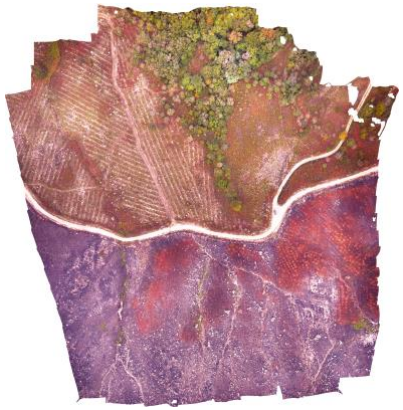
The impact of **extreme fire events** is expected to increase across Southern Europe landscapes due to increasing effects of global climate change and regional land abandonment and large-scale reforestation programs. The current fire management policies are mostly focused on **suppression** and ignore land management issues, which may paradoxically accelerate the transition to **more flammable and fire-prone landscapes** and magnify the problem.



'Fire-smart' management, by focusing on fire regime control through interventions on vegetation to foster more fire-resistant/resilient environments, might constitute an appropriate **nature-based solution** (i.e., measures continuously supported by and using nature) for improving wildfire mitigation, while contributing for biodiversity conservation and for sustainable supply of ecosystem services in rural socioecological systems under global change scenarios. Surprisingly, these **potential trade-offs between wildfire mitigation and ecosystem services** and co-benefits of 'fire-smart' strategies remain largely unexplored.

Photos: João Gonçalves & Silvana Pais.
Diagrams: Judit Lecina.

Project consortium: Research Center in Biodiversity and Genetic Resources of the Network in Biodiversity and Evolutionary Biology (CIBIO/InBIO); The Centre for the Research and Technology of Agro-Environmental and Biological Sciences of the University of Trás-os-Montes and Alto Douro (CITAB/UTAD); Mountain Research Centre of the Polytechnic Institute of Bragança (CIMO/IPB); Forest Sciences Centre of Catalonia - CTFC, Spain; University of Santiago de Compostela (USC); University of York.

Website:
https://firesmartproject.wordpress.com

FIRE-SMART PROJECT

Nature-based solutions for preventive fire management and sustainable supply of ecosystem services

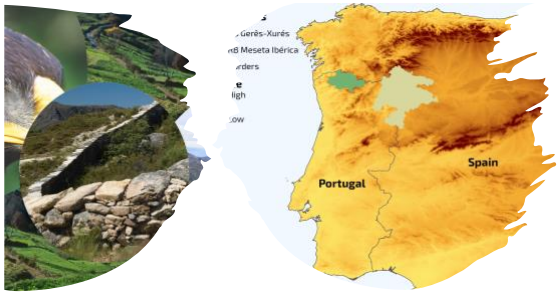
The FirESmart project aims to reduce **wildfire hazard** while ensuring **biodiversity conservation** and the delivery of **ecosystem services**, by integrating both **ecological** and **socio-economic** dimensions of the wildfire problem under a socio-ecological narrative and framework.

Study areas

FirESmart is implemented in two cross-border testing systems:

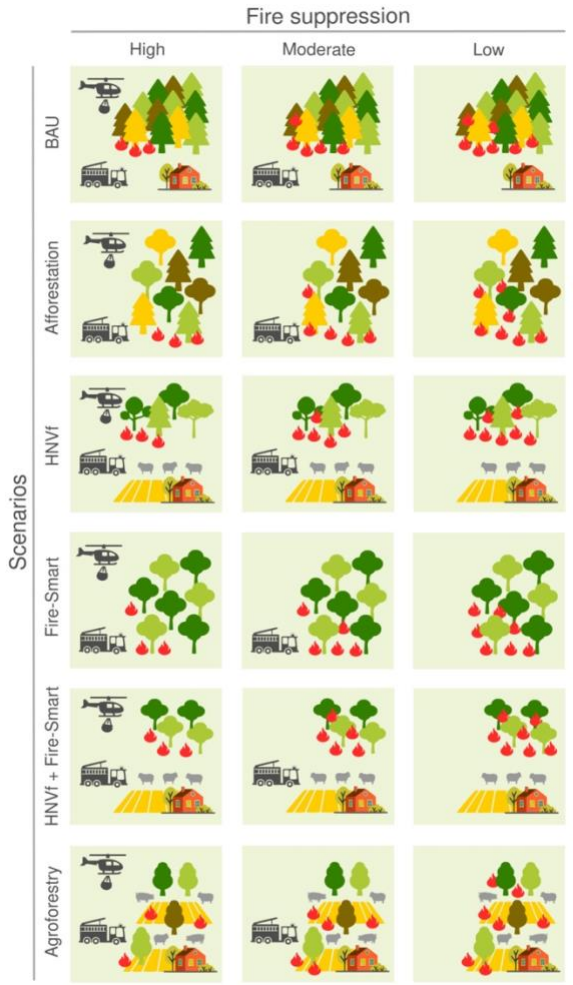
- Biosphere Reserve *Gerês-Xurés*
- Biosphere Reserve *Meseta Iberica*

These regions represent two mountainous rural areas between Portugal and Spain, with unique cultural, socioeconomic and natural values, but also widely affected by fires and rural exodus.



Storylines

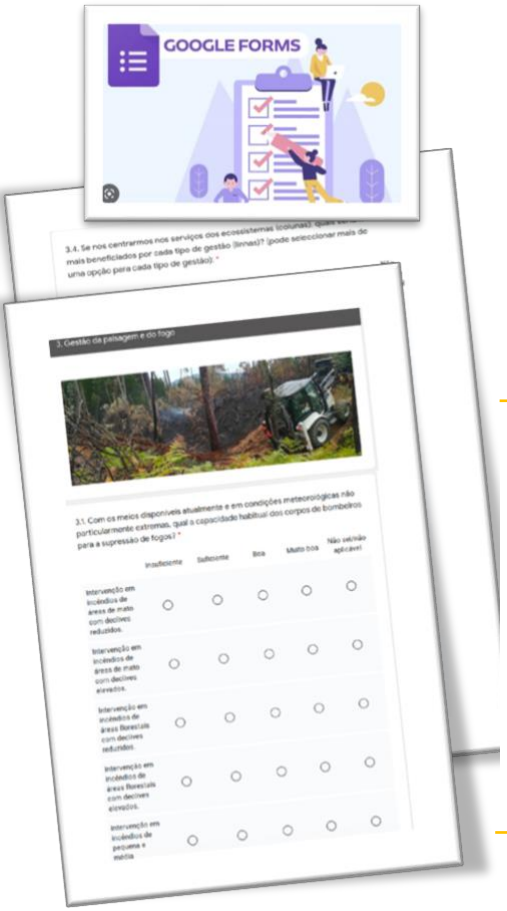
Business-as-usual scenario (BAU) describes the current trend of land abandonment; Afforestation aims to boost forested areas through tree planting and forest restoration; High Nature Value Farmland (HNVf) represents a policy promoting traditional agricultural activities; Fire-smart scenarios aim to create landscapes more resistant to wildfire; HNVf plus Fire-smart combines these two policies.

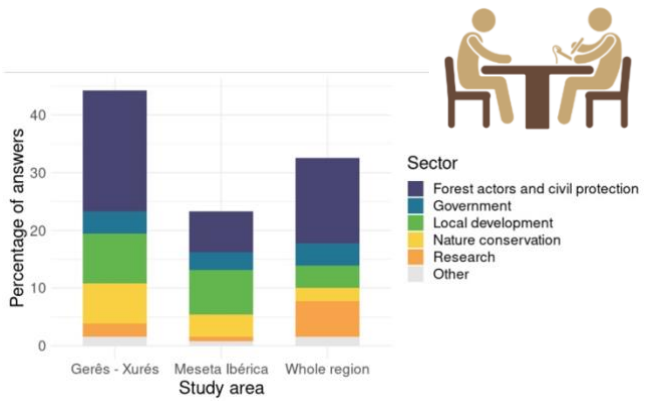


Agroforestry recovery focuses on replacing highly flammable areas with mixed systems of agropastoral and agroforestry. The storylines are implemented with three levels of fire suppression, from high to low fire-fighting capacity, respectively.

