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REVISED Integrated Fire Management and Closer to Nature Forest Management at the Landscape Scale as a Holistic Approach to Foster Forest Resilience to Wildfires

[version 4; peer review: 5 approved with reservations, 2 not approved]

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Abstract

Unprecedented wildfires are expected to remain a major challenge for Europe in the future due to their increasing frequency and intensity. However, there is currently no standardized framework for managing wildfire risk, with no common definition of integrated wildfire risk management, and lack of consensus within sustainable forest management (SFM), with over 20 (semi-)synonyms used for Continuous Cover Forestry, such as Close-to-Nature Forest management. This open letter highlights the importance of implementing two key approaches, the Integrated Fire Management (IFM) and the EU's proposed Closer-To-Nature Forest Management (CTNFM) approach with spatiotemporal connectivity in the face of human and natural induced drivers that enhance wildfire frequency and severity. The document discusses options to address wildfire risk challenges, and associated impacts such as forest degradation and biodiversity loss. It emphasizes the urgent need for action by EU Member States considering a bottom-up approach (local to regional and national level), political commitment, and public awareness to address these issues effectively. Key topics covered include wildfire adaptation and mitigation strategies of plant species, and the impact of climate change and land use on today's uncharacteristic fire regimes conditions. Silvicultural closer-to-nature practices, where needed and appropriate, such as the promotion of natural forest regeneration with enhancement of native or non-native broadleaves, mixed stand composition and strategic tree spacing are examined as

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means to reduce the spread of fires in wildfire-prone areas. It also highlights the benefits of a multifaceted spatiotemporal scale approach to SFM that includes wildfire prevention, ecological resilience, habitat conservation and resource management. Options are presented for policy makers and relevant stakeholders to support these strategies through collaboration, enforcement, ecological stewardship, monitoring capabilities, public education, research support, and international cooperation. The integration of IFM and CTNFM can improve wildfire mitigation, preparedness, and adaptive capacity, thereby promoting resilient landscapes and communities in the long-term.

Keywords
Integrated Fire Management, Closer-to-Nature Forest Management, Landscape Scale Approach

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REVISED **Amendments from Version 3**

In this updated version (V4), the authors have addressed most of the comments from the previous review. Notably, they made a concerted effort to identify and remove repetitions, improve syntax and grammar, and reduce the overall length. Figure 1 has been thoroughly revised in response to reviewer feedback and now better illustrates the paper's core concepts, framework, and current needs. Moreover, the structure of IFM section has been slightly improved, including more examples regarding forests that have not evolved with fire and there is no history of fire management.

They also aimed to clarify the rationale for combining the two proposed approaches. Specifically, they want to emphasize that IFM (widely accepted worldwide, e.g., by FAO) and CTNFM (endorsed by the EU) are both well-established methodologies. However, they have not been implemented together, as they often deploy in isolation rather than as complementary strategies. This segregate approach leads to conflicts among key stakeholders in CTNFM and IFM (forest managers and fire managers, forest- and fire scientists). The issue is compounded by the absence of coherent EU regulations, standardized guidelines, and clear criteria and indicators to assess the integration's effectiveness and the necessary thresholds necessary to achieve such integration.

This version clarifies one of the paper's main novelties: the potential for integrating IFM and CTNFM. The goal is to develop a combined framework that accounts for both spatial and temporal scales, considering local needs, specific site conditions, wildfire risk reduction, and climate change adaptation. This dynamic, regularly updated approach provides a more integrated strategy for implementing, were appropriated and needed, both frameworks effectively.

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Introduction

Climate crisis affects significantly weather patterns around the world with the increasing occurrence of extreme weather events. These changes lead to a variability in the fire seasons, especially an extension, as well as in a higher frequency of days with extreme weather conditions favorable to wildfires (Jain *et al.*, 2017; Jain *et al.*, 2022; Jones *et al.*, 2022; Richardson *et al.*, 2022; Silva *et al.*, 2023). The last years, fire seasons appeared to be more disastrous than ever with devastating wildfires occurring worldwide even in areas that are not considered as fire-prone (UNEP, 2022), while the discussion is moving toward the study of extreme wildfire events (Duane *et al.*, 2021; Tedim *et al.*, 2018). One of the most characteristic and recent examples in Europe, is the 2023 wildfire in Greece, which was the largest wildfire ever recorded in the EU from EFFIS, with over 95,000 ha in Northern Greece (Alexandroupolis and Dadia forest), destroying a protected Natura 2000 area (European Commission, 2024).

The impact of forest composition and management on wildfire risk

The forests of today are far from their natural composition, structure and functions, and are likely to be very different from those of the future because of the constantly changing environmental conditions (Kirilenko & Sedjo, 2007; Kölling & Zimmermann, 2007; Lindner *et al.*, 2010) and by unsustainable human influences (Kalapodis, 2009; O'Hara, 2014). Additionally, the landscapes of Southern Europe are undergoing a significant recovery of native forest vegetation, which includes the emergence of pioneer species and early-stage structures that are particularly prone to wildfire (Corona *et al.*, 2015). The Mediterranean region is expected to experience the most significant impact of wildfires in the future and, boreal and temperate regions of Europe are expected to experience a moderate increase with more frequent and intense wildfires (El Garroussi *et al.*, 2024; Fernandez-Anez *et al.*, 2021; Moreno *et al.*, 2014a; Pereira *et al.*, 2016). Specific trends in the burned area or the number of fires (larger than 30 ha) occurring in Europe cannot be clearly identified (Oom *et al.*, 2022). According to the same study, multi-annual trends are also difficult to be assessed either in terms of burned areas or number of fires. A decrease in burned areas and number of fires (for wildfires less than 30ha) is apparent based on data from the period 1985–2011 (Turco *et al.*, 2016). Climate change may significantly alter the fire regime in Europe in the 21st century, also pointing out that in Europe, and especially in the Mediterranean, there is no significant positive trend regarding the area burned (Grünig *et al.*, 2023). In the Mediterranean area, a declining trend may appear, something that is not consistent with the patterns in the western United States and Australia. This particular trend in the Mediterranean could partially be explained by improvements in fire prevention, in fire-fighting measures, law reinforcement, as well as improved awareness and education, inter-regional collaboration and advances in research and technologies (Turco *et al.*, 2016).

The consequences of land abandonment and ecological transitions

On the other hand, the abandonment of rural areas, industrialization, and preference for fossil fuels and renewable energies (from wind, solar and hydro power) over wood is having a significant impact on traditional agricultural land use, leading to various ecological and socio-economic consequences. This trend has led to increased fuel accumulation and structural changes in fuel complexes, increasing the risk of wildfires (Moreira *et al.*, 2020). The encroachment of humans, through urbanization, into natural environments such as forests, along with poor landscape management and unmanaged vegetation regrowth in abandoned agricultural areas, exacerbates these fire risks (Mitri *et al.*, 2014; Moreira *et al.*, 2020).

Moreover, in the aftermath of wildfires or land abandonment, ecosystems often undergo a significant transition towards more homogeneous and dense and extensive tree cover forested areas (Neidermeier *et al.*, 2023). These landscapes typically exhibit vegetation that is predominantly composed of a similar age and species type, leading to reduced species diversity (Moreira *et al.*, 2011; Moreno *et al.*, 2014b). Specifically, Mediterranean

areas may become dominated by shrublands or pine species, which further contributes to the decline in biodiversity (Baudena *et al.*, 2020; Fayet & Verburg, 2023; Jones *et al.*, 2020; Lasanta, 2019; Vasques *et al.*, 2023). Additionally, this process is characterized by a densification in the spatial organization of fuels, increasing the risk of future wildfires and altering the ecological dynamics of the region. Studies have shown that high wildfire frequency can lead to the replacement of pine and oak forests with shrublands that are more fire-prone, particularly when the shrub species are pyrophytic (fire-adapted) (Baudena *et al.*, 2020; Francos *et al.*, 2016; Vasques *et al.*, 2023).

Fire-adapted ecosystems and resilience building

The restoration of degraded forest ecosystems involves several key activities, which have been identified to support the restoration. In particular, these activities have the greatest potential to prevent and reduce the impact of natural disasters (e.g. wildfires), taking into account environmental, social, cultural, economic, livelihood and health aspects (Halleux, 2024). To enhance the resistance, resilience and adaptive capacity of forest ecosystems and fire regimes to wildfires, it is important to consider both the conditions before and after a fire event (Romero & Ganteaume, 2020). The pre-fire condition of the ecosystem should support a diverse, adaptive to fire regimes, and resilient vegetation community (Keeley *et al.*, 2011b; Ne'eman *et al.*, 2012). It may be necessary to establish new target conditions that align with changing fire regimes and environmental conditions (Romero & Ganteaume, 2020). Promoting natural regeneration of forests is crucial, but in cases where natural regeneration fails or is not adequate, techniques such as planting and seeding may be needed to enhance resistance, resilience and biodiversity (Lamont *et al.*, 2019; Romero & Ganteaume, 2020). Native plant species and communities that are adapted to fire can help create resilience against future climate changes or fire disturbances, even in new combinations (Sample *et al.,* 2022). Efforts to support the recovery of these native plants and habitats can take place both prior to and following a fire event.

Fire-adapted species and their role in ecosystem recovery

While many species possess regenerative traits, such as vegetative resprouting and heat-stimulated seed germination, high-frequency fire regimes can lead to species loss and hinder ecosystem recovery (Huerta *et al.*, 2022; Oliveira *et al.*, 2012; Quintano *et al.*, 2015). In the pursuit of enhancing forest resistance and resilience, it becomes imperative to delve into the adaptive strategies of various plant species towards wildfires. In fire-prone ecosystems, numerous plant species have developed mechanisms to withstand and even thrive in the face of wildfires (Fernandez-Guisuraga *et al.*, 2021; Huerta *et al.*, 2022; Pausas & Vallejo, 1999; Pausas *et al.*, 2008). These mechanisms encompass serotiny, where seeds remain enclosed in cones or fruits until stimulated by fire, robust bark or specialized tissues that shield the plant from fire-related harm, and the capacity to regenerate through subterranean structures like bulbs or rhizomes (Huerta *et al.*, 2022; Pausas & Vallejo, 1999; Pausas *et al.*, 2008). Such fire adaptive plant traits play a pivotal role in the recovery post-fire and the natural regeneration of ecosystems, thereby bolstering the overall resilience of forests (Fernandez-Guisuraga *et al.*, 2021; Huerta *et al.*, 2022). Particularly in Mediterranean ecosystems, species display remarkable adaptations to fire, showcasing their resilience in the face of such disturbances (Balao *et al.*, 2018; Rundel *et al.*, 2018). Nevertheless, the efficacy of these adaptations can fluctuate depending on variables such as the intensity and frequency of fires (Keeley *et al.*, 2011a). It is crucial to acknowledge the nuanced interplay of these factors in shaping the resistance and resilience of forest ecosystems.

In contrast to the Mediterranean forests, the spread of wildfire into non-fire-prone ecosystems, i.e. those that have had little or no fire (Mitchell, 2013), poses a significant threat to biodiversity and ecosystem resilience (Forzieri *et al.*, 2021). For instance, temperate and boreal rainforests are poorly equipped to cope with frequent or intense fires (Pinto *et al.*, 2020; Seidl *et al.*, 2017). Without the aforementioned adaptive traits (e.g., thick bark or serotinous cones), native species struggle to regenerate, leading to shifts in species composition, loss of biodiversity, and disruption of ecosystem functions and services. The introduction of invasive species, which may be more fire-tolerant, further exacerbates these impacts. Climate change is increasing the frequency and intensity of wildfires, thereby pushing non-fire-adapted ecosystems beyond their natural thresholds and threatening long-term ecological stability. Conversely, the frequency of wildfires is projected to rise in Europe, a phenomenon that is not only directly associated with the escalating temperatures triggered by climate change (Sutanto *et al.*, 2020) but also with the interaction of these fires with other natural disturbances.

Understanding the key drivers of wildfire dynamics

However, the challenge of reducing the spread of wildfires in fire-prone forest stands without compromising the key characteristics of the ecosystem is crucial. Before continuing, it seems to be appropriate to get a deeper understanding of the complexities of wildfire dynamics at hand. It is essential to distinguish between key concepts of fire spread and burn severity. Fire spread deals with how fast or slow the fire is propagating in the continuum (e.g., forest). The propagating heat flux associated with the spread of a flaming fire front depends upon a combination of radiative, convective, and conductive heat transfer (Rego *et al.*, 2021). Rego *et al.* (2021) defined the term "burn severity" as "*the immediate and direct ecological impacts of wildland fires* (as noted by Keeley, 2009; Morgan *et al.*, 2014; Ryan & Noste, 1985)". Burn severity is typically categorized into different levels—such as unburned, low, moderate, or high— through ground-based sampling methods or by analyzing satellite images taken before and after the fire. Wind speed and direction, temperature and slope are important factors, along with the type of fuels present, that influence how heat spreads during a fire. These elements play a significant role in determining how quickly a fire front moves.

Nature-based silvicultural approaches for risk mitigation

Building on the definitions discussed earlier, it is possible to explore how to mitigate the wildfire risk without changing the key characteristics of a forested area and its fire regime.

Nature based silvicultural approaches that mimic nature by restoring a more natural overstory and understory with a mixture of site-adapted indigenous or non-indigenous tree species are suggested to minimize the severity of wildfires in a closer to nature horizontal and vertical composition. Nevertheless, in regions like the Mediterranean with drier weather conditions, this poses a major challenge. A number of studies (Carey & Schuman, 2003; Fernandes & Rigolot, 2007; Graham *et al.*, 2004; Johnson *et al.*, 2007; Peterson *et al.*, 2005; Piqué, 2012; Piqué *et al.*, 2011; Piqué *et al.*, 2015; Serrada *et al.*, 2008) provide managers with information on fuel reduction and the creation of fire resistant and resilient forest structures through proactive forest management (Kalapodis, 2009; Kalapodis, 2010). Over the years, a variety of forest management systems have been introduced outside the central and northern regions of Europe. In addition to central and northern Europe, a variety of forest management systems have been introduced in various regions of the Mediterranean as well, resulting in predominantly mixed compositions and a variety of benefits. These systems encompass a wide array of approaches, including mixed-stand silviculture (Pach *et al.*, 2018), single-tree silviculture (Mairota *et al.*, 2016), irregular management (Berretti *et al.*, 2014), mixed regeneration (Motta *et al.*, 2015), sporadic species valorization, and enhancement (Bianchetto *et al.*, 2014), among several others (European Commission, 2023). Each of these methodologies brings its unique blend of benefits and challenges to the table, contributing to the rich tapestry of silvicultural practices particularly in Mediterranean forest management.

Problem statement of this document

Unprecedented wildfires are expected to remain a significant challenge for Europe in the coming years in terms of frequency and intensity during prolonged fire seasons. However, it is subject to scientific discourse that there is currently no standardised framework for managing wildfire risks as highlighted by Plana *et al.* (2024). The absence of a common standard definition and concept for integrated wildfire risk management, which is further supported by Kirschner *et al.* (2024), who identify a wide range of conceptual approaches to wildfire management globally, such as 'living with fire,' 'integrated fire management,' 'sustainable fire management,' 'ecological fire management,' and 'fire-smart territories' point out a lack of consensus. Similarly, a comparable diversity of terminology exists within the field of sustainable forest management in which more than 20 synonyms or semi-synonyms are being used in connection with Continuous Cover Forestry (CCF), including 'continuous forest', 'close-to-nature forestry', 'ecological forestry', 'holistic forestry', and the last one proposed by the EU, Closer-to-Nature Forest Management (Pommerening & Murphy, 2004). Both CTNFM and IFM have been proposed by the EU as two approaches that can contribute to sustainable forest management and to climate adaptation and mitigation as well as wildfire risk reduction. Their implementation can be achieved by a collaborative and inclusive approach by forest and fire managers to adopt a unified vision and mandate to address the existing and future challenges. Standards can offer space for collaboration, build consensus and help to create widely accepted concepts and common language. Consequently, standardization in CTNFM and IFM can pave the way to the future with specific biogeographically consistent criteria and region-based thresholds on the basis of scientific evidence. Efforts on standardization related to Closer-to-Nature-Forest Management have already begun showcasing the respective need (Porteron, 2025), while a similar approach should be considered for the Integrated Fire Management as well.

