iForest
Biogeosciences and Forestry

Review Paper
doi: 10.3832/ifor4786-018
vol. 18, pp. 163-175

Shifting to a holistic approach in national wildfire management policies: the Italian case

Valentina Bacciu [(1)],
Michele Salis [(1)],
Bachisio Arca [(1)],
Grazia Pellizzaro [(1)],
Davide Ascoli [(2)],
Giuseppe Mariano Delogu [(3)],
George Eftychidis [(4)],
Emilio Chuvieco [(5)],
Ioannis Gitas [(4)],
Domingos X Viegas [(6)]

Recent fire seasons have highlighted the growing threats posed by wildfires, despite efforts in suppression policies. These challenges arise from the complex interplay of climate change, fuel availability, land use, and socio-economic conditions. In Italy, the community of scientists, policy- and decision-makers, and practitioners is converging on the urgent need for changes in the prevailing paradigm that governs wildfire policy and management strategies, and advocate for new perspectives and a holistic approach that integrates prevention, mitigation, and response strategies. In recent years, Italy has significantly restructured its wildfire governance system, highlighting both the strengths and limitations of shifting paradigms in fire management in Europe. This paper examines the current wildfire management in Italy, providing a historical timeline of wildfire management in the country and highlighting its distinct features compared to other Mediterranean countries. Conducting an exhaustive review of recent Italian scientific research on wildfire management, this study outlines key observations that highlight areas for improvement. The paper finally aims to provide specific recommendations, presented as future policy considerations, for improving the resilience and sustainability of the Italian wildfire management system.

Keywords: Fire Management, Fire Governance, Fire Prevention, Key Observations, Policy Recommendations

Introduction

Italy is one of the southern EU countries most affected by forest fires which have significant economic and public health consequences (San-Miguel-Ayanz et al. 2022). According to official Italian statistics published by several national and EU agencies, such as the National Forestry Information System (SinFor), and the European Forest Fire Information System (EFFIS), an average of 8,545 wildfires occurred annually during the 1980-2023 period, resulting in a total burnt area of approximately 4.5 M ha (San-Miguel-Ayanz et al. 2022). In southern and insular Italy, wildfires are typically observed from June through September, when hot and dry weather conditions reduce fuel moisture and increase fire occurrence and propagation (Elia et al. 2022). Conversely, the fire season in the Alpine area primarily occurs during the winter months (Maringer et al. 2016). Between 2012 and 2017, in the 15 Italian Ordinary Regions (excluding Friuli-Venezia Giulia, Sardinia, Sicily, Trentino-Alto Adige, and the Aosta Valley, which have special forms of autonomy due to their unique geographical and/or cultural characteristics), natural causes – like lightning strikes – accounted only for about 1.2% of total fire ignitions. In contrast, human-caused factors, including accident/negligence, deliberate actions and agro-pastoral fire uses (Ascoli & Bovio 2010), were the primary causes of fire ignitions (about 72%). The remaining 26.8% of fire causes were reported as not classified or uncertain (ISPRA 2019, Almeida et al. 2023). According to Scarpa et al. (2024), from 2007 to 2017, wildfires released a substantial quantity of greenhouse gases and particulate matter. The years 2007, 2017, and 2012 peaked with 7020 Gg, 5788 Gg, and 4096 Gg per year, accounting for about 60% of the total fire emissions for the period above.

In the XXI century, the most critical years in terms of area burned were 2007 (≈ 228,000 ha), 2017 (≈ 162,000 ha), and 2021 (≈ 152,000 ha) (San-Miguel-Ayanz et al. 2022). The area burned in 2021 was wider than the 1980-2020 mean (+49%), while the number of events was lower (-31%) than the above period. The largest events recorded in the aforementioned years include those that occurred in Sardinia (Nuoro wildfire, in 2007, about 9,000 ha; Bonorva wildfire, in 2009, about 10,500 ha; Montiferru wildfire, in 2021, over 13,000 ha –Almeida et al. 2023), in Sicily in 2021 (San Mauro wildfire, about 10,000 ha; approximately 3.5% of the regional area was burned in that fire season), and in Calabria in 2021 (San Lorenzo wildfire, about 7,100 ha – see https://effis.jrc.ec.europa.eu/apps/effis_current_situation/).

The 2023 fire season was also characterized by significant losses and impacts on southern Regions, which suffered from injuries, deaths, relevant property damages and evacuations. Large events affected ap-

(1) National Research Council, Institute of BioEconomy of Sassari - CNR-IBE, Sassari (Italy); (2) University of Torino, Torino (Italy); (3) University of Sassari, Sassari (Italy); (4) Aristotle University of Thessaloniki, Thessaloniki (Greece); (5) University of Alcalá, Alcalá de Henares (Spain); (6) Association for the Development of Industrial Aerodynamics - ADAI, Coimbra (Portugal)

@ Valentina Bacciu (valentina.bacciu@ibe.cnr.it)

Received: Dec 31, 2024 - Accepted: Jun 05, 2025

Citation: Bacciu V, Salis M, Arca B, Pellizzaro G, Ascoli D, Delogu GM, Eftychidis G, Chuvieco E, Gitas I, Viegas DX (2025). Shifting to a holistic approach in national wildfire management policies: the Italian case. iForest 18: 163-175. - doi: 10.3832/ifor4786-018 [online 2025-06-30]

Communicated by: Marco Borghetti

proximately 69,000 ha, including over 10,000 ha of forest ecosystems (ISPRA 2023). July was an off-scale month at the National level, recording a +87% in area burned in few days compared to the average data of the 2006-2022 period. The forests affected by wildfires were primarily represented by Mediterranean shrubs and holm oak forests (61%), as well as areas covered by woodlands and conifer reforestation (21% – ISPRA 2023). About 71% of the area burned was concentrated in Sicily and Calabria. In Sicily, over two thousand people had to evacuate their homes. In addition, wildfires affected very sensitive areas, such as landfills, causing the emission of highly polluting substances. Further, blackouts and major problems related to air traffic and damage to numerous infrastructures were reported (https://www.rivistasherwood.it/t/novita-e-notizie/incendi-luglio-2023.html).

Over the past few decades, significant changes in various factors have influenced fire disturbance in Italy, resulting in an increased proportion of burnt area within forest land use classes (Fig. 1 - left). Notably, there has been a high concentration of burnt areas during years of extreme weather conditions, such as in 2007, 2012, 2017, and 2021 (Fig. 1 - right). Socioeconomic changes in rural areas (Salis et al. 2022) have led to a strong increase in rural depopulation and population aging. This led to a progressive decline in land management practices, with direct effects on biomass dynamics at the landscape scale. The consequent increase in vegetation fuels in previously cultivated rural areas, pastures, and managed forests, led to crucial changes in the structure and continuity of plant communities, thereby affecting the landscape's susceptibility to fire (Ascoli et al. 2021). Furthermore, decades of fire policies that banned controlled burning in fire-prone forests and rangelands have led to increased fuel loads, increasing the risk of large and severe wildfires when initial suppression fails (Parisien et al. 2020, Spies et al. 2018). Finally, the recorded increase in temperatures and the occurrence of extreme weather events, such as prolonged drought and heatwaves (Elia et al. 2024), have contributed to extreme wildfire occurrence. For example, in 2021, a significant number of consecutive days without rain (over 100 days in southern Sicily, western and central Sardinia, and the Tyrrhenian coast), combined with numerous heatwaves, created the perfect conditions for the formation of large wildfires (San-Miguel-Ayanz et al. 2022).

Climate change is expected to lengthen the fire season and exacerbate wildfire danger, particularly in central and southern Italy, by favoring longer heat waves, hotter and drier conditions, and increased vegetation dehydration and flammability (Spano et al. 2020). In addition, climatic change is expected to broaden the wildfire-prone areas, making fire occurrence more likely in vegetation types that have historically been less fire-prone, such as mountain beech forests (Maringer et al. 2016), which in Italy cover more than 1 million ha in both Alpine and Apennine Mountain systems.

In this context, fire suppression policies, although necessary, are increasingly considered by experts and the scientific community as insufficient in addressing modern wildfire challenges (Kirschner et al. 2024). There is a growing consensus among experts that a shift towards prevention, preparedness, and adaptation is needed (Bacciu et al. 2022, Ascoli et al. 2023).

The aim of this paper is to describe the Italian approach to wildfire management at National and Regional levels, presenting key observations and policy recommendations towards the overall improvement of the general governance structure derived from the analysis of the most recent research activities on the multifaceted elements influencing wildfires. This review is divided into three sections. The first one presents the evolution of wildfire governance and management in Italy, from the late 19th century to present. The second section highlights the recent Italian scientific research delving in integrated wildfire management and wildfire activity drivers (land use, socioeconomic factors, and climate). Finally, the third section proposes some insights for enhancing wildfire management in Italy.

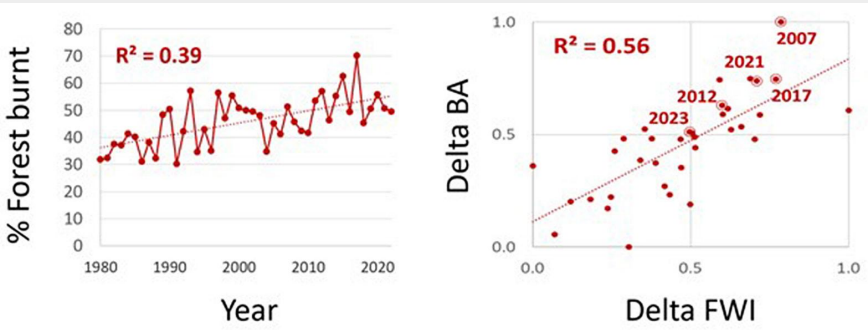

Fig. 1 - On the left, percentage of burnt area in forest land use classes over the total burnt area in Italy. On the right, the relationship between burnt areas and fire-predisposing weather. A significant proportion of the inter-annual variability in total area burned in Italy is explained by fire weather. The graph shows the mean daily fire weather during the fire season versus the total area burned during that season for years 1988-2023. The burnt area was provided by the State Forestry Police (Carabinieri Forestali, in Italian). Fire weather was indexed using the Canadian Fire Weather Index according to the global fire danger re-analysis (Vitolo et al. 2020). Calculations used the first-difference method for detrending. Consequently, a change in FWI from one year to the next (Delta FWI) was matched with the corresponding change in BA (Delta BA). Changes are standardized from 0 to 1 across the series. The graph shows that the more severe a fire season is (indicated by red circles), the greater the area burned annually in Italy.

Timeline of fire management in Italy

A glimpse into the past: brief history of wildfire management agencies and policies from the late 19th to early 20th century

In the late 19th and early 20th centuries, wildfires in Italy were considered an inevitable natural phenomenon, partly due to the use of fire in agricultural activities, such as restoring pastures and renewing stubble. Little organized fire suppression resources existed, except for local volunteer efforts. In 1822, King Carlo Felice of Sardinia issued the "Regie Patenti" (Royal Patents), devoted to forest protection and supervision. In 1877 (sixteen years after the proclamation of the Kingdom of Italy), the Royal Forestry Corps absorbed the Royal Patents: the forestry regulations were then unified in the Kingdom (Caruso 2022). The "Majorana-Calatabiano" law (Forest Law n. 3917/1877 – Governo Italiano 1877) introduced the concept that private properties should be managed considering the community interests and defined some lines and prescriptions to regulate tree cuttings and activities in hilly and mountain areas; in addition, the "*Vincolo Forestale*" (Forest Constraint) was defined, in order to protect forests and woodlands on mountain peaks and hills, up to the upper limit of the chestnut tree (approximately 800 m a.s.l.).