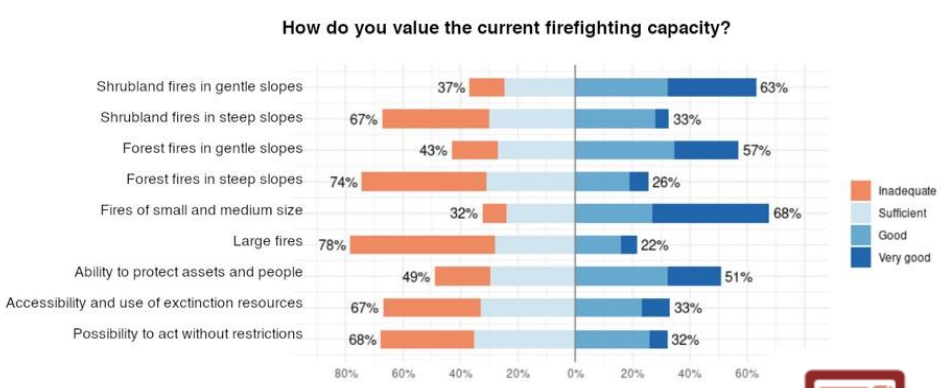
Stakeholder engagement and scenario design

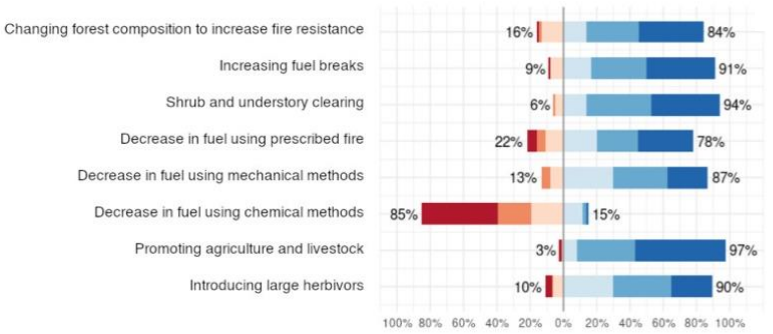
Online questionnaires were sent out to different stakeholders using Google Forms and the Convertkit platform, and 114 answers were received.

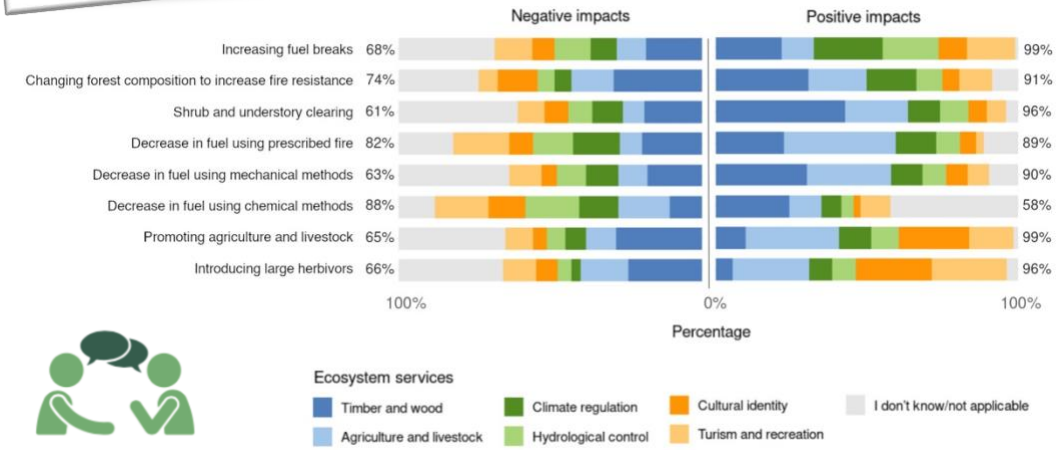


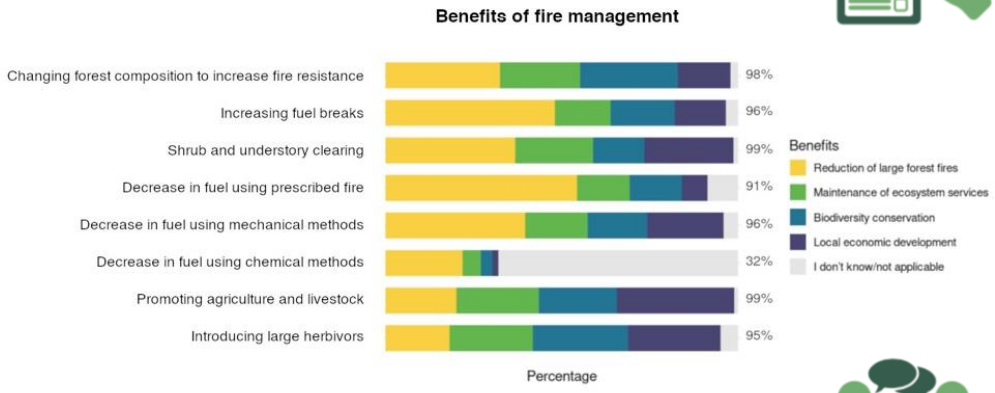


Overall, there is general agreement among stakeholders across sectors and study areas. They state that fire must be managed and support fire prevention rather than suppression policies. They also perceive that rural abandonment is the main cause of large wildfires, with more high-intensity fires impacting the study regions than in the last 30 years, a trend expected for the future in the absence of management. Regarding fuel management, all strategies except chemical treatments were accepted by the stakeholders who perceive more positive than negative effects of fire management on forest ecosystem services. In particular, promoting agricultural and livestock uses, modifying forest species composition to increase fire resistance, and introducing large herbivores have potential to become effective **Nature-based Solutions** in the regions.









REMAINS model

A spatially explicit process-based model that integrates the main factors driving fire-landscape dynamics

The model allows investigating the spatial interaction between fire (fire ignition, spread and extinction) and vegetation dynamics (natural succession and post-fire regeneration) under land-use policy scenarios

REMAINS

Fire module
Fire ignition, spread and extinction
Two fire suppression strategies
Ignition probability layer

Vegetation dynamics module
Natural succession
Post-fire regenerations

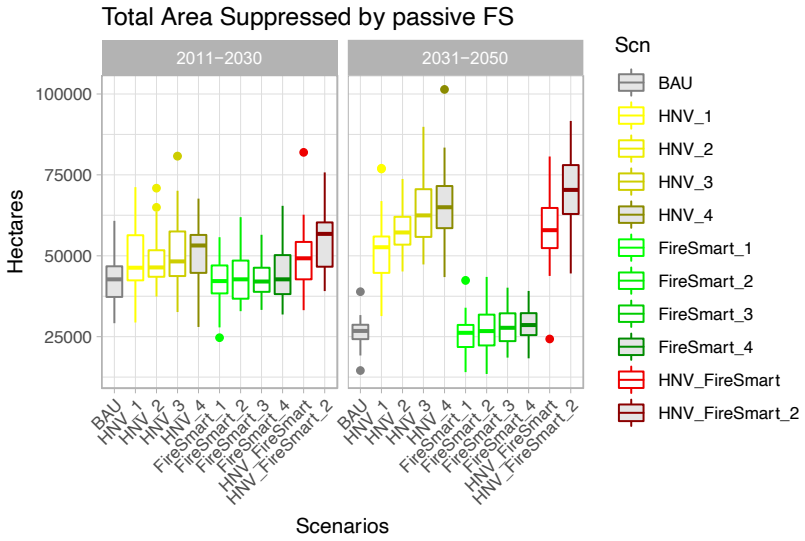
Land-use change module
Rural abandonment
Forest type conversions
Agriculture intensification

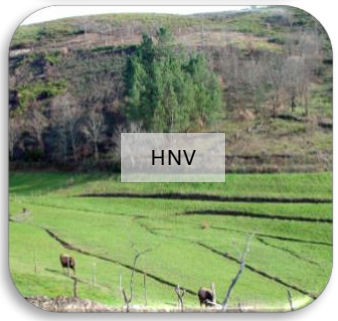
Context

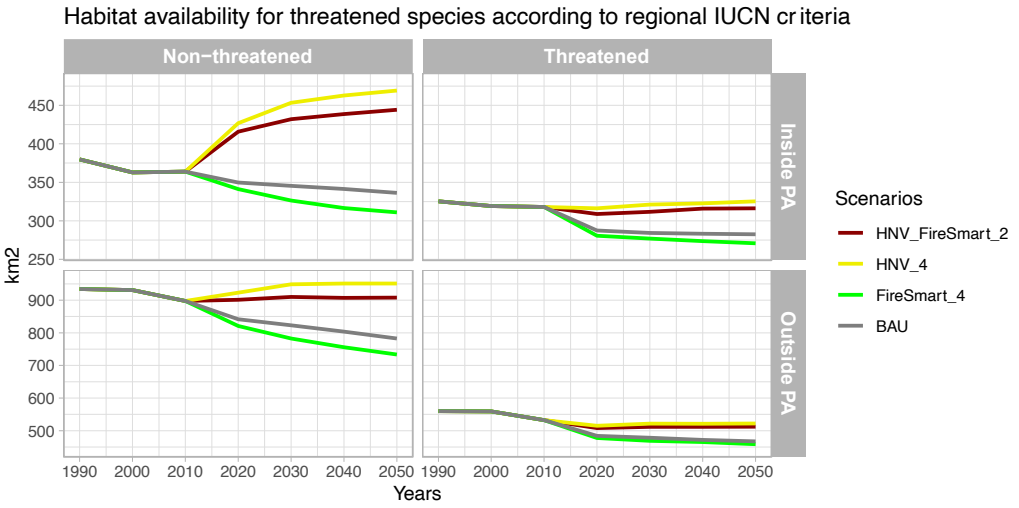
It has been calibrated for a transboundary region in northern Iberian Peninsula