Additionally, the considerable variability in political measures and regulatory frameworks surrounding fire management and fire use (legal restrictions or prohibitions in most European countries), coupled with their often insufficient or inadequately tailored nature, underscores the need for a comprehensive and unified approach that consider national, regional and local contexts (Montiel & Kraus, 2010; Rego *et al.*, 2010; Rego *et al.*, 2021). This heterogeneity is particularly pronounced across Europe, where diverse fire management practices and regulatory landscapes coexist. At the same time, the ecological regulatory power of fire has been lost due to artificially extensive fire suppression and exclusion in fire-adapted areas (Houghton & Hackler, 2000; Kimmerer & Lake, 2001; Kreider *et al.*, 2024; Noss *et al.*, 2006; Sample *et al.*, 2022) which has resulted in the accumulation of hazardous fuel loads that have led to extreme wildfire events outside the historical range of variation (Keane *et al.*, 2002). Additionally, in the aftermath of wildfires, when not needed, intensive practices such as post-fire salvage logging and planting dramatically alter fuel characteristics, increasing the risk of extreme wildfires events as well (Covington & Moore, 1994; Pechony & Shindell, 2010; Sample *et al.*, 2022). Moreover, given the increasing complexity of wildfire risks, driven by human caused climate change, abandonment of traditional land use and unsustainable forest and fire management practices it is essential to establish a normative framework that can update, harmonize, and integrate the disparate policies and legislations currently in place. The establishment of such a framework would facilitate an effective integration of nature-based forest management concept and a holistic approach to fire management, thereby promoting a comprehensive strategy that aligns ecological restoration, biodiversity conservation, and fire risk mitigation, ultimately enhancing resilience to both wildfires and climate-induced environmental changes.

Countries have often resorted to ad-hoc policy adjustments in response to catastrophic fire events, yet proactive and comprehensive changes are essential for effective fire management. Successful case studies, like the reform of Portugal's national fire defense system, highlight the potential for a new legal framework that acknowledges proactive actions (e.g., prescribed burning) on par with traditional fire suppression methods (Montiel & Kraus, 2010; Rego *et al.*, 2021). However, the interplay of public perception and political support can complicate these reforms, suggesting that while effective fire management can reduce the frequency and intensity of wildfires, it may inadvertently foster disinterest of the general public in ongoing fire management initiatives, thus creating a cycle of ambivalence towards essential fire use policies. The management of fire use in forested and open landscapes has been historically governed by stringent policies aimed at minimizing the threat of wildfires, which are often exacerbated by careless or

deliberate ignition (Montiel & Kraus, 2010). While such prohibitive frameworks were conceived as protective measures, evidence from Mediterranean regions indicates that these approaches can paradoxically lead to increased instances of uncontrolled fires. The challenge lies in developing an adapted policy framework that permits the controlled use of fire for ecological and land management purposes, such as prescribed burning and suppression fire, and navigates the entrenched barriers of existing legislation.

Despite widespread recognition in EU policy and discourse of the critical role of Sustainable Forest Management (SFM) and Integrated Fire Management (IFM) in wildfire risk reduction, there remains a significant gap between theoretical frameworks and practical implementation. These approaches often operate in isolation rather than as complementary, integrated strategies, exacerbated by the absence of a unified EU regulation, standardized guidelines, and clear criteria or indicators to measure the effectiveness and thresholds for achieving this integration (AGIF, 2023a; Ascoli *et al.*, 2023; Casartelli & Mysiak, 2023; Corona *et al.*, 2015; European Commission, 2021b; European Commission, 2018; Held & Pronto, 2023; Tedim *et al.*, 2015).

Scope of this document

This document proposes the implementation of the combination of two well established methodological approaches: a) Closer-to-Nature-Forest-Management (CTNFM) (European Commission, 2023; Larsen *et al.*, 2022) and b) Integrated Fire Management (IFM) (FAO, 2023; FAO, 2024; Myers, 2006; Rego *et al.*, 2021; Silva *et al.*, 2010), as a holistic approach on managing wildfires in Europe, considering the spatial and temporal scale necessities.

Integrated Fire Management (IFM) is a comprehensive approach to wildfire risk management that incorporates a combination of preventive, suppressive, and restorative strategies. IFM integrates apart from traditional and ancestral fire use techniques, controlled (tactical options for suppression fire use) or prescribed burns to reduce the accumulation of fuel loads, direct or slow down fire spread, mitigate re-ignition risks, and limit suppression actions to an anchor point, and restore ecological processes. In recent years, the urgency of addressing climate change has prompted a re-evaluation of traditional forestry practices, leading to the emergence of innovative approaches like Closer-to-Nature Forest Management (CTNFM). This ecologically focused strategy emphasizes the sustainable management of forests as a vital Nature-based Solution (NbS) to combat climate change, as highlighted in the European Union's Biodiversity Strategy 2030 (European Commission, 2021a). The European Commission's DG Environment underscored the necessity of adopting biodiversity-friendly forestry practices to enhance ecosystem resilience and promote sustainability. Following this, the New EU Forest Strategy for 2030 (European Commission, 2021b) further solidified the commitment to CTNFM by encouraging the development of specific definition, principles and objectives (Larsen *et al.*, 2022), paving the way for a more harmonious relationship between forest management and biodiversity enhancement and conservation. In 2023 (European Commission, 2023), these efforts culminated in the establishment of comprehensive guidelines, setting the stage for a transformative shift in how forests are managed across Europe. This approach emphasizes the maintenance of natural forest structures and processes. This approach is predicated on the objective of preserving or reestablishing forest ecosystems by fostering natural ecological processes and the incorporation of ecosystem dynamics into forest management practices. It is designed to enhance biodiversity and ensure the preservation of ecosystem functionality and resilience in managed forests throughout Europe. This includes fostering natural tree regeneration, native or site adapted non-native diverse tree species compositions and structures, and complex habitat features and avoidance of intensive management operations all of which contribute to enhanced biodiversity and resilience. Effectively combining IFM and CTNFM, while adapting their frequency and intensity to specific local contexts such as climate, forest type, and site characteristics, holds significant promise for creating more resilient and ecologically sound forest ecosystems.

Both approaches (objectives and tools) take a holistic view of the ecological, socio-economic and technical aspects of sustainable forest and fire management, (1) to address the social and conservation problems as well as the issues that result from the degradation of forests before and after wildfires; and (2) to meet the goal of sustainable ecosystems functions and services for human livelihoods in fire prone and/or degraded environments. This paper establishes a foundation for an examination of the advantages and difficulties associated with the integration of IFM and CTNFM, as well as their prospective applications in fostering sustainable forest management and mitigating wildfire risk in fire-prone environments in Europe. The advantages and disadvantages of the two approaches are discussed, and examples from Europe, US and Australia are provided. These examples can be used as lessons learned and best practices of the aforementioned approaches to enhance the resilience of forest against wildfires, to support biodiversity and adaption of forests, forested and agroforestry landscapes in the era of climate crisis.

Finally, options for consideration by policymakers, practitioners (firefighters, emergency responders, forest and land managers, conservation managers), scientists (e.g., foresters, wildfire experts, conservation experts), and communities on how to manage wildfire risk are provided to create a realistic vision of a more resistant and resilient forest ecosystem in the context of climate change.

In the light of these worrying trends, the role of restoration is becoming increasingly important, particularly in Europe (EU Nature Restoration Regulation, 2024). The restoration of degraded forest ecosystems is imperative for the long-term and sustainable restoration of biodiversity and nature's resilience. This is not only a means of limiting global warming and contributing to the EU's climate mitigation and adaptation objectives, but also a means of meeting international

commitments. In addition, it plays a crucial role in strengthening resilience against natural disasters, such as future fires. This assertion becomes particularly important when considered in conjunction with methodologies such as Integrated Fire Management (IFM) and Closer-to-Nature Forest Management (CTNFM), which prioritise sustainable practices and adaptive strategies to ensure ecosystem steady state.

Methodology

This chapter presents an approach for assessing the impacts of climate change-induced wildfires on forest ecosystems and their surrounding landscape mosaics, with an emphasis on integrating wildfire management and sustainable forest management strategies. Specifically, it explores two key management approaches: Integrated Fire Management (IFM) and Closer to Nature Forest Management (CTNFM). These strategies are examined within a comprehensive theoretical framework that draws upon a comprehensive literature review.

The literature review is based on both academic and gray literature encompassing wildfire ecology, wildfire risk management, forest ecology, the impacts of climate change, and sustainable forest management practices in terms of integrative multifunctional forest management. This synthesis of studies, reports, and policy documents provides a critical understanding of the dynamics of fire, forest structure, biodiversity, and the ecological roles of fire within these systems. Key themes addressed include strategies for managing wildfire risk, the shifts in fire regimes driven by climate change, the ecological functions of fire, and the core principles of IFM and CTNFM. These concepts are explored across both temporal and spatial scales, as illustrated in Figure 1.

Integrated Fire Management

In Myers (2006) the following statement from the special fire issue of Aborvitae (Stolton & Dudely, 2003) of the International Union for Conservation of Nature (IUCN) is stated: "*Disturbance is present in all natural ecosystems. Forest management therefore needs to be able to accommodate chance episodes of natural disturbance, including fire. Managers also need to distinguish between harmful and harmless or beneficial fires. Fire is sometimes essential for forest regeneration or provides tangible benefits for local communities; in other cases, it destroys forests and has direct social and economic consequences*." Starting with the aforementioned statement from IUCN, this subchapter introduces the shift from a traditional way of managing fires (suppression, control, exclusion) to a more proactive and holistic approach (wildfire mitigation,

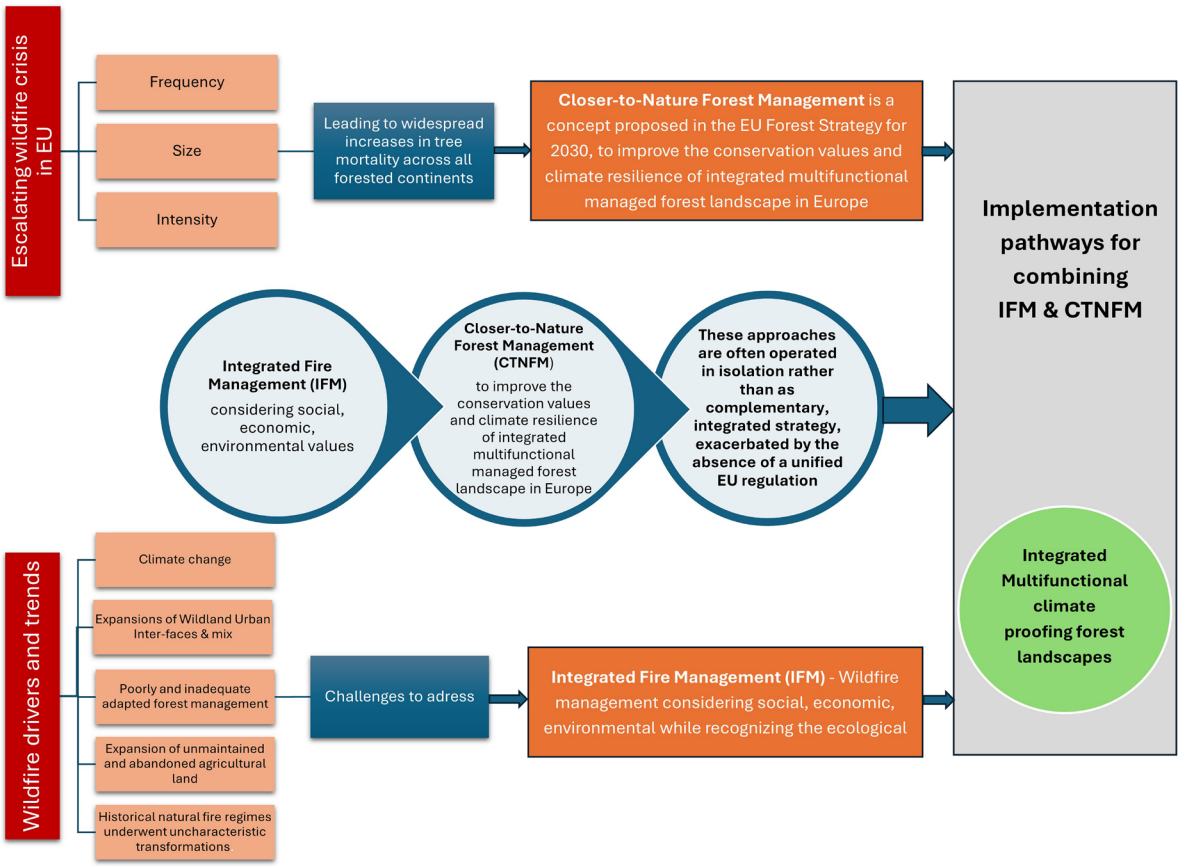

Figure 1. Schematic representation of the methodological concept behind the suggestion of combining IFM with CTNFM to create wildfire resilient forests and societies.

preparedness, suppression and adaptation) titled Integrated Fire Management (IFM) to increase wildfire (risk) management capacity.

Integrated Fire Management is an approach that combines fire prevention, response, and recovery while integrating ecological, socio-economic, and cultural factors into fire management strategies. This approach combines scientific data with traditional knowledge, particularly from Indigenous and local communities, for more equitable and effective fire strategies. Community-based fire management (CBFiM) empowers local groups to actively participate in fire prevention, readiness, and response, encouraging ownership and accountability (FAO, 2024).

Fire management has historically focused on the suppression, control, and exclusion of wildland fires ("Smokey Bear effect"), primarily to protect human life and health, property (homes, infrastructure and critical entities), livelihoods, traditional and indigenous cultures, and natural resources in landscapes and rural areas. Traditional fire management has involved a wide range of activities united by the primary goal of controlling fuels, ignition, or fire spread. This approach often overlooked the ecological benefits of fire, such as maintaining biodiversity and ecosystem health. The prevailing view was that all fires were detrimental, leading to a reactive rather than proactive management approach (FAO, 2002; FAO, 2006; FAO, 2011; FAO, 2023; FAO, 2024; Myers, 2006; Rego *et al.*, 2010; Rego *et al.*, 2021; Silva *et al.*, 2010).

Fire ecology has expanded significantly since the middle of the 20th century (Komarek, 1976) and provides adequate evidence to fire science and management nowadays (Rego *et al.*, 2021). Additionally, it has been recognized how critical it is to be reoriented on fire mitigation (prevention) and adaptation (recovery) as opposed to the traditional portfolio of fire suppression, control and exclusion. Various EU-funded initiatives, particularly in the Mediterranean regions (e.g., PREFER, FORESTERRA, FUME, FIRE PARADOX, PROTECT, HOLISTIC, READINESS) have provided important information. Moreover, initiatives such as "LIFE Granatha" and "Landa Carsica" in Italy, as well as "LIFE Montserrat" in Spain, integrate prescribed burning into landscape management strategies, to decrease wildfire risk and improve biodiversity and habitat.

Additionally, several European examples of fire use in land management, highlighting the diverse applications and benefits of prescribed burning and other fire-related techniques are provided in Montiel & Kraus (2010). These case studies range from nature conservation efforts in Sweden and Germany, where prescribed burns are strategically implemented in protected areas, to the deeply ingrained traditional practice of 'muirburn' in Scotland, demonstrating the cultural significance of fire. Further examples include the French Prescribed Burning Network's multi-faceted approach to wildfire prevention and biodiversity management, as well as national programs in Spain, Portugal, and Catalonia that focus on grazing improvement, tactical firefighting, and forest fire risk management, respectively. Each case study explores the context, objectives, implementation, and outcomes of these fire use practices, ultimately aiming to disseminate knowledge and promote the social and ecological opportunities presented by these techniques.

