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Report C

Wildfires and the restoration of burnt areas

Prevention, extinction and post-fire management in Spain

CONGRESO DE LOS DIPUTADOS

FECYT INNOVACIÓN

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Production method

Reports C are brief documents on subjects chosen by the Bureau of the Congress of Deputies that contextualise and summarise available scientific evidence on the analysed subject. They also inform about areas of agreement, disagreement, unknowns, and ongoing discussions. The preparation process for these reports is based on an exhaustive bibliographical review, complemented with interviews of experts in the field who subsequently conduct a two-stage review process of the text. The Oficina C conducts this process in collaboration with the management team of the Spanish Parliament's Lower House Documentation, Library and Archive service.

To produce this report the Oficina C referenced 325 documents and consulted 18 experts in the subject. Of this multi-disciplinary group, 56% come from the field of life sciences (ecology, ecological restoration, environmental sciences, botany), 33% from physical sciences and engineering (forest engineering, forestry, agricultural engineering, technical personnel and operations specialists) and 12% from humanities and social sciences (geography and sociology). 79% work in Spanish institutions or centres, whereas 21% have affiliations with at least one institution outside Spain.

Oficina C is the editorial supervisor of this report.

Summary C

El informe en 5 minutos

In 2022, the Mediterranean experienced one of the worst seasons of forest fires in recent decades. Although fire is a natural element of ecosystem dynamics, and habitual in traditional practices related to agriculture and livestock grazing, in a scenario of increasingly high temperatures and droughts, the recurrence and intensity of fires can compromise the regeneration of natural areas. For several decades, the number of days per year with a high fire weather index has increased in many countries worldwide. Forecasts for Spain suggest it will one of the countries with the highest increase. In this context, we have seen a significant, constant increase in burnt area due to large wildland fires, which endangers people and infrastructures as well as generating significant economic loss. This situation demands that we reflect on the extensive efforts devoted to extinction and the comparatively lower amount of resources devoted to prevention and mitigation.

This Oficina C report on "Wildfires and the restoration of burnt areas" discusses a range of subjects including the social and environmental heterogeneity of Spain's territory, as well as prevention, extinction and post-wildfire management. It also acknowledges the significant role that different sector policies and multidisciplinary approaches can play.

Wildfires

A high risk of wildfires continues to exist, despite the fact that the number of fires and total burnt area remain relatively stable and controlled (or have even dropped in some areas, partly due to a high investment in extinction capacity and improved coordination between firefighters and authorities). There is also an increase in average burnt area due to large wildfires, with a significant rise in the number of fires that affect an area larger than 5000 hectares. This is why the scientific community notes that, in addition to addressing the causes of ignition, we need to reduce the capacity of fire to spread over the landscape and so prevent the most extreme wildfires. A major reason for the current situation is that forest cover in Spain has been increasing for decades thanks to reforestation plans and a reduction in traditional activities. This reduction of activities, derived from rural population drift, has generated very continuous stands of young vegetation with the potential to generate wildfires that exhibit very intense behaviour. Behaviour is also influenced by meteorological factors: higher temperatures, less precipitation and recurrent, prolonged droughts. These circumstances make it important to understand the impact of climate change scenarios throughout the territory of Spain, in order to predict extreme fires or megafires and adapt our response to them.

Spain coordinates its wildland policy by means of the strategy EFE 2050 (Estrategia Forestal Española Horizonte 2050, the Horizon 2050 Spanish Forest Strategy). In terms of legislation, the strategies and plans for prevention, extinction and post-wildfire management are governed by the 43/2003 Basic Wildland Act and the regulations of each autonomous community. There are also different protocols, recommendations and technical documents enabling coordination that are prepared by the Wildland Firefighting Committee formed by the General State Administration and the autonomous communities.

On the horizon

In Spain, 72% of wildlands are privately owned. This reality makes it essential for authorities to collaborate with the public, different stakeholders and social actors involved in the rural world, and in particular with landowners. Likewise, conservation and environmental policies need to consider the major impact of wildfires on protected areas, whether they are national, regional, or part of the Natura 2000 network. In all cases, higher monitoring of the areas at greater risk is necessary. Increasing the resistance and resilience of forest stands in general, and to the passage of fire in particular, is a priority management and policy goal for the European Union. In this sense, plans derived from such policies should integrate the singular characteristics of Spanish ecosystems (both Mediterranean and Atlantic) and their heterogeneity as well as the socioeconomic reality of the land.

Both experts and authorities highlight that there is a great imbalance in Spain between prevention and extinction, with more spending allocated to extinction. The public policy of extinguishing all fires, due to the risk that uncontrolled fire represents for both the public and ecosystems, has the collateral effect of not reducing fuel while increasing the risks of greater intensity and spread. However, some sources advocate a different relationship with fire in the landscape, for instance, with controlled burns, a strategy requiring collaboration between the authorities and landowners, which seeks to harness the positive effects of fire. This approach is particularly useful in the northeast of Spain, where many of the wildfires are due to traditional practices aimed at modifying the vegetation (e.g., the regeneration of pasture, for hunting, to improve access,

Imagen FOTCIENCIA Fires © Victoria Arcenegui Baldó

etc.). Likewise, mosaic ecosystems, which combine forest stands with open spaces, have proved to be a good example of maintaining good conditions and a high level of ecosystem biodiversity as well as incorporating natural barriers to potential fires.

On the horizon

Different disciplines are showing increasing interest in generating ecosystems that maintain and maximise benefits for people: ranging from the economy and wildland produce to recreation areas, the tourist industry or services such as clean water and air. But wildlands also need to be resistant to fire and capable of recovering after a wildfire. Due to the complexity of this subject, it is not usually possible to make blanket recommendations. So, the research community is working to gain specific knowledge adapted to each territory and present scenarios that can: 1) forecast wildfire risk at local level and predict which zones and conditions will have favourable conditions for a wildfire with behaviour that exceeds extinction capacities; 2) after a wildfire, define both urgent and -if possible- long-term measures to protect the zone and enable its regeneration; and 3) prepare ecosystems for future climate conditions and wildfires.

Today, the European Union is developing laws for the quantitative analysis of the status of woodlands and the restoration of ecosystems. Due to timescales determined by social and environmental processes of landscapes, the effects of actions taken today will not be seen for several decades. So, in the current context of climate change and rural exodus it is of paramount importance to achieve resistant, resilient ecosystems and a thriving social fabric that is prepared to face large wildland fires.

Wildfires and the restoration of burnt areas

Introduction

Spain is one of the countries with the highest risk of experiencing wildfires.

Spain is among the European Union (EU) countries with the highest risk of suffering wildfires. In 2022, it was the EU country that experienced the highest number of fires and had the largest burnt area: 315,705 hectares[1], which is an area slightly larger than that of the whole province of Álava. However, the data of historic series do not show a trend to an increase in either the number of wildfires or the area affected by them[2]. Mediterranean ecosystems, where fire is a habitual, natural phenomenon, occupy 80% of Spain's territory[3], and historically, fire has played a role in both natural dynamics and landscape conservation[4,5]. So species have developed specific adaptations to recover or resist[6-8]. Nevertheless, many ecosystems can be significantly altered by the large, intense wildfires that are increasingly recurrent[5], which compromises the ecosystem's subsequent regeneration and may also cause its collapse since fire reduces its adaptive capacity[6,9].

Spain's defence against this risk consists of a high capacity extinction management system[10,11]. This means that most fires remain within the category of small fires and are extinguished before they spread[2]. The current problem is that the likelihood of a fire turning into a large wildfire fire is increasing[12]. Among the main reasons for this are the disappearance of traditional non-intensive agriculture practices and woodland management techniques, often as a consequence of the depopulation of rural areas or outsourcing in the rural economy, which create an increase in and accumulation of fuel load and biomass that is very continuous[13-15]. Other influences include the wildland, agricultural and territorial policies at different administrative levels over the last century that have shaped our current landscape[16]. Another factor in the equation is the general context of climate change with a tendency towards higher temperatures, less precipitation, and a higher frequency of prolonged, severe droughts[17,18]. This process is known as global change.

Wildfires have ecological, environmental, social and economic consequences. Worldwide, fires account for an amount of CO_2 per year that equals 10-16% of emissions produced by the use of fossil fuels[19,20]. Regarding biodiversity, the Iberian peninsula is home to around 50% of all of the species of plants and vertebrate animals in Europe and over 30% of Europe's endemic species[21]. As a whole, as well as in terms of their relationships and ecosystem functions, these endemic species are directly affected by wildfires[22]. Wildland ecosystems and their associated biodiversity can be protected with different legal regulations and conservation instruments[23], which are governed by numerous rules and strategies[24-26]. However, these alone do not prevent the exposure of ecosystems to a high incidence of wildfires[27], some of which are large or very large[28]. The propensity of natural Mediterranean ecosystems to recurrent fire[5,13] is a factor that fire management must consider. This is why a strategic element of environmental policies is the inclusion of aspects related with fire management and prevention strategies agreed between the stakeholders responsible for conservation and extinction[10]. Other impacts are on soil[29], water[30] or air quality that abruptly fall during a wildfire and may cause respiratory conditions not only for humans but also for animals and livestock[31-33]. Some studies show that the people who live in affected areas suffer psychological sequelae[34-36] and may worsen their long-term quality of life[37]. Along the same lines, in civil defence there is an impact with the evacuation of people, consequences

- Wildfire: An uncontrolled fire that spreads to forests, shrubland etc. These fires are defined by their combustion that is uncontrolled in space and time.
- Small fire: Fires that are extinguished before burning one hectare of land.
- Global change: Global change is the set of environmental changes affected by human activity, with particular reference to changes in processes that determine the functioning of natural systems. They have effects that transcend a local or regional scope and affect the whole planet.
- Endemic species: Species that only inhabit a specific continent, country, province or mountain range, for instance.

for infrastructures, accidents or loss of human life[38,39]. On the other hand, the economic impact on these populations is significant and affects infrastructures, businesses, tourism, the production of wood, cork, resin or edible fungi[40].