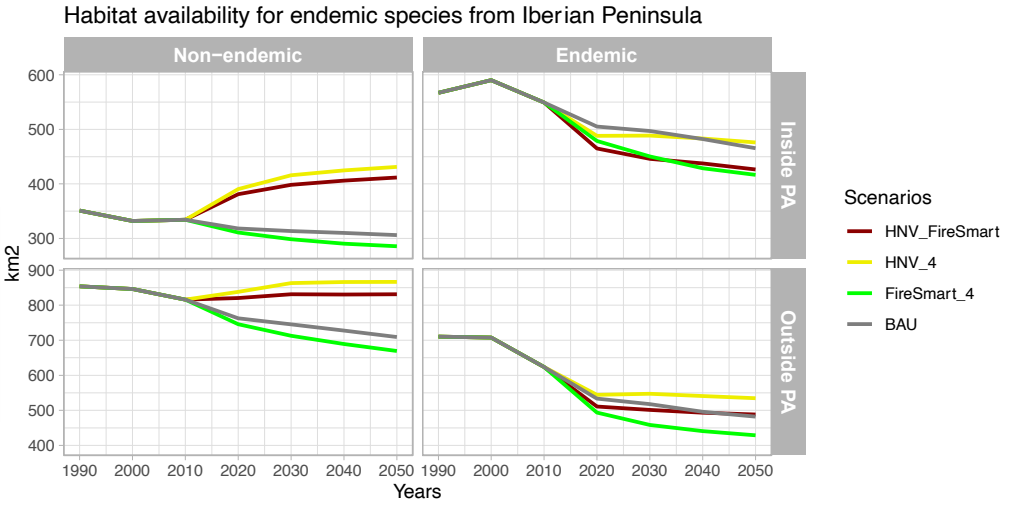
Business-as-Usual (BAU)

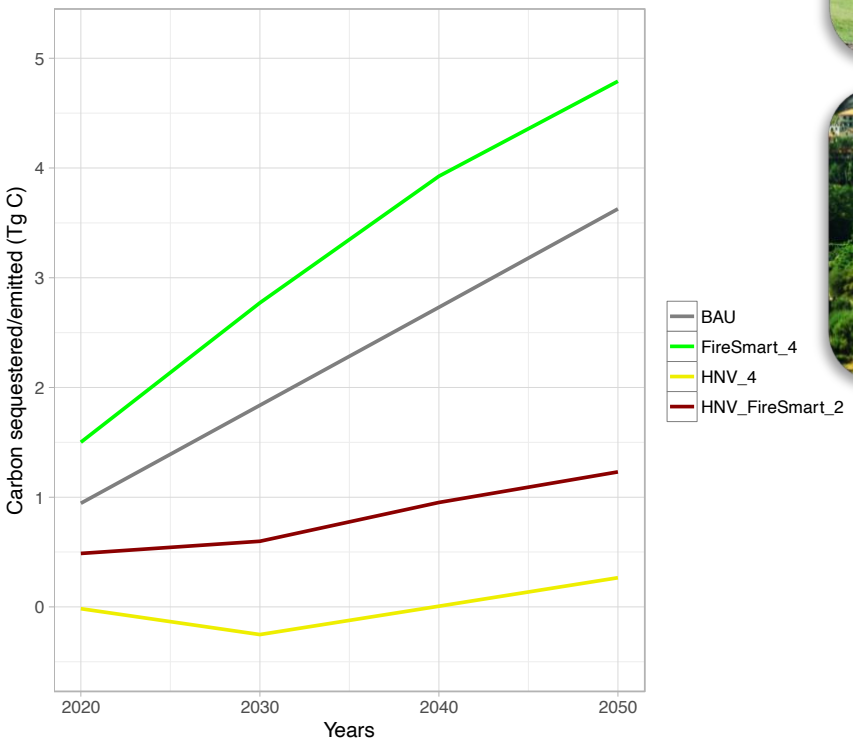
BAU plus strategic fire







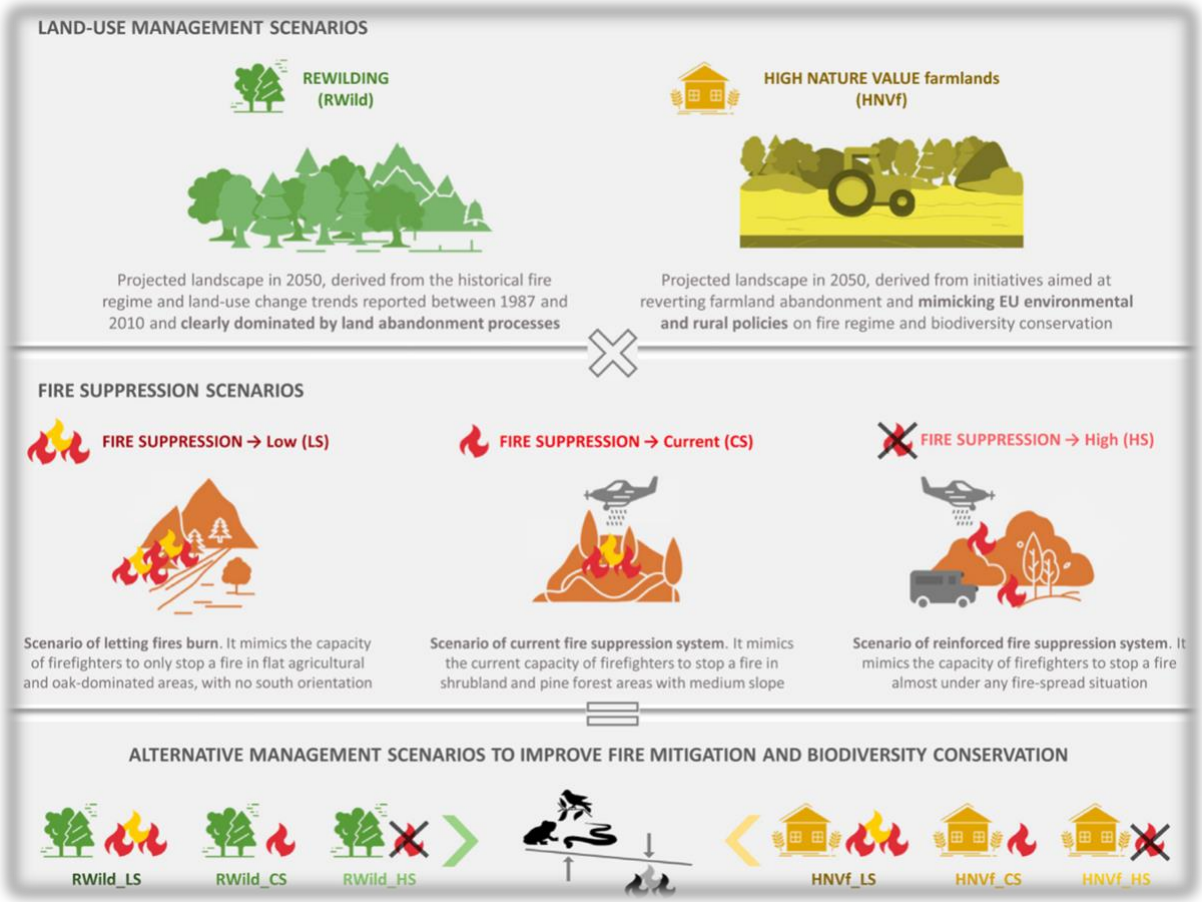




Management and policy implications:

Fire-landscape simulations reveal an increase of up to 25% of annual burned area for the four next decades. HNVf areas may counterbalance this increasing fire impact, especially when combined with fire-smart strategies (reductions of up to 50% between 2031 and 2050). The Fire-Smart and BAU scenarios attain the highest estimates for total carbon sequestered. A decrease in habitat suitability (around 18%) since 1990 is predicted for species of conservation concern under the BAU scenario, while HNVf would support the best outcomes in terms of conservation. Our study highlights the benefits of integrating fire hazard control, ecosystem service supply and biodiversity conservation to inform better decision-making in mountain landscapes of Southern Europe.

But what if the Common Agricultural Policy and the upcoming revisions still fails at reversing rural abandonment trends? Could be 'rewilding' an option in marginal mountain areas considering its expected side-effects on fire regime?