In 1910, the Royal Forestry Corps and the Company of State Forests constituted the Forestry Administration of that time. The 1920s and 1930s marked the first attempts to manage wildfires. In 1925, a decree recommended the use of firebreaks, while in 1935, the Fire Brigades were established, divided into provincial corps under the Ministry of the Interior (https://www.vigilfuoco.it/chi-siamo/memoria-storica/la-storia-del-corpo). Furthermore, the forest law expressed in the Royal Law Decree no. 3267 ("*Legge Serpieri*" – Governo Italiano 1923) defined the extension of forests devoted to hydrogeological protection of the hills/mountains, as well as the main regulations to manage forests and woodlands, the

sanctions to contrast violations in forest cutting, cave opening, and damages to soils, as well as the rules to avoid or limit wildfire ignitions. This Royal Law Decree also prohibited grazing in burnt areas.

Later, the Royal Forestry Corps underwent several name changes, and in 1948 officially became the National Forest Service (*Corpo Forestale dello Stato* – Caruso 2022) following Legislative Decree no. 804/1948 issued by the Italian Government (Governo Italiano 1948). The first task assigned was "reforestation, reinforcement and related construction works". Indeed, wildfires did not represent a national problem until the 1970s (Caruso 2022), so specific laws or organizations dealing with the management or suppression of forest fires were lacking.

In 1954, the first aerial means (AB.47G-2) was purchased by the National Fire Corps (*Corpo Nazionale dei Vigili del Fuoco*) and assigned to the Provincial Command of Modena for the establishment of the first helicopter fire brigade (https://www.antincendio.it/aerei-antincendio/). However, this helicopter was devoted to public assistance, not only to firefighting (Fig. 2).

In June 1967, a conference entitled "The increase of forestry assets and its protection from fires" was held in Bergamo (northern Italy), marking the first turning point in addressing the emerging problem of wildfires at the national scale (Calabri 1984). From the 1970s onwards, the wildfire phenomenon increased in importance and severity. The wildfire issue was recognized as a national problem, and its prevention and management were officially assigned to the National Forest Service, acknowledging its extensive experience in this area (Law no. 47/1975 – Governo Italiano 1975). Regional coordination centers were set up to consolidate wildfire management. In late July 1983, nine people died in Northern Sardinia (Curraggia wildfire), and several others were injured in a severe wildfire driven by strong southern winds, which affected about 18,000 ha of land near Tempio Pausania (Cabiddu et al. 2012). A second dramatic event in North-Eastern Sardinia (Portisco wildfire) in 1989 was responsible for 18 casualties, including tourists, in a highly valued touristic area. After these tragedies, the Sardinia Region decided to strengthen and re-organize the Regional Forest Service, progressively increasing terrestrial and aerial forces; the first step was the definition of the Regional Law no. 26/1985 (Regione Sardegna 1985), after which the Sardinian Forest Service also became responsible for environmental supervision in this Region.

In the 1980s, the National Air Firefighting Center was established to manage aerial resources at the national level. The 1990s and 2000s witnessed significant developments in wildfire policy. Italy's comprehensive approach to wildfire management was mainly framed by Law no. 353/2000 (Governo Italiano 2000, later updated by Law no. 155/2021 – Governo Italiano 2021c), aimed at "the conservation and defense of the National Forest heritage from wildfires as an irreplaceable asset for the quality of life". Law no. 353/2000 (Governo Italiano 2000) defined forest fires as a major problem for Civil protection, due to the possibility that the fire could affect houses, assets, networks, and human activities in a highly populated country such as Italy. The Law mandated the administrative Regions and the two autonomous provinces for planning and regularly updating the forecasting, prevention, and firefighting activities in a Regional strategic tool called AIB plans (Plan for the forecasting, prevention, and active fight against forest fires – Pandey et al. 2023, Regione Sardegna 2023).

Aerial support from the National means is provided when Regional capacities are overwhelmed by wildfires; these interventions are coordinated at the National level through the Civil Protection Department and the National Fire Corps within the Unified Air Operations Center (COAU) framework. National-level regulations also apply to National Parks and protected areas managed by the State, where fire management is regulated by the Park Fire Management Plan approved by the Ministry of the Environment. The Regions could also establish specific agreements with the National Forest Service (up to 2016) and the National Fire Corps (starting in 2017) for wildfire suppression. Additionally, they could collaborate with police, forestry agencies, and volunteer organizations for specific activities related to fire management. Until 2016, the National Fire Corps was responsible for extinguishing wildfires that threatened rural-urban interfaces and populated areas. Starting in 2017, this Institution also extended its authority to wildfires spreading into forests and vegetated areas in the Italian Ordinary Regions.

The current context: from the abolition of the National Forest Service to the National Forestry Strategy

In recent years, we have witnessed several changes from structural, organizational, legislative, and planning perspectives. Indeed, before 2016, the National Forest Service addressed wildfire risk as a State-level Agency within a broader array of sustainable forest management tasks and land planning. In 2016, the National Forest Service was dissolved under Law no. 124/2015 (Governo Italiano 2015) and integrated into other police forces (*e.g.*, the State Forestry Police "*Carabinieri Forestali*") by 2017. This restructuring was part of a broader initiative aimed at streamlining operations and improving efficiency in the Regions with Ordinary Statute. However, the Regional Forest Services in the five Autonomous Regions, remained operational.

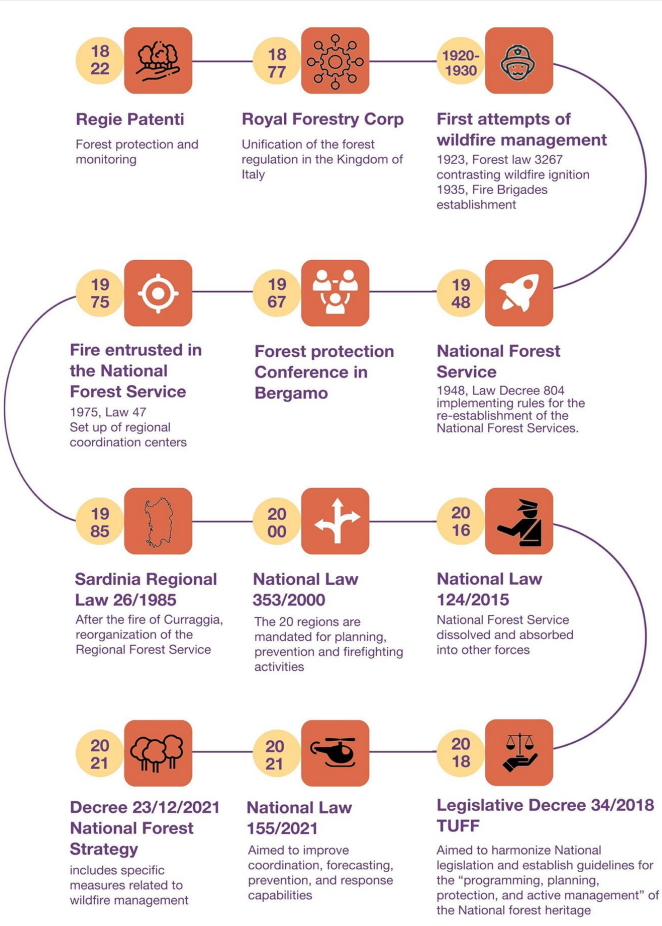

Fig. 2 - Schematic timeline of fire management in Italy, from 1822 to 2021.

Following the reorganization, a National Technical Committee on wildfires was established (Kirschner et al. 2024), which included several agencies, each with specific roles and responsibilities:

- Regional and Local Authorities – The Regional and Local administrative authorities are responsible for forecasting, preventing and actively fighting wildfires based on guidelines and directives prepared by the abovementioned National authorities and through Regional fire management (AIB) plans. Ordinary Regions have a specific wildfire fighting system structured according to the availability of Regional economic resources (Forestry and Civil Protection Regional sectors, Forest workers, Volunteers, etc.), while in Autonomous Regions and Provinces wildfire management is entrusted to Regional Forest Services, namely: "*Corpo Forestale e di Vigilanza Ambientale*" (CFVA) in Sardinia; "*Corpo Forestale della Regione Siciliana*" in Sicily; "*Corpo Forestale della Regione Autonoma Friuli-Venezia Giulia*"; "*Corpo Forestale della Valle d'Aosta / Corps Forestier de la Vallée d'Aoste*"; "*Corpo Forestale della Provincia Autonoma di Trento*" (CFT) and "*Corpo Forestale della Provincia Autonoma di Bolzano*" (CFBZ) in Trentino Alto-Adige. In Ordinary Regions, as well as in Sardinia and Sicily Autonomous regions, the Permanent Unified Operational Rooms (SOUP) coordinates wildfire responses. Both Ordinary and Autonomous Regions can implement special agreements with the National Fire Corps to be supported in firefighting activities.
- *Dipartimento della Protezione Civile* (Civil Protection Department) – This department coordinates emergency response activities, including those related to forest fires, and guarantees, coordinates, and provides aerial support with the National Fire Corps aerial firefighting fleet within the Unified Air Operations Center (COAU) framework. This Centre oversees the National Forest firefighting fleet, which comprises 18 Canadairs CL 415 and 6 heavy helicopters Erickson S64 (data updated to 2023), all managed by the National Fire Corps. The State fleet is called to intervene when needed, upon request of a specific region. Additional resources, such as military helicopters, are also available during the summer fire season. Following Law no. 155/2021 (Governo Italiano 2021a), the Civil Protection Department coordinates the Technical Committee on wildfires, which is responsible for setting the "*Piano Nazionale Incendi*" (National Wildfire Plan) and for monitoring the Regional system organizations, to ensure a homogeneous approach and highlight possible critical points.
- *Corpo Nazionale dei Vigili del Fuoco* (CNVVF) – The National Fire Corps provides support activities during wildfire events through specific agreements with the Regional administrations and has the responsibility for events affecting wildland-urban interfaces. They own and manage the National Forest firefighting aerial fleet (Canadair CL 415 and S64 helicopters). Moreover, it represents Italy in the European Expert Group on Forest Fires and coordinates the Italian section of the annual EFFIS report on wildfires.
- *Carabinieri Forestali* – The National Forest Service was primarily absorbed into the Carabinieri, Italy's national gendarmerie, which has a specific division called *Carabinieri Forestali* (State Forestry Police). They are responsible for enforcing environmental laws, including those related to forestry, and have competencies in fire cause investigations, sanctions, and monitoring in Ordinary Regions. Moreover, in Ordinary Regions, they survey wildfire perimeters and transmit the geo-referenced data to Regions, Municipalities, and Ministries, providing wildfire statistics (number of fire events and burnt area by Region) to EFFIS.
- Ministry of Agriculture, Food Sovereignty, and Forestry – This Ministry is involved in long-term forest planning and policy-making, including the National Forestry Strategy and the SinFor (the information system on national forest resources, which includes wildfire data). Moreover, it has competencies at the international level, such as contributing to the European Expert Group on Forest Fires and the annual EFFIS report on wildfires.
- Ministry of Environment and Energy Security – This Ministry defines guidelines for fire management in National Parks and Nature Reserves of the State and approves the Fire Management Plans in these protected areas.

Several other Agencies, from the European to the National scale, contribute to the wildfire information system. The European Forest Fire Information System (EFFIS) provides real-time monitoring of the burnt area, which, starting in 2021, is reclassified by the Italian Environmental Agency (ISPRA) by land uses in a spatial dataset, the "Burnt Area in Italian Terrestrial Ecosystem" (BA-ITE), to allow the statistical study of the events and monitor the recovery of ecosystems over time (ISPRA 2023). Furthermore, the CIMA Foundation (https://www.cimafoundation.org/) is the Center of Competence and National Operational Structure (Legislative Decree no. 1/2018 - Governo Italiano 2018a) of the National Service of Civil Protection. Within the framework of this agreement, the CIMA Foundation conducts activities aimed at developing knowledge, methodologies, technologies and training useful for the creation of National forecasting, monitoring, prevention, and control systems in the field of natural risks of meteorological origin (Fiorucci et al. 2008, 2015, Trucchia et al. 2020). Moreover, the Major Risk Commission ("*Commissione Grandi Rischi*") is another agency that supports the Civil Protection Department in developing fire management strategies at the national level.