IFM benefits

IFM is positioned as a complete and multifaceted strategy that provides a framework for operational and planning processes that is designed with the aim to balance the risks associated with wildfires while maximizing their ecological benefits (FAO, 2023; FAO, 2024; Myers, 2006; Rego *et al.*, 2010; Rego *et al.*, 2021; Silva *et al.*, 2010). For example, IFM emphasizes the importance of wildfire mitigation, advocates the use of fire as a management tool, and emphasizes the central role of local communities and indigenous as active participants in the entire process. On the one hand, understanding natural and anthropogenic fire regimes is essential for effective landscape management. On the other hand, the traditional knowledge and practices of local and indigenous people contribute significantly to sustainable land management and fire use. IFM can be used to reduce wildfire risk through fuel management, restoration of degraded ecosystems, firebreaks and public awareness (prevention and mitigation phase). In the preparedness phase is a tool to develop plans and strategies, while in the suppression phase is directly related to the efficient use of fire to control wildfire spread. Finally, IFM is a short- and long-term restoration measure to ensure a healthy forest and to mitigate other potential hazards.

By integrating ecological knowledge with socio-economic considerations and community engagement, IFM aims for sustainable land management that acknowledges the dual nature of fire as both a threat and a tool for ecological balance in a holistic way. This evolution is critical in addressing contemporary challenges posed by climate change and increasing wildfire risks globally.

IFM – a worldwide successful approach to mitigate wildfire risk

Integrated Fire Management has been used with success internationally (Boer *et al.*, 2009; Davim *et al.*, 2022; Kaoukis *et al.*, 2023; Rego *et al.*, 2021) from Australia, to South Africa, United States of America, and Europe with positive results in wildfire suppression, elimination of extreme wildfires, conservation of biodiversity and mitigation of wildfire risk by using prescribed burning as the main tool for conducting IFM.

Among the various success stories of using prescribed burning for fuel management, and biodiversity conservation in Australia since the indigenous people, the use of prescribed burning in France in the Pyrénées-Orientales for pastoral purposes and to re-learn how to control fire and the response of ecosystems, one modern example also worths to be mentioned; the use of prescribed burning in Florida (USA) for ecological benefits and to reduce fuels, even in the Wildland Urban Interface (Rego *et al.*, 2021). Several noteworthy examples exist

of effective fire utilization across Europe, including the prescribed burning initiatives in Sweden (nature conservation in protected areas in Västernorrland) and Germany (use of Prescribed Fire for Maintaining Open Calluna Heathlands in North Rhine-Westphalia, in the State of Baden-Württemberg where the first large prescribed burning took place as a research program), in Finland, in the Koli National park (boreal coniferous forests), traditional fire management in Scotland and UK (Fire Use Practices for Habitat and Wildlife Management in Scotland and the UK with a Case Study from Glen Tanar Estate), organized fire management networks in Spain (The EPRIF or 'Integral Prevention Teams') and Portugal (Portuguese National Programme of Fire Use and Analysis Group-GAUF team Actions) and the Catalonian Programme on Fire Management (Grup de Recolzament d'Actuacions Forestals - GRAF Team Actions). Each of the aforementioned case studies demonstrates the transformative capacity of fire when strategically utilized, addressing ecological imperatives while fostering community involvement and sustainable practices (Montiel & Kraus, 2010). In areas where fuel treatments have been applied to reduce burn severity, firefighters or other responders could allow specific fires to burn in order to promote the long-term benefits of the fire to the ecosystem.

The benefits of treating prescribed fire include reducing the intensity and severity of wildfires and the threat of such extreme future wildfires in the same area (e.g., Boer *et al.*, 2009; Halofsky *et al.*, 2020; Strom, 2005). In addition, safe buffer zones can be created, ladder fuels and debris from logging or thinning are reduced, growth of trees, plants and fungi is promoted, while invasion of non- site adapted native species, insects and disease is minimized (Halofsky *et al.*, 2020; Wollstein *et al.,* 2022). Also, the use of prescribed burning is proposed by Manton *et al.* (2022) as tool of forest management in the Dzūkija dry pine forests (hemi-boreal forests) in Lithuania. Moreover, experiments with prescribed burning have been conducted in Russia to study new concepts in wildfire management introducing natural fire and prescribed treatments to replace fire exclusion policies (Goldammer, 2013). In Southeastern Europe, specifically Greece, among the continuous use of fire by shepherds (Papanastasis, 1976; Papanastasis, 1980), the practice of prescribed burning has remained largely experimental, with only isolated trials conducted in forest plots, shrublands, and mountain pastures (Liacos, 1977; Papanastasis, 1976; Papanastasis, 1980). This hesitance to embrace fire management practices reflects a broader reluctance to integrate such methods into environmental stewardship strategies, hindering the potential benefits of controlled burning for ecological health and landscape management. As the complexities of wildfire risks and land management evolve, revisiting and potentially redefining these practices may prove essential for sustainable resource management in the Mediterranean region. Recently, pilot prescribed burnings have been conducted in Chios island in order to identify and setup the necessary requirements for its use in Greece and provide these to build the relevant legal framework (Athanasiou *et al.*, 2022; Athanasiou *et al.*, 2023). The first results are promising, and prescribed burning can be used with other traditional measures such as thinning and grazing. The use of prescribed burning did not show any significant impacts on the soil. Also, the biodiversity in flora showed an increase after the use of prescribed burning (Kaoukis *et al.*, 2023).

Another important advantage of prescribed burning is being noted by the study of Khabarov *et al.* (2016) in which adaptation options in the context of wildfires in Europe are being examined. They have calculated the burned areas in various European regions with and without the reduction of fuel load through prescribed burning. Based on their projections an increase to the average annual burned area in all European regions is expected to be experienced in the future, even in Central Europe and Baltic although fires are infrequent compared to the Mediterranean region. The increase is expected to be of the order of 120–340% in 2090 over 2000. When prescribed burn is applied, there is a 70% decrease in the average annual burned area compared to the "no prescribed burning" case. Similar results have been calculated for the entire Europe (Khabarov *et al.*, 2016).

Challenges in the implementation of prescribed burning

Prescribed burning requires favorable weather conditions to be implemented as well as intensive training and understanding of fire behavior, otherwise effectiveness may be limited and fire control can be lost (Myers, 2006). Contingency measures have always to be considered. Due to climate change the "safe" periods for conducting prescribed burns may be limited. Its implementation in narrow, in time, fire regimes may potentially lead to the extinction of species (Gill & Bradstock, 1995; Myers, 2006). Raising awareness on the positive role of fire, especially to the general population, is also challenging, as a large percentage of the population and some disaster managers consider fires disastrous (Myers, 2006). Scale problems between habitat size and habitat diversity (Myers, 2006) which require clear goals and continuous monitoring of the results acquired with the use of prescribed burns can be challenging. The differentiation of the use of fire for restoration and maintenance purposes is an issue that needs to be considered when using fire as a tool (Myers, 2006). Prescribed burns may affect air quality in the short-term and at local scale (Haikerwal *et al.*, 2015). Increasing run-off and erosion rates could be observed (Fernandez *et al.*, 2012). While prescribed fires protect fire-sensitive species from the effects of wildfires (Pastro *et al.,* 2011), in some cases may affect wildlife mortality (Lyet *et al.,* 2009). Frequent prescribed burns have better results (Boer *et al.*, 2009) but invasion of non-native species is possible, thus a compromise between reduction of fire hazard and alien species invasion should be made (Keeley & McGinnis, 2007; Kerns & Day, 2017). Although it is a co-effective approach, in some cases, prescribed burns may be cost-ineffective (Florec *et al.*, 2020; Pacheco & Claro, 2021; Penman *et al.*, 2020). The restrictions in current legislation in the use of fire as well as the still non-adapted traditional fire use regulations in other countries (Silva *et al.*, 2010). Spring and fall burning may not serve the same ecological benefits as summer burning (Kantor *et al.*, 2020). Finally, prescribed burns may work poorly in forests with infrequent, stand-replacing wildfires (Halofsky *et al.*, 2018).

IFM, during suppression phase, promotes the use of fire techniques such as burn out or backfiring in order to control a wildfire (NWCG, 1996; Silva *et al.*, 2010). One the most recent adoptions of these suppression fires in operational levels, made in Greece on March of 2022, in which the Hellenic Parliament approved the law to use backfire and burnout techniques for fire suppression, while in June 2022, the government published the technical aspects on how to use them (Athanasiou *et al.*, 2022).

IFM integration into the legal framework of EU member states under the subsidiarity principle

As far as it concerns the adoption of prescribed burning in national laws of the EU Member States, Portugal and France were the pioneers in establishing legal frameworks for prescribed burning. Spain and Italy have only implemented regulations at a regional level (D'Amelio, 2022). France introduced the Forest Management Law, modifying the Forest Code of 1987. This law allows responsible authorities to use fire for prevention outside of risk periods (Art. L321-12). Additionally, local regulations (arrêtés préfectorales) have been developed by "Départements" to create prescribed burning plans.

Portugal, in 2004, enacted a specific regulation on prescribed burning known as *fogo controlado*. Significant policy changes in 2009 led to the adoption of the term *fogo técnico*, which includes prescribed burning and suppression fire. The region of Catalonia, in Spain, has developed Decree 312/2006 on Tactical Fire that regulates fire use for wildfire prevention and suppression. Other regions, such as Galicia and the Balearic Islands, have incorporated prescribed burning within their basic forest fire regulations. In Italy, regions, such as Piemonte, Basilicata, and Liguria, have considered the use of prescribed burning in their laws and programs. However, practical implementation remains limited, with Sardinia being a notable exception. Outside the Mediterranean region, Sweden and Poland are reported to have unclear regulations on fire management. Conversely, Lithuania, Italy, and Germany, which previously banned the use of fire, are beginning to reintroduce it experimentally for the management of protected areas (Montiel-Molina, 2013). In northern Europe, particularly in Estonia, Finland, Latvia, Lithuania, and Sweden, the natural role of fire in boreal and hemi-boreal ecosystems is recognized; however, negative public perceptions of fire use persist alongside a lack of regulatory frameworks (Montiel-Molina, 2013). It is important to recognize that fire governance is currently undergoing significant changes in emerging fire regions, suggesting that regulations may have evolved since 2013. A recent global review of fire policy suggests that regulations on fire use remain ambiguous or poorly enforced in several European countries, including the United Kingdom and Italy, where fire management is primarily handled at the local rather than national level (Pandey *et al.*, 2023).

Fernandes *et al.* (2013; 2022) highlighted significant barriers hindering the broader application of prescribed burning (PB) across Southern Europe. Although France and Portugal integrated PB into their national laws in 2001 and 2004 respectively, Italy's second national wildfire law (L. 353/2000) notably omitted any provisions for it (Bovio & Ascoli, 2012; Lázaro, 2010). Similarly, despite initial attempts to introduce PB in Greece during the 1970s, the practice remains largely absent from fuel management and fire prevention strategies, lacking a formal institutional framework for implementation even decades later (Athanasiou *et al.*, 2023).

Closer-to-Nature Forest Management

Throughout Europe's history, there have been different views on the idea of "sustainable forest management" (SFM) and how to implement it, depending on the different forest biomes, geographical locations, and stakeholder and management planning portfolios. Under the broad framework of Sustainable Forest Management (SFM), a constellation of diverse approaches and terminologies has emerged, reflecting the growing recognition of the multifaceted role forests play globally. These include, but are not limited to, Close-to-Nature Forest Management, Climate Smart Forestry, Climate Smart Sustainable Forest Management, Community-Based Forest Management, Continuous Cover Forestry, Nature-Based Forest Management, and other terms. Each approach, while distinct in its methodology, shares the common goal of enhancing and conserving a broad spectrum of forest functions and services. This encompasses the preservation and promotion of forest biodiversity, ensuring the economic viability of timber resources (with a shift towards prioritizing quality and long-term value over sheer volume), maintaining forest health and ecological stability, and satisfying the diverse needs of society in a manner that respects and integrates local social, cultural, and environmental contexts. These nuanced approaches are particularly vital for the unique needs of diverse forest biogeographic regions and the communities that depend on them. Forests provide a multitude of essential ecosystem services, ranging from critical food supply and clean water conservation to essential forest preservation, all of which contribute to the broader well-being of regional, national, and even global communities. However, as societal demands continue to evolve and the impacts of climate change intensify – including increased frequency and severity of natural hazards such as wildfires – it becomes imperative to move beyond segregated, single-objective management practices. The future of forestry is such that there is a necessity for the development and deployment of more integrative and adaptive management strategies, which may even be combined.

In 1993 at Helsinki, the European Union (EU) decided that all member states' degraded forests, caused by overexploitation, should be restored and maintained in the future through new, more strategic planning that takes into account sustainability and multifunctionality. In 2023, the European Commission published a set of guidelines, a staff working document (European Commission, 2023), on the Closer-to-Nature Forest Management (CTNFM) approach to assist competent authorities, forest owners and managers and other key stakeholders in the implementation of a biodiversity-friendly and adaptive forest management practices under the prism of

climate change and the Green Deal actions. This requires strengthening the ability of forests to provide a wide range of ecosystem services and support for these services. These include wood production, biodiversity conservation, wetland protection, water quality preservation, recreation opportunities, carbon sequestration, and carbon storage. To achieve this, it is necessary to bolster both the environmental aspect of sustainable forest management and the resilience of forest ecosystems (European Commission, 2023).

CTNFM (Larsen *et al.*, 2022) practices can effectively address these environmental and climate-related needs in a sustainable way. Furthermore, managing forests according to closer-to-nature principles wherever possible and needed, considering the local conditions, could enhance their resistance, resilience, and adaptive capacity, thereby reducing the significant and escalating socioeconomic risks associated with forest damage and losses caused by climate change. CTNFM integrates technical, economic, and social considerations to safeguard ecosystem functioning and resilience. This approach recognizes forests as complex ecosystems with various organisms and abiotic elements, working together to support multiple functions. Instead of imposing uniformity, CTNFM relies on natural processes and avoids manipulating natural site conditions. It considers factors such as species interactions, environmental conditions, and climate to make decisions about managing forests. Diverse forest structure and composition are crucial for biodiversity, and forests should include different stages of development to provide habitats for a variety of species.

The principles of CTNFM include:

- Embracing and allowing natural processes to unfold
- Maintaining the diversity and complexity of forest structures and patterns
- Connecting and integrating forest functions across various spatial scales
- Utilizing a variety of silvicultural systems that align with the natural disturbance patterns of the region
- Conducting timber harvesting activities with a minimal environmental footprint is crucial. Emphasis should be placed on considering what is preserved in the forest alongside what is harvested, thereby safeguarding habitats, forest soil, and microclimates.

By adhering to these principles, forest managers can promote the long-term health, biodiversity, and ecological integrity of forest landscapes, ensuring their sustainability for future generations. The study of Bauhus *et al.* (2013) echoes Larsen *et al.* (2022) by emphasizing the importance of using tree species appropriate to the site, promoting diverse mixed-age forest structures, avoiding clearcutting, stand stability, relying on natural processes and encouraging individual tree growth. CTNFM acts as a catalyst for biodiversity restoration, conservation, and enhancing forest resilience to climate change (Larsen *et al.*, 2022) by focusing on two primary objectives, enhancing structural complexity and facilitating natural forest dynamics.

By prioritizing these objectives, CTNFM not only supports biodiversity restoration and conservation efforts but also bolsters the adaptation of forest ecosystems in the face of climate change challenges.

CTNFM Benefits, limitations and challenges

Forests throughout the EU vary significantly in terms of their environmental attributes, current status, biodiversity, and challenges posed by climate change. This diversity also extends to the forestry measures that have historically influenced these forests (European Commission, 2023).