Spain's main response is structured around the Horizon 2050 Spanish Forest Strategy[41]. In terms of legislation, the 43/2003 *Ley de Montes*[42] governs prevention, extinction and post-wildfire management programmes including restoration; it also transfers competence in the development of regional legislation and action plans to the autonomous community governments. For purposes of coordination, the Wildland Firefighting Committee, formed by the General State Administration and the autonomous communities, prepares recommendations and technical documents[43]. Likewise, national and autonomous community civil defence legislation governs the action plans and protocols[44-46]. The environmental, social and political heterogeneity of Spain's territory mean that laws, regulations and specific plans addressing this issue have to be formulated according to the different realities of each autonomous region. At the same time, wildfires are a transversal challenge that transcends the forestry sector, with an enormous complexity requiring multi-scale approaches[47] and innovative responses from different spheres[10]. In particular, this involves sector-specific public policies that directly or indirectly affect the territory itself[10] and social and economic sectors like livestock farming or agriculture, and various fields of knowledge, in addition to management and operational resources[10].

Profile of current fire regimes in Spain

Spain is prone to large, extremely hazardous wildfires. This is due to an accumulation of available fuel, increasing temperatures and more frequent droughts.

Fires are a natural component of Mediterranean ecosystems and a common element of traditional rural practices in the Atlantic ecosystems of the Pyrenees and northeast of the Peninsula. Fires in Spain have varied in size, frequency and intensity over the years, in what is known as changes of fire regimes[48]. Such changes are related with long-term socioeconomic dynamics that have generated different types of ecosystems and landscapes, which may be more or less vulnerable to fire[12,49]. Current trends do not show an increase in the number of wildfires or total burnt area[2], but there is an increase in the risk indexes[50,51] and of burnt areas, with more aggressive, more widespread fires than in the past[52].

Future scenarios of large wildland fires

Towards the end of the 1990s, there was a general decrease in the number of wildfires and amount of burnt area that continues to date. This is thanks to improvements in strategies and protocols, investment in extinction, as well as a result of technical, logistical, operational and regulatory experience[41] (although the number of incidents in the autonomous communities in the centre of the country and the Mediterranean area remained stable between 2006 and 2015 52). On the other hand, since the early 2000s, we have seen a trend towards higher numbers of large wildland fires[53] that affect increasingly large areas[52].Today, extremely serious fires[54] are referred to as megafires[55], sixth generation wildfires [56], or extreme wildfire events[57] (three slightly different concepts that are often used interchangeably). Countries with ecosystems analogous to those of Spain have suffered major wildfires, such as Portugal (2017)[58], Australia (2019)[59] and Greece (2023)[60]. However, they can also occur in colder regions that have extensive woodlands, such as Canada, which has suffered its worst fire season since records exist[61].

- Fire regime: General description of the pattern of a fire in a specific area or ecosystem. This refers to the typical characteristics of the fires that occur over a long period of time in an area. Specifically, it refers to the variability in the physical characteristics and effects subsequent to a wildfire over time. Fire regimes are normally defined in terms of the frequency, severity, size and pattern of the fires.
- Large wildland fires: Definition based on burnt area. In Spain, the classification of a large wildland fire (LWF) is one that spreads over an area larger than 500 hectares.
- Megafires: This kind of fire generally spreads rapidly, is extremely hazardous for people and the environment, and feeds off itself, creating its own climate. These fires usually affect more than 10,000 hectares. Their severity has the potential to transform landscapes at very high speeds on a very large scale. But there is no exact definition, and the scientific community warns against use of this term.
- Sixth generation wildfires: This non-scientific term is based on the classification of fires by generations, in which each new generation refers to an obstacle that extinction operations must overcome. In the case of sixth generation fires, the fire is impossible to extinguish due to its intensity, speed and unpredictability unless meteorological conditions change.
- Extreme wildfire events: A pyroconvective phenomenon that exceeds the control speed (fireline intensity of ≥10,000 kWm-1; rate of spread >50 m/min) with erratic, unpredictable behaviour. They are a threat for firefighters, the population, and natural heritage, and are likely to have a significant environmental and socio-economic impact.

Spain has experienced several large scale wildfires, whether defined by burnt area or dangerous conditions (**Key point 1**). Wildfires usually generate a major social impact, and it can take several decades or even centuries to fully recover the affected areas[62].

One of the main factors behind a change in fire regimes in Spain is the accumulation of available combustible materials (biomass in the form of trees, shrubs, leaves, trunks or branches in dry conditions)[48]. Unlike the tropics, where there are serious deforestation issues[63], the area of woodlands in Spain has increased in the last 15 years and now occupies up to one million hectares[64]. Some studies observe that this increase, currently derived from rural abandonment, can have both positive and negative effects on biodiversity, depending on different circumstances[65,66]. In both cases, there is the paradox that the depopulation of areas where the land had been used for agriculture, livestock farming and/or silviculture has generated young forest stands that are very homogeneous, very continuous and very vulnerable to extreme fires[67,68]. Ignoring this fact could cause an increase in the rate of burnt areas higher than 25% for each future decade[69].

Large wildland fires have occurred historically in Spain, but current trends show an increase in the average area. There were notable examples of large fires in 2022.

Key point 1. Large wildland fires (LWF) in Spain

Large wildland fires have existed historically in Spain. However, the current trend indicates that they will affect increasingly larger areas[52] due to a worsening of incidental factors. Some recent examples:

2023 Season. Precipitation immediately before the summer season reduced the risk of fires in the Iberian Peninsula as they added moisture to the biomass[17]. However, the Candelaria wildfire in Santa Cruz de Tenerife burnt almost 15,000 hectares, affecting 12 towns and had an estimated impact of 80.4 million euros[76]. 2023 was also notable for large fires outside the traditional season, such as the ones in Pinofranqueado, Caceres, in May (10,843 hectares) or in Valdés, Asturias, in March (9,722 hectares).

2022 Season. The worst wildfire season this century, affecting over 309,000 hectares (as a reference, the average between 2012 and 2021 was 94,248 hectares)[2]. Large fires represented 80.78% of the total affected area, although they were only 0.54% of total ignitions that year. Two of the most serious were the megafires in Zamora's protected area of Sierra de la Culebra (Castile and Leon). They were caused by thunderstorms, affecting 66,000 hectares that included 52 towns and villages[2]. They were worsened by dense vegetation, heatwaves during the ignitions, and an unusually dry winter and spring77. It took 10 days to consider them under control and 4 brigade members died[78]. As they began outside the wildfire campaign season (15 June), only 30% of the crews were under contract when the first fire began[79].

Other seasons. In August 2021 there was a major fire in the Sierra de Paramera, caused by a road accident within the municipal district of Navalacruz (Avila), in which approximately 22,000 hectares burned[80]. In the same year, in Sierra Bermeja (Málaga), 8,401 hectares burned in an extremely hazardous context with particularly adverse meteorological conditions: less than 30% humidity, temperatures over 30° C and winds higher than 30 km/h[81]. In October 2017, there was a spate of wildfires between Galicia and the north of Portugal, in which the main difficulty was multiple simultaneous spotting that broke through geographical obstacles or existing firebreaks[58]. In addition to the direct deaths of 47 people, smoke inhalation increased the death toll82,83. Of similar severity, the Riba de Saelices fire (Guadalajara) in 2005, claimed the lives of 10 wildland firefighters and a forestry police officer from the Cogolludo extinction reservist crew[84].

· Silviculture: Techniques that deal with the conservation, improvement, use and regeneration or restoration, if necessaryof woodlands.

Climate change (which some research claims could be increasing faster than initially believed[70]) is the second key factor after the already mentioned changes. It could modify fire regimes (as evidenced in the events of 2022[2]) due to an increase in temperatures and extreme droughts[17,18,47]. Mathematical models reaching to the year 2100 forecast a higher fire weather index throughout almost all the Iberian peninsula[69,71,72]. However, data do not show a correlation between risk indexes and the real occurrence of fires, which indicates that there are other incidental factors to consider[50]. Moreover, worldwide, there has been a progressive increase in the length of the wildfire season[73,74]: in many countries they no longer occur only in summer[69,74]. In Spain, the projected increase is between 34 and 69 days[74] (forecast for global temperature increases between 2 and 4°C, in line with United Nations estimates[75]).

Causes of ignition

Although reasons vary countrywide, the main causes of ignition are predominantly human, whether due to negligence or intention. The number of ignitions has decreased in recent decades.

It is important to distinguish between the causes of the start of a fire, ignition, and the causes behind its spread because each requires a different approach. On average, the known causes of ignition in Spain are mostly human activity, either due to negligence (31%) or intention (understood as the deliberate desire to burn wildland terrain) (60%), whereas only 5% are caused naturally by lighting[52,71]. This information is particularly important when it comes to evaluating the autonomous communities with the highest number of registered incidents: Galicia (29%), Castile and Leon (13%) and Asturias (12%)[52]. In the 2006-2015 period, the main reasons for intended burning were traditional agricultural sector practices to clear scrub and agricultural waste (28% of ignitions), burning started by shepherds or livestock farmers to renew pasture (23%) and, to a lesser degree, arsonists (5%), vandalism (5%), burning started by hunters to make hunting easier (2.5%) or personal revenge (1.7%)[52]. These general figures are not a faithful reflection of the whole of Spain due to the heterogeneity of the country. For instance, in Asturias, 70% of all ignitions were the result of intentional burns by shepherds or livestock farmers in order to improve the quality of pasture (to feed their livestock)[85]. For this reason, the strategy for prevention and wildfires (EPLIFA) is based on adaptation to each part of the territory's socioeconomic context and natural dynamics. It is therefore necessary to avoid general approaches and reach a consensus on technical criteria and on the needs of livestock farmers to carry out controlled burns[86].

