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Towards a systemic approach to fire risk management

Valentina Bacciu [a,b,*], Costantino Sirca [a,c], Donatella Spano [a,c]

[a] Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, IAFES Division, Via De Nicola, 9, 07100 Sassari, Italy
[b] National Research Council, Institute of BioEconomy (CNR-IBE), Traversa La Crucca 3, 07100, Sassari, Italy
[c] University of Sassari, Dipartimento di Agraria, Viale Italia 39, 07100 Sassari, Italy

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ABSTRACT

Fire risk management is at a crossroads. The last three fire seasons worldwide, dotted by extreme fire behavior and "megafire" events, highlighted the need for a shifting mentality towards a novel and integrated fire management framework, flexible, adaptive, and responsive to the changing environmental and societal conditions. In this context, the pandemic outbreak added other elements of concern due to its impacts on fire management. The health crisis shined also a spotlight on the government's capacity to manage interconnected risks and anticipatory risk management and the urgent need to change the dominating paradigm in fire policy and management. Based on the review of several proposed approaches framing the impelling fire management perspectives, from the socio-ecological systems to the fire resilience concepts, here we provide a new "systemic fire management framework". The approach integrates the multiple perspectives in fire management (multi-level, multi-actor, cross-sectoral and multi-purpose) in four pillars: (i) disaster risk reduction and climate change adaptation connection; (ii) community engagement support; (iii) adaptive management towards system resilience; (iv) and adaptive governance. The approach aims to contribute to go beyond the short term and sectoral governance toward a more sustainable long term perspective, promoting a multifunctional, fire-resistant, and resilient mosaic landscape based on sustainable development processes.

1. The need for a systemic fire management framework

Fire is a structural and systemic risk in fire-prone ecosystems shaping vegetation traits and landscape dynamics since its occurrence (He et al., 2016; Scott et al., 2014), contributing to the evolution of human societies (Keeley et al., 2012), and providing several types of ecosystem services (Pausas and Keeley, 2009; Driscoll et al., 2010; Moritz et al., 2014a). Simultaneously, wildfires have severe impacts on ecosystem services and trigger significant impacts on human capital, often difficult to quantify or account for (Venn and Calkin, 2011), including air quality, human health (Analitis et al., 2012; Dorman and Ritz, 2014), operational safety (Miranda et al., 2010), global carbon budget, and climate change (Miranda et al., 2014; Randerson et al., 2006; Urbanski et al., 2011). Recent changes recorded in fire regimes at the global level, and the occurrence of some of the most catastrophic fire seasons in terms of impacts on society (e.g., Boer et al., 2020; CalFire, 2020; Couto et al., 2020; Turco et al., 2019), were related to multiple interacting drivers that have undergone significant changes: land use, socio-economic processes, fire and forest management (Chergui et al., 2018; Gómez-González et al., 2019; Moreira et al., 2011; Spies et al., 2018; Syphard et al., 2017). Decades of fire policies excluding fire in fire-frequent forests and rangelands have often contributed to an increase in fuel loading and, consequently, in fire size and severity (Parisien et al., 2020; Spies et al., 2018). The "fire exclusion" strategy required high investments[1] to sustain a very efficient fire-fighting structure, promptly intervening with terrestrial and aerial means on a vast territory (Bovio et al., 2017). Although the high success rate in extinguishing low and medium intensity fires, this approach seems not to be enough when extreme fire weather conditions occur (e.g., Bovio et al., 2017; Rego et al., 2018; Moreira et al., 2020).

Furthermore, future climate, promoting hot and dry conditions (Jia et al., 2019), is expected to play an increasing role in fire regimes, enhancing wildfire risk and severity also in those biomes not naturally prone to burn. According to Jolly et al. (2015), fire weather seasons have already globally lengthened by about 20% between 1979 and 2013, and other regional studies investigated the impact of anthropogenic climate change on fire weather and fire season length (Abatzoglou et al., 2019; Barbero et al., 2020; Krikken et al., 2019; van Oldenborgh et al., 2021;

* Corresponding author at: Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, IAFES Division, Via De Nicola, 9, 07100 Sassari, Italy.
E-mail address: valentina.bacciu@cmcc.it (V. Bacciu).