From a legislative and planning perspective, it is also worth noting the evolution of the concept of fire management. Before Law no. 353/2000 (Governo Italiano 2000), the general approach to fire management did not differentiate between wildfires according to their severity and prioritized quick suppression with all possible means. Law no. 353/2000 introduced AIB plans, establishing that wildfire suppression efforts should be modulated according to the actual wildfire risk and the exposure of vulnerable assets to fire hazards. This approach, known as fire management, has gradually replaced the previous approach of "fire control" (Bovio & Marchi 2010). However, Legislative Decree no. 177/2016 (Governo Italiano 2016) integrated the National Forestry Service into the State Forestry Police and transferred active forest firefighting duties to the National Fire Corps. Since then, there has been greater enphasis on firefighting rather than on fire prevention and planning. The Regions have bolstered their firefighting structures and their potential to intervene quickly with numerous means over a vast territory (Bovio et al. 2017). As a result, fire management and planning moved away from prioritizing prevention measures and strategies (Bovio et al. 2017, Kirschner et al. 2024).

In 2021, the Italian Government issued new regulations, particularly the Legislative Decree no. 120/2021 (Governo Italiano 2021b) and the Law no. 155/2021 (Governo Italiano 2021c), to improve coordination, forecasting, prevention, and response capabilities (Kirschner et al. 2024), allocating resources almost exclusively for wildfire suppression. Indeed, the main objectives of the laws were to: (i) improve the forecasting and alerting capacity of the Civil Protection Department for the entire Italian territory; (ii) increase the response capacity of the National air fleet with additional aircrafts and helicopters and more infrastructures to service the fleet; (iii) improve the air and ground response resources and to increase training activities; (iv) improve the update rates of the burnt area databases. These laws also led to the development of the "National Coordination Plan for the Technological Update and Improvement of Forecasting, Prevention and Firefighting Activities", prepared by the Civil Protection Department in collaboration with an inter-institutional technical committee. Law no. 155/2021 (Governo Italiano 2021c) also proposed tougher administrative fees and amendments to the Penal Code. This law contained undoubtedly positive aspects, such as the definition of prescribed burning and counterfires, defined for the first time in a National Law. It established a three-year funding plan (2021-2023) that allocates part of the resources of the National Strategy for the development of inner areas of the Country (100 million euros for the period 2021-2023) by financing local Authorities for projects, actions, and

measures aimed at: (i) preventing wildfires in fire-prone areas; (ii) discouraging the abandonment of forest and rural activities; and (iii) enhancing and protecting forest heritage.

Other important policy documents include the Legislative Decree no. 34/2018 (Governo Italiano 2018b), also known as TUFF ("*Testo unico in materia di foreste e filiere forestali*"), and the National Forest Strategy (SFN), issued by Decree on Dec 23, 2021 (MIPAAF 2022). The TUFF aimed to create a unified framework for forestry management and forest supply chains. It sought to harmonize National legislation and established guidelines for the "programming, planning, protection, and active management" of the National forest heritage. TUFF also outlined key principles governing the forestry sector, such as protecting ecological diversity, preventing natural and human-caused risks, and involving local communities in forestry development. In summary, the law defined three levels of forest planning: the Regional Forest Programme at the Regional level (1st level), the landscape forest management plans ("*Piani Forestali di Indirizzo Territoriale*" – 2nd level), and the local forest management plan (3rd level). The 2nd level plans should include the planning of strategic wildfire risk reduction measures such as fuel breaks and pyrosilvicultural interventions. Tuscany, Piedmont, and Lombardy have developed and implemented such landscape-scale fuel management plans (La Mela Veca et al. 2024).

The SFN is a strategic document valid for 20 years, reviewed every five years, which recognizes forests as a national asset. The SFN included specific measures related to wildfire management, such as strengthening the coordination among actors of National and Regional fire management systems or improving the harmonization and accessibility of wildfire data (Tab. 1).

In summary, each Italian Region has its own legislation and policies for wildfire management, which must both comply with National legislation and define specific measures and responsibilities for the different phases of wildfire management, based on local climate, topography, vegetation types and socio-economic conditions. On the positive side, the Country benefited from Regional autonomy, which allowed for rapid, localized decision-making. The legal framework, including Law no. 353/2000 and Legislative Decree no. 120/2021, provided a strong legal backbone. On the other hand, these laws often respond to events rather than proactively preventing them (Kirschner et al. 2024). Furthermore, while significant investments have been made in aerial assets, ground resources, and preventive measures have often been underfunded. Also, public awareness campaigns exist, but they are not widespread enough to significantly reduce human ignitions.

Coordination at the National level has improved with the establishment of bodies such as the Civil Protection Department and the Unified Air Operational Centre, as highlighted in the National Forest Strategy. Nonetheless, gaps remain in inter-agency and inter-regional coordination (Ascoli et al. 2022). A common need in firefighting is the adoption of common languages and procedures and the definition of lines of responsibility for strategic decisions. Some Regions, such as Tuscany and Piedmont, have tried to overcome these critical issues by adopting a kind of "Incident Command System". In this context, the SFN proposed strengthening wildfire management coordination through an inter-institutional round table for forest fire monitoring, led by the Presidency of the Council of Ministers.

In conclusion, the Italian wildfire management system is a multi-level and multi-agency effort, coordinated by a solid legal and strategic framework. However, the system faces challenges that require continuous policy evaluation and technological advances to adapt to changing environmental and social conditions (Kirschner et al. 2024).

Sharing the challenges: a comparative look at fire governance and management strategies in Mediterranean countries

Italy faces similar wildfire governance and management as Portugal, Spain, France, and Greece, the most fire-affected countries in Mediterranean Europe. These countries have all undergone deep structural, organizational, and legislative reforms in recent years. By examining their institutional frameworks, key policies and strategic priorities, and the balance between prevention and suppression, in this subsection

Tab. 1 - National Forest Strategy (SFN) sub-actions under Specific Action 2, aimed at addressing inter-institutional coordination for fire governance.

Specific Sub-Action	Title	Description
2.1	Inter-institutional coordination for fire governance, planning and management	Promote coordinated planning and integration at regional and national levels between sectors involved in forest fire management, considering the interdependence of land use, forecasting, prevention, and firefighting (A.S.2.1.a). Establish a permanent control room under MASAF to support Civil Protection and enhance institutional coordination (A.S.2.1.b). Ensure consistent application of guidelines and development of regional fire planning and prevention maps of national relevance (A.S.2.1.c).
2.2	Coordination and convergence of forestry, agro-pastoral and environmental policies and interventions with fire governance strategies	Promote the coordination between fire management strategies, environmental and conservation policies, and agricultural and forestry policies, encouraging prevention in agro-sylvo-pastoral areas and high-risk abandoned areas and enhance the use of RDP tools to reduce fire risk in strategic areas (e.g., rural settlements, interface zones) (A.S.2.2.a). Encourage diversified agro-sylvo-pastoral activities in strategic areas, such as rural settlements, to create less flammable landscapes (A.S.2.2.b). Integrate fire prevention with biodiversity conservation in protected areas, addressing their vulnerability to large forest fires (A.S.2.2.c).
2.3	Regulatory update and post-fire recovery planning	Support post-fire recovery by prioritizing areas and technical solutions, using public funds for urgent interventions, even under exceptions to Law No. 353/2000 (A.S.2.3.a). Update Law No. 353/2000 on forest fires to reflect climate change and recent legislative reforms, introducing penalties for municipalities that neglect Fire Registry regulations (A.S.2.3.b). Standardize forest fire danger and risk mapping at a national level for improved accuracy and consistency (A.S.2.3.c). Regulate and incorporate prescribed fire into regional, park, and territorial forest plans, financing interventions in fire-prone areas through Rural Development Program measures (A.S.2.3.d).
2.4	Fire statistics and cadaster	Enhance data collection, analysis, and dissemination on forest fires in Italy by creating national guidelines for standardized reporting, mapping, and a georeferenced system integrating regional data (A.S.2.4.a). Develop a system for collecting economic data on prevention, control costs, and damages to better evaluate cost-benefit ratios and inform environmental accounting and investment planning (A.S.2.4.b).

we aim to highlight the distinct features of the Italian wildfire management approach (see also Tab. S1 in Supplementary material).

Regarding the institutional framework, Italy shares similarities with Spain and, to some extent, France, with a two- (or more) level structure (national and regional). After the devastating 2017 wildfires, Portugal restructured its wildfire governance framework by establishing the Agency for Integrated Rural Fire Management (AGIF) in 2018 (Governo Português 2021). AGIF cooperates with other organizations, including the National Authority for Emergency and Civil Protection (ANEPC), the Portuguese Institute for Nature Conservation and Forests (ICNF), and the Portuguese Institute for Sea and Atmosphere (IPMA). Wildfire management in Spain mirrors the country's political organization, with national coordination through the Ministry for Ecological Transition and the Demographic Challenge (MITECO) and 17 Autonomous Communities managing regional responsibilities. Under Law no. 43/2003 on Forests (Gobierno de Espana 2003), MITECO oversees multiple entities involved in wildfire management, including the National Forest Fire Information Coordination Center (CCINIF), which coordinates wildfire suppression resources, and the Committee for the Fight Against Forest Fires (CLIF), that brings together state and regional representatives to focus on both prevention and response efforts. In France, the Ministry of Agriculture is responsible for the forest defense against wildfire policies (DFCI) delegating operational tasks to the National Forestry Office (ONF). Firefighting, however, is overseen by the Ministry of the Interior's Department of Crisis Management and Civil Security. Fire prevention follows a multi-tiered structure involving authorities at departmental, forest massif, and forest owner association levels. In Greece, Law no. 2690/1999 on Forest Fire Prevention and Suppression (Government Gazette of the Hellenic Republic 2020), amended by Law no. 4069/2021 (Government Gazette of the Hellenic Republic 2022), established the Hellenic Fire Corps (coordinated by the General Secretariat for Civil Protection and now belonging to the new Ministry of Civil Protection and Climate Crisis) as the lead agency for firefighting efforts. Meanwhile, the Forest Service, part of the Ministry of Environment and Energy, handles forest management and fire prevention. Regional and municipal governments also contribute to fire prevention and first intervention, including maintaining local firebreaks and conducting public education campaigns.

Most of these countries have recently overhauled their key policies and strategies. Portugal's National Plan for Integrated Rural Fire Management (PNGIFR) for 2020-2030 emphasizes building a sustainable rural landscape, protecting rural spaces, and safeguarding people and properties. The PNGIFR is implemented through the National Action Plan (PNA), aimed at prioritizing prevention over suppression (Pandey et al. 2023, Ferreira et al. 2024) through a number of initiatives, including forest management and fuel treatments, the National Cadastral Information System establishment, and promoting an integrated approach to governance and multi-level adaptive management under Law Decree no. 82/2021.

In Spain, wildfires have long been central to the Spanish Forestry Strategy (1999) and the Spanish Forestry Plan (2002) and are primarily governed by the Forest Fire Prevention and Suppression Law (Law no. 21/2015 - Gobierno de Espana 2015). Each Autonomous Community enforces its own legislation, aligned with national policies. In 2022, MITECO proposed a unified national framework for wildfire management, that outlines strategic guidelines to enhance suppression efforts while integrating proactive measures for land sustainability, shared responsibility in land management, and future risk preparedness (https://civil-protection-knowledge-network.europa.eu/media/strategic-guidelines-wildland-fire-management-spain).