Transitioning from even-aged monocultures of conifers-which can lead to a "domino effect" during wildfires-to uneven-aged mixed forests (del Rio *et al.*, 2016; del Rio *et al.*, 2017; del Rio *et al.*, 2018; Morin *et al.*, 2011; Morin *et al.*, 2014; Puettmann, 2011; Sánchez-Pinillos *et al.*, 2016; Vilà *et al.*, 2013), which incorporate a higher proportion of less flammable broadleaf species (Amiro *et al.*, 2001; Campbell & Flannigan, 2000; Hély *et al.*, 2001; Hirsch *et al.*, 2004; Krawchuk & Cumming, 2011; Päätalo, 1998; Terrier *et al.*, 2013) and fire-resistance species (Moris *et al.*, 2022) can significantly improve the resilience, resistance, and adaptive capacity of both current and future forest stands in the face of various natural disturbances, including those caused by wildfires and climate change (Jactel *et al.*, 2017; Messier *et al.*, 2022) by promoting compositional, functional, and structural diversity (i.e., tree age, size, height), where appropriate and possible.

In addition, by establishing such uneven-aged mixed stands, the risk is dispersed over a larger number of different tree species, thus increasing the resilience of the forest stands (Kohnle & Klädtke, 2011). This transition can be achieved among the aforementioned silvicultural approaches also through appropriate management and restorative harvest practices such as controlled clear cuttings, pruning, thinning in overstocked forests, mastication of woody material, and reductions of herbaceous fuels through grazing or mechanical means (Agee & Skinner, 2005; Bernau *et al.*, 2018; Brennan & Keeley, 2015; Diamond *et al.*, 2012; Forestry Commission, 2014; Jain *et al.*, 2012; Krawchuk & Cumming, 2011; Shinneman *et al.*, 2019). Such strategies foster a phenomenon often referred to as the "portfolio effect", in which the various species (in mixture) are affected in a different way by wildfires, and thus the risk is dispersed and reduces the individual's (even-aged conifers plantations) vulnerability to wildfires. The latter one may not be valid in temperate broadleaved forests but in this case wildfire ignition and risk are significantly smaller compared to coniferous forests.

Nevertheless, the choice of adaptive silvicultural system for enhancing wildfire resilience, resistance and adaptive capacity, particularly those that align closer to nature processes such as "Irregular Shelterwood" and "Selection Systems (both

group and single tree)" should be carefully evaluated on a site-specific basis, considering various factors. These factors encompass annual atmospheric conditions, the current and anticipated stages of vegetation and tree species composition and structure, as well as the terrain, all of which affect fire risk, combustion, and behavior. It is important to mention here that these systems, while promoting high biodiversity, can also be susceptible to wildfire due to the accumulation of surface and ladder fuels (Forestry Commission, 2014).

In addition, mixed forests pose several management challenges throughout their life cycle (natural succession stages), requiring more intensive regeneration efforts, especially on calcareous soils, as well as enhanced protection and maintenance strategies as pointed out in Kalapodis (2010). They require a higher level of spatial organization and detailed planning than pure stands. While mixed forests can be beneficial, as noted by Thomasius (1992), they are not universally applicable; their effectiveness varies with site and species combinations. Furthermore, and despite the aforementioned benefits of mixed forest formations, there is a notable lack of management models tailored to these ecosystems (Coello *et al.*, 2022). Existing silvicultural guidelines tend to be vague and mainly qualitative (Pretzsch *et al.*, 2021) due to complexity associated with establishing guidelines, significant diversity of the combination of these stands formations with compatible species in an area and limited empirical evidence of the outcomes of silvicultural treatments on the field (Bauhus *et al.*, 2017; Piqué & Vericat, 2014).

The establishment of heterogeneous stands that integrate a diverse array of tree sizes in horizontal distribution and intricate vertical groupings has demonstrated benefits for wildlife habitat and forest resilience, as highlighted by various studies (Larson & Churchill, 2012; O'Hara, 2014; Ritter *et al.*, 2020; Stephens *et al.*, 2014), including at stand and landscape scale (O'Hara, 2014). This strategy has the potential to augment biodiversity, offer diverse habitats for wildlife species, and bolster the overall resilience of the forest ecosystem against environmental stressors. Despite concerns about fire hazards and crown base height which often lead to simplified stand structures with uniform tree size distributions (Agee & Skinner, 2005), it is worth noting that a homogeneous structure may not always be essential. Crown base height is a crucial parameter in understanding how fires move from the ground surface through ladder fuels into tree canopy. Enhancing fire resistance can be achieved by diversifying tree sizes within groups and restricting the horizontal connectivity of the overstory or large tree component (Ritter *et al.*, 2023). The implementation of a discontinuous overstory layer allows for the movement of heated air between tree crowns, reducing the likelihood of crown fires, as suggested by Ritter *et al.* (2020) and Tachajapong *et al.* (2009).

The management of wildfire resilience in such forest ecosystems is a complex challenge, particularly as forest structures evolve over time through the different natural succession stages. Thus, fire hazard ratings for surface, ladder, and crown fuels are critical in understanding the potential for extreme fire behavior, such as crown fires and torching, which can occur when surface fires escalate through ladder fuels to reach the canopy. Therefore, a primary objective in forest management should be to prevent such extreme fire behaviors (Forestry Commission, 2014). Moreover, functional diversity within the pre-fire vegetation community emerges as a crucial factor in enhancing ecosystem recovery and resilience following disturbances, including wildfires (Sample *et al.*, 2022). Diverse plant communities, characterized by a variety of growth forms, functional types, and adaptive traits, are generally more capable of withstanding stressors such as climate change and can better recover from significant disturbances such as wildfires. This functional diversity is particularly important in landscapes that have experienced large fires, as it can facilitate ecosystem reorganization and recovery (Hurteau *et al.*, 2014; Noss, 2001; Spasojevic *et al.*, 2016).

Nature-Based Forest Management (NBFM) is currently implemented on 22–30% of the forested areas in Europe (Larsen *et al.*, 2022). This percentage is gradually increasing due to various environmental, economic, and social factors (Mason *et al.*, 2021). The extent of NBFM varies significantly, with only a small percentage in countries like Portugal, Finland, and Sweden, while it approaches nearly 100% in Switzerland, Slovenia, and certain German states where it is mandated by forest legislation. In Denmark, NBFM follows the principles of Close-to-Nature Forest management and is compulsory for all public forests (Larsen, 2012).

Part V of the Guidelines on Closer-to-Nature Forest Management (European Commission, 2023) offers a brief overview of the primary forest types and management strategies across various EU biogeographical regions (Alpine, Atlantic, Boreal, Continental and Mediterranean) illustrating how closer-to-nature forest management is applied in practice. The regional profiles include specific case studies, concentrating on particular areas within the region, or address the region in its entirety. The unique challenges and experiences related to closer-to-nature forest management in each region are evident in the differing levels of emphasis and attention given to the individual elements and principles of this management approach. Specifically, the aforementioned EU regions demonstrated that the manner in which forests are currently managed has undergone significant alterations in recent decades. Forest managers are now employing novel methodologies that integrate conventional practices with the pressing necessity to ensure the sustained provision of vital ecosystem services. This change is especially important in Mediterranean regions, where biodiversity and natural disturbances such as wildfires are critical for the environment to be healthy.

Closer-to-Nature Forest Management and Integrated Fire Management – A framework for combination at spatial and temporal scale

Spatial scale

The higher frequency of fires in certain topographical locations and in previously burned areas leads to homogeneous

landscapes covered with shrub and bush cover (Moreira *et al.*, 2011). The frequency and intensity of these wildfires can further increase the vulnerability of such uniform landscapes (Arrogante-Funes *et al.*, 2022). So, the composition, continuity, and condition of fuels across landscapes are crucial factors in wildfire management (Fulé, 2008; Moreira *et al.*, 2011). Implementing landscape-level fuel management strategies fosters fuel-structure heterogeneity, which can effectively mitigate fire risk. This is particularly evident in mosaic-type landscapes, where diverse fuel arrangements contribute to reduced vulnerability to wildfires (Krawchuk *et al.*, 2020; Moreno *et al.*, 2014b; Salis *et al.*, 2018).

CTNFM and IFM are two ecologically driven approaches with the purpose of restoring forest ecosystems and current fire regimes, at both spatial (stand and landscape) and temporal scales, that have been disturbed by significant human activities over the past several centuries (Abatzoglou & Williams, 2016; Fulé *et al.*, 2002; Pechony & Shindell, 2010). Given that close-to-nature forests have also suffered significant damage in recent years because of climate change (Hinze *et al.*, 2024), CTNFM seeks to transform forest ecosystems from close to a closer to nature conditions in terms of natural forest dynamics and structural complexity, recognizing that this transformation may involve non-native but site adapted tree species. This emphasizes a continuous process of adaptation, balancing the need for sustainable, climate-resilient forests with the inherent challenges of commercial forestry, where deviations from pristine natural conditions are sometimes unavoidable but ultimately intended to enhance ecological adaptive capacity and stability (Krumm *et al.*, 2023). On the other hand, IFM primarily uses traditional fire and prescribed burning (Noss *et al.*, 2006) as a method of restoring uncharacteristic fire regimes to characteristic or "closer-to-nature" reference conditions to effectively restore the regulatory ecological power of fire. Additionally, IFM promotes suppression fires as an additional tool in the quiver of civil protection authorities. All these components have different levels of importance according to specific situations (Rego *et al.*, 2010).

The prevention and maintenance of conditions of forest ecosystems and fire regimes, at both aforementioned scales, that are closer to the natural state should be a key objective (Arkle *et al.*, 2012; Fulé *et al.*, 2002; Hunter *et al.*, 2011; Lake *et al.*, 2017). When managing forest ecosystems to improve wildfire resistance and resilience and adaptive capacity by restoring forest structure, composition, functions and fire regime, it is important to consider an entire landscape mosaic, or at least the areas that are situated in high-risk, if this is cost expensive (Forestry Commission, 2014). It is not always a case of bigger is better, but rather of working at the appropriate scale to achieve the desired objectives (Ahern & Cole, 2012). The goal should be to create a forest ecosystem at spatial scale that reduces fire risk and, when fire occurs, to have the ability to disperse resource-beneficial fires across landscapes, which is likely to be an important mechanism to restore fire regimes at landscape scale. To minimize the risk of escaping the resource benefit fire, prescribed fire is often applied to a limited set of fuels at a stand scale and under weather conditions that produce low fire severity and is completed in a matter of hours or days (Hunter *et al.*, 2011). By integrating these approaches, landscape management can achieve desired objectives and promote long-term sustainability.

Neidermeier *et al.* (2023), tried to contribute to the ongoing discourse surrounding landscape-level planning and policy aimed at utilizing landscape management strategies (LMS) to mitigate fire risk in Europe. Nonetheless, she underlined that effective LMS decision-making mandates a comprehensive evaluation of local factors. These factors encompass the costs and potential incentives, the position of local stakeholders—whether supportive or opposed—and the appropriate management of areas with high conservation value. Additionally, she stated that is essential to meticulously assess potential trade-offs between fire risk, biodiversity, ecosystem services, and any unintended consequences to ensure balanced decision-making.

Moreover, understanding community diversity and the dynamics of social cohesion or conflict within shared landscapes is crucial (Edgeley & Paveglio, 2024). Such comprehension enables the scaling up of adaptation efforts beyond individual community boundaries (Abrams *et al.*, 2015; Paveglio *et al.*, 2019; Tedim *et al.*, 2016). However, addressing the challenges posed by emerging policies for landscape-level wildfire management is complex. It necessitates the establishment of shared decision-making processes among various stakeholders. This includes determining which communities warrant priority, where to implement fuels treatments, and how to navigate intricate social conditions (Ager *et al.*, 2019; Paveglio, 2021; Steelman & Nowell, 2019; Williams *et al.*, 2012).

The Commission guidelines on land-based wildfire prevention (European Commission, 2021c) offer a comprehensive overview of wildfire trends, existing concepts of wildfire prevention, and good practices in Europe. These guidelines focus on managing landscapes, forests, and woodlands with the aim of enhancing resistance and resilience in the face of wildfires. The lack of prescribed fire and allowing natural fires to burn has already significant and long-term negative substantial consequences (AFAC, 2015; USDA, 2023). Landscapes with higher structural community and species diversity may benefit from enhanced resilience to the anticipated effects of climate and fire regime changes (Davis *et al.*, 2018; Eiswerth *et al.*, 2009; Greiner *et al.*, 2020; Guirguis *et al.*, 2018; Hof *et al.*, 2017; Lavorel *et al.*, 2015; Morelli *et al.*, 2016; Sample *et al.*, 2022; Yocom-Kent *et al.*, 2015). Maintaining landscape-level diversity can provide a buffer against disturbances and create pathways for recovery across broader spatial scales (Jactel *et al.*, 2017; Halofsky *et al.*, 2018; Leys *et al.*, 2018; Sample *et al.*, 2022). Therefore, integrating silvicultural practices that enhance functional diversity within the pre-fire vegetation community is vital for mitigating wildfire risks at both stand and landscape levels. By fostering a structurally, visually, and biologically diverse forest, we can improve resilience to wildfires while promoting ecological health and stability.

Temporal scale

IFM is applied on a temporal scale by using fire as a tool for management before, during and after the fire, having local communities in the centre of its activities to maximize the benefits of fire and minimize the risk (FAO, 2024; Myers, 2006). In this cyclical and continuous timeframe, IFM constantly accounts for time specific parameters (seasonality, weather conditions, frequency of applying prescribed burns) in order to fulfill its scope (Myers, 2006). CTNFM is based on natural forest dynamics mimicking natural succession phases, which can be observed in natural disturbance regimes (e.g., fire, pests, storms) as well. The succession phases span from the rapid growth and pioneer species in the initial stage, to increasing competition (mid-successional stages), to mature and stable forest structures (late successional stages), and finally, to old-growth forest stands. Silvicultural tools are applied in each phase to replicate the natural forest succession and promote components, structures and processes that are characteristics of natural forests and cultural woodlands (Larsen *et al.,* 2022).

Over time, it is becoming clear that climate change is or will significantly affect vegetation distributions and ecological processes through changes in temperature (with rising temperatures leading to more frequent droughts) and changes in precipitation patterns, that consequently may lead to a decline in plant adaptability to these rapid changes under changing future climate and fire regimes (Bemmels & Anderson, 2019; Bloom *et al*., 2018; Coop *et al.*, 2020; Cudmore *et al.*, 2010; Franks *et al.*, 2007; Jump *et al.*, 2006; Loehman *et al.*, 2020; Siepielski *et al.*, 2017). As a result, some plant and tree communities are expected to migrate northward or to higher elevations. Therefore, it is crucial to start identifying various climate proofing species and phenotypic genotypes that may possess greater adaptive capacity and phenotypic plasticity for future conditions (Kalapodis, 2010) as well as those that may not, by monitoring and documenting species and individuals that are currently surviving and adapting to modified climate and fire regimes. Conserving and promoting climate- and fire-resilient species and genotypes that are already present in a given area may allow a similar vegetation community to persist further into the future (Hultine *et al.*, 2020; Simonson *et al.*, 2021). By focusing on conserving and promoting climate- and fire-resilient species and phenotypic genotypes that have the potential to be adapted to an area, we can help ensure that similar vegetation communities continue to thrive in the future.

Implementing both IFM and CTNFM across spatial and temporal scales is essential for maximizing their effectiveness in transforming or restoring forest ecosystems and fire regimes closer to nature. Recognizing that forests function as interconnected ecosystems, management strategies must consider the broader ecological context and historical fire patterns. This approach should also account for predicted atmospheric conditions to enhance overall forest resilience. By integrating these strategies, we can promote healthier ecosystems that are better equipped to withstand and adapt to the challenges posed by climate change and increased wildfire events.