[1] Balch et al. (2018) estimated US federal fire-fighting expenditure exceeding in 2017 US$ 2.9 billion.

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Williams et al., 2019). However, as also expressed above, climate is one of the drivers of the complex interactions and feedbacks among environmental, ecological, and human factors influencing fire regime and fire impacts (Aldersley et al., 2011). Thus, global change-driven fire regimes risk level also depends on societies' increased vulnerability to fire disturbance and on "how population, technological development, and land management patterns will evolve" (IPCC, 2019).

In this context, the outbreak of the COVID-19 pandemic triggered short and long-lasting impacts and cascading effects on wildfire management (Field and Appel, 2020; Riley, 2020; Rodrigues et al., 2021). In fact, synergistic factors (e.g. high-stress degree, smoke and dust inhalation) can favor the infection during a fire event (e.g., Montrose, 2020; Navarro et al., 2021), thus requiring additional preventive measures to promote effective health behavior (AGIF, 2020; Moore et al., 2020; MPHAT, 2020; Santana et al., 2020; Thompson et al., 2021). In addition, the community of scientists, policy and decision-makers, and practitioners in fire management warned about the disruption of training, pre-season community engagement, fuel management, and other risk reduction activities that could impact not only on fire-fighting crews but also on local communities (Field and Appel, 2020; Stoof et al., 2020). Rodrigues et al. (2021), for example, suggested a possible fire risk amplification due to fuel build-up and lack of forest management, following the reduction of winter-spring 2020 fire activity due to containment pandemic measures.

Although several other risks can interact with wildfires and affect fire management, the administrative and management paralysis and the competition for budgetary resources due to the COVID-19 pandemic are probably comparable only to profound economic crisis impacts (e.g., Gellert, 1998; Salvati and Ranalli, 2015; Sunniva, 2020). If, on the one hand, the last three fire seasons worldwide highlighted the need for a shifting mentality towards implementing a multidisciplinary framework of integrated management, the pandemic (in conjunction with climate changes, depletion of economic resources due to the economic recession, and the need for a new type of human resources organization) outlined an unprecedented scenario in terms of pervasive fragility of the current governance system (Phillips et al., 2020). It served as a wake-up alarm (Flyvbjerg, 2020) on the urgent and no longer postponable need to change the dominating paradigm almost totally based on emergency response. Since pursuing the socio-ecological *status quo* maintenance and the adoption of fire suppression as a unique strategy revealed to be a failure approach, other pathways need to be encouraged and put in place. Systemic issues require systemic answers, such as the use of complex models, multidisciplinary knowledge integration, and, most importantly, awareness of the interdependence of multiple factors.

We feel that it is mandatory and urgent to seize this opportunity to rethink and reshape our pathway toward resilience through planning and preparing ourselves and our territories to avoid or minimize the risk, as well as fostering the capacity to adapt and change after a shock (UNDRR, 2019). The paper's main objective is to go beyond the short-term and sectoral governance toward a more sustainable long-term perspective, promoting a multifunctional, fire-resistant, and resilient mosaic landscape based on sustainable development processes and strengthening synergies and coherence among policy objectives and territorial governance. Toward this aim, the paper reviews several proposed approaches framing the impelling new fire management perspectives, highlighting main features and gaps, and finally proposes a new "systemic fire management framework".

2. Recent approaches to prepare ourselves and our systems for incoming wildfire scenarios

Several contexts have recently been proposed to frame new perspectives and integrated approaches in fire management and governance (e.g., Moritz et al., 2014b; Tedim et al., 2020; Wunder et al., 2021). The proposed solutions range from general concepts (e.g., human and environmental system interaction, the need to adapt to living with fire, integrated fire management, resilience thinking) to specific activities (e.g., the wise use of fire, fuel management, exposure and vulnerability reduction, fire preparedness and response improvement) (Tedim et al., 2020; Schultz et al., 2019). Table 1 draws the distinctive elements of the scientific literature analyzed, also provided in the following sections.

