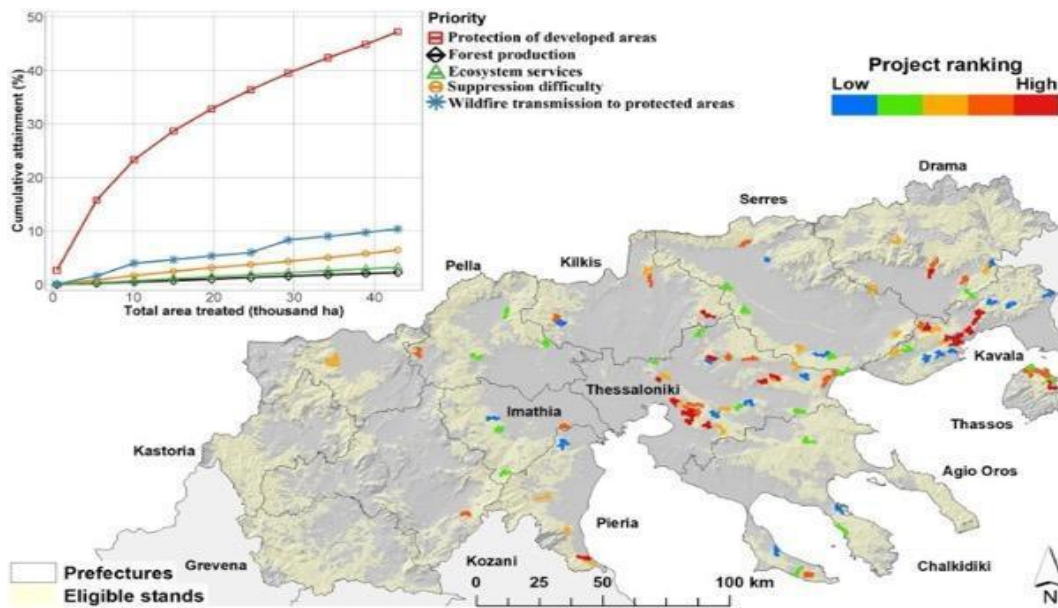


Figure 13. Prioritization of wildfire risk reduction actions for residential areas in Macedonia, Greece. The graph shows the cumulative attainment of multiple priorities when projects are ranked by their effectiveness in reducing wildfire risk to settlements (Palaiologou et al., 2021).

Postfire Recovery and Ecosystem Restoration

In fire-sensitive ecosystems, fires are severe disturbances that can disrupt ecosystem processes and hinder recovery. Restoration efforts must focus on building resilience by promoting nonflammable vegetation, creating fire refuges, and supporting risk reducing recovery processes (He et al., 2019). Conversely, fire-adapted ecosystems rely on periodic fires for their ecological functioning. Decades of fire suppression in such systems have created undesirable conditions, including fuel accumulation and altered fire behaviour (Bond et al., 2005).

Forests play a vital role in regulating microclimates and hydrological cycles. Old-growth forests, in particular, are highly effective at cooling landscapes and mitigating extreme heat, underscoring the importance of preserving forest cover and connectivity (Gohr et al., 2021). Conversely, practices such as salvage logging can increase fire risk by drying soils and altering microclimates (Blumröder et al., 2021).

Fire refugia—areas that remain unburned during fires—are critical for conserving biodiversity and facilitating postfire ecosystem recovery. These refugia often include wetlands, riparian zones, and shaded areas with high water retention capacity, which act as sources for ecosystem recolonization and resilience (Meddens et al., 2018).

Restoration strategies must be tailored to specific ecosystems. For example, boreal forests benefit from promoting low-severity surface fires, whereas Mediterranean ecosystems require preserving biological legacies and encouraging natural regeneration (Castro, 2021; Salesa et al., 2022). In grasslands, integrated fire-grazing models can reduce biomass and wildfire risk while supporting biodiversity (Bond & Keeley, 2005; Davies et al., 2022).

Postfire soil management is crucial for ecosystem recovery. High-intensity fires can irreversibly damage soils, whereas postfire activities such as salvage logging or ploughing exacerbate erosion and hinder recovery. Effective soil restoration techniques include mulching, log erosion barriers, and non-intervention scenarios, which promote soil stability and vegetation recovery (Pereira et al., 2018; Lucas-Borja et al., 2024).

Although salvage logging can have several negative consequences, the removal of damaged trees after wildfires is a common practice, and in some cases, it can mitigate some social damage in the affected areas. It can: 1) reduce the risk of blocking and damaging roads or protective infrastructure in the affected areas, 2) reduce the risk of clogging torrent channels, which could lead to erosion risks for infrastructure and settlements, 3) facilitate and make safer the implementation of erosion control measures and reforestation. For this reason, it is important that any post-fire logging operations are well planned and that nature-based solutions are preferred in order to maximise the positive impacts over the negative ones.

Summary: Wildfire Risk Reduction: Proactive Approaches

Integrated fire management emphasizes proactive approaches such as prescribed burning and fuel management to reduce wildfire risk. Restoration strategies focus on enhancing ecosystem resilience, preserving fire refugia, and promoting natural recovery processes. Tailored solutions address ecosystem-specific needs, from grasslands to forests, whereas investments in prevention and restoration complement suppression efforts to build sustainable, fire-adapted landscapes.

12. Synergies and Trade-offs

Firewise² landscape management has the potential to create synergies while navigating trade-offs with other land-use approaches. This integration is crucial for fostering positive outcomes, minimizing land-use conflicts, and promoting resilient ecosystems and communities. Understanding these dynamics is key to managing landscapes sustainably and balancing multiple objectives, such as wildfire risk reduction, biodiversity conservation, agricultural productivity, and social well-being (Sayer et al., 2013; Moreira et al., 2020).

Synergies between Firewise Practices and Landscape Management

1.

Agriculture

Firewise practices align with various agricultural activities that reduce wildfire risk. For example, well-managed grasslands, annual crops, and irrigated croplands act as natural firebreaks by limiting the continuity of flammable vegetation. These agricultural systems reduce the risk of fire spread while maintaining productivity (Moreira & Pe'er, 2018). Introducing payments for ecosystem services (PES) can incentivize farmers to adopt firewise

² An approach to managing landscapes and communities that reduces wildfire exposure and vulnerability while maintaining ecological, economic, and cultural value. This includes promoting fire-resilient vegetation, sustainable land use, and community preparedness. (see Glossary).

practices, such as rotational grazing or maintaining fire-resistant field margins, contributing to overall risk reduction (Lecina-Diaz et al., 2023).

2. *Urban and Peri-Urban Planning*

Integrating firewise principles into urban planning significantly enhances resilience at the wildland–urban interface (WUI). Zoning regulations, risk-informed infrastructure development, and the strategic placement of vegetation buffers reduce the exposure of settlements to wildfires (Gonzalez-Mathiesen & March, 2018; Intini et al., 2020) (see chapter 8). Additionally, by promoting land use regulation, building standards and community preparedness programs, urban areas can reduce vulnerability and improve adaptive capacity.

3. *Tourism and outdoor recreation*

Sustainable landscapes benefit tourism by preserving natural assets and reducing the disruption caused by wildfires. Fire-resilient landscapes protect vital tourism infrastructure and natural and cultural heritage, ensuring economic stability for rural areas dependent on tourism revenues (Molina et al., 2019). Efforts to mitigate fire risk through proactive land use management can also increase the recreational value of landscapes, attracting more visitors and generating local income.

4. *Biodiversity Conservation*

Firewise environmental management can support biodiversity by creating diverse habitat mosaics. Prescribed burning, for example, can maintain ecosystems that depend on periodic low-intensity fires, such as Mediterranean scrublands and some grasslands, fostering species that thrive in such conditions (Pereira et al., 2021). By promoting structural diversity and ecological heterogeneity, fire practices can enhance the habitat quality of various species.

5. *Public Health*

Reducing wildfire risk directly benefits public health by minimizing exposure to hazardous air pollutants, particularly fine particulate matter (PM_{2.5}). These pollutants are linked to respiratory and cardiovascular diseases, which are exacerbated during wildfire events (Rappold et al., 2019). Proactive fire management reduces the frequency and intensity of wildfires, mitigating their health impacts.

Trade-Offs and Conflicts between Firewise Practices and Landscape Management

1. *Forestry Practices*

Monoculture plantations of flammable species, such as *Pinus* and *Eucalyptus*, conflict with firewise principles if poorly managed by increasing fuel loads and fire intensity (Hermoso et al., 2021). Such plantations also compromise biodiversity and resilience (see section below on Wildfires: Managing Risks in European Tree Planting Programs). Transitioning to mixed-species forestry with more fire-resistant trees can reduce risks and enhance ecosystem services.

2. *Residential and Industrial Development*

Expanding settlements, infrastructure and industrial areas into fire-prone areas heightens wildfire risk. Residential areas in the WUI (see chapter 8) often lack sufficient buffers or defensible spaces, making them highly vulnerable (Planas et al., 2023). Industrial facilities, especially those involving hazardous materials, exacerbate fire risk and might be the cause of

wildfires in the case of accidents. Fire-wise land-use planning must prioritize safe development practices and establish protective measures for these zones (Sudmeier-Rieux et al., 2015).

3. *Biodiversity Conservation*
Fuel management can conflict with conservation goals when it reduces habitat continuity. For example, maintaining firebreaks or fuel-reduced zones may fragment habitats critical for certain species. Balancing these needs requires careful planning to ensure that fire prevention measures do not disproportionately harm biodiversity (Pereira et al., 2021).

4. *Agricultural activities*
Some agricultural practices, such as the burning of crop residues, pastoral fires, and the use of heavy machinery during dry seasons, contribute to wildfire ignition (Moreira & Pe'er, 2018). Regulatory measures, including restrictions on these practices and incentives for safer alternatives, are essential to align agriculture with firewise strategies.

5. *Prescribed burning*
Although prescribed burning is an effective tool for reducing fuel loads, it can negatively impact air quality and increase resistance in nearby communities (Valkó & Deák, 2021). To address these challenges, governments must ensure planning and public awareness and establish clear protocols for safe implementation.

Summary: Synergies and Trade-offs Firewise landscape management fosters synergies between wildfire risk reduction, biodiversity conservation, agriculture, urban planning, and public health. This approach minimizes conflicts by integrating forestry, sustainable agriculture, and spatial planning. Challenges include balancing prescribed burning, habitat conservation, and afforestation risks.

Wildfires: Managing Risk in European Tree Planting Programs

Forests and trees in diverse settings provide crucial ecosystem services, notably carbon sequestration, which underpins tree planting as a key strategy for climate change mitigation (Bastin et al., 2019). Global commitments such as the Bonn Challenge aim to restore millions of hectares of degraded land by 2030. In Europe, the EU Biodiversity Strategy and Forestry Strategy for 2030 envision the planting of 3 billion trees, which requires the conversion of 2 million hectares of treeless land into woodlands (Abeli & Di Giulio, 2023).

Challenges of Overprioritizing Tree Planting. Tree-planting efforts often overlook the ecological value of nonwoody habitats because of "Biome Awareness Disparity," which is rooted in 19th-century European forestry traditions and postcolonial environmental governance (Davis & Robbins, 2018; Silveira et al., 2021). This overemphasis on tree planting has drawn criticism for overestimating short- and medium-term carbon sequestration benefits compared with those of grasslands and for underestimating adverse effects, including habitat loss, exotic species invasions, and local livelihood disruptions (Temperton et al., 2019; Terrer et al., 2020; Silveira et al., 2021). Planting flammable non-native species such as *Eucalyptus* and *Pinus* spp. is also criticised for its contribution to fuel accumulation leading to increased fire risk (Hermoso et al., 2021).

Principles for Firewise Tree Planting

To mitigate wildfire risk, tree planting in Europe must follow key principles related to site selection, stand management, spatial patterns, and species selection:

1. Site Selection, Stand Management and Spatial Pattern

Strategic site selection and stand management are essential for minimizing fire risk and afforestation should consider the following:

- Agroforestry should be supported, and open woodland vegetation should be protected in high-fire-risk regions (Moreira & Pe'er, 2018).
- Tree planting should be avoided in areas where native vegetation consists of open habitats, such as grasslands and (semi)arid zones (Veldman et al., 2019).
- Alternative ecosystems such as grasslands in fire-prone areas should be restored to provide climate mitigation benefits without increasing wildfire hazards (Hermoso et al., 2021).
- Manage existing exotic woody plantations to control their spread and reduce flammable fuel continuity (Brundu & Richardson, 2016; Mirra et al., 2017).
- Manage stand structure and understorey vegetation to decrease flammability, i.e., reduce the vertical structure of the understorey fuel; reduce the use of ladder fuels to avoid crown fires; and prescribe burning, pruning, and forest management (Fernandes, 2009, Barros and Pereira, 2014).
- In continental and boreal regions, maintaining a dense understorey that supports a cool and moist microclimate reduces fuel flammability

Tree planting should contribute to fire-resilient landscape mosaics, integrating firebreaks, buffer zones, and varied vegetation structures to minimize fire spread and intensity. Combining this approach with other land uses, such as agriculture and pasturelands, enhances ecosystem resilience and reduces fire risk (Moreira & Pe'er, 2018).

2. Species

Selection

Biodiversity conservation principles prioritize native species for afforestation, but this is often not considered by private landowners. The EU Forestry Strategy 2030 allows the conditional use of nonnative species, raising concerns due to their flammability and ecological risk (Abeli & Di Giulio, 2023; Pötzelsberger et al., 2020). Poorly designed afforestation campaigns often result in landscapes that are more prone to wildfires, which threatens both ecosystems and human safety (Fernandes et al., 2016; Veldman et al., 2019).

In general, transitioning from monoculture plantations to landscape mosaics and emphasizing fire-resistant native species are critical measures to reduce these risks. Native species adapted to future climatic conditions can be identified through climate niche modelling (Barragán et al., 2023). Avoiding flammable forest structures and pyrophytic tree species such as *Eucalyptus* spp. and *Acacia dealbata* is important for reducing fuel loads and wildfire hazards (Guiomar et al., 2023; Brundu & Richardson, 2016). However, species selection alone cannot sufficiently reduce fire risk, especially in regions with a generally flammable native vegetation. This highlights the critical role of forest management in wildfire risk reduction (Fernandes et al., 2019; Guiomar et al., 2023).

Enhancing synergies while addressing trade-offs

A holistic, firewise approach can optimize the multifunctionality of landscapes. For example, combining agroforestry, sustainable forestry, and habitat conservation can deliver multiple ecosystem services while mitigating wildfire risk (Palaiologou et al., 2021). Tools such as stochastic fire simulations, multiobjective spatial planning and using faster-than-real-time models for enhancing fire management operations (Grasso and Innocente 2020) can guide decision-making to achieve these synergies.

In addition, incorporating payments for ecosystem services, carbon credits, and agri-environmental schemes can incentivize firewise practices. Such mechanisms can generate funding streams from diverse sectors, supporting integrated fire management and rural development.

Finally, addressing wildfire risk requires participatory planning processes that incorporate local knowledge and community priorities and concerns. Inclusive governance ensures the equitable distribution of benefits and burdens, particularly for marginalized rural communities (Maezumi et al., 2024).

13. Wildfire Risk Reduction—Enablers and Barriers

In previous chapters, we outlined a variety of proactive approaches for managing wildfires through diverse landscape interventions aimed at reducing fuel loads. These approaches involve distinct governance models. *Direct wildfire prevention* involves strategic landscape fuel treatments, such as mechanical thinning or prescribed burns, which are mostly funded by public agencies and maintained periodically. *Indirect wildfire prevention* leverages private, economy-driven land uses—such as livestock grazing, agriculture, or forestry practices—that simultaneously reduce fuel loads and create “productive fuel breaks” (Pulido et al., 2023). These two approaches may be integrated into a smart prevention model, blending public and private governance to develop “smart fire territories” (Tedim et al., 2016; Pulido et al., 2023).

Direct Prevention: Focused but Costly

Direct prevention is typically planned and implemented by forestry or fire management departments, often in state-owned forests. Recently, pilot projects have extended these practices to private stakeholders, including forest owners, with public funding (Ascoli et al., 2023). However, direct prevention is resource intensive and often short-lived, limiting its application across large regions. Statewide plans have been proposed to address concerns about extreme fires, but implementation remains challenging (Ager et al., 2021; Aparicio et al., 2022).