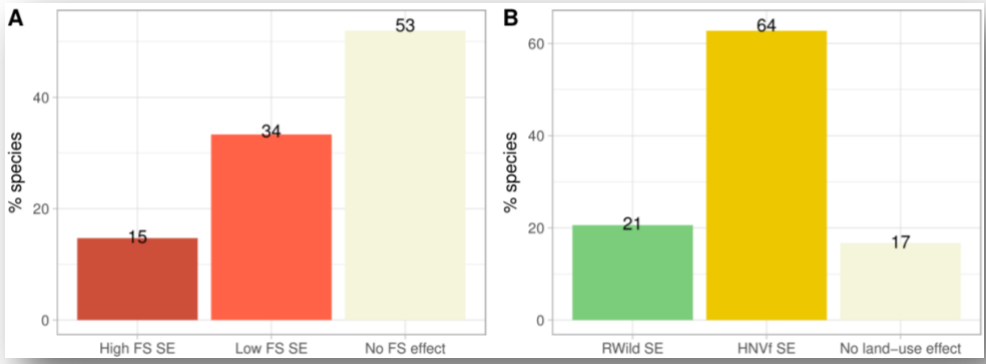


Letting unplanned fire burn

Around 33% of species are benefited by open habitats created by fire

Promoting HNVf

Benefits most of the species (>60%)

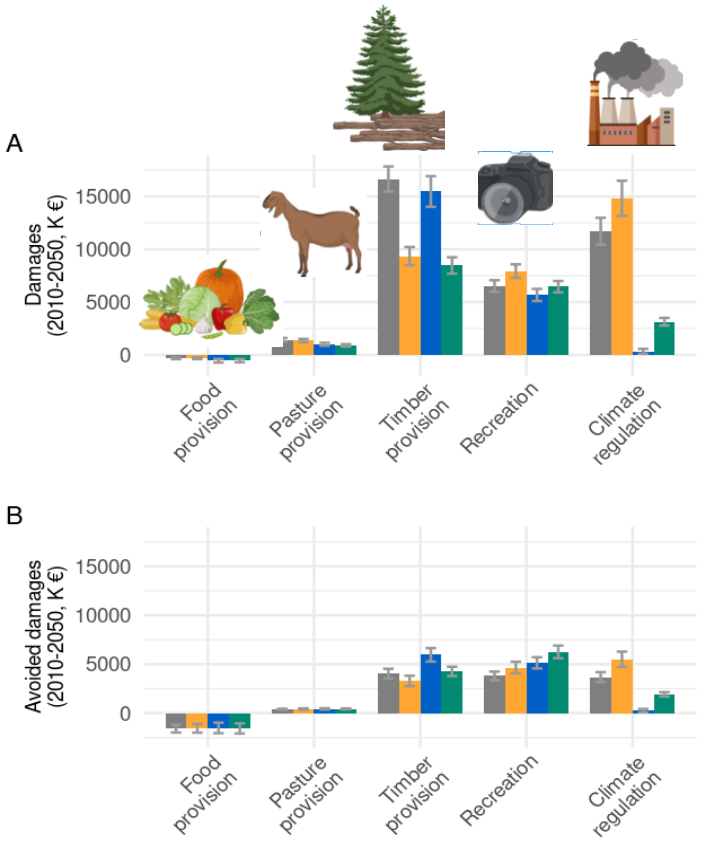


Effects of management scenarios on biodiversity. (A) Percentage of species benefited by fire suppression (FS) management scenarios (2050), independently of the land-use scenario and (B) percentage of species benefited by land-use management scenarios, independently of the fire management scenarios.

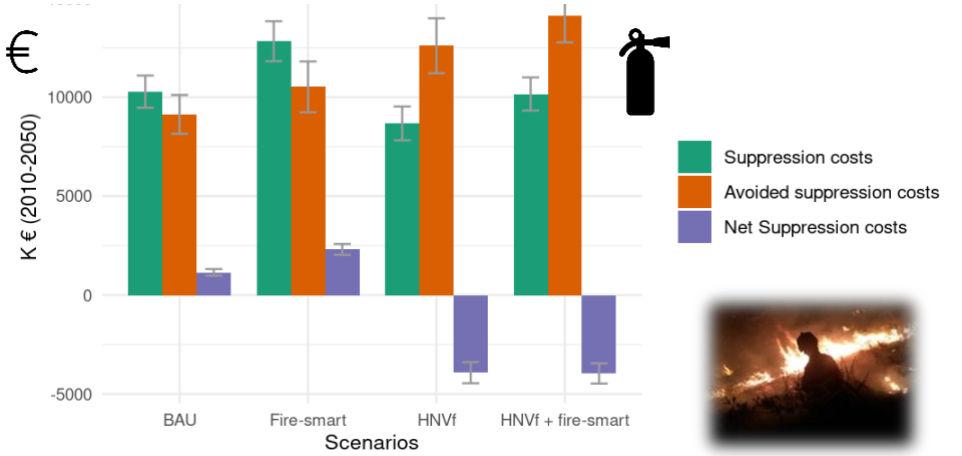
Management and policy recommendations:

This study contributes to the increasing evidence of agricultural policies as essential tools to ensure biodiversity while reducing fire hazard, an aspect that has been frequently neglected when assessing the beneficial effects of agricultural policies. Also, our study suggests using fire to enhance rewilding as an alternative management strategy in our study area — an issue that decision makers and managers should consider when implementing rewilding initiatives in other fire-prone regions. Additionally, our study highlights the need for renewed political and socio-economic efforts exploring different solutions to economic incentives and/or management strategies integrating both rewilding and HNVf. In this context, our study demonstrates how an effective implementation of European agricultural policies could benefit biodiversity (through the creation of new open habitats for endangered species) while providing further fire-suppression opportunities. Our study also shows how fire suppression policies can help navigate rewilding initiatives in other abandoned, fire-prone mountain areas across Southern Europe. It also goes beyond the business-as-usual scenarios and provides plausible future pathways wherein rewilding modulated by fire suppression can emerge as nature-based solution if the new EU Common Agricultural Policy continues to fail at reversing rural abandonment trends.

According to our simulations, policies **promoting HNV farmlands**, especially when combined with fire-smart forest conversion strategies, would be able to counterbalance the increasing wildfire impact. But considering the **rural abandonment** trends that took place since the last part of XX century, and that the CAP was not able to reverse such trends, are these policies feasible options from socio-economic viewpoint? How could the revised CAP overcome these socioecological constraints?



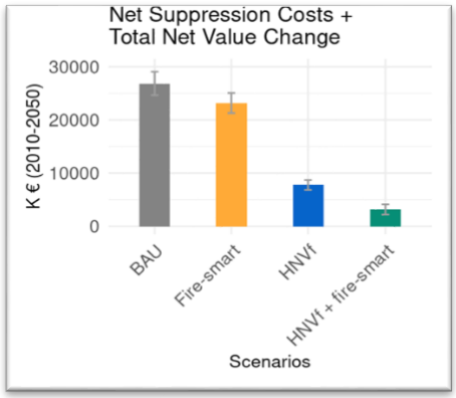
We combined scenario analysis, fire-landscape modelling, and economic tools to identify which land-use policies would minimise the expected wildfire-related losses To do so, we applied the **least-cost-plus-net-value-change approach** of wildland fire economics, and estimated net changes in wildfire damages based on their implications for the ecosystem services that affect financial returns to landowners in the study area (i.e. agriculture, pasture, and timber), and the wider economic benefits (i.e. recreation and climate regulation) for the 2010-2050 period.



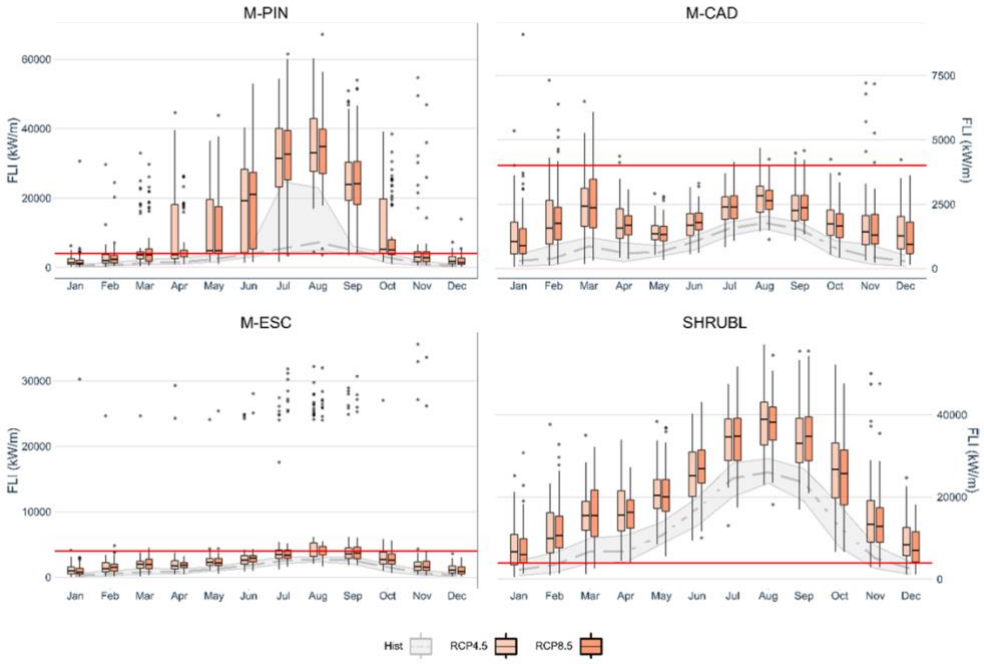
Present value of wildfire suppression costs, avoided suppression costs and net suppression costs under land-use management scenarios (Business-as-Usual (BAU), fire-smart, High Nature Value Farmlands (HVNf), and HVNf + fire-smart) over the 50 years simulated period.