Similarly, forest policy in France integrates wildfire management based on three national codes. The Forest Code outlines the regulations governing forest management, protection, and utilization; the Environment Code provides local plans to prevent and protect communities from fire risks (PPRIF); and the General Code of Territorial Authorities (CGCT) coordinates civil protection and rescue operations. Following the catastrophic wildfires of summer 2022, a new action plan was introduced to enhance fire danger forecasting, increase public awareness campaigns, and promote reforestation efforts. Furthermore, Law no. 580/2023 (Legifrance 2023), also strengthens wildfire prevention by, among other measures, implementing a national strategy for forest and non-woodland land protection, improving regulations on forest-urban interfaces to mitigate fire occurrence and reduce vulnerability, and mobilizing the agricultural sector due to its crucial role in wildfire prevention.

Despite lacking a comprehensive national wildfire risk management strategy covering the whole wildfire management cycle in an integrated manner, Greece has implemented various planning instruments to address wildfire threats. The National Forest Strategy (2018-2038; see Tab. S1 in Supplementary material) focuses on proactive fire planning, reforestation, and the development of regional roadmaps. Furthermore, the Action Plan for Forest Fire Management (2018) includes prevention, preparedness, and response actions at different administrative levels. New institutional changes, such as the establishment of the Ministry for Climate Crisis and Civil Protection in 2021 and recent legislation (Law no. 4662 /2020, Law no. 4936 2022, Law no. 5075/2023), highlight Greece's commitment to a more integrated and climate-adaptive approach to disaster risk management, including wildfire management. These laws emphasize harmonization of climate change adaptation with disaster risk reduction in response to growing climate threats (Casartelli & Mysiak 2023) and improving coordination between agencies, risk assessments, and public engagement in preventive actions (Mavroulis et al. 2025).

Research insights into wildfire governance

Wildfire management in Italy is facing significant challenges due to increasingly frequent and intense wildfires caused by the interactions between socio-economic changes and land use in rural areas, combined with increased extreme weather conditions (Ascoli et al. 2021, Salis et al. 2022). These events often overwhelm Regional firefighting systems, leading to emergency management responses that overlook critical land management strategies for creating fire-resilient landscapes (Kirschner et al. 2024). This urgent situation prompted a strong reaction from the Italian scientific community in recent years, resulting in increased research on integrated fire management approaches (Bovio et al. 2017, Tonarelli et al. 2020, Bacciu et al. 2022, Ascoli et al. 2023, Salis et al. 2023, Spadoni et al. 2023) and on the multiple components that influence fire management, such as land use, socio-economic factors, and future climate changes.

In the following sections, we summarize current Italian research to provide a comprehensive overview of recent advances and challenges in wildfire management. This analysis is based on the annual national survey conducted within the Italian scientific community and compiled in the "Research Activities Aimed at Improving Fire Management" section of recent EFFIS reports (from 2018 to 2023). Our ultimate goal is to identify knowledge gaps and strategic approaches, highlight effective strategies, and pinpoint areas that require further investigation. This holistic review aims to enable policy and decision makers to make informed decisions, optimize resource allocation, and implement evidence-based practices to improve wildfire management efforts across Italy.

Land use and land use change

Significant research has focused on understanding the interactions between land use and wildfires. Salvati & Zitti (2009) assessed the land degradation processes using an integrated analysis of socio-economic and ecological indicators in a study area subjected to large variations of land use. A similar analysis conducted in Sardinia by Bajocco et al. (2010, 2012) revealed that land-use and land-cover structure affect wildfire patterns and land degradation dynamics. Guglietta et al. (2011) analyzed

remote sensing data in rural-forest interface in Sardinia, revealing a strong positive correlation between fire risk and anthropogenic land use, and a negative correlation with semi-natural and natural vegetation cover. Salis et al. (2019) observed an expansion of cork oak forests in Sardinia, linked to various environmental and socioeconomic factors, alongside a negative correlation between population density and cork oak expansion, contributing to increased fuel load and continuity. A comprehensive National-scale analysis by Ascoli et al. (2021) investigated the selective burning patterns of large wildfires and recurrent fires in relation to intense land use changes. The study revealed that large fires mainly impacted areas experiencing high rates of forest expansion, while recurrent fires were prevalent in regions transitioning from abandoned pastures and grasslands to shrublands. The study suggested that continuous agroforestry management can help mitigating large fires by enhancing firefighting accessibility and effectiveness. Parente et al. (2023) analyzed the spatial relationship between wildfires and land use changes in Italy over the past two decades. They identified decreases in forest and arable land alongside increases in shrub cover, with wildfires mostly occurring in forests, leading to transitions to woodland and shrubland. Recurrent wildfire ignitions were noted in several areas, including near urban interfaces. Bianchini et al. (2021) examined the relationship between urban expansion and land use change in the metropolitan area of Rome, finding a reduction in croplands and buffer zones between urban settlements and forests. They emphasized the need for spatial planning to create and maintain natural or agricultural buffers. A similar approach was applied by Salvati et al. (2014), which analyzed peri-urban landscape changes, highlighted the role played by land use change and forest transition as driving factors, and suggested the adoption of sustainable land management practices by integrating urban planning and environmental policies into a unique strategy for the protection of agroforestry systems. The studies of Bajocco et al. (2020) and Mantero et al. (2020) confirmed the influence of land use and land use changes on current fire regimes. Several studies have demonstrated the viability to estimate and predict the impacts of fuel type and land-use change. For example, Salis et al. (2022) applied a wildfire simulator at the landscape level to predict the effects of increasing levels of land abandonment, that substantially raised annual areas burned, high flame length probabilities, average fire size, and the likelihood of large and fast-spreading events at the landscape level in central-western Sardinia. Modugno et al. (2016) analyzed the relationship between wildland-urban interface (WUI) distance and wildfires, proposing the adoption of a wise land management based on mapping WUI areas and defining buffer zones between urban areas and surrounding vegetation. Lari et al. (2009) proposed a multi-risk assessment framework in which wildfire risk was calculated by integrating various land-use factors.

Socio-economic factors

Numerous studies have delved into the socio-economic dynamics affecting wildfire risk and regimes. Carlucci et al. (2019) analyzed national socio-economic trends in Italy from 1961 to 2017, uncovering correlations between rapid socioeconomic development, demographic changes, and shifting wildfire patterns. The study highlighted significant differences in agricultural production, population distribution, education, and demographic trends across decades, from the "baby boom" of the early 1960s to trends like land abandonment and increased environmental protection, which have influenced fire attributes over time. Ferrara et al. (2019) found higher values of wildfire frequency, intensity, and severity in socioeconomic contexts characterized by rural poverty, unemployment, and deregulated urban expansion, especially in southern Italy. Similarly, Canepa (2024), employing a non-additive quantile panel regression model to analyze the impact of socioeconomic factors on wildfire crimes, identified material inequality, poverty, and unemployment as significant drivers, particularly in southern Italy. It is interesting to note that Canepa (2024) suggested a dualism between areas with high and low agricultural employment. In the former, higher employment rates correlate with higher rates of arson, possibly due to intentional forest fires to expand agricultural land. Conversely, in the latter scenario, increased agricultural employment seems to have a protective effect on forests. Both studies advocated for an integrated and robust policy framework approach to comprehend the role of local communities in fire-prone area management (Ferrara et al. 2019), mitigate income inequality and stimulate economic growth, and, in turn, curb wildfire occurrences (Canepa 2024). Spadoni et al. (2023) recently employed a random forest approach to analyze the impact of socioeconomic variables on wildfire incidence. Their results revealed that territories with active land governance exhibit low wildfire impacts, even under adverse environmental conditions.

Bajocco et al. (2019) studied how demographic changes affect wildfire trends on Sardinia. They found that wildfire occurrences are increasing in heavily managed areas with positive demographic trends, while less impacted regions, typically inland, show a decrease in wildfire occurrences and negative demographic changes. Other studies on this topic, conducted in different Regions of Italy (Carlucci et al. 2019, Oliveira et al. 2012), could together contribute to the promotion of an informed approach to wildfire management by incorporating the effects of socio-economic and demographic variables in policies aimed at increasing the preparedness to large fires and the mitigation of wildfire impacts.

Regarding the effectiveness of common policies on forest fire management, both Colonico et al. (2022) and Spadoni et al. (2023) explored the relationship between the expenditures of the European Union Rural Development Program (RDP) and several fire activity indicators. Their results suggested a role for managed rural areas in mitigating fire activity, and a spatial mismatch between wildfire prevention expenditure and high fire activity contexts. In particular, Spadoni et al. (2023) demonstrated that territories with more active land governance, including RDP investments, experience lower wildfire impacts, even under severe flammability and climatic conditions. The authors suggest the integration of territorial planning information within the RDP funding allocation criteria and the integration of RDP indirect prevention measures within fire management plans as a cost-effective approach, aiming to leverage the impact of public policies on wildfire risk management.

Climate change and adaptation strategies

Recent reviews by Bacciu et al. (2017) and Spano et al. (2020) examined the impacts of climate change on future fire metrics in Southern Europe, considering projection studies and climate-fire relationships. Studies by Moriondo et al. (2006), Arca et al. (2012), and Bedia et al. (2014) predict a 20% to 40% increase in fire danger in Italy by the end of the century using AR4 scenarios. Faggian (2018) forecasts a minimum 20% increase in summer temperatures and dry conditions across most of Italy by 2050. Additionally, Moriondo et al. (2006) and Bedia et al. (2014) predict a fire season extension of 20 to 40 days by the end of the century due to prolonged droughts. Future burned areas are projected to increase significantly, ranging from 37% to 187% for the Euro-Mediterranean region by the end of the century (Migliavacca et al. 2013, Turco et al. 2018). Few studies have simulated the impacts of climate change on potential wildfire spread and behavior in Italy (Lozano et al. 2017). Southern Italy and the Islands are particularly susceptible to increased fire intensity and risk by the end of the century.

In this context, recent reports and strategies (SRACC 2019, PNACC 2023) identified adaptation objectives, including integrated wildfire governance actions across territorial levels and agencies (Bovio et al. 2017, Cacciatore et al. 2020, Bacciu et al. 2022, Kirschner et al. 2024). These actions encompass coordination with environmental policies and advancements in the bioeconomy sector (Marchetti & Ascoli 2018, Ascoli et al. 2022, 2023) to mitigate fire risk and benefit farmers and forest owners. An-

other objective is promoting a sustainable forest management for immediate and long-term community benefits and resilience to impacts (Nocentini et al. 2017). Fuel management through the application of closer-to-nature silviculture principles enhances forest resistance and resilience to fire (Ascoli & Bovio 2013, Bovio et al. 2014, Vacchiano et al. 2020), improving efficiency and adaptation to climate change. To mitigate the potential impacts of wildfires and limit their spread, prevention strategies based on fuel and land management in rural and forest areas can play a key role and need to be fostered at the National scale (Corona et al. 2015, Salis et al. 2016, 2018a). In recent years, promising methods and results have emerged to identify high-risk zones and prioritize areas for fire prevention activities (Elia et al. 2020, 2022, Salis et al. 2021, 2023, Trucchia et al. 2022). Moreover, some studies have evaluated how land governance measures can influence wildfire patterns in Italy and mitigate wildfire risk (Colonico et al. 2022, Spadoni et al. 2023). Kirschner et al. (2024) analyzed how different national and subnational governance procedures interrelate to promote particular risk management strategies. Their findings show that these procedures can both facilitate and hinder a paradigm shift in wildfire risk management practices in Italy, ultimately affecting adaptive change. Adaptive governance was a central pillar of the systemic fire risk management framework outlined by Bacciu et al. (2022). They emphasized the importance of cooperation and coordination across different scales to address short-term and fragmented governance and promote the creation of fire-resilient landscapes.

Future improvements for fire management in Italy

Based on the analysis of the Italian wildfire management and governance structure and the recent Italian research summarized for a comprehensive understanding of the latest advances and challenges in the field, key observations and policy recommendations can be derived to improve fire management strategies, focusing on enhancing coordination, prevention, risk assessment and policy effectiveness.