Fuel reduction efforts, when strategically placed, effectively reduce wildfire spread and severity, even under severe fire weather conditions (Kalies & Kent, 2016). For example, thinning and prescribed burning have been shown to significantly lower fire severity in treated areas (Cansler et al., 2022). However, treatments may become less effective under extreme wind speeds or high fuel loads (Beverly et al., 2020).

Prescribed burning is increasingly gaining attention in Europe. Long-term projects, such as pastoral burning in southern France, have resulted in a 35% reduction in average burned areas and have successfully prevented very large fires (Robios, 2012). Despite these benefits, challenges such as limited weather windows, regulatory barriers, and cost inefficiencies hinder widespread adoption. Cost optimization strategies, such as combining prescribed burns with grazing or utilizing nontimber forest products such as biomass, resin, or mushrooms, could increase the viability of these treatments (Varela et al., 2018; Soliño et al., 2018).

Southern Europe predominantly focuses on fire management efforts to protect populated areas and infrastructure. Firebreaks and fuel breaks, while effective, are concentrated in high-value forest areas and rarely extend to marginal regions (Xanthopoulos et al., 2006). Modelling studies have highlighted their potential: for south Portugal, fuel breaks reduce burned areas up to 17% and burn probability between 4 and 31% (Oliveira et al. 2014) while for central Portugal different fuel treatments reduce the burn are from 12–31% and decrease the probability of large wildfires by 10–40% (Benali et al., 2021). In Sardinia and Greece, fuel treatments have demonstrated measurable reductions in wildfire intensity and extent (Salis et al., 2016; Palagiologou et al., 2020).

Indirect prevention: Harnessing productive landscapes

Indirect prevention relies on creating productive fuel breaks, which integrate agroforestry, grazing, or other land uses that reduce fuel loads while providing economic benefits (Pulido et al., 2023). These efforts have proven effective in reducing wildfire size and severity, particularly in heterogeneous landscapes that combine agriculture, shrublands, and forests (Damianidis et al., 2020; Bertomeu et al., 2022). Compared with direct prevention, indirect measures often cover larger areas at lower public costs, generate economic returns, and encourage stakeholder engagement (Table 2).

Successful examples abound. In Catalonia, Spain, the *Ramats de Foc* initiative employs livestock grazing to reduce fuel loads while marketing the meat produced as an ethical product (Soy-Massoni et al., 2022). Similarly, the *LIFE Granatha* project in Italy reduced biomass and shrub cover while creating marketable organic brooms (Ascoli et al., 2023). These initiatives demonstrate how indirect prevention can align wildfire risk reduction with rural economic development.

However, legal and administrative barriers often restrict indirect prevention efforts, particularly in fire-prone and depopulated areas. Regulatory reforms and certification programs could incentivize private land managers to adopt fire-smart practices (Pulido et al., 2023).

Table 2. Barriers and Enablers of wildfire prevention approaches (see also Ascoli et al. 2023).

	Barriers	Enablers
	Limited public budget	Strategic application relative to fire spread
	Hard to implement in private land	Straightforward negotiation and implementation
	Interventions with short-term effects	Interventions may help fire suppression
	Excess of limitations for fuel management according to spatial planning	Increasing awareness of fuel management as a risk reduction measure
	Regulatory restrictions to implement prescribed burns in certain countries	Several fuel reduction options through multiple well-known techniques
	Nonstrategic location	Low/zero public implementation budget
	Lack of resources and skills to undertake participatory processes	Long life span of interventions
	Constrained regulatory framework	Associated co-benefits
	Noneconomic viability of some local activities	Monitoring by landowners
	Lack of investment capacity in rural areas and low economic value of products	Convergence of multiple land management goals maximizing cost-benefits
	Lack of regulatory mechanisms to involve beneficiaries of ecosystem services	Diversity of initiatives adaptable to the complexity of risk
	Complex, private–public governance	Straightforward spatial planning and technical support provided
	Lack of enhancing policy	Funds potentially accessible from several missions of the EC Adaptation Strategy
	Limited budget and lack of human resources	Alignment among risk reduction measures through direct and indirect prevention
	Segmentation of competences in wildfire management	Policy request for integration in disaster risk management
	Excess of bureaucracy and administrative burdens before implementation	Acknowledgement in EC documents of the need of having resilient landscapes

Smart Prevention: Integrated Governance

Smart prevention combines the strengths of direct and indirect approaches through public–private partnerships. This integrated model has gained traction in recent years, driven by the alignment of wildfire risk reduction with broader land management goals (Tedim et al., 2016; Pulido et al., 2023). Recent modelling studies highlight the advantages of combining strategies, showing substantial reductions in suppression costs and improved outcomes (Sil et al., 2019; Lecina-Díaz et al., 2023; Figure 14).

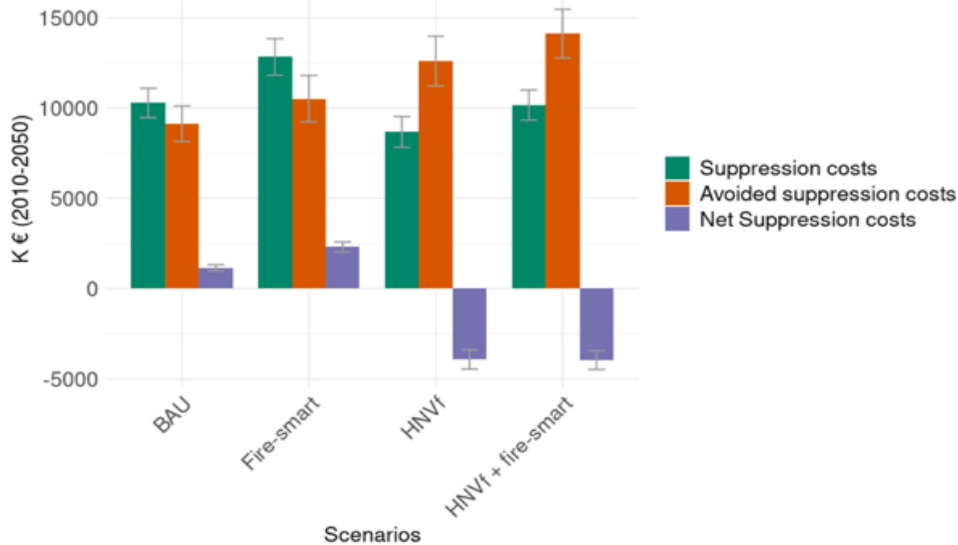


Figure 14. Cost–Benefit Analysis of Land-Use Scenarios Over 50 Years.

The present value of wildfire suppression costs, avoided suppression costs and net suppression costs under various land-use management scenarios (Business-as Usual (BAU), fire-smart, High Nature Value Farmlands – HNVF-, and HNVF + fire-smart) over a 50-year simulation period (Lecina-Díaz et al. 2023).

Case studies in smart prevention

Several innovative projects across Europe illustrate the potential of smart prevention. The RAPCA program in southern Spain engages local shepherds to manage fuel breaks via guided livestock grazing, covering nearly 6,000 hectares under a payment for environmental services framework (Varela et al., 2018). Similarly, the *Plan for Shrub Clearing* in La Rioja, Spain, has created landscape mosaics that significantly reduced burned areas over three decades (Lasanta et al., 2022; Figure 15).

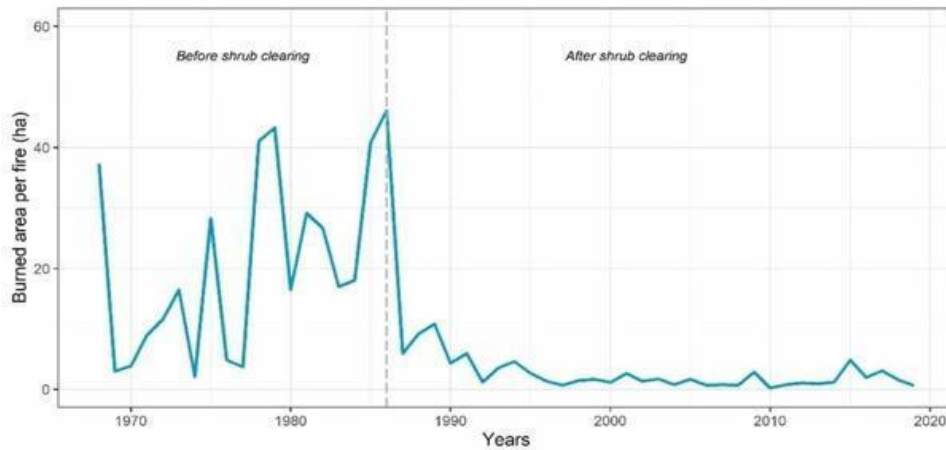


Figure 15. Burned area trends before and after landscape mosaic interventions in La Rioja
Average annual burned area per fire in the La Rioja community. The plot shows the temporal pattern before and after the adoption of fire control approaches based on landscape mosaics (Lasanta et al. 2022).

The *MOSAICO* project in Extremadura (central-western Spain) takes a participatory approach, funding local land managers to implement fire-smart strategies. Despite administrative challenges, the project demonstrated moderate reductions in burned areas, which highlights the importance of integrating private and public actions to maximize impact (Pulido et al., 2023; Figure 16).

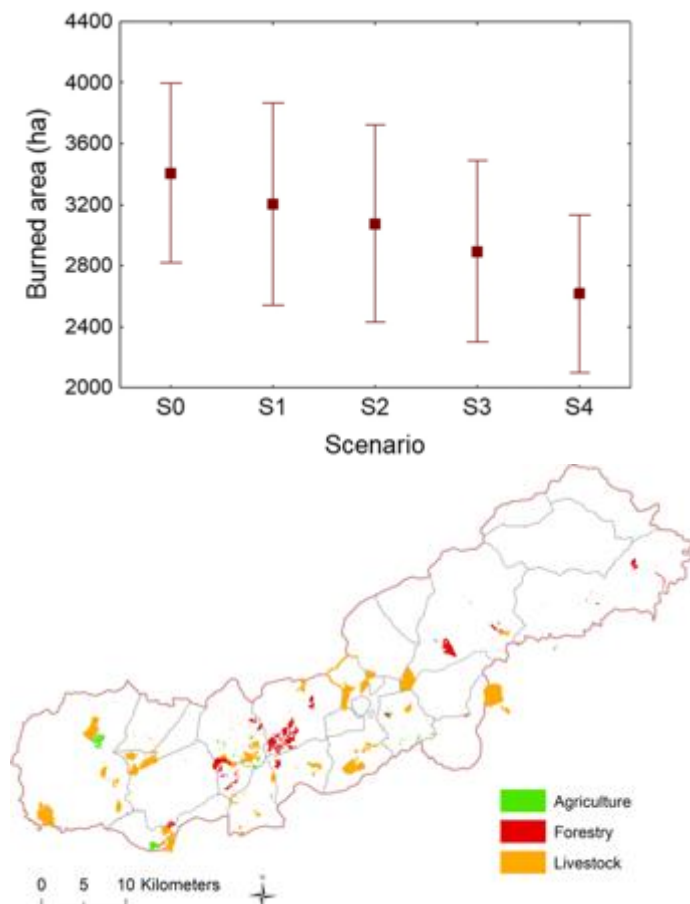


Figure 16. Impact of Different Intervention Scenarios on Burned Areas in Extremadura
Top: Mean (\pm 95% CI) burned area in the S0--S4 scenarios from 20 random simulated ignition points.

S0, control scenario, i.e., business as usual; S1, with private interventions of local land managers; S2, S1 plus public interventions; S3, S2 plus mixed interventions proposed; and S4, S3 plus interventions failed mainly due to administrative constraints. Bottom: Map of private interventions carried out by agriculturalists, shepherds and forest dwellers (mainly resin tappers) in northern Extremadura (central Spain; Pulido et al. 2023).

Barriers and Opportunities for Improvement

While promising, smart prevention faces significant challenges, including complex governance structures, limited budgets, and regulatory barriers. Long-term success depends on the alignment of fire-smart strategies with broader land-use and disaster risk reduction policies. Increasing awareness among decision-makers and integrating pilot projects into knowledge-sharing platforms such as FIRELOGUE will be critical for scaling up these efforts (<https://firelogue.eu/>).

Efforts to reduce wildfire risk must also address the causes and effects of underlying processes such as rural depopulation, land abandonment, and climate change through intersectoral policies. By fostering partnerships between the public sector, private landowners, and local communities, Europe can develop resilient landscapes that balance wildfire prevention with economic, ecological, and social objectives.

Summary: Wildfire Risk Reduction—Enablers and Barriers

A multifaceted approach to reduce wildfire risk is essential for addressing the growing threat of wildfires in Europe. Direct prevention, indirect prevention, and smart prevention each play a role in creating fire-resilient landscapes. However, their success depends on overcoming regulatory, financial, and administrative barriers, as well as fostering collaboration among stakeholders. By integrating these approaches into cohesive strategies, Europe can mitigate wildfire risk while promoting sustainable land management.

D. Towards an Integrated Wildfire Policy Framework

Disaster risk governance involves the interaction of social, political, and administrative actors to manage hazards, vulnerabilities, and exposures, aiming to reduce risk and mitigate the impacts of disasters. Building on Kooiman's (2003) concept of governance, this approach encompasses the actions of governments, the private sector, and civil society across multiple levels to address emerging challenges effectively (Fra Paleo, 2015). Collaborative, multilevel, and multiactor systems—spanning local communities to national and multilateral entities—are key to their success.

In the context of wildfires, governance is often confined to forest departments, with a predominant focus on suppression rather than integrated, proactive strategies. This reactive approach overlooks the interconnected nature of hazards, failing to address the interplay

between wildfire risk and other factors, such as land-use changes, climate change, and socioeconomic vulnerabilities.

The need for Integrated Wildfire Policies

Wildfires are not standalone events; they represent ecological processes, hazards, and cultural phenomena interconnected with broader risk. Current wildfire governance often neglects the multihazard perspective emphasized in the Sendai Framework for Disaster Risk Reduction (2015–2030). The midterm review of the framework (UNDRR, 2023) underscores the urgency of systemic risk management, which considers interactions between multiple hazards.

Fragmented governance and sectoral policies exacerbate wildfire risk. For example, policies focused narrowly on forest preservation through suppression can inadvertently lead to fuel accumulation, intensifying future wildfire severity (Collins et al., 2013; Moreira et al., 2020). Breaking silos to develop integrated and proactive wildfire management approaches is critical.

As stated previously, adopting a **landscape approach** allows for the integration of ecological, economic, cultural, and social objectives, balancing synergies and trade-offs among competing land uses (Plieninger et al., 2020). This perspective aligns with calls to view wildfires as complex risk problems, necessitating shifts from top-down management to participatory strategies (Essen et al., 2023; Moritz et al., 2014; Tedim et al., 2020).

Collaborative knowledge coproduction and diverse stakeholder engagement are essential for fostering adaptive and inclusive fire governance (Stoof and Kettridge, 2022). Lessons from integrated water management in the Netherlands, which emphasize adaptive management and stakeholder participation, provide valuable insights for wildfire governance (Lambrechts et al., 2023).

Sayer et al. (2013) identified principles for landscape approaches that are particularly relevant to wildfire management, including resilience, stakeholder capacity-building, and participatory monitoring. These principles form the foundation for integrated wildfire risk governance, highlighting the need for inclusive, multistakeholder processes.

Advancing Fire Governance: Frameworks and Initiatives

The recently proposed **Landscape Fire Governance Framework (LFGF)**, endorsed at the 8th International Wildland Fire Conference (8IWFC, 2023), marks a significant evolution from the FAO's 2006 voluntary guidelines for integrated fire management (IFM). The Landscape Fire Governance Framework emphasizes multistakeholder engagement at the institutional level, fostering collaboration among governments, businesses, academia, and civil society. Its goals include improving rural area stewardship, changing fire-related behaviors, and enhancing risk management to safeguard lives, property, and environmental assets.

