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NATURA 2000

The role of fire in the conservation of the black pine (*Pinus nigra* Arn.) habitat

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Description and functioning of black pine forests

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1.1. Black pine forests

Characteristics and distribution

The black pine (*Pinus nigra* Arn.) is a tree typically found in mountain areas in the Mediterranean basin. This species includes several pine forest formations within its distribution area, due to the fragmentation and archaic characteristics of the species (Tapias *et al.*, 2004), among other reasons. Catalan forests correspond to *Pinus nigra* Arn subsp. *salzmannii* (Dunal) Franco var. *pirenaica.*

In certain environmental conditions, black pine can grow up to 40 m high with a considerably longer maximum lifespan in comparison to other pine trees, in the region of eight hundred years. The silver bark of the adult trees, often straight and cylindrical with the crown in the upper third section, is one of the species' main characteristics. The black pine forest habitat stands out in the Mediterranean ecosystem, because of the specific characteristics of the tree and the associated biodiversity and the great variety of uses and functions that society has required of it for centuries.

The last Spanish Forest Map (DGDRPF, 2016) quantifies the surface area of black pine forests in Catalonia at around 140,000 ha, of which around 65,000 ha are mixed stands. They are mainly distributed in the Pre-Pyrenees and in mountain areas of the pre-coastal mountain ranges, as well as in the last spurs of the Iberian system (Beltrán *et al.*, 2012). This is why black pine forests in Catalonia are separated in two geographic areas, the "Pre-Pyrenees and central area" and the "meridional area" (Piqué *et al.*, 2014). The meridional formations show a coastal influence and a mild climate, while those in the Pre-Pyrenees and central area enjoy more water availability and continentality (Figure 1).

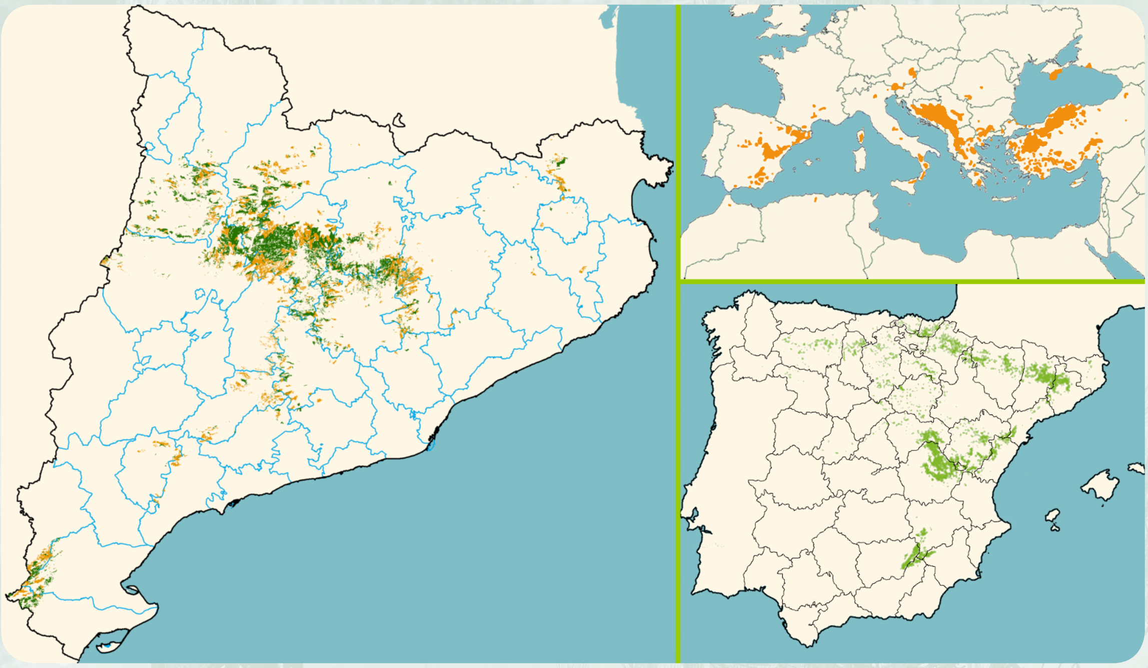


Figure 1. Catalan and Iberian distribution according to the Spanish Forest Map (DGDRPF, 2016) and worldwide distribution according to Euforgen (Critchfield and Little, 1966) of *Pinus nigra*. The map of Catalonia shows pure black pine forests in green and mixed forests dominated by this species in orange.

Black pine forests grow mainly on calcium-carbonate substrates, on the lower montane zone, usually between 400 and 1,400 metres (but most frequently between 500 and 1,000 metres), especially valley sides facing north in continental Mediterranean climate areas. In this strip it shares habitat with the quejigo oak (*Quercus faginea*) and in the altitudinal boundaries it competes with the Scots pine (*Pinus sylvestris*), the downy oak (*Quercus pubescens*) or the mossy oak (*Quercus cerrioides*) in the higher elevations, and the Aleppo pine (*Pinus halepensis*) and the holm oak (*Quercus ilex*) in the lower elevations (Figure 2).

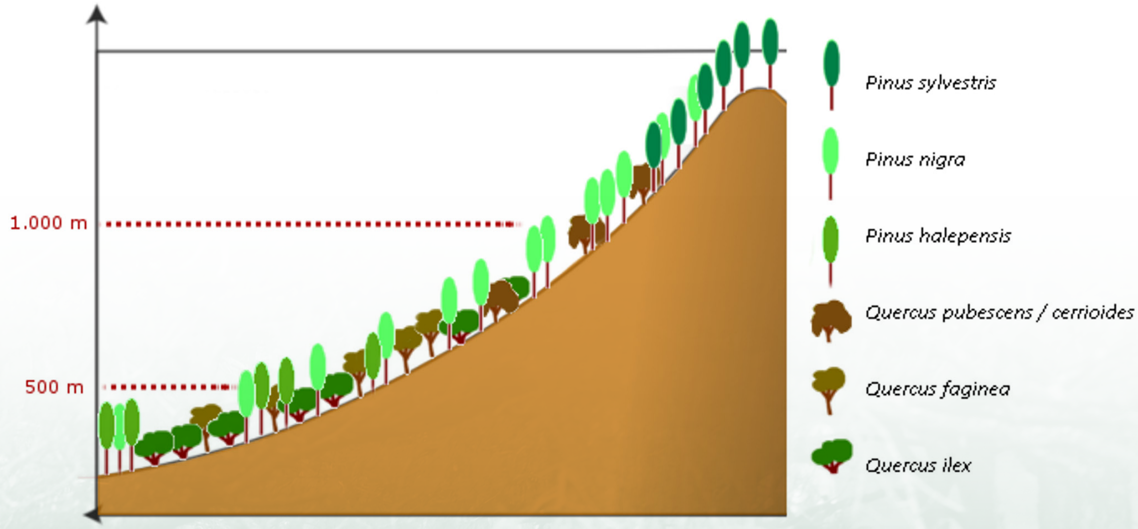


Figure 2. Altitudinal distribution of black pine.

Black pine forests constitute a habitat of priority Community interest described in annex 1 of Directive 92/43/EEC, on the conservation of natural habitats and wild flora and fauna: 9530* Endemic black pine (south-) Mediterranean pine forests. The Catalan Habitat Catalogue (Manual dels Hàbitats de Catalunya, Vigo *et al.*, 2005) identifies four habitats in Catalonia with CORINE classification for black pine forests (Figure 3 and Figure 4).

Annex I Directive 92/43/EEC	9530* Endemic *Pinus nigra* (south-) Mediterranean pine forests
Catalan Habitat Catalogue	42.632 Black pine forests of the Pre-Pyrenees, centre-north of Catalonia and septentrional Mediterranean mountains 42.637+ Black pine forests of the meridional Mediterranean mountains (from Prades and Montsant to El Port) 42.67 Black pine forests, or reforestations, without understory 43.7713 Mixed forests including Mediterranean *Quercus* and Scots pine and black pine

Figure 3. Black pine forest habitat of priority Community interest and habitats of Catalonia that include black pine forests.

Figure 4. Black pine forest in the Pre-Pyrenees (left) and black pine forest in the Catalan meridional region (right). Photography: Jordi Bas.

History of uses of black pine forests

Human interaction with the forest for millennia has intensively shaped the structure and distribution of black pine forests, mainly due to herding use and the extraction of products (wood, large and small firewood, foliage, pine cones, bark, brands and resin), as well as for its conversion into arable land. The conversion of the valley-sides of the mid-mountain regions populated by black pine, which was more or less constant throughout the 19th century due to the population momentum and the disentailment process (Casals *et al.*, 2005) is noteworthy.

Nevertheless, the open black pine structures allowed for shaded pastures in mountain Mediterranean climate, which extended the greenness and palatability of the pastures as well as diversified the species. For this reason, the black pine habitat favoured unploughed valley-sides of the mid-mountains in Catalonia, and never disappeared from places such as Els Ports, Cardó, Tivissa-Vandellòs, Llaberia or Montsant.

Black pine wood has been one of the most valued historically for civil and naval construction, as well as for joinery, mainly due to its favourable properties with regards to mechanical resistance, durability and ease of use, but also because it was located in relatively easily-accessible areas for harvesting. Additionally, black pine has been the main species used to produce one of the most specific products with regards to technological requirements, utility poles. In general, due to multifunctional demand (Figure 5), both the structure and composition of these forests has been conditioned by several management actions. A forest structure with a dense tree canopy dominated by black pine under which there is a more or less abundant lower layer of underdeveloped Mediterranean *Quercus* can often be found. Black pine has been favoured by wood production while the Mediterranean *Quercus* was used for firewood.

Figure 5. Different uses and functions of black pine forests. Top left: marks on the trunk due to old brand extractions. Top right: forest used for herding. Bottom: black pine logging. Photography: AGS-CTFC, Mario Beltrán and Jarkov Reverté.

The socio-economic changes of the 20th century, with the general decrease in rural activity, kick-started forest densification and expansion processes, also in black pine forests. At the same time, the abandonment of pasture use and wood logging has led to an increase in mixed formations with Mediterranean *Quercus*, and the appearance of oaks and holm-oaks in the understory of black pine forests. The catastrophic fires of the 1990s, which affected this species in particular, are also linked to the densification and biomass accumulation process in black pine forests (Plana, 2004).

Ecology and dynamics of black pine forests

The adaptations of trees to surviving fire is vital in the ecology of forests in frequent –fire landscapes (Figure 6 and Figure 7). Although fire normally kills small conifers with thin barks due to the effects of temperature on the cambium (van Mantgem and Schwartz, 2003), many conifers in the mature state have thick, insulating bark, which is relatively non-flammable, long needles, self-pruning lower branches, umbrella crown and deep roots. This is the case of the black pine, which also has thick bud scales that protect shoots, tight needle bunches that enclose and protect the meristems and a high foliar moisture. Needles and buds are also often high above the ground, away from the flame zone. Likewise, its high foliar moisture content allows it to endure a lot of heat, as long as the buds and twigs, that tolerate higher temperatures than the needles, are not badly scorched. In addition, young trees are capable of producing green leaves if the leaf has been charred (without flames), because the bud is well protected by the large needles.

Persistence attributes

The black pine, in adult stages, develops different physiological characteristics so as to not be affected by fire, strategies that work as long as it is organised in forest structures without much understory, discontinued vertical vegetation layers and a more or less open woodland cover. These characteristics are the following:

- Self-pruning and umbrella shaped crown. Capacity to create vertical discontinuity between the crowns and the lower vegetation.
- Large and thick bark plates that insulate from high temperatures.
- Protection of the needle bundles and scales that surround the branch buds.
- The crown can re-grow if scorched.
- Maximum lifespan that allows for maximum development.
- Straight and resistant trunk that prevents rotting.

In addition, seed dispersion through the wind, and a large seed production, especially when adult trees are located on exposed summits, is a positive factor for the black pine's persistence.

Successful regeneration conditions

Regeneration is a critical phase for black pine forests, because the seeds have more restrictive edaphic and environmental condition requirements than other pines present in the habitat (Aleppo pine or Scots pine) or even those required by Mediterranean *Quercus* when sprouting. In general, seeds need to be in contact with mineral soil and, at the same time, a certain degree of moisture and cover to avoid direct insolation. Therefore, the understory has a complex competition-enabling relationship with the black pine. Nevertheless, the presence of an adult canopy does not hinder the establishment of a new cohort, especially in mixed structures with denser and thinner stands. Black pine does not participate in the first response after a forest fire, because it needs more pioneering tree and shrub species to recover first. This means that during the first stages after a large fire, species such as the holm-oak, oak, Aleppo pine or even the Scot pine dominate the habitat and the black pine reappears years later, under the shade of their cover.

Critical life stages

- Propagule production and growth. The black pine shows certain alternate bearing in its seed production, which determines a high variability of the pine seed bank each year. The black pine reproduces late in life, its first reproduction occurring between 14 and 23 years of age. This hinders its regeneration after a fire if they are very recurrent. Black pine seeds do not have a dormancy period and their viability on the ground lasts only a few months. Germination takes place in spring and the beginning of summer under certain humidity conditions. During years with a noticeably variable climate, it is possible that pine seeds do not find appropriate conditions to germinate and do not last long enough to experience an improvement in the environment.
- Maturity. Maturity, in terms of the reproductive capacity of the tree canopy, is achieved at between 40 and 80 years, depending on the quality of the season. Seeds do not possess any serotiny characteristics, they open as they mature and do not respond to any thermal stimuli. The black pine requires certain cover to grow, when there is an intense fire its seed does not compete well with other species that tolerate direct sunlight on burnt soil better. However, after a low-intensity fire where the tree canopy survives, the black pine seed has more chances of germinating and growing.
- Old age. The black pine's long lifespan makes it difficult to determine when it reaches old age and senescence. Nevertheless, one of its symptoms is a decline in pine cone production.

Figure 6. Black pine adaptive traits.

Figure 7. Silver appearance of adult black pine trunks. Photography: AGS-CTFC.