Although natural causes, specifically lightning, are responsible for comparatively fewer fires than humans, the associated atmospheric instability tends to cause more extreme fires, which burn more hectares[87]. Lightning has predictable seasonal and spatial dynamics[88,89]; however, according to the forecasts of the International Panel on Climate Change, greater atmospheric instability in Europe could change these patterns[74]. The specific mathematical models for Spain indicate a slight reduction in lightning activity in summer, but an increase in autumn and spring. Also, in general, there could be an increase in the amount of lightning at higher altitudes, above 1,000 metres, with a greater risk in higher areas[90] with lower humidity[89]. Another aspect to consider is countrywide distribution: there are a higher number of lightning bolts in Catalonia, Aragón and the Community of Valencia[88]. In particular, lightning is the cause of 52% of ignitions in the province of Castellón[91], whereas in Catalonia it is responsible for 11%[92].

Factors influencing higher risk and spread

Many factors can feed off one another, increasing both risk and hazard.

There are several risk factors that can enable the spread of fire and increase the hazards that arise when it gets out of control, burns large areas of land, or passes close to population centres[93]. These are meteorology (temperature, wind, precipitation) drought (**Key point 2**)[17], specific topography of the location, the use and management of the terrain affected, and

· Fire weather index: The fire weather index (FWI) is a numeric rating of fire intensity, dependent on weather conditions. It takes into account fuel moisture, moisture in moderate and deep organic layers, the effects of wind, accumulated precipitation and temperature. It represents the intensity of fire spread and can serve to predict its behaviour. The index classifies days from low risk to extreme risk.
· Duration of the wildfire season: This is defined as the number of days each year that the risk of fires (estimated in accordance with the FWI) is above half of the average range (equivalent of high or extreme risk).

the existence of wildland-urban interface. All of which interact, feeding off each other[94]. An example of maximum risk might be a mountainous area with a lot of continuous vegetation close to an urban centre after a prolonged drought during a heatwave on days with gusts of wind. But the critical factor is fuel moisture; using data for burnt area in Portugal, it was observed that when moisture dropped below 12%, burnt area drastically increased[95].

Droughts worsen fires and compromise the natural regeneration capacities of vegetation.

Key point 2. Drought and the water cycle

Mediterranean wildland ecosystems are well adapted to drought. Nevertheless, when droughts are too frequent or prolonged, they generate low productivity, defoliation and tree death[96], which enables fire to start and spread[97]. Moreover, in very dense woodlands, the trees compete for the little water available, causing a greater impact of the drought[96] and dehydration of lower soil layers[98]. The combination of drought and wildfires (whether recurrent and/or high intensity) can affect sprouting and the subsequent renewal of ecosystems[99].

Today, 74% of the country is composed of arid zones (including arid, semi-arid and dry sub-humid zones)[100]. In 2020, calculations found that 20% of the terrain had become desert and 1% was in the process of desertification[101]. Overexploitation of resources, changes in land use, rural exodus and climate change explain this phenomenon. The future trend will be for more frequent, longer-lasting droughts in most of Europe[18]. Projections indicate a reduction of 5 to 30% in precipitation in the arid and semi-arid areas of the Mediterranean region[102]. Likewise, it is predicted that environmental thresholds will be crossed, changing from one type of potential ecosystem to another by the year 2100[103]. A severe drought in Europe lasted from 2022 to the spring of 2023, when partial alleviation came with some precipitation[104].

On the other hand, another line of research relates the structure and large-scale changes of woodlands with the regime of precipitations and water cycle[105-107]. Nevertheless, due to the high number of related factors, current mathematical models are very uncertain[107], which makes it difficult to design reforestation projects that aim to increase precipitation[108,109].

Wildland-urban interface areas are the places with the highest risk for people.

Wildland-urban interface. In wildland-urban interfaces or transition zones (also called peri-urban areas), the wildland comes into contact with land developed by human activity, which is why the risks of wildfire are very high for people and their properties [110-112]. These types of area have increased in Spain and are related with a dispersion of settlements (particularly in metropolitan and coastal areas) and a progression of vegetation[110]. They are particularly extensive in Galicia, Asturias and the Canaries, the metropolitan areas of Madrid and Barcelona, or in coastal areas intensely used in tourism[113]. Studies have investigated the vulnerability of these areas in different autonomous communities, such as Galicia, where findings show that ignitions within interface areas are double those of other zones[112]. Another finding is that scattered buildings in areas with a predominance of dense stands of vegetation in the form of trees or shrubs are more susceptible to high intensity fires, which place inhabitants at risk[114,115].

Rural exodus and the abandonment of rural activities have generated larger amounts of fuel for wildfires.

Accumulation of fuel and use of the terrain. Rural exodus, in addition to the abandonment of agriculture and traditional activities (silviculture or exploitation of woodland resources), has generated homogeneous woodlands throughout a large part of Spain with no obstacles to halt a potential fire, and the accumulation of dead biomass and scrub that serve as fuel[116]. Influences on the behaviour of wildfires include the load (amount) of fuel, form, size, compactness, density and distribution over an are[117]. Studies show a lower probability of wildfire spreading in areas where woodlands are combined with active agricultural smallholdings that act as natural barriers[118]. At the opposite end of the spectrum, there is a higher probability of propagation in valleys, where more fuel can accumulate[119].

Risk is greater for higher terrains.

Topography of the location. In terms of a location's specific type of terrain, the risk of ignition is generally lower at higher altitudes and on the north slopes of mountains, but only outside wildland-urban interface areas (possibly due to less public accessibility[94]).

In terms of propagation risk, topography can affect the behaviour of fires if there is over 50% slope and the existence of V-shaped gullies or canyons, which promote the generation of eruptive fire, i.e., with a rapid acceleration of burning intensity and spread rate[120].

The complexity of Spain's territory

Spain has a complex, heterogeneous land system in terms of climate, environment, landscape, socio-economic situation, ownership, management and legal status. Within this highly heterogeneous framework, public authorities provide for prevention, extinction and post-fire measures, but there is no single solution, rather many different approaches that have to be coordinated at different phases. Legislation and management are structured around wildlands which, by definition includes wildland areas, a subcategory of which is wooded wildlands[42].

Diversity of ecosystems and their vulnerability

The wildlands that occupy 56% of Spanish territory may not be prepared for climate change and are more vulnerable to fire.

The total wildland surface area occupies 56% of Spain's terrain (in official terms, shrublands or pasture are considered non-wooded wildlands)[64] with Castile and Leon, Castilla-La Mancha, Extremadura, Catalonia and Galicia the autonomous communities that have the largest tracts of wooded wildland[41]. These areas are found in locations with the two main Spanish climates: 80% have a Mediterranean climate and the remaining 20% a temperate climate[121,122]. Communities of plant species adapt and are distributed over the terrain according to specific climatological conditions and local fire regimes[121,122]: 56% are woodlands consisting of broad-leaved trees (like holm oak or oak), 37% are coniferous (different species of pine, juniper, or fir) and 7% are mixed woodlands[64].

However, the territorial distribution of current wildland areas may not be adapted to increases in temperature and changes in the water regime. Due to their longevity, wildland systems may take long periods of time to adapt to new meteorological conditions, which increases their vulnerability to wildfires. For instance, in the context of a drought (**Key point 2**) re-sprouting of many species that would happen naturally after a wildfire is becoming more difficult because it requires moisture and precipitation to use the root reserves. If this requirement is not met, the ecosystem cannot return to its pre-fire status[123]. At the same time, the ecosystems of temperate zones may experience situations that are more typical of a Mediterranean climate, such as harsh summer droughts and an increase in the risk and frequency of fires in areas where that climatic propensity did not previously exist[123]. So, bad adaptation can worsen the impact of a wildfire. In this sense, one official report indicates that some of Spain's most important habitats already exhibit a deficient state of conservation[124]. Meanwhile, at European level, research shows a deterioration of woodlands caused by defoliation (loss of leaves)[125].

Socioeconomic diversity

Management of Spain's wildlands, which are 72% privately owned, can be complicated if the owners lack resources. A thriving rural community contributes to preventing wildfires.

The woodlands of Spain's wildlands may be publicly or privately owned and are classified as of public utility or not. This defines how they are used and may determine the economic activities that can be conducted, as well as decisions about prevention or post-wildfire restoration[42]. Many different stakeholders are affected by wildfire, and they also play a significant collaborative role in prevention[126,127]. It is, therefore, pertinent to understand the social dynamics and political structures of rural areas, with particular emphasis on the extractive relationship between cities and the rural world, which conditions rural drift and depopulation[128] as contemplated in certain regional government's strategies against depopulation[129].

· Wildlands: For the purposes of the 43/2003 *Ley de Montes*, wildlands are any terrain with woodlands or non-woodland terrain that contains growths of wildland species of tree, shrub, scrub or herbaceous plant life. Wildlands also include wasteland, wilderness, rocky and sandy terrains, constructions and infrastructures for the provision of wildland services, terrains assigned for replanting or transformation to woodland use, or, in certain cases, abandoned agricultural lands. Each autonomous community determines the size of the minimum administrative unit that will be considered wildlands for the purposes of applying the national law. For legal purposes "wildland area" includes any type of wildland.
· Wildland surface area: In accordance with the Spanish National Forest Inventory, hectares of wildland area are quantified, distinguishing between wooded wildland (predominantly with trees, but also with scrub and pasture) and unstocked land/shrubland (predominance of scrub and pasture). The difference between the two is the "percentage of canopy cover" value, which indicates the proportion of the wildland covered by the tree crowns.
· Wooded wildland: A terrain populated with wildland tree species as the dominant vegetation, whose percentage of canopy cover reaches a specified threshold. It includes scrublands and pasture.