Other European initiatives complement the LFGF. For example, the European Forest Institute and Spain's Ministry of Ecological Transition have proposed recommendations for Mediterranean ecosystems (Mauri et al., 2023). These initiatives advocate integrating fire prevention into cross-sector policies, enhancing financial mechanisms, fostering wildfire education, harmonizing information systems, and promoting international cooperation.

Despite these efforts, EU disaster risk management funding remains skewed toward response rather than prevention and preparedness (World Bank, 2021). Civil protection agencies across Europe report limited influence over other departments and insufficient resources for wildfire prevention. Addressing these barriers requires increased investment in prevention, improved institutional coordination, and capacity building to address systemic challenges.

Public Policies and Risk Analysis

Public policies are foundational to wildfire risk governance, shaping planning, preparedness, and recovery efforts. Effective wildfire risk management must intersect with climate adaptation, agriculture, spatial planning, and water management policies. Comprehensive risk analysis, involving monitoring, inventories, and assessments, is crucial to understanding wildfire dynamics, identifying vulnerable elements, and informing decision-making processes.

Spatial planning plays a critical role in wildfire risk reduction. By incorporating wildfire risk assessment into urban, regional, and landscape planning, policymakers can minimize exposure and vulnerability (Fra. Paleo, 2009) of rural and WUI resident populations and assets while promoting sustainable development. Such approaches can reduce conflicts between social and environmental priorities, fostering resilience at multiple scales.

Community Engagement and Fire Literacy

Public perceptions of wildfire risk significantly influence policy decisions. When risks are underestimated or misunderstood, essential wildfire management measures may face resistance. For example, prescribed burns or zoning regulations, while effective, can be politically challenging due to their potential unpopularity (Stedman, 2004). Community-based training programs can bridge these gaps by raising awareness and fostering preparedness, equipping residents with practical knowledge about evacuation routes, procedures and home ignition zone maintenance, which is eventually translated into behavioral change through mitigation (Brenkert-Smith et al., 2012).

Fire literacy extends beyond professional expertise to encompass public understanding of fire behavior, ecological roles, and socioecological dynamics (McGranahan & Wonkka, 2018). Building a fire-literate society involves integrating fire awareness into school curricula, community programs, and risk communication campaigns. Reviving fire culture through education can reduce vulnerabilities, both for local residents and for those travelling as visitors to fire-prone regions.

Professional training should adopt interdisciplinary approaches, equipping practitioners in navigating the complexities of integrated fire management. This includes bridging disciplinary divides, engaging diverse stakeholders, and addressing knowledge gaps in emerging fire regimes (Stoof & Kettridge, 2022).

Risk communication and inclusive governance

Effective risk communication is critical for fostering public support and understanding of wildfire management strategies. Policymakers should tailor messages to resonate with diverse audiences, emphasizing shared values and actionable solutions. Inclusive planning processes

that engage communities as active participants enhance the legitimacy and effectiveness of wildfire governance (Milner-Gulland et al., 2014).

Environmental justice considerations are equally vital. Integrating distributional, procedural, and restorative justice into wildfire governance ensures equity and inclusivity, reducing conflicts and promoting community buy-in (Fra Paleo, 2015). Justice-oriented frameworks can guide the development of strategies that balance risk reduction with social and ecological priorities.

Summary: Towards an Integrated Wildfire Policy Framework

An integrated framework for fire adaptation and literacy in the EU must prioritize proactive approaches that align with broader disaster risk governance principles. By fostering fire literacy, engaging communities, and addressing systemic risks, policymakers can create more resilient landscapes and societies. Coordinated efforts across sectors and levels of governance, supported by inclusive and justice-oriented frameworks, are essential for mitigating wildfire risk in the face of a changing climate.

E. What is currently happening in the EU?

14. Emergency response approaches in the EU

Wildfire policies across Europe differ significantly due to variations in fire risk, fire history, wildfire information and emergency response organizational structures. While the *European Forest Fire Information System (EFFIS)* provides a common platform for assessing fire danger, many countries also maintain their own fire risk systems to guide response strategies, personnel allocation, and infrastructure readiness (EFFIS, 2024).

During high-fire seasons, wildfire monitoring systems include preposition cameras with multisensor capabilities, ground teams, watchtowers, and aerial spotting teams equipped with airplanes or drones. Access infrastructure is a key component of the fire emergency response. Networks of forest and public roads, often originally built for forestry purposes, are critical for reaching fire locations. In fire-prone Mediterranean countries such as France, Greece, Italy, Portugal, Spain, and parts of Croatia and Slovenia, "fire road networks" are well established (Pičman et al., 2011; Laschi et al., 2019; Saražin, 2025). In Central Europe, countries such as Poland also maintain fire-specific road networks (Bartosz-Sroka, 2019).

Additionally, *fuel breaks*—areas with a reduced amount of vegetation to slow wildfire spread—are increasingly adopted alongside road networks. These have been widely implemented in Portugal, Spain, and parts of France and Italy. Other essential infrastructure includes water resources for fire suppression, hydrant systems, and logistical hubs such as heliports for aerial suppression.

For the 2023 wildfire season, the rescEU—a reserve of personnel, equipment and infrastructure, integrated into the EU Civil Protection Mechanism—wildfire suppression capabilities include 24 fire response planes, 4 helicopters, and over 400 ground fire personnel

deployed to Portugal, France, and Greece. These joint resources provide critical support for managing extreme wildfire events across the EU (European Commission, 2024).

However, the majority of initial emergency response resources for low-intensity wildfires remain organized at the national or regional level. Fire response teams vary significantly across member states, ranging from multipurpose units to specialized wildfire response teams found in countries such as Portugal, Spain, and Italy. In several countries, additional units trained for remote areas, such as smokejumpers or hotshot crews, crews or hand crews, can be deployed via helicopters or on the ground (Portugal, Spain, Switzerland, The Netherlands, Norway, Slovenia). Volunteer teams also play a critical role, particularly in Central Europe, where they constitute 95–99% of all active fire response units (CTIF, 2024).

Aerial suppression capabilities vary widely across the EU. Southern European countries, which face greater wildfire risk, tend to maintain state-owned aircraft fleets, including medium- and large-capacity airplanes. In contrast, Central and Northern European countries rely primarily on helicopters, which are often operated by the military or the police for multipurpose use. Private concessionaires or companies increasingly provide aerial suppression services in countries such as Austria, Italy, Norway, Portugal, and Spain.

15. Wildfire Policies in the EU

Current EU wildfire policies and funding mechanisms primarily emphasize emergency responses to wildfire prevention, limiting their effectiveness in addressing the root causes of wildfire risk. Several key EU policies and financial instruments influence wildfire risk reduction, including the EU Regional Policy (cohesion policy), the Common Agricultural Policy (CAP), and specific programs such as the European Regional Development Fund (ERDF) and the European Agricultural Fund for Rural Development (EAFRD). Approximately 90% of EU funding for forests comes from the EAFRD, with 27% allocated to afforestation, 18% to increasing forest resilience, and 18% to damage prevention during the 2014–2020 programming period (Miličević 2023).

The EU also has other instruments, such as the LIFE program, the Union Civil Protection Mechanism (UCPM), and the Solidarity and Emergency Aid Reserve (SEAR), which have direct and indirect impacts on wildfire policy. For example, the UCPM facilitates resource sharing among member states in disasters, coordinated through the Emergency Response Coordination Centre. The rescEU reserve, established in 2019, provides additional disaster response resources.

In terms of information systems, platforms such as the Civil Protection Knowledge Network (CPKN), EFFIS, and the Disaster Risk Management Knowledge Centre (DRMKC) operate as information hubs that promote risk analysis and better preparedness. EFFIS supports real-time wildfire monitoring and postfire damage assessment, whereas DRMKC translates scientific data into actionable policies (see also Appendix A).

Despite these efforts, EU wildfire risk management is hampered by the lack of a targeted, cohesive policy framework. Instead, wildfire risk is managed indirectly, disconnectedly, and

fragmentarily through sectoral policies such as the EU Forest Strategy 2030, the Biodiversity Strategy, and the Climate Strategy. These strategies often mention wildfires as a secondary concern rather than addressing them directly. For example, the Biodiversity Strategy acknowledges fire as a threat to ecosystems but focuses primarily on nature-based solutions and forest health. Still, recent reports within the EU have given thought to governance issues, such as the wildfire peer review reports on Greece and Italy (Arbinolo et al., 2024; Verde et al., 2024), with both reports calling for cross-sectoral approaches and governance revision, towards increased dialogue between all relevant stakeholders. While these calls are made for each reviewed country, the issuance of such recommendations on EU reports could signal acknowledgment of the need for policy changes on a broader scale.

Challenges to EU Wildfire Policy

The fragmented nature of EU wildfire policies stems partly from regulatory constraints. Article 196 of the Treaty on the Functioning of the European Union (TFEU) limits the EU's ability to harmonize civil protection laws across member states. This prevents the formulation of a comprehensive, integrated wildfire risk management policy. For example, Regulation (EC) No. 1485/2001, which amended earlier Council regulations on forest fire management, primarily addressed forest fire zoning but lacked the authority to enforce planning mandates.

In addition, the cohesion policy, which aims to promote territorial cohesion, has limited applicability for wildfire recovery efforts. As Pronto et al. (2023) noted, "Cohesion Policy funding schemes are suitable mechanisms to finance wildfire prevention, preparedness, mitigation and adaptation, but less so for recovery."

Some member states with frequent wildfires, such as Portugal, Spain, France, Italy, and Greece, have developed national wildfire policies. However, the lack of coordinated EU-level policies creates significant challenges for transboundary wildfires and for Central and Northern European countries, where wildfires have historically been less of a concern but are now increasing due to climate change.

Opportunities for Harmonization and Synergies

The EU's existing strategies, such as the CAP, Climate Strategy, Biodiversity Strategy, and Farm-to-Fork Strategy, could be better harmonized with wildfire risk reduction principles. For instance:

- **Ecological Corridors:** The biodiversity strategy's goal of increasing landscape connectivity could inadvertently facilitate fire spread. These corridors could be designed as firebreaks by avoiding flammable vegetation.
- **Urban Greening:** Increasing tree cover in cities and peri-urban areas requires the consideration of fire risk. Restoring grasslands and avoiding highly flammable vegetation can reduce vulnerability at the wildland–urban interface (WUI).
- **Tree Planting Initiatives:** The EU's goal of planting 3 billion trees by 2030 must prioritize fire-resistant, native species and diverse, multiaged plantations. Afforestation should be avoided in regions where open habitats are ecologically critical, such as semiarid areas (Veldman et al., 2019) (see also Wildfires: Managing Risks in European Tree Planting Programs, in chapter 12).

There are also significant opportunities for reducing wildfire risk through synergies with CAP-related measures, including the following:

- Promoting extensive livestock grazing in abandoned areas to reduce fuel loads.
- Agricultural activities in the WUI should be supported to create fire-resistant buffers around settlements.
- Firewise forest management practices, such as maintaining open woodlands and agroforestry systems and utilizing understorey biomass for bioenergy, should be encouraged (Moreira & Pe'er, 2018).

Summary: What is currently happening in the EU?

The EU wildfire response focuses mainly on reactive suppression, with various approaches across member states. Monitoring systems, road networks, and tools such as EFFIS support assessment preparedness. EU policies such as the CAP and Biodiversity Strategy offer potential but lack integration for managing wildfire risk. Harmonizing these strategies, prioritizing fire-resistant vegetation, and scaling prevention funding can improve EU-wide risk management

F. What should the EU address in the future?

To prepare for the escalating challenges posed by wildfires, the EU must adopt an integrated approach that combines proactive and reactive strategies. We list three urgent key messages from our review of the evidence and propose a toolbox of **eight policy options** that address both the social-ecological systems and spatial dimensions of wildfire risk management. The interconnected policy options can be tailored to specific contexts, reflecting the diverse social-ecological landscapes across the EU. In Appendix B, we provide successful examples across Europe about projects implementing each of the eight policy options to provide guidance and inspiration for their wide adoption.

Urgent key messages:

1. Prioritize the Implementation of Climate Mitigation and Land Use Policies

Swiftly implement existing EU climate mitigation and adaptation plans and land use policies to address wildfire risk intensified by climate change, rural depopulation, abandoned farmland and changing landscapes. The new Nature Restoration Law should also be swiftly implemented with a particular focus on European peatland restoration. This is critical for preventing significant carbon loss and mitigating climate change feedback loops, since peatlands, the most carbon-dense ecosystems on Earth, store approximately ten times more carbon per hectare than boreal forests do.

2. Incorporating Assessments of Wildfire Risk into Biodiversity and Tree Planting Initiatives

Ensures that wildfire risk scenarios are thoroughly assessed and integrated before the Kunming–Montreal Global Biodiversity Framework’s 30x30 strategy and the EU tree-planting program are fully implemented until 2030. These initiatives must be aligned with fire-wise landscape management to avoid unintended consequences, such as increased fire vulnerability in afforested areas.

3. “Living with fire” - enhance Public Health Interventions and Education on Wildfire Risk

Address the severe health risks posed by wildfire smoke, particularly for vulnerable populations, by improving preparedness and public health interventions. Elevate awareness through comprehensive education programs for all ages, fostering a fire-literate society equipped to adapt to the growing challenge of “living with fire” in Europe.

Eight EU Policy Options for Long-term Proactive Wildfire Management

Wildfire risk reduction: A systems approach

Policy Option 1: Adopt an Integrated Approach to Wildfire Risk Reduction

Current wildfire policies emphasize fire suppression, a reactive approach that has led to biomass accumulation, increasing the severity of today's fires. While suppression can mitigate immediate losses, it is uneconomical in the long term and insufficient for addressing evolving fire regimes, which are influenced by climate change and increasing fuel loads.

Actions

- Shift from suppression-focused policies to a balanced framework of proactive and reactive actions.
- Wildfire risk policies should be integrated into broader disaster risk and climate change adaptation frameworks, adopting a multihazard approach.
- Investments in biomass management strategies should be increased, particularly near high-risk areas.
- Implement transitional models: prioritize proactive actions in the short term while gradually reducing reactive measures.

Benefits: Improved policy integration, reduced costs of suppression, and prevention of cascading hazards linked to wildfires.

Costs: Potential resistance from stakeholders in the fire suppression industry and local communities concerning perceived security risks.

Policy Option 2: Adopt Nature-Based Solutions (NBSs) for Wildfire Risk Reduction

Nature-based solutions leverage natural processes to address societal challenges while providing environmental, social, and economic benefits. Ecosystem-based disaster risk reduction (ecoDRR) uses these principles to mitigate wildfire risk and restore ecosystems after fires.

Actions

- Understorey grazing in forests and woodlands, especially in high-risk areas near communities, should be promoted.
- Postfire salvage logging should be avoided to minimize soil erosion and compaction.
- Implement bioengineering techniques for slope stabilization and erosion control.
- Adhere to the IUCN global standards³ on nature-based solutions for project implementation.

Benefits: Biomass reduction, erosion prevention, diversified rural economies, and job creation.

Costs: Resistance to proactive measures due to misconceptions about safety.

Policy Option 3: Embrace the Ecological and Cultural Role of Fire

Fire suppression policies disregard the ecological and cultural significance of fire, which contributes to biomass accumulation and more severe wildfires. Fire is an integral component of certain ecosystems and has cultural significance in traditional land management practices.

Actions

- Recognizing the ecological role of fire in specific ecosystems.
- Local communities should be supported in applying controlled burning for e.g. agriculture, forestry, and biodiversity conservation.

³ : <https://iucn.org/our-work/topic/iucn-global-standard-nature-based-solutions>

- Prescribed burns should be adopted under planned conditions to manage biomass and conserve biodiversity.
- Manage wildfires at acceptable levels to minimize harm to non fire-adapted ecosystems and human settlements.

Benefits: Reduced wildfire intensity, restored ecosystem services, and reconciliation of cultural fire practices with contemporary management.

Costs: Public concerns about prescribed burning, potential health effects, and resistance to "let it burn" policies.

Policy Option 4: Build Educational and Risk Communication Capacity

Integrated fire management requires interdisciplinary knowledge and skills that are often absent from traditional education and professional training. Increasing fire literacy across generations and sectors is essential for improving awareness, preparedness, and decision-making.