2.1. Socio-ecological systems (SES)

Chapin et al. (2006) firstly advanced these systems to explore, at different spatial and temporal scales, dynamics of human-environment interaction and thus provide a sound scientific basis for policy strategies enhancing and contributing to sustainability, including a more sustainable coexistence with wildfire (Moritz et al., 2014). Towards this end, the comprehensive approach developed by Chapin et al. (2006) integrated four policy strategies linking human adaptability, vulnerability, resilience and transformability (Table 1), which offered opportunities in addressing the socio-ecological concept and the consequences of significant changes (e.g. climate/socio-economic changes). Based on the recognition of the pivotal importance of context-specific and place-based approaches, Moritz et al. (2014) reframed the SES challenge under WUI's context, suggesting the need for a more coordinated approach to support policy, planning, management and to enhance correct risk perceptions, community preparation, and response.

Fischer et al. (2016) further included governance systems (interactive and collaborative stakeholder partnership) and innovative strategies (planning approaches, analytical tools, and policies) for accounting for socio-ecological interaction at multiple spatial, temporal, and organizational scales and promoting complex thinking.

2.2. Integrated fire management (IFM)

Integrated approaches addressing fire preparedness and response while seeking fire causes and long term sustainable solutions have been framed out (Moore et al., 2003) by considering the five different components of fire management.[2] In this context, key stakeholders, especially local communities, are recognized to play a pivotal role in fire management planning. An initial distinctive feature of the IFM concept is combining prevention and suppression strategies, especially the wise use of fire through traditional burning, prescribed fire, and suppression fire. Furthermore, under this concept, fuel management has a prominent role in fire management to foster fire-resistance and fire-resilient landscapes (Fernandes, 2013), especially in rural-urban interfaces.

2.3. Fire resilience (FR)

A growing body of research is recently focusing on the concept of FR, strictly related to the socio-ecological dimension of wildfire. Smith et al. (2016) introduced the "*risk-to-resilience*" framework, composed of the risk, adaptation, mitigation, and resilience components, to define strategies for communities and landscapes to coexist with wildland fires. Pivotal to this framework is the extension of the "firescape" and "fire smart territories" concepts (Tedim et al., 2016; Wood et al., 2011), which couple the landscape/territory features with the inclusion of human values, perceptions, and processes (Smith et al., 2016). The framework proposed by Smith et al. (2016) presents a set of priorities and guidelines for achieving resilience, ranging from the identification of firescape vulnerabilities (also in terms of second-order and cascading consequences of fire, as well as early-warning vulnerability signal) to the recognition of community's responsibility, ability, and capacity to

[2] (1) Review of fire ignition and drivers' history; (2) Risk reduction through the use of fire for education, mitigation, and ecosystem maintenance; (3) Readiness to fire-fighting; (4) Response through fire-fighting operations; and (5) Post-fire recovery.

Table 1
A summary of the recent approaches advocating for a paradigm shift in fire management under the new wildfire scenarios. The approaches are characterized in their main mechanisms (e.g., socio-ecological systems, integrated fire management, fire resilience), the changes in the drivers underpinning the new wildfire scenarios, the primary goals and the main strategies/policies whose implementation can lead to the system shift, and finally other synergistic and/or complementary approaches integrated into the one under examination.