Key observations include the acknowledgement of two main components: (i) the changing fire dynamics due to the complex interactions between land use, socio-economic, and climate changes; and (ii) the increasingly ineffective response to wildfires in case of extreme weather conditions.

Extended fire danger, season, and proneness

Climate change leads to extended periods of high temperatures and drought conditions, prolonging the fire seasons and positively impacting on vegetation flammability, thereby increasing the occurrence of high fire danger days. This will expand the areas prone to wildfires and the scale of risk, increase vulnerability of ecosystems and anthropogenic values to larger fires and losses, and escalate firefighting costs.

Socio-economic changes

Socio-economic changes have a significant correlation with the wildfire patterns in Italy. Rural depopulation and deregulated urban expansion are identified as key drivers of wildfire risk, particularly in southern Italy. In particular, the expansion of the wildland-urban interface (WUI) stands out among the possible risk factors. According to Tang et al. (2024), Europe experienced the largest absolute increase of the WUI fraction from 2001 to 2020 (0.08% per year), and urbanization is expected to increase, with seven out of ten people living in cities by 2050 (https://www.worldbank.org). Simultaneously, there is a growing trend of "second homes" in natural and high-value tourist areas, which contributes to exacerbating wildfire risk (Mancini et al. 2018, Bar-Massada et al. 2023). The latest research underscore the need for integrated, informed, and well-governed approaches to wildfire management that should consider socio-economic contexts, effective land management, and targeted public policies to mitigate the impacts of wildfires.

Land use change

The abandonment of agricultural and pastoral land has led to unmanaged shrubland and forest regrowth, thereby increasing the biomass available for burning and increasing wildfire risk (Bovio et al. 2017). Recent researches highlight the complex interactions between land use, land cover change and fire dynamics, and emphasizes the need for integrated and sustainable land management practices and policies that discourage abandonment, promote sustainable agriculture and forestry, implement preventive land management and prescribed burning to manage excess biomass, and define zoning regulations to effectively manage land uses.

Simplistic interpretations

Wildfires are often attributed to arson without sufficient evidence obtained through criminal investigations. This oversimplification results from multiple factors, including insufficient media and public awareness, inadequate education regarding the causes of wildfires, and limited wildfire forensic and investigative techniques.

Inadequate management

The current strategies for managing wildfires in many Italian Regions primarily focus on suppressing wildfires, rather than preventing them. This approach is unsustainable in the long term. It is necessary to implement policies that support a paradigm shift from a suppression-centric approach to a more holistic one, which considers the landscape resilience (Bacciu et al. 2022). Rather than isolating prevention, preparedness, and mitigation efforts and assigning them to different organizations with their specific objectives, a comprehensive approach should integrate these elements with forest and landscape management (Ascoli et al. 2023). Current landscape planning approaches for wildfire risk mitigation implemented in Lombardy, Piedmont, and Tuscany (Cacciatore et al. 2020, La Mela Veca et al. 2024) represent a model for other Italian Regions. Moreover, investment policies are essential for promoting the forest economy and utilizing biomass as a means to encourage wildfire prevention. Early detection systems, awareness-raising efforts, and active community engagement are also crucial. Furthermore, there is a lack of regular audits and evaluations of existing wildfire management strategies, which are essential for continuous improvement.

To manage these challenges, policy makers should identify more effective wildfire management strategies. Research and development for adaptive forest fire management and enhancing landscape resilience should focus on new wildfire regimes influenced by potential weather extremes and climate change. Existing policies should incorporate new scientific findings on fire dynamics to ensure that management practices align with the latest knowledge and enhance the ability to mitigate and respond to wildfires effectively. Overall, these implications provide a comprehensive framework for addressing the challenges associated with wildfires and improving management strategies.

Policy recommendations

It is essential to adopt integrated policies that address multi-dimensional aspects and multiple root causes of wildfires, including climate change, land use, and socio-economic dynamics. In this context, it is essential to ensure adequate resource allocation for research on local ecosystems, fire behavior, and climate projections to inform wildfire prevention, mitigation, and response efforts.

The integrated policies should promote prevention through active landscape management, implementation of wildfire regulations, public awareness and education, and engagement in wildfire risk prevention and mitigation.

In terms of landscape management, we advocate for sustainable land use practices and preventive silviculture to reduce forest density and continuity as a key strategy for wildfire risk mitigation. This involves integrating short-term wildfire risk management into long-term forest management practices and planning. Indeed, we recommend balancing forest and landscape resilience objectives with preventive forest management (including closer-to-nature silviculture principles) while acknowledging the importance of responding to wild-

fires. There is also an urgent need for including wildfire as natural hazards, and adequately considering wildfire risk in urban and development planning, focusing on building resilience and, in general, making wildfire prevention and management mainstream into current land planning and programming policies.

It is furthermore crucial to define a holistic framework comprising an integrated wildfire management approach that identifies vulnerable areas and populations exposed to wildfires, coupled with active community engagement and education programs to involve local communities in prevention, preparedness, and response efforts. Research has demonstrated that using fire modeling to characterize and measure fine-scale wildfire risk factors can be beneficial. By considering historical fire regimes, fuel sources, weather conditions, and other factors related to the occurrence of large wildfires, this approach can help generate a wide range of potential wildfire footprints. Additionally, it can predict future large-scale events and assess the likelihood of severe incidents affecting forests, rural areas, human communities, and valuable assets (Salis et al. 2023). A key point is that wildfire modeling systems would benefit from the availability of high-resolution remote sensing data, particularly LiDAR observations, to monitor the fuel state and its characteristics. These systematic observations, already available in other European countries (such as Spain, Sweden, France, among others), could be used to improve the assessment and mapping of canopy fuels or estimate canopy understory. Integrating climate change models into risk assessment and planning is imperative to better understand the impact of climate change on wildfire behavior, and develop accurate and effective strategies to enhance our preparedness and adaptation to the new conditions triggered by climate and socio-economic changes.

On the other hand, policies should also encourage active community engagement and collaboration between different stakeholders, including local communities, landowners, public authorities, and researchers, to develop shared approaches and innovative solutions. Casartelli & Mysiak (2023) emphasized the crucial importance of education, knowledge and fire awareness among decision-makers and people (especially for those living in fire-prone areas), suggesting targeted awareness campaigns and training programs to educate the population on evacuation procedures and/or "stay in shelter" practices. One step further is represented by empowering communities to actively participate in wildfire risk management (*e.g.*, in landscape management) through the integration of bottom-up demands and positions in participatory processes of discussion and negotiation among the various stakeholders (Bacciu et al. 2022), including private companies, such as the insurance industry (Kron et al. 2019).

New policies for sustainable management could include several approaches. For example, the introduction of incentives for landowners to adopt fire-resistant practices and fire prevention measures, such as the payment mechanisms for ecosystem services, where the value of the management by landowners for community protection is recognized (Marchetti & Ascoli 2018), or the activation of supply chains through the valorization of products resulting from prevention actions, such as those for bioconstruction, biomass for heat and energy production, or dairy products derived from prescribed grazing, thereby aligning with the principles of the circular economy (Ascoli et al. 2020, 2023). Additionally, the promotion of forms of forest associations for wildfire prevention (Pettenella & Loreggian 2023) and effective measures to allow active interventions on abandoned and silent lands (La Mela Veca et al. 2024) are strategic to overcome the challenges posed by land fragmentation and to encourage management by small landowners. In more rural areas, grazing and agricultural activities represent valuable means to maintain well-managed land-use mosaics and simultaneously reduce the spread and intensity of wildfires and increase the fire-fighting effectiveness (Salis et al. 2022). In this sense, rural development policies can play a key role in reducing wildfire risk by supporting agriculture and farming activities and fostering the maintenance of extensive livestock grazing and agricultural productions in remote zones and in areas prone to abandonment (Moreira & Peer 2018, Salis et al. 2022). Furthermore, as suggested by Colonico et al. (2022) and Spadoni et al. (2023), it is crucial to integrate rural development policies and incentives with fire management planning to define reward criteria with direct and indirect effects on fire prevention and landscape flammability.

Finally, we deem that a revision of National legislation is needed in order to better regulate the governance structure at Regional and National levels. In agreement with La Mela Veca et al. (2024), we strongly suggest the establishment of a multidisciplinary task force at the Regional level to develop and oversee a holistic and flexible approach to wildfire management, with the aim of facilitating the information exchange between the various Regional and National Agencies that support Regional administration. A well-structured emergency management strategy is essential for timely large-scale post-fire restoration plans following landscape fires. This strategy should include National support for Regional administrations to reduce regulatory constraints, enhance post-fire severity assessments, strategically allocate resources, and coordinate all key stakeholders, including land managers, trained professionals, and enterprises within the wood value chain (Cesco et al. 2024). In addition, given the increasing frequency of extreme weather events, the wildfire management strategy needs to be revised accordingly to be flexible and adaptable to changing conditions and new challenges that emerge over time.

As part of the preparedness activities, this may also involve (i) developing comprehensive training programs for firefighters, first responders, and communities on wildfire safety, prevention, and mitigation; (ii) fostering the psychophysical and athletic preparation of fire and forest operators to avoid accidents and injuries during operations, considering the challenges of working in a changing climate; (iii) developing specialized protocols, languages and functions (*e.g.*, wildfire analyst, incident commander, communication officer) tailored to operate under such conditions. Policymakers should conduct periodic reviews to ensure that strategies remain up-to-date and effective, identify gaps, incorporate new knowledge, and adapt strategies accordingly. For example, it would be beneficial to periodically conduct a comprehensive cost-benefit analysis and reallocate resources more efficiently (La Mela Veca et al. 2024), considering maintenance costs during periods of low fire activity. Inter-regional collaboration for resource sharing and best practices is highly beneficial for exchanging knowledge, experiences, and resources with other countries. We feel urgent establishing a permanent inter-agency coordination body to promote collaboration, information sharing, and coordination among various organizations involved in wildfire management at the National level.

Conclusions

Wildfire management in Italy is at a crossroads. The increasingly complex wildfire landscape demands a holistic and integrated approach that synergistically amalgamates prevention, mitigation, and response, while also fostering dynamic adaptability to evolving wildfire scenarios.

Revisiting and recalibrating current policies is imperative to strengthen the system resilience and maximize the potential benefits of reduced wildfire damage, improved ecosystem vitality, and bolstered community resilience.

Pyro-silvicultural principles and effective fuel management in rural and forest areas are vital to build fire-resistant and resilient territories over time, and prevention strategies based on these principles need to be promoted on a National scale (Bovio et al. 2014, Corona et al. 2015, Salis et al. 2016, 2018b, Vacchiano et al. 2020). Furthermore, integrated wildfire governance actions, coordination with environmental policies, advancements in the bioeconomy, sustainable forest management, and rural development are also identified as crucial, in terms of adaptation objectives, to mitigate fire risk and enhance resilience (SRACC 2019, Cacciatore et al. 2020, Bacciu

et al. 2022, PNACC 2023, Kirschner et al. 2024).

Acknowledgements

This study was conducted within the FirEUrisk project (https://fireurisk.eu), which has received financial support from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101003890. The work of DA was carried out within the Agritech National Research Center and received funding from the European Union Next-Generation EU (*Piano Nazionale di Ripresa e Resilienza* (PNRR) - *Missione 4 Componente 2, Investimento 1.4* - D.D. 1032 17/06/2022, CN00000022). Additionally, the work of VB, MS, and GP was undertaken within the CRITERIA Project (Grant No. B53D23029500001), while BA contributed through the FIRE-BOX Project (Grant No. P2022MXRK9). Both projects were funded by the Italian Ministry of Education, University and Research (MIUR) under the EU Next Generation Program (PNRR – PRIN).

The Authors would like to extend their acknowledgements to the Working Group "Forest Fire Management" of the Italian Society of Sylviculture and Forest Ecology (SISEF) and to Giovanni Fresu and Gianfilippo Micillo (Vigili del Fuoco) for their diligent review of the paper and for providing valuable feedback.