Actions

- Include fire management and landscape fire dynamics into primary, secondary, vocational, and higher education curricula.
- Foster interdisciplinary training programs for professionals in fire management, combining engineering, natural sciences, and social sciences.

Benefits: Improved decision-making, greater fire literacy, fewer accidental ignitions, and better preparedness in emerging fire-prone regions.

Costs: Financial costs of developing and localizing educational materials and adjustments to existing curricula.

Wildfire risk reduction: A spatial approach

Policy Option 5: Adopt Landscape Management to Reduce Vulnerability

Extensive monocultures and poorly managed landscapes exacerbate wildfire risk. Transitioning to multifunctional landscapes with mixed land uses can improve fire resistance while supporting biodiversity, agriculture, and forestry.

Actions

- The use of mosaic landscape structures should be promoted to reduce fuel continuity.
- Foster agroforestry, extensive livestock farming, and rewilding initiatives with large herbivores.
- Manage biomass through prescribed burn, grazing, and mowing
- Restore degraded ecosystems using native species and create linear fuel breaks along roads and energy corridors.

Benefits: Fire-resilient landscapes, diversified rural economies, and ecosystem restoration.

Costs: Reduced short-term economic returns for landowners and potential habitat fragmentation.

Policy Option 6: Harmonizing Sectoral Policies to Address Wildfire Risk

Current EU sectoral policies often have unintended consequences that exacerbate wildfire risk. For example, afforestation under the CAP has led to forest encroachment near residential areas, increasing exposure to wildfire hazards.

Actions

- Review sectoral policies at all governance levels to assess their wildfire risk implications.
- Promote synergies between policies while addressing trade-offs.
- Strategic environmental assessments are used to evaluate the wildfire risk of national plans and programs.

Benefits: Avoidance of negative policy spillovers and progress toward integrated, multisectoral wildfire policies.

Costs: Increased complexity in policy design and coordination.

Policy Option 7: Reducing urban sprawl and fostering compact urban areas

Urban sprawl amplifies wildfire risk by expanding the wildland–urban interface (WUI). Compact urban development can reduce exposure while offering co-benefits such as lower carbon emissions.

Actions

- Encourage compact urban planning and reduce urban sprawl into wildfire-prone areas.
- Wildfire risk management should be integrated into urban planning, particularly in suburban and periurban areas.
- Incentivize fire-resistant construction and vegetation in WUI zones.

Benefits: Reduced WUI vulnerability, safer urban environments, and cobenefits such as emissions reduction.

Costs: Potential resistance from developers and property price instability with increased social injustice. Loss of certain ecosystem services in suburban areas.

Policy Option 8: Promotion of Private Sustainable Land Management Practices

Private landowners play a critical role in managing landscapes. However, current practices often fail to adapt to changing wildfire risk and climate conditions, leaving landscapes vulnerable.

Actions

- Encourage diverse and fire-resistant land use practices in forestry, shrubland, and grassland management that decrease fire risk.
- Provide incentives for silvicultural techniques that reduce biomass density and diversify forest composition.
- Foster extensive grazing and mowing to manage grasslands sustainably.
- The insurance sector should be incentivized for supporting firewise landscape management.

Benefits: Reduced fuel loads, biodiversity conservation, and economic opportunities for rural communities.

Costs: Higher costs may initially occur for sustainable farming and forestry practices, potentially reducing short-term profitability.

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Glossary

Direct fire prevention
Proactive measures that directly reduce the likelihood of wildfire ignition or spread by addressing fuels in strategic locations. Examples include mechanical fuel treatments, prescribed burning, and the establishment of firebreaks and fuel breaks.

Ecosystem-based disaster risk reduction (ecoDRR)

Approaches that seek to reduce the adverse impacts of disasters on vulnerable communities and countries through nature-based solutions and ecosystem management

Fire danger
The likelihood and potential intensity of wildfires in a specific area are influenced by factors such as weather conditions, fuel load, fuel moisture, and vegetation type. Fire danger is often measured via indices such as the fire weather index (FWI).

Fire deficit

The reduced frequency and intensity of wildfires resulting from the exclusion of fires from fire-adapted ecosystems lead to fuel load accumulation and an increased risk of high-intensity damaging fires.

Fire prevention
Actions are taken to reduce both the occurrence and negative impacts of wildfires, including public awareness campaigns, the regulation of fire-prone activities, fuel management, and the maintenance of infrastructure such as firebreaks.

Fire regime
The characteristic patterns of fire occurrence, frequency, intensity, seasonality, and type in a given landscape are shaped by natural and human factors that may change over time.

Fire risk and fire risk management

- **Fire risk:** The probability of a wildfire occurring and its potential impact on ecosystems, human lives, and infrastructure. The potential loss of life, injury, or destroyed or damaged assets that could occur in a system, society or community in a specific period of time are determined probabilistically as a function of wildfire, hazard exposure, vulnerability to wildfire, and coping capacity (adapted from the Sendai Framework for Disaster Risk Reduction).
- **Fire risk management:** Strategies, plans and actions to reduce fire risk through prevention, preparedness, response, and recovery measures, integrated across multiple sectors and scales.

Fire **wise**
An approach to managing landscapes and communities that reduces wildfire exposure and vulnerability while maintaining ecological, economic, and cultural value. This includes promoting fire-resilient vegetation, sustainable land use, and community preparedness.

Fire **suppression**
Immediate emergency response to wildfire consists of control and extinguishment, involving fire response teams, water, equipment, and aerial resources. Fire suppression is a reactive measure focused on limiting wildfire loss and damage.

Fuel **management**
The modification of vegetation and organic matter—consisting of its reduction—may serve as potential fire fuel to reduce the intensity and spread of wildfires. Techniques include thinning, grazing, prescribed burning, and mechanical removal of biomass.

Indirect **fire** **prevention**
Land-use practices that indirectly reduce wildfire risk by promoting economic activities that limit fuel build-up. Examples include agroforestry, sustainable grazing, and the cultivation of fire-resistant crops.

Integrated **landscape** **management**
A framework for managing landscapes that balances multiple objectives, such as agriculture, forestry, biodiversity, development, and wildfire prevention. It emphasizes collaboration among stakeholders to address interconnected challenges.

Integrated **fire** **management**
A holistic approach to wildfire governance that combines prevention, early warning, emergency response and suppression, and soil and vegetation recovery, considering ecological, social, and economic factors. It integrates wildfire policies with broader climate and disaster risk management strategies.

Key **vulnerable** **element**
Critical components of a landscape or community that are particularly susceptible to wildfire impact. These include the human population, communities, infrastructure, industry and energy, biodiversity hotspots, and ecosystem services such as the water supply and air quality.

Landscape **fires**
Fires occurring in natural or seminatural landscapes, including wildfires and prescribed fires, that affect vegetation and ecosystems. These fires can be either beneficial or detrimental, depending on their context and management.

Landscape **vulnerability**
The susceptibility of a landscape to wildfire impacts is determined by factors such as fuel load, vegetation type, land use, ecosystem, topography, and climate. Vulnerable landscapes often have fuel continuity and limited coverage of firebreaks.

Natech

Natural hazards can trigger technological accidents (Showalter et al., 1994).

Nature-based solution (NbS) solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more and more diverse natural and natural features and processes into cities, landscapes, and seascapes through locally adapted, resource-efficient and systemic interventions (EC, 2015).

Prescribed**burning**

A fuel management technique consisting of the intentional use of fire under controlled conditions to reduce fuel loads, promote biodiversity, or achieve other land management objectives. Prescribed burns are carefully planned and monitored to avoid unintended consequences.

Proactive**approach**

Fire management strategies and actions aimed at preventing the occurrence of fires and mitigating wildfire risk. These include fuel management, community awareness programmes, and the adoption of firewise land-use practices.

Salvage logging

Economically motivated practice of logging trees in forest areas that have been damaged by wildfire or other natural disturbances. The removal of damaged trees after a wildfire to mitigate ecological or social damage in the affected areas, is not referred as salvage logging in this document.

Vapour pressure deficit (VPD)

The VPD is the difference between the amount of moisture present in the air and the potential amount of moisture the air can contain when it is saturated, also expressed as Air Relative Humidity (RH), offered in weather forecasts.

Wildfire

Unplanned or uncontrolled fires affect vegetation across natural, cultural, industrial, and residential areas (adapted from FAO, 2006). It is driven by weather conditions, fuel availability, and human activity. Wildfires can cause significant ecological, economic, and social impacts.

Wildland-urban**interface****(WUI)**

The zone where natural landscapes meet urban and suburban areas, such as residential areas adjacent to forests or shrubland. The WUI is particularly vulnerable to wildfires because of the presence of flammable vegetation, population, assets, cultural and natural heritage, infrastructure, industry and energy.

References

- Abeli, T. and Di Giulio, A. (2023), Risks of massive tree planting in Europe should be considered by the EU Forestry Strategy 2030. *Restor Ecol*, 31: e13834. <https://doi.org/10.1111/rec.13834>
- Acácio, V., Holmgren, M., Jansen, P. A., & Schrotter, O. (2007). Multiple recruitment limitations cause arrested succession in Mediterranean cork oak systems. *Ecosystems*, 10, 1220-1230.
- Ager, A.A., Day, M.A., Alcasena, F.J., Evers, C.R., Short, K.C., Grenfell, I. (2021). Predicting Paradise: Modelling future wildfire disasters in the western US. *Science of the Total Environment*, 784, p. 147057.
- Agnoletti M., Santoro A. (2018). Rural landscape planning and forest management in Tuscany, Italy. *Forests*, 9, 473.
- Arbinolo, M., Patimo, G., Rey, E., Stokkeland, O., Verde, J. C., Casartelli, V., Marengo, A., Melinato, S., Mysiak, J., Salpina, D., Afentoulidis, S., Brăilescu, C., & Sørensen, J. (2024). UCPM Wildfire Peer review report: Greece 2024. <https://doi.org/10.25424/CMCC-79TS-VV91>
- Amiro B.D., MacPherson J. I., Desjardins R. L., Chen J. M., Liu J. (2003). Postfire carbon dioxide fluxes in the western Canadian boreal forest: evidence from towers, aircraft and remote sensing. *Agricultural and Forest Meteorology*, 115, 91–107.
- Andela N. et al. 2017. A human-driven decline in global burned area. *Science* 356,1356-1362(2017). DOI:10.1126/science.aal4108
- Aparício, B. A., Alcasena, F., Ager, A., Chung, W., Pereira, J. M., & Sá, A. C. (2022). Evaluating priority locations and potential benefits for building a nation-wide fuel break network in Portugal. *Journal of environmental management*, 320, 115920.
- Archibald, S., Lehmann, C. E., Belcher, C. M., Bond, W. J., Bradstock, R. A., Daniou, A. L., ... & Zanne, A. E. (2018). Biological and geophysical feedbacks with fire in the Earth system. *Environmental Research Letters*, 13(3), 033003.
- Ascoli, D., & Bovio, G. (2013). Prescribed burning in Italy: issues, advances and challenges. *iForest-Biogeosciences and Forestry*, 6(2), 79.
- Ascoli, D., Moris, J. V., Marchetti, M., & Sallustio, L. (2021). Land use change towards forests and wooded land correlates with large and frequent wildfires in Italy. *Annals of Silvicultural Research*, 46(2), 177–188. <https://doi.org/10.12899/asr-2264>
- Ascoli, D., Plana, E., Oggioni, S. D., Tomao, A., Colonico, M., Corona, P., ... & Barbati, A. (2023). Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. *International Journal of Disaster Risk Reduction*, 92, 103715.
- Astrup, R., Bernier, P. Y., Genet, H., Lutz, D. A., & Bright, R. M. (2018). A sensible climate solution for the boreal forest. *Nature Climate Change*, 8, 2-12.
- Bachantourian M., Kalabokidis K., Palaologou P., Chaleplis K. (2023). Optimizing fuel treatments allocation to protect the wildland–urban Interface from large-scale wildfires in Greece. *Fire* 6(2), 75.
- Bansal, A., Cherbuin, N., Davis, D. L., Peek, M. J., Wingett, A., Christensen, B. K., ... & Nolan, C. J. (2023). Heatwaves and wildfires suffocate our healthy start to life: Time to assess impact and take action. *The Lancet Planetary Health*, 7(8), e718-e725.

- Bar-Massada, A., Alcasena, F., Schug, F. and Radeloff, V.C. (2023). The wildland–urban interface in Europe: spatial patterns and associations with socioeconomic and demographic variables. *Landscape and Urban Planning*, 235, p. 104759.
- Barbosa, J. V., Nunes, R. A., Alvim-Ferraz, M. C., Martins, F. G., & Sousa, S. I. (2024). Health and economic burden of wildland fires PM2. 5-related pollution in Portugal–A longitudinal study. *Environmental Research*, 240, 117490.
- Barnes et al. 2025. Climate change increased the likelihood of wildfire disaster in highly exposed Los Angeles area. *World Weather Attribution*. <https://www.worldweatherattribution.org/climate-change-increased-the-likelihood-of-wildfire-disaster-in-highly-exposed-los-angeles-area/>
- Barragán, G., Wang, T., & Rhemtulla, J. M. (2023). Trees planted under a global restoration pledge have mixed futures under climate change. *Restoration Ecology*, 31(3), e13764.
- Barreiro S., Benali A., Rua J.C.P., Tomé M., Pereira, J.M.C. (2021). Combining landscape fire simulations with stand-level growth simulations to assist landowners in building wildfire resilient landscapes. *Forests*, 12(11), 1498.
- Barros, A.M.G.; Pereira, J.M.C. Wildfire Selectivity for Land Cover Type: Does Size Matter? *PLoS ONE* 2014, 9, e84760
- Bartosz-Sroka, A. 2019. Fire roads - Drogi pożarowe w lesie. *Nadleśnictwo Cierpiszewo* https://cierpiszewo.torun.lasy.gov.pl/aktualnosci/-/asset_publisher/1M8a/content/drogi-pozarowe-w-lesie
- Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., ... & Crowther, T. W. (2019). The global tree restoration potential. *Science*, 365(6448), 76-79.
- Bednar-Friedl, B., Biesbroek, R., Schmidt, D. N., Alexander, P., Børshiem, K. Y., Carnicer, J., ... & Whitmarsh, L. (2022). Europe (Chapter 13).
- Benali A., Sá A.C.L., Pinho J., Fernandes P.M., Pereira J.M.C. 2021. Understanding the impact of different landscape-level fuel management strategies on wildfire hazard in central Portugal. *Forests* 12(5), 522. <https://doi.org/10.3390/f12050522>
- Bénichou N., Adelzadeh, M., Singh, J., Gomaa, I., Elsagan, N., Kinateder, M., Ma, C., Gaur, A., Bwalya, A., Sultan, M. (2021). National Guide for Wildland-Urban Interface Fires. National Research Council Canada. ISBN 978-0-660-36308-0. <https://doi.org/10.4224/40002647>.
- Bertomeu, M., Pineda, J., & Pulido, F. (2022). Managing wildfire risk in mosaic landscapes: a case study of the Upper Gata River catchment in Sierra de Gata, Spain. *Land*, 11(4), 465.
- Beverly, J. L., Leverkus, S. E., Cameron, H., & Schroeder, D. (2020). Stand-level fuel reduction treatments and fire behaviour in canadian boreal conifer forests. *Fire*, 3(3), 35.
- Bird et al. 2024. Late Pleistocene emergence of an anthropogenic fire regime in Australia’s tropical savannahs. *Nature Geoscience*, Vol 17: 233–240
- Blumröder, J. S., May, F., Härdtle, W., & Ibisch, P. L. (2021). Forestry contributed to warming of forest ecosystems in northern Germany during the extreme summers of 2018 and 2019. *Ecological Solutions and Evidence*, 2(3), e12087.
- Blumröder, J.S. & Pierre L. Ibisch (2023). Wald- und Forstbrände im Klimawandel. *Geographische Rundschau* 11-2023:32-36.
- Blumröder, J.S., F. Schmidt, A. Gordon, S. Grosse & P.L. Ibisch (2022). Ecosystemic resilience of a temperate postfire forest under extreme weather conditions. *Front. For. Glob. Change* 5: <https://doi.org/10.3389/ffgc.2022.1070958>.
- Bond, W. J., & Keeley, J. E. (2005). Fire as a global ‘herbivore’: the ecology and evolution of flammable ecosystems. *Trends in ecology & evolution*, 20(7), 387-394.
- Bond, W. J., Woodward, F. I., & Midgley, G. F. (2005). The global distribution of ecosystems in a world without fire. *New phytologist*, 165(2), 525-538.
- Bowman, D. M., Perry, G. L., Higgins, S. I., Johnson, C. N., Fuhlendorf, S. D., & Murphy, B. P. (2016). Pyrodiversity is the coupling of biodiversity and fire regimes in food webs. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1696), 20150169.
- Bowman, W.S, Rebecca J. Schmidt, Gursharan K. Sanghar, George R. Thompson III, Hong Ji, Amir A. Zeki, Angela Haczk; “Air That Once Was Breath” Part 1: Wildfire-Smoke-Induced Mechanisms