Source	Approach	Change in exogenous drivers	Main goal	Levers of transformation	Other approach incorporated
Chapin et al. (2006)	Socio-ecological system	Climate warming	Identifying policy strategies for a cohesive policy response	(i) human adaptability; (ii) enhance resilience; (iii) mitigate vulnerability; (iv) facilitate transformability	Adaptability[1], Resilience, Transformability[2]
Moritz et al. (2014)	Socio-ecological system	Climate warming Wildland urban interface expansion	Sustainable coexistence with wildfire under WUI's context	(i) context-specific knowledge and place-based approaches; (ii) research to support land-use and WUI policy, planning, and management; (iii) enhance correct risk perceptions and community preparation and response	Resilience
Fischer et al. (2016)	Socio-ecological system	Fuel build-up Population change (expansion of exurban areas and rural exodus) Conflicting governance system	Integrating wildfire governance in SES, thus reducing wildfire risk while mitigating human and ecological vulnerability	(i) policies accounting for socio-ecological interaction at multiple spatial, temporal, and organizational scales; (ii) building social network of stakeholder; (iii) engage stakeholders in scenario planning	Adaptability
Tedim et al. (2016)	Fire Smart Territory based on Socio-ecological system	Not specified	Preparing territories to be less fire-prone and inhabitants less vulnerable	(i) social solution; (ii) establishment of agreement and partnership between institutions and communities; (iii) increasing diversity of land use toward sustainable development; (iv) interactive communication	Resilience
Moore et al. (2003);Moore (2019)	Integrated fire management	Land-use change Economic development and demographic changes Climate trends Fuel build-up	Minimizing the damage from fire and maximizing its benefits	(1) review of fire ignition and drivers history; (2) risk reduction through the use of fire for education, mitigation, and ecosystem maintenance; (3) readiness to fire-fighting; (4) response through fire-fighting operations; and (5) post-fire recovery.	Not specified
Smith et al. (2016)	Fire resilience	Climate warming Wildland urban interface expansion	Provide insight on fire-resilient community building	(i) holistic characterization of firescape vulnerabilities; (ii) recognizing fire cascading effects; (iii) identifying early-warning signals of vulnerability; (iv) facilitating adaptation planning through fire data standards; (v) addressing barriers and capacities to design resilience strategies	Socio-ecological system
Schoennagel et al. (2017)	Fire (adaptive) resilience	Climate warming Wildland urban interface expansion Fuel build-up	Fostering adaptive resilience	(i) reducing fire suppression and endorsing prescribed fire in the WUI; (ii) targeting fuel treatments in strategic areas; (iii) fostering fire-adapted shifts in ecosystem and communities	Socio-ecological system
McWethy et al. (2019)	Adaptive and transformative resilience	Climate warming Wildland urban interface expansion Fuel build-up	Identifying actions promoting socio-ecological resilience to wildfire	(i) human exposure and vulnerability; (ii) fire severity; (iii) fire novelty	Socio-ecological system
Tedim et al. (2020)	Shared Wildfire Governance	Not specified	Tackling the distinct parts of the fire cycle to "thrive with fire"	(i) fostering societal engagement to cope with EWEs and community partnerships between agencies and citizens; (ii) context-specific knowledge and place-based approaches; (iii) identification of action synergies and monitoring of action efficacy; (iv) abating "silos" and enhancing the level and the accuracy of knowledge and information	Socio-ecological system
Wunder et al. (2021)	Fire resilience	Wildland urban interface expansion Fuel build-up	Integrating fire prevention strategies toward fire-resilient landscape and people	(i) breaking the fire issue into manageable nodes of information; (ii) integration of direct and indirect group of actions; (iii) integrating multiple benefits and community engagement; (iv) making pivotal socio-economic consideration	Adaptive governance

[1]According to Chapin et al. (2006), adaptability refers to "the capacity of actors to respond to, create, and shape variability and change in the state of the system".
[2]According to Chapin et al. (2006), transformability is "the capacity to create a fundamentally new system with different characteristics".

achieve resilience. Schoennagel et al. (2017) took another step forward, promoting the nested concept of "specified, adaptive, and transformative resilience[3]" in coupled SES and embracing wildfire as an unavoidable catalyst of change. According to these authors, three main convergent actions merging ecosystems and community goals (i.e., prescribed fire in WUI, strategic fuel treatments, and firewise and fire-smart community planning) promote adaptive resilience under a changing scenario. McWethy et al. (2019) explored and classified possible actions within the resilience perspectives to prioritize the wildfire coexistence efforts in SES using three gradients (human exposure and vulnerability, fire severity, and fire novelty). In particular, actions supporting adaptive capacity focus on fuel management and community planning to reduce fire severity and improve fire protection. Recently, Wunder et al. (2021) tackled the socio-economic dimension for constructing fire-resilience landscape based on (i) interdisciplinary approaches, (ii) multiple stakeholder perspective, and (iii) system thinking. All these aspects were broken down into nodes of information through the "theory of change" framework, which allows to understand how intermediate input and treatments could relate to log-term and desirable goals. The activities' efficacy depends on multi-level collaborations, involving and actively engaging landowners, planners and developers, land managers, and local to regional decision-makers towards long-term planning and management (Shindler et al., 2014).