Management and policy recommendations:

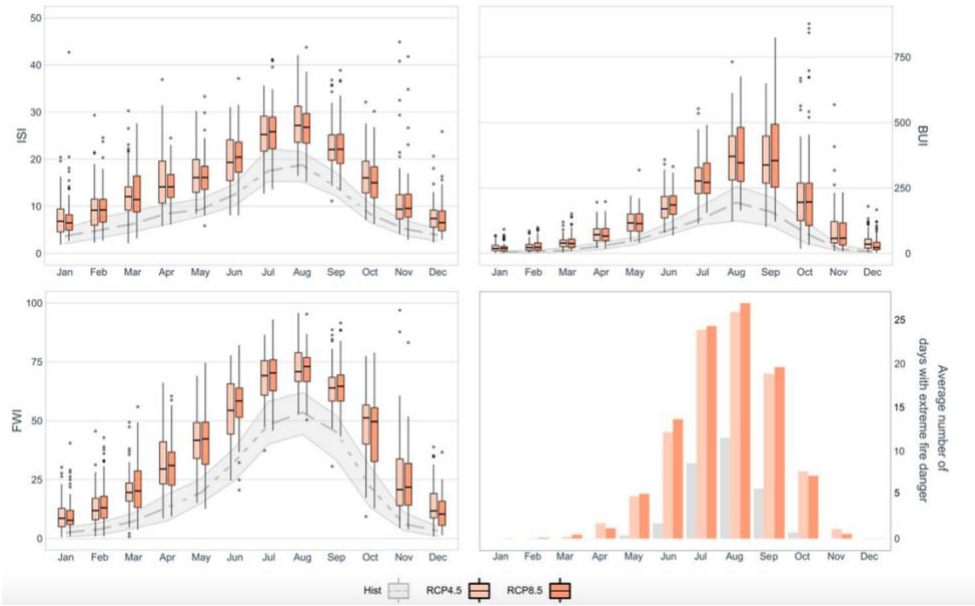
Our results added economic evidence to recent research about the **critical role that fire-smart agroforestry policies** could play to promote sustainable solutions to the wildfire problem in abandoned rural landscapes of Southern Europe. Promoting extensive agriculture would provide fire-suppression opportunities, **generating societal benefits in the form of savings in fire suppression costs**. However, the effect on suppression costs must be weighed against the effect on ecosystem services from these landscape changes as wildfire strategies. Our results showed that large-scale forest conversions to more fire-resistant forests would not be on their own the most economically effective solutions to reduce potential burned area and consequently suppression costs; however, when integrated with HNVf policies to jointly reduce fire hazards, this strategy generates the smallest net cost to society. This generates the lowest net suppression cost and wildfire ecosystem services damages. In this sense, the new European Common Agricultural Policy offers an excellent opportunity to incorporate fire-smartness into **renewed EU agricultural policies** that would contribute to wildfire cost mitigation. Our findings emphasise the **need for payments for ecosystem services as a governance approach to reward private landowners' services for the wildfire protection** of their crops.



The Mediterranean Basin is a hot spot of **climate change**. In addition to the effect of rural abandonment on fire regime, regional climate change projections highlight warmer and drier climates throughout the region, which will significantly increase future fire danger, especially in late spring and early autumn. This is expected to lead to changes in fire regimes, with higher fire danger, and a longer and more severe fire season, even if the Paris agreement efforts to limit the temperature increase to 1.5 ˚C are successful. Such harsh conditions may decrease the effectiveness and opportunities for wildfire suppression, pushing local authorities far beyond their response capacities. Nonetheless, climate-induced changes in fire behavior might be counteracted by lower fuel load because of decreased plant productivity.



Distribution of simulated **fireline intensity (FLI)** adjusted for NPP, for the different fuel models studied, under climate change scenarios RCP4.5 (light orange) and RCP8.5 (dark orange) for the period 2031–2050.

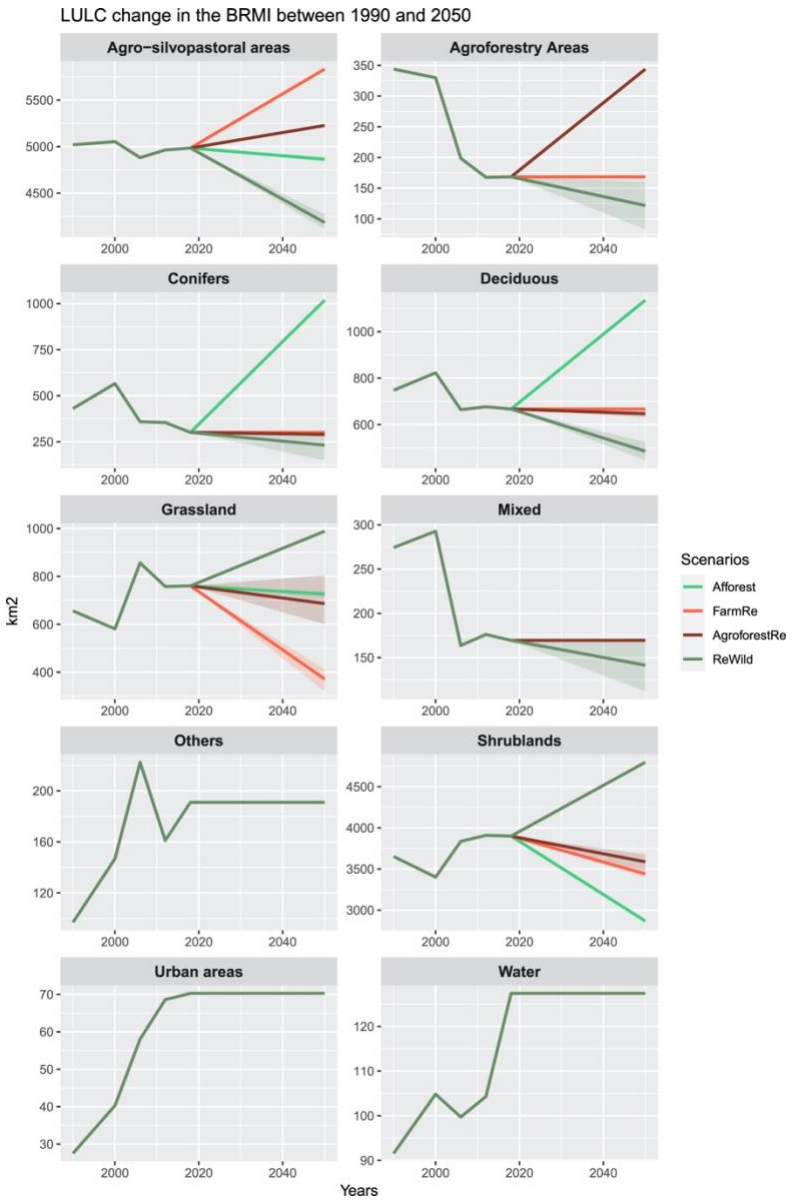


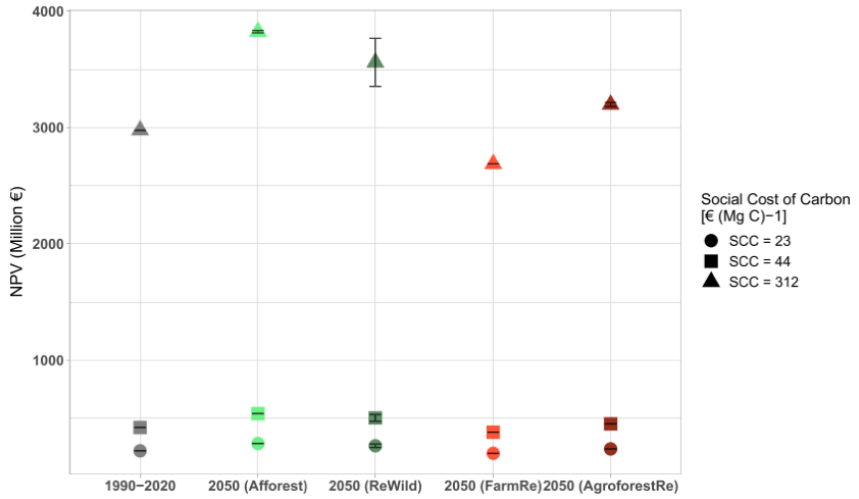
Boxplots of monthly **Initial Spread Index (ISI), Buildup Index (BUI) and Fire Weather Index (FWI)** for the 2031–2050 period under RCP4.5 (light orange) and RCP8.5 (dark orange) scenarios. Median historical monthly FWI are shown as grey dashed lines, while the percentile 25 and the percentile 75 are represented by the grey shaded area.