- of Airway Inflammation – “Climate Change, Allergy and Immunology” Special IAAI Article Collection: Collegium Internationale Allergologicum Update 2023. *Int Arch Allergy Immunol* 3 June 2024; 185 (6): 600–616. <https://doi.org/10.1159/000536578>
- Bowring, S.P.K., Jones, M.W., Ciais, P., Guenet, B., Abiven, S. (2022). Pyrogenic carbon decomposition critical to resolving fire’s role in the Earth system. *Nature Geoscience*, 2022; 15 (2): 135 DOI: 10.1038/s41561-021-00892-0
- Brown, T. P., Duff, T. J., Inbar, A., Lane, P. N., & Sheridan, G. J. (2024). Forest reorganisation effects on fuel moisture content can exceed changes due to climate warming in wet temperate forests. *Global Change Biology*, 30(1), e17023.
- Brundu, G., & Richardson, D. M. (2016). Planted forests and invasive alien trees in Europe: a code for managing existing and future plantings to mitigate the risk of negative impacts from invasions. *NeoBiota* 30: 5–47 doi: 10.3897/neobiota.30.7015 <http://neobiota.pensoft.net>
- Brus, R., Pötzelsberger, E., Lapin, K., Brundu, G., Orazio, C., Straigyte, L., & Hasenauer, H. (2019). Extent, distribution and origin of nonnative forest tree species in Europe. *Scandinavian journal of forest research*, 34(7), 533-544.
- Cansler, C. A., Kane, V. R., Hessburg, P. F., Kane, J. T., Jeronimo, S. M., Lutz, J. A., ... & Larson, A. J. (2022). Previous wildfires and management treatments moderate subsequent fire severity. *Forest Ecology and Management*, 504, 119764.
- Carnicer, J., Alegria, A., Giannakopoulos, C., Di Giuseppe, F., Karali, A., Koutsias, N., ... & Vitolo, C. (2022). Global warming is shifting the relationships between fire weather and realized fire-induced CO2 emissions in Europe. *Scientific Reports*, 12(1), 10365.
- Castellnou, M., Prat-Guitart, N., Arilla, E., Larrañaga, A., Nebot, E., Castellarnau, X., ... & Miralles, M. (2019). Empowering strategic decision-making for wildfire management: avoiding the fear trap and creating a resilient landscape. *Fire ecology*, 15, 1-17.
- Castro, J., Morales-Rueda, F., Navarro, F. B., Löf, M., Vacchiano, G., & Alcaraz-Segura, D. (2021). Precision restoration: a necessary approach to foster forest recovery in the 21st century. *Restoration Ecology*, 29(7), e13421.
- Cervera, T., Pino, J., Marull, J., Padró, R., & Tello, E. (2019). Understanding the long-term dynamics of forest transition: From deforestation to afforestation in a Mediterranean landscape (Catalonia, 1868–2005). *Land Use Policy*, 80, 318–331 <https://doi.org/10.1016/j.landusepol.2016.10.006>
- Chen, Y., Hall, J., van Wees, D., Andela, N., Hantson, S., Giglio, L., van der Werf, G. R., Morton, D. C., and Randerson, J. T. 2023. Multidecadal trends and variability in burned area from the fifth version of the Global Fire Emissions Database (GFED5), *Earth Syst. Sci. Data*, 15, 5227–5259, <https://doi.org/10.5194/essd-15-5227-2023>, 2023.
- Cheng, Y., Luo, P., Yang, H., Li, H., Luo, C., Jia, H., & Huang, Y. (2023). Fire effects on soil carbon cycling pools in forest ecosystems: A global meta-analysis. *Science of The Total Environment*, 895, 165001.
- Clifford, A., Lang, L., Chen, R., Anstey, K. J., & Seaton, A. (2016). Exposure to air pollution and cognitive functioning across the life course—a systematic literature review. *Environmental research*, 147, 383-398.
- Cochrane, M. A., & Bowman, D. M. (2021). Manage fire regimes, not fires. *Nature Geoscience*, 14(7), 455-457.
- Collins R.D., De Neufville R., Claro J., Oliveira T. & Pacheco A.P. (2013). Forest fire management to avoid unintended consequences: a case study of Portugal using system dynamics. *Journal of Environmental Management* 130 1–9
- Connolly, R., Marlier, M. E., Garcia-Gonzales, D. A., Wilkins, J., Su, J., Bekker, C., ... & Jerrett, M. (2024). Mortality attributable to PM2. 5 from wildland fires in California from 2008 to 2018. *Science Advances*, 10(23), ead1252.
- Copernicus: 2024 virtually certain to be the warmest year and first year above 1.5°C | Copernicus
- Cseresnyés, I., & Tamás, J. (2014). Evaluation of Austrian pine (*Pinus nigra*) plantations in Hungary. *Tájökológiai lapok*, 12(2), 267-284.

- CTIF – International Association of Fire and Rescue Services – member countries. <https://ctif.org/member-countries> (march, 2024)
- Cunningham, C.X., Williamson, G.J. & Bowman, D.M.J.S. Increasing frequency and intensity of the most extreme wildfires on Earth. *Nat Ecol Evol* **8**, 1420–1425 (2024). <https://doi.org/10.1038/s41559-024-02452-2>
- Damianidis C, Santiago-Freijanes JJ, den Herder M, Burgess P, Mosquera-Losada MR, Graves A, Papadopoulos A, Pisanelli A, Camilli F, Rois-Díaz M, Kay S (2020) Agroforestry as a sustainable land use option to reduce wildfires risk in European Mediterranean areas. *Agroforestry Systems* 95:1–11.
- Davies, B., Power, M. J., Braun, D. R., Douglass, M. J., Mosher, S. G., Quick, L. J., ... & Faith, J. T. (2022). Fire and human management of late Holocene ecosystems in southern Africa. *Quaternary Science Reviews*, 289, 107600.
- Davies, I. P., Haugo, R. D., Robertson, J. C., & Levin, P. S. (2018). The unequal vulnerability of communities of color to wildfire. *PloS one*, 13(11), e0205825.
- Davim, D. A., Rossa, C. G., Pereira, J. M., & Fernandes, P. M. (2022). The Effect of Prescribed Burning in Decreasing Wildfire Extent in Portugal. *Environmental Sciences Proceedings*, 17(1), 36.
- Davis, D. K., & Robbins, P. (2018). Ecologies of the colonial present: Pathological forestry from the *taux de boisement* to civilized plantations. *Environment and Planning E: Nature and Space*, 1(4), 447–469. <https://doi.org/10.1177/2514848618812029>
- Dore, S., Kolb, T.E., Montes-Helu, M. 2008. Long-term impact of stand-replacing fire on ecosystem CO₂ exchange of a ponderosa pine forest. *Global Change Biology*, 14, 1801-1820.
- Duveiller, G., Hooker, J., Cescatti, A. 2018. The mark of vegetation change on Earth's surface energy balance. *Nature Communications* 9:679. doi: 10.1038/s41467-017-02810-8
- EADO (2023). Resilience of the Greek Forest Ecosystems to Climate Change; Committee for the Resilience of the Greek Forest Ecosystems to Climate Change (EADO). Arianoutsou, M., Zerefos, C., Kalabokidis, K., Poupkou, A., Aravanopoulos, F., Eds. Academy of Athens: Athens, Greece. 547 pp. ISBN 978-960-404-413-9.
- EASAC (2019), The imperative of climate action to protect human health in Europe, https://easac.eu/fileadmin/PDF_s/reports_statements/Climate_Change_and_Health/EASAC_CCH_Main_Report_WEB_2August.pdf
- EFFIS. 2024. European Forest Fire Information System <https://forest-fire.emergency.copernicus.eu/> (march, 2024)
- El Garroussi, S., Di Giuseppe, F., Barnard, C. et al. Europe faces up to tenfold increase in extreme fires in a warming climate. *npj Clim Atmos Sci* **7**, 30 (2024). <https://doi.org/10.1038/s41612-024-00575-8>
- Essen, M., McCaffrey, S., Abrams, J., & Paveglio, T. (2023). Improving wildfire management outcomes: shifting the paradigm of wildfire from simple to complex risk. *Journal of Environmental Planning and Management*, 66(5), 909-927.
- European Commission, 2024
- European Environment Agency, 2020, The European Environment – state and outlook, knowledge for transition to a sustainable Europe. <https://www.eea.europa.eu/en/topics/in-depth/land-use>
- Eurostat, 2020. Share of main land types in utilized agricultural area (UAA) by NUTS 2
- Ewald, M., Labenski, P., Westphal, E., Metzsch-Zilligen, E., Großhauser, M., & Fassnacht, F. E. (2023). Leaf litter combustion properties of Central European tree species. *Forestry: An International Journal of Forest Research*, cpad026.
- FAO - Food and Agriculture Organization - (2006). Fire management: voluntary guidelines: principles and strategic actions. FAO Fire Management Working Paper 17.
- FAO - Food and Agriculture Organization - (2024) (Updated). Fire management: voluntary guidelines: principles and strategic actions. FAO Fire Management Working Paper 17. <https://www.fao.org/forestry-fao/firemanagement/en/>
<https://openknowledge.fao.org/items/12eb1bc4-ce90-4901-a2f6-ba2f83fd9e38>

- Felton, A., Nilsson, U., Sonesson, J., Felton, A. M., Roberge, J. M., Ranius, T., ... & Wallertz, K. (2016). Replacing monocultures with mixed-species stands: Ecosystem service implications of two production forest alternatives in Sweden. *Ambio*, 45, 124-139.
- Fernandes, M. E., & Simões, P. (2024). Private forest owners' organizations adherence to policy tools. Insights from Portugal. *Forest Policy and Economics*, 160, 103147.
- Fernandes, P. M. (2013). Fire-smart management of forest landscapes in the Mediterranean basin under global change. *Landscape and Urban Planning*, 110, 175-182.
- Fernandes, P. M., Davies, G. M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., ... & Molina, D. (2013). Prescribed burning in southern Europe: developing fire management in a dynamic landscape. *Frontiers in Ecology and the Environment*, 11(s1), e4-e14.
- Fernandes, P. M., Delogu, G. M., Leone, V., & Ascoli, D. (2020). Wildfire policies contribution to foster extreme wildfires. In *Extreme wildfire events and disasters* (pp. 187-200). Elsevier.
- Fernandes, P. M., Monteiro-Henriques, T., Guiomar, N., Loureiro, C., & Barros, A. M. (2016). Bottom-up variables govern large-fire size in Portugal. *Ecosystems*, 19, 1362-1375.
- Fernandes, P.M. 2009. Combining Forest Structure Data and Fuel Modelling to Classify Fire Hazard in Portugal. *Ann. For. Sci.* 66, 415.
- Feurdean A, Vannièrè B, Finsinger W, Warren D, Connor SC, Liakka J, Panait A, Andric M, Bobek P, Carter VA, et al.: Fire risk modulation by long-term dynamics in land cover and dominant forest type in Eastern and Central Europe. *Biogeosciences* 2020, 17:1213–1230.
- Feurdean, A., Liakka, J., Vannièrè, B., Marinova, E., Hutchinson, S. M., Mosburgger, V., & Hickler, T. (2013). 12,000-Years of fire regime drivers in the lowlands of Transylvania (Central-Eastern Europe): a data-model approach. *Quaternary Science Reviews*, 81, 48-61.
- Finlay, S. E., Moffat, A., Gazzard, R., Baker, D., & Murray, V. (2012). Health impacts of wildfires. *PLoS currents*, 4.
- Fra Paleo, U. (ed.). 2009. Building safer communities. Risk governance, spatial planning, and responses to natural hazards. Amsterdam: IOS Press.
- Fra.Paleo, U. (ed.). 2015. Risk governance. The articulation of hazard, politics and ecology. Dordrecht: Springer.
- Frelich, L. E., Johnstone, J., Kuuluvainen, T. 2024. Boreal forests. In *Future Forests* (pp. 221-242). Elsevier.
- Ganteaume, A., Camia, A., Jappiot, M. et al. A Review of the Main Driving Factors of Forest Fire Ignition Over Europe. *Environmental Management* 51, 651–662 (2013). <https://doi.org/10.1007/s00267-012-9961-z>
- Girona-García, A., Vieira, D., Doerr, S., Panagos, P., Cristina, S. (2024). Into the unknown: The role of postfire soil erosion in the carbon cycle. *Global Change Biology*, 30, e17354. <https://doi.org/10.1111/gcb.17354>
- Gjedrem, A.M., Metallinou, M.M. 2023, Wildland-urban interface fires in Norwegian coastal heathlands – Identifying risk reducing measures, *Safety Science*, 159, 1-32, <https://doi.org/10.1016/j.ssci.2022.106032>
- Glasspool, I.J., Edwards, D., and Axe, L., 2004, Charcoal in the Silurian as evidence for the earliest wildfire: *Geology*, v. 32, p. 381–383, <https://doi.org/10.1130/G20363.1>.
- Gohr, C., Blumröder, J. S., Sheil, D., & Ibisch, P. L. (2021). Quantifying the mitigation of temperature extremes by forests and wetlands in a temperate landscape. *Ecological Informatics*, 66, 101442.
- Gonzalez-Mathiesen, C., & March, A. (2018). Establishing design principles for wildfire resilient urban planning. *Planning Practice & Research*, 33(2), 97-119.
- Gould, C. F., Heft-Neal, S., Johnson, M., Aguilera, J., Burke, M., & Nadeau, K. (2024). Health effects of wildfire smoke exposure. *Annual Review of Medicine*, 75(1), 277-292.
- Grant, E., & Runkle, J. D. (2022). Long-term health effects of wildfire exposure: a scoping review. *The Journal of Climate Change and Health*, 6, 100110.
- Grasso P. and Innocente M.S. (2020) Physics-based models of wildfire propagation towards faster-than-real-time simulation. *Comp. and Math. with Appl.*, 80,790-808.