Policy and management options

It is important to remember that a solution of the "one-size-fits-all" is not applicable when it comes to forest and wildfire risk management, as different regions have unique needs that require different management approaches. CTNFM and IFM are not schematic management systems but they demand a thorough understanding of local conditions, as well as the ecology and science of forests and fire (Bauhus *et al.*, 2013; Brang *et al.*, 2014; Diaci, 2006; Gayer, 1880; Gayer, 1886; Larsen *et al.,* 2022; Leibundgut, 1986; Mayer, 1984; Mlinsek, 1990; Möller, 1922; Myers, 2006; Puettmann *et al.*, 2009; Rego *et al.*, 2021; Schütz, 1999; Silva *et al.*, 2010; Thomasius, 1992).

The following preliminary options (Figure 2) for consideration to various stakeholders for the integration of IFM and CTNFM practices refer to the entire disaster management cycle, encompassing prevention, preparedness, response, and recovery phases. This includes fostering collaborative governance structures that empower local communities in decision-making related to land use planning, fuel management (prescribed burning), and fire suppression tactics. Furthermore, investing in training and capacity building for communities in fire-safe practices, early detection, and safe suppression techniques is crucial. Financial incentives and regulatory frameworks should also be designed to encourage sustainable land management practices that reduce fuel loads and promote ecosystem health, thereby mitigating wildfire risk. Moreover, these include recognition of recent reports and initiatives addressing climate change adaptation in wildland fire management (AGIF, 2023a; AGIF, 2023b; Casartelli & Mysiak, 2023; European Commission, 2018; European Commission, 2021c; FAO, 2024; Mauri *et al.,* 2023; OECD, 2023; Robinne *et al.*, 2019; The Nature Conservancy and Aspen Institute, 2023; UNEP, 2022; UNESCO, 2024; World Bank, 2020). The Commission Staff Working Document - Guidelines on CTNFM (European Commission, 2023) also provides preliminary options for combining fire management with nature-centered approaches to manage wildland fires and promote resilience in forest and wildland-urban interface areas. These preliminary options are specific activities for the implementation of the above-mentioned Strategic Action Plan.

The disaster management phases have been added to emphasize that the proposed approach is a holistic one, capable of supporting the entire disaster management cycle for the case of wildfires. The position of the options is not related to the disaster management phases.

Disaster management can be approached through six key options (Figure 2) across different phases of the management cycle: prevention (green), preparedness (yellow), suppression (orange) and restoration (blue) (Figure 3). All of the proposed options are considered relevant to varying degrees for



Figure 2. Policy and management options for the implementation of the combination of CTNFM and IFM framework that enhances landscape and community resilience to wildfires. The position of the options is not related to the disaster management phases.

prevention, preparedness and restoration, contributing to a holistic approach in mitigating disaster, ecosystem and community resilience. However, for the suppression phase, the focus narrows considerably. In this case, the promotion of CTNFM and IFM, foster cross-border and international collaboration and the promotion of controlled burning as a firefighting tactic are considered as most relevant. The suggested options are presented as follows:

Option 1: Follow a multi-stakeholder approach and facilitate cross-level and cross-organization collaboration with clear jurisdiction, improving governance, conducting common exercises and creating living labs to promote CTNFM and IFM

The benefit: By establishing demonstration and reference areas (living labs), platforms for stakeholder engagement and education could be created. These platforms will aim at advancing CTNFM and IFM approaches, critical for addressing current ecological challenges. These areas could also serve multiple purposes, including practical demonstrations of sustainable practices, data collection to fill knowledge gaps, silvicultural treatments, prescribed burning, and, in general, adaptation actions to new fire regimes driven by climate change.

Who is expected to contribute?
Policy makers, forest and land managers, civil protection and firefighters as well as scientists and researchers.

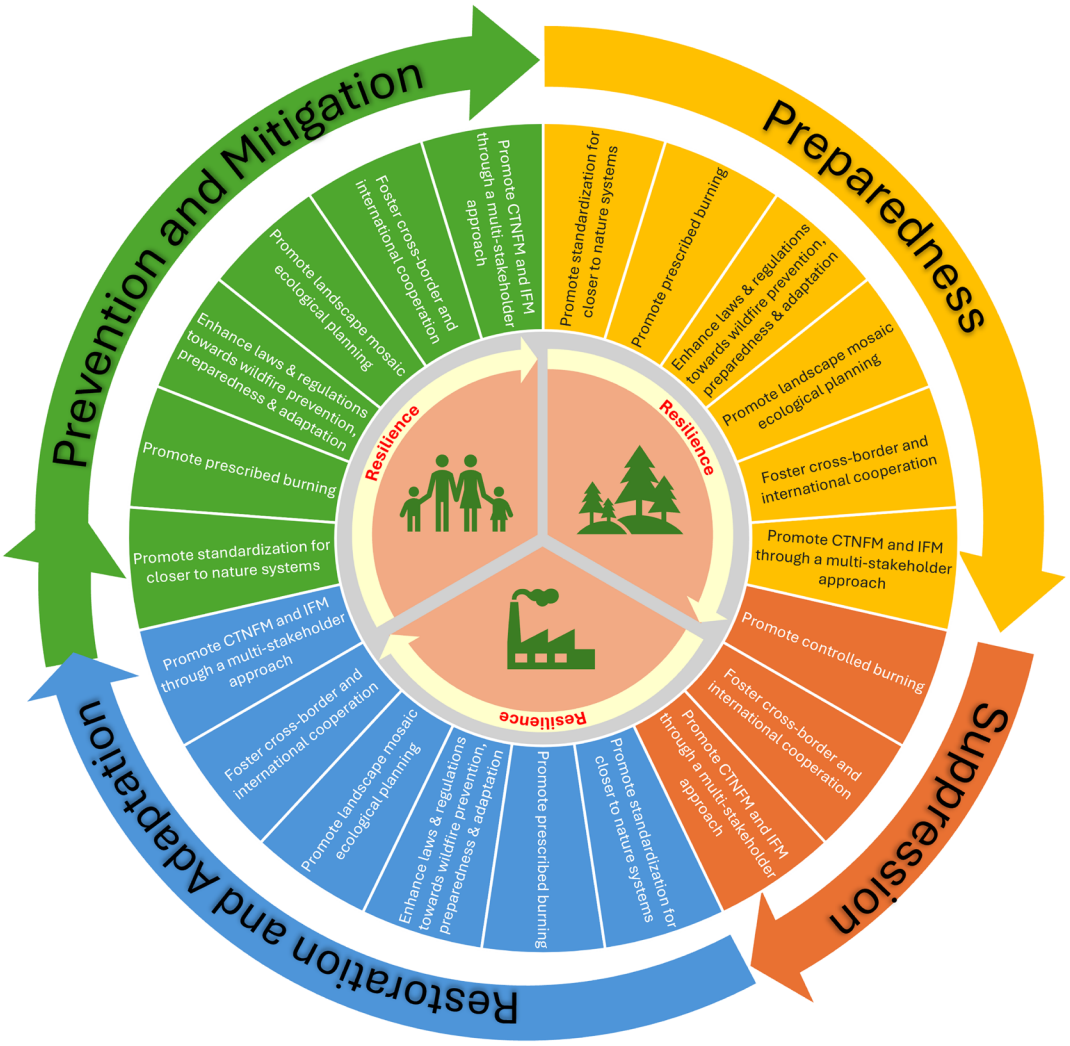

Figure 3. The six proposed options in relation to the disaster management phases. For each phase the options are presented with the same colour. Blue for restoration, green for prevention, yellow for preparedness and orange for suppression. For prevention, preparedness and restoration all the six suggested options are considered relevant, while for suppression mainly the promotion of CTNFM and IFM, foster cross-border and international collaboration and the promotion of controlled burning as a firefighting tactic are considered as most relevant.

What is the expected contribution?

- Policy makers should target to simplify governance schemes that promote clear jurisdictions between organizations and avoid overlapping in the various activities. In addition, consultation with every stakeholder is necessary in order to gather relevant feedback. Through regulations and other measures promote the creation of demo areas (living labs).
- Forest managers and Land managers should be trained on the CTNFM and IFM, work with scientists and learn from them. Identify and create living labs (demo areas).
- Firefighters and civil protection officers should be trained on the CTNFM and IFM, work with scientists and learn from.
- Researchers and scientists should delve more into effective management practices that can reduce fire risks while enhancing ecosystem health. Also, data collection and bridging knowledge gaps is important towards this option.

Potential challenges: The adaptive transformation of forest stands under uncharacteristic evolving fire regimes, driven by climate change and anthropogenic stressors, is a subject

of considerable interest. There is an urgent need to comprehend the ecological dynamics linked to various forest and fire management strategies, especially considering climate change. Significant knowledge gaps remain regarding how different types of closer-to-nature forests respond to altered fire regimes. Successful management will require collaboration among diverse stakeholders, each with their own interests and concerns, particularly at the landscape level, which includes local communities, policymakers, and scientists. The researchers involved in the two linked approaches should break out of their siloed thinking and foster integrative and interdisciplinary collaboration. Moreover, funding for the living labs (training on the relevant silviculture treatments and prescribed fires) is a crucial matter which can be a true barrier.

Option 2: Foster cross-border (EU level, between member states) and international cooperation
The benefit: Cross-border and international cooperation is essential for effective forest and wildfire management strategies. Countries can benefit from each other's research, data, and technological advancements, which can lead to more effective management practices. Participating in joint initiatives and learning from global best practices as well as lessons learned will enable the various stakeholders to propose sustainable solutions that benefit both regional and local environments and the global community.

Who is expected to contribute?
Policy makers, Official state authorities, researchers and scientists.

What is the expected contribution?

- Policy makers could participate in international forums and discussions, "copy" frameworks from other countries (e.g., USA, Canada, Australia)), if proven to work well, and make the necessary adaptations to the EU reality.
- Official authorities or research organisations can provide data from nation to nation to improve wildfire risk management. A knowledge transfer (data, methods, tools, experience, best practices) mechanism from advanced to less advanced neighboring countries should be created available to all Member States.
- Provision of financial support to the "weaker" countries is important. Finally, funding projects of small consortia with enhanced international collaboration focusing on international knowledge exchange as an eligibility criterion, is important.

Potential challenges: The various different national governance schemes among Member States is an equation that is very difficult to solve. Also, funding for collaboration, exchange of know-how and for creating new data can be an obstacle.

Option 3: Promote landscape mosaic ecological planning
The benefit: Planning at the spatial, and especially, the landscape scale plays a critical role in wildfire, mitigation, adaptation and biodiversity enhancement. The use of strategic land use and ecologically based treatments such as controlled burning, mastication, slashing and piling and mechanical forest thinning can create forest conditions that manage the risks, costs and benefits of wildfire while supporting land management goals. This approach focuses on creating defensible space around properties, using fire-resistant plant species, and implementing land use mosaics (e.g. crop production areas next to pasture areas next to forest areas) that reduce fire risk.

Who is expected to contribute?
Forest managers, land managers, local communities, policy makers, civil protection as well as researchers and scientists.

What is the expected contribution?

- Forest managers should explain their needs, the respective vulnerabilities to land managers and communities, enhancing the dialogue between them.
- On the one hand, land managers should consider the needs of the local communities and the forest sector under the prism of landscape and climate change. Planning based on break fuel continuity at the landscape scale is important: Integrating different types of land use – such as agricultural areas, pastures, and forests – can disrupt the continuity of fuel load and accumulation that wildfires rely on. Land managers should consider the interface and intermix of forests and urban areas (WUI) and create fire resilient communities.
- Local communities should understand the vulnerabilities, especially in the WUI zones and be always prepared for the worst-case scenario.
- Civil Protection and scientists should clearly promote education and training to the general public.

Potential challenges: Considering various factors in landscape planning, such as fuels, topography, prevailing winds, fire or treatment history, infrastructure, local societies and economies of scale.

Option 4: Enhance legal and regulatory framework towards wildfire risk management mitigation, preparedness and adaptation
The benefit: Focusing on prevention and preparedness always costs less compared to suppression, saving lives and being a matter of justice.

Who is expected to contribute?
Policy makers with the support of foresters and local communities

What is the expected contribution?

- Policy makers should conduct a comprehensive review of current forest management and fire management policies. Identify gaps and areas for improvement in light of contemporary environmental challenges and community needs along with foresters and local

communities. Enforcement mechanisms that encourage sustainable forest management and effective fire management strategies, including penalties for non-compliance should be introduced. Implementing robust monitoring systems to effectively track compliance with regulations is also important. Establish a legal framework that facilitates enforcement actions against violators (e.g., illegal land use changes, illegal grazing in the aftermath of wildfire, illegal hunting) and ensures that penalties are enforceable through local courts or relevant regulatory bodies. Develop clear and concise guidelines that outline expected practices for forest management and fire prevention. Create a tiered system of penalties that escalates based on the severity and frequency of non-compliance. Consider both financial penalties and corrective measures to promote compliance. Introduce rewards or incentives for individuals or organizations that consistently follow regulations, such as tax breaks, grants for sustainable practices, or public recognition. Engage all stakeholders in the design phase of the strategy. Make use of open debates.

Potential challenges: Overcoming the entrenched traditions, customs, and practices of local and regional mountainous populations, forest and farmer owners. Transparency – necessitating regular reporting from landowners and managers to maintain accountability. Offer training sessions for stakeholders on sustainable practices and the significance of compliance.

Option 5: In risk-informed ecological management strategies, promote prescribed or controlled use of fire as a safeguarding regulator of wildfire risk management and ecological processes at landscape scale, ensuring safety of populated areas
The benefit: The use of prescribed fires promotes ecosystem health and community resilience. Wildfires will burn with lower severity.

Who is expected to contribute?
Policy makers, local communities, forest and land managers, firefighters and civil protection officers, as well as researchers and scientists.

What is the expected contribution?

- Policy makers should pass the prescribed burns or controlled burns in the legal system based on scientific criteria. They should advocate for national and regional legislation that allows for conditional decriminalization of human errors related to the use of prescribed and control fires. National and regional authorities should provide training programs for their personnel and the local communities on fire prevention techniques and emergency response strategies to bolster overall community resilience against wildfires.

- Firefighters and civil protection officers should establish comprehensive guidelines and protocols for conducting controlled burns. They should develop relevant curricula for prescribed fire education programs and relevant training programs. They should implement stringent safety protocols for executing controlled burns, ensuring they are conducted under optimal weather conditions to minimize risks to human life and property.

- Land managers, forest managers and scientists should conduct thorough assessments to identify areas at high risk for wildfires, taking into account factors such as vegetation type, historical fire data, insights from local residents, and the impacts of climate change. In addition, land managers should influence urban planning by incorporating fire safety measures into the design of buildings and infrastructure in fire-prone areas, which may include creating defensible spaces around properties.

- Researchers and scientists should also support the establishment of comprehensive guidelines and protocols for conducting controlled burns and develop relevant curricula for prescribed fire education programs. Finally, they should develop guidelines that outline suitable fire regimes (including interval, frequency, and intensity) tailored to various ecosystems. Local communities should be aware through education of the good role of fire and the use of prescribed burns.

Potential challenges: Encourage a mindset among regional and local communities, as well as firefighters, to adapt to living with fire as a natural element.

Option 6: Promote standardisation for closer to nature systems that increase forest and community resistance and resilience to disturbances such as wildfires
The benefit: Measuring the effectiveness and efficiency of the implementation of CTNFM and IFM approaches in a standardised way will improve the continuous monitoring of health, resistance and resilience of forest ecosystems in the context of environmental, economic and social aspects, thus making improvements where and whenever needed.

Who is expected to contribute?
Policy makers, local communities, forest and land managers, standardisation bodies.

What is the expected contribution?

- Policy makers should enforce or update, if necessary, regulations at EU level (& Member States) for the certification of CTNFM and IFM application and ask pressure for the use of existing standards.