Conclusions and policy recommendations

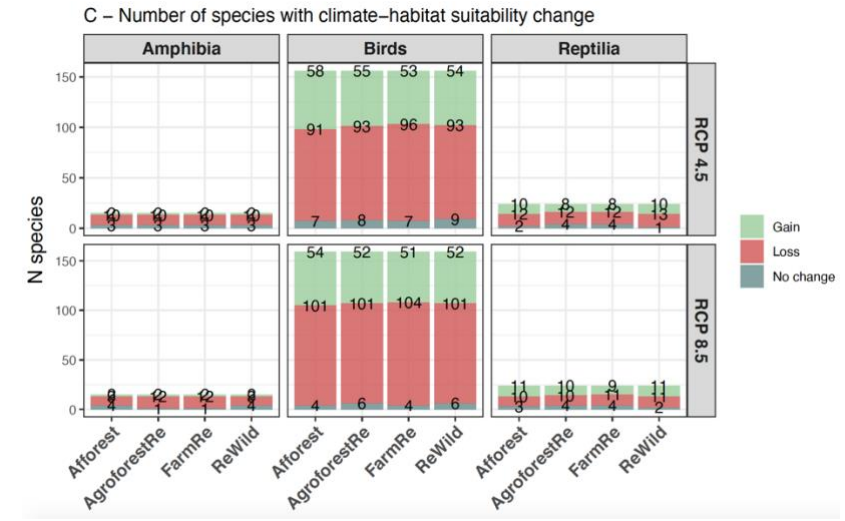
Our results showed that **climate change will increase fire danger**, increasing the frequency of fire weather conditions associated with large wildfires in the target region. Both RCP4.5 and RCP8.5 point to an increase **in fire-spread rate and fireline intensity** in the fuel types considered, which are broadly representative of the Mediterranean Basin. Nonetheless, while pine forests and shrublands may experience an **increase in fire intensity to levels that further exceed wildfire suppression capacity**, mainly from spring to autumn, **broadleaved forests will not typically exceed such thresholds**. The consistency in results regardless of the climate scenario considered reinforces the need to address the effects of climate change in wildfires when planning future management. Although we acknowledge that the "challenges of wildfire management through the twenty-first century include not just dealing with an increased number of fires, but also an increased incidence of unmanageable crown fire", our results clearly show that **climate change effects in certain fuel types, such as broadleaved forests, may not imply further ineffectiveness of firefighting operations in the medium term**. Likewise, **landscape-level fuel treatments that reduce fuel load will be crucial to mitigating the future fire regime**. Hence, through better planning and management of wildfire-prone landscapes, decision-makers would be, consequently, protecting communities, even when considering climate change.

The implementation of **climate-smart policies** to enhance carbon sequestration and reduce emissions is being encouraged worldwide to fight climate change. **Afforestation practices and rewilding initiatives** are climate-smart examples suggested to tackle these issues. In contrast, **fire-smart approaches**, by stimulating **traditional farmland activities or agroforestry practices**, could also assist climate regulation while protecting biodiversity. However, there is scarce information concerning the potential impacts of these alternative land management strategies on climate regulation ecosystem services and biodiversity conservation.





Total avoided economic damages of carbon sequestration between 1990 and 2020, and the alternative landscape scenarios (2020–2050) considering three social cost of carbon (SCC) prices. Markers in the graphic show the mean net present value (NPV) in million €.

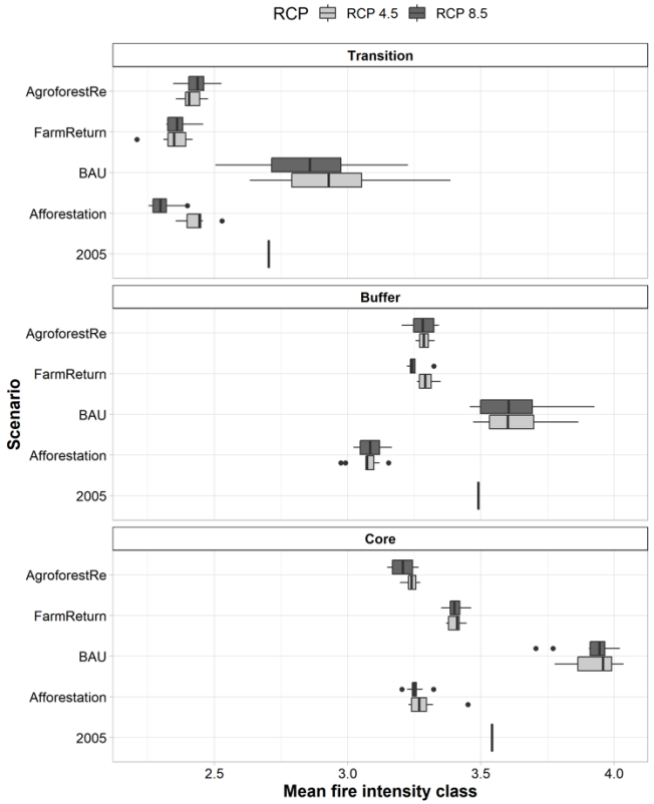


Management and policy recommendations

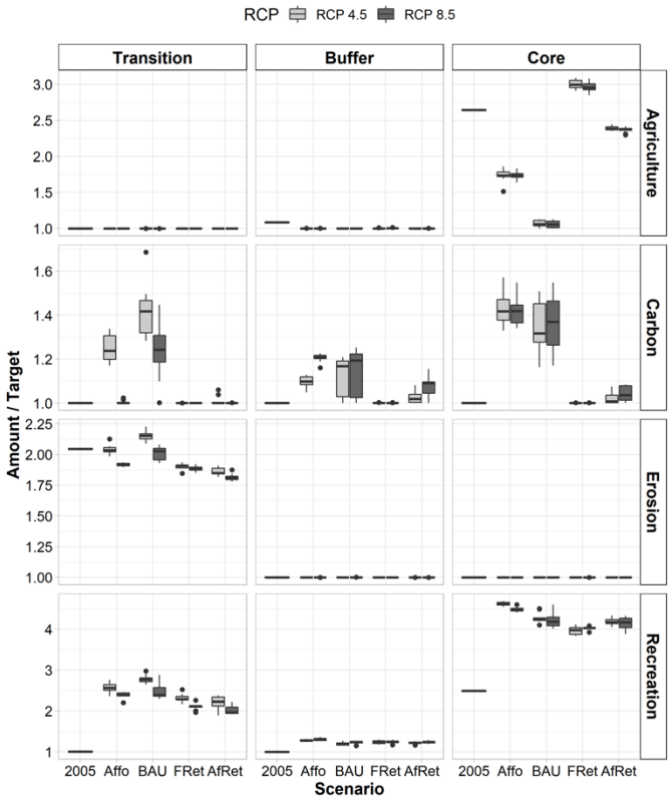
Climate-smart scenarios were predicted to deliver the highest rates of carbon sequestration and storage, and also to prevent more economic damages due to carbon emissions reduction in comparison to fire-smart scenarios. Also, climate-smart scenarios were predicted to deliver more benefits for species of conservation concern. In contrast, fire-smart scenarios were predicted to secure the habitat suitability of species adapted to semi-natural habitats under future climate change.

This study provides valuable data to support a more informed landscape planning and decision making in abandoned rural mountains in Southern Europe. Still, this study should be complemented with the analyses of other regionally relevant ecosystem services (e.g., fire regulation), which would contribute to a wide-ranging risk assessment needed for the successful implementation of these alternative nature-based solutions.