Ownership of wildlands. Most Spanish wildlands, 72%, are privately owned, whether by individuals or in co-ownership, such as the *montes vecinales en mano común*, wildlands that are held in common for use by the community[130]. Management and terms of use for this type of land are decided by the co-owners by democratic process[131] (this legal entity accounts for 25% of wildlands ownership in Galicia). Local authorities own 21% of public wildlands, whereas 3.7% are owned by the state or autonomous communities[41]. When wildlands are of general public interest or fulfil a protective function, whether social or environmental, they may be declared a wildland area of public interest (*monte de útilidad pública*) if they are publicly owned, or a protective wildland (*monte protector*) for both publicly and privately owned land.

In all cases, management of wildlands (whose practices may be directly or indirectly related with better or worse prevention of fires) must comply with each autonomous community government's wildland management plans, responsibility for which corresponds to the owners of privately owned land[42]. Nevertheless, associations representing silviculture and landowners state that they do not receive sufficient support in management and forestry activities. They also indicate a lack of an updated register of exploitations, that the profitability of these lands is low, and that long production cycles leave them vulnerable to risks like wildfire. They also express specific demands at national level, such as the promotion of a new framework act on the Promotion of Forest Activities[132].

Use of wildlands and rural exodus. Any change of land use has an impact on the ecosystem services related with fires, both in terms of the damage they may cause and costs of extinction[133]. Different academic disciplines advocate maintaining a thriving rural world, with an environmentally sustainable primary sector that promotes consumption of local produce and values woodland products[134] (not only wood but also cork, resin, nuts and fruits, edible fungi, medicinal plants or honey)[135]. Indirectly, and related with stable occupation of the land, this would contribute to preventing wildfires[133] (see "prevention"). However, the employment-to-population ratio in rural municipalities is lower than in cities, and the rural population has continuously dropped in the last ten years: currently 84% of the territory is inhabited by 16% of Spain's population. From the Pau Costa Foundation, different groups argue in favour of economic measures, such as reducing the tax burden for inhabitants and managers in the rural world, and that the cost of ecosystem services should be borne by society as a whole[134]; this would include traditional rural activities such as fire prevention[133]. Along these lines, a scientific review revealed the need for more evidence about the impact of tax incentives to prevent rural exodus, and a periodical impact assessment of policies against depopulation[136]. It is also important to understand the causes of the opposite situation: counterurbanization, the arrival of neo-rural migrants[137], which may be a route to the sustainability of rural areas. These people may be attracted to undertake organic farming or by the possibilities of remote working and online activities[138,139].

Heterogeneity of protected areas and its implications

Data indicates the high impact of wildfire on protected areas.

In Spain, 41% of wildland area is in a protected zone (the equivalent of 22.4% of the whole territory)[64]. In 2021, Spain had 47 different categories of protection, in accordance with national and regional government regulations[64], with the highest level of protection being the category a National Park. These parks have characteristics of particular environmental and scenic value, and their protection is a priority. Although their management plans sometimes contain special measures for prevention, extinction and restoration, they comply with the legislation of the corresponding autonomous region[140]. Likewise, the European Natura 2000 Network includes protected areas of national, regional or even private land that are governed by management

· Rural municipality: A municipality is classified as rural if it has fewer than 20,000 inhabitants or fewer than 100 inhabitants per km2, in accordance with Law 45/2007 on sustainable development in rural areas.
· Ecosystem services: Benefits that an ecosystem brings to society that improve people's health, economy and quality of life. The services result from the functions of the ecosystem. Examples are the production of clean water, wood, or use of the countryside for sport.
· National Parks: Regulated under Law 30/2014, 3 December, on National Parks, and Royal Decree 289/2016, 22 October, approving the Master Plan and its respective Guiding Plans for Use and Management (PRUG) presented by each park and approved by the corresponding managing authority (autonomous community government).
· Natura 2000 Network: European network composed of Sites of Community Importance, Special Areas of Conservation and Special Protection Areas for Birds. These sites are protected areas and have a specific denomination as Natura 2000 network protected areas. In accordance with Law 42/2007, 13 December, on Natural Heritage and Biodiversity, they must have management plans.

plans determined by each autonomous community's government[25]. All of these legal mechanisms seek to protect and restore biological diversity and ecosystems, enabling sustainable exploitation and land use in different ways, in compliance with specific regulations, as stated in the National Law on Natural Heritage and Biodiversity[25].

Protected areas, like the rest of the land, are vulnerable to wildfire, and conferring a preservation status does not in itself protect these sites from large wildland fires (as a study on Galicia found[141]). Europe-wide data show a high impact of wildfires on Natura 2000 network sites[142]. In Spain, between 2006 and 2015 the area of wildlands affected in protected zones reached an average 23.75%[52] and in 2022 it was 47%[27], although there are great differences between years and regions[143]. In the Mediterranean protected areas of central Spain, findings show a high probability of fires spreading and becoming large fires because there is a larger amount and continuity of fuel than in areas that are not protected[28]. It should be noted that in areas with a temperate climate close to the Atlantic, this pattern may be different. The legal mechanisms for protection and their associated management plans also vary in terms of risk assessments, which may consider the probability or occurrence of ignition and the surface area affected by fire. This is also a field of active research, which is arousing great interest and debate within the technical community[27,28,141].

It is, therefore, important to take fires into account in the planning and management of protected areas. Current legislation does not limit integrated prevention against fires[27,28] but at many sites it does not exist, largely due to shortfalls in coordination and communication between managers[144]. Research into the perceptions of technical and management personnel at Natura 2000 network sites found that the current mechanisms do not sufficiently provide for actions necessary to reduce risk. So, the majority of technical personnel consider that there is a great need to establish a common methodology for management plans that identifies vulnerable areas[144]. Some scientific research seeks formulas to integrate wildfire management into biodiversity conservation planning, and prioritise areas with reference to their fire regime, vegetation dynamics and possible land uses[133,145,146]. Indeed, there may be a greater wealth of certain protected species in landscapes moulded by fire[147], which has led to advocating the use of fire as a planning and conservation tool[148], at the same time as fighting against large wildland fires in protected areas[149]. Even so, half of the technicians and managers of Natura 2000 network protected areas indicate that prescribed burn (see the prevention section on biomass reduction techniques) is used either never or in exceptional circumstances[144].

Prevention: a long-term perspective

Recommendations suggest management of 1% of national wildland surface area each year as a wildfire prevention strategy.

Woodlands management includes a whole range of techniques and strategies that can be used to manage woodlands. Not intervening in woodlands or applying a specific silviculture approach are both considered management strategies. Although a large number of woodlands management measures contributing to the prevention of wildfires exists, there is still an imbalance between the high investment in extinction and lower investment in allocations for prevention or integrated management[10]. Management to prevent wildfires can reduce ignitions, reduce or modify the structure of available fuel and promote areas of landscape structure that are more resistant and resilient to fire[53]. Natural spaces allow use and exploitation (livestock grazing, agriculture, woodlands management, etc.)[25] although there is currently a degree of abandonment due to low profitability and depopulation. Conversely, environmental strategies which focus exclusively on the conservation of

· Integrated prevention: A set of measures to avoid, counteract or reduce the risk of fire. This is called integrated or integral when management is addressed in a broad, multi-disciplinary way.
· Woodlands management: Sustainable management of woodlands refers to management and use that maintain biodiversity and the potential to fulfil the environmental role of woodlands, now and in the future, without causing harm to other ecosystems. Integrated management includes consideration of the fire's dimensions when decision-making about other manageable aspects.

ecosystems that limit intervention could, in practice, imply restrictions on modifying fuel and increase the risks of wildfire spreading[150,151]. There are mechanisms that make these objectives compatible in order to achieve sustainable use and management[152]. The European Union promoted the "New EU Forest Strategy for 2030" to tackle existing risks, seeking to guarantee appropriate protection, restoration and resilience for all ecosystems in the future[153].

The Pau Costa Foundation coordinated a declaration with the support of a large number of academics, public authorities, private sector, tertiary sector and individual stakeholders that recommends, at a minimum, the yearly management of 1% of national wildland area (260,000 hectares). The goal is to prepare the land against large wildland fires, prioritising strategic action zones[134,154]. To set up this action would require around 1,000 million euros per year, with periodic maintenance to maintain its effectiveness[134].

Historical management of woodlands

Decisions taken in the first half of the 20th century explain the reality of today's wildlands.

Trees and woodlands take decades to grow and reach maturity, which is why the political and woodlands management decisions taken in Spain during the first half of the 20th century partly explain the reality of the country's woodlands 100 years on[16]. In the same way, the effects of decisions taken today will be seen in the long term in the conditions that exist in the future. Today, there are large, very dense stands of pine trees, resulting from the reforestation plans of the 1940s[16]. These plantations had the advantage of enabling quick reforestation, were intended to regenerate and protect the soil, to reduce the probability of flooding and avoid erosion[16]. Moreover, in many cases they were profitable, and thus adapted to the needs of the forest industry[16]. However, the current socio-economic situation is not the same now as it was a century ago. There is a decline in traditional primary activities that is related to population ageing and the rural exodus[155], although the production of edible fungi, cork and pine nuts remain profitable activities[156]. On the other hand, some of the pine and eucalyptus plantations established in the 20th century for wood production now show little profit and are consequently poorly managed or not at all[6], which increases the risk of high-intensity fires[157]. This is also the case of the protective, high-density reforestation carried out in the past which is no longer sufficiently managed[157]. This situation has made it difficult to achieve the objectives of the reforestation campaigns, which was to develop soil that would be effective for the natural or assisted regeneration of mixed woodlands[158] with greater resilience to wildfires, among other environmental benefits. In this sense, experts indicate that long-term planning must adapt to forecasts about climate, and social projections for the country (the current Spanish Forest Strategy 2050 accounts for these factors[41]).