- Graus, S.; Ferreira, T.M.; Vasconcelos, G.; Ortega, J. Changing Conditions: Global Warming-Related Hazards and Vulnerable Rural Populations in Mediterranean Europe. *Urban Sci.* 2024, 8, 42. <https://doi.org/10.3390/urbansci8020042>
- Gray, A., Davies, G.M., Doménech, R., Taylor, E., Levy, P.E. (2021). Peatland wildfire severity and postfire gaseous carbon fluxes. *Ecosystems* 24, 713-725. <https://doi.org/10.1007/s10021-020-00545-0>
- Greiser, C., Hederová, L., Vico, G., Wild, J., Macek, M., & Kopecký, M. (2024). Higher soil moisture increases microclimate temperature buffering in temperate broadleaf forests. *Agricultural and Forest Meteorology*, 345, 109828.
- Grünig, M., Seidl, R., & Senf, C. (2023). Increasing aridity causes larger and more severe forest fires across Europe. *Global Change Biology*, 29(6), 1648-1659.
- Guiomar, N. G., Pereira, J. M., & Fernandes, P. M. (2023). A Planning Model for Fire-Resilient Landscapes in Portugal Is Riddled with Fallacies: A Critical Review of “FIRELAN” by Magalhães et al., 2021. *Fire*, 6(10), 398.
- Halada, L., Evans, D., Romão, C., & Petersen, J. E. (2011). Which habitats of European importance depend on agricultural practices? *Biodiversity and Conservation*, 20, 2365-2378.
- He, T., Lamont, B. B., & Pausas, J. G. (2019). Fire as a key driver of Earth's biodiversity. *Biological Reviews*, 94(6), 1983-2010.
- Hearn, K. P., & Álvarez-Mozos, J. (2021). A diachronic analysis of a changing landscape on the Duero river borderlands of Spain and Portugal combining remote sensing and ethnographic approaches. *Sustainability (Switzerland)*, 13(24). <https://doi.org/10.3390/su132413962>
- Hermoso, V., Regos, A., Morán-Ordóñez, A., Duane, A., & Brotons, L. (2021). Tree planting: A double-edged sword to fight climate change in an era of megafires. *Global Change Biology*, 27(13), 3001-3003.
- Hetzer, J et al 2024. The fire weather in Europe: large-scale trends towards higher danger. *Environ. Res. Lett.* **19** 084017 [DOI 10.1088/1748-9326/ad5b09](https://doi.org/10.1088/1748-9326/ad5b09)
<https://doi.org/10.1016/j.jaci.2024.01.016>.
- Hugelius, G., ..., Yu, Z. (2020). Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw. *Earth, Atmospheric, and Planetary Sciences* 117 (34) 20438-20446. <https://doi.org/10.1073/pnas.191638711>
- InterAcademy Partnership (2022). Health in the climate emergency: a global perspective, https://www.interacademies.org/sites/default/files/2022-08/Health%20in%20the%20Climate%20Emergency_A%20global%20perspective_IAP%20report.pdf
- Intini, P., Ronchi, E., Gwynne, S. et al. Guidance on Design and Construction of the Built Environment Against Wildland Urban Interface Fire Hazard: A Review. *Fire Technol* 56, 1853–1883 (2020). <https://doi.org/10.1007/s10694-019-00902-z>
- IPCC 2021 - Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, Ö., Yu, R. and Zhou, B., eds., 2021, 'Summary for policymakers', in: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*,
- Jaffe, M. R., Kreider, M. R., Affleck, D. L., Higuera, P. E., Seielstad, C. A., Parks, S. A., & Larson, A. J. (2023). Mesic mixed-conifer forests are resilient to both historical high-severity fire and contemporary reburns in the US Northern Rocky Mountains. *Forest Ecology and Management*, 545, 121283.
- Jepsen, M. R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P. H., Haberl, H., Vesterager, J. P., Andrič, M., Antrop, M., Austrheim, G., Björn, I., Bondeau, A., Bürgi, M., Bryson, J., Caspar, G., Cassar, L. F., Conrad, E., Chromý, P., Daugirdas, V., ... Reenberg, A. (2015). Transitions in European land-management regimes between 1800 and 2010. *Land Use Policy*, 49, 53–64. <https://doi.org/10.1016/j.landusepol.2015.07.003>

- Johnstone, J. F., Celis, G., Chapin III, F. S., Hollingsworth, T. N., Jean, M., & Mack, M. C. (2020). Factors shaping alternate successional trajectories in burned black spruce forests of Alaska. *Ecosphere*, 11(5), e03129.
- Jones, G. M., & Tingley, M. W. (2022). Pyrodiversity and biodiversity: A history, synthesis, and outlook. *Diversity and Distributions*, 28(3), 386-403.
- Jones, M. W., Santín, C., van der Werf, G. R., & Doerr, S. H. (2019). Global fire emissions buffered by the production of pyrogenic carbon. *Nature Geoscience*, 12(9), 742-747.
- Jones, M. W., Veraverbeke, S., Andela, N., Doerr, S. H., Kolden, C., Mataveli, G., Lucrecia, M., Pettinari, Corinne Le Quéré, Thais M. Rosan, Guido R. van der Werf, van Wees, D., & Abatzoglou, J. T. (2024). Global rise in forest fire emissions linked to climate change in the extratropics. *Science* 386, NO. 6719, [DOI: 10.1126/science.adl58](https://doi.org/10.1126/science.adl58)
- Jonsson, M., J. Bengtsson, L. Gamfeldt, J. Moen & T. Snäll. 2019. Levels of forest ecosystem services depend on specific mixtures of commercial tree species. *Nature Plants* 5: 141-147
- Kahraman A. et al 2022. Contrasting future lightning stories across Europe *Environ. Res. Lett.* 17 114023 DOI 10.1088/1748-9326/ac9b78
- Kaland, P. E. (1986). The origin and management of Norwegian coastal heaths as reflected by pollen analysis. *Anthropogenic indicators in pollen diagrams*, 19, 36.
- Kalies, E. L., & Kent, L. L. Y. (2016). Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. *Forest Ecology and Management*, 375, 84-95.
- Kasischke, E.S N. L. Christensen, Jr. and Brian J. Stocks. 1995. Fire, Global Warming, and the Carbon Balance of Boreal Forests. *Ecological Applications*. Vol. 5, No. 2 (pp. 437-451)
- Kelly, L. T., & Brotons, L. (2017). Using fire to promote biodiversity. *Science*, 355(6331), 1264-1265.
- Kooiman, J. 2003. *Governing as governance*. London: Sage
- Kotroni, V., & Lagouvardos, K. (2008). Lightning occurrence in relation with elevation, terrain slope, and vegetation cover in the Mediterranean. *Journal of Geophysical Research: Atmospheres*, 113(D21).
- Krebs, P., Pezzatti, G.B., Mazzoleni, S. et al. Fire regime: history and definition of a key concept in disturbance ecology. *Theory Biosci.* 129, 53–69 (2010). <https://doi.org/10.1007/s12064-010-0082-z>
- Kuemmerle, T., Levers, C., Erb K., Estel, S., Jepsen, M. R., Müller, D., Plutzer, C., Stürck, J., Verkerk, P.J., Verburg, P. H., Reenberg, A. (2016). Hotspots of land use change in Europe. *Environmental research letters*, 11(6), 064020.
- Körner, C. 2003. Slow in, rapid out – Carbon flux studies and Kyoto targets, *Science*, Vol. 300, 1242 – 1243.
- Lal, R. (2020). Soil organic matter and water retention. *Agronomy Journal*, 112(5), 3265-3277.
- Lambrechts, H. A., Paparrizos, S., Brongersma, R., Kroeze, C., Ludwig, F., & Stoof, C. R. (2023). Governing wildfire in a global change context: lessons from water management in the Netherlands. *Fire Ecology*, 19(1), 6.
- Landesmann, J. B., Tiribelli, F., Paritsis, J., Veblen, T. T., & Kitzberger, T. (2021). Increased fire severity triggers positive feedbacks of greater vegetation flammability and favours plant community-type conversions. *Journal of Vegetation Science*, 32(1), e12936.
- Lasanta, T., Cortijos-López, M., Errea, M. P., Khorchani, M., & Nadal-Romero, E. (2022). An environmental management experience to control wildfires in the mid-mountain mediterranean area: Shrub clearing to generate mosaic landscapes. *Land use policy*, 118, 106147.
- Laschi, A., Foderi, C., Fabiano, F., Neri, F., Cambi, M., Mariotti, B., & Marchi, E. (2019). Forest road planning, construction and maintenance to improve forest fire fighting: a review. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering*, 40(1), 207-219.
- Leal, O.A., Dick D.P., de la Rosa, J.M., Barbosa Leal, D.P., González-Pérez, J.A., Campos, G.S., Knicker, H. 2019. Charcoal fine residues effects on soil organic matter humic substances, composition, and biodegradability. *Agronomy* 9: 384, doi:10.3390/agronomy9070384

- Lecina-Diaz, J., Chas-Amil, M. L., Aquilué, N., Sil, Â., Brotons, L., Regos, A., & Touza, J. (2023). Incorporating fire-smartness into agricultural policies reduces suppression costs and ecosystem services damages from wildfires. *Journal of Environmental Management*, 337(December 2022). <https://doi.org/10.1016/j.jenvman.2023.117707>
- Lucas-Borja, M. E., Plaza-Álvarez, P. A., Yáñez, M. D. C., Miralles, I., Ortega, R., Soria, R., ... & Zema, D. A. (2024). Long-term evaluation of soil functionality in Mediterranean forests after a wildfire and postfire hillslope stabilization. *Forest Ecology and Management*, 555, 121715.
- MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., & Gibon, A. (2000). Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management*, 59(1), 47–69. <https://doi.org/10.1006/jema.1999.0335>
- Mack M.C., X.J. Walker, J.F. Johnstone, H.D. Alexander, A.M. Melvin, M.Jean, S.N. Miller (2021) Carbon loss from boreal forest wildfires offset by increased dominance of deciduous trees. *Science* 372, 280–283
- Maezumi, S. Y., Fletcher, M. S., Safford, H., & Roberts, P. (2024). Fighting with fire: Historical ecology and community-based approaches to fire management, stewardship, and ecosystem resilience. *One Earth*, 7(6), 936-941.
- Malmström, A. (2010). The importance of measuring fire severity—Evidence from microarthropod studies. *Forest Ecology and Management*, 260(1), 62-70.
- Mantero, G., Morresi, D., Marzano, R., Motta, R., Mladenoff, D. J., & Garbarino, M. (2020). The influence of land abandonment on forest disturbance regimes: a global review. *Landscape Ecology*, 35(12), 2723–2744. <https://doi.org/10.1007/s10980-020-01147-w>
- Marcolin, E., Marzano, R., Vitali, A., Garbarino, M., and Lingua, E. (2019). Postfire management impact on natural forest regeneration through altered microsite conditions. *Forests* 10:1014. doi: 10.3390/f10111014
- Maringer, J., Ascoli, D., Dorren, L., Bebi, P., & Conedera, M. (2016). Temporal trends in the protective capacity of burnt beech forests (*Fagus sylvatica* L.) against rockfall. *European Journal of Forest Research*, 135, 657-673.
- Matsala, M., Odruzhenko, A., Hinchuk, T. et al. War drives forest fire risks and highlights the need for more ecologically-sound forest management in post-war Ukraine. *Sci Rep* 14, 4131 (2024). <https://doi.org/10.1038/s41598-024-54811-5>
- Mauri, E., Hernández Paredes, E. Núñez Blanco & I. Garcia Feced, C. (2023). Key Recommendations on Wildfire Prevention in the Mediterranean. European Forest Institute.
- Mauri, E., Jankavić, M. 2024. Wildfire risk planning and prevention - Innovations in the Mediterranean and beyond. European Forest Institute. DOI: <https://doi.org/10.36333/rs8en>
- McGranahan, D. A., & Wonkka, C. L. (2018). Wildland fire science literacy: Education, creation, and application. *Fire*, 1(3), 52.
- McWethy, D.B. et al. 2019. Rethinking resilience to wildfire. *Nat Sustain* 2, 797–804 (2019). <https://doi.org/10.1038/s41893-019-0353-8>
- Meddens, A. J., Kolden, C. A., Lutz, J. A., Smith, A. M., Cansler, C. A., Abatzoglou, J. T., ... & Krawchuk, M. A. (2018). Fire refugia: what are they, and why do they matter for global change? *BioScience*, 68(12), 944-954.
- Menemenlis D., Palaiologou P., Kalabokidis K. (2023). Wildfire-residential risk analysis using building characteristics and simulations to enhance structural fire resistance in Greece. *Fire* 6(10), 403.
- Milicevic, V. 2023. The European Union and Forests. Fact Sheets on the European Union – 2025. www.europarl.europa.eu/factsheets/en
- Millikin, R.L.; Braun, W.J.; Alexander, M.E.; Fani, S. Unintended Effects of Fuel Thinning on the Microclimate in the Coastal Forests of Southwestern British Columbia, Canada. Preprints 2023, 2023101426. <https://doi.org/10.20944/preprints202310.1426.v1>

- Milner-Gulland, E.J., McGregor, J.A., Agarwala, M., Atkinson, G., Bevan, P., Clements, T., Daw, T., Homewood, K., Kumpel, N., Lewis, J. and Mourato, S. (2014). Accounting for the impact of conservation on human well-being. *Conservation Biology*, 28(5), pp. 1160-1166.
- Miralles, D. G., Gentine, P., Seneviratne, S. I., & Teuling, A. J. (2019). Land-atmospheric feedbacks during droughts and heatwaves: state of the science and current challenges. *Annals of the New York Academy of Sciences*, 1436(1), 19-35.
- Molina, J. R., González-Cabán, A., & y Silva, F. R. (2019). Wildfires impact on the economic susceptibility of recreation activities: Application in a Mediterranean protected area. *Journal of environmental management*, 245, 454-463.
- Morales-Molino, C., Vescovi, E., Krebs, P., Carlevaro, E., Kaltenrieder, P., Conedera, M., ... & Colombaroli, D. (2015). The role of human-induced fire and sweet chestnut (*Castanea sativa* Mill.) cultivation on the long-term landscape dynamics of the southern Swiss Alps. *The Holocene*, 25(3), 482-494.
- Moreira, F., & Pe'er, G. (2018). Agricultural policy can reduce wildfires. *Science*, 359(6379), 1001-1001.
- Moreira, F., Ascoli, D., Safford, H., Adams, M. A., Moreno, J. M., Pereira, J. M., Catry, F. X., Armesto, J., Bond, W., & González, M. E. (2020). Wildfire management in Mediterranean-type regions: Paradigm change needed. *Environmental Research Letters*, 15(1), 011001
- Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbat, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F., & Bilgili, E. (2011). Landscape - wildfire interactions in southern Europe: Implications for landscape management. *Journal of Environmental Management*, 92(10), 2389–2402. <https://doi.org/10.1016/j.jenvman.2011.06.028>
- Moritz, M. A., Morais, M. E., Summerell, L. A., Carlson, J. M., & Doyle, J. (2005). Wildfires, complexity, and highly optimized tolerance. *Proceedings of the National Academy of Sciences*, 102(50), 17912-17917.
- Moritz MA, Batllori E, Bradstock RA, Gill AM, Handmer J, Hessburg PF, Leonard J, McCaffrey S, Odion DC, Schoennagel T, Syphard AD. (2014). Learning to coexist with wildfire. *Nature*, 515:58-66.
- Moser, B., Temperli, C., Schneiter, G., & Wohlgemuth, T. (2010). Potential shift in tree species composition after interaction of fire and drought in the Central Alps. *European Journal of Forest Research*, 129, 625-633.
- Muona, J., & Rutanen, I. (1994). The short-term impact of fire on the beetle fauna in boreal coniferous forest. *Annales Zoologici Fennici* 31(1): 109-121.
- Müller M.M., Vilà-Vilardell L., Vacik H. (2020): Forest fires in the Alps – State of knowledge, future challenges and options for an integrated fire management. EUSALP Action Group 8
- Newsham, N., & Rowe, F. (2023). Understanding trajectories of population decline across rural and urban Europe: A sequence analysis. *Population, Space and Place*, 29(3), e2630.
- Niklasson, M., & Granström, A. (2000). Numbers and sizes of fires: long-term spatially explicit fire history in a Swedish boreal landscape. *Ecology*, 81(6), 1484-1499.
- Novick, K.A., Ficklin, D.L., Grossiord, C., Konings, A.G., Martínez-Vilalta, J., Sadok, W. et al. (2024) The impacts of rising vapour pressure deficit in natural and managed ecosystems. *Plant, Cell & Environment*, 47, 3561–3589. <https://doi.org/10.1111/pce.14846>
- Oliveira, T. M., Barros, A. M., Ager, A. A., & Fernandes, P. M. (2016). Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission. *International Journal of Wildland Fire*, 25(6), 619-632.
- Oliveira, T. M., Guiomar, N., Baptista, F. O., Pereira, J. M., & Claro, J. (2017). Is Portugal's forest transition up in smoke? *Land Use Policy*, 66, 214-226.
- Ormeño, E., Ruffault, J., Gutigny, C., Madrigal, J., Guijarro, M., Hernando, C., et al. (2020). Increasing cuticular wax concentrations in a drier climate promote litter flammability. *Forest Ecology and Management* 473.
- Ottolini, I.; Arenas Conejo, M.; Prat-Guitart, N.; Uyttewaal, K.; Pandey, P.; Rodríguez-Giralt, I. & Cifre Sabater, M. 2023. A toolkit for fostering cocreation and participative community engagement with vulnerable communities at risk. PyroLife Project (deliverable D17). 35pp