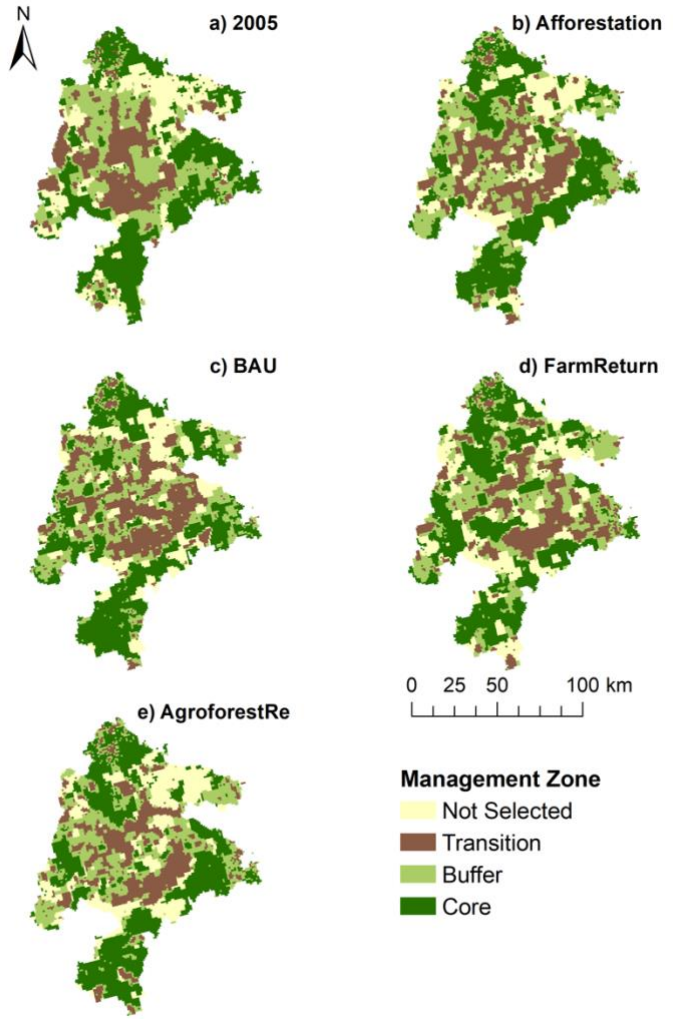
Integrated management of biodiversity and ecosystem services (ES) in heterogeneous landscapes requires considering the **potential trade-offs between conflicting objectives**. The UNESCO's Biosphere Reserve zoning scheme is a suitable context to address these trade-offs by considering multiple management zones that aim to minimize conflicts between management objectives. Moreover, in Mediterranean ecosystems, **management and planning also needs to consider drivers of landscape dynamics** such as wildfires and traditional farming and forestry practices that have historically shaped landscapes and the biodiversity they host.



Amounts of ecosystem services secured as a ratio between the amount of ecosystem service held in each zone and the zone target required for each landscape scenario and RCP.



Mean potential fire intensity class per zone in each landscape management scenario and RCP. Affo: Afforestation scenario; FRet: FarmReturn scenario; AfRet: AgroforestRe scenario.



Conclusions and management implications

Our results showed that the **Meseta Ibérica BR** could maintain habitat for most species and conditions to the supply of several groups of ES. To do so, changes in management and planning would be needed in order to ensure the maximum potential of the BR in terms of biodiversity conservation and ecosystem services supply in the coming decades. We mainly identified two required changes: i) An internal redesign of the zoning of the BR, especially regarding **Core Areas, which would need a considerable expansion** to help mitigate changes in biodiversity and accommodate ES supply under expected changes in climate and species distribution. ii) The BR needs to deviate from current management policies, since they will result in encroached landscapes prone to high intensity, uncontrollable wildfires with the potential to heavily damage ecosystems and compromise the supply of ES. Instead, **management should focus on either climate- or fire-smart policies**, since both can enhance the effectiveness of the BR, although focusing on different management goals. Implementation of these changes, together with species-oriented management plans, will help promote **multifunctional landscapes that help mitigate and adapt to climate change and ensure the best possible maintenance of biodiversity and ES supply under uncertain future climate conditions**.

Synthesis – Policy recommendations

Our modeling simulations support local stakeholder's perspective 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.

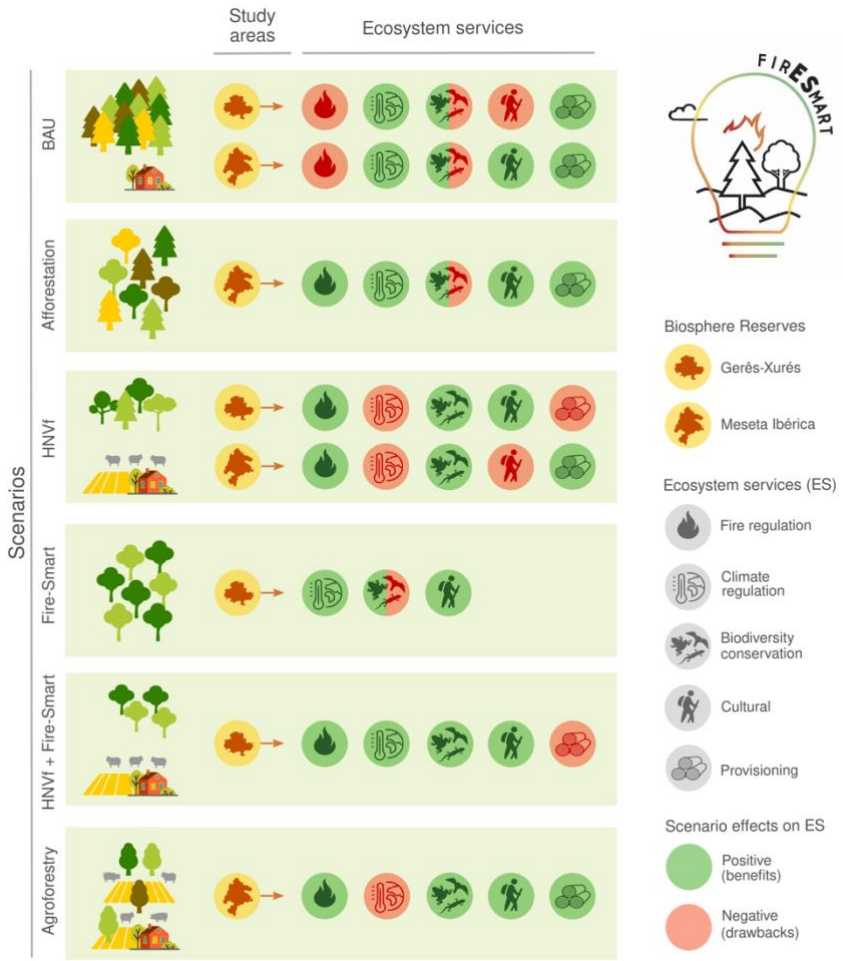
1) **Land-use policies promoting farmland areas** would provide further fire-suppression opportunities by creating open spaces while simultaneously ensuring biodiversity conservation within (and around) protected areas.
   a. A large amount of strategically allocated cropland areas should be gradually incorporated into the landscape over the next four decades to significantly **reduce the risk of large wildfires**. Therefore, a **greener path for the European Common Agricultural Policy** (EU CAP) would enhance **fire regulation capacity and fire protection ecosystem service** in mountain landscapes.
   b. These policies would be also **positive for biodiversity conservation** since most of the species considered in our simulations would benefit from the recovery of habitats associated with traditional agropastoral activities.

2) 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 and Fig. 3) would be indeed the most advantageous. 'Fire-smart' management also stands out as very efficient solutions for climate regulation services while also contributing to fire regulation, facilitating the transition toward landscapes more resilient to climate change and large wildfires.

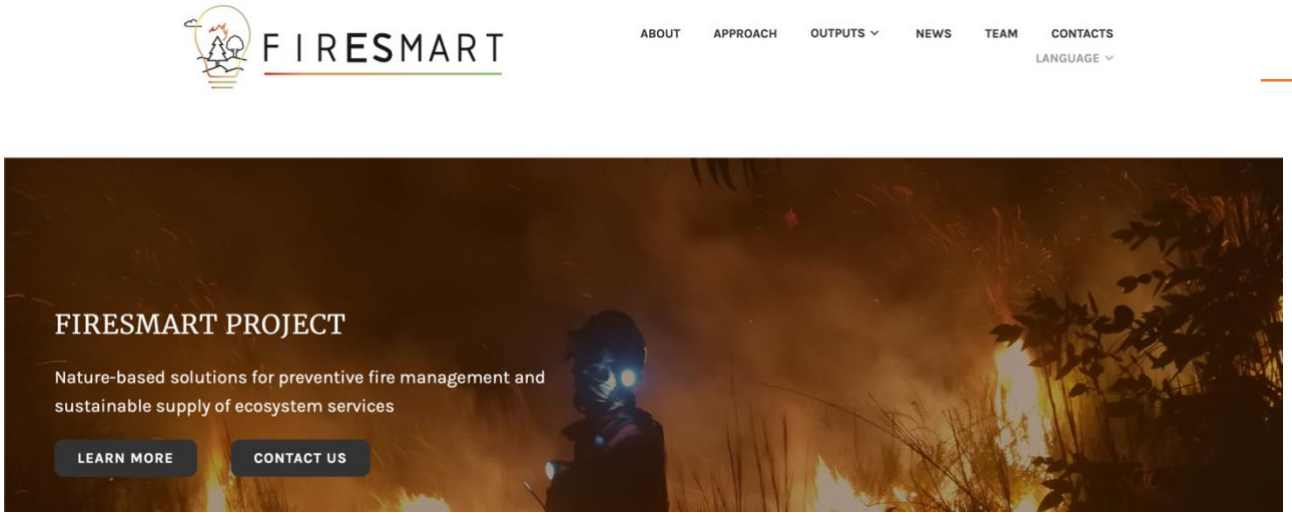
3) Although **'fire-smart' forest conversion** scenarios would be beneficial for a long-term supply of carbon sequestration, its implementation should be **integrated within agricultural policies** to jointly reduce fire hazard and preserve local biodiversity adapted to these semi-natural systems (Fig. 3). In fact, this integrated scenario would also reduce the wildfire impacts on **pasture production and recreation ecosystem services** (Fig 3). 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.