Although not exhaustive, most of the above-mentioned studies advocating for a paradigm shift oscillate between the two poles of the fire management issues, either focusing only on the biophysical side of the problem or providing general strategies. The studies based on SES, for example, promoted innovative approaches incorporating multiple problem definitions and encouraging policies and governance shifts mainly influencing the human-land-forest nexus and the fire management behavior (Fischer et al., 2016). Furthermore, although climate warming is recognized as a possible driver, this variable is somewhat on the edge of the big picture, slightly addressed or even absent. IFM approach expresses the need for merging social, economic, cultural, and ecological evaluation into a planning and management system at the level where the fires occur (Myers, 2006; Rego et al., 2010; Wingard, 2000). Nevertheless, it focuses on the use of fire and its dual role, not advocating for a governance change (Tedim et al., 2020). Other studies based on FR approach dealt with climate changes and used the language of adaptive resilience; though, their focus continued to be fire and fuel management, encouraging community planning but not explicitly requiring the integration of multiple perspectives (e.g. forest management) nor clear governance shift.

3. Promoting a systemic fire management framework

The high interdependency between forest management, civil protection policies, land-use planning, agriculture development, climate, and energy policies impacting fire management (and in general disaster prevention, preparedness, and response), calls for an energetic and courageous change of paradigm (Moreira et al., 2020). We need to move from "silos" focused on specific aspects of the wildfire problem to an integrated (multi-level, multi-actor, cross-sectoral, and multi-purpose) and adaptive strategy and governance approach that, as suggested by Moreira et al. (2020), would focus more on reducing damages rather than burned area.

We here define a "systemic fire management framework". This approach, integrating the understanding of the wildfire issue from multiple perspectives (of which climate change is central), should substantially contribute to shift the focus from fire emergency management to fire risk management and prevention. The principal elements and recommendations for addressing the proposed systemic fire management framework are discussed as follows.

The first, central, and distinctive element is represented by bridging disaster risk reduction (DRR) with climate change adaptation (CCA). The interacting processes of climate change, land-use change, socio-economic, and fire management modifications are expected to trigger significant fire risk changes. In particular, climate change will exacerbate the difficulties in anticipating, evaluating, and communicating both probabilities and consequences of extreme events such as wildfire, affecting their management (IPCC, 2012). In this sense, CCA and DRR can complement developing cross-cutting approaches for the weather- and climate-related natural hazards management to build a resilient ecosystem and society (EEA, 2017; Mysiak et al., 2018). Although CCA and DRR look at weather and climate-related hazards with different temporal perspectives, they share many concepts, goals, and processes (EEA, 2017). Both emphasize the value of a more holistic, integrated, trans-disciplinary approach to risk management (ICSU-LAC, 2009), supporting and promoting sustainability in social and economic development (IPCC, 2012). To this end, the 5th Assessment Report (IPCC, 2014) shifted the focus from vulnerability to risk as a combination of hazards, exposure, and vulnerability.[4] CCA is an integral part of a sustainable development process and must have the same priority as other development goals and strategies. In Europe, policy coherence CCA and DRR have been galvanized by several commitments (e.g., 2030 Agenda for Sustainable Development) and frameworks (e.g., Sendai Framework for Disaster Risk Reduction 2015–2030, Paris Agreement on Climate Change, EU Civil Protection Mechanism), but still this concept struggles to take flight at the governance level. On top of that, COVID-19 set back progress, requiring immediate responses and resources, and thus overshadowing the climate crisis. Although, there is room for optimism since the global health crisis forced the different levels of society to turn attention from short-term response to longer-term strategy (Phillips et al., 2020), acknowledging the costs of not integrating resilience and adaptation thinking into decision-making (Quevedo et al., 2020). Bridging DDR and CCA is substantiated by several activities that overall require: (i) the risk framing (including climate-related and socio-economic factors) and analysis (central part in Fig. 1); (ii) the identification, prioritization and implementation of options for climate risk management, mainly focusing on those that potentially offer benefits now and address projected changes (IPCC, 2012); and (iii) the continuous review and integration of new scientific knowledge also through a learning process of monitoring and evaluation (Leitner et al., 2020).