- Forest managers should apply criteria, indicators and metrics to monitor sustainability of their forest based on existing standards, guidelines and directives. They should apply the metrics in relation to the surrounding area and local communities, and do not

handle the forest independently of the needs of the surrounding communities and landscape. Thinking in the long-term is also crucial instead of the short-term.

- Land managers should also plan in the long-term and not in the short-term and in the context of landscape scale, considering the relevant standards.

- Local communities instead of thinking in the short-term, should target on the long-term and consider forests as part of their community while understanding the challenges of functioning the landscape based on rules and requirements.

- Certification and standardisation bodies should simplify the processes for using existing standards and reduce any relevant costs. Also, the need to develop new standards is important towards this pathway.

Potential challenges: Setting "thresholds and ranges" to determine the limits of sustainability means: Different regions with different forest ecosystems and landscape mosaics may need different thresholds and ranges. Long-term measures are needed to establish thresholds and ranges; Multistakeholder engagement can lead to conflict over thresholds and ranges.

As in the past, some ambitious goals will be difficult to achieve without concerted efforts at the level of EU Member States and their communities. The EU will, therefore, have an important role to play in promoting the necessary changes. Perhaps the options suggested in this paper will help to facilitate the much-needed perspective of reorienting sustainable forest and fire management strategies based on projections for an uncertain future due to climate change, rather than on past situations that have contributed to a satisfactory degree but have not prevented adequately from the current extreme wildfire events. The future of managing forests and fires lies in adapting to instability rather than clinging to historical models. It is for this reason that Kurth's (1994) statement that, in spite of an understanding of the past and an awareness of the present, definite knowledge fails, is more relevant than ever.

Ethics and consent

Ethical approval and consent were not required.

Data availability

No data are associated with this article.

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Open Peer Review

Current Peer Review Status: ? ✗ ? ? ? ✗ ?

Version 4

Reviewer Report 12 September 2025

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?

Francisco J Escobedo
Pacific Southwest Research Station, USDA Forest Service, Riverside, California, USA
Carl Norlen
National Land Imaging Program, United States Geological Survey, Reston, Virginia, USA

The manuscript proposes a new framework and a series of options that can be used to implement the concepts of IFM and CNFM for fire management in Europe. Although it does not really delve into different views or opinion it does use the literature to substantiate their framework and options. So it is generally well cited and presents factual information. The figures and option that resulted from their manuscript are informative and should be of interest to readers.

That said the manuscript – as written – is very long and at times is difficult to read since much of the introductory text is much too detailed and not really relevant to their title or problem statement. Although the technical language is adequate, there is just too much technical detail at times focused on species-level fire ecology or presentation of fire ecology and land management concepts that most readers will likely already know. As a result there is a level of exhaustion with so much information.

So as indicated below, we provide specific recommendations that will hopefully help you synthesize information from your manuscript and make your message more effective. In short below we recommend you remove some unnecessary, often repetitive text, develop a succinct general and specific objectives section and present you framework and options information in the form of tables. Below are the specific comments.

Overall Comments

- This is an interesting framework for managing forests in the face of climate change to both reduce wildfire risk and promote forests as Nature Based Climate Solutions (NbCS). For this reader, the manuscript could be improved by removing or condensing some of the background information throughout. There is a lot of great background information, but the main points of the text seem to be lost and much of the background could be summarized and cited in a few sentences. The current text is almost 13,000 words. Other

Open Letters appear to be in the 2,000 to 3,000 word range. As described in the guidelines for authors, “Open letters are short, peer-reviewed articles discussing policies relevant to a broad research community, presenting guidelines or white papers, or announcing new initiatives.” As currently written the text appears to better fit the format for a Review article focused Integrated Fire Management and Closer to Nature Forest Management. Similarly the manuscript states that it is a literature review and then a framework. It should not be both. So, we recommend either revising the text down to about 3,000 words or presenting the article as a review instead of an Open Letter.

Comments by Section

Title

- A more concise title would be helpful. Here’s one possibility but other options could also work, “A Holistic Approach to Forest Resilience to Wildfires Combining Integrated and Closer to Nature Forest Management”

Introduction

- Assuming the authors decide to revise this manuscript to align with the Open Letter format, for this reader it would be helpful to either delete paragraphs 2 – 9 from the Introduction or condense to 1-2 paragraphs to summarize the key points. If it is not relevant or germane to your problem statement or aim of the document, it should not be included. You should only provide the minimum amount of background to justify your problem statement. This is reading like a literature review on European fire ecology and management. But it is not written or prepared as a systematic literature review.
- Second paragraph is too long, divide into 2 paragraphs. The discussion of burned area and number of fires in the second half seems repetitive.
- Page 4, The Section “Fire-adapted species and their role in ecosystem recovery” and “Understanding the key drivers of wildfire dynamics” are unnecessary. The topic is not species specific and should be kept at landscape scales and above. Second, much of this is basic information that readers will likely already know.

Problem statement

- This section is providing the reader the necessary background and justification we are referring to above. Arguably, all text and sections before this are unnecessary and should be mostly deleted.

Scope of this document

- Move the first paragraph in this section to the end and create an Objectives paragraph immediately before the Methods section. This will provide a synthesis to the reader of what you intend to do in your methods and what you will eventually report as findings.
- Move the last paragraph in this section on restoration to your introduction and be sure to include references.

Methodology

- Move the first paragraph to the previous section in the new Objectives paragraph. This is an objectives paragraph- not a method.

Integrated Forest Management Section

- Currently the section on Integrated Forest Management (IFM) appears to provide a global review of literature on the benefits and challenges of implementing this approach. For this reader this level of detail detracts from the main point of the article as stated by the authors to present a novel synthesis of two complementary approaches to forest management for the EU. Similar to the above comment, for this reader it would be helpful to delete paragraphs 3 – 14 or condense them to a total of 1-2 to highlight the key points.

Closer to Nature Forest Management

- Currently the section on Closer to Nature Forest Management provides a description of the principles of this management approach and its potential benefits as for promoting a variety of benefits including climate mitigation as a nature-based climate solutions. For this reader it would be helpful to revise and condense this section by > 50% for clarity so that it provides only the information needed to understand the proposed synthesis of Integrated Forest Management and Closer to Nature Forest Management approaches. Similar to the previous section, one approach to improving the clarity of the section would be to either delete paragraphs 3 – 13 or condense to 1 -2 paragraphs. We suggest synthesizing this information and text in 2-3 tables.

Closer-to-Nature Forest Management and Integrated Fire Management – A framework for combination at spatial and temporal scale Spatial scale

- Currently this section restates some of the material from the previous section and describes the importance of temporal and spatial scale when considering how to combine these two approaches. For this reader it would improve clarity of the text to remove some of the repeated material and focus this section more on the why temporal and spatial scale are important and how that relates to the implementation of these approaches. Similar to the previous section, one approach would be to delete paragraphs 2 – 6 or condense them into 1 paragraph that highlights the essential points and otherwise points the readers to where in the research literature to find more detailed information.
- This section should have the exact same subtitles and sections as the previous IFM section. It should also use tables to synthesize definition and frameworks, and text can be reduced by 50%.
- What does “Nature-Based Forest Management (NBFM)” have to do with Closer-To-Nature forest management. A Figure or Table is needed to ‘link’ all these related concepts together in a succinct manner.

Policy and Management Options

- It is great to the see the specific policy options presented in this section. For this reader it could have been clearer how the policy options compare to each other. For this reader it would be helpful to further refine and condense this section similar to the previous section. One option that would have been helpful for this reader would be to create a table that summarizes the four sections outlined for each of the 6 policy options: The benefit, Who is expected to contribute?, What is the expected contribution?, Potential challenges. With that table created the authors could further condense the descriptions of the six policy options to highlight key differences, similarities and key points with the details displayed in the table.
- Figures 2 and 3 on pages 15-16 are very informative. We suggest replacing ‘Resilience’ in the inner circle with “Social” (where the family icon is), “Economic/Environmental” (where the factory icon is) and “Ecological” (where the forest icon is).
- Are there possibilities to combine or borrow different features from the 6 different options and create a separate new option that is more relevant to your geographic area, management goal, or ecosystem of interest? Also can you suggest to readers in which geographic areas (northern versus southern Europe) or ecosystems (boreal conifer forests versus Mediterranean shrublands) each option is more appropriate or relevant?
- Conclusion
    - A short conclusion is needed that synthesizes the main findings and how this framework and options can be used by policy makers, researchers and practitioners across Europe and elsewhere.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)
No

Does the article adequately reference differing views and opinions?
Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Yes

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
No

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Fire ecology, Ecology, Fire management, Landscape ecology, Remote sensing, Wildland-Urban Interface, Fire effects, Forest policy

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Version 3

Reviewer Report 28 May 2025

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Victoria M. Donovan
University of Florida, Gainesville, Florida, USA
Noah Weidig

School of Forest, Fisheries, and Geomatics Science, University of Florida (Ringgold ID: 3463), Gainesville, Florida, USA

This Open Letter by Kalapodis and Sakkas presents a framework for enhancing the resilience of forests against the increasing wildfire issue in Europe by integrating Integrated Fire Management (IFM) and Closer-to-Nature Forest Management (CTNFM). The authors cover a wide array of topics concerning fire suppression, fuel management, wildfire preparedness, and forest resilience. While addressing the recent rise in both the frequency and intensity of wildfires in Europe is relevant, it is unclear whether this paper makes a significant contribution to this effort. A primary concern is that much of the language throughout the letter is unclear and requires numerous changes to improve the flow and readability of the manuscript. Additionally, this manuscript is rather long and winding making it difficult to follow. A key missing piece upon reading the paper is why the authors specifically choose to focus on these two approaches and why do they argue they need to be integrated? It is difficult to assess the validity for the paper since it is unclear what the justification is for the integration of the approaches. Overall, the current version requires substantial revision to clarify their arguments, reduce repetitive language, and improve of the general flow of the manuscript.

Major Comments

1. Much of the introduction could be shortened and summarized more concisely so that the problem being addressed by the manuscript becomes clear far earlier. For example, the section “Managing wildfire dynamics and burn severity” within the introduction could be entirely removed. Other subsections could be shortened to a few sentences.
2. As other reviewers note, the authors need to focus more specifically on why they chose to focus their efforts on these two management approaches and why these approaches need to be integrated. What holes exist in each approach that the other fills? In addition to reorganization and clarifying the text, a summary table perhaps could be useful for the authors to highlight these points?
3. The manuscript’s use of terminology is confusing and inconsistent. A few examples are provided below.

Minor Comments:

- General: “Controlled burning” and “prescribed burning” are used interchangeably throughout the manuscript. Please change all instances to one or the other for consistency.
- Page 3: The phrase, “but the most interesting is the fact that”, is unclear in “The Mediterranean region is expected…”
- Page 4: The use of “spontaneous” seems out of place in “The interactions of climate change with unmanaged spontaneous vegetation cover and fire regimes shift should be understood and appropriately considered in fire management.”
- Page 4: The sentence “Before continuing it seems to be appropriate to come into a deeper understanding of the complexities of wildfire dynamics at hand” is rather convoluted.
- Page 4: The section “Managing wildfire dynamics and burn severity” switches between discussing fire spread and burn severity, which are two very different things. While fire spread can affect burn severity, it is unclear what this section adds to the manuscript.
- Page 5: The first paragraph of the “Problem statement of this document” section is almost identical to the abstract, with large portions taken verbatim. Please change your language to specifically identify the problem this Open Letter seeks to address without repetition.
- Page 8: The opening sentence of the section “IFM benefits, limitations and challenges” contains incorrect grammar: “IFM is positioned as a complete and multifaceted strategy that

provides a framework for operational and planning processes *designed and aims* to balance the risks associated with wildfires while maximizing their ecological benefits."
- Page 8: The sentence "Among the various success stories of using prescribed burning for fuel management..." is a run-on sentence and needs to be split into multiple sentences. The next sentence is an almost exact repeat of this sentence as well. Please remove one of them and split the other into two or more sentences.
- Page 14: Within the "Temporal scale" section, the same idea is repeated almost verbatim in the first and second paragraphs: "As far as it concerns the temporal scale, it is already obvious that climate change is or will significantly impact vegetation distribution and ecological dynamics due to changes in temperature (rising temperatures contribute to more frequent droughts) and precipitation patterns..." and "Over time, it is becoming clear that climate change is or will significantly affect vegetation distributions and ecological processes through changes in temperature (with rising temperatures leading to more frequent droughts) and changes in precipitation patterns."
- Page 16: The text in Figure 3 is quite busy. I would suggest removing unnecessary text and increasing the text size to improve its readability. That said, it the figure necessary given the text and Figure 2?

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)
Partly

Does the article adequately reference differing views and opinions?
Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
No

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Fire Ecology, Landscape Ecology, North America wildfire regime dynamics

We confirm that we have read this submission and believe that we have an appropriate level of expertise to state that we do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 28 May 2025

Georgios Sakkas

We thank you for reviewing our Open Letter and for your comments. Nevertheless, we have already uploaded an updated version (V4) on the 19th May 2025, as can be seen from the Open Peer Review process. We would also like to provide you with some answers to your comments. Answers to Major comments: Much of the introduction could be shortened and summarized more concisely so that the problem being addressed by the manuscript becomes clear far earlier. For example, the section "Managing wildfire dynamics and burn severity" within the introduction could be entirely removed. Other subsections could be shortened to a few sentences. ***In Version 4 some changes have been made to the title of the paragraph. Also, we want to clarify that specifically this analysis on fire spread has been asked by the 1st reviewer in his 1st review.*** As other reviewers note, the authors need to focus more specifically on why they chose to focus their efforts on these two management approaches and why these approaches need to be integrated. What holes exist in each approach that the other fills? In addition to reorganization and clarifying the text, a summary table perhaps could be useful for the authors to highlight these points? ***"One-size-fits-all" solution cannot be applied in Europe regarding the recent climate crisis, land use changes and extreme wildfire events challenges. This is something that is clearly mentioned in the Open Letter. In order to invest in IFM maximizing its ecological benefits, and the cases that this approach is not applicable, the implementation of CTNFM as a nature-based solution is recommended, as well as the combination of the two approaches, wherever is needed and appropriate.*** The manuscript's use of terminology is confusing and inconsistent. A few examples are provided below. ***This is answered below.*** Answers to Minor comments:

- General: "Controlled burning" and "prescribed burning" are used interchangeably throughout the manuscript. Please change all instances to one or the other for consistency.

Controlled burning is being mentioned only 4 times in the text, while prescribed burning is being mentioned 53 times. Two times is being mentioned for fire tactics, close to figure 3, in the other two it refers more to prescribed burning. We are eager to make this change, and in general check it once again (the prescribed burning term as well), when the review of version 4 is finalized.

- Page 3: The phrase, "but the most interesting is the fact that", is unclear in "The Mediterranean region is expected…"

In Version 4, the above phrase does not exist.

- Page 4: The use of "spontaneous" seems out of place in "The interactions of climate change with unmanaged spontaneous vegetation cover and fire regimes shift should be understood and appropriately considered in fire management."

In Version 4, the use of spontaneous does not exist.

- Page 4: The sentence "Before continuing it seems to be appropriate to come into a deeper understanding of the complexities of wildfire dynamics at hand" is rather convoluted.

Why?

- Page 4: The section "Managing wildfire dynamics and burn severity" switches between discussing fire spread and burn severity, which are two very different things. While fire spread can affect burn severity, it is unclear what this section adds to the

manuscript.

We understand why you suggest deleting this but it has been added, because the first reviewer in his first report has suggested to describe the terms of burn severity and fire spread so that people that are not aware of this, to understand it.

- Page 5: The first paragraph of the "Problem statement of this document" section is almost identical to the abstract, with large portions taken verbatim. Please change your language to specifically identify the problem this Open Letter seeks to address without repetition.

Why is this a problem, even a minor one? The problem statement is the core of the open letter.