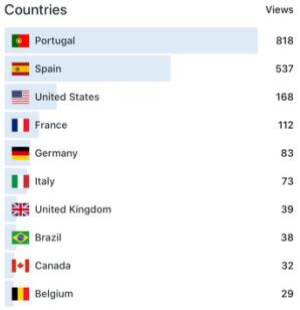
4) Nevertheless, if the **new EU CAP fails** at reversing rural abandonment **'rewilding' and 'tree-planting' initiatives** will keep gaining attention as nature-based solutions to climate change. According to our simulations, 'BAU' and 'Afforestation' scenarios, characterized by a gradual increase in semi-natural and forest would be the best option for climate regulation (both in terms of carbon sequestration and avoided economic losses) (Fig. 3). These findings support the recent 'climate-smart' initiatives proposed by the EU to follow the Green Deal roadmap towards a decarbonization of the economy.

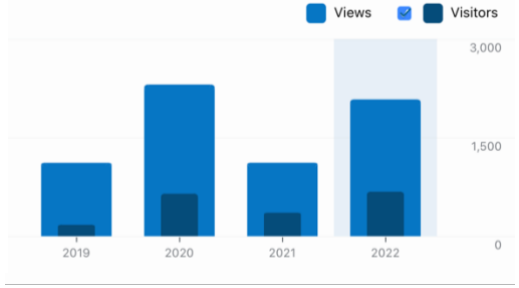
5) Our simulations showed that such scenarios would also be good for forest-dwelling species However, these 'climate-smart' forest policies entail important challenges associated with wildfire risk that need to be carefully considered before implementation. For instance, our simulations predicted an increase in fire intensity and burnt area for the next decades in both Biosphere Reserves due to the joint effect of rural abandonment and climate change. The wildfire hazard associated with **rewilding and afforestation programs could be reduced by reintroducing large herbivores and/or fire as a tool 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 Biosphere Reserve 'Gerês-Xurés') —an issue that will rely on the fire suppression policies and/or more strategic burning programs to be implemented in the decades to come, being a cost-effective solution only achievable with the full recognition of fire as a critical factor in our ecosystems.



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.







FirESmart is now coming to an end, and the outcomes are being published in prestigious journals and having a great media impact (see outputs). Our team has so far published 17 scientific publications in top-ranking journals such as *Nature*, *Science*, *Global Change Biology*, *Science of Total Environment or Frontiers in Ecology and Environment*. Two datasets freely available at Zenodo (see 1,2). Products such as the fire-landscape **model REMAINS**. Dissemination and transfer of knowledge is a fundamental piece of the project (see e.g., FirESmart's **outreach** video). We would remark, for instance, that the last WWF report was partially based on results of the FirESmart project. The project has been well accepted by **local stakeholders**, having a great media impact at Iberian Peninsula level (see project dissemination). Project results were presented in several **national and international conferences,** totalizing 25 communications (Portugal, Spain, Italia, France and Estonia, and USA, see conferences subsection). Three master thesis supervised in the context of the project (Silvana Pais, Sara Rodrigues and Jader Lamas) and one PhD thesis (Ângelo Sil).

Main publications

Regos A, Pais S, Campos JC, Lecina-Díaz J (2023). Nature-based solutions to wildfires in rural landscapes of Southern Europe: let's be fire-smart! ***International Journal of Wildland Fire*** (under review).

Lecina-Díaz J, Chas-Amil ML, Aquilué N, Sil Â, Brotons Ll, Adrián Regos, Julia Touza (2023). Incorporating fire-smartness into agricultural policies minimises suppression costs and ecosystem services damages from wildfires. ***Journal of Environmental Management*** (under review).

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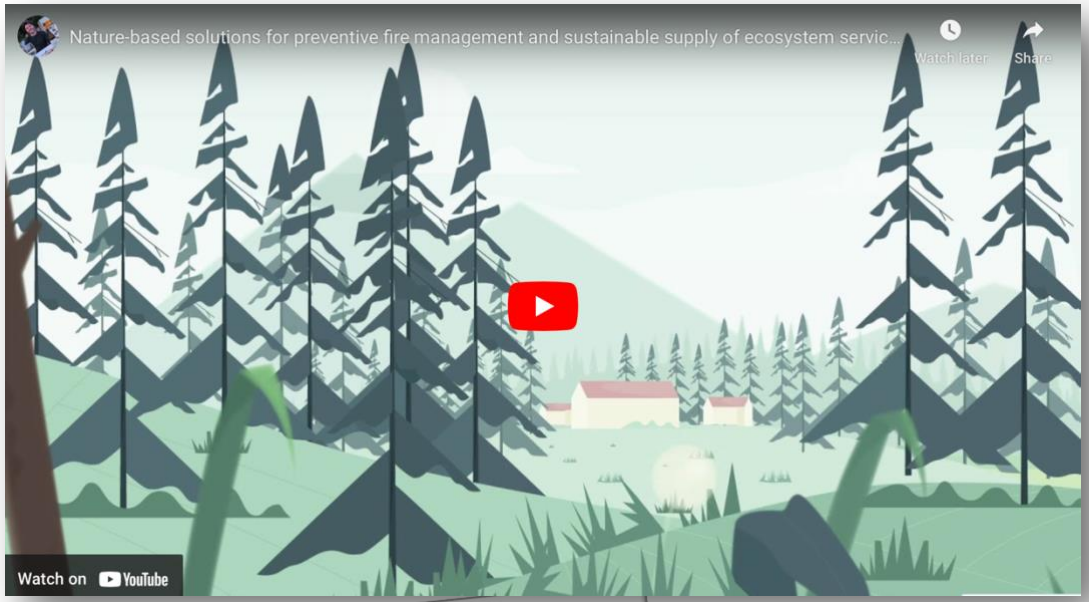

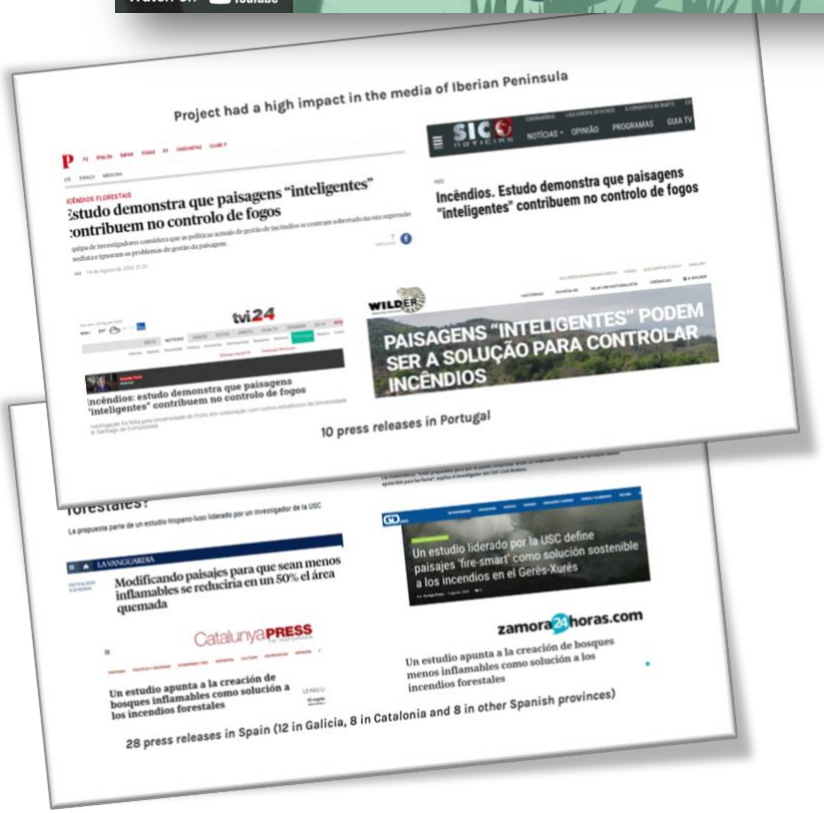

Campos JC, Rodrigues S, Freitas T, Santos JA, Honrado JP and Regos A (2021). Climatic variables and ecological modelling data for birds, amphibians and reptiles in the Transboundary Biosphere Reserve of Meseta Ibérica (Portugal-Spain). ***Biodiversity Data Journal***, 9: e66509.

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