- Ottolini, I, David Salesa, Luis del Romero Renau and Núria Salvador Fernández. 2024. Kindling Change: Shaping a New Fire Culture in Mediterranean socioenvironmental systems from the roots. *Human Geographies - Journal of Studies and Research in Human Geography*. Volume 18, Issue 1.
- Palaiologou P., Kalabokidis K., Ager A.A., Galatsidas S., Papalampros L., Day M.A. (2021). Spatial optimization and tradeoffs of alternative forest management scenarios in Macedonia, Greece. *Forests* 12(6), 697.
- Palaiologou P., Kalabokidis K., Day M.A., Ager A.A., Galatsidas S., Papalampros L. (2022). Modelling fire behavior to assess community exposure in Europe: combining open data and geospatial analysis. *ISPRS International Journal of Geo-Information* 11(3), 198.
- Palaiologou, P., Ager, A.A., Nielsen-Pincus, M., Evers, C.R., Kalabokidis, K. (2018). Using transboundary wildfire exposure assessments to improve fire management programs: a case study in Greece. *International Journal of Wildland Fire*, 27(8), pp. 501-513.
- Palaiologou, P., Kalabokidis, K., Day, M. A., & Kopsachilis, V. (2020). Evaluating socioecological wildfire effects in Greece with a novel numerical Index. *Fire*, 3(4), 63.
- Pan, Y. et al. 2011. A large persistent carbon sink in the world's forests. *Science*, Vol. 333. 6045, 988-993.
- Pan, Y., Birdsey, R. A., Phillips, O. L., Houghton, R. A., Fang, J., Kauppi, P. E., ... & Murdiyarso, D. (2024). The enduring world forest carbon sink. *Nature*, 631(8021), 563-569.
- Pashley, C., Hemming, D., Adams-Groom, B., Borman, A., Johnson, E., Anees-Hill, S., ... & Skjøth, C. (2023). Health Effects of Climate Change (HECC) in the UK: 2023 report. Chapter 10: Wildfires and health.
- Pausas JG and Keeley JE. 2019. Wildfires as ecosystem services. *Front Ecol Environ* 2019; 17(5): 289–295, doi:10.1002/fee.2044
- Pausas, J. G., & Fernández-Muñoz, S. (2012). Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. *Climatic Change*, 110(1), 215-226
- Paveglio, T.B., C. Moseley, M.S. Carroll, D.R. Williams, A.P. Fischer, and E.J. Davis. 2015. "Categorizing the Social Context of the Wildland Urban Interface: Adaptive Capacity for Wildfire And Community "Archetypes." *Forest Science* 61 (2): 298–310.
- Pawlewicz, A., & Pawlewicz, K. (2023). The risk of agricultural land abandonment as a socioeconomic challenge for the development of agriculture in the European Union. *Sustainability (Switzerland)*, 15(4). <https://doi.org/10.3390/su15043233>
- Pellegrini, A.F.A, Harden, J., Georgiou, K., Hemes, K.S., Malhotra, A., Nolan, C.J., Jackson, R.B. (2021). Effects of fire on the persistence of soil organic matter and long-term carbon storage. *Nature Geoscience*, 2021; DOI: 10.1038/s41561-021-00867-1
- Pereira, José M.C., Duarte Oom, Pedro C. Silva, and Akli Benali (2022). Wild, Tamed, and Domesticated: three fire macroregimes for global pyrogeography in the Anthropocene. *Ecological Applications* e2588. <https://doi.org/10.1002/eap.2588>.
- Pereira, P., Francos, M., Brevik, E. C., Ubeda, X., & Bogunovic, I. (2018). Postfire soil management. *Current Opinion in Environmental Science & Health*, 5, 26-32
- Pérez-Izquierdo, L., Bengtsson, J., Clemmensen, K. E., Granath, G., Gundale, M. J., Ibáñez, T. S., ... & Nilsson, M. C. (2023). Fire severity as a key determinant of aboveground and belowground biological community recovery in managed even-aged boreal forests. *Ecology and Evolution*, 13(5), e10086.
- Pickering, B. J., Duff, T. J., Baillie, C., & Cawson, J. G. (2021). Darker, cooler, wetter: Forest understories influence surface fuel moisture. *Agricultural and Forest Meteorology*, 300, 108311.
- Pičman, D., Pentek, T., Nevecerel, H., Papa, I., & Lepoglavec, K. (2011). Possibilities of Application of relative openness in secondary forest opening of slope forests in Croatia/Mogućnosti primjene relativne otvorenosti pri sekundarnom otvaranju suma nagnutih terena Republike Hrvatske. *Croatian Journal of Forest Engineering*, 32(1), 417-431.

- Pinto-Correia, T., & Kristensen, L. (2013). Linking research to practice: The landscape as the basis for integrating social and ecological perspectives of the rural. *Landscape and Urban Planning*, 120, 248–256. <https://doi.org/10.1016/j.landurbplan.2013.07.005>
- Planas, E., Paugam, R., Àgueda, A., Vacca, P., & Pastor, E. (2023). Fires at the wildland-industrial interface. Is there an emerging problem? *Fire safety journal*, 141, 103906.
- Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Bürgi, M., Kizos, T., Kuemmerle, T., Primdahl, J., & Verburg, P. H. (2016). The driving forces of landscape change in Europe: A systematic review of the evidence. *Land Use Policy*, 57, 204–214. <https://doi.org/10.1016/j.landusepol.2016.04.040>
- Plieninger, T., Kohsaka, R., Bieling, C., Hashimoto, S., Kamiyama, C., Kizos, T., Penker, M., Kieninger, P., Shaw, B.J., Sioen, G.B., Yoshida, Y., Saito O. (2018). Fostering biocultural diversity in landscapes through place-based food networks A “solution scan” of European and Japanese models. *Sustainability Science* 13, 219-233.
- Podschwit, H., & Cullen, A. (2020). Patterns and trends in simultaneous wildfire activity in the United States from 1984 to 2015. *International journal of wildland fire*, 29(12), 1057-1071.
- Prats, S. A., Malvar, M. C., & Wagenbrenner, J. W. (2021). Compaction and cover effects on runoff and erosion in post-fire salvage logged areas in the Valley Fire, California. *Hydrological Processes*, 35(1), e13997.
- Pulido, F., Corbacho, J., Bertomeu, M., Gómez, Á., Guiomar, N., Juárez, E., ... & Palomo, G. (2023). Fire-Smart Territories: a proof of concept based on Mosaico approach. *Landscape Ecology*, 1-18.
- Pyke DA, Brooks ML, D’Antonio C: Fire as a restoration tool: a decision framework for predicting the control or enhancement of plants using fire. *Restor Ecol* 2010, 18:274–284.
- Pötzelsberger, E., Spiecker, H., Neophytou, C., Mohren, F., Gazda, A., & Hasenauer, H. (2020). Growing nonnative trees in European forests brings benefits and opportunities but also has its risks and limits. *Current Forestry Reports*, 6, 339-353.
- Quintas-Soriano, C., Buerkert, A., & Plieninger, T. (2022). Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: A review. *Land Use Policy* 116, 106053.
- Ramberg, E., Berglund, H., Penttilä, R., Strengbom, J., & Jönsson, M. (2023). Prescribed fire is an effective restoration measure for increasing boreal fungal diversity. *Ecological Applications*, 33(6), e2892.
- Rappold, A. G., Hano, M. C., Prince, S., Wei, L., Huang, S. M., Baghdikian, C., ... & Hubbell, B. (2019). Smoke Sense initiative leverages citizen science to address the growing wildfire-related public health problem. *GeoHealth*, 3(12), 443-457.
- Reid CE, Brauer M, Johnston FH et al. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives*, 124, 1334–1343.
- Requia, W. J., Amini, H., Mukherjee, R., Gold, D. R., & Schwartz, J. D. (2021). Health impacts of wildfire-related air pollution in Brazil: a nationwide study of more than 2 million hospital admissions between 2008 and 2018. *Nature communications*, 12(1), 6555.
- Ribeiro-Kumara, C., Santín, C., Doerr, S.H., Pumpanen, J., Baxter, G., Köster, K. 2022. Short- to medium-term effects of crown and surface fires on soil respiration in a Canadian boreal forest. *Can. J. For. Res.* 52: 591–604 [dx.doi.org/10.1139/cjfr-2021-0354](https://doi.org/10.1139/cjfr-2021-0354)
- Robin, V., & Nelle, O. (2014). Contribution to the reconstruction of central European fire history, based on the soil charcoal analysis of study sites in northern and central Germany. *Vegetation history and archaeobotany*, 23, 51-65.
- Robios, B. 2012. La cellule de brûlage dirigé des Alpes-Maritimes. XXIIIes Rencontres Réseau des équipes de brûlage dirigé. Conseil Général des Alpes-Maritimes. Nice.
- Rochi, E., Vaiciulyte, S., Lahbiri, A. (2024). Wildland-Urban Interface Fire Touristic Infrastructure Protection Solutions – Guidelines for good practices for human protection. ISRN: LUTVDG/TVBB-3262-SE, pp. 72. WUITIPS – GA #101101169,
- Rodrigues, M., Jiménez-Ruano, A., & de La Riva, J. (2020). Fire regime dynamics in mainland Spain. Part 1: Drivers of change. *Science of the Total Environment*, 721, 135841.

- Rogers, B. M., Soja, A. J., Goulden, M. L. & Randerson, J. T. (2015). Influence of tree species on continental differences in boreal fires and climate feedbacks *Nat. Geosci.* 8 228–34
- Romps David M. et al. Projected increase in lightning strikes in the United States due to global warming. *Science* **346**,851-854(2014). DOI:[10.1126/science.1259100](https://doi.org/10.1126/science.1259100)
- Rovithakis, A., Grillakis, M. G., Seiradakis, K. D., Giannakopoulos, C., Karali, A., Field, R., ... & Voulgarakis, A. (2022). Future climate change impact on wildfire danger over the Mediterranean: the case of Greece. *Environmental Research Letters*, *17*(4), 045022.
- Royé, D., Tedim, F., Martin-Vide, J., Salis, M., Vendrell, J., Lovreglio, R., ... & Leone, V. (2020). Wildfire burnt area patterns and trends in Western Mediterranean Europe via the application of a concentration index. *Land Degradation & Development*, *31*(3), 311-324.
- Ruffault, J., Curt, T., Moron, V., Trigo, R.M., Mouillot, F., Koutsias, N., Pimont, F., Martin-StPaul, N., Barbero, R., Dupuy, J.L. and Russo, A., 2020. Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. *Scientific reports*, *10*(1), p.13790.
- Rundel, P. W., Arroyo, M. T., Cowling, R. M., Keeley, J. E., Lamont, B. B., & Vargas, P. (2016). Mediterranean biomes: evolution of their vegetation, floras, and climate. *Annual Review of Ecology, Evolution, and Systematics*, *47*(1), 383-407.
- Salesa, D., Baeza, M. J., Pérez-Ferrándiz, E., & Santana, V. M. (2022). Longer summer seasons after fire induce permanent drought legacy effects on Mediterranean plant communities dominated by obligate seeders. *Science of The Total Environment*, *822*, 153655.
- Salis, M., Laconi, M., Ager, A. A., Alcasena, F. J., Arca, B., Lozano, O., ... & Spano, D. (2016). Evaluating alternative fuel treatment strategies to reduce wildfire losses in a Mediterranean area. *Forest Ecology and Management*, *368*, 207-221.
- San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Liberta`, G., Jacome Felix Oom, D., Branco, A., De Rigo, D., Suarez-Moreno, M., Ferrari, D., Roglia, E., Scionti, N., Broglia, M., Onida, M., Tistan, A. and Loffler, P., *Forest Fires in Europe, Middle East and North Africa 2022*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/348120, JRC135226.
- San-Miguel-Ayanz, J., Rodrigues, M., de Oliveira, S. S., Pacheco, C. K., Moreira, F., Duguay, B., & Camia, A. (2012). Land cover change and fire regime in the European Mediterranean region. *Postfire management and restoration of southern European forests*, 21-43.
- Santín, C., & Doerr, S. H. (2016). Fire effects on soils: the human dimension. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1696), 20150171.
- Santos, J. L., Martins, A., Novais, A., & Canadas, M. J. (2021). A choice-modelling approach to inform policies aimed at reducing wildfire hazard through the promotion of fuel management by forest owners. *Forests*, *12*(4), 403.
- Saražin, J. 2025. Accessibility of Slovenian Forests for Firetrucks. In: Dobrinkova, N., Fidanova, S. (eds) *Environmental Protection and Disaster Risks (EnviroRisks 2024)*. *EnviroRISKS 2024. Lecture Notes in Networks and Systems*, vol 883. Springer, Cham. https://doi.org/10.1007/978-3-031-74707-6_10
- Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E., Ventera, M., Boedhihartono, A.G., Dayb, M., Garciab, C., van Oosten, C. & Buck, L.E. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences*, *110* (21): 8349-8356.
- Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E., Ventera, M., Boedhihartono, A.G., Dayb, M., Garciab, C., van Oosten, C. & Buck, L.E. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences*, *110* (21): 8349-8356.
- Scherr Sara J and McNeely Jeffrey A 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. *Phil. Trans. R. Soc.* B363477–494. <http://doi.org/10.1098/rstb.2007.2165>
- Schils, R. L., Bufe, C., Rhymer, C., Francksen, R. M., Klaus, V. H., Abdalla, M., ... & Price, P. N. (2022). Delivery of ecosystem services from permanent grasslands in Europe: a systematic review. In *Grassland at the heart of circular and sustainable food systems* (pp. 274-276).