The second element of the proposed framework is represented by the reformulation of the relationship between fire and society, recognizing that focusing on ecological or social research alone cannot solve the fire issue complexity (Liu et al., 2007). In the last decades, the detachment of local populations from the socio-ecologic phenomenon of wildfire (Steelman, 2016) was accompanied by a top-down suppression approach, ensuring that communities are not prepared for non-standard events. In this context, it is thus impossible to drastically reduce fire incidence and damages in the long term (Tedim et al., 2016). Overall, social vulnerability, the lack of fire-fighting cost references, and the lack of planning over the long term aggravate the actual risk reduction and management capacity, further emphasized by social and environmental

[3] Specified resilience applies when fire characteristic is within the historical variability. Adaptive resilience implies change, learning, and adaptability aspects on ecological and social contexts due to climate changes or fire disturbance regime changes. Indeed, adaptive resilience takes "*advantage of opportunities to moderate potential impacts and cope better with the consequences*" (Schoennagel et al., 2017). Transformative resilience invokes drastic changes in response to radically altered disturbances.

[4] According to this new definition, hazards are driven by changes in climate trends, variability, extremes, and cascading physical impacts. Exposure represents the people and valuable assets at risk. Vulnerability is made of sensitivity (the degree to which a system is likely to be affected by or responsive to a change) and adaptive capacity.

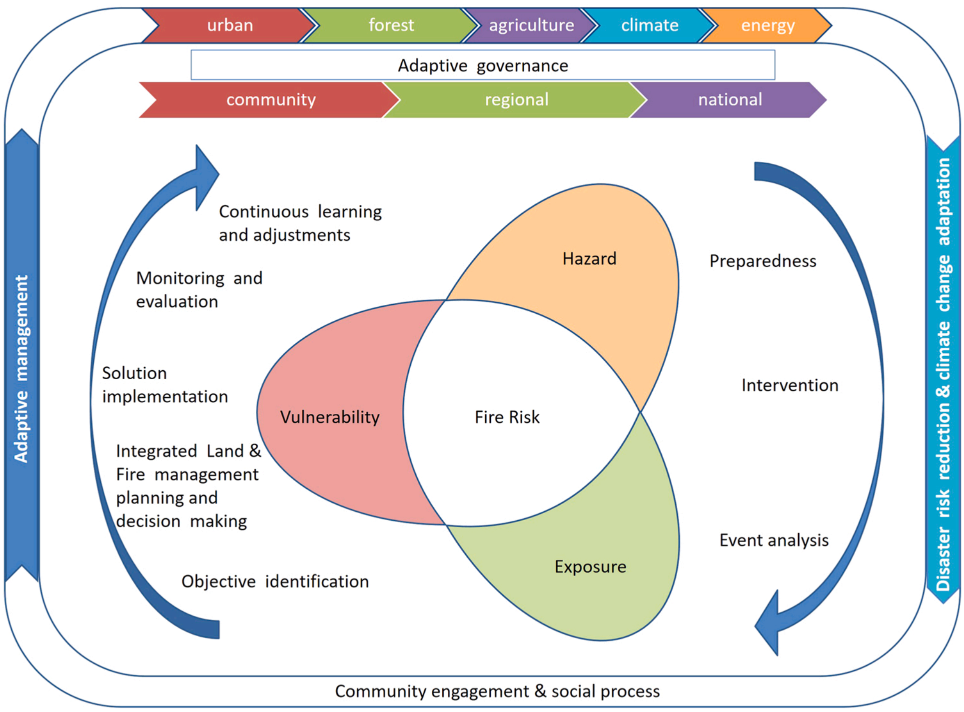

Fig. 1. – The main pillars of the proposed systemic fire management framework. The approach consists in: (i) the integration of climate change adaptation (CCA) and disaster risk reduction (DRR) in developing cross-cutting approaches for weather- and climate-related natural hazards management to build a resilient ecosystem and society; (ii) reconnecting and empowering communities with their territory; (iii) the adoption of adaptive management approach to connect local needs to national strategies and international agreements; and (iv) reframing vertical and horizontal interactions and coherence through adaptive governance. The scheme is adapted from the IPCC (2019).