- Page 8: The opening sentence of the section "IFM benefits, limitations and challenges" contains incorrect grammar: "IFM is positioned as a complete and multifaceted strategy that provides a framework for operational and planning processes *designed and aims* to balance the risks associated with wildfires while maximizing their ecological benefits."

Please review Version 4, not version 3. A slight revision of the syntax has already been made.

- Page 8: The sentence "Among the various success stories of using prescribed burning for fuel management…" is a run-on sentence and needs to be split into multiple sentences. The next sentence is an almost exact repeat of this sentence as well. Please remove one of them and split the other into two or more sentences.

We would like to improve this paragraph after the review of Version 4 is completed, if needed.

- Page 14: Within the "Temporal scale" section, the same idea is repeated almost verbatim in the first and second paragraphs: "As far as it concerns the temporal scale, it is already obvious that climate change is or will significantly impact vegetation distribution and ecological dynamics due to changes in temperature (rising temperatures contribute to more frequent droughts) and precipitation patterns…" and "Over time, it is becoming clear that climate change is or will significantly affect vegetation distributions and ecological processes through changes in temperature (with rising temperatures leading to more frequent droughts) and changes in precipitation patterns."

In Version 4 this has been corrected.

- Page 16: The text in Figure 3 is quite busy. I would suggest removing unnecessary text and increasing the text size to improve its readability. That said, it the figure necessary given the text and Figure 2?

This Figure has been added to clarify a comment made by reviewer No 3. The figure can be enlarged in the online version. Thus, we prefer to keep it "as is".

Competing Interests: No competing interests were disclosed.

Reviewer Report 15 May 2025

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?

Tessa Maurer
Drought, Fondazione CIMA, Savona, Liguria, Italy

This open letter describes two frameworks relevant for wildfire management in Europe, the Integrated Fire Management (IFM) framework and the Closer-to-Nature Forest Management framework (CTNFM), arguing that combining the two would strengthen the continent's response to and management of wildfires.

While I am sympathetic to the argument the authors are trying to make and also acknowledge that considerable works seems to have gone into this article since its original submission, I share many of the same reservations as the other reviewers regarding the thoroughness of the argument and the organization of the letter as it stands. I shall try to offer some actionable changes that would help the authors strengthen the piece.

Major comments

1. *Argument for integration*: I echo other reviewers in feeling that this is still lacking. Currently, the sections on spatial and temporal integration of IFM and CTNFM seem to more list case studies and literature than to argue for *why* integrate. (The policy section then seems to jump straight to *how* they could be merged.) Moreover, the two sections dedicated to explaining IFM and CTNFM respectively seem to be a combination of factual reporting (what the frameworks entail and how they have been used) and opinions from the authors (e.g. last two paragraphs of the "IFM integration into the legal framework…" section). I think 1) having clearly different sections for explanation of the frameworks versus the authors' thoughts on them, akin to Results and Discussion in a research paper and 2) overhauling the spatial/temporal scale sections would both help with the organization of the piece as well as provide this critical missing part of the authors' argument. Specifically, I would ask: what do each of these frameworks bring that the other is lacking? Are they compatible in all ecosystems and across all levels of governance/decision-making? Are there any ways in which they are not compatible? What is currently the first paragraph of the "Policy and management options" section and the paragraph on page 13 beginning "CTNFM and IFM are two ecologically driven…" are both nicely written and move in the direction of what I am proposing.

Relatedly, embedded throughout this piece and something that I think should be addressed directly in a discussion on integration of the frameworks is the tension between top-down standardization (e.g. Policy Option 6) and flexibility to account for local conditions (e.g. Option 1). This is echoed by other reviewers' questions about how to handle situations in which prescribed burns do not align with promoting ecosystem resilience. What parts of these frameworks do the authors feel should be standardized? What should be decided on a project-by-project basis? How could the authors imagine handling the need for standardized metrics with different project and ecosystem resilience goals?

2. *Confusing use of terminology*: the authors seem to treat prescribed burning and IFM as synonymous (e.g. discussion starting on page 8 with "Worldwide…") when in reality, the

framework is considerably broader. In focusing on prescribed burns, the authors fail to address fully how the two frameworks in their entireties could be combined.

Another, perhaps more fundamental problem that this raises is that, at face value, prescribed burns seem incompatible with the hands-off approach that CTNFM (seems to) support. This echoes Reviewer 4's point that interventions to assist landscapes in responding to climate change seem incompatible with frameworks advocating for more "natural" management. I do not (personally) think this tension necessarily causes the frameworks to be odds, and I think addressing it head-on could make for a very interesting and novel argument. At very least, I encourage the authors to clarify what is meant by "natural" (both by them and by the frameworks they cite); does it allow space for human intervention? If so, are there types or intensity of activities that would *not* be considered natural?

On a related, but more minor note, the authors should be careful with the term "wildfire" as well. Since, as acknowledged, low intensity fire can be beneficial in many areas, is wildfire any fire that is damaging or catastrophic? Or any fire that starts or expands beyond the control of humans? Is prescribed fire the only desirable fire for the authors or is it more about the characteristics (e.g. low intensity, regenerative) of the fire that distinguishes good fire from bad?

3. *Clarity and organization*: the writing style at present undermines the authors' main argument. Information is presented in a disjointed and repetitive way, which obfuscates the main points and makes the piece longer than it needs to be. I would encourage a critical examination of the information and citations throughout to determine which should be included and where. *A more specific note on the introduction*: currently, the introduction feels like it is trying to cover all nuances, aspects, and characteristics of wildland fire. I appreciate this may have been a response to previous rounds of review, and much of the information is certainly relevant, it feels disorganized and sometimes repetitive with other parts of the paper. For example, the authors lead with climate change as a main motivator, but then switch to forest composition & management impacts. The connection or overlap of these two effects is unclear, as is the extent to which IFM and CTNFM can mitigate the impacts of each. Perhaps because there is so much detail, I feel the problem statement comes far too late to frame the information for the reader. I would encourage the authors to move the problem statement much earlier (after 2-3 paragraphs of motivation) and then follow up with any critical information for understanding the nature of wildfire and the challenge. I could imagine one section that is Introduction & Problem Statement and followed by Current Challenges in Wildfire Management, though I'm sure there are other ways it could be handled.

Minor comments

1. The text could use a thorough copy edit to help address places where the phrasing or wording feels unnatural and confusing. Some examples (not comprehensive):
    1. In the abstract, "in light of a bottom-up approach" seems like it should be "following a bottom-up approach" or similar. "In light of" presupposes that action, but I think the authors here are intending to advocate for a bottom-up approach.
    2. On page 5, the two sentences from "Over the years…resulting in predominantly mixed compositions and a variety for benefits" are confusing. It seems they should talk about contrasting geographic areas, but both talk about regions "outside of" or "in addition to" central and northern Europe
    3. There are a couple spots where sentences are incomplete (e.g. top of page 10, "The

restrictions in current legislation...").

2. The paragraph beginning "Among the various success stories..." in section "IFM benefits, limitations and challenges" is repeated immediately below.
3. In the first sentence of the Methodology section, the authors use the term "climate change-induced wildfires". This feels potentially dangerous to me in the sense that it is hard for any single event to be directly and entirely attributed to climate change and also seems to undermine the work the authors have done to argue that land management practices are relevant to the behavior and management of these fires. I would consider softening the language (e.g. "wildfires in the era of climate change").
4. On page 7, in the paragraph that starts "Fire management has historically focused on the suppression...", I caution that as currently worded, it sounds like fire suppression efforts have been performed with the protection of traditional and Indigenous cultures (among other things) in mind. Perhaps this is true in parts of Europe, but several of the citations are globally focused publications (Myers, 2006; Rego, et al., 2021; multiple of the FAO reports cited) and it is certainly not true everywhere – quite the opposite. In the Western U.S., for example, fire suppression was also a tool of cultural oppression against Indigenous peoples. I encourage the authors to either change the wording and/or specify where it applies.
5. Another copyediting note is related to abbreviations: the authors should take care that they always use the full name the first time (e.g. EFFIS in the first paragraph of the introduction and DG on page 6) and should be consistent about the use of abbreviations ("prescribed burn," for example, is used many times before being abbreviated for the first time on page 15; I would suggest either using the abbreviation throughout or not at all).

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

Yes

Does the article adequately reference differing views and opinions?

Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?

Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)

Partly

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: I am a hydrologist by training with a current focus on landscape ecology, primarily to understand the ecosystem service impacts of forest management in fire-prone forested regions of the Western U.S. I have a second appointment as a researcher on drought exposure and impacts at a European institution (CIMA Research Foundation in Savona, Italy), so I have a reasonable but not in-depth understanding of fire ecology of Mediterranean ecosystems and the European policy landscape.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 03 April 2025

https://doi.org/10.21956/openreseurope.21420.r52182

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?

Kyra Clark-Wolf
University of Colorado Boulder (Ringgold ID: 1877), Boulder, Colorado, USA

This paper provides a detailed review of two management frameworks, Integrated Fire Management (IFM) and Closer to Nature Forest Management (CTNFM), and discusses how they could be integrated to improve ecosystem resilience in Europe. The authors review relevant literature and present a comprehensive set of policy options that would advance the implementation of these frameworks. While the paper makes a strong case for the compatibility of these two frameworks and the benefits they can provide, I have several questions and suggestions for improvement.

One of my main reservations about the paper concerns the policy and management options described in the last section. It is unclear if these options are entirely new ideas being proposed by the authors, or to what extent they are supported in the literature. The links between these options and the research reviewed in earlier sections of the paper should be strengthened. Additionally, these management options are more strongly-stated than I would typically expect in a scholarly article. They sound very much like policy recommendations, which I am not sure belong in a scientific publication.

Secondly, while the paper includes a strong discussion of spatial scale and landscape planning, how the proposed framework deals with temporal scale was less clear to me. My understanding of the section on temporal scale is that it focuses on future impacts of climate change. While climate change is an important issue, I suggest that “temporal scale” may not be the best way to describe it; or, rather, if the emphasis is on long-term planning to address impacts of ongoing and future climate change, that point could be made more clearly. More importantly, there is a potential contradiction between the proposed framework – focused on restoring “natural” states and processes – and adapting to climate change, which requires managing for change rather than

stationarity. This challenge of climate change adaptation in forest and fire management may warrant a more careful discussion in the paper.

Additionally, the paper could benefit from greater attention to variation among ecosystem types and fire regimes. Although the authors note the importance of local considerations, particularly in reference to silvicultural systems, they provide few examples to discuss how applications of IMF or CTNFM might be adapted in different ecosystems that have distinct vegetation types and structure, in which fire may play a range of ecological roles. Additionally, the paper draws on examples and research from around the globe and in particular the western U.S., and while this wealth of knowledge of fire ecology and management is certainly relevant, it would help to discuss more explicitly how general insights from global ecosystems translate to European forests.

Lastly, although the paper was submitted as an Open Letter, it is not as concise as would be expected for a letter. I encourage the authors to consider ways to present their ideas more succinctly.
In my detailed comments below, I highlight a few places where text revisions could improve accessibility and clarity:

- The Introduction is one place where length could be reduced. I suggest that the broad review of fire ecology concepts in the Introduction, while comprehensive, is perhaps unnecessary in a scholarly publication; moreover, not all statements about disturbance processes are fully generalizable (i.e., without reference to specific ecosystem types or fire regimes). The article would be much improved by condensing this introductory material and framing it more carefully to support the problem statement; or, simply starting with the problem statement.
- Suggest revising non-scientific language (e.g., “seem to be more dramatic than ever”, “even more interesting” on page 3; “promoting good, punishing bad” on page 17). The author guidelines are for Open Letters to be “*presented as a scholarly communication*”.
- Please check to ensure all statements are properly cited (e.g., Page 3-4: “This trend has led to increased fuel accumulation and structural changes in fuel complexes, increasing the risk of wildfires”).
- Under the Problem Statement (Page 5), I did not understand the phrase “fire becomes a clandestine tool in rural activities”; consider rephrasing and adding a citation.
- Figure 1: I find the bullets under “Existing Situation” somewhat confusing; are those referring to broad concepts reviewed in the paper, or particular issues relevant to the IFM and CTNFM frameworks? Some bullets are very general (e.g., wildfire dynamics), while others are more specific. Additionally, the meaning of the second bullet is unclear. Consider reframing.
- Last full paragraph on page 8: This sentence is repeated in the following paragraph, and the phrasing is very difficult to follow.
- Page 9: I am not sure what “narrow fire regimes” means.
- Page 14: The first two paragraphs under “Temporal scale” read very similarly. Consider cutting the first.
- Page 15: Barriers to implementing prescribed burning were already discussed in an earlier section. What is the relevance here?
- Figure 3: Is this needed? What is being communicated in the figure is well described in the text and Figure 2.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether

existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)
Yes

Does the article adequately reference differing views and opinions?
Yes

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
Partly

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My expertise is in fire and forest ecology, with a geographical focus in western North America. I am not familiar enough with the EU's policy landscape to fully evaluate the merit of the proposed policy options in the final section of the paper.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 05 May 2025

Georgios Sakkas

We would like to thank all of the reviewers for their thoughtful and constructive comments. In this version (V4) of the document, we have made significant efforts to address all of the feedback provided by the reviewers. We streamlined the text, corrected grammatical and syntactical errors, and updated Figure 1 based on insights from Reviewers 1 and 4.
While we have done our best to respond to each comment, we recognize that it is not always possible to fully meet every request given the interdisciplinary nature of the feedback. Additionally, while we highly value the reviewers' expertise and insights, it is important to note that this is an open letter and not a course textbook.
Therefore, some comments relating to areas outside the scope of this study have not been integrated into the text.
We trust that the revisions are in line with the paper's objectives and intended audience.

Competing Interests: No competing interests were disclosed.

Reviewer Report 10 March 2025

https://doi.org/10.21956/openreseurope.21420.r51860

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?

Juergen Bauhus
Department of Environment and Natural Resources, University of Freiburg, Freiburg, Germany

The present manuscript has improved considerably when compared to the previous version. However, the authors do still not succeed in developing a convincing narrative why and how the two concepts dealt with here, IFM and CTNFM, should be integrated. The authors offer somewhat improved descriptions of the two concepts, but it is still not clear what the real novel contribution is. Regarding the integration of the two concepts, the authors dwell largely on the principles of the concepts (still with much repetition) and what can potentially or hopefully achieved with them, but the proposed integration consists largely of wishful thinking (along the lines of policy documents). I still miss a scientifically critical evaluation of the consequences of integrating the concepts for different types of forests in Europe: where would it be possible and where not, and how would the approaches need to be modified or adopted to fit different contexts. One does get the impression that the main measure of IFM is prescribed burning. Yet, if that is not possible or sensible in forests composed of fire sensitive species (such as most broadleaf and mixed forests of temperate Europe) what should be done in these cases. Or how should natural regeneration work in forests that are repeatedly treated with prescribed burning. All these quite essential questions are not being addressed. The only problem that is being addressed is that of fuel ladders in vertically structured forests, but there would be many more, e.g. how to maintain a deadwood resource and protect large old trees in repeatedly burned forests, etc. Here the problem may be that the authors stick to closely to the literature, where these questions may be neither asked nor studied. To identify these critical questions, it would need a proper analytical framework, which I cannot see. I also miss a critical distance of the researchers to their study. One does not get the impression that they would be equally willing to disprove the possible integration of these two concepts than to approve it. Therefore, many sections give the impression of wishful thinking, without in-depth assessment of uncertainties and impediments.