- Schug, F., Bar-Massada, A., Carlson, A.R. et al. (2023). The global wildland–urban interface. *Nature* 621, 94–99. <https://doi.org/10.1038/s41586-023-06320-0>
- Shafizadeh, F., Chin, P. P. S., and DeGroot, W. F. (1977). Effective heat content of green forest fuels. *Forest Science* 23, 81–89.
- Sil, Â. F., Azevedo, J., Fernandes, P. M., Regos, A., Vaz, A. S., & Honrado, J. P. (2019). (Wild) fire is not an ecosystem service. *Frontiers in Ecology and the Environment*, 17(8), 429-430.
- Silveira, F. A., Ordóñez-Parra, C. A., Moura, L. C., Schmidt, I. B., Andersen, A. N., Bond, W., ... & Pennington, R. T. (2022). Biome Awareness Disparity is BAD for tropical ecosystem conservation and restoration. *Journal of Applied Ecology*, 59(8), 1967-1975.
- Silveira, F. A., Ordóñez-Parra, C. A., Moura, L. C., Schmidt, I. B., Andersen, A. N., Bond, W., ... & Pennington, R. T. (2022). Biome Awareness Disparity is BAD for tropical ecosystem conservation and restoration. *Journal of Applied Ecology*, 59(8), 1967-1975.
- Skevaki, C, Kari C. Nadeau, Marc E. Rothenberg, Barrak Alahmad, Blandina T. Mmbaga, Gileard G. Masenga, Vanitha Sampath, David C. Christiani, Tari Haahtela, Harald Renz. 2024. Impact of climate change on immune responses and barrier defense, *Journal of Allergy and Clinical Immunology*, Volume 153, Issue 5. Pages 1194-1205, ISSN 0091-6749,
- Soliño, M., Yu, T., Alía, R., Auñón, F., Bravo-Oviedo, A., Chambel, M. R., ... & Del Barrio, J. M. G. (2018). Resin-tapped pine forests in Spain: Ecological diversity and economic valuation. *Science of the Total Environment*, 625, 1146-1155.
- Soy-Massoni, E., Uyttewaal, K., Prat-Guitart, N., & Varela, E. (2022). Fire Eaters: Exploring Consumer Preferences for Labelling Extensive Livestock Products Providing Wildfire Prevention Services. *Land*, 11(5), 700.
- Spadoni, G. L., Moris, J. V., Vacchiano, G., Elia, M., Garbarino, M., Sibona, E., Tomao, A., Barbati, A., Sallustio, L., Salvati, L., Ferrara, C., Francini, S., Bonis, E., Dalla Vecchia, I., Strollo, A., Di Leginio, M., Munafò, M., Chirici, G., Romano, R., ... Ascoli, D. (2023). Active governance of agro-pastoral, forest and protected areas mitigates wildfire impacts in Italy. *Science of the Total Environment*, 890(May). <https://doi.org/10.1016/j.scitotenv.2023.164281>
- Spalt, K. W., & Reifsnnyder, W. E. (1962). Bark characteristics and fire resistance: a literature survey.
- Stedman, R.C., 2004. Risk and climate change: perceptions of key policy actors in Canada. *Risk Analysis: An International Journal*, 24(5), pp.1395-1406.
- Steel, Z. L., Miller, J. E., Ponisio, L. C., Tingley, M. W., Wilkin, K., Blakey, R., ... & Jones, G. (2024). A roadmap for pyrodiversity science. *Journal of Biogeography*, 51(2), 280-293.
- Steffenson, V. 2020. *Fire Country: How Indigenous Fire Management Could Help Save Australia*. Hardie Grant Explore, ISBN 978-1741177268
- Stokes, S. C., Romanowski, K. S., Sen, S., Greenhalgh, D. G., & Palmieri, T. L. (2021). Wildfire burn patients: a unique population. *Journal of Burn Care & Research*, 42(5), 905-910.
- Stoof, C. R., & Kettridge, N. (2022). Living with fire and the need for diversity. *Earth's Future*, 10, e2021EF002528. <https://doi.org/10.1029/2021EF002528>
- Strahan, K., Whittaker, J., Handmer, J. (2018). Self-evacuation archetypes in Australian bushfire. *International Journal of Disaster Risk Reduction*, 27, 307-316.
- Swain, D. L., Prein, A. F., Abatzoglou, J. T., Albano, C. M., Brunner, M., Diffenbaugh, N. S., ... & Touma, D. (2025). Hydroclimate volatility on a warming Earth. *Nature Reviews Earth & Environment*, 6(1), 35-50.
- Tang W., He C., Emmons L., Zhang J. (2024). Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI). *Environmental Research Letters* 19 044028. DOI 10.1088/1748-9326/ad31da.
- Tedim F, Leone V, Xanthopoulos G (2016) A wildfire risk management concept based on a social-ecological approach in the European Union: Fire Smart Territory. *Int J Disaster Risk Reduct* 18:138–153.
- Tedim, F., McCaffrey, S., Leone, V., Delogu, G. M., Castelnou, M., McGee, T. K., & Aranha, J. (2020). What can we do differently about the extreme wildfire problem: An overview. *Extreme Wildfire Events and Disasters*, 233-263.

- Temperton VM, Buchmann N, Buisson E, Durigan G, Kazmierczak Ł, Perring MP, de Sá Dechoum M, Veldman JW, Overbeck GE. 2019. Step back from the forest and step up to the Bonn Challenge: How can a broad ecological perspective promote successful landscape restoration? *Restoration Ecology* 27: 705–719.
- Terrer, C., et al. (2020). A trade-off between plant and soil carbon storage under elevated CO₂. *Nature* 591, 599–616. <https://doi.org/10.1038/s41586-021-03306-8>.
- Thacker, F.E.N., Ribau, M.C., Bartholomeus, H. et al. What is a fire resilient landscape? Towards an integrated definition. *Ambio* 52, 1592–1602 (2023). <https://doi.org/10.1007/s13280-023-01891-8>
- Tikkanen, O. P., Martikainen, P., Hyvärinen, E., Junninen, K., & Kouki, J. (2006). Red-listed boreal forest species of Finland: associations with forest structure, tree species, and decaying wood. *Annales Zoologici Fennici* 43:373-383.
- Tinner, W., Conedera, M., Ammann, B., & Lotter, A. F. (2005). Fire ecology north and south of the Alps since the last ice age. *The Holocene*, 15(8), 1214-1226.
- To, P., Eboreime, E., & Agyapong, V. I. (2021). The impact of wildfires on mental health: a scoping review. *Behavioral Sciences*, 11(9), 126.
- Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., ... & Provenzale, A. (2016). Decreasing fires in mediterranean Europe. *PLoS one*, 11(3), e0150663.
- Tzamtzis I., Ganatsas P., Kokkoris I.P., Samaritakis V., Botsis D., Tsakalidimi M., Tziritis I., Kalevra N., Georgiadis N.M. (2023). A sustainable strategy for reforestation and restoration of burnt natural areas in Mediterranean regions: A case study from Greece. *Sustainability*, 15, 15986.
- UNDRR 2023. The Report of the Midterm Review of the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030. UNDRR: Geneva, Switzerland.
- Valese, E., Conedera, M., Held, A. C., & Ascoli, D. (2014). Fire, humans and landscape in the European Alpine region during the Holocene. *Anthropocene*, 6, 63-74.
- Valkó O, Török P, Deák B, Tóthmérész B: Review: Prospects and limitations of prescribed burning as a management tool in European grasslands. *Basic Appl Ecol* 2014, 15:26–33.
- Valkó, O and Deák, B. 2021. Increasing the potential of prescribed burning for the biodiversity conservation of European grasslands. *Current Opinion in Environmental Science & Health*, Volume 22, 100268, ISSN 2468-5844 <https://doi.org/10.1016/j.coesh.2021.100268>.
- van Daalen, K. R., Tonne, C., Semenza, J. C., Rocklöv, J., Markandya, A., Dasandi, N., ... & Lowe, R. (2024). The 2024 Europe report of the Lancet Countdown on health and climate change: unprecedented warming demands unprecedented action. *The Lancet Public Health*.
- Varela E, Górriz-Mifsud E, Ruiz-Mirazo J, López-i-Gelats F (2018) Payment for targeted grazing: integrating local shepherds into wildfire prevention. *Forests* 9:464
- Varela E, Pulido F, Moreno G, Zavala MÁ. Targeted policy proposals for managing spontaneous forest expansion in the Mediterranean. *J Appl Ecol.* 2020; 57: 2373–2380. <https://doi.org/10.1111/1365-2664.13779>
- Veldman JW, et al. 2019. Comment on “The global tree restoration potential.” *Science* 366: eaay7976.
- Verde, J. C., Torres, J.S., Marques, R., Franc, R., Flores, E., Casartelli, V., Marengo, A., Melinato, S., Mysiak, J., Salpina, D., Brăilescu, C., Marteil, E., Sørensen, J., Spitoni, G. (2024). UCPM Wildfire Peer review report: Italy 2024. <https://doi.org/10.25424/cmcc-xx3k-we21>
- Vigna, I., Millington, J., Ascoli, D., Comino, E., Pezzoli, A., & Besana, A. (2024). A picit jeu: Agent-based modelling with serious gaming for a fire-resilient landscape. *Journal of Environmental Management*, 370, 122529.
- Vogel, J., Paton, E., Aich, V., & Bronstert, A. (2021). Increasing compound warm spells and droughts in the Mediterranean Basin. *Weather and Climate Extremes*, 32, 100312.
- Wallenius, T. (2011). Major decline in fires in coniferous forests-reconstructing the phenomenon and seeking for the cause.
- Weir, J. R., & Scasta, J. D. (Eds.). (2022). *Global application of prescribed fire*. CSIRO PUBLISHING.
- White, A. R. (2024). The firestorm within: A narrative review of extreme heat and wildfire smoke effects on brain health. *Science of the total environment*, 171239.

- Wilgus, M. L., & Merchant, M. (2024). Clearing the air: understanding the impact of wildfire smoke on asthma and COPD. In *Healthcare* (Vol. 12, No. 3, p. 307). MDPI.
- Wilkinson, S. L., Andersen, R., Moore, P. A., Davidson, S. J., Granath, G., & Waddington, J. M. (2023). Wildfire and degradation accelerate northern peatland carbon release. *Nat. Clim. Chang.* 13, 456–461. <https://doi.org/10.1038/s41558-023-01657-w>
- Witze, A. (2020). Why Arctic fires are bad news for climate change. *Nature* Vol. 585, 336 - 337.
- Wooster, M. J., & Zhang, Y. H. (2004). Boreal forest fires burn less intensely in Russia than in North America. *Geophysical Research Letters*, 31(20).
- World Bank (2021). Investment in Disaster Risk Management in Europe Makes Economic Sense – Executive Summary of the Report for DG ECHO. P91
- Wunder, S., Calkin, D. E., Charlton, V., Feder, S., de Arano, I. M., Moore, P., ... & Vega-García, C. (2021). Resilient landscapes to prevent catastrophic forest fires: Socioeconomic insights towards a new paradigm. *Forest Policy and Economics*, 128, 102458.
- Xanthopoulos, G., Caballero, D., Galante, M., Alexandrian, D., Rigolot, E., & Marzano, R. (2006). Forest fuels management in Europe. In *Fuels management-how to measure success: Conference proceedings*. USDA Forest Service, Portland, OR.
- Zheng B. et al. 2021. The increase in forest fire emissions despite the decline in global burned area. *Sci. Adv.* 7eabh2646(2021). DOI:10.1126/sciadv.abh2646

Appendices

Appendix A: Recent Policy Reports on Wildfires

- Camia, A., Liberta, G., San-Miguel-Ayanz, J., 2017. Modelling the impacts of climate change on forest fire danger in Europe, doi:10.2760/768481. European Union.
- Casartelli V, Mysiak J (2023). Union Civil Protection Mechanism - Peer Review Programme for disaster risk management: Wildfire Peer Review Assessment Framework (Wildfire PRAF).
- de Rigo, D., Libertà, G., Houston Durrant, T., Artés Vivancos, T., San-Miguel-Ayanz, J., Forest fire danger extremes in Europe under climate change: variability and uncertainty, EUR 28926 EN, Publications Office of the European Union, Luxembourg, 2017,
- European Commission (2024): *2023 Among the Five Worst Years for Wildfires in Europe, but 2024 Provides Some Relief*. This report provides an overview of the wildfire seasons in 2023 and 2024, analysing the factors that led to severe wildfires and the measures that contributed to a less severe season in 2024. [Link](#)
- European Commission (2024): *Wildfires: 2023 Among the Worst in the EU in This Century*. This report highlights the severity of the 2023 wildfire season in the EU, discussing the contributing factors and the implications for future wildfire management. [Link](#)
- European Commission Joint Research Centre (2023): *Forest Fires in Europe, Middle East and North Africa 2022*. This comprehensive report provides an analysis of the wildfire season across Europe and neighboring regions, highlighting trends, impacts, and the effectiveness of prevention measures. [Link](#)
- European Commission Joint Research Centre (2024): *Advance Report on Forest Fires in Europe, Middle East and North Africa 2023*. Offering preliminary insights into the 2023 wildfire season, this report discusses the conditions under which wildfires developed and their impact across the pan-European territory. [Link](#)

European Environment Agency (2022): *Forest Fires in Europe: An Overview*. This report examines the increasing frequency and intensity of forest fires in Europe, attributing changes to climate dynamics and land use patterns. It emphasizes the need for integrated management strategies. [Link](#)

European Forest Fire Information System (EFFIS) Annual Fire Reports: EFFIS provides annual reports detailing forest fire incidents, affected areas, and trends across Europe. These reports are essential for understanding the evolving wildfire landscape. [Link](#)

OECD (2023), *Taming Wildfires in the Context of Climate Change*, OECD Publishing, Paris, <https://doi.org/10.1787/dd00c367-en>.

Oom, D., de Rigo, D., Pfeiffer, H., Branco, A., Ferrari, D., Grecchi, R., Artés-Vivancos, T., Houston Durrant, T., Boca, R., Maianti, P., Libertá, G., San-Miguel-Ayán, J., et al. 2022. Pan-European wildfire risk assessment, EUR 31160 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55137-9. doi:10.2760/9429, JRC130136

Project WUITIPS - Wildland-Urban Interface Fire Touristic Infrastructure Protection Solutions, Living Lab of Knowledge Transfer (<https://civil-protection-knowledge-network.europa.eu/projects/wuitips>).

UNEP (2022). Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires. A UNEP Rapid Response Assessment. Nairobi.

USDA Forest Service (2022). Wildfire Crisis Strategy: Confronting the Wildfire Crisis. United States Department of Agriculture. FS-1187a. Washington, D.C. USA. 25 p. Available at: <https://www.fs.usda.gov/managing-land/wildfire-crisis>

Appendix B.

Examples of long-term proactive initiatives show the application of Policy options 1--8. For each option, the name and geographical location of the initiative are shown together with the relevant reference.

Policy option 1. Adopt an integrated approach to wildfire risk reduction, combining proactive and reactive wildfire risk policies, and integrating climate change adaptation		
ZIFs	Portugal	Fernandes & Simões 2024
AIGPs	Portugal	https://www.dgterritorio.gov.pt/paisagem/ptp/aigp
Mosaico	Spain	Pulido et al. 2023
RAPCA	Spain	Varela et al. 2018
Rioja	Spain	Lasanta et al. 2022
Ramats de Foc	Spain	Soy-Massoni et al. 2022
Landa Carsica	Italy	Ascoli et al. 2023
PRE-FEU/CFAVS	Italy	https://cfavs.it/it-it/servizi/
LIFE Granatha	Italy	Ascoli et al. 2023
Omikron	Greece	Ascoli et al. 2023
Policy option 2. Adopt nature-based solutions (NBS) approaches for wildfire risk reduction		

AIGPs	Portugal	https://www.dgterritorio.gov.pt/paisagem/ptp/aigp
Mosaico	Spain	Pulido et al. 2023
RAPCA	Spain	Varela et al. 2018
Ramats de Foc	Spain	Soy-Massoni et al. 2022
Landa Carsica	Italy	Ascoli et al. 2023
LIFE Granatha	Italy	Ascoli et al. 2023
Policy option 3. Acknowledge the ecological and cultural role of fire, and being prepared for living with more frequent fires		
Official Program	Portugal	Davim et al. 2022
LIFE Montserrat	Spain	Ascoli et al. 2023
LIFE Granatha	Italy	Ascoli et al. 2023
Piemonte	Italy	Ascoli et al. 2023
Landa Carsica	Italy	Ascoli et al. 2023
Policy option 4. Build educational and risk communication capacity to increase wildfire awareness and preparedness across generations in urban and rural populations, and across science, policy, and practice		
Kythira project	Greece	Mauri et al. 2024
ONF	France	https://hal.science/hal-04152846v1
Official program	France	Mauri et al. 2024, https://agriculture.gouv.fr/
Policy option 5. Adopt landscape management to reduce vulnerability to wildfire		
ZIFs	Portugal	Fernandes & Simões 2024
AIGPs	Portugal	https://www.dgterritorio.gov.pt/paisagem/ptp/aigp
Mosaico	Spain	Pulido et al. 2023
RAPCA	Spain	Varela et al. 2018
Rioja	Spain	Lasanta et al. 2022
Ramats de Foc	Spain	Soy-Massoni et al. 2022
Landa Carsica	Italy	Ascoli et al. 2023
PRE-FEU/CFAVS	Italy	https://cfavs.it/it-it/servizi/
LIFE Granatha	Italy	Ascoli et al. 2023
Omikron	Greece	Ascoli et al. 2023
Policy option 6. Harmonize the current sectoral policies to reduce wildfire risk		
AGIF	Portugal	https://www.agif.pt/
Policy option 7. Reduce urban sprawl and foster compact urban areas through urban and regional planning to reduce risk		
PPU Barcelona	Spain	https://www.diba.cat/es/web/incendis/ppu)
PDPFCI Gard	France	https://www.gard.gouv.fr/Media/Files/Guide-de-normalisation-des-interfaces-amenagees2
Policy option 8. Foster the adoption of private sustainable management practices to decrease landscape vulnerability		

AIGPs	Portugal	https://www.dgterritorio.gov.pt/paisagem/ptp/aigp
Mosaico	Spain	Pulido et al. 2023
CPF	Spain	Ascoli et al. 2023
PRE-FEU/CFAVS	Italy	https://cfavs.it/it-it/servizi-/
Pratomagno	Italy	Ascoli et al. 2023
Omikron	Greece	Ascoli et al. 2023