changes. Adopting a systemic view thus requires planning resilience through community engagement and social process, making it imperative to reformulate the relationship between fire and society through more collaborative and process-oriented decision-making (Greiving et al., 2012). This element implies integrating bottom-up demands and positions in a participatory process of discussion and negotiation among the various stakeholders (Nocentini et al., 2017; Schultz et al., 2019), including private companies (e.g., the insurance industry (Kron et al., 2019)). Instead of deciding on the community's behalf, the public authority's role is to coordinate the collective decisions that can also be re-discussed and re-constructed through continuous learning (Lawrence, 2007).

This context will generate considerable complexity for policy and decision-making (Hurlbert et al., 2019), which need to balance different and competing ambitions and objectives at different scales, connecting local needs and agendas to national strategies and international agreements. Among various decision-making tools and approaches, adaptive management and adaptive governance have emerged as approaches towards the holistic, integrated, and sustainable management of complex environmental problems (Dietz et al., 2003; Folke et al., 2005; Walker et al., 2004), mediating multiple stakeholder interests. Adaptive management, defined as a systematic approach, aims at improving environmental management and building knowledge by learning from management output (Murray and Marmorek, 2003). To be successful, the process requires identifying the objectives to be achieved, defining the evaluation criteria, and considering uncertainties and trade-offs within a framework that includes stakeholder participation, continuous learning, and adjustments (Fig. 1, on the left). In the context of wildfires, this process requires a portfolio of analytical tools, approaches and strategies, at both the short- and the long-term, that can contribute to reducing fire risk, adapting, and diversifying forest towards a less prone (Lauer et al., 2017) and more resilient structure, also in the context of global changes (Moritz et al., 2014). In this sense, sustainable forest management, focused on maintaining now and in the future forest health and biodiversity (Fürstenau et al., 2007; Mackey et al., 2015; Seidl et al., 2016), can also contribute to taking into consideration the capacity of the system to react to impacts and learn how to support system resilience (Nocentini et al., 2017). In doing so, sustainable forest management "*can provide cost-effective, immediate, and long-term benefits to communities and support several Sustainable Development Goals (SDGs) with co-benefits for adaptation (very high confidence) and mitigation (high confidence)*" (IPCC, 2019).

According to Dunn et al. (2020), although adaptive management remains marginal in fire-prone ecosystem because it requires a profound institutional change, its implementation involving tools, risk assessment, and stakeholder engagement is a necessary process for facilitating change in the predominant fire management paradigm (Abrams et al., 2015; Steelman and Nowell, 2019). To this end, adaptive governance is more appropriate to support collective actions, actors' ability to mutual learn and respond to change, and evaluating governance strategies over time (Cosens et al., 2018). This approach, offering an overall framework for fostering change and building resilience (Abrams et al., 2015; Chaffin et al., 2014; Folke et al., 2005), incorporates the science, the social context, and conditions necessary for sustainable social-ecological landscapes (Sharma-Wallace et al., 2018). Good examples of adaptive governance are represented by Countries and Regions' efforts to adopt steering mechanisms facilitating vertical and horizontal[5] coordination between various institutional levels, and the climate change mitigation and adaptation mainstreaming in adopted plans and strategies. Towards these aims, innovative approaches and technologies could conveniently be applied, also promoting income and employment. In this sense, bio-economy, defined as an economy based on the sustainable use of renewable natural resources (EC, 2018), offers promising results to reduce fire risk (Evans and Finkral, 2009; Verkerk et al., 2018), while creating new business models to benefit farmers and forest owners (Marchetti and Ascoli, 2018). Furthermore, this approach provides possibilities to replace fossil-based products (Sillanpää and Ncibi, 2017) and explore new emerging markets (Martinez De Arano et al., 2018),

[5] Vertical coordination entails the definition of objectives and macro-actions consistent with the highest institutional level, to be tailored at the local context and matched at the appropriate scale of the problem preferably balancing between top-down and bottom-up multi-actor decision-making. Horizontal coordination implies the identification of coherence and synergies among services and agencies at the same institutional and administrative level.

thus contributing to climate change mitigation and creating employment in rural areas.