In addition to the shortcomings of the analytical approach, the readability of the text could still be greatly improved. There is much repetition in many sections. There are also many text sections that do not fit under the headers chosen. In that regard, the text would benefit from thorough editing, which one would have expected in the third version of the manuscript. I have made many more specific comments in a PDF file of the text, which may help the authors to revise it further. https://s3-eu-west-1.amazonaws.com/openreseurope/linked/248108.Article_ID_17802__response_by_J%C3%BCrgen_Bauhus_v3.pd

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Forest Ecology, Silviculture and Forest Adaptation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 05 May 2025

Georgios Sakkas

We would like to thank all of the reviewers for their thoughtful and constructive comments. In this version (V4) of the document, we have made significant efforts to address all of the feedback provided by the reviewers. We streamlined the text, corrected grammatical and syntactical errors, and updated Figure 1 based on insights from Reviewers 1 and 4. While we have done our best to respond to each comment, we recognize that it is not always possible to fully meet every request given the interdisciplinary nature of the feedback. Additionally, while we highly value the reviewers' expertise and insights, it is important to note that this is an open letter and not a course textbook. Therefore, some comments relating to areas outside the scope of this study have not been integrated into the text. We trust that the revisions are in line with the paper's objectives and intended audience.

Competing Interests: No competing interests were disclosed.

Version 2

Reviewer Report 19 February 2025

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?

Kushartati Budiningsih
National Research and Innovation Agency (BRIN), Jakarta, Indonesia

This paper attempts to explore an integrating Integrated Fire Management (IFM) and Close-to-Nature Forest Management (CTNFM) in addressing forest fires, which are expected to pose significant challenges for Europe in the coming years, particularly during prolonged drought seasons.

The discussion stems from the gap in the absence of a standardized framework for managing

wildfire risks, despite the existence of numerous conceptual approaches to wildfire risk management and various terminologies related to Sustainable Forest Management (SFM).

For an open letter, this topic is highly relevant; however, several aspects require further strengthening:

Introduction: This section should be added by an explanation of IFM and CTNFM that have been implemented in some countries and the weaknesses of those, to make a clear problem framing that justifies why these approaches are needed to be integrated as alternatives to current policies.

Result. The integration of IFM and CTNFM practices proposed by the author is structured within the framework of the disaster management cycle. Furthermore, further justification is needed to explain the underlying principles for positioning each option within specific stages of the disaster management cycle, such as landscape mosaic ecological planning, which is categorized under the suppression stage.

Regarding the recommendations, they should be made more specific within the EU context, clearly identifying the key actors responsible for each aspect (proposed actions). This clarification would enhance the applicability of the recommendations and ensure their feasibility for implementation.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)
Partly

Does the article adequately reference differing views and opinions?
Partly

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
Yes

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
No

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 25 Feb 2025

Georgios Sakkas

We would like to thank you for the constructive comments which have been considered and answered.

More specifically:
Comment: Introduction: This section should be added by an explanation of IFM and CTNFM that have been implemented in several countries and the weaknesses of those, to make a clear problem framing that justifies why these approaches are needed to be combined as alternatives to current policies.

Answer: Regarding this comment, the section has been updated following your recommendation in the following way: The introductory section has been improved by the addition of a new sub-section entitled 'Problem Statement', which focuses on the considerable variability in policies and regulatory frameworks for fire management and use, and the lack of a common approach to more holistic fire management. In addition, the introduction highlights the increasing complexity of wildfire risks, driven by human-induced climate change, abandonment of traditional land uses and unsustainable forest and fire management practices, to underline the need for a normative framework that can update, harmonise and integrate the disparate policies and legislation currently in place. In addition, the introductory section elaborated on the management of fire use in forested and open landscapes and the historically strict regulatory policies aimed at minimising the threat of wildfires, which are often exacerbated by careless or deliberate ignition. The scope of the document has been expanded to include explanations of the specifics of IFM and CTNFM approaches, the ways in which both are recognised, and the efforts of EU Member States at the local level to implement both approaches. It also includes a summary of some notable examples from Europe. Furthermore, we have expanded upon the utilisation of IFM in Europe and globally (sections IFM and IFM benefits), in addition to augmenting the CTNFM section with insights on forest management (section CTNFM benefits).

Comment: Result. The integration of IFM and CTNFM practices proposed by the author is structured within the framework of the disaster management cycle. Furthermore, further justification is needed to explain the underlying principles for positioning each option within specific stages of the disaster management cycle, such as landscape mosaic ecological planning, which is categorized under the suppression stage.

Answer: Thank you for this comment. Figure 2 was built in a way that the options can show that are related to all disaster management phases. The position of the options does not coincide with the position of the arrow depicting the phases. For this reason, and to make this clear, we updated the caption of Figure 2. Following this, a new figure (Figure 3) has been incorporated into the document, with the purpose of correlating the various options with the disaster management phases. In addition, In the policy options section, the starting discussion has been extended and the description of the options has also been updated.

Comment: Regarding the recommendations, they should be made more specific within the EU context, clearly identifying the key actors responsible for each aspect (proposed actions). This clarification would enhance the applicability of the recommendations and ensure their feasibility for implementation.

Answer: We changed the structure of the description of each option, and now clarity has been significantly improved, on the suggested actions and relevant key stakeholders.

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 12 September 2024

https://doi.org/10.21956/openreseurope.19245.r43489

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Toddi Steelman
Nicholas School of the Environment, Duke University, Durham, North Carolina, USA

Review of Integrated Fire Management and Closer to Nature Forest Management at the Landscape Scale

The open letter titled "Integrated Fire Management and Closer to Nature Forest Management at the Landscape Scale as a Holistic Approach to Foster Forest Resilience to Wildfires" explores two key approaches to increasing forest resilience to wildfires: Integrated Fire Management (IFM) and Closer-to-Nature Forest Management (CTNFM). It emphasizes the need for global action, political commitment, and public awareness to address the challenges posed by wildfires, such as forest degradation and biodiversity loss. The article highlights strategies including promoting natural forest regeneration, enhancing biodiversity, and implementing landscape-scale approaches to sustainable forest management. Recommendations for policymakers include collaboration, enforcement, ecological stewardship, public education, and international cooperation to achieve long-term forest sustainability and resilience.

It is unclear who the policy audience is for this article? Clarifying the audience would be useful.

The article is overly generic to be helpful and fails to identify what is new or original about this contribution. A much stronger problem framing, including why IFM and CTNFM are needed as alternatives to status quo policies would strengthen the letter. Additionally, while the letter recommends implementation at the landscape scale, it is unclear how this is an original contribution to the field or how this would actually take place in the EU (the presumed audience).

Much has been written about IFM and that literature is not acknowledged or built upon in the letter. The discussion of the IFM needs to be embedded in the extant literature on the topic. For instance, how do the insights presented by the authors differ from those by Silva et al. (2010), Rego et al. (2010; 2021), Wollstein et al. (2022) or Erdozain et al. (2024)? What is the contribution or insight the authors of this letter bring that hasn't already been made?

Likewise, while the authors invoke Larsen et al (2022) and Bauhus et al (2013), it is a repeat of what has already been established. It is unclear what is new. CTNFM has been around for nearly two decades. What is original about invoking it now in this context? The authors should make their contribution clear.

Integrated Fire Management (IFM) is a comprehensive approach to fire management that encompasses prevention, preparedness, suppression, and recovery strategies. It involves understanding the ecological, social, economic, and cultural aspects of fire management to create resilient and sustainable landscapes. IFM integrates traditional fire management practices with modern techniques, emphasizing the role of fire as a natural ecological process. It includes measures like fuel management, early warning systems, community engagement, and post-fire restoration to reduce wildfire risks and enhance ecosystem resilience.

Closer to Nature Forest Management (CTNFM) is a sustainable approach to forest management that mimics natural processes to maintain or enhance the ecological integrity of forest ecosystems. It focuses on maintaining diverse forest structures, promoting natural regeneration, and allowing natural processes to unfold. CTNFM aims to create resilient forests capable of withstanding disturbances, including wildfires, while providing multiple ecosystem services such as biodiversity conservation, carbon sequestration, and sustainable timber production. This approach emphasizes minimal human intervention and respects natural site conditions.

A contribution to the literature would be to more clearly describe how these two concepts fit together. How would CTNFM improve IFM? But this would need to be much more specifically laid out to be an actual contribution to the literature.

- What is the current problem? Why are current alternatives not working and why are IFM and CTNFM needed to improve the situation? What is original about bringing these two concepts together?
- What is the goal?
- Why is this goal important and a contribution to the field, as demonstrated and supported in the literature?
- What are the trends and conditions that currently keep these concepts (and the goal) from being implemented? There is empirical literature on this that should be consulted for each concept and the lessons learned distilled to inform why and how these approaches could move forward. A very crisp delineation of the obstacles and opportunities for implementing this approach is needed and could be an original contribution, but it needs to be grounded in the extant knowledge on the topic.
- What are the final recommendations that could be made at a much more specific level to advance these concepts and who should be implementing these measures in what specific decision arenas and processes to make progress?

If the authors were to go this direction, the re-write would need to pay much better attention to the narrative flow. The letter is very list-y and reads more like an outline of a paper rather than an

actual integrated narrative. The narrative is overly repetitive in places and could be tightened up considerably. The authors are not clear on their main points and the paragraphs are not well defined, as is currently written.
Erdozain, M., Cardil, A., & de-Miguel, S. (2024) [Ref-1].

Rego, F., et al.,(2010) [Ref-2].

Rego, F. C., et al., (2021) [Ref-3].

Silva, J.S. et al., 2010. [Ref-4].

Wollstein, K., et al., (2022). [Ref-5].

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4. Silva, Joaquim and Rego, Francisco and Fernandes, Paulo and Rigolot, Eric: Towards Integrated Fire Management: Outcomes of the European Project Fire Paradox. *Finland: European Forest Institute*. 2010.
5. Wollstein K, Creutzburg M, Dunn C, Johnson D, et al.: Toward integrated fire management to promote ecosystem resilience. *Rangelands*. 2022; **44** (3): 227-234 Publisher Full Text

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)

No

Does the article adequately reference differing views and opinions?

No

Are all factual statements correct, and are statements and arguments made adequately supported by citations?

Partly

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)

No

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental and natural resource policy and governance, wildland fire policy

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 17 Dec 2024

Georgios Sakkas

The authors would like to express their gratitude to the reviewers for their constructive comments and suggestions on the scientific aspects of the document which led to its current improved version.

The second version is a fully revised version that reflects the comments and suggestions made in the first version of the paper.

A methodology section has been added. The Section of “Integrated Fire Management” has been improved as advantages and disadvantages and legal framework in the EU Member states and the EU subsidiarity principle have been added.

Also, the section “Closer-to-Nature-Forest Management” section has also been enhanced by adding a sub-section on limitations, benefits and challenges.

Finally, the section “Importance of landscape scale approach” has been renamed to “Closer-to-Nature Forest Management and Integrated Fire Management – A framework for combination at spatial and temporal scale” as the implementation of the two approaches at spatial and temporal scale is discussed.

The “Recommendations” section has been renamed to “Policy and Management Options” and its internal structure has changed providing now, the option as well as specific provision of benefits, actions to implement the suggestion and potential challenges. We believe that the options suggested are clear in this version (audience and wording).

“Discussion” and “Conclusion” sections of the first version have been deleted as these have been incorporated in the other chapters of the document.

Also, literature review has been significantly expanded. Some of the comments inside the document have also been answered, whereas other have been deleted, as the text has been revised thoroughly.

Competing Interests: No competing interests were disclosed.

Reviewer Report 06 September 2024

https://doi.org/10.21956/openreseurope.19245.r41778

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Juergen Bauhus
Department of Environment and Natural Resources, University of Freiburg, Freiburg, Germany

The main message of this manuscript is that merging of two important management concepts, integrated fire management and closer to nature forest management, would generate considerable benefits regarding the resilience of European forest ecosystems and their provision of ecosystem services. There is documented evidence for the benefits of each of these approaches, however, there is practically no evidence for the benefits of a combined to approach. This has to do with the fact that most experiences with close to nature forest management in Europe stem from central and Eastern Europe, where fires have so far not been an important factor in shaping forest ecosystems. In contrast, most experiences with integrated fire management exist in Mediterranean and Nordic countries, where fires do or can have a large influence on forest systems. Yet in these regions, there has been little practice of closer to nature forest management. Thus, the authors of this paper derive their recommendations largely from a theoretical basis (which is partly not relevant, i.e. indigenous fire management). From a scientific perspective, it is somewhat irritating and also naïve that the authors focus only on the potential benefits of combining these two approaches for the management of European forests. Potentially negative effects, which could have also severe repercussions, are not being discussed. Likewise, the obstacles and impediments to combine these approaches are not being mentioned or discussed. Instead, the authors list with much repetition the often proclaimed benefits of these approaches in a rather uncritical way. The authors seem to ignore, that we do not have a shortage of good ideas, but a shortage of successful implementation of these. I agree with the authors, that the scale at which the two concepts may be interlinked is the landscape. Yet, the authors seem to ignore the realities of European forest dominated landscapes, where we do have a patchwork of ownerships with many landscapes that are dominated by small land/forest owners. The greatest obstacle to a landscape approach to fire and forest management is therefore a working mechanism of coordination between all the different landowners with their different objectives. This lack of landscape coordination, would likely be one of the largest obstacles to be faced for the approach that is advocated in this paper. However, I cannot see any proposed solutions here.
The paper would also benefit from a clear understanding of policy recommendations. Policy has largely only three types of approaches to direct natural resource management: regulative law, incentives, and informational approaches. These three different types of policy interventions to promote the application of IFM and CTNFM (or there combination) could be addressed in a much more structured way. Instead, many of the recommendations proposed by the authors, do actually not qualify as recommendations to policymakers, they are recommendations for managers. It would therefore be helpful to rethink what kind of policy interventions could facilitate the kind of management that is being proposed. In this context, it would also be helpful to think about the level of government for which the policy recommendations are formulated: EU, national, regional, or local.

The readability of this paper suffers from a lack of structure, much repetition, and unnecessary length. The text in some sections is written similarly to that typically generated by simple use of large-language models in terms of the structure of text, the shallow depiction of content, as well as irrelevant content. I therefore suggest a complete revision of this paper and I have made many detailed suggestions on the digital copy of the manuscript https://s3-eu-west-1.amazonaws.com/openreseurope/linked/235734.17802-Reviewer-Juergen_Bauhus-Comment_file.pdf.

Is the rationale for the Open Letter provided in sufficient detail? (Please consider whether existing challenges in the field are outlined clearly and whether the purpose of the letter is explained)
Yes

Does the article adequately reference differing views and opinions?
No

Are all factual statements correct, and are statements and arguments made adequately supported by citations?
No

Is the Open Letter written in accessible language? (Please consider whether all subject-specific terms, concepts and abbreviations are explained)
Partly

Where applicable, are recommendations and next steps explained clearly for others to follow? (Please consider whether others in the research community would be able to implement guidelines or recommendations and/or constructively engage in the debate)
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Forest Ecology, Forest Management, Silviculture, Forest Adaptation to Global Change

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 17 Dec 2024

Georgios Sakkas

The authors would like to express their gratitude to the reviewers for their constructive comments and suggestions on the scientific aspects of the document which led to its current improved version.

The second version is a fully revised version that reflects the comments and suggestions made in the first version of the paper.

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Also, the section “Closer-to-Nature-Forest Management” section has also been enhanced by adding a sub-section on limitations, benefits and challenges.

Finally, the section “Importance of landscape scale approach” has been renamed to “Closer-to-Nature Forest Management and Integrated Fire Management – A framework for combination at spatial and temporal scale” as the implementation of the two approaches at spatial and temporal scale is discussed.

The “Recommendations” section has been renamed to “Policy and Management Options” and its internal structure has changed providing now, the option as well as specific provision of benefits, actions to implement the suggestion and potential challenges. We believe that the options suggested are clear in this version (audience and wording).

“Discussion” and “Conclusion” sections of the first version have been deleted as these have been incorporated in the other chapters of the document.

Also, literature review has been significantly expanded. Some of the comments inside the document have also been answered, whereas other have been deleted, as the text has been revised thoroughly.

Competing Interests: No competing interests were disclosed.