Biomass reduction techniques and silviculture

Selective thinning or controlled burns focus on reducing the connectivity and fuel load in woodlands.

Reducing biomass (potential fuel) by means of thinning, clearings, removal of scrub and undergrowth, pruning or controlled burns can reduce the risk of fire spreading[159,160]. Another method is to encourage extensive grazing. These strategies can reduce horizontal or vertical connectivity. For instance, to reduce vertical connectivity, making clearings or performing sustainable pruning creates discontinuities in undergrowth vegetation and tree crowns to prevent fire spreading upwards[161]. In addition, keeping some areas clear, without dense vegetation, contributes to a mosaic landscape, providing habitats for animal and plant species that cannot live in dense woodlands[7,162].

Thinning. This silviculture technique is typical of forest engineering and wildlands management planning, and consists of selecting the trees that should be cut to meet the objectives of the area managed.

· Strategic action zones: The optimal areas to conduct safe extinction manoeuvres and limit the propagation of large wildland fires, whether because the zone has suitable infrastructures or thanks to previous preparation of the terrain and fuel, among other reasons.
· Horizontal and vertical connectivity: How close trees are within a woodland over the surface area (horizontal) or in terms of the biomass between the soil and the tree crowns (vertical).

Goals include improving the health of the woodland as a whole. The technique is also useful in specific situations such as drought[96] (**Key point 2**), gives resilience to disturbances (adverse weather conditions or small fires)[163] and reduces the risk of fire spreading. Nevertheless, not considering spatial distribution or a bad selection of the trees to fell[164] can bring negative consequences for animal life, causing a reduction in its presence or activity[165,166]. In this sense, monitoring wildlife with automatable tools enables evaluation of the effects of felling on the ecosystem, and subsequent decision-making with the least possible negative effects[167].

Controlled burns: This consists of burning woodland fuel (pasture, scrub or undergrowth) when the weather and characteristics of the site allow low intensity fires. This reduces degradation of the soil and other impacts[10,168,169]. It achieves a fire regime that is compatible with the terrain while eliminating the biomass that herbivorous animals (wild or extensive livestock) do not usually eat. Science has shown that if such burns are conducted correctly, there are no negative effects on either ecosystems or soil, although they are not appropriate for all ecosystems[170]. In Portugal, which has singular characteristics similar to those of Spain, controlled burns have been used since the 1990s[171]. Interest in this technique has grown in several Spanish autonomous communities[172] and its application is governed by the corresponding regional government legislation. Likewise, the Spanish Ministry for Ecological Transition and Demographic Challenge (MITECO) issued common technical recommendations for management of this technique in 2021[173] and has regularly carried out actions at the request of autonomous regional governments since 1998[174]. Among the objectives of controlled burns are the protection of isolated urban centres, habitat improvement or the creation of strategic sites for carrying out manoeuvres in the case of future fire[175]. On the other hand, according to the type of personnel who undertake or participate in the burns, a high degree of training is necessary[176]. This is the reason the Ministry emphasises the need to increase legal mechanisms pertaining to people who participate in these practices[10]. Studies show that woodlands where burns form part of the management strategy benefit from greater resilience to potential wildfir[177]. For instance, in Australia, a high-risk territory, controlled burns are a common practice in eucalyptus woodlands, where studies calculate that management of three hectares in this way can avoid one hectare burnt by wildfire[178].

The role of agriculture and livestock in the landscape

Woodland landscapes combined with clear areas create natural firebreaks while maintaining biodiversity.

In terms of protection, increasing scenic heterogeneity by opening up woodlands areas combined with others to form mosaic ecosystems (vineyards, pasture, etc.) avoids a continuity of vegetation[161]. Therefore, the risk of fire spreading reduces, and there may be a positive economic impact on the area[53,133]. Scientists have established that combining agriculture and sustainable extensive livestock with woodlands managed to be resistant to fire is the best way of reducing the damage caused by wildfires[133,141,179]. It is also compatible with the conservation of biodiversity and European climate goals[180]. Some examples of this are regenerative agriculture[183], the *dehesa* -a type of ecosystem developed by humans which supports a high degree of biodiversity and whose physical structure makes the propagation of fire difficult-[181] or high natural value agricultural and woodland areas[182].

Biodiversity is kept high when the mosaic has a particular distribution and function[184] as long as corridors and connections between the different parts of the mosaic are guaranteed[118]. Spain already has a large part of its terrain structured in some way in a mosaic or fragmented by its extensive agricultural activity; although this type of landscape is in decline due to rural drift[47]. MITECO recommends specific subsidies or payments aimed at fostering livestock such as sheep and goats, which contribute to reducing fuel[10]. The Ministry also indicates that conditions to access the Common Agricultural Policy (CAP) could be reinforced to foster good practices and withdraw subsidies from surface areas that have been affected by deliberately caused fire[10]. The Wildland Firefighting Committee (Spanish acronym, CLIF) argues in favour of the need for a larger contribution from the CAP to promote, conserve and support woodland ecosystems[185] and that this should be reflected in the national strategy[186]. This objective aligns with the EU Forest Strategy[153].

In the mid to long term, one of the sector's problems is generational renewal[187]: between 2009 and 2020 the number of farms dropped 7.6%[188]. A high productivity model of agriculture, which is predominant in Spain, has come at the cost of simplifying the landscape and reducing biodiversity, and has historically resulted in the loss of work in the rural environment, encouraging migration from rural areas to cities[128]. Scientific literature on this subject argues that the type of agrarian model being developed is related with rural use or population drift and, therefore, there is a need to find formulas that promote the capacity of agriculture to contribute to the revitalization of rural areas[189].

Finally, it is important to note that even with optimised landscapes, megafires can generate spot fires dozens of kilometres away that pass over the natural barriers that would stop moderate intensity fires[57,190].

Increasing environmental resilience as a prevention strategy

Improving and restoring ecosystems gives them greater resilience to wildfires.

Woodland ecosystems that have deteriorated and simplified are the most vulnerable to fire. In Spain, 91% of community-interest types of habitats with the potential to burn (woodlands, scrub, shrublands...) are in an "unfavourable" or "very unfavourable" state of conservation[124], particularly in the Mediterranean region. Meanwhile, within Europe, there is a deterioration of woodlands caused by defoliation (loss of leaves)[125]. Ecological restoration includes actions that enable ecosystems to gain both resistance (less susceptibility to burning) and resilience (greater capacity to regenerate if they suffer fire) and mitigates the effects of climate change[191].

Along these lines, the proposal for a Regulation of the European Parliament and of the Council on nature restoration[192] obliges Member States to draw up restoration plans to improve at least 20% of ecosystems from its approval to 2050[192]. To achieve this goal, it establishes obligatory targets, which in the case of woodlands are, among others: improving forest connectivity, increasing organic carbon stock and more accumulation of standing or lying deadwood[192]. Growing values of these targets are positive for biodiversity and for the general health of ecosystems[193-196]. However, in Mediterranean ecosystems, in some cases, they could have the effect of enabling fires that are more severe[40]. For all of these reasons, implementation will be beneficial in Spain if is it supported by an assessment that fosters biodiversity and healthy ecosystems (the general objective) but takes into account the integration of woodland management related with fire (as a singular characteristic of the Mediterranean). For instance, in the case of accumulations of deadwood, small fragments, such as branches and fallen leaves, increase the risk of fire[93]; however, this target could be compatible if there were large-sized trunks, which retain moisture, near the forest floor as they are not very combustible and could form a barrier against certain types of fire[93]. Indeed, the indiscriminate elimination of deadwood, understood only as fuel and not as a value in biodiversity, would be prejudicial for certain species and for parts of the ecosystem[193,197]. Even so, in the context of a high-intensity fire, large-sized wood can also contribute to fire spread and burn for days[198]. It is therefore a matter of scale: scientific evidence indicates that maintaining a certain amount of dead trunks of less than 3kg/m^2 avoids fires that exceed extinction capacity (for other types of biomass: scrub and fallen leaves, this is 2 kg/m^2, only scrub is 1 kg/m^2 or dry pasture, 0.5 kg/m^2[199]. In addition, when designing a national restoration plan it is essential to bear in mind both current and future variations in environmental conditions caused by climate change[192]. Other obstacles detected are poor funding, conflicts of interest between the different territorial stakeholders and low political priority for restoration[200].

On the other hand, the European Union has proposed regulations for a forest monitoring framework, which promotes full information, provides data that is useful for Member States and managers, and aims at improving the response to risks that woodlands are subject to while strengthening their resilience[201].

· Ecological restoration. The return of ecosystems to their previous state.

Peri-urban prevention

There are specific preventive strategies for wildland-urban interfaces.

Over half of the population of Spain lives in wildland-urban interface areas, which represented 16.9% of the total burnt area between 2013 and 2020[202]. In the Mediterranean region, wildfires typically spread over the landscape quickly and propagate within the first 12 to 24 hours, with the greatest risk for the population during the first hours[11]. MITECO's strategic guidelines emphasise the need to make the general public and specific groups aware of the risks[10]. Likewise, they highlight the importance of setting up collaboration and participation mechanisms including different stakeholders: forest landowners, land managers and the people responsible for urban planning and infrastructure design[10]. For their part, the forest sector indicates the urgent need to develop self-protection plans for housing developments and infrastructures[134]. Civil defence regulations make it mandatory for many municipal councils to adopt fire prevention plans[44,45], however, estimates in 2019 suggested that two of every three at-risk municipal areas still had no plan[203]. In response, the Environmental Crime Prosecutor's Office increased its compliance monitoring[204].

Some specific strategies proposed for peri-urban areas include the use of flocks of "firefighting" sheep or herds of goats (*fireflocks*)[205], irrigation systems (which require water)[206] or the creation of broad strips of land without any vegetation in the area[206]. Nevertheless, this last measure may not be socially acceptable and could be difficult for landowners to put into practice[207].

Extinction

Spain has a policy of zero fire, with the collateral effect of accumulating more fuel, and potentially generating more intense fires.

In Spain, fire is a natural element that has always existed and environmentally contributes to the management of its woodlands, generating recurrent cycles of renewal and reduction of fuel[148,157,208]. Spain currently has a public policy of suppressing all fires due to the risk that out of control wildfires represent for ecosystems and the public. Scientists note that this policy has the collateral effect of creating an accumulation of more fuel load, in a more homogeneous way (as it is not eliminated by fire). This is why more intense wildfires can occur, which in turn obliges the authorities to invest in more resources for extinction. This phenomenon is known as the "firefighting trap"[11]. The same policy in the USA, combined with public awareness campaigns from the 1950s onwards, caused some areas to accumulate fuel load, with the consequence of current fires that are particularly catastrophic[209]. Spain had a similar awareness campaign in 1990 "*Todos contra el fuego*" (Everyone against fire)[210]. There are proposals to advance from the view that all small fires should be extinguished, to the inclusion of fire and its functions as a part of the natural dynamics of the landscape (allowing it in certain specific contexts)[211]. Along these lines, scientists and technicians argue for establishing legal certainty and protocols for controlled burns[10] or even suggest that, under certain very specific conditions, some low intensity fires that begin due to natural causes should be allowed to burn in a controlled way[212,213]. A case in point is the experience of the Arán Valley in Catalonia, where, for the first time in Europe, a programme of controlled burns provides for letting unplanned fires burn under specific conditions when the projected effects are positive[214,215].

In the face of the current trend to more serious fires out of season, the Royal Decree-law of urgent measures, 2022, modifying the 43/2003 *Ley de Montes* obliges autonomous communities (who are vested with the authority for extinction) to have plans ready year-round, instead of exclusively at times of maximum risk[216].

Monitoring and early detection technologies

Monitoring is the front line of defence in extinguishing fire. It includes risk analysis and early detection of fire by means of warning systems. In Spain, the arrival of firefighting crews ranges between 15-30 minutes after fire is declared.

Active monitoring is the first line of defence in extinguishing wildfires. It covers risk analysis (the behaviour of active wildfires or before they appear), issuing early warnings, early detection of wildfire and coordination in the field. In view of the intensity of fire regimes, the industrial sector is heavily involved in the development of new technologies related with early detection; between 2010 and 2021 there were 1,727 patent or utility model documents published worldwide for this purpose[217]. Likewise, the Spanish State Research Agency included the promotion of new systems for preventing and fighting wildfires with advanced technologies amongst its thematic priorities[218]. For their part, the Spanish National Information Coordination Centre on Wildfires (Spanish acronym, CCINIF) acts to centralise and provide information to authorities about fire risk, resources, and personnel available in real time[219]. Nevertheless, experts call for more support so that the centre can improve the exchange of information between the different authorities[10].

Analysis of potential and active risks. Before a fire, assessment of plant life, fuel moisture[95] or meteorological conditions among others, enables identification of the areas most prone to burn and the strategic distribution of operational resources. AEMET, the Spanish meteorological agency, publishes a daily national fire weather index[220]; in addition, many autonomous communities have their own risk indexes[221]. Technology is helping improve their efficiency and reliability[222]. During the course of a wildfire, it is also possible to identify its spread capacity and the fire perimeters that have the greatest capacity to spread, and in so doing offer realistic extinction options to fire crews and appropriately manage emergency response[223].

Risk zoning and legislation. After the legal reform RDL 15/2022[216], article 48 of 43/2003 *Ley de Montes* established that autonomous community plans must indicate the seasons and territories of greatest risk. It also establishes that when meteorological agencies forecast a very high or extreme risk of fire, the prohibitions established in annual plans to avoid ignitions and the use of fire must be applied immediately[42]. It is important to note that the meteorological warning in itself does not inform of the fire's potential behaviour; to know this, it is necessary to have other data, such as the dryness, amount and availability of fuel[95]. The Royal Decree states that the Ministry for Ecological Transition must have a tool for risk levels throughout the territory to make operational decisions about the prevention, monitoring and extinction of wildfires. Along these lines, in conjunction with the Ministry for Agriculture, Fisheries and Food, it developed the ARBARIA tool, based on artificial intelligence, which takes into account historical data about fires, meteorological and socioeconomic factors[2]. The tool's forecasts are correct in approximately 80% of cases[224].

Early detection of fire. It is possible to use satellite monitoring and detection systems, watchtowers, patrols in the field[225], citizen reporting by means of the emergency services[226] or automated cameras[227] to detect fire in its initial stages. Satellite information (e.g., from Sentinel-2 or the Copernicus system[228]) is useful when fires have already spread to large areas, but they are not operatively more efficient during the initial stages[229]. Conversely, analysis with artificial intelligence and automatic learning[230] permit efficient early detection, using data from images, video or sound from sensors, aerial still images[231] remote sensing[232] and other devices. Sensors can even be placed in the field, powered by solar energy and connected to internet[233]. On the other hand, there are also new technologies that use centralised servers to issue warnings both to the corresponding authorities and people living nearby[229]. The rapid arrival of resources that exists in Spain suggests that there is no noticeable problem in detection[217].

Management of operational resources, tactics and strategy

Current efforts centre on moving away from a focus on immediate problems towards achieving previously defined outcomes.

To fight wildfire in an effective way, it is necessary to effectively manage operational resources, as well as tactical and strategic approaches. Operational resources are the means available during the course of each fire for its extinction. The tactical level is how efforts are distributed in space and time during the course of the wildfire to achieve the objectives and priorities defined in the strategy. And the strategic level is the chosen final scenario, which maximises certainty and contributes credibility to tactical and operational decisions[11] while taking into account the fire's behaviour (**Key point 3**).

Fire analysts propose that there should be a more in-depth extinction methodology which modifies tactical and operational decisions, based on a strategy seeking previously defined outcomes rather than allowing immediate problems to become the main criteria that are followed[11]. This would seek to increase the capacity and resilience of the response system as a whole, allowing operational resources to maintain the initiative instead of allowing the wildfire conditions to dictate actions[11]. Coordination of civil defence, evacuation planning, establishing safe routes and their communication to the public in order to guarantee safety should occur simultaneously. In Spain, this method is structured around the autonomous region INFO plans, which are the framework for decision-making processes. The plans apply the protocols specified in the Incident Management System (the *Sistema de Manejo de Incidentes* -SMI), which organises special operations and works according to a plan based on expected fire behaviour[234].

The first alarm is sent to territorial defence centres, who launch the first attack. In Spain, operational resource deployment and arrival times for most small fires are between 15 and 30 minutes[217]. If personnel (e.g., a technical officer of a brigade or fire company) decides that more resources are necessary, the operation is made larger and more resources are requested, in order, from the area, the province, other provinces or regions. After this, a request can be made for backup from other autonomous communities or the state[42]. Large wildfires require most coordination and make the most use of technological innovations[217]. Although coordination protocols exist between each autonomous community and MITECO, which can send resources and aircraft if the autonomous community authority requests it[235,236] there are no standard collaboration protocols between non-adjacent autonomous communities; the only exception is the recently approved FAST (Forest Fire Assessment and Advisory Team). Although its role is pre-eminently international, FAST has also been mobilised to provide support nationally[237,238].

National resources are deployed differently in different areas of the country during the summer and winter campaigns[239]. These resources include aerial support, the support brigades (BRIF), preventive work brigades (BLP), full prevention teams (EPRIF), mobile planning and analysis units (UMAP) and planning and analysis teams (EPAIF)[240]. At autonomous community level, the resources and groups are organised in different ways, and at times there are no equivalent units in each autonomous community or units with additional functions. Wildland firefighters, the front line against fires, are exposed to many risks and supported the creation of basic statutes that formalise their rights and obligations, in the shape of a Bill, which was generally well received but progressed no further due to the 2023 general elections[241]. The statutes sought to regulate the functions of personnel who undertake the activities of extinction, prevention, detection, monitoring, informing society or providing support during contingencies that arise in the natural and rural world. They also called for the corresponding authorities to promote continuous, officially recognised training of their workers[241]

· Fire company (*retén*): Group of firefighters and technicians whose function it is to control and extinguish fires with the appropriate resources, intervening in any place where an emergency, accident or catastrophe occurs.

Wildfire can also be classified according to the part of vegetation affected or its behaviour, with areas exhibiting behaviours of different severity.

Key point 3. Behaviour of fire during a wildfire

When a fire burns out of control in a rural area, it is called a wildfire[242]. A wildfire maintains a temperature between 1000 and 1200 °C as long as there is oxygen in the air and available fuel. The simplest classification uses the strata of fuel that is reached: ground fires[243], surface fires[244] or crown fires, which are the most serious as they are the most complicated to extinguish and have the worst effect on woodlands[117]. They can also be categorised by their behaviour and their shape in space (circular, elliptical, irregular...), which depends on the distribution of vegetation and the wind force[117].

There are different parts of a wildfire, in accordance with location and behaviour, among which are the origin, the fire front (the area with most propagation), the tail of the fire (the opposite end to the fire front) or spot fires (outside the wildfire perimeter)[117]. Although a classic example of a wildfire has a fire front that advances like a wall, leaving behind a burnt, spent area, in megafires the terrain continues to burn but does not burn out[245]. These types of fire can form cumulonimbus flammagenitus, a cloud of evaporated moisture from trees and plants mixed with smoke, which feeds back into the wildfire and can ignite spot fires at large distances from the main fire, either due to thunderstorms or burning currents of air[190,246].

Resources and support technologies for extinction

Resources are being devoted to replacing and updating the Spanish national aerial firefighting fleet, which is old. New technologies can enable the fight against large-scale fires. These technologies should also reach front line firefighting personnel.

Between 2010 and 2021, there were 1,928 patents filed worldwide with a focus on fire extinction, 6.88% within Spain. They mostly involved technological devices such as cars, chemical retardants (some of which create subsequent environmental problems), long-range or missile launching technologies, or portable equipment for personnel[217]. There are also developments underway in small-scale, automated machinery and robotics[247]. To date, aerial technologies are the area with greatest innovations in extinction. In addition to planes and helicopters, the trend is towards developing drones that can combat fire. However, due to the volumes that they can transport or legal restrictions when other aerial firefighting resources are deployed, they currently have limited applicability[217].

State-owned fleet of planes. In 2023, MITECO owned 18 amphibious aircraft[248,249], but only nine could be simultaneously deployed in the 2020 campaign to provide support in the autonomous communities[250]. Some of these resources were acquired and have been in use since the 1970s[251], which means they require frequent maintenance and restricts their availability . The MITECO Strategic Guidelines for Management of Wildfires therefore indicate the need to renew the aerial firefighting resources, either because the current craft are obsolescent or because new technological developments are available[10]. The industrial sector in Europe is showing an increasing interest in developing amphibious aircraft with new technology specifically designed to combat megafires, with higher load and pump capacity for water or retardants, better speed, operative precision and safety[252,253]. The 2021 Plan for Recovery, Transformation and Resilience contemplates the national acquisition of new amphibious aircraft and updating the electronic instrumentation of aircraft[250]. At European level, 12 new Canadair amphibious aircraft are on order for the European rescEU fleet (the EU's updated civil defence mechanism), but they are not due for delivery until 2027[254,255] .

Human resources and portable equipment. Firefighters on the front line against wildfires may carry backpacks with extinguishing agents (in Spain, they only carry water with or without retardants, although there are other possibilities)[217]. This group of workers uses fire-resistant personal protective equipment (PPE), which is essential to avoid burns and suceed in carrying out their work[256]. There are numerous textile and physiological criteria for the technological development of their PPE[257]. Wearing this PPE is physically demanding and so productivity progressively diminishes during extinction exercises[258]. It is during extinction work that this professional group experiences highest mortality[84]. Studies have also found that due to their professional activity this group has a higher probability than the general population of suffering cardiovascular problems and a higher risk of certain types of cancer[259-264]. Indeed, the World Health Organisation (WHO) classifies this activity as carcinogenic[265]. In Spain, higher mortality has been associated with possible malfunction or misuse of breathing equipment during extinction, although further research is necessary to reach conclusions on this point[266]. The CLIF has adopted minimum recommendations for the autonomous communities, in accordance with the 2011 update of the PPE Catalogue[267]. Among the latest technological advances incorporated in the equipment that could help their work in the field are thermal imaging visors, ultrasound devices for real-time monitoring of a firefighter's state of health, geolocation devices (including barometers and accelerometers) or sensors of real-time environmental conditions[268].

Restoration of burnt areas

After a wildfire, immediate special measures should be taken to avoid further harm to the soil, people and infrastructures. These should reflect the socio-environmental reality of the territory in the mid to long-term.

In Spain, it is forbidden to reclassify wildland use for at least 30 years after a fire, or to carry out any activity incompatible with regeneration of the groundcover[42]. The restoration of burnt areas, which does not always involve reforestation, represents the opportunity to foster the development of ecosystems that will be resilient to the challenges of climate change in coming decades, and that are specifically more resilient to large wildfires[6]. The 43/2003 *Ley de Montes*[42] establishes that autonomous communities can request state collaboration for restoration work in burnt areas with certain characteristics: larger than 10,000 hectares, larger than 5,000 hectares of which 70% was woodland, or larger than 500 hectares in municipalities that contribute 50% to the Natura 2000 network (thresholds are lower in island territories). Work can cover hydrologic recovery and forest restoration, regeneration and recovery of Natura 2000 network sties, support for the removal and treatment of woodland biomass, pest control and restoration of infrastructures[269]. The European Common Agricultural Policy can also provide European aid packages to recover wildland potential after a wildfire[270].

Assessment and decision-making during the first year

After a wildfire, the need to apply measures must be evaluated, since active management is not always necessary because the aim is to avoid further damage and allow the area to regenerate. The burnt area and the severity are assessed immediately after the fire by means of images and satellite data (e.g., from Sentinel-2 or Landsat-8)[271] and in greater detail on the terrain with LIDAR sensors mounted or aerial drones[272,273]. This information contributes to understanding which areas need to be restored and which do not, as well as the measures required. One of the most serious problems is the possible loss of topsoil due to erosion, which is essential for regenerating an area (**Key point 4**). This must be addressed from the first year, particularly if natural regeneration is too slow. Before taking any steps, the capacity of ecosystems to regenerate themselves must be assessed during the first year; there are many situations in which they adapt to the fire and naturally regenerate. This means that some types of intervention may be counterproductive. For instance, there are trees that can naturally produce new shoots[274] such as species of the *Quercus* genus (holm oak, cork oaks, gall-oaks, oak…)[275], numerous scrub plants (heathers, brooms…) or the Canary Island pine[276]. Another adaptation is the persistence of the ecosystem with natural regeneration through seeds, which accumulate in the soil or in tree crowns over decades and germinate en masse after fire[277].

· LIDAR. The acronym for "light imaging detection and ranging". Using a pulsed laser beam, these devices enable determination of the distance from an issuing laser to an object or surface.

Key point 4. Erosion and soil protection

Soil is a non-renewable resource that has a direct relationship with human health, agrarian economies, quality and fitness for consumption of water and food security[278]. In general terms, in addition to fire and erosion, soil is threatened by climate change, overexploitation and pollution. Indeed, calculations indicate that within the European Union (EU) 60% of soil does not have a good state of health. Health is defined as the soil's capacity to function as an ecosystem and sustain animal, plant life and humans[279]. Many of these functions are performed by soil-living species[280]: microorganisms[281] and invertebrates like arthropods[282] that make nutrients available, foster the growth of plants by root contact or promote their tolerance to stress[281]. These facts mean that soil is a priority for the EU and a directive has already been proposed to monitor its health and resilience[283].

Immediately after a wildfire, the soil's fertility can reduce due to a loss of nutrients caused by the combustion[29], with a consequent prejudice for the biological communities in the soil and the plants that live in it[284]. The deterioration of soil also increases the risk of erosion, landslides and flooding[283]. After a wildfire, if there are rains of a high or moderate intensity, they can quickly erode the soil[285] particularly in the current context of climate change, in which there is an increasing trend to extreme weather phenomena[286]. They also compromise water quality in nearby population centres with displacement of ash, which can affect the health of people and the whole ecosystem[287]. All of which results in a loss of diversity and interactions of the soil's microbial communities[288], changing the soil's capacity to fulfil its functions[280] with a particular impact on the economy in agroecosystems[289]. Technological improvements of recent years allow use of these microbial communities as bioindicators of the soil's health in healthy or deteriorated systems and help evaluate possible improvements[278,289].

After a wildfire it is more economical to protect the soil than to restore it after erosion. This is why the scientific community recommends that in areas where a substantial loss of soil is expected, the burnt soil should be covered with agricultural and wood waste (mulch) as the main tool to protect the area[285,290], or physical barriers such as terraces or fascines (bundles of brushwood) should be constructed[291]. The greatest information gap is in evidence that associates mulching with the quality or quantity of water in a drainage basin[292].

After a wildfire it is essential to preserve soil and reduce erosion. Soil is the basis for recovery of vegetation.

Removing deadwood is a complex decision with pros and cons, requiring consideration of the environmental characteristics of each situation and the management objectives for each specific burnt site.

Removal (or not) of burnt wood[93]. Salvage logging (cutting down or extracting burnt wood) is a measure that is recommended close to roads and infrastructures, where a falling tree could put people's lives at risk, but in other cases it is not recommendable. Application of this measure should balance out the conservation of biodiversity and the possible financial returns over different sections of the burnt landscape[293]; as a whole, it should return environmental functions to the burnt area so as to improve response to subsequent disruptions[293]. Some species of tree can produce new shoots and so cutting them down should be avoided. Moreover, the remains of deadwood help preserve soil and facilitate the natural regeneration of the communities that will be established, for instance, by fertilising the soil in the mid to long term, generating a certain level of shade and maintaining moisture[294]. An important reason why salvage logging is done is that burnt dead wood represents an economic value of approximately 40,000,000 euros/year (total for Spanish woodlands, data for 2005), which is 10 times lower than that of timber[135], but its value rapidly decreases due to decomposition or colonisation by insects that feed off wood. It is usually done soon after a wildfire because if the natural deterioration process begins, the economic value is lost[293]. This logging has environmental disadvantages and can be a disruption in itself: it increases soil erosion (**Key point 4**) and the impacts of possible torrential rains, eliminating the protective function of wood to combat rock falls or avalanches. It also increases the microclimatic stress on plants due to solar radiation on the soil and the associated fluctuations in temperature[295]. This logging affects animal as it reduces the possibilities of herbivores to hide from predators and eliminates the habitats and food of insects specialised in deadwood, including many species of wood beetle. All of which affects the area's biodiversity[296].

Along the same lines, it reduces the provision of ecosystem services, especially when it is performed shortly after a wildfire[297]. Even so, if salvage logging is performed, the official technical guidelines recommend leaving at least 15-30% of trees standing[298]. Among its advantages are that it reduces the total amount of fuel available for possible future fires[93] or that the trunks can be reused to build fascines (structures to prevent the displacement of masses of rock or water, although they are not always effective for recovery purposes[299]), or that it can facilitate implementation of other wildland work in the area.

Restoration strategies in the mid to long term

In temperate and Mediterranean ecosystems, after a wildfire the recovery of plant life that existed before the fire is very common[275]. Nevertheless, this process does not always occur sufficiently. In the case of severe damage and/or a scarce capacity for natural regeneration, recovery by means of reforestation or specific actions may be an option. Such steps may include clearing scrub or thinning out certain species when they are too abundant or prevent the generation of more diverse plant life. Although there is no general consensus, it seems that promoting greater biodiversity may contribute to avoiding future damage to the ecosystem and its functions[300].

Active restoration should focus on vegetation adapted to climate change and current or future disturbance regimes.

A biological communities focus. Long-term restoration must be considered as a process that will take several decade and involves not only the number and identity of species, but also the stability of the whole biological community, the relations and interactions between species, their abundance and their ecosystem functions[62]. After a wildfire, the new community does not necessarily have to coincide with the one that burned. Natural disturbances can also represent an opportunity to improve the biodiversity and restore deteriorated ecosystems[301] or adapt them to the future climate and fire regimes[161,302,303]. First, small to medium sized fires reduce the biomass in the affected area, introducing heterogeneity in the landscape, thus reducing the probability of new wildfires within a certain period of time[304]. Another example of the positive effects is in single species plantations of pine in the Mediterranean region, which currently present major management challenges[6]. Apart from adapting some stands of pine woods, for instance, by creating clearings, another tactic could be to recover other ecosystems that are better adapted to different situations: active restoration should focus on the types of vegetation adapted to climate change and current or future disturbance regimes[7,301]. For instance, in reforestation, the use of species adapted to fire (such as cork oaks, whose bark is highly resistant) at low density (which could minimise an aggressive behaviour of a fire) and with wide diversity could help halt the advance of a future fire[161]. Along the same lines, the use of native re-sprouting species could create a swift regeneration capacity and mitigate erosion[161]. Another possibility is the restoration of scrubland-pastureland ecosystems in which fire and grazing are integrated[7]. It is important to highlight that before the appearance of humans and the decline of megafauna, this type of open ecosystems covered temperate climate zones, corresponding to over 50% of Europe[208].

Heterogeneous woodlands may be more resilient to environmental disturbances thanks to their diverse functional characteristics, or to behaviours of varieties that may be adaptive in a context of great uncertainty.

Selection of plant species in restoration. When thinking about revegetation in a restoration plan, the first consideration should be what type of vegetation is desirable (e.g., open, *dehesa* pastureland, or a closed forest). Once this has been defined, the plant species can be chosen, justified by the type and state of the soil, pre-existing vegetation and topography, the origin of the new species and the climate of the zone. Nevertheless, the choice of species requires a theoretical framework for plant selection and origins adapted to climate change[305], a subject which does not yet have a scientific consensus and is not always required in restoration plans themselves. Plants are reared in forest nurseries whose operation is subject to Spanish Royal Decree 1054/2021, 30 November[306]. Revegetation by planting species or by direct sowing of seeds must comply with this regulation[42]. Companies that supply plants obtain the seeds and rear plants destined for restoration based on different criteria, but they must always have a region of origin certificate[307]. The choice of species in accordance with region of origin generally helps ensure they are adapted to the territory for which they are destined (e.g., a variety of holm oak originating in the Pyrenees may not be successful in Extremadura, given the soil and climate conditions of its place of origin). In the case of certain species of pine, with pine nuts and seeds adapted to fire, their capacity to germinate and survive after a wildfire is related to the regions of origin and associated fire regimes, which means that the selection should be of the population best adapted to ensure survival[308].

Nevertheless, while the regions of origin system does admit certain flexibility, it is based on historical environmental characteristics which assume that meteorological parameters will not change, a premise that is questionable in the current scenario of climate change[307]. In a context of environmental changes, the survival of plant species depends on the genetic variability of individuals within the population and their dispersion capacity in space[309]. So, one proposal is to introduce genetic variants from other locations that improve the population's resilience as a whole[305]. Heterogeneous woodlands could be more resistant and resilient to environmental disturbances as they have diverse functional characteristics[62]. One step further, which is increasingly debated in academic circles, but with pockets of dissent, is assisted migration: facilitation of a change in the geographical distribution of species to new environmental ranges, even with non-native varieties of plant[310,311]. This focus appears to be attractive with land managers, at least in the United States[312]. The effects of climate change mean that increasing numbers of managers and wildland landowners are considering these options in their revegetation projects[312]. In Spain, the application *ForestAdaptTool*, focussed on the province of Soria, has been developed to perform simulations about the suitability of a terrain to harbour diverse tree species depending on future climate scenarios[313].

Socio-environmental resilience to wildfire

Social collaboration has improved trust between authorities and inhabitants.

Fire is a natural element in the natural dynamics of wildland ecosystems, particularly in the Mediterranean region[5,49] so the general public should know how to suitably respond when there is a fire or, at a minimum, receive sufficient information about it[314]. In a country like Spain, where the terrain has been profoundly modified by humans for centuries, the problem of wildfires cannot be understood without understanding the terrain and its environmental dynamics combined with social and political dynamics[315]. In a context of rural exodus, generating opportunities and giving value to an emotional attachment to the land, as well as increasing socio-environmental resilience to fire is a necessary political and management objective[316]. But it is important to understand what this resilience means. In terms of society, it is a process that seeks welfare and sustainability in situations of change or disturbance, whether expected or unexpected[315]. In this sense, the socio-environmental relations in areas prone to fire in rural areas of the Mediterranean region are dependent on the urban system[128,129,135].

On the other hand, specifically making the rural world more dynamic is related with greater social resilience. People in these areas are aware of urban-rural imbalances, which is why they advocate better woodland management related with the prevention of fires[317]. Specifically, in wildlands, strategies exist to improve the performance and productivity of woodlands[135,318], but there are also positive experiences of an associative approach by wildland landowners, and voluntary activities related with the prevention and effects of fires[314]. For instance, in Catalonia, there are the *Agrupacions de Defensa Forestals* which, despite being non-profit organisations, have institutional recognition and are formed of wildland landowners, municipal councils, volunteers and municipal groups who are involved in fire prevention and fighting wildfires. Although these associations are almost exclusive to Catalonia[319] their existence enables the dialogue and collaboration between the authorities and organised civil society as a whole[316] and improves trust between the stakeholders[319]. This allows for the implementation of solutions and techniques both in land and woodlands management[320] and new governance strategies[315]. In terms of prevention, MITECO recommends public participation in and awareness of wildfire management, with inclusion of landowners and users of the rural environment, land managers and those responsible for urban planning or the design of infrastructures[10]. There are mechanisms that facilitate collaboration and the creation of relationships between stakeholders (researchers, ecosystems restorers and others)[321,322]. They include recognition of the unique needs and contributions of each party, in addition to transmitting information or implementing prevention plans[126]. Examples of this already exist, such as the MOSAICO initiative in Extremadura, whose objective is the mutual exchange of knowledge between local stakeholders and collaboration in mitigating effects using "productive firebreak" areas that are maintained thanks to agroforestry practices[36]. Likewise, some fire prevention plans in certain autonomous communities like Galicia (PLADIGA)[227] or Asturias (EPLIFA)[86], contemplate collaborative measures between farmers, livestock farmers and authorities, with mechanisms to coordinate controlled burns. In terms of the post-fire management of burnt areas, the greater the damage, the greater the willingness of volunteers to contribute to restoration, which is also important for emotional recovery. Emotional attachment to the land and its woodlands is a major catalyst for action among volunteers[320,323] above all for young people[127]. It has also been shown that trust and relationships improve between stakeholders[320], and results receive more support from the local population[126] when there is collaboration between authorities and society in carrying out an action, in which managers provide the resources and technical knowledge while the public contributes work and dissemination[126,324,325]. The extension and improvement of educational programmes related to wildfires, whether in primary or secondary education or at higher vocational training level can help the public to cope better in the event of wildfires and, in short, contribute to generating landscapes that are more resistant and resilient to fire[326].

Key concepts

•Although the number of wildfires in Spain is decreasing, the average area affected by large wildland fires is increasing, with serious ecological, environmental, social and economic consequences. The increased risk means that wildfires have become a social and environmental problem of the first magnitude, involving loss of life, effects on health and emissions, and an impact on ecosystems .

•In Spain, the area of woodlands increased throughout the 20th century due to reforestation that began in the 1940s, and to natural recovery derived from a progressive rural exodus. Some woodlands (many of which consist of shrublands or young trees) have high continuity and fuel load, which can favour large fires that are more difficult to extinguish.

•Wildfire management must involve an adaptation of ecosystems, landscapes and society to the increased probability of fire, for instance, by generating mosaic landscapes, fostering rural development and livestock grazing, promoting species with a higher regenerative capacity and extending protection programmes for species sensitive to fire.

•Experts advocate the integration of prevention and mitigation strategies against the negative effects of wildfires. This should include conservation of biodiversity and rural development, since Spain is one of the countries with the largest natural heritage and many protected areas are affected by major wildfires.

•Spain's defence against wildfires consists of experienced personnel and a high capacity extinction management system. However, there is room for improvement in work protocols, updating aerial firefighting resources, the use of controlled burns and improved working and safety conditions for firefighting crews.

•Restoring burnt areas, both actively and by promoting natural regeneration, represents an opportunity to foster ecosystems and landscapes that are adapted and sustainable in terms of climate forecasts and the new fire regimes that could arise in coming decades.

•In a context of rural exodus, improving governance and the productive and social fabric in addition to better educational programmes on the subject of wildfire in rural areas would facilitate socio-environmental resilience to wildfires and can achieve comprehensive land management, in which all stakeholders form part of the solutions and management measures to be implemented.

•Although the responsibility for woodlands management and extinction has been transferred to autonomous communities, addressing the problem should consider different sector policies and administrative levels, from local and national government to Europe, and include public and private stakeholders. The decisions taken today in diverse sector policies directly or indirectly affecting the land will determine the fire regimes in several decades' time, and the decision with greatest negative impact is political inaction.

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