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Nature-based solutions to wildfires in rural landscapes of Southern Europe: let's be fire-smart!

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ABSTRACT

Extreme wildfires are expected to increase in Southern Europe, due to climate change and rural abandonment. Fire management is focused on suppression, which accelerates the transition to more flammable landscapes. Here, we synthesise the knowledge acquired over the 'FirESmart' project (https://firesmartproject.wordpress.com). Our findings show how agroforestry policies could benefit biodiversity while providing further fire suppression opportunities. The EU Green Deal offers an opportunity to incorporate 'fire-smartness' into upcoming agroforestry policies. Still, if these policies fail at reversing rural abandonment, the use of fire could enhance rewilding and tree-planting as 'climate-smart' strategies in the fire-prone mountains of Southern Europe.

Keywords: Ecosystem services, fire-smart, High Nature Value farmlands, land-use scenarios, nature conservation, rewilding, rural abandonment, stakeholders, wildfires.

Setting the scene

Wildfires are a major component of disturbance regimes worldwide (Keeley *et al.* 2012). In Southern Europe, rural abandonment is one of the most important factors affecting fire regime and vegetation dynamics in mountain landscapes (Estoque *et al.* 2019). Rural communities have traditionally used fire as a tool for land management (e.g. clearing land for pastures; Chas-Amil *et al.* 2015; Tedim *et al.* 2016). However, society still perceives fire as a threat rather than an ecological process, which has reinforced fire exclusion and suppression policies. The increasing investment in fire suppression, at the expense of prevention, has paradoxically contributed to fuel accumulation (see 'fire-fighting trap' in Moreira *et al.* 2020). Consequently, rural mountain landscapes in Southern Europe have become more homogeneous and flammable and, in turn, more susceptible to extreme wildfires (Moreira *et al.* 2011). These extreme wildfires show increasingly strong responses to fire–weather severity, highlighting the difficulty in constraining fire spread in the absence of large-scale fuel treatments (Fernandes *et al.* 2016; Duane and Brotons 2018). Climate change is expected to bring drier conditions, with longer and more frequent drought periods, which would translate into an increasing wildfire risk in Mediterranean Europe (Turco *et al.* 2019). Besides, the cessation of traditional farming (many farmers are known to support 'High Nature Value farmlands', hereafter HNVf) is a major cause of biodiversity losses – accelerating population declines of species adapted to grasslands, pastures and other extensive agricultural areas (Ribeiro *et al.* 2014; Franks *et al.* 2018). Land management should therefore consider multiple objectives and involve the needs and views of local stakeholders and conservation practitioners. However, the complex interactions between fire-vegetation dynamics and land-use changes under climate change scenarios hinder efficient management of rural landscapes (Oliveira *et al.* 2016; Thompson *et al.* 2017; Alcasena *et al.* 2018).

UNESCO Transboundary Biosphere Reserves have served as 'learning laboratories' of cross-border cooperation for sustainable development of border areas characterised by unique natural and cultural heritage (Nguyen *et al.* 2011; de Castro-Pardo and Azevedo 2021). Biosphere Reserves involve local communities and all other stakeholders in planning and management – being used as 'open labs' to seek local solutions to global environmental challenges (de Castro-Pardo *et al.* 2019). In Southern Europe, the impacts of rural abandonment on biodiversity and ecosystem services are still debated, being seen as a threat but also as an opportunity for habitat and ecosystem restoration (see the 'Rewilding' concept; Queiroz *et al.* 2014; Perino *et al.* 2019). Rewilding abandoned landscapes in Europe is an appealing but hotly debated nature-based solution to global climate change (Navarro and Pereira 2012; Osaka *et al.* 2021). Nevertheless, rewilded landscapes are more prone to extreme wildfires due to shrub encroachment and forest densification (Moreira *et al.* 2011). Tree planting, as well as other afforestation programs, are also supported by global and European initiatives toward a decarbonisation of the economy (e.g. https://www.1t.org/). However, these 'climate-smart' policies need to be carefully considered to avoid side-effects on fire regimes, especially in areas prone to wildfires (Hermoso *et al.* 2021; Leverkus *et al.* 2022).