References

Almeida M, Ribeiro L, Alves D, Viegas D, Vaz Pinto V, Marques R, Gomes A, Ballereau D, Lahaye S, Romain M, Salis M, Arca B, Bacciu V, Canu A, Del Giudice L, Duce P, Pellizzaro G, Stroppiana D, Ventura A, Cabiddu S, Casula A, Cuccu G, Pinna T, Vaccargiu M, Campesi S, Casule F, Chessa M, Cinus S, Massidda P, Peddes M, Soi F, Tola F, Usai A, Castiglia C, Dessy C, Delitala A, Trudu P, Angotzi S, Murtas F, Barone A, Erriu N, Fresu G, Melis G, Fiorucci P, Pampanoni V, Laneve G, Eftychidis G, Varela V, Gkotsis I, Petrou K, Boustras G, Senekkis I, Kirschner J, Pandey P, San-Miguel-Ayanz J, Durrant T, Liberta G, Boca R, Maianti P, Branco A, Oom D, De Rigo D, Roglia E, Scionti N, Suarez-Moreno M (2023). Analysis of 2021 critical wildfire events in the Mediterranean region. JRC Technical Reports, Publication Office of the European Union, Luxembourg, pp. 116. - doi: 10.2760/562495

Arca B, Pellizzaro G, Duce P, Salis M, Bacciu V, Spano D, Ager A, Scoccimarro E (2012). Potential changes in fire probability and severity under climate change scenarios in Mediterranean areas. In: "Modelling Fire Behaviour and Risk" (Spano D, Bacciu V, Salis M, Sirca C eds). Nuova Stampa Color, Muros, Sassari, Italy, pp. 92-98.

Ascoli D, Bovio G (2010). Tree encroachment dynamics in heathlands of north-west Italy: the fire regime hypothesis. iForest 3: 137-143. - doi: 10.3832/ifor0548-003

Ascoli D, Bovio G (2013). Prescribed burning in Italy: issues, advances and challenges. iForest - Biogeosciences and Forestry 6: 79-89. - doi: 10.3832/ifor0803-006

Ascoli D, Vacchiano G, Scarpa C, Arca B, Barbati A, Battipaglia G, Elia M, Esposito A, Garfì V, Lovreglio R, Mairota P, Marchetti M, Marchi E, Meytre S, Ottaviano M, Pellizzaro G, Rizzolo R, Sallustio L, Salis M, Sirca C, Valese E, Ventura A, Bacciu V (2020). Harmonized dataset of surface fuels under Alpine, temperate and Mediterranean conditions in Italy. A synthesis supporting fire management. iForest 13: 513-522. - doi: 10.3832/ifor3587-013

Ascoli D, Moris JV, Marchetti M, Sallustio L (2021). Land use change towards forests and wooded land correlates with large and frequent wildfires in Italy. Annals of Silvicultural Research 46: 177-188. - doi: 10.12899/ASR-2264

Ascoli D, Ferlazzo S, Marchetti M, Motta R, Pompei E, Stefani A (2022). Strategia Forestale Nazionale italiana e governo integrato degli incendi boschivi [The National Forestry Strategy of Italy and the forest fire governance]. Forest@ - Journal of Silviculture and Forest Ecology 19: 31-35. [in Italian with English summary] - doi: 10.3832/efor4093-019

Ascoli D, Plana E, Oggioni SD, Tomao A, Colonico M, Corona P, Giannino F, Moreno M, Xanthopoulos G, Kaoukis K, Athanasiou M, Colaço MC, Rego F, Sequeira AC, Acácio V, Serra M, Barbati A (2023). Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. International Journal of Disaster Risk Reduction 92: 103715. - doi: 10.1016/j.ijdrr.2023.103715

Bacciu V, Salis M, Sirca C, Chiriacò MV, Spano D (2017). Vegetazione in fiamme. Quali i fronti del problema? [Vegetation on fire. What are the fronts of the problem?]. Equilibri 21: 352-367. [in Italian]

Bacciu V, Sirca C, Spano D (2022). Towards a systemic approach to fire risk management. Environmental Science and Policy 129: 37-44. - doi: 10.1016/j.envsci.2021.12.015

Bajocco S, Pezzatti GB, Mazzoleni S, Ricotta C (2010). Wildfire seasonality and land use: when do wildfires prefer to burn? Environmental Monitoring and Assessment 164: 445-452. - doi: 10.1007/S10661-009-0905-X

Bajocco S, De Angelis A, Perini L, Ferrara A, Salvati L (2012). The impact of land use/land cover changes on land degradation dynamics: a Mediterranean case study. Environmental Management 49: 980-989. - doi: 10.1007/s00267-012-9831-8

Bajocco S, Ferrara C, Guglietta D, Ricotta C (2019). Fifteen years of changes in fire ignition frequency in Sardinia (Italy): a rich-get-richer process. Ecological Indicators 104: 543-548. - doi: 10.1016/j.ecolind.2019.05.030

Bajocco S, Ferrara C, Guglietta D, Ricotta C (2020). Easy-to-interpret procedure to analyze fire seasonality and the influence of land use in fire occurrence: a case study in Central Italy. Fire 3 (3): 46. - doi: 10.3390/fire3030046

Bar-Massada A, Alcasena F, Schug F, Radeloff VC (2023). The wildland-urban interface in Europe: spatial patterns and associations with socioeconomic and demographic variables. Landscape and Urban Planning. 235: 104759. - doi: 10.1016/ j.landurbplan.2023.104759

Bedia J, Herrera S, Camia A, Moreno JM, Gutiérrez JM (2014). Forest fire danger projections in the Mediterranean using ENSEMBLES regional climate change scenarios. Climatic Change 122: 185-199. - doi: 10.1007/S10584-013-1005-Z

Bianchini L, Egidi G, Alhuseen A, Sateriano A, Cividino S, Clemente M, Imbrenda V (2021). Toward a dualistic growth? Population increase and land-use change in Rome, Italy. Land 10 (7): 749. - doi: 10.3390/land10070749

Bovio G, Corona P, Leone V (2014). Gestione selvicolturale dei combustibili forestali per la prevenzione degli incendi boschivi [Silvicultural management of forest fuels for forest fire prevention]. Compagnia delle Foreste, Arezzo, Italy, pp. 202. [in Italian]

Bovio G, Marchetti M, Tonarelli L, Salis M, Vacchiano G, Lovreglio R, Elia M, Fiorucci P, Ascoli D (2017). Gli incendi boschivi stanno cambiando: cambiamo le strategie per governarli [Forest fires are changing: let's change the fire management strategy]. Forest@ - Journal of Silviculture and Forest Ecology 14: 202-205. [in Italian with English summary] - doi: 10.3832/efor2537-014

Bovio G, Marchi E (2010). Silviculture: forest fires, grazing. L'Italia Forestale e Montana 65: 113-119. - doi: 10.4129/ifm.2010.2.03

Cabiddu S, Brigaglia S, Congiu F, Delogu G, Lara G, Muntoni G, Usai L (2012). The Curraggia wildfire, analysis of an entrapment (28 July 1983). In: "Modelling Fire Behaviour and Risk" (Spano D, Bacciu V, Salis M, Sirca C eds). Nuova Stampacolor, Muros, Sassari, Italy, pp. 150-159. [in Italian]

Cacciatore I, Calvani G, Delogu G, Gottero F, Romano R (2020). Pianificazione della prevenzione degli incendi boschivi. L'approccio a differenti scale [Forest fire prevention planning. the different scale approach]. Sherwood 347: 18-21. [in Italian]

Calabri GC (1984). La prevenzione degli incendi boschivi: i problemi e le tecniche di difesa [Forest fire prevention: problems and defense techniques]. Edagricole, Bologna, Italy, pp. 236. [in Italian]

Canepa A (2024). Socio-economic risk factors and wildfire crime in Italy: a quantile panel approach. Empirical Economics 66: 431-465. - doi: 10.1007/s00181-023-02462-2

Carlucci M, Zambon I, Colantoni A, Salvati L (2019). Socioeconomic development, demographic dynamics and forest fires in Italy, 1961-2017: a time-series analysis. Sustainability 11: 1305. - doi: 10.3390/su11051305

Caruso C (2022). Il Corpo Forestale dello Stato, dalle origini alla unificazione con l'Arma dei Carabinieri. Due secoli di storia [The State Forestry Corps, from its origins to its unification with the Carabinieri. Two centuries of history]. Italian Ministry of Defense, Rome, Italy, website. [in Italian] [online] URL: http://www.carabinieri.it/media---comunicazione/silvae/la-rivista /aree-tematiche/storia/il-corpo-forestale-dello-stato-dalle-origini-alla-unificazione-con-l-arma-dei-carabinieri.-due-secoli-di-storia

Casartelli V, Mysiak J (2023). Wildfire peer review assessment framework (Wildfire PRAF). CMCC, Union civil protection peer review programme for disaster risk management, Brussels, Belgium, pp. 71. - doi: 10.25424/cmcc-6a3v-5g64

Cesco S, Ascoli D, Bailoni L, Bischetti GB, Buzzini P, Cairoli M, Celi L, Corti G, Marchetti M, Mugnozza GS, Orlandini S, Porceddu A, Gigliotti G,