3.1. Final remarks

In the last decades, wildfire management agencies worldwide have been characterized by a common denominator, the typical “zero fire policy” focusing mainly on suppression and professionalization as part of the welfare state towards population and assets safety. The recent events of destructive fires out of the extinction capacities in many regions and the phenomenon’s inherent complexity highlighted that the current policies present a crucial weakness in efficacy. Although it is a contingent event, the actual COVID-19 pandemic adds other elements of concern at the short- and medium-term to the fire management sector, highly stressed by the convergence of recent changes in land use, socio-economic, and climate factors. Several “alternative” fire management frameworks have been recently suggested, from recognizing the wildfire’s socio-ecological system dimension to fire resilience. However, the suggested approaches are focused, on the one hand, on the ecological side of the issue, mainly recommending fuel reduction and prescribed fire management to influence fire behavior, also under climate change conditions. Other approaches do not explicitly mention the integration of multiple perspectives nor advocate for a governance change. Several studies promoted innovative approaches incorporating multiple problem definitions and promoting policies and governance shifts, but climate changes future conditions are slightly addressed or even absent.

The “systemic fire management” suggested here entails a conceptual framework coherent with complex socio-ecological systems under climate change, based on an integrated (multi-level, multi-actor, cross-sectoral and multi-purpose) and adaptive strategy and governance approach. In conclusion, the proposed framework is based on the following pillars and requires the following corresponding actions:

1. **Connecting disaster risk reduction with climate change adaptation**. Innovative approaches tackling multi-hazard and multi-risk under current and future conditions are needed to enhance understanding of resistance and resilience of eco- and human-systems. Besides, these approaches should deal with uncertainties and move from short-term actions towards long-term transformations while considering ecosystem health and sustainable economic growth.
2. **Supporting community engagement and social process**. The best prevention and emergency management of both current and future fire risk can be achieved by reconnecting communities with their territory and empowering them through learning spaces, partnerships, and alliances building on mutual strengths and interests.
3. **Adopting adaptive management to support system resilience.** Some of the steps to facilitate the process, characterized by permanent learning, are: set clear objectives; provide analytical tools and data to inform the process; engage with multi-entry stakeholders to consider barriers and opportunities and have a common understanding of the values at risk; monitor and evaluate the trade-off of the implemented actions and the possible fire and forest management alternatives.
4. **Reframing vertical and horizontal interactions and coherence through adaptive governance.** It is of utmost importance to foster collaboration across actors and scales aiming at (i) promoting cooperative planning and decision-making, including socio-ecological aspects; (ii) identifying best practices, adaptation, and climate-resilient pathways enabling fire resilient landscapes; and (ii) integrating a long-term adaptation perspective in planning and implementation capacity.

The proposed framework is not a one-size-fits-all solution: it needs to be tailored accounting for the peculiarity of the socio-ecological system in a given territory, from the fire regime characteristics to the policies, plans, and strategies governing it. Indeed, fire risk management is at a crossroads. First of all, this requires a change of paradigm from a suppression oriented strategy to integrated fire management, where all the components of the fire risk are considered, from the communities to the institutions, from land use and landscape planning to the design of policies tackling urban, agriculture, and rural development.

CRediT authorship contribution statement

Donatella Spano: Conceptualization, Supervision, Writing – review & editing. **Valentina Bacciu:** Conceptualization, Writing – original draft, Writing – review & editing. **Costantino Sirca:** Conceptualization, Writing – review & editing.

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Ethics

No ethics approval was required as this is a comment without data collection.

Declaration of Competing Interest

The authors declare that they have no conflict of interest or known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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