In this new era of fire, the societal challenge is how to integrate competing land-use policies and local stakeholders' objectives into a holistic landscape management to solve the growing problem of extreme wildfires in a sustainable way. 'Fire-smart' management has been defined as 'an integrated approach primarily based on fuel treatments through which the socio-economic impacts of fire are minimized while its ecological benefits are maximized'; Hirsch *et al.* 2001). Such an integrated approach could help find sustainable, effective and equitable solutions to the wildfire problem in fire-prone regions (Cohen-Shacham *et al.* 2019). Over the last few years, the fire-smart concept has been reinforced as a plausible pathway toward more fire-resistant and resilient landscapes (Fernandes 2013; Tedim *et al.* 2016). However, the potential trade-offs among wildfire hazard, ecosystem services and biodiversity remain largely unknown, being an appealing but still under-studied management option.

This research communication aims to help navigate decision and policymakers toward an integrated fire-smart management as a nature-based solution to the growing wildfire hazard in complex socio-ecological systems. Here, we synthesise the knowledge acquired over the development of the 'FirESmart' project (https://firesmartproject.wordpress.com), a 4-year project funded by Portuguese national funds (PCIF/MOG/0083/2017) in response to the dramatic wildfire events of 2017. The FirESmart project analyses potential trade-offs and synergies among wildfire hazard, ecosystem services and biodiversity conservation in two UNESCO transboundary biosphere reserves (between Spain and Portugal), both in biophysical and economic terms, and under a wide range of land-use and fire-suppression scenarios. In particular, the FirESmart project aims to answer the two overarching questions (Fig. 1): (1) Can fire-smart management reduce wildfire hazard in the future under any combination of land-use change and fire-suppression scenarios? If so, (2) Is a fire-smart approach compatible with biodiversity conservation and the long-term supply of ecosystem services?

Material and methods

The FirESmart project used stakeholder engagement and simulation modelling to design and test a wide range of scenarios storylines to (1) assess the impacts of fire-smart management scenarios on fire mitigation, biodiversity and ecosystem services and (2) analyse the trade-offs and 'win-win' solutions among fire mitigation, biodiversity and ecosystem services (Fig. 1).

Study sites

The FirESmart project was implemented in two transboundary systems: the Biosphere Reserve 'Gerês-Xurés'; and the Biosphere Reserve 'Meseta Ibérica'. These regions represent two mountain rural areas between Portugal and Spain with unique cultural, socio-economic and natural values, but are also largely affected by wildfires and rural exodus.

Gerês-Xurés

The Gerês-Xurés transboundary Biosphere Reserve (established in 2009) is located at the transition between the Mediterranean and Eurosiberian biogeographic zones (41° 35′ 18″ to 42° 10′ 26″ N, –7° 35′ 4″ to –8° 31′ 54″ W), mainly with an Atlantic climate (monthly average temperature below 22°C; Kottek *et al.* 2006). The landscape is dominated by heathlands, fragmented forests of deciduous trees (mostly *Quercus robur* and *Q. pyrenaica*) and conifers (mainly *Pinus pinaster*). Rural abandonment, a common trend in the area during the last century, resulted in forest increase (Regos *et al.* 2015). Frequent human-caused wildfires, such as deliberate pastoral fires (at least 80% of fires) and unintentional agricultural burning escapes (up to 5%), are common in the study area (Chas-Amil *et al.* 2010, 2015; Calviño-Cancela *et al.* 2016), resulting in a large number of fires and burned area (12 755 fires between 1983 and 2010 burning a total of 195 000 ha) (Regos *et al.* 2015).

Meseta Ibérica

The Meseta Ibérica transboundary Biosphere Reserve (established in 2015) has a predominantly mediterranean continental climate (40° 40′ 32″ to 42° 15′20″ N, –5° 48′ 52″ to –7° 25′ 52″ W). The landscape is characterised by crops, pastures, heathlands and forest. Native woodlands (*Quercus pyrenaica*, *Q. suber* and *Q.rotundifolia*) and pine plantations (*Pinus pinaster*) dominate the latter. Depopulation is also a common trend in this area (Azevedo 2012; Sil *et al.* 2017). Between 2003 and 2019, the number of fires greater than 20 ha averaged 359 fires per year, and the annual burned area averaged 8912.7 ha per year (Andela *et al.* 2019). Despite a decreasing trend in the annual number of fires, the annual burned area has slightly increased over time (Andela *et al.* 2019).

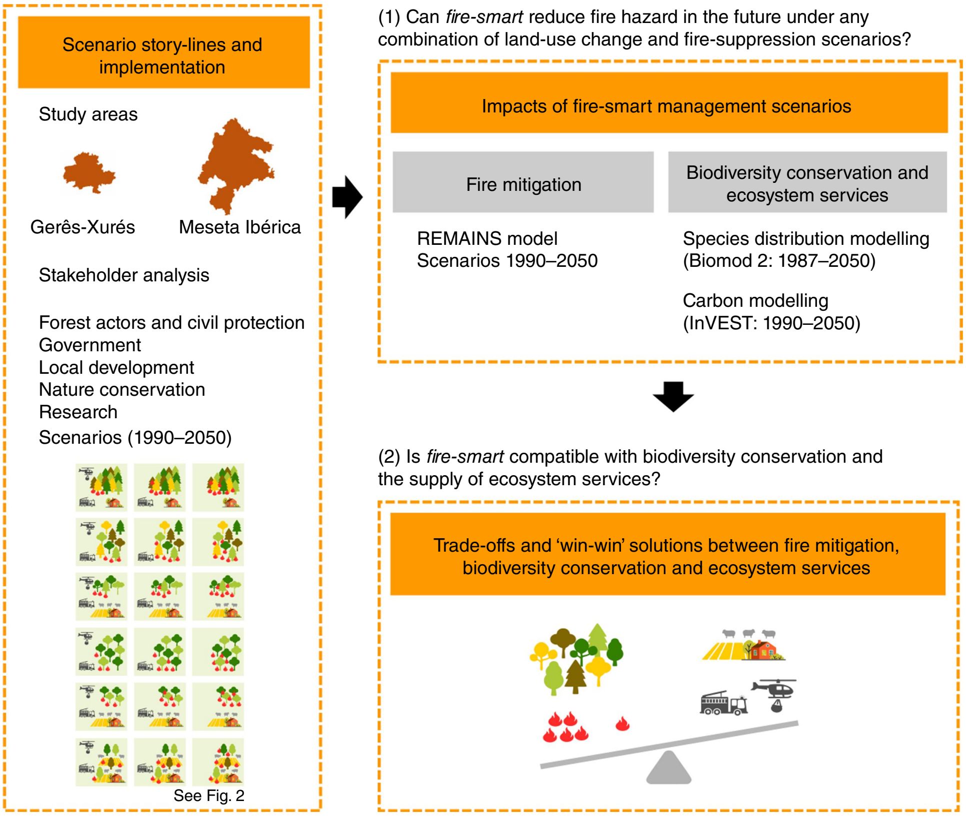

Fig. 1. Schematic workflow of the FirESmart project. Scenario storylines and their implementation are fundamental to answering Question (1): can fire-smart reduce fire hazard in the future and under any combination of land-use change and fire-suppression scenarios? and (2) is fire-smart compatible with biodiversity conservation and the supply of ecosystem services?

Stakeholders' perception and scenarios design

To co-design fire and land-use management scenarios, an online questionnaire was sent to a wide range of relevant local stakeholders: forest actors and civil protection; government; local development; nature conservation; and research. In this questionnaire, we asked stakeholders about their perception on how fire regimes have changed in the study areas in the last 30 years, how it is expected to change in the future 30–40 years, and what are the main causes of large fires and chosen policies to prevent them. We received 33% responses ($N = 114$) from the total number of questionnaires sent ($N = 347$). The stakeholders' perception helped us to envisage future changes in the landscape, as well as how landscape should be managed to avoid large wildfires. Thus, six land-use management scenarios were designed under three different levels of fire-suppression capacity (Table 1, Fig. 1). In addition, we also asked about potential benefits of these management options on ecosystem services, the effectiveness of fire-prevention policies, and the transboundary coordination and cooperation. A complete description of the questionnaire will be available in Lecina-Diaz *et al.* (2023*a*).

Integrated modelling framework

To assess the potential trade-offs and synergies among wildfire hazard, ecosystem services and biodiversity conservation, we developed a spatially explicit process-based model – the REMAINS model. This model allows simulating the spatiotemporal interactions among fire-vegetation dynamics, fire management and land-use changes under predesigned scenario storylines (see details in Pais *et al.* 2020, Fig. 2). It simulates wildfires (fire ignition, spread, burning and extinction), vegetation dynamics (natural succession and post-fire regeneration), land-use changes (e.g. agriculture abandonment) and forest type conversions. Two fire-suppression strategies are currently implemented: (1) 'active fire suppression', in which suppression of a fire front starts when the fire spread rate is below a specific threshold, mimicking the current capacity of fire brigades to extinguish low-intensity fires; and (2) 'passive fire suppression', based on opportunities derived from agricultural areas (set as 1 ha), which are assumed to break the continuity of highly flammable vegetation.

We combined fire-landscape simulations derived from REMAINS (in the RB 'Gerês-Xurés') and FlamMap

Table 1. Description of alternative land-use policy scenarios considered for the two study areas.

Scenario name	Story-line description	Challenges	Nature-based solution	Land-use policy
Business-as-usual – BAU	Represents the historical fire regime and land-use change trends, dominated by land abandonment processes (i.e. shrubland encroachment and forest expansion) (Regos *et al.* 2015; Sil *et al.* 2019). It allows the simulation of 'Ecological rewilding' initiatives that would support climate regulation and biodiversity (Perino *et al.* 2019).	Climate change	Climate-smart	Ecological/passive Rewilding initiatives
Afforestation	In this scenario, afforestation actions favour forest species (e.g. coniferous species and deciduous/broad-leaved species), emulating recent EU policies against climate change and biodiversity loss. Under the EU Green Deal, large afforestation programs will be supported by the EU Biodiversity and Forest Strategies and the development of renewable energy sectors under Renewable Energies Directives (e.g. wood production and bioenergy) and Rural Development policies.	Climate change	Climate-smart	EU Biodiversity and Forest Strategies, and Rural Development policies
High Nature Value farmlands – HNVf	The effects of a potential return to traditional farming activities are simulated in this scenario. The main effects derive from a new, 'greener' CAP policy through economic incentives to revert farmland abandonment and promote environmentally friendly agricultural management. Therefore, agropastoral areas are expected to increase, mainly in formerly semi-natural areas to support local development, fire mitigation and biodiversity conservation (Pais *et al.* 2020; Campos *et al.* 2022).	Rural exodus + extreme wildfires	Fire-smart	Greener CAP policy
Fire-smart forest conversion	Aims to control final burned area by intervening on vegetation covers (e.g. promoting the gradual conversions of coniferous forests to native oak woodlands) to foster more fire-resistant (less flammable) and/or fire-resilient landscapes (Fernandes 2013; Pais *et al.* 2020). Assuming the same amount of fire suppression resources applied nowadays, a more effective fire-suppression system would be expected due to lower fire spread rates found in oaks than in coniferous forests (Pais *et al.* 2020).	Climate change + extreme wildfires	Fire-smart	Forest restoration policies
HNVf + Fire-smart	Envisages an integrated management policy that combines the promotion of native oak forest woodlands (Fire-smart forest conversion) with a renewed CAP policiy aimed at gradually increasing agricultural areas (HNVf), as an opportunity for fire suppression and farmland/grassland biodiversity conservation (Pais *et al.* 2020).	Rural exodus + extreme wildfires	Fire-smart	Forest restoration policies + Greener CAP policy
Agroforestry recovery	This scenario is based on a new CAP policy that promote agropastoral activities (i.e. moderate increase of farmlands), combined with agroforestry cultures (i.e. increase in sweet chestnut groves). Semi-natural and forest areas (particularly coniferous forests) are forced to decrease. The scenario aims to decrease landscape flammability while maintaining the sustainable development of the region (Campos *et al.* 2022).	Rural exodus + extreme wildfires	Fire-smart	Greener CAP policy + Rural development policies

Each scenario is designed to address a societal challenge (climate change, rural abandonment and extreme wildfires), being defined as nature-based solutions under the umbrella of broad land-use policies. Different levels of fire suppression (from low to high fire-fighting capacity) were also considered within each storyline to incorporate the role of fire into landscape management (see Fig. 2).

(https://www.firelab.org/project/flammap; in the BR 'Meseta Iberica') with species distribution models and an integrated valuation of Ecosystem Services and Tradeoffs (InVEST model) to identify the best strategies for wildfire prevention, biodiversity conservation and climate regulation ecosystem services (see methodological details in Pais *et al.* 2020; Campos *et al.* 2021*a*, 2022). These analyses included both the biophysical and economic evaluations of ecosystem services related to the area suppressed (i.e. the avoided costs) under each management scenario (Lecina-Diaz *et al.* 2023*b*). The suppressed area is estimated from the difference between the target area to be burned according to model calibration (based on fire statistics) and the area finally burned in each model simulation (that depends on the firefighting strategies implemented in the model and the landscape configuration of each scenario) (see details in Pais *et al.* 2020).

Species distribution and Fire Weather Index (FWI) were modelled considering several climate models: CNRM, ICHEC, IPSL and MPI, generated within the EURO-CORDEX project for the two Representative Concentration Pathways (RCP 4.5 and RCP 8.5). For the data collected, temporal and spatial (Biosphere Reserve of Meseta Ibérica and the Iberian Peninsula) domains were extracted, and data were bilinearly interpolated to common 9-km grids. A spatial downscaling of temperatures was also performed, using the digital elevation model from the Shuttle Radar Topography Mission databases, at 1-km grid resolution and the vertical temperature gradient. Precipitation totals were bilinearly interpolated to the same 1-km grid (climate datasets are available in Campos *et al.* 2021*b*).

Insights from the FirESmart project: a synthesis

The online questionnaire shed light on stakeholders' perceptions about fire and its suppression policies, past and future landscape trends, and the impact of different fuel management options on fire regime, ecosystem services and biodiversity. Stakeholders stated that fire should be managed, and they supported fire prevention rather than fire suppression policies. Rural abandonment is perceived as the main cause of large wildfires, with high-intensity fires impacting the study regions more in the recent past, a situation that they expect to continue in the absence of management. All suggested fuel management strategies (i.e. vegetation type conversion, linear fuel treatments, shrub and understory clearing, prescribed fire, mechanical fuel treatments, promoting agriculture and livestock, and introducing large herbivores), except chemical fuel treatments were accepted by the stakeholders, who perceive more positive than negative effects of fuel management on ecosystem services. We did not find differences among stakeholder sectors and Biosphere Reserves, indicating a general agreement on perceptions about wildfire and associated impacts at the landscape level. Finally, local stakeholders were in favour of promoting agricultural and livestock uses, modifying forest species composition to increase fire resistance, and introducing large herbivores, as nature-based solutions in our region. This

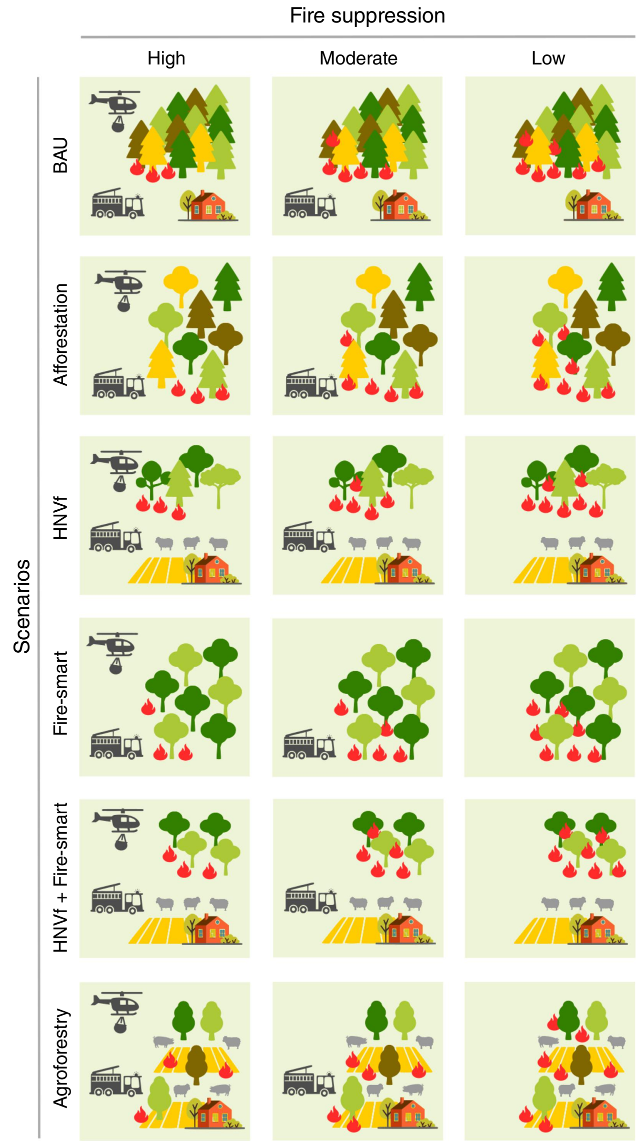

Fig. 2. The six sorylines: (1) Business-as-usual scenario (BAU) describes the current trend of land abandonment; (2) Afforestation aims to boost forested areas through tree planting and forest restoration; (3) High Nature Value Farmland (HNVf) represents a policy promoting traditional agricultural activities; (4) Fire-smart scenarios aim to create landscapes more resistant to wildfire; (5) HNVf plus Fire-smart combines these two policies; (6) Agroforestry recovery focuses on replacing highly flammable areas with mixed systems of agropastoral and agroforestry activities (see details in Pais *et al.* 2020; Campos *et al.* 2021*a*, 2022). The storylines are implemented with three levels of fire suppression, from high to low fire-fighting capacity, respectively. Regarding climate change, two Representative Concentration Pathways were considered in the FirESmart project: one intermediate scenario where emissions start to decline after 2040 (RCP 4.5) and one extreme scenario where emissions experience a continuous increase (RCP 8.5).

step allowed us to identify the scenario storylines implemented in the modelling approach (Table 1, Fig. 2).

Our modelling simulations support both local stakeholders' perspectives and recent research about the critical role that agroforestry policies could play to promote sustainable solutions to the wildfire problem in abandoned rural landscapes of Southern Europe (Pais *et al.* 2020; Campos *et al.* 2022; Cánibe-Iglesias *et al.* 2022). Overall, our results highlight that land-use policies promoting farmland areas (HNVf scenarios in Table 1, Fig. 3) would provide further fire-suppression opportunities by creating open spaces while simultaneously ensuring biodiversity conservation within (and around) protected areas. A large amount of strategically allocated cropland areas (at least 1200 ha per year in the Biosphere Reserve 'Gerês-Xurés') should be gradually incorporated into the landscape over the next four decades to significantly reduce the risk of large wildfires (Pais *et al.* 2020). Therefore, a greener path for the European Common Agricultural Policy (EU CAP; *sensu* Pe'er *et al.* 2019) would enhance fire regulation capacity and fire protection ecosystem service in mountain landscapes (*sensu* Sil *et al.* 2019). These policies would also be positive for biodiversity conservation because most of the species considered in our simulations would benefit from the recovery of habitats associated with traditional agropastoral activities (Pais *et al.* 2020; Campos *et al.* 2022; Cánibe-Iglesias *et al.* 2022). In terms of climate regulation capacity and climate change mitigation ecosystem service (measured through carbon storage and sequestration), our models predicted that climate-smart scenarios (BAU and Afforestation; Table 1, Fig. 3) would be the most advantageous. However, fire-smart management also stands out as a very efficient solution for climate regulation services – while also contributing to fire regulation (Campos *et al.* 2022; Cánibe-Iglesias *et al.* 2022), which facilitates the transition toward landscapes more resilient to climate change and large wildfires (Fernandes 2022; Regos 2022). Nonetheless, although fire-smart forest conversion scenarios would be beneficial for a long-term supply of carbon sequestration, its implementation should be integrated within agricultural policies to jointly reduce fire hazard and preserve local biodiversity adapted to these semi-natural systems (Fig. 3) (Sil *et al.* 2019; Pais *et al.* 2020; Campos *et al.* 2022). In addition, this integrated scenario would be the most cost-efficient, with the lowest societal discounted net suppression costs and change on ecosystem services damages – it generates suppression cost savings from agricultural expansion and leads to a significant reduction in damages on timber and recreational benefits (Fig. 3). Payments for ecosystem services should therefore reward farmers and landowners for their role in wildfire prevention (Lecina-Diaz *et al.* 2023*b*). In this sense, the European Green Deal offers an excellent opportunity to incorporate 'fire-smartness' into renewed EU agricultural policies that would contribute to climate change and wildfire mitigation in the upcoming decades (Regos 2022).

Nevertheless, if the new EU CAP fails at reversing rural abandonment (Pe'er *et al.* 2014; Pe'er *et al.* 2020), rewilding and tree-planting initiatives will keep gaining attention as Nature-based Solutions to climate change (Osaka *et al.* 2021). According to our simulations, BAU and Afforestation scenarios, characterised by a gradual increase in semi-natural (e.g. shrublands) and forest areas (e.g. coniferous and/or deciduous species), would be the best option for climate regulation (both in terms of carbon sequestration and avoided economic losses) (Pais *et al.* 2020; Campos *et al.* 2022; Sil *et al.* 2022) (Fig. 3). These findings support the recent climate-smart initiatives proposed by the EU to follow the Green Deal roadmap towards a decarbonisation of the economy (e.g. large-scale afforestation programs, forest restoration and development of wood production and bioenergy sectors). Our simulations showed that such scenarios would also be good for forest-dwelling species (e.g. with benefits for around 50% for endangered and critically endangered vertebrates under rewilding scenarios in the Biosphere Reserve Meseta Iberia; Campos *et al.* 2022) (Fig. 3). However, these climate-smart forest policies entail important challenges associated with wildfire risk that need to be carefully considered before implementation (Hermoso *et al.* 2021; Leverkus *et al.* 2022). For instance, our simulations predicted an increase in fire intensity and burned area for the next decades in both Biosphere Reserves (Meseta Iberia and Gerês-Xurés) due to the joint effect of rural abandonment and climate change (Sil *et al.* 2019; Pais *et al.* 2020; Aparício *et al.* 2022; Cánibe-Iglesias *et al.* 2022). The wildfire hazard associated with rewilding and afforestation programs could be reduced by reintroducing large herbivores and/or fire, as tools to manage landscapes. Our studies suggested that, in the current context of land abandonment, new open habitats created by unplanned fires could be beneficial for many species (up to 33% of vertebrates in the Gerês-Xurés) – an issue that will rely on the fire suppression policies (Campos *et al.* 2021*a*) and/or more strategic burning programs to be implemented in the decades to come (Kelly *et al.* 2020). In addition, both unplanned and planned fires would provide further opportunities to suppress large wildfires (Fernandes *et al.* 2013; Regos *et al.* 2014; Duane *et al.* 2019; Davim *et al.* 2021), being a cost-effective solution only achievable with the full recognition of fire as a critical factor in our ecosystems (see McLauchlan *et al.* 2020).

In conclusion, our simulations confirm that rural abandonment will result in encroached landscapes prone to high-intensity, large wildfires with the potential to strongly damage ecosystems and compromise the supply of ecosystem services. The FirESmart project sheds light on how an effective implementation of renewed EU agroforestry policies could benefit biodiversity (through the creation of new open habitats for endangered species) while providing further fire suppression opportunities. If these policies continue to fail, the use of fire (mediated by fire suppression) can help the implementation of climate-smart strategies (such as rewilding

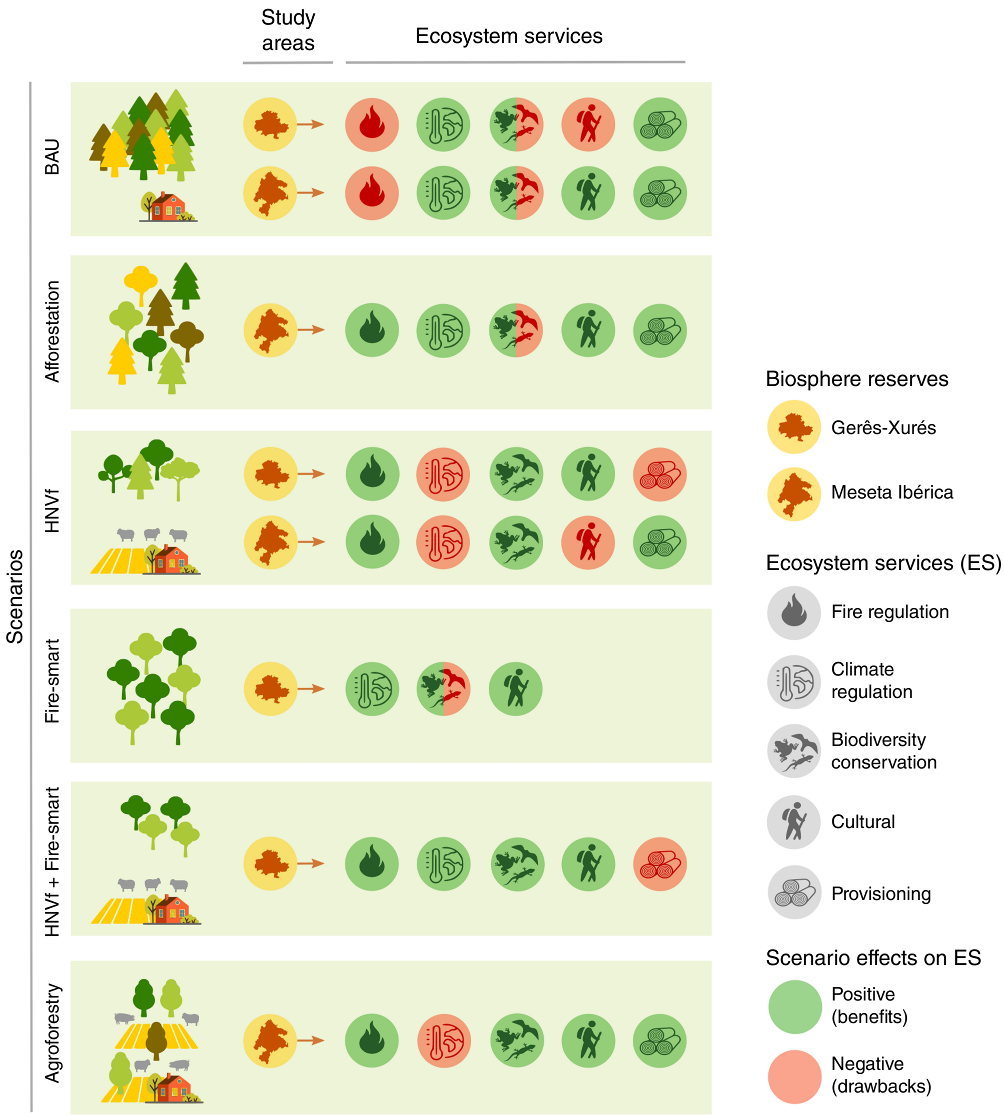

Fig. 3. Positive and negative impacts of each management scenario on regulating (i.e. fire protection and climate change mitigation), provisioning (food and wood harvesting) and cultural (recreational and ecotourism) ecosystem services, and biodiversity (birds, amphibious and reptiles) conservation for each study area.

and/or tree-planting) in abandoned, fire-prone mountain areas across Southern Europe (see outreach video at https://youtu.be/x7ouTIBp_E). Therefore, our project confirms the need for a holistic and integrated fire-smart management of biodiversity and ecosystem services to successfully address the societal challenge of extreme wildfires while ensuring conservation goals. A redesign of the protection regime of the Biosphere Reserves (Lanzas *et al.* 2021; Cánibe-Iglesias *et al.* 2022), including a considerable expansion of 'core' protected areas and the sustainable use of unprotected lands, would be also essential to ensure biodiversity conservation goals and accommodate multiple ecosystem services under expected changes in fire regime, climate and species distribution.

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Data availability. This communication synthesises and interlinks the main results of the FirESmart project (PCIF/MOG/0083/2017), mostly already published in other journals (under the Creative Common License Attribution 4.0 International – CC BY 4.0).

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