Mazzetto F (2024). Smart management of emergencies in the agricultural, forestry, and animal production domain: tackling evolving risks in the climate change era. International Journal of Disaster Risk Reduction 114: 105015. - doi: 10.1016/j.ijdrr.2024.105015
Colonico M, Tomao A, Ascoli D, Corona P, Giannino F, Moris JV, Romano R, Salvati L, Barbati A (2022). Rural development funding and wildfire prevention: evidences of spatial mismatches with fire activity. Land Use Policy 117 (4): 106079. - doi: 10.1016/j.landusepol.2022.106079
Corona P, Ascoli D, Barbati A, Bovio G, Colangelo G, Elia M, Garfì V, Iovino F, Lafortezza R, Leone V, Lovreglio R, Marchetti M, Marchi E, Menguzzato G, Nocentini S, Picchio R, Portoghesi L, Puletti N, Sanesi G, Chianucci F (2015). Integrated forest management to prevent wildfires under Mediterranean environments. Annals of Silvicultural Research 39: 1-22. - doi: 10.12899/asr-946
Elia M, D'Este M, Ascoli D, Giannico V, Spano G, Ganga A, Colangelo G, Lafortezza R, Sanesi G (2020). Estimating the probability of wildfire occurrence in Mediterranean landscapes using Artificial Neural Networks. Environmental Impact Assessment Review 85: 106474. - doi: 10.1016/j.eiar.2020.106474
Elia M, Giannico V, Ascoli D, Argañaraz JP, D'Este M, Spano G, Lafortezza R, Sanesi G (2022). Uncovering current pyroregions in Italy using wildfire metrics. Ecological Processes 11 (1): 6442. - doi: 10.1186/s13717-022-00360-6
Elia M, Lafortezza R, Onofrio C, Costa-Saura JM, Bacciu V, Giannico V, Shao C, Sanesi G (2024). Coupling heat wave and wildfire occurrence across multiple ecoregions within a Eurasia longitudinal gradient. Science of The Total Environment 912: 169269. - doi: 10.1016/j.scitotenv.2023.169269
Faggian P (2018). Estimating fire danger over Italy in the next decades. Euro-Mediterranean Journal for Environmental Integration 3: 1-13. - doi: 10.1007/S41207-018-0053-1
Ferrara C, Salvati L, Corona P, Romano R, Marchi M (2019). The background context matters: local-scale socioeconomic conditions and the spatial distribution of wildfires in Italy. Science of The Total Environment 654: 43-52. - doi: 10.1016/j.scitotenv.2018.11.049
Ferreira C, Pinto LC, Valente M (2024). Forest fire causes and prevention strategies in Portugal: Insights from stakeholder focus groups. Forest Policy and Economics 169 (1): 103330. - doi: 10.1016/j.forpol.2024.103330
Fiorucci P, Gaetani F, Minciardi R (2008). Development and application of a system for dynamic wildfire risk assessment in Italy. Environmental Modelling and Software 23: 690-702. - doi: 10.1016/j.envsoft.2007.05.008
Fiorucci P, Andrea M, Bastia S, Gollini A, Gualtieri S, Negro D, Severino M (2015). Manuale d'uso del sistema previsionale della pericolosità potenziale degli incendi boschivi [User manual for the forecasting system of the potential danger of forest fires]. Website. [in Italian] [online] URL: http://www.mydewetra.org/wiki/images/6/67/Manuale_RISICO.pdf
Gobierno de Espana (2015). Modificación de la Ley 43/2003, de 21 de noviembre, de Montes [Amendment to Law 43/2003 of Nov 21st, 2003 on forests]. Agencia Estatal Boletin Oficial del Estado, Madrid, Spain, pp. 39. [in Spanish] [online] URL: http://www.boe.es/eli/es/l/2015/07/20/21/con
Gobierno de Espana (2003). Ley 43/2003, de 21 de noviembre, de Montes [Law 43/2003 of Nov 21st, 2003, on forests]. Agencia Estatal Boletin Oficial del Estado, Madrid, Spain, pp. 47. [in Spanish] [online] URL: http://www.boe.es/eli/es/l/2003/11/21/43/con
Government Gazette of the Hellenic Republic (2020). Law no. 4662 - National crisis management and risk management mechanism, restructuring of the General Secretariat of Civil Protection, upgrade of a civil protection volunteer system, reorganisation of the firefighting and other provisions. Website, pp. 156. [in Greek] [online] URL: http://www.et.gr/api/DownloadFeksApi/?fek_pdf=20200100027
Government Gazette of the Hellenic Republic (2022). Law no. 4936 - National Climate Law 4936/2022 on the transition to climate neutrality and adaptation to climate change. [in Greek] [online] URL: https://climate-laws.org/documents/national-climate-law-4936-2022-on-the-transition-to-climate-neutrality-and-adaptation-to-climate-change_2d6a
Governo Italiano (1877). Prima legge forestale "Maiorana Calatabiano", n. 3917 [Forest Law no. 3917 "Maiorana Calatabiano"]. Gazzetta Ufficiale no. 161, Rome, Italy. [in Italian] [online] URL: http://www.gazzettaufficiale.it/eli/gu/1877/07/11/161/sg/pdf
Governo Italiano (1923). Regio Decreto Legge n. 3267 - Riordinamento e riforma della legislazione in materia di boschi e di terreni montani [Royal Decree Law No. 3267 - Reorganization and reform of legislation on forests and mountain lands]. Gazzetta Ufficiale n.117, Rome, Italy, website. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:regio.decreto:1923-12-30;3267
Governo Italiano (1948). Decreto Legge n. 804 - Norme di attuazione per il ripristino del Corpo forestale dello Stato [Legislative Decree no. 804 - Implementation provisions for the restoration of the State Forestry Corps]. Gazzetta Ufficiale n.149, Rome, Italy. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:1948-03-12;804
Governo Italiano (1975). Legge n. 47 - Norme integrative per la difesa dei boschi dagli incendi boschivi [Law no. 47 - Supplementary provisions for the protection of forests from forest fires]. Gazzetta Ufficiale no. 161, Rome, Italy, website. [in Italian] [online] URL: http://www.gazzettaufficiale.it/eli/gu/1975/03/14/72/sg/pdf
Governo Italiano (2000). Legge n. 353 - Legge-quadro in materia di incendi boschivi [Law No. 353 - Framework law on forest fires]. Gazzetta Ufficiale no. 280, Rome, Italy, website. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2000;353
Governo Italiano (2015). Legge n. 124 - Deleghe al Governo in materia di riorganizzazione delle amministrazioni pubbliche [Law no. 124 - Delegations to the Government regarding the reorganization of public administrations]. Gazzetta Ufficiale no. 187, Rome, Italy, website. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2015-08-07;124~art11
Governo Italiano (2016). Decreto Legge n. 177 - Disposizioni in materia di razionalizzazione delle funzioni di polizia e assorbimento del Corpo forestale dello Stato, ai sensi dell'articolo 8, comma 1, lettera a), della legge 7 agosto 2015, n. 124, in materia di riorganizzazione delle amministrazioni pubbliche [Legislative Decree no. 177 - Provisions regarding the rationalization of police functions and absorption of the State Forestry Corps, pursuant to Article 8, paragraph 1, letter a), of Law no. 124 of 7 August 2015, regarding the reorganization of public administrations]. Gazzetta Ufficiale n.213, Rome, Italy. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2016;177~art19
Governo Italiano (2018a). Decreto Legge n. 1 - Codice della protezione civile [Legislative Decree no. 1 - Civil Protection Code]. Gazzetta Ufficiale n.17, Rome, Italy. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2018-01-02;1
Governo Italiano (2018b). Decreto Legge n. 34 - Testo unico in materia di foreste e filiere forestali [Legislative Decree no. 34 - Consolidated law on forests and forestry supply chains]. Gazzetta Ufficiale n.92, Rome, Italy. [in Italian] [online] URL: http://www.gazzettaufficiale.it/eli/id/2018/04/20/18G00060/sg
Governo Italiano (2021a). Decreto 23/12 - Approvazione della strategia forestale nazionale [Decree 23/12 - Approval of the National Forestry Strategy]. Gazzetta Ufficiale no. 33, Rome, Italy. [in Italian] [online] URL: http://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2022-02-09&atto.codiceRedazionale=22A00834&elenco30giorni=false
Governo Italiano (2021b). Decreto Legge n. 120 - Disposizioni per il contrasto degli incendi boschivi e altre misure urgenti di protezione civile [Legislative Decree no. 120 - Provisions for combating forest fires and other urgent civil protection measures]. Gazzetta Ufficiale n.216, Rome, Italy. [in Italian] [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legge:2021-09-08;120
Governo Italiano (2021c). Legge n. 155 - Conversione in legge, con modificazioni, del decreto-legge 8 settembre 2021, n. 120, recante disposizioni per il contrasto degli incendi boschivi e altre misure urgenti di protezione civile [Law no. 155 - Conversion into law, with amendments, of decree-law no. 120 of 8 September 2021, containing provisions for combating forest fires and other urgent civil protection measures]. Gazzetta Ufficiale no. 266, Rome, Italy. [in Italian]. [online] URL: http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2021-11-08;155
Governo Português (2021). Decreto-Lei n. 82 - Sistema de gestão integrada de fogos rurais no território continental [Law Decree no. 82 - Integrated rural fire management system in mainland Portugal]. Pub. L. No. 82, Lisbon, Portugal. [in Portuguese]
Guglietta D, Conedera M, Mazzoleni S, Ricotta C (2011). Mapping fire ignition risk in a complex anthropogenic landscape. Remote Sensing Let-

ters 2: 213-219. - doi: 10.1080/01431161.2010.512927
ISPRA (2019). Entità degli incendi boschivi [Extent of forest fires]. Istituto Superiore per la Protezione e la Ricerca Ambientale - ISPRA, Rome, Italy, web site [in Italian] [online] URL: http://indicatoriambientali.isprambiente.it/it/patrimonio-forestale/entita-degli-incendi-boschivi
ISPRA (2023). Ecosistemi forestali ed incendi: aggiornamento 1 settembre 2023 [Forest Ecosystems and Fires: Update September 1, 2023]. Istituto Superiore per la Protezione e la Ricerca Ambientale - ISPRA, Rome, Italy, website. [online] URL: http://www.isprambiente.gov.it/it/archivio/notizie-e-novita-normative/notizie-ispra/2023/09/ecosistemi-forestali-ed-incendi-aggiornamento-1-settembre-2023
Kirschner JA, Ascoli D, Moore P, Clark J, Calvani S, Boustras G (2024). Governance drivers hinder and support a paradigm shift in wildfire risk management in Italy. Regional Environmental Change 24 (1): 245. - doi: 10.1007/S10113-023-02174-4
Kron W, Löw P, Kundzewicz ZW (2019). Changes in risk of extreme weather events in Europe. Environmental Science and Policy 100: 74-83. - doi: 10.1016/j.envsci.2019.06.007
La Mela Veca DS, Piroli E, Bacciu V, Barbera G, Brunori A, Calvani G, Mariano Delogu G, Elia M, La Mantia T, Laschi A, Lovreglio R, Masiero M, Salis M, Tonarelli L, Motta R, Ascoli D (2024). Governare gli incendi in Italia: superare l'emergenza, pianificare la prevenzione [Managing fires in italy: overcoming the emergency, planning prevention]. Forest@ - Journal of Silviculture and Forest Ecology 21: 37-47. [in Italian with English summary] - doi: 10.3832/efor4606-021
Lari S, Frattini P, Crosta GB (2009). Integration of natural and technological risks in Lombardy, Italy. Natural Hazards and Earth System Sciences 9: 2085-2106. - doi: 10.5194/nhess-9-2085-2009
Legifrance (2023). Loi n. 580 - Renforcer la prévention et la lutte contre l'intensification et l'extension du risque incendie [Law No. 580 - Strengthening prevention and the fight against the intensification and spread of fire risk]. Legifrance, Paris, France. [in French] [online] URL: http://www.legifrance.gouv.fr/loda/id/JORFTEXT000047805414/
Lozano OM, Salis M, Ager AA, Arca B, Alcasena FJ, Monteiro AT, Finney MA, Del Giudice L, Scoccimarro E, Spano D (2017). Assessing climate change impacts on wildfire exposure in Mediterranean areas. Risk Analysis 37: 1898-1916. - doi: 10.1111/risa.12739
Mancini LD, Elia M, Barbati A, Salvati L, Corona P, Lafortezza R, Sanesi G (2018). Are wildfires knocking on the built-up areas door? Forests 9 (5): 234. - doi: 10.3390/f9050234
Mantero G, Morresi D, Marzano R, Motta R, Mladenoff DJ, Garbarino M (2020). The influence of land abandonment on forest disturbance regimes: a global review. Landscape Ecology 35: 2723-2744. - doi: 10.1007/s10980-020-01147-w/tables/3
Marchetti M, Ascoli D (2018). Landscape, bioeconomy and wildfire management: a challenge to face very soon. Forest@ - Journal of Silviculture and Forest Ecology 15: 71-74. [in Italian with English summary] - doi: 10.3832/efor0072-015
Maringer J, Conedera M, Ascoli D, Schmatz DR, Wohlgemuth T (2016). Resilience of European beech forests (*Fagus sylvatica* L.) after fire in a global change context. International Journal of Wildland Fire 25: 699-710. - doi: 10.1071/WF15127
Mavroulis S, Lekkas E, Grambas A, Mavrouli M, Mokos V, Kourou A, Thoma T, Karagiannis F, Stamati E, Kaviris G, Kouskouna V, Lozios S, Vassilakis E, Kalligeris N, Charalampakis M, Stefanou N (2025). Enhancing preparedness and resilience for seismic risk reduction: the "Minoas 2024" full-scale exercise for earthquakes and related geohazards in Crete (Southern Greece). Geosciences 15 (2): 59. - doi: 10.3390/geosciences15020059
Migliavacca M, Dosio A, Camia A, Hobourg R, Houston-Durrant T, Kaiser JW, Khabarov N, Krasovskii AA, Marcolla B, San Miguel-Ayanz J, Ward DS, Cescatti A (2013). Modeling biomass burning and related carbon emissions during the 21st century in Europe. Journal of Geophysical Research: Biogeosciences 118: 1732–1747. doi: 10.1002/2013JG002444
MiPAAF (2022). Strategia forestale nazionale. Direzione Generale dell'Economia Montana e delle Foreste, Ministero delle Politiche Agricole, Alimentari e Forestali - MiPAAF, Rome, Italy, pp. 74. [online] URL: https://www.reterurale.it/foreste/StrategiaForestaleNazionale
Modugno S, Balzter H, Cole B, Borrelli P (2016). Mapping regional patterns of large forest fires in wildland-urban interface areas in Europe. Journal of Environmental Management 172: 112-126. - doi: 10.1016/j.jenvman.2016.02.013
Moreira F, Peer G (2018). Agricultural policy can reduce wildfires. Science 359 (6379): 1001. - doi: 10.1126/science.aat1359
Moriondo M, Good P, Durao R, Bindi M, Giannakopoulos C, Corte-Real J (2006). Potential impact of climate change on fire risk in the Mediterranean area. Climate Research 31: 85-95. - doi: 10.3354/cr031085
Nocentini S, Buttoud G, Ciancio O, Corona P (2017). Managing forests in a changing world: the need for a systemic approach. A review. Forest Systems 1: eR01. [online] URL: http://revistas.inia.es/index.php/fs/article/view/9443
Oliveira S, Oehler F, San-Miguel-Ayanz J, Camia A, Pereira JMC (2012). Modeling spatial patterns of fire occurrence in Mediterranean Europe using multiple regression and Random Forest. Forest Ecology and Management 275: 117-129. - doi: 10.1016/j.foreco.2012.03.003
Pandey P, Huidobro G, Lopes LF, Ganteaume A, Ascoli D, Colaco C, Xanthopoulos G, Giannaros TM, Gazzard R, Boustras G, Steelman T, Charlton V, Ferguson E, Kirschner J, Little K, Stoof C, Nikolakis W, Fernández-Blanco CR, Ribotta C, Lambrechts H, Fernández M, Dossi S (2023). A global outlook on increasing wildfire risk: current policy situation and future pathways. Trees, Forests and People 14: 100431. - doi: 10.1016/j.tfp.2023.100431
Parente J, Tonini M, Stamou Z, Koutsias N, Pereira M (2023). Quantitative assessment of the relationship between land use/land cover changes and wildfires in Southern Europe. Fire 6: 198. - doi: 10.3390/fire6050198
Parisien MA, Barber QE, Hirsch KG, Stockdale CA, Erni S, Wang X, Arseneault D, Parks SA (2020). Fire deficit increases wildfire risk for many communities in the Canadian boreal forest. Nature Communications 11: 1-9. - doi: 10.1038/s41467-020-15961-y
Pettenella D, Loreggian F (2023). L'associazionismo per il contrasto dell'abbandono gestionale delle foreste: tra tradizione, innovazione e nuove sfide [Associationism for fighting against the abandonment of forest management: between tradition, innovation and new challenges]. AE - Agricoltura Alimentazione Economia Ecologia 1: 77-95. [in Italian]
PNACC (2023). Piano nazionale di adattamento ai cambiamenti climatici. Ministero dell'Ambiente e della Sicurezza Energetica, Rome, Italy, website. [in Italian] [online] URL: http://www.mase.gov.it/notizie/clima-approvato-il-piano-nazionale-di-adattamento-ai-cambiamenti-climatici
Regione Sardegna (1985). Legge Regionale n. 26 - Istituzione del Corpo forestale e di vigilanza ambientale della regione sarda [Establishment of the Forestry Corps and Environmental Surveillance of the Sardinian Region]. Regione Sardegna, Cagliari, Italy. [online] URL: http://www.edizioneuropee.it/law/html/138/sa4_06_013.html
Regione Sardegna (2023). Piano regionale di previsione, prevenzione e lotta attiva contro gli incendi boschivi [Regional plan for forecasting, prevention and active fight against forest fires]. Regione Sardegna, Cagliari, Italy. [in Italian] [online] URL: http://delibere.regione.sardegna.it/protected/65822/0/def/ref/DBR65797/
Salis M, Arca B, Alcasena-Urdiroz F, Massaiu A, Bacciu V, Bosseur F, Caramelle P, Dettori S, Fernandes De Oliveira AS, Molina-Terren D, Pellizzaro G, Santoni PA, Spano D, Vega-Garcia C, Duce P (2019). Analyzing the recent dynamics of wildland fires in *Quercus suber* L. woodlands in Sardinia (Italy), Corsica (France) and Catalonia (Spain). European Journal of Forest Research 138: 415-431. - doi: 10.1007/S10342-019-01179-1
Salis M, Arca B, Del Giudice L, Palaiologou P, Alcasena-Urdiroz F, Ager A, Fiori M, Pellizzaro G, Scarpa C, Schirru M, Ventura A, Casula M, Duce P (2021). Application of simulation modeling for wildfire exposure and transmission assessment in Sardinia, Italy. International Journal of Disaster Risk Reduction 58 (3): 102189. - doi: 10.1016/j.ijdrr.2021.102189
Salis M, Del Giudice L, Alcasena-Urdiroz F, Jahdi R, Arca B, Pellizzaro G, Scarpa C, Duce P (2023). Assessing cross-boundary wildfire hazard, transmission, and exposure to communities in the Italy-France Maritime cooperation area. Frontiers in Forests and Global Change 6: 1241378. - doi: 10.3389/ffgc.2023.1241378/bibtex
Salis M, Del Giudice L, Arca B, Ager AA, Alcasena-Urdiroz F, Lozano O, Bacciu V, Spano D, Duce P (2018a). Modeling the effects of different fuel treatment mosaics on wildfire spread and behavior in a Mediterranean agro-pastoral area. Journal of Environmental Management 212: 490-505. - doi: 10.1016/j.jenvman.2018.02.020
Salis M, Del Giudice L, Arca B, Ager AA, Alcasena-Urdiroz F, Lozano O, Bacciu V, Spano D, Duce P (2018b). Modeling the effects of different fuel treatment mosaics on wildfire spread and be-

havior in a Mediterranean agro-pastoral area. Journal of Environmental Management 212: 490-505. - doi: 10.1016/j.jenvman.2018.02.020
Salis M, Del Giudice L, Jahdi R, Alcasena-Urdiroz F, Scarpa C, Pellizzaro G, Bacciu V, Schirru M, Ventura A, Casula M, Pedes F, Canu A, Duce P, Arca B (2022). Spatial patterns and intensity of land abandonment drive wildfire hazard and likelihood in Mediterranean agropastoral areas. Land 11 (11): 1942. - doi: 10.3390/land11111942
Salis M, Laconi M, Ager AA, Alcasena FJ, Arca B, Lozano O, Fernandes De Oliveira A, Spano D (2016). Evaluating alternative fuel treatment strategies to reduce wildfire losses in a Mediterranean area. Forest Ecology and Management 368: 207-221. - doi: 10.1016/j.foreco.2016.03.009
Salvati L, Zitti M (2009). Assessing the impact of ecological and economic factors on land degradation vulnerability through multiway analysis. Ecological Indicators 9: 357-363. - doi: 10.1016/j.ecolind.2008.04.001
Salvati L, Ferrara A, Carlucci M (2014). Understanding the spatial distribution of forest fires in a growing urban region: socioeconomic indicators tell you more. Modern Economy 5: 211-218. - doi: 10.4236/me.2014.53022
San-Miguel-Ayanz J, Durrant T, Boca R, Maianti P, Libertà G, Artes VT, Oom D, Branco A, De Rigo D, Ferrari D, Pfeiffer H, Grecchi IR, Onida M, Loffler P (2022). Forest fires in Europe, Middle East and North Africa 2021. Publications Office of the European Union, Luxembourg, pp. 184. - doi: 10.2760/34094
Scarpa C, Bacciu V, Ascoli D, Costa-Saura JM, Salis M, Sirca C, Marchetti M, Spano D (2024). Estimating annual GHG and particulate matter emissions from rural and forest fires based on an integrated modelling approach. Science of The Total Environment 907: 167960. - doi: 10.1016/j.scitotenv.2023.167960
Spadoni GL, Moris JV, Vacchiano G, Elia M, Garbarino M, Sibona E, Tomao A, Barbati A, Sallustio L, Salvati L, Ferrara C, Francini S, Bonis E, Dalla Vecchia I, Strollo A, Di Leginio M, Munafò M, Chirici G, Romano R, Corona P, Marchetti M, Brunori A, Motta R, Ascoli D (2023). Active governance of agro-pastoral, forest and protected areas mitigates wildfire impacts in Italy. Science of The Total Environment 890 (2): 164281. - doi: 10.1016/j.scitotenv.2023.164281
Spano D, Mereu V, Bacciu V, Marras S, Trabucco A, Adinolf M, Barbato G, Bosello F, Breil M, Chiriacò MV, Coppini G, Essenfelder AH, Galluccio G, Lovato T, Marzi S, Masina S, Mercogliano P, Mysiak J, Noce S, Pal J, Reder A, Rianna G, Rizzo A, Santini M, Sini E, Staccione A, Villani V, Zavatarelli M (2020). Analisi del rischio. I cambiamenti climatici in Italia: Evidenze, Vulnerabilità e Impatti [Climate Change in Italy: Evidence, Vulnerabilities and Impacts]. Euro-Mediterranean Center for Climate Change - CMCC, Lecce, Italy, website. [in Italian] - doi: 10.25424/cmcc/analisi_del_rischio
Spies TA, Scheller RM, Bolte JP (2018). Adaptation in fire-prone landscapes: Interactions of policies, management, wildfire, and social networks in Oregon, USA. Ecology and Society 23 (2): 11. - doi: 10.5751/es-10079-230211
SRACC (2019). Metodi e strumenti per la strategia regionale di adattamento ai cambiamenti climatici - Allegato 1 [Methods and tools for regional climate change adaptation strategy - Annex 1]. Regione, Sardegna, Cagliari, Italy, website. [in Italian] [online] URL: https://delibere.regione.sardegna.it/protected/45525/0/def/ref/DBR45368/
Tang W, He C, Emmons L, Zhang J (2024). Global expansion of wildland-urban interface (WUI) and WUI fires: insights from a multiyear worldwide unified database (WUWUI). Environmental Research Letters. 19: 044028. - doi: 10.1088/1748-9326/ad31da
Tonarelli L, Vacchiano G, Ascoli D, Delogu GM, Bacciu V (2020). Un paese che brucia: cambiamenti climatici e incendi boschivi in Italia [A country on fire: climate change and forest fires in Italy]. Grenpeace - SISEF, The Italian Society of Silviculture and Forest Ecology, pp. 33. [in Italian] [online] URL: http://www.greenpeace.org/static/planet4-italy-stateless/2020/08/1e5628b6-report_incendicc_finale.pdf
Trucchia A, D'Andrea M, Baghino F, Fiorucci P, Ferraris L, Negro D, Gollini A, Severino M (2020). Propagator: an operational cellular-automata-based wildfire simulator. Fire 3: 1-24. - doi: 10.3390/fire3030026
Trucchia A, Meschi G, Fiorucci P, Gollini A, Negro D (2022). Defining wildfire susceptibility maps in Italy for understanding seasonal wildfire regimes at the national level. Fire 5: 30. - doi: 10.3390/FIRE5010030/S1
Turco M, Rosa-Cánovas JJ, Bedia J, Jerez S, Montávez JP, Llasat MC, Provenzale A (2018). Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. Nature communications 9 (1): 3821. - doi: 10.1038/s41467-018-06358-z
Vacchiano G, Berretti R, Motta R, Ascoli D (2020). Selvicoltura preventiva prossima alla natura [Preventive forestry close to nature]. Sherwood 347: 29-32. [in Italian]
Vitolo C, Di Giuseppe F, Barnard C, Coughlan R, San-Miguel-Ayanz J, Libertá G, Krzeminski B (2020). ERA5-based global meteorological wildfire danger maps. Scientific Data 7 (1): 216. - doi: 10.6084/m9.figshare.12497732

Supplementary Material

Tab. S1 - Comparative analysis of recent fire governance and current management approaches in Southern European countries.

Link: Bacciu_4786@suppl001.pdf