Historically, black pine has grown in certain places forming what is known as **frequent-fire forests**, defined as forests with a fire return intervals less than 35 years according to Reynolds *et al.* (2013). These forests form a mosaic typically made up of tree groups, scattered individual trees and open spaces with grass or shrub communities (Larson and Churchill, 2012). Unlike mature forests in Central European humid climates, often times mature black pine forests are located in mountain regions with a high recurrence fire regime and drier environmental conditions (annual pluviometry below 700 mm spread irregularly throughout the year and noticeable summer drought). These kinds of forests are typical of meridional massifs, from the mountains of Prades and Montsant to Els Ports, through Tivissa-Vandellòs, Llaberia and Cardó (Figure 8).

Figure 8. Mature forests in mountain regions with a recurrent fire regime fill landscapes such as Els Ports Natural Park. Photography: Jordi Bas.

Concept of mature forest

A group of mature trees does not make a mature forest. Mature forests feature special characteristics that appear after many years of growth. The structure of mature forests varies according to the type of forest, the climate, the location's characteristics and disturbance regime, but it stands out for: dominance of large, older trees close to their maximum lifespan (trees with an average age in the region of half their maximum lifespan), variation in size and distribution of the trees, accumulation of snags and large dead and downed woody material, decay, multiple canopy heights, empty spaces and non-continuous understory (Kaufmann *et al.*, 1992).

The expression "old-growth forest" is the most used for mature forests, especially in North America (Wirth *et al.*, 2009), although in Great Britain the expressions "ancient forest" or "ancient woodland" are also used. In French it has been translated as "forêt ancienne" or "forêt a caractère naturel", among others (Gilg, 2005). In Catalonia both "boscos madurs" and "boscos vells" are used (EUROPARC-España, 2017).

Black pine is a long-lived species that lives in climate conditions with several stressors. However, current formations are far below their natural maximum lifespan. In Catalonia there are only a few samples of stands with a certain degree of maturity and with a small surface area (Camprodon *et al.*, 2018).

Another adaptive trait of forests against fire is spatial distribution, which can be described in three hierarchical levels: fine scale (a tree or group of trees), mid-scale (a more or less homogenous stand) and landscape (massif) (Figure 9). The fine scale is characterised by species composition with regards to age, structure and spatial distribution of trees (in single and grouped). The mid-scale is made up of relatively homogenous in vegetation composition and structure. The landscape scale is composed of stands with variable slopes, aspects, altitudes, soil types, disturbances processes and land uses. Mature black pine forests present this typical spatial pattern typical spatial pattern (Reynolds *et al.*, 2013).

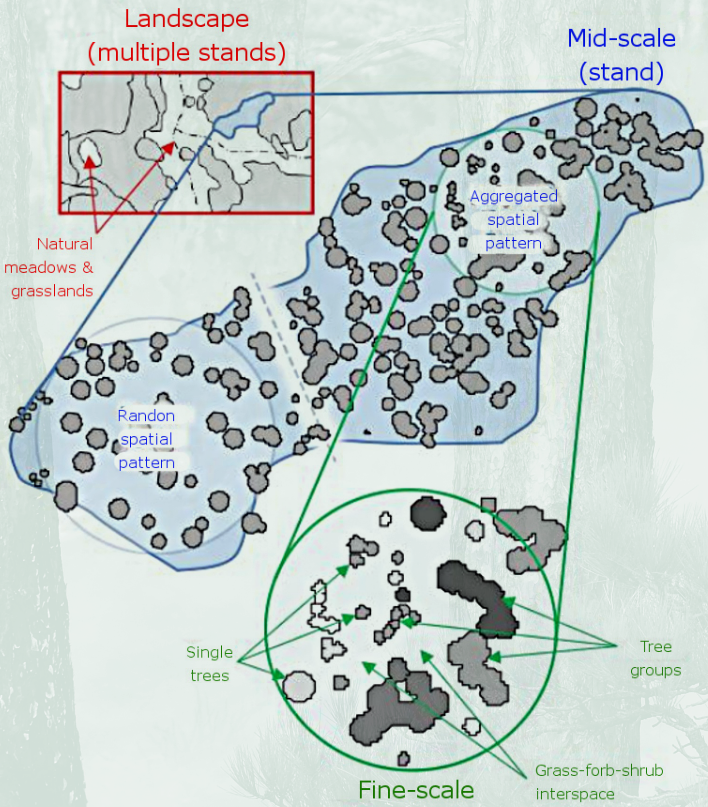


Figure 9. Vegetation patterns at three spatial scales for frequent-fire forests. Source: Reynolds *et al.* (2013).

1.2. Current problems associated to black pine forests

The main threat to the black pine forest habitat is the current global change. Climate changes, always interacting with socio-economic and rural activities changes, can worsen several issues that can result in a habitat decline. Intense disturbances such as large forest fires, plagues or persistent droughts are noteworthy.

Current climate predictions mostly point towards an **altered rainfall pattern** (mainly with a much more irregular pattern) **and an increase in temperature**, with more intense droughts and storms (extreme phenomena). At a European level, the worst **conditions (high temperatures and drought) are predicted for the Mediterranean region**.

The effects of extreme phenomena (especially extreme droughts) can have drastic consequences on tree growth and survival (Loustau *et al.*, 2005; Granier *et al.*, 2007); and also on the black pine regeneration (Tíscar and Lucas-Borja, 2010; Tíscar and Linares, 2014).

It is likely that climate change, together with change in land use, have significant effects on black pine forests, most notably (Beltrán *et al.*, 2012):

- **Change in distribution area.** In lower and warmer areas, it is likely that the presence of black pine is reduced and restricted to particularly cool enclaves. Moreover, black pine formations are predicted to move towards currently more humid and/or elevated areas.
- **Changes in specific composition.** The increase in mixed formations, especially with flat-leaved species, at the expense of pure stands, is a notable trend linked to changes in use and distribution area. In addition, changes in ecological conditions will promote the arrival of Mediterranean species in temperate vegetation communities (Peñuelas and Boada, 2003). In low and medium elevations, these processes will alter the competitive relationships of black pine forests. The combined effect of decay and fires can lead to open tree structures or a brush type.
- **Increase in decay and plague effects.** Black pine forests will suffer from water stress situations most often linked to prolonged droughts and heat waves, worsened by the more intensive competition with broadleaved trees. In addition, defoliator plagues will benefit from higher temperatures (Hódar *et al.*, 2004).
- **Increase in fire risk.** An increase in the frequency, length and intensity of adverse climate events, responsible for large fires in Catalonia, is predicted. As well as a higher evapotranspiration of the plant cover and, therefore, a lower moisture content in plants, factors that have an impact on the increase in fire intensity.

Fire is the main natural disturbance that affects black pine. Black pine is a species adapted to frequent, low-intensity and low-severity fire regimes, but with little chance of survival after large forest fires.

Black pine forests developed in a context of frequent low-intensity fires do not have a dense understory or accumulated biomass. However, black pine forests, in the absence of these low-intensity fires, generate structures that become more and more vulnerable to cause high-intensity fires (Figure 10), due to the development of understory that provides more fuel and more continuity between vegetation layers.

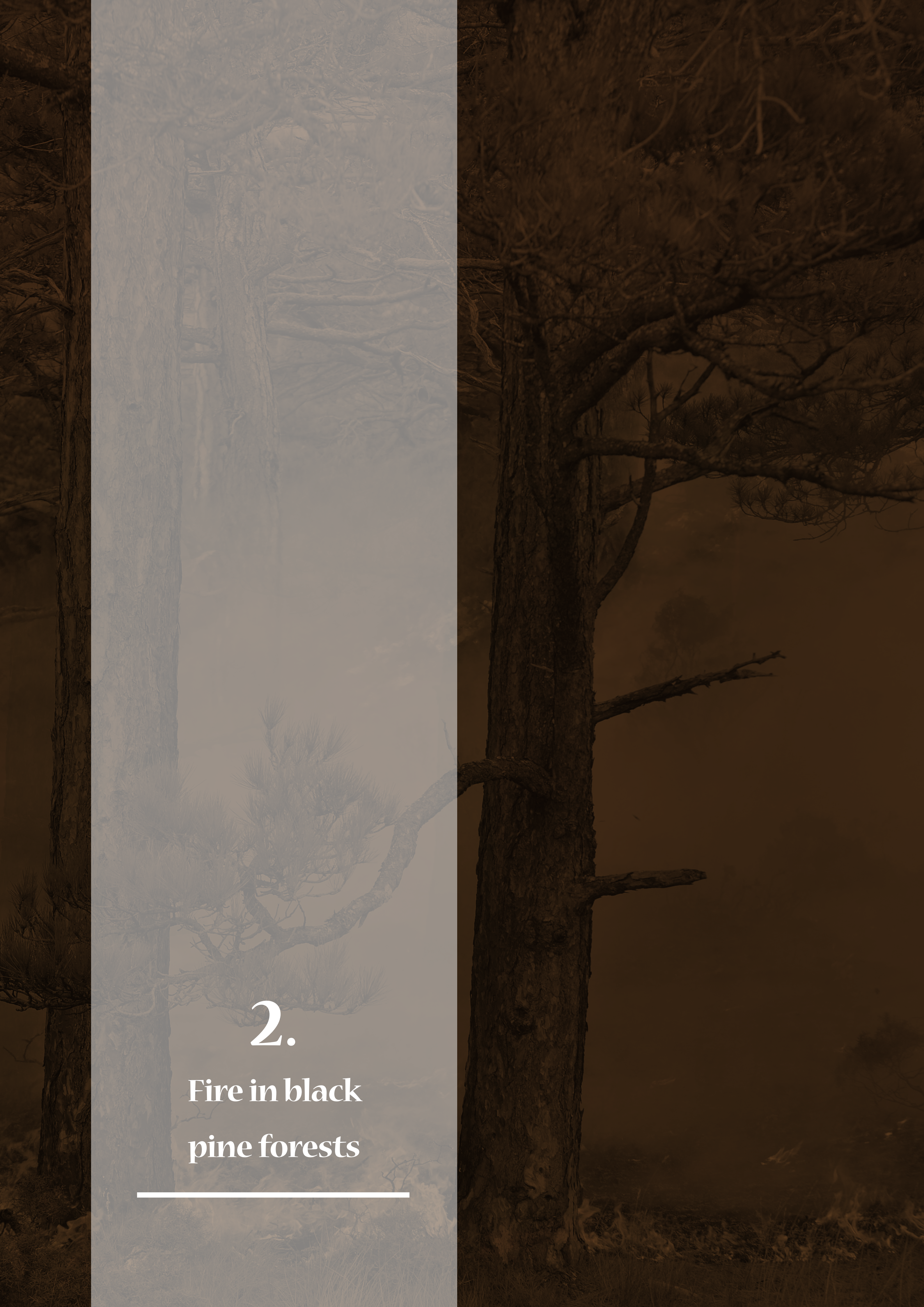
Figure 10. Images of high-intensity fires in black pine forests in Cardona (Bages) during (left) and after (right) a wildfire in 2005. Photography: Catalan Fire Service.

Moreover, the environmental conditions can favour the development of plagues such as the processionary that, although it is not capable of massively removing pines, it affects the growth of the forest, damages certain uses and functions and increases other associated risks such as droughts and fires. In any case, the natural dynamics of the black pine habitat are altered when plagues are widely spread.

Another significant factor that has an impact on the state of forests and that can become a threat to the habitat is the change in rural activities (Figure 11). Rural abandonment, together with a decline in forestry, agricultural and herding activity, has implied a **change in the landscape uses in recent years**, which affects the black pine forests in three ways:

- **Expansion of black pine.** Although black pine is not a particularly pioneering species, it does colonise open spaces when conditions are favourable, especially in abandoned pasture areas with a small presence of large trees. In the Pre-Pyrenees, in the case of abandoned marginal croplands, a joint colonisation with oaks can be seen, which creates a more homogenous landscape with forest continuity, which can become a risk with regards to large fires spreading.
- **Densification and modification of forest structure.** Without the constant logging that the black pine forests were historically submitted to and with the fire disturbance eliminated, due to abandoning traditional burning and fire extinguishing policies, current forests increase their coverage and the amount of accumulated biomass, whether in the tree layer or, in the case of more open structures, in the shrub layer. In the case of black pine, the increase in biomass is mainly due to other, fundamentally broadleaved, species, which affect its structure.
- **Change in composition of current forests dominated by black pine.** A progressive decline in black pine is occurring, with a larger presence of oaks, holm-oaks and other flat-leaved species less favoured by traditional management.

Figure 11. Ortophotomap from 1946 (left) and 2016 (right) of the surroundings of the Castell de Besora (Solsonès), where the expansion and densification of black pine forests can be observed due to rural abandonment processes. Source: ICGC.



2.

Fire in black pine forests

2. Fire in black pine forests

2.1. Fire as a natural element

Fire as a natural component within the ecosystem

Fire is a natural element in many ecosystems, and as such it interacts with its abiotic and biotic components. **Fire is an integral component within the function and biodiversity of many natural habitats** and the organisms within these communities have adapted to resist and even take advantage of natural forest fires. In general, fire is considered a natural disturbance, similar to floods, storms and landslides, which has promoted the evolution of species and controls the characteristics of the ecosystems.

Researching the role fire plays in ecosystems, or **fire ecology**, is a field that has been largely developed in recent years with particular interest in determining which is the natural frequency of fire in certain ecosystems. A **fire regime** is defined by the pattern, frequency and intensity of the fires that dominate an area during long periods of time (Figure 12). Weather or climate patterns, the type of vegetation or human action can modify this regime (Pausas and Keeley, 2009). Many species are adapted to a particular fire regime, typical of their evolutionary history, which needs to be maintained for the species to survive.

Fire as a natural element, in the form of storms and lightning ignitions, is something **common and frequent**, also in Catalonia. The areas which are most affected are interior basins, the Pre-Pyrenees and the last spurs of the Iberian system. Its historical significance has been key in shaping the landscape (Cunill *et al.*, 2012). Recently, lightning strikes have been the source of important fires such as the one in Margalef (Priorat), in July of 1994, with 4,500 ha burnt, the fire in Tivissa (Ribera d'Ebre), in June of 2014, covering 830 ha, or the fire in Cerbi (Pallars Sobirà), in October of 2016, affecting 620 ha.

However, **humans also have an impact on fire patterns**, in three different ways: by provoking new ignitions, changing the vegetation characteristics and actively supressing fires. Given the long history of human occupation in Europe, these aspects are relevant and include fire as a landscape management tool. Knowledge and control of fire in the forest is called fire culture. For centuries fire has been used with different objectives, shaping a landscape that became sustainable over the years, without fire posing a significant threat. In fact, there are transhumance routes in the Iberian Peninsula that run from the Iberian system to the Pyrenees, curiously between the two black pine habitats separated by the Ebro valley, keeping **landscape burning as the main shaping agent of black pine forests**.

Today, this culture has been slowly lost and fire as a tool has gradually disappeared. Paradoxically, it only appears in the news as a catastrophic event as a result of large forest fires. But fire is still very much present in the field of culture, especially in festive celebrations (Carrera, 2012), that are celebrated throughout the year such as the Falles dels Pirineus (recognised as intangible cultural heritage by UNESCO), the bonfires for Sant Joan or Sant Antoni, among others.

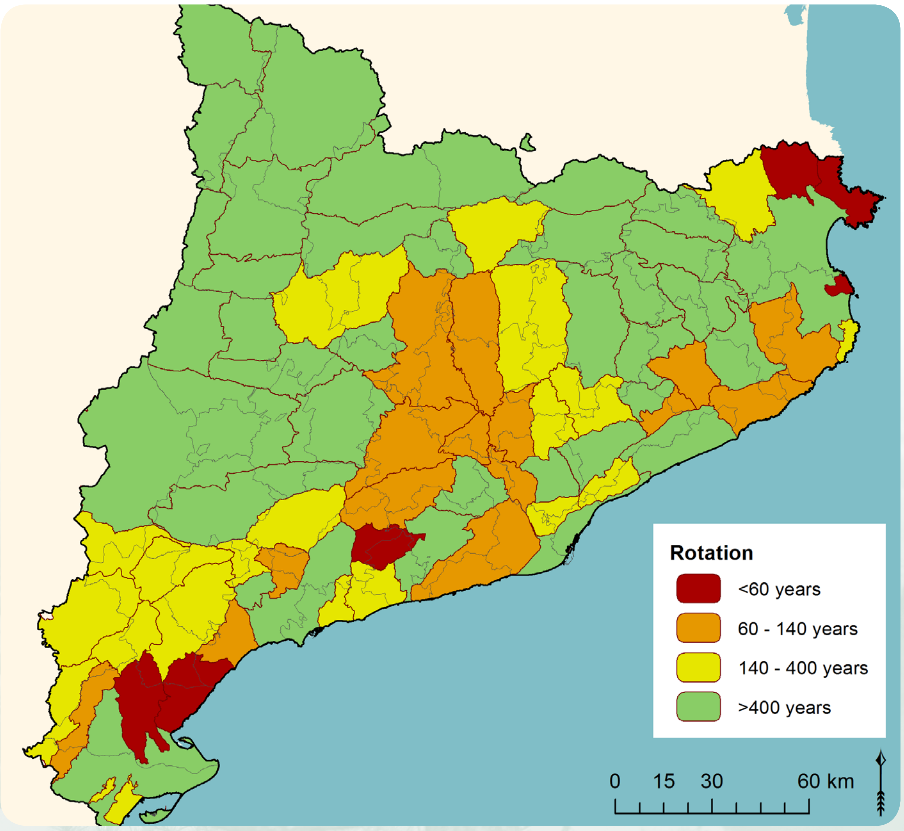


Figure 12. Map of Homogeneous Fire Regime Zones in Catalonia (HFR, red outline) and approximate intervals of fire rotation periods (adapted from Piqué *et al*., 2011). The fire rotation period represents the time it will take an HFR zone to burn completely (from a statistical point of view).

High-intensity fires, low-intensity fires, prescribed fires and managed fires

Fire can be categorised according to its effects into high-intensity fire and low-intensity fire.

High-intensity fire. It symbolises the negative aspect of fire and is the most well-known by the general public. In recent years, though, due to the accumulation of forest biomass and drier climate conditions, the effects of fire are becoming devastating (Figure 13). It **causes severe damage** to the ecosystems and situations over fire service threshold of control.

Figure 13. High-intensity fire in a black pine forest in Balsareny (Bages). Fire in Castellnou de Bages (2005). Photography: Catalan Fire Service.

Low-intensity fire. It symbolises the positive side of fire. According to Terradas (1996), this kind of fire does not **cause general mortality** and does cause changes in species, dominance or resource availability. Low-intensity fires can have effects such as removing surface fuel, thermal pruning of lower branches or emptying the canopy. Depending on its recurrence, it can result in fire-resistant forest structures (Figure 14).

Figure 14. Effects of a lightning strike fire in a black pine forest in Lladurs (Solsonès). Damage can be observed on two of the central trees, the fire mainly affected the grass and shrub layer, respecting the vitality of the tree layer canopy. Photography: Joan Rovira.

Generally, **areas with low-frequent forest fires** contain high fuel loads, **burn at high intensity and gravely affect the ecosystem**, whereas areas with **frequent natural fire** regimes or where **fuel management burning** is performed (prescribed burning or managed fires) contain light fuel loads and **burn at low intensity, favouring the natural dynamics and the ecosystem's persistence** (Agee, 1996).

Therefore, the benefits of low-intensity fire in forest structures can be promoted in two different ways: through **planned, prescribed burning** in terms of passive or active extinguishing, or through **following and monitoring fires** (managed fires) which, due to their low-intensity behaviour, generate a positive effect on the habitat and for which a monitoring strategy up to pre-set control limits is adopted.

Prescribed burning or managed fires are actions performed with low-intensity fire with the aim to manage the ecosystem through an interaction with fire (Figure 15). Often times, **this burning is used in research** to broaden the knowledge regarding the effects of fire on the biodiversity of the understory, the reduction of fuel, the growth and the structure of the tree layer. This is achieved either by monitoring the burning to know its intensity or rate of spread, analysing the effects of burning on the vegetation, comparing prior or later situations, or comparing areas burnt at different intensities, among others.

a)

b)

c)

Figure 15. Examples of prescribed burns in black pine forests, performed within the framework of the Life+ PINASSA project. Photography: AGS-CTFC and Catalan Fire Service.

a) Mature forest prescribed burn at Montsant Natural Park before (left) and after (right) applying fire.
b) Prescribed burn for fire prevention in Navès (Solsonès) before (left) and after (right) applying fire.
c) Prescribed burn for slash reduction in an adult black pine forest in Llobera (Solsonès) before (left) and after (right) applying fire.

2.2. Black pine forests adapted to frequent, low-intensity fires

Characteristics of frequent-fire forests

Black pine forests adapted to frequent, low-severity fires are usually mature forests with little understory, especially with regards to height, with vertical discontinuity, with **large trees with tall crowns**, and with **less tree density and more open** tree coverage. Compared to other forest structures developed in the absence of fire, **frequent–fire mature forests have less tree density and a more open structure made up of a larger amount of large and old trees** (Figure 16). In addition, frequent recurrence of fires in these forests reinforces their **spatial heterogeneity**, promoting forests with a high, small-scale variety in plant species composition, animal habitat, and ecological processes. The pattern of shady spaces made up of groups of trees and small open spaces provides a large amount of **biodiversity at a local scale** (Reynolds *et al.*, 2013).

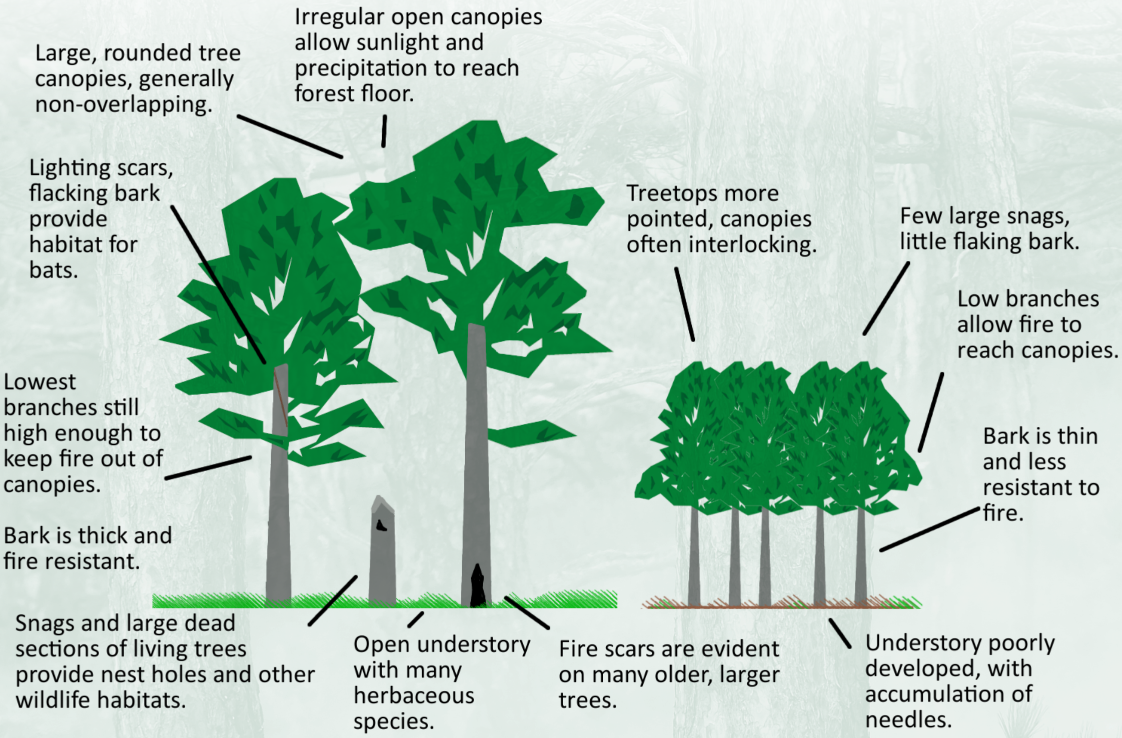


Figure 16. Main characteristics of mature forests adapted to fire recurrence in comparison to young forests in the absence of fire. Adapted from Binkley *et al.* (2007).

Another important element within these forests is the **snags and large dead and downed woody material** they contain, which accumulate over many years and show different stages of decomposition. This wood creates **cavities that become shelters** for many birds and insects and function as a **substrate** for moss, fungi and bacteria.

Now there are few places in Catalonia with examples of frequent-fire mature black pine forests (Figure 17). Its **distribution** has been reduced to **remote areas**, the top of crest lines with high humidity due to fog, which in turn coincides with areas where frequent natural lightning strikes occur. In these places, wood logging stopped several decades ago, at the beginning of the 20th century, due to difficult accessibility conditions. However, grazing use has been more present, given the structure of the forest. Currently, these forests appear in **extremely fractioned habitats in isolated islands** which **hinder their survival**.

Figure 17. Black pine adapted to recurrence of low-intensity fires, which spread along the surface, at Els Port Natural Park, where a fire wound can be observed. Photography: AGS-CTFC

Adaptation process of black pine forests to low-intensity fires

First, these forests need time to grow. Black pine forests can take between 150 and 200 years to start to begin to show the whole structure and process spectrum of mature forests. But time alone is not sufficient to encourage mature frequent-fire forest (Figure 18 and Figure 19). **In addition, the understory and tree density of these structures must be regulated through disturbances.** These disturbances can be of natural origin, such as lightning strikes or wildlife, or disturbances of human origin, such as pasture and silviculture (either with conventional mechanical tools or prescribed burning). If the aim is to advance natural dynamics towards mature forest structures, forest management allows for the improvement of key elements and promotes tree growth and vitality and, ultimately, moves the forest towards a higher degree of maturity. In addition, forest management (with or without use of fire) can integrate black pine habitat conservation with forest production objectives, which in many cases will be required by the forest property in the framework of a multifunctional forest management (Figure 20).

Figure 18. General appearance of a black pine forest with trees of different ages, with a mainly grassy understory at Els Port Natural Park. Photography: AGS-CTFC.

Figure 19. Structure that combines individual and grouped trees at Els Port Natural Park. Photography: Jordi Bas.

Figure 20. Forest management in Llobera (Solsonès) where silvicultural treatments as thinning and clearing (top) and prescribed burning (bottom) have been performed to promote forest structures more resistant to fires. Left, before the treatments, and right, after. Photography: AGS-CTFC.

Without any of the aforementioned phenomena, tree density and understory vegetation tend to remain high (Figure 21) and the resulting forest structure, with vegetation vertical continuity, is more vulnerable to generate large devastating fires that eliminate most of the trees. In these cases, when a fire occurs, it spreads rapidly among the understory vegetation, from the understory to the crowns of smaller trees with low branches, and from the small trees up to the crowns of the adult trees.

The composition, structure and spatial pattern in frequent-fire forests is maintained by frequent, low-severity fires, through a functional relationship between the pattern and the process, that is, **frequent, low-severity fires produce forest structures that in turn favour low-severity fires** (Hiers *et al.*, 2009; Mitchell *et al.*, 2009). Over time, shifting mosaics of tree groups and individual trees of different ages have coexisted in a grass-shrub open matrix thanks to the relationship between the severity and frequency of the fires, the presence of surface fuel and the trees regeneration sites that escaped fire (Larson and Churchill, 2012). Therefore, a landscape with mosaic, with different types of structures combined, with young, adult, mature forests, open spaces and regeneration is a good strategy to create forests and landscapes adapted to fire.

In this context, it is vital to **ensure minimum levels of regeneration**, to guarantee the persistence of the forest and this mosaic structure, with groups of trees, isolated trees and open spaces. Regeneration of black pine occurs when conditions are favourable, with rainfall and viable seeds, and normally forming abundant groups of trees or groves. Surface fires that occur every few years or decades eliminate most of the small trees that have managed to establish themselves in recent years. Trees that survive a fire, those most dominant and vital, experience less competition for light and soil moisture, which make them more resistant to future surface fires.

Figure 21. Forest structure with different canopy heights and trees of different ages at Els Port Natural Park, where younger trees grow under adult trees. In this case the *Buxus sempervirens* understory is starting to become quite abundant due to the lack of pasture and lightning strikes. Photography: Jordi Bas.

Importance of mature black pine forests

Black pine forests may be considered fragile in the short term following a fire, due to their difficulty to regenerate in open spaces and not having serotinous pine cones. Therefore, after catastrophic fires, which appear as a result of long periods of fire suppression and/or abandonment of management and traditional uses, combined with extreme climate conditions, the resilience of black pine forests is compromised.

Mature forests that are adapted to frequent fires are one of the best guarantees to avoid large, devastating forest fires and preserve the black pine habitat. Additionally, they are a good opportunity to study the function, processes and structures typical of these kinds of forests. Old magazines, photographs or other documents in archives (a good example is the collection by Pellisa, 2003) provide additional information regarding the size and number of existing trees before the changes in landscape uses. Also, the use of techniques, such as dendrology (Figure 22) or the study of the snags and large dead and downed woody material, present today, allows us to investigate the function and processes that occur to achieve the current mature forest structure.

Figure 22. Core extraction in black pine forests allows us to know the fire regime and the effect of fires and droughts on the growth of the black pine. Photography: AGS-CTFC.

2.3. Effects of fire on vegetation and fauna

Effects of fire on vegetation

The effect of fire on plants varies according to their organisation level. Individual plants can survive if they avoid damage during combustion, but at population level plants persist through the survival of individuals or regeneration from the seed bank (Figure 23). Communities and ecosystems are submitted to succession after the fire and the landscape's mosaic structure is re-shaped by the fire.

The fire's properties (intensity, duration, etc.) also have different effects on plants, and interact with different strategies that these have to survive or re-colonise burnt land. Fire can cause a significant immediate mortality, even in woody species.

The vegetation's response to fire at landscape level depends on the fire regime, which plays a very significant role in the landscape's shaping. Variation in the frequency, space and intensity (high, medium or low) of fires draw different kinds of patterns in the landscape. Martin and Sapsis (1991) argued that diverse fire regimes (pyrodiversity) promote biodiversity in environments where fire is a key disturbance. According to this hypothesis, higher spatial and temporal variation in fires produces a greater variety of ecological niches and therefore favours the coexistence of more species and especially favours different combustibility and age classes. As a result, the resilience of the population is significantly widened.

In Mediterranean shrubs, time variation of the fire can favour or penalise certain species. The time to reproductive maturity and senescence can be used to estimate the optimum intervals between fires that favour biodiversity (Kelly and Brotons, 2017) .

In areas where traditional agricultural activities have been abandoned, fire is progressively becoming the key factor for the preservation of open areas. Diversity at landscape level can be crucial for the preservation of species in open habitats associated to disturbances. Current landscape change trends point towards a progressive homogenisation and afforestation that will probably lead to a gradual decrease in areas available for open habitat species (Brotons *et al.*, 2005). Biodiversity can benefit from the variation in fire regimes, fires tailored to suit particular ecosystems and species.

Figure 23. Regeneration of European fan palm (*Chamaerops humilis*) after a fire at Garraf Natural Park. Photography: Catalan Fire Service.

Effects of fire on fauna

Animals also show a series of abilities to face fire and many need fires for their survival. They must avoid exposure to fire or intense heat at all costs, mobility being their main responsiveness.

Birds are the most studied group of animals to research the effects of fire both at high and low intensity. Although birds are vulnerable when it comes to nesting, in general they can escape a fire and often benefit from hunting prey that flee from a fire and afterwards return to quickly recolonise burnt areas. There are numerous studies that confirm an increase in bird richness in the years after a fire (Taylor, 1971, 1973; Pons *et al.*, 2003), especially due to the occupation of open areas favourable to many species. After fires, different behaviours have been observed in birds such as the resistance to abandon previous territories, flexibility to adapt to new habitat conditions, a modest effect of fire on the demographics of many species and the improbability of colonising at long distances.

Burnt areas offer recolonisation areas for many species, which can move from one place to another, looking for those areas that offer the most benefits. In burnt areas many birds find food and refuge in dead wood on the ground that remains after a fire.

Moreover, mammals are often capable of escaping a fire, or seeking shelter in dens or other places. Amphibians and reptiles can avoid flames by burying themselves under ground or using the burrows of other animals. Amphibians in particular can seek shelter in water or very wet mud. Soil microorganisms vary in their heat tolerance, but those that are located deeper in the soil tend to survive a fire more. An increase in available nutrients after a fire (Alcañiz *et al.*, 2016) results in larger microbial communities than before the fire. Bacteria's generally higher heat tolerance than fungi allows the soil's microbial population diversity to change after a fire, depending on the severity of the fire, the depth of the microorganisms in the soil and the presence of vegetation cover.

At landscape level, spatial and time variation of fires also impact the fauna biodiversity. The variation in fire intensity creates unique habitats at a local and regional level, including areas with different percentages of tree coverage that favour the biodiversity of birds. A study performed in California on how the fire regime variation shapes bird diversity shows that conifer forests with a high variation in fire severity (high, medium and low) are critical for sustaining biodiversity (Tingley *et al.*, 2016). Knowledge of how animals are influenced by the diversity, size and severity of fire can be useful for conservation management.

2.4. Fire-forest structure relationship

Forest structure is determined by the distribution of vegetation or fuel that are part of it. Fuel can be found in multiple combinations of type, quantity, size, shape, position and arrangement. The fuel of a certain place can be mainly grasses or be made up of slash and thick dead trunks, it can consist of dense conifer canopies, thick layers of dead leaves, or a dense accumulation of dead slash or a mixture of any of these elements. This forest structure will condition the spread and behaviour of fire; therefore, forest fires can be categorised according to the vegetation layer they spread through (Figure 24):

- Surface fire: the flame spreads through the surface fuel and higher understory vegetation.
- Crown fire: initiated from the convection heat that surface fire transfers to the tree canopy (Wagner, 1977). This includes two subgroups:
    - Passive: individual or small groups of trees torch out but flames are not maintained in canopy
    - Active: fire spreads among the crowns

Active crown fire represents the biggest threat to the survival of black pine forests and to the extinguishing systems, because it generates extremely high fire intensities and rates of spread, massive spotting and very long flames.

When we speak about fire behaviour, the term **fuel** is often used, which refers to all the organic material, alive or dead, that can ignite and burn.

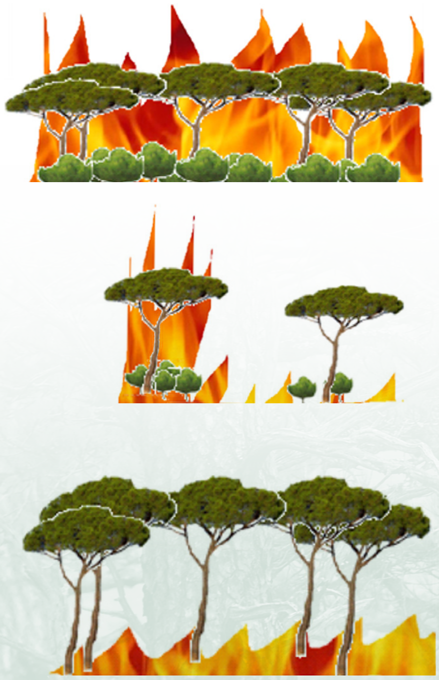


Figure 24. Types of fire according to the vegetation layer they spread through. Source: Piqué *et al.* (2011).

To characterise the vulnerability of a forest stand, Piqué *et al.* (2011) developed a key to determine the vulnerability of a forest stand to generate crown fires (CVFoC), distinguishing between A structures (highly vulnerable to generate active crown fires), B structures (medium vulnerability) and C structures (low vulnerability, where when a fire occurs, it will stay on the surface). These keys can also be applied to black pine forests and are based on the main vegetation layers and the distances between them (Figure 25). In general, the main vegetation layers that become fuel for the fire are the aerial fuel, ladder fuel, surface fuel and ground fuel (Figure 26):

- **Aerial fuel** is made up of the tree crowns of the highest dominant and co-dominant layer. The openness of the canopy and its density have an impact on the kind of fire that can occur. For example, when canopies are open, the wind can reach the surface more easily, and more rapid and intense surface fires can occur. Nonetheless, in open canopies with a lack of wind, active spread along the canopy is hindered.
- **Ladder fuel** is all vegetation located above 1.3 m that is not part of the dominant or co-dominant tree layer, and includes small trees, tall shrubs, fallen trees or lower parts of the tree canopy. Due to its position between surface fuel and crown fuel it is very significant with regards to fire spreading from the surface to the canopy.
- **Surface fuel** is all material that is immediately on top of the soil up to a height of 1.3 m and is made up of shrub, saplings, herbaceous fuel, branches, fallen trees, slash or lower parts of tree canopy. If there is no fuel above, it is directly affected by the wind and solar radiation. Surface fuels are those that are mainly consumed in a prescribed burning, are considered the most important type of fuel and are described more in depth. Load, surface-volume ratio, compactness, chemical composition and moisture content are the surface fuel characteristics that affect fuel behaviour the most.
- **Ground fuel** is all material that is located under the surface, including humus, roots, decomposing buried trunks and other woody fuels. Due to being so compact, fires that occur in this kind of fuel are slow-spreading fires without flames.

Figure 25. Examples of vertical and horizontal continuity in black pine forests. A structures are highly vulnerable to generate crown fires, B structures are medium vulnerable and C structures low vulnerable. Photography: AGS-CTFC.

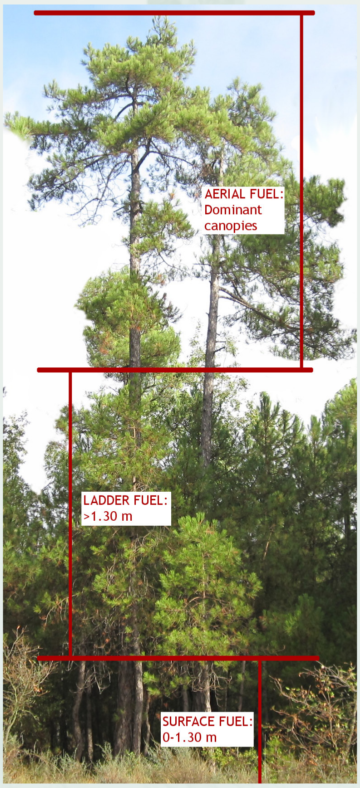


Figure 26. Distribution and definition of types of vegetation layers or fuels that feature forest structures (Beltrán *et al.*, 2012).

Forests with little vegetation accumulation and forest structures without vertical or horizontal continuity are more resistant to the spread of fire along the canopy, reducing the intensity and the rate of spread of forest fires.

Vertical arrangement determines which layer will be involved in the fire. When there is vertical continuity, the fire can easily reach the canopy and become a much more intense fire. The intensity of the surface fire and the moisture contents of the live fuel normally determine whether the fire will reach the canopy through the ladder fuel.

The horizontal arrangement makes a fire spread more easily. It will be harder for the fire to spread in open areas than in areas where fuel is spread out more uniformly and continuously, and it normally requires stronger winds and spotting to spread. In the case of closed canopies, they reduce the amount of wind that reaches the fire, increase the moisture of the surface fuel and reduce the growth of the understory vegetation, although once fire reaches the canopy it spreads more quickly than in more open canopies.

The main characteristics that determine the fire's spread to the canopy and its intensity and spread are:

- **Canopy Cover** gives an idea of the horizontal continuity of the canopy layer.
- **Canopy base height** is defined as the height from which there is enough canopy fuel to spread the fire vertically through the canopy (Scott and Reinhardt, 2007).
- **Fuel load**. It is the amount of fuel per surface unit (t ha^{-1}). The main fuel that participates in combustion is the fine dead fuel (separated between <0.6 cm, 0.6-2.5cm, and 2.5-7.6 cm in diameter), but fine live fuel also contributes to it.
- **Fuel bed depth**. Surface fuel height together with fuel load determines fuel compactness. If it is very compact, there will be little oxygen and combustion will be more difficult.
- **Available canopy bulk density** gives an idea of how compact canopy fuel is, and how it is spread out along the canopy.
- **Distance between layers**, that is, the difference between the base of the tree crowns and the average height of the surface layer, which can be made up of dead leaves, grass layer and shrub layer. It also provides information regarding vertical continuity. The larger this distance is, the harder it will be for the fire to reach the canopy.

As discussed earlier, of the different kinds of forest fires that can occur, crown fires, which are often intense and spread quickly, are the biggest threat, and challenge, for fire services and land managers. Vertical continuity of the vegetation allows fire to reach the crowns much more easily and, from here, it can actively spread from crown to crown. Therefore, if this structural continuity is altered, a decrease in vulnerability to active crown fires can be expected (Fulé *et al.*, 2001; Brown *et al.*, 2004; Agee and Skinner, 2005; Johnson *et al.*, 2007).

The interaction between **meteorology, topography and vegetation** (referred to as fuel) determines how a fire spreads and if it can turn into a large forest fire (Rothermel, 1983). Of these parameters, vegetation is the only one that can be modified, with the aim to influence the fire spread. The use of strategic forestry actions at stand level aimed at reducing the surface fuel load, increasing the crown base height, reducing the tree crown density and/or preserving trees of resistant species should diminish the vulnerability of forest stands and make it much easier to extinguish fires (Agee, 1993; Graham *et al.*, 2004) (Table 1).

Principle	Effect	Advantage	Concerns
Reduce surface fuel	Reduces potential flame length	Control easier, less torching	Surface disturbance less with fire than other techniques
Increase height to live crown the distance to the canopy	Requires a longer flame length to begin torching	Less torching	Open understory; may allow surface wind to increase
Decrease crown density	Makes tree to tree crown fire less probable is less likely	Reduces potential for crown fire	Surface wind may increase and surface fuels may be drier
Keep big trees of resistant species	Less mortality for the same fire intensity	Generally restores historic structure	Less economical; may keep trees at risk for insects

Table 1. Factors that increase resilience to fire. Source: Brown *et al*. (2004).

2.5. Fire behaviour simulation

Simulation tools are useful to study the relationship between the forest structure and fire's behaviour (for example, rate of spread, flame length, etc.). The variability in shape, size, amount, position, type and disposition of fuel requires information to be organised through fuel models for the use of simulation tools. Fuel models include a simplified version of all the information necessary to characterise surface fuel, such as fuel load (t ha^{-1}) or fuel bed depth (m), among others. Within these models, there are standard fuel models that describe different basic structures (Anderson, 1982 o Scott and Burgan, 2005) and custom fuel models produced with specific data, such as those presented in Table 2, in this case obtained within the framework of the Life+ PINASSA project for forests of this species. Fuel models presented in this table refer to relatively young black pine forests, between 40-80 years of age, where forest management actions to reduce the spread of crown fires have been performed, either through conventional mechanical treatments or through direct prescribed burning (without previous treatment). Table 2 shows the surface fuel characteristics before and two years after treatment, as well as the results of the fire behaviour simulation in each case. Table 3 shows stand characteristics of these stands.

Municipality (Region)	Treatment	Fuel load (t ha^{-1})								Fuel bed depth (m)	R (m min^{-1})	FL (m)
		Duff	Litter	1h	10h	100h	Lh	Lw	Total			
Navès (Solsonès)	Before treatment	16.43	2.66	1.37	0.68	0.00	1.03	3.56	25.73	1.16	11.6-15.6	11.3-12.7
	Two years after mechanical treatment	11.61	2.99	5.66	8.01	5.30	0.13	1.83	35.53	0.30	2.9-3.2	1.5-1.6
	Two years after burn treatment	14.52	1.04	2.24	2.16	0.41	1.26	0.79	22.43	0.31	3.2-3.8	1.0-1.3
Llobera (Solsonès)	Before treatment	17.49	2.21	2.58	0.72	0.00	3.83	7.50	34.34	1.17	9.6-12.5	6.2-10.0
	Two years after mechanical treatment	15.57	2.49	6.78	10.60	3.31	0.83	0.51	40.10	0.27	2.5-3.2	1.4-1.5
	Two years after burn treatment	16.44	1.79	2.47	4.64	0.00	0.37	1.66	27.37	0.34	3.7-5.5	1.4-1.7

Table 2. Black pine fuel models, performed within the framework of the Life+ PINASSA project. 1h, 1h fuel load (with a diameter below 6mm); 10h, 10h fuel load (with a diameter between 6 and 25 mm); 100h, 100h fuel load (diameter between 25 and 76 mm); Lh, Live grass fuel load; Lw, Live woody fuel load; R, Rate of spread; FL, Flame length.

Municipality	Treatment	CC (%)	N (trees ha^{-1})	Dg (cm)	BA (m^2 ha^{-1})	Do (cm)	H (m)	CBH (m)	ACBD (kg m^{-3})	Shrub_AC (%)
Navès (Solsonès)	Before treatment	90	1,910	13.6	27.6	23.6	8.9	4.6	0.38	31
	Two years after mechanical treatment	81	1,496	14.0	23.1	24.6	10.1	5.3	0.29	18
	Two years after burn treatment	89	1,602	14.3	25.9	24.1	9.2	4.8	0.31	6
Llobera (Solsonès)	Before treatment	89	1,341	15.9	26.9	23.8	9.1	4.8	0.29	72
	Two years after mechanical treatment	83	1,188	16.0	24.0	30.0	10.1	5.3	0.23	20
	Two years after burn treatment	78	1,178	16.6	25.4	28.3	9.8	5.1	0.22	14

Table 3. Black pine stand characteristics, performed within the framework of the Life+ PINASSA project. CC, Canopy Cover; N, Tree density; Dg: Mean quadratic diameter; BA, Basal area; Do, Average diameter of the 100 largest trees per hectare; H, Average height; CBH, Average canopy base height; ACBD, Available canopy bulk density; Shrub_AC, Average shrub cover.

When structures with low, normally grass, understory are compared with structures with a high tree density and dense and tall understory, simulation tools give an idea of the behaviour of a potential fire. Table 2, with weather and topographical conditions typical of fires in the area, (Piqué and Domènech, 2018), shows how in treated black pine stands (thinning or prescribed burning), both the spread rate (below 4-5 m s^{-1}) and flame length (below 1.7 m) of a potential fire are significantly reduced.

Other simulations performed to assess fire's behaviour in black pine forests in Solsonès, with a high vertical and horizontal continuity and fuel models with high loads, where the lower understory has been mechanically cleared, followed with slash lopped and scattered or burnt, also show how burning significantly reduces the behaviour of a potential fire (Figure 27) (Piqué and Domènech, 2018). This work shows that the rate of spread, flame length and fire intensity experience decreases of more than 90% with prescribed burning (rate of spread 8 m min^{-1} before burning, 1 m min^{-1} after; flame length from 8 m to 0.6 m; and intensity from more than 5,000kW m^{-1} to less than 100 kW m^{-1}).

Burning reduces surface fuel (decreasing the intensity and flame length of a potential surface fire); increases the distance between the surface fuel and the canopy (hindering the fire's access to the canopy); and causes a thermal pruning of the crowns by reducing their bulk density (in the case that the fire reached the canopy, it would be difficult for it to spread actively).

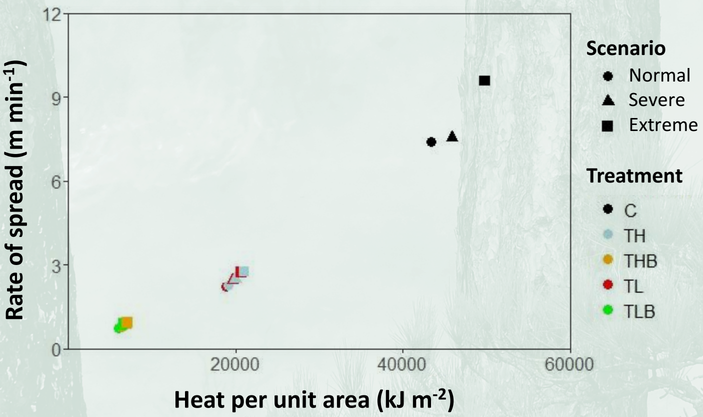


Figure 27. Rate of spread versus heat released per area in black pine stands where different treatments have been performed (C, no treatment; TH, heavy thinning and lop and scatter; THB, heavy thinning and burn; TL, light thinning and lop and scatter; TLB, light thinning and burn), and taking into account different meteorological scenarios (normal, severe, extreme).

Fire's behaviour varies greatly between a surface fire or an active crown fire. Depending on its intensity, fires will be more or less controllable by fire-fighters and the effects on the ecosystems will be larger or smaller. In any case, structures with low fuel loads or without ladder fuel and crowns that are far from the surface will offer better fire control opportunities to fire-fighters and generate low-intensity surface fires, which can have positive effects on the ecosystem.

3.

Prescribed burning

3. Prescribed burning

3.1. What is a prescribed burning?

Prescribed burning in a global context

In Europe, fire has been an important element in **agriculture, hunting, pastures and forest management.** The use of fire has shaped landscape patterns and added ecological and cultural diversity.

The rapid socioeconomic changes that occurred after World War II in Europe also changed the landscape uses and patterns. Due to new air quality standards and a generalised opinion that fire damaged ecosystems' stability and biodiversity, public administrations **imposed bans on the use of fire in most European countries.** During the second half of the 20th century, traditional use of fire was preserved in few places, for example in Scotland, where it was used to maintain the capercaillie's habitat or in Finland where it was used as a forest management tool.

From the 1970s it became more evident that **abandoning traditional landscape use methods had removed disturbances**, which had shaped many kinds of landscapes and valuable ecosystems. The paradigm shift in ecology and conservation has led to a reconsideration of fire-banning policies in certain sectors such as conservation, hunting and forest management. The existence of different research projects on prescribed burning and revival of traditional fire use practices indicate a restored functional role of fire in landscape and ecosystem management.

In the United States, the use of fire ended at the beginning of the 20th century when policies against fires were promoted with the aim of eliminating all fires. Since 1995, the United States Forest Service has slowly incorporated prescribed burning as a tool in their forest management policies.

Pinus ponderosa plays a similar role to the black pine (Agee, 1993) in interior areas in the west of the US, mainly in mid-mountain regions of interior areas, where drought, fire and large mammal pastures are the most significant disturbances that make their ecosystem evolve. Likewise, their fire regime ranges between 5 and 35 years and it regenerates forming groves that become open old-growth forests. Decades with an active fire-fighting policy and a forestry practice that did not integrate disturbances as management elements led these forests towards a deteriorated situation, mainly due to the large forest fires suffered in the context of global change. Currently, the extensive use of fire in the form of burning is the basic tool for restoring forests towards sustainability.

Burning objectives

Prescribed burning is the **planned and precise application of fire to specific vegetation fuels** and under **certain meteorological conditions** to achieve **specific forest management objectives**. Prescribed burning can be used to limit the scope of large forest fires as part of pre-extinguishing and prevention plans, as well as to emulate natural processes that allow for the maintenance of ecosystem biological capacity.

The main objectives of prescribed burning are:

Protecting the ecosystem from the risk of devastating fires (Figure 28).

- To eliminate the vegetation fuel load that could promote the spread of destructive fires with devastating effects on the vegetation and fauna.
- To restore and maintain a fire-resistant structure. For example, preserving structures with low available fuel load.
- To transform forest structures to ease the control of large forest fires in strategic areas and reduce their impact. To create a mosaic in the landscape that combines structures with different degrees of vulnerability to fire.


Figure 28. Burning at Mola Castellona (Els Ports Natural Park) performed within the framework of the Life+ PINASSA project. Photography: Jordi Bas and Catalan Fire Service.

Restoring and improving fauna habitats (Figure 29).

- To preserve pastures for large herbivores.
- To open the forest stand and create open spaces for bird species, for example, large birds of prey.
- To improve nesting areas, for example, in the case of Ebro Delta's reed regeneration burning.


Figure 29. Management burning at Ebro's Delta Natural Park to manage and favour nesting areas and pasture burning in Collada de Tosses (Ripollès). Photography: Catalan Fire Service.

Managing vegetation and its succession.

- To favour certain species. Fire intensity, season and fire recurrence are the main parameters that condition certain species' responsiveness with regards to others. The vital strategies of seeders and and sprouters are different when faced with fire and this allows for prescribed burning application patterns that condition each species or groups of species' responsiveness to be established. These patterns known by shepherds have marked the traditional burning pattern to favour grasses over re-sprouting species such as *Genista*. The season and burning recurrence, guiding and ignition pattern are part of popular knowledge to favour more palatable species for herds.
- To protect sensitive species when invaded by other species. As is the case of protecting the Phoenicean juniper (*Juniperus phoenicea*) on calcareous crest lines or the black pine in the meridional region of Catalonia, where it has been limited to remote crest lines after the proliferation of Aleppo pine forests or Maquis shrublands.

Managing forestry (Figure 30 and Figure 31)

- To favour clearing and tree growth improvement processes, by affecting the cambium of the most dominant and less vital trees.
- To eliminate surface and ladder fuel to reduce the vulnerability to crown fires.
- To elevate crowns to the top of the trunk through thermal pruning.
- To favour the regeneration of species adapted to low-intensity fire.
- To eliminate forestry treatment slash to reduce the risk of fire spreading and favour the recirculation of nutrients.

Figure 30. Slash burning in black pine forests in Llobera (Solsonès), performed within the framework of the Life+ PINASSA project. Photography: Catalan Fire Service.

Figure 31. Burning under trees in black pine forests in Colldejou (Baix Camp), performed within the framework of the Life+ PINASSA project. Photography: Catalan Fire Service.

Prescribed burning was introduced in southern-European countries seeking to reduce the risk of forest fires. The experience gained in these practices has made it possible to broaden the objectives towards other management objectives such as the conservation of natural spaces, forest management or fauna recovery (Lázaro and Montiel, 2010).

How is prescribed burning performed?

Burning is based on the **execution of low-intensity fire** always carried out in a **guided way**, following an ignition pattern that does not allow for the fire to spread uncontrollably.

Burning is performed following a previously-designed and approved **Burning plan** where the prescription window is clearly specified. The **prescription window** is the set of meteorological, topographic and fuel conditions that must be meet to achieve the goals set for a secure and prescribed burning. The Burning plan includes the **aims, the prescribed meteorological window, prior conditioning work, resources needed and ignition particularities**, among others. It is essential that burns are planned and executed by specialised personnel. In Catalonia prescribed burning is performed by specialised units from the Fire Service and the Forest Service.

The prescription window indicates meteorological (temperature, relative humidity and wind speed), fuel moisture (live and dead per diameter) and fire behaviour (rate of spread, intensity, flame length) ranges within which it is possible to carry out the burn safely and meeting the desired objectives.

The preparation work consists of making delimiting or anchoring lines to limit and divide the burn plot in a physical line (Figure 32). If the structure to be burnt is excessively complex for direct fire applications, it is possible to modify the vertical continuity of the fuel with manual tools, clearing the lower areas.

Figure 32. Clearing control lines before performing a burn in a stand belonging to the Life+ PINASSA action, at Montsant Natural Park. Photography: Catalan Fire Service.

The slash generated while preparing the terrain (for example, eliminating vertical continuity) is distributed uniformly along the plot with the aim to avoid generating a high intensity when carrying out the burn.

Guiding the burn (Figure 33) is performed based on the **ignition pattern** that must adapt to the objectives and safety of the burn according to the weather, slope and fuel load. Likewise, the ignition pattern **can modify the intensity of the head of the fire** (length of the flame) by varying the ignition pattern to adjust the optimal fire behaviour to achieve the objectives described in the Burning plan.

Denser areas, with higher shrubs or piles of slash are burnt locally adjusting the ignition pattern and its pace with the aim to keep the fire at low intensity.

Figure 33. Different phases of a prescribed burning applying a back burn, in a black pine forest in Navès (Solsonès). The aim is to reduce the understory and dominated trees and preserve the adult trees. Photography: Catalan Fire Service.

Once the ignition phase is over, the **post-extinguishing phase** begins, where **hot spots must be cooled and the perimeter must be sealed** to ensure that the fire does not escape the set boundaries. Above a certain drought value and in places with a large percentage of organic matter, part of the humus continues burning in a second combustion phase during the days after the prescribed burning. This combustion is slow but it can allow the fire to surpass the control lines along the undersoil and affect adjoining plots that were not meant to be burnt.

Moreover, the presence of dried stumps makes it easier for some of them to catch fire, forcing the team to ensure its stability to avoid it rolling and sending incandescent sparks outside of the plot boundaries. Depending on the degree of drought and the availability of organic layer to be burnt, the perimeter sealing actions will vary. With high drought values, the combustion process of the organic layer can last several days, meaning there is a high risk of the fire escaping and making post-extinguishing actions mandatory, such as steeping the **20 meters closest to the control line, or creating a deep control line that impedes the fire from running along the undersoil and roots**.

Effects of burning and monitoring

To **reduce potential impacts** of burning and also study their effect on the soil, vegetation and fauna, the following aspects must be **monitored**:

• **Soil temperature.** Soil temperature must not increase significantly: high temperatures cause high severities. The existence of hot spots some time after the burning or a high temperature when touching the ground with the hand are indicators of a severe burn.

• **Monitoring the natural regeneration process** of herb, shrub and tree species. This implies two key aspects:

- Evolution over time of the degrees of vegetation coverture to assess the effect of the changes on the forest structure.
- Characterisation of the populations that regenerate in terms of species and structure. The fire application season and intensity are related to favoured regeneration of different species depending on their recruitment strategy, seed dispersion, sprouting or both.

The main objective of the burn will therefore determine the ideal season and intensity to apply the fire.

• Degraded areas (% of uncovered soil and/or rock formations) and steep slopes can become vulnerable to **erosion processes** if there is a deficit in regeneration.

• **Burning recurrence period**. Setting the recurrence period is fundamental to balance fire's positive and negative effects. A recurrence period that is too short can mean that the vegetation might not have had time to create adequate seed banks and therefore the regeneration after burning might not be successful, or there may be loss of some nutrients due to soil washing away in vulnerable areas.

• **Tree vegetation**. When the burn objective is to preserve adult tree structures, the effects of fire on this layer must be assessed (Figure 34). Monitoring the number and severity of scars on trunks and assessing the percentage of canopy affected by the fire are some of the aspects that determine the severity degree in the tree layer. Mitigating fire's effects on adult trees means: *i*) choosing the season where live tissues will be less vulnerable, *ii*) defining an adequate meteorological window to control the intensity of the fire, and *iii*) if necessary, previously modifying the fuel structure through mechanical tools to minimise damage due to vertical continuity.

• **Fauna**. Choosing an adequate season will help to prevent damage to fauna. Burning must be avoided during bird nesting periods and when invertebrate species are most active. In addition, it is important to take care of the technique used to regulate the rate of spread so that there are escape routes in the closures.

Some time after a burn, the terrain that has been treated with fire must be observed and certain **checks must be performed to confirm that objectives have been met**:

- Satisfaction level of the petitioners and beneficial owners of the plot. Level of compliance of agreements by the petitioner must also be assessed if the reason is for farming use of the plot.
- Satisfaction level of the forest administration responsible for forest management and conservation.
- Level of compliance of technical objectives set in the burning plan, for example, reducing the understory, percentage of eliminated dominated trees with small diameters, breaking vertical continuity of vegetation layers, incidence of regeneration, etc.

a)

b)

Figure 34. Prescribed burining under black pine trees in Navès (Solsonès). a) During the burn; b) 7 months later. Photography: AGS-CTFC.

3.2. Experience gained regarding the use of prescribed burning for the conservation of black pine forests

The ecology of black pine and the dynamics of the species' natural structures is related to a high-frequency fire regime (< 35 years), which allow for structures with few possibilities of generating devastating high-intensity fires that put adult trees in danger, and where the viability of regeneration of black pine requires this high fire recurrence to limit the competition with other tree and shrub species.

Currently, the percentage of black pine stands with the properties described is minimal in Catalonia and remains restricted to specific locations with a small surface area. Traditional forest activity mainly aimed at extracting commercial wood product and the generalised abandonment of forest management and use of the forest in the last decades, together with the abandonment of using burning to improve pastures and the eradication of natural fires by extinguishing systems has promoted the proliferation of understory structures with high concentrations of biomasses and immature forests extremely vulnerable to developing crown fires. The effect of large forest fires in the last 30 years on black pine forests has been very significant and has reduced the surface area this species occupies considerably.

Different **examples of actions performed with prescribed burning** to restore the black pine population's capacity to improve its resilience and preserve its habitat are presented below.

Reducing the black pine forests' vulnerability to crown fires

Black pine structures with high surface and ladder fuel loads are vulnerable to active crown fires and large forest fires that put their habitat in danger. Forestry treatments aimed at reducing the biomass in these layers improve fire behaviour values in a wide range of meteorological conditions and vegetation fuel availability. The result will be a high probability of low and medium intensity fires if they occur, and hindered spreading of the fire along the canopy, which impedes the appearance of large fires with devastating effects.

These actions therefore aim to reduce fuel vertical and horizontal continuity to create discontinuity and reduce the total biomass available, as well as improve the growth and vitality of the remaining stand. This can be achieved in two ways (Figure 35):

- **Applying prescribed fire directly to the forest stand** without prior mechanical treatment, mainly affecting the surface and ladder fuel (dead leaves, grasses, dead branches, shrubs, regeneration and dominant trees).

Pros:

- Prescribed burning emulates fire's natural action, generating a more diverse structure conditioned by the particularities of ignition and the availability of fuels.
- Cost reduction since treatment is simplified to a single action.

Cons:

- It requires more specific meteorological conditions to achieve the desired effects, reducing the number of days in which the burning can be performed.
- It requires expert burning teams to achieve the desired effects.
- Poor performance, if the effect of the dominant tree layer must be minimised, due to the application of conservative, low-intensity and slow-progression burning patterns.

However, it must be noted that when prescribed burning is applied to conservatively, it can provoke an inefficient consumption of fuels, the survival of undesired understory and a significant expense (Zimmermann, 2003).

- **Combination of mechanical thinning and clearing and fire application afterwards** to extensively slash burning.

Pros:

- More homogenous results and a general perception from the forest property, managers and visitors of a significant reduction of vulnerability and better results with regards to fire prevention.
- Wider availability of days in which the burning can be performed.
- Better performance of burning teams.

Cons:

- It is recommended to wait a few months between the mechanical treatment and the slash burning to reduce the intensity of the fire and its effects on the remaining trees.
- It tends to homogenise the effects of the treatment, if before the mechanical treatment steps have not been taken to create diversity.
- Higher total cost.

As a general guide, when the aim is to reduce fuel and the forests' vulnerability to generate large fires, directly applying prescribed burning is advised, and the combined treatment of "mechanical thinning and clearing and slash burning" is reserved for multi-layered forest structures with ladder fuel cover values above 70%.

Annex I shows two examples of prescribed burnings carried out within the framework of the Life + PINASSA project. First, a prescribed burn in an uneven-aged pine forest with a high continuity of fuel that aims to reduce the vulnerability of the stand against forest fires and, secondly a prescribed burn in a mature black pine forest that pretends to emulate the effects of natural lighting fires.

a) **b)**

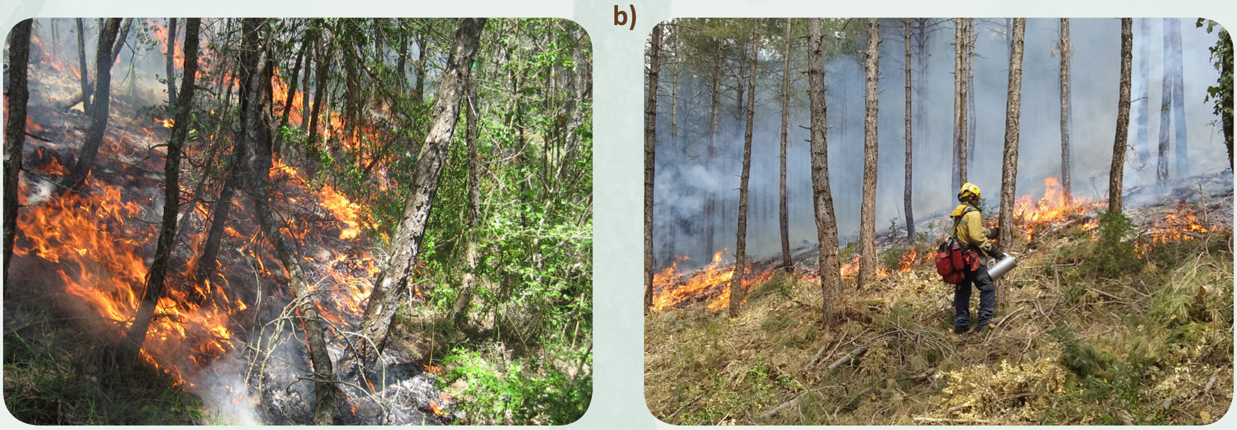


Figure 35. Examples of prescribed burns. a) Prescribed burn applied directly without prior treatment; b) slash burning after thinning and clearing treatment. Both in Llobera (Solsonès). Photography: Catalan Fire Service.

Helping the natural regeneration of black pine in adult forests

Natural regeneration in adult black pine forests is often conditioned by the presence of abundant understorey and shrubs, which proliferate in the absence of recurrent fires and/or herbivores who limit the vertical growth and horizontal cover of understorey vegetation.

In this case, prescribed burning partially removes shrubs competition, providing longer time for establishment and growth of regeneration because the increase of the trees growing space.

Black pine regeneration, normally, is stablished forming groves, and the use of fire can be a good way to control the competition between trees (clearing and thinning effect) and to reduce shrub cover and surface fuel in the case of high accumulations what can put at risk the adult tree crowns (Figure 36).

As with treatment to reduce vulnerability to crown fires, treatments to promote regeneration can include: applying directly prescribed burning or applying a combined treatment including “mechanical thinning and clearing followed by slash burning”, according to the characteristics of the forest stand.

Figure 36. Effects of low-intensity fire on black pine regeneration. Fire recurrence cuts down the presence of shrubs and eases the selection of black pine regeneration. Photography: Catalan Fire Service.

Preserving mature forests, emulating natural low-intensity fire dynamics associated with ignition regimes caused by lightning strikes

There are few black pine structures that present tree dimension characteristics related to low-intensity, recurrent fires, with ancient mature trees (>200 years) and umbrella shaped crowns, where damage to the bark or cambium can be seen. These kinds of forests can become endangered when the surface and ladder fuel develop beyond a certain boundary that could generate a fire behaviour that is intense enough to kill adult trees (Figure 37).

The application of prescribed burning to these structures allows for a more controlled surface layer cover and height and to preserve the stand’s natural characteristics (Figure 38). Applying fire during the summer is recommended to bring the prescribed fire’s effects closer to the natural conditions of lightning strike fires, keeping in mind the phenology of the species, the incidence in the seed bank and favouring seeders over sprouting species.

Figure 37. Behaviour of intense fire under a mature black pine structure in Els Ports. The possibility of the crowns being affected and spreading along the canopy is increased due to the developed shrubs. Photography: Catalan Fire Service.

Figure 38. Prescribed burning in a mature black pine stand in Els Ports Natural Park with an average age above 180 years and signs of fire damage on the oldest trees of the plot. Photography: Catalan Fire Service.

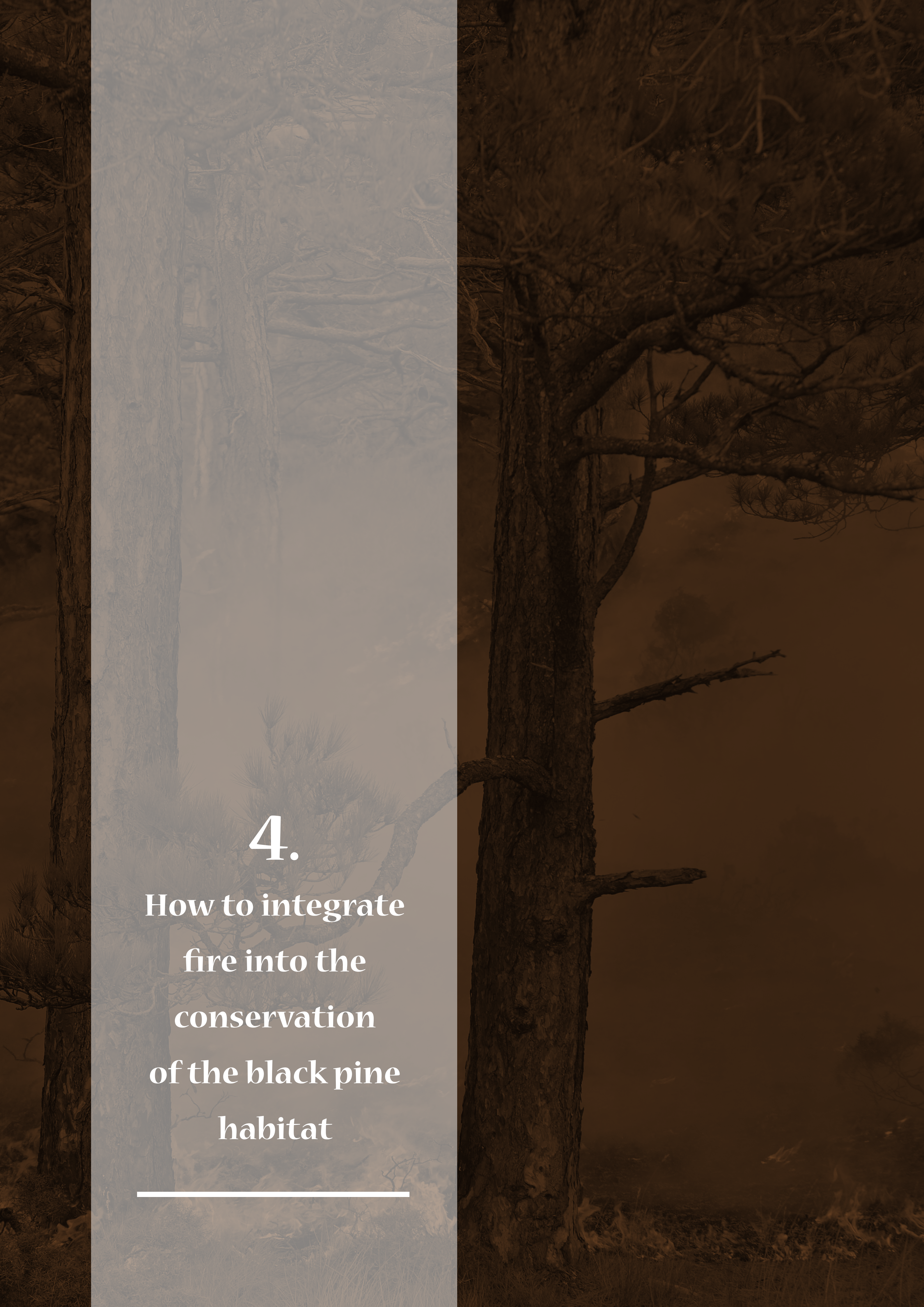
Free fire spread

The most used burning techniques to ensure the desired effects are those that guarantee a burning intensity below certain set levels. They are normally flank or back burning with little flame time to ensure the least penetration into the soil's organic layer. During this kind of burning, the aim is for it to **spread freely** most of the time, with fire-fighters only intervening in isolated cases or linearly to ensure that the fire spreads at the desired intensity. Fire spreading freely is essential to respect the diversity of its effects on the forest stand, since burning intervenes in all the processes in the ecosystem: seeds, regeneration, nutrients, carbon, water, etc. The future diversity of the forest stand will partially depend on the **diversity of these effects** (Miralles, 2016).

Burning season

The season during which the burning is performed also has an effect on the results. In Catalonia, after more than 20 years' experience of burning performed by the Catalan Fire Service, **a clear difference between those performed in winter and those performed in spring or autumn** has been observed. Basically, burning performed in winter favours the regeneration of shrubs, whereas those performed in autumn favour herb and pasture species, and those performed in spring are neutral or, in the case of being too intense, they affect the vigour of the trees. This observation coincides with the fact that burns that favour the natural dynamics of mature forests are those that occur during the season of natural lightning strikes (end of summer and beginning of autumn) (Miralles, 2016).

During spring burning, treated areas with heavy fuels can be burned more safely, soil damage is minimal because forest floor and duff materials are only partially dried, spotting is reduced because vegetation is more hydrated, post-burn mop-up is simpler and cheaper, and it is easier to retain coarse woody materials desired for ecological objectives. However, tree crowns are particularly vulnerable if a burn is conducted after growth has begun, because if they are affected, they are more likely to die than in autumn (Valor *et al.*, 2017). Autumn prescribed burning better approximates natural fire, because the understory vegetation has cured, so a larger proportion of the area is burned (Fiedler *et al.*, 2007). In spite of this, the moisture content of the dead leaves and humus must be checked so as to not affect the tree roots, especially when there is moss (Valor *et al.*, 2017). In comparison with winter burns, those performed in spring or autumn can be more complex logistically and require much control.



4.

How to integrate fire into the conservation of the black pine habitat

4. How to integrate fire into the conservation of the black pine habitat

4.1. Restoring natural processes typical of black pine forests and their evolution towards becoming mature forests

Restoring natural processes typical of black pine forests (such as the disturbance regime, nutrient cycle, food webs and hydrological function) and ecosystem services that depend on them (such as biodiversity, habitat for different species, pastures, wood production and leisure use) are key elements to achieve a mature forest structure and composition. Disturbances from fire within a variable regime with a recurrence period of between 10 and 30 years is one of the key processes that determines the forest's evolution towards advanced maturity stages.

Re-establishing natural processes must be done while respecting the **Natural diversity range** typical of the black pine, and applied to current forests it can be understood as a **restoration process**. As previously mentioned, the percentage of mature forests in Catalonia is low, but enough for them to be benchmarks for the effects of natural processes. The goal forest structure of restoring mature black pine forests is one that is diverse, with different layers, tall and large trees and the presence of regeneration in the form of groves. Ultimately, complex structures that promote the resilience of the ecosystem when faced with natural disturbances, especially fire, in the current context of global change.

At landscape level, a mature forest structure is achieved with an **organised integral management** where the **proportions of different kinds of ages** are maintained and **multifunctionality** is ensured through the proportional distribution of structures and successional moments.

Natural diversity range

Species in a forest ecosystem evolved under its characteristic disturbance regime, resulting in a natural range of variability or the range of ecological and evolutionary conditions appropriate to an ecosystem (Landres *et al.*, 1999).

The natural diversity range is a best estimate of a resilient and functioning ecosystem, because it reflects the evolutionary ecology of these forests and represents an ideal framework to restore the composition and structure of forests (Kaufmann *et al.*, 1994; Keane *et al.*, 2009). Nevertheless, this diversity must be framed within the uncertainty that future ecological conditions generate due to climate change (Choi *et al.*, 2008; Bolte *et al.*, 2009).

In any case, given the current situation of black pine forests, which have reduced their distribution area due to the effects of large forest fires and other climate change impacts, applying an **active forest management** that preserves the dynamics of natural processes or emulates its effects is more vital than ever to make black pine forests evolve towards maturity. Among the different management options available, the Sustainable Forest Management Guidelines of Catalonia (Orientacions de Gestió Forestal Sostenible de Catalunya, ORGEST) for black pine (Beltrán *et al.*, 2012) are a good reference, because:

- They integrate natural dynamics aspects of black pine forests and fire prevention, through CVFoC and the creation of fire-resistant structures that are less vulnerable to active crown fires.
- They include prescribed burning and the use of fire as silvicultural treatments.
- They present a wide variety of management options to account for forest production and large forest fires prevention, including management models of even and uneven-aged stands, mixed stands, etc. with different adaptations and rotations, together with a code for best forest practices.
- In addition, they suggest management models towards physical rotations beyond 250 years, which can work as a guideline to guide current forests towards maturity stages.

A landscape with mature forests will be less vulnerable to the effects of large forest fires and, therefore, to advance in forest maturity can become a good management option when the forest manager's main objective does not require regenerating the stand before the physical rotation. In this case, the challenge will be to account for forest management and large forest fires prevention following sustainable management models such as ORGEST, among others.

Therefore, active management is presented as one of the options to re-establish functional old-growth forests. Old-growth forests can probably maintain themselves for decades or centuries with thoughtful management but will probably not be permanent on a multi-century or millennial time scale. Therefore, **potential mature forest areas must be identified and treated now to develop replacements for existing**

areas over the longer term. Silvicultural cutting and prescribed burning in these areas should reduce fuels, recycle nutrients, preserve the grass seed bank, invigorate trees and understory plants, and regenerate a new age class of black pine. **Treating landscapes instead of stands** will further increase the functionality and ecological value of these areas over time and will increase their resiliency to disturbance and climatic change.

On the other hand, restoration, performed at any scale, cannot be accomplished without a **supporting infrastructure that includes specialised personnel and equipment and markets for the associated wood products** (Arno and Fiedler, 2005). The availability of skilled forest workers and appropriate equipment allows treatments to be implemented as designed, with minimal negative effects. The availability of markets for different types and sizes of trees reduces the amount of woody fuel that must be treated on site to reduce hazard, while provides incomes that can help compensate the treatment costs, allowing greater numbers of hectares to be treated, always under the premise of sustainability. Nonetheless, black pine mature forest restoration will not be possible if society is not adequately informed and forest management is not interpreted as a basic and necessary tool for forest conservation in the face of the global change challenge.

Guidelines for mature black pine forest restoration

1. **Set objectives**, both for functions (improvement of nutrient cycle, regeneration promotion, fire prevention, etc.) and for final structure (tree density, diameter, specific composition, spatial distribution, amount of dead wood, etc.).
2. **Prioritize treatment** according to the potential risk of loss of forest, but taking into account the ecological, biological, environmental, economic and social constraints.
3. **Identify the most adequate treatments or combination of treatments** (natural fire, prescribed fire, farming management or mechanical treatment) to meet management objectives.
4. **Implement the treatment.**
5. **Assess the effects of the treatment.**

Tools to integrate fire into the conservation of the black pine

1. **Interpret the Sustainable Forest Management Guidelines of Catalonia** (ORGEST) and introduce management with fire, into those steps where its low-intensity and pyrodiversity-enabling role is ensured.
2. **Prepare and plan prototype burning plans** so as to integrate them into sustainable forest management, where appropriate. Include them in the policy planning for the selected areas.
3. Introduce **Fire management as a fire service strategy within the framework of the planning**. Integrate natural fire into black pine habitat conservation with management plans that integrate risk, so that if the disturbance occurs, it is also a management tool. Transform a fire that becomes an emergency into a planned management tool.
4. **Generate monitoring indicators** of the effectiveness of treatments and fire management in the long term.

4.2. Integrating prescribed burning as a forest management tool

Integrating prescribed burning into forest management requires accepting fire as a natural element that can invigorate and transform the ecosystem, by adapting its effects to the desired objectives with forest management. This acceptance requires a paradigm shift of the common perception of fire's role in the ecosystem, which is based on a negative perception due to large uncontrolled forest fires, which damage people and goods, put agroforest activities at risk and threaten the preservation of ecosystem processes when intensity and recurrence surpass certain values. To value fire again as a natural element requires isolating it from the aforementioned factors and analysing it synthetically as a natural phenomenon. For this analysis, knowledge and information are needed, and research becomes one of the key elements.

The experience gained in Catalonia regarding fire application since 1999 to different kinds of forest structures, both open and dense stands, and in locations with different dominant species, has been accompanied by multiple research studies to determine the effects of fire in different areas: soil, succession, regeneration, growth of trees, vitality, bird or invertebrate species, among others.

Therefore, to integrate the use of prescribed burning in forest management and planning, more in-depth knowledge regarding the effects of fire and the ecology of species when faced with fire disturbance is needed, as well as developing a regulatory framework of burning use, writing and broadcasting technical recommendations regarding the use of burning to achieve certain objectives and performing specialised training programmes.

Regulatory framework of the use of fire

The main aim of the application of prescribed burning in the last 20 years has been the re-introduction of fire as a natural ecosystem management element, within a context where forest fire limiting policies had restricted the use of fire to marginal activities regulated by restrictive regulations.

Catalonia's current landscape is vulnerable to large forest fires due to the continuity of forests and high fuel loads. The application of prescribed burning implies a series of risks that, as with other activities performed in nature, must be diminished by taking adequate preventive measures in the current setting.

The knowledge acquired in the last years with regards to **fire risk prediction**, the **methodologies applied to the safe execution and guidance of burning** and the evolution of **meteorological predictions** help to **create a framework to regulate the use of prescribed burning** safely as a forestry tool.

A regulatory framework of fire use with objectives that are open to forest management and habitat conservation scales is still to be determined, and requires setting the groundwork in three main areas:

- **Legal framework for the use of fire as a management tool** based on the extensive application of prescribed burning, identifying the agents responsible and the authorisation and execution administrative procedures. The current legal framework with regards to prescribed burning is circumscribed to Order 21/06/1993 and subsequent modification of Order 17/06/2006 regarding prescribed burning in high mountain areas, that regulates burning activities performed by the Department of the Catalan government with power with regard to fire prevention, and by the Decree 312/2006 of 25 July that regulates technical fire management by the Catalan Fire Service. Therefore, it is a regulation limited to two collectives within the administration, which limits the widespread use of fire. It is important to note that the legal framework of the emergency plan for forest fires (INFOCAT), under Civil protection frame, includes as a strategy to attend forest fires three options: extinguishing the fire, managing the fire or containing the fire. This framework allows to implement management or containment if planned and accepted under emergency situations or prevention planning. This is the main and first step in restoring natural fire, and in Catalonia at least, it is completed.
- **Agent training and accreditation** (institutions and companies) for planning and executing prescribed burning. As with other activities related to forest management and planning, as well as the execution and direction of forestry works and treatments, it is necessary to set a framework that regulates the competences and responsibilities to plan, direct and execute prescribed burning. The Civil protection and emergency agency training center (ISCP) has developed the career plan and the standards of competences for training such capabilities. At the moment they are constrained to the officials in Fire Service. But all the platform is ready to implement. In fact, other nationalities had already used them, as United Kingdom, France and Portugal.
- Integrating **prescribed burning into the framework of forestry grants** for forest management. Extending the use of fire as a management tool requires easing its use, making it part of the forest managers tool box, with the same conditions to access grants as those granted by the administration with regards to forestry.

In countries like the United States or Australia, with years of experience using and managing fire, programmes are developed identifying the agents involved to bring together the different objectives and establish fire use planning, execution and verification procedures. Biological constraints with regards to the effects on the fauna (mainly during breeding season), ecological constraints with regards to the specific preservation of flora and fauna habitats (mainly specific vegetation formations) and environmental constraints, related to water contamination processes through ash, smoke management, stabilising steep valley-sides, etc. must be included in fire use programmes.

To ensure the viability of fire use programmes, **society must be duly informed and the knowledge must be offered**. These programmes will only work with the **tolerance and commitment** of society **to take on the risks needed that will guarantee the survival** of forests when faced with the challenges of climate change.

4.3. Natural fires and fire management

Fire is an integral treatment or a disturbance process to restore mature forests. The way this disturbance process is implemented depends largely on the management objectives. Natural fire (lightning) is only feasible currently during favourable meteorological conditions and in ordered and planned spaces, as long as it is transformed into management burning and the corresponding protocols are followed. Even in these environments, additional vigilance, monitoring and control of the effects is required until this practice is fully accepted by society. Natural fires are not frequently used to treat forests, and they are more likely in areas where the forest has achieved maturity (Fiedler *et al.*, 2007). In Catalonia specifically, this practice has been used during fires such as the one in Tivissa (2014) (*Pinus halepensis),* Cerbi (2016) (*Pinus uncinata, Abies alba* and *Betula* sp*.,* Figure 39) and sporadically during two lightning fires (2017) (*Pinus nigra* and *Quercus faginea)* in the mountain range of Ancosa-Montmell.

Figure 39. Managed forest fire in Cerbi (Pallars Sobirà) in 2016. Photography: Catalan Fire Service.

The implantation of fire management is currently incipient and experimental. In the case of Catalonia, it would be supported by:

1. Twenty years of burning programmes, which have allowed for an expert command of fire as a tool to manage forest structures and mosaics at landscape level.

2. Legal framework accepting management or containment such as INFOCAT (the emergency plan for forest fires in Catalonia) and Decree 312/2006 for the use of fire.

3. Research that has partially tested and validated the effects of fire on flora, fauna, soil and habitats in the short and long term.

4. Currently, the use of fire as a tool has extended throughout Europe and fire's role as a natural element is no longer discussed.

Any fire management programme, together with the burning programmes, must keep in mind two main aspects:

a) In all ecosystems a significant difference regarding the effects of fire when applied outside of the natural fire season was detected. That is, burning in winter for security allows for fuel management, but alters the specific composition of the habitat.

b) Overall fire problem continue to grow and suppression as the only alternative tool is not viable any more. Neither is prevention with punctual intervention. No burning programme has managed to introduce fire extensively and to slow the progression of fires towards high-intensities. Megafires in 2017, which affected different ecosystems throughout the globe, and specially in Portugal, has pointed out the need to implement fuel management extensively. This extensive management involves managing fires or preparing the implantation of programmes where fire, under a planned and monitored schedule, is allowed in the form of natural fire and not in the form of punctual prescribed burning.

To restore low and medium intensity fire regime, having learnt the aforementioned lessons, first fire management should be extended to landscape level, since the most traditional prevention allows fires to be avoided but cannot change the regime. Moreover, this management with fire should be performed during summer or at the end of summer, when fire occurs naturally, therefore avoiding the creation of new disturbances.

To achieve this objective, fire use programmes would have to evolve from the classic approach of introducing fire to manage structures, while controlling its behaviour parameters and its effects, towards a more daring vision to manage landscapes controlling the final extension of the fire concretely, but assuming a wider range of effects.

Fire management can be applied when a fire from a lightning strike is monitored in a specific structure and its effects are assessed as beneficial to preserve it. This kind of natural fire management is tackled following the same monitoring diagram as for a prescribed burning, with physical boundaries, a predetermined behaviour and pre-set effects, at stand level. The action impact does not take into account the scale of the potential "problematic" fire that can affect that landscape, and in general terms the improvement will be slight. In the current background of greater potential for Megafires, there is an increasing consensus about the importance of evolving towards fire management that has effects according to the scale of the potential "problematic" fire, raising to a strategic view of the time and spatial planification of risk-reducing actions. This implies defining clear final confinement boundaries, but letting the fire spread diversely, creating a natural but uncertain landscape for the forest manager. Control over the fire's effects and behaviour may not be as accurate or detailed as when the fire is managed with a vision of improvement of concrete structures.

Therefore, the new concepts of fire reintroduction allow the fire to model the landscape. This is a conceptual leap where decision making follows a logical pattern to determine the fire management framework based on four main elements (Figure 40):

- Geography
- Meteorology
- Forest scenography
- Vulnerable elements (goods and people)

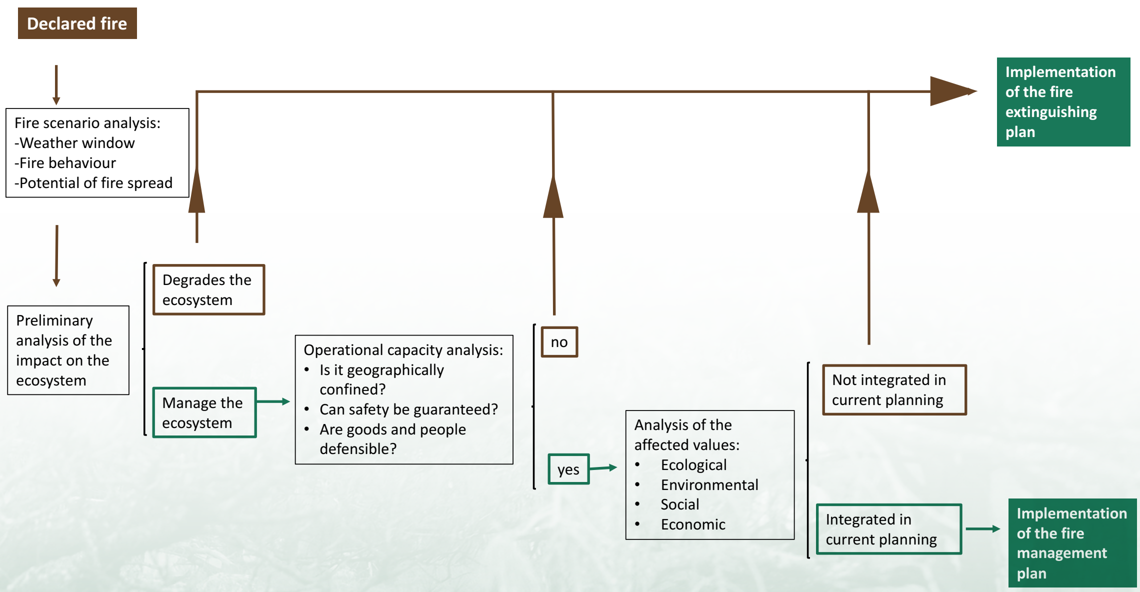


Figure 40. Example of factors to be considered for the implementation of a fire management plan in Catalonia.

Once the application of a fire management plan is assumed, it is necessary to determine a monitoring team that guarantees the following actions:

- Ability to monitor and re-evaluate the scene until the fire is extinguished.
- Ability to deploy the necessary manoeuvres and resources to ensure the pre-established confinement.
- Ability to maintain a permanent communication plan for the public with the update of relevant information until the extinction of the fire.
- Ability to monitor and analyse scientifically the effects of the fire to improve the evaluation of the fire impacts in the future.

The implementation of a fire management plan is complex and requires administrative structures, planning and previous agreements between the agents involved. Table 4 identifies, as an example, the most important components that configured the implementation of fire management, as well as the responsible agents and an assessment of the work capacity based on the current development situation.

Component	Agent responsible	Assessment of work capacity	Current development range
Fire scenario analysis (window, behaviour and potential)	Support structure of support of the Fire Service Command and Control Center	Structure of Firefighters permanently operated by fire monitoring	9/10
Preliminary analysis of the impact on the ecosystem	Components of the INFOCAT Forest Fires Evaluation Group	Current structure existing but without established work procedures. Unstructured current response.	4/10
Operational capacity analysis	Support structure of support of the Fire Service Command and Control Center	Fire service analysis structure with a proven methodology to set confining limits for scenarios of less 1000 ha or periods of 3 to 7 days. Short-term experience (3 days in Tivissa 2014 and 7 in Cerbi 2016)	8/10
Analysis of affected values	Components of the INFOCAT Forest Fires Evaluation Group	Current structure existing but without established work procedures. Unstructured current response.	3/10
Evaluation of current integration planning	Administrations with competence in forest management and territorial planning. Forest property	Current planning does not contemplate this type of scenario and is disaggregated in different figures with varying objectives. It would be necessary to bring together the figures of planning and consensus among the responsible agents.	2/10
Operational tasks of the fire management plan	Components of the INFOCAT Forest Fires Evaluation Group	Equipment ready to carry out the task. The sizing of them can condition the limits of confinement. The need for resources in other fires can condition the length of confinement.	7/10
Follow-up plan for the effects and evaluation of the impact of the fire	Research centres and universities	Expanded experience in the subject. Limited or unfunded resources at this point.	5/10
Public communication plan	All	Need to set a clear communication strategy to change the message that the fire is always bad. In the cases that have been done, the press has responded correctly, but with improvisation.	2/10

Table 4. Example of factors to be considered for the implementation of a fire management plan in Catalonia.

5.

Bibliography

5. Bibliography

- Agee, J. K. (1993) *Fire ecology of Pacific Northwest forests*. Island Press.
- Agee, J. K. (1996) "The influence of forest structure on fire behavior," *Proceedings of the 17th Annual Forest Vegetation Management Conference, January 16−18*. Redding, USA, p. 52−68.
- Agee, J. K. and Skinner, C. N. (2005) "Basic principles of forest fuel reduction treatments," *Forest Ecology and Management*, 211(1–2), pp. 83–96. doi: 10.1016/j.foreco.2005.01.034.
- Alcañiz, M., Outeiro, L., Francos, M., Farguell, J. and Úbeda, X. (2016) "Long-term dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgrí Massif, Catalonia, Spain)," *Science of The Total Environment*, 572, pp. 1329–1335. doi: 10.1016/J.SCITOTENV.2016.01.115.
- Anderson, H. E. (1982) *Aids to determining fuel models for estimating fire behaviour. General Technical Report INT-122.* USDA Forest Service. Ogden, USA: USDA Forest Service.
- Arno, S. F. and Fiedler, C. E. (2005) *Mimicking nature's fire: restoring fire-prone forests in the West.* Washington, USA: Island Press.
- Beltrán, M., Vericat, P., Piqué, M. and Cervera, T. (2012) *Models de gestió per als boscos de pinassa (Pinus nigra Arn.): producció de fusta i prevenció d'incendis forestals. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST).* Centre de la Propietat Forestal. Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural. Generalitat de Catalunya, Barcelona. 152 p.
- Binkley, D., Sisk, T., Chambers, C., Springer, J. and Block, W. (2007) "The role of old-growth forests in frequent-fire landscapes," *Ecology and Society*, 12(2), p. 18.
- Bolte, A., Ammer, C., Löf, M., Madsen, P., Nabuurs, G. J., Schall, P., Spathelf, P. and Rock, J. (2009) "Adaptive forest management in central Europe: Climate change impacts, strategies and integrative concept," *Scandinavian Journal of Forest Research*. Taylor & Francis Group, 24(6), pp. 473–482. doi: 10.1080/02827580903418224.
- Brotons, L., Pons, P. and Herrando, S. (2005) "Colonization of dynamic Mediterranean landscapes: where do birds come from after fire?," *Journal of Biogeography*, 32, pp. 789–798. doi: 10.1111/j.1365-2699.2004.01195.x.
- Brown, R. T., Agee, J. K. and Franklin, J. F. (2004) "Forest Restoration and Fire: Principles in the Context of Place," *Conservation Biology*, 18(4), pp. 903–912. doi: 10.1111/j.1523-1739.2004.521_1.x.
- Camprodon, J., Guixé, D. and Sazatornil, V. (2018) *Manual de caracterització i conservació dels boscos singulars de pinassa. Life+ PINASSA.* Centre de la Propietat Forestal i Centre Tecnològic Forestal de Catalunya.
- Carrera, M. (2012) *Calendari de les festes amb foc*. Els llibres de festes.org. Botarga produccions.
- Casals, V., Pardo, F., Xalabarder, M., Postigo, J. M. and Gil, L. (2005) *La transformación histórica del paisaje forestal en Cataluña*. Ministerio de Medio Ambiente, Madrid.
- Choi, Y. D., Temperton, V. M., Allen, E. B., Grootjans, A. P., Halassy, M., Hobbs, R. J., Naeth, M. A., Torok, K. and Martínez, M. L. (2008) "Ecological restoration for future sustainability in a changing environment" *Écoscience*, 15(1), pp. 53–64. doi: 10.2980/1195-6860(2008)15[53:erffsi]2.0.co;2.
- Critchfield, W. B. and Little, E. L. (1966) *Geographic distribution of the pines of the world.* Forest Service, U.S. Department of Agriculture, Washington, D.C.
- Cunill, R., Soriano, J.-M., Bal, M.-C., Pèlachs, A. and Pérez-Obiol, R. (2012) "Holocene treeline changes on the south slope of the Pyrenees: a pedoanthracological analysis," *Vegetation History and Archaeobotany*. Springer-Verlag, 21(4–5), pp. 373–384. doi: 10.1007/s00334-011-0342-y.
- DGDRPF (2016) *Mapa Forestal de España. Escala 1:25.000. Catalunya*. Dirección General de Desarrollo Rural y Política Forestal. Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid.
- EUROPARC-España (2017) *El papel de los bosques maduros en la conservación de la biodiversidad*. Fundación Fernando González Bernaldez, Madrid.
- Fiedler, C. E., Friederici, P., Petruncio, M., Denton, C. and Hacker, W. D. (2007) "Managing for old growth in frequent-fire landscapes," *Ecology and Society*, 12(2), p. 20.

- Fulé, P. Z., Waltz, E. M., Covington, W. W. and Heinlein, T. A. (2001) "Measuring forest restoration effectiveness in reducing hazardous fuels," *Journal of Forestry*, 99(11), pp. 24–29. doi: 10.1093/jof/99.11.24.

- Gilg, O. (2005) *Old-Growth Forests: characteristics, conservation and monitoring*, *L'Atelier technique des espaces naturels & Réserves Naturelles de France*.

- Graham, R. T., McCaffrey, S. and Jain, T. B. (2004) *Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity. General Technical Report RMRS-GTR-120*. USDA Forest Service. Fort Collins, USA.

- Granier, A., Reichstein, M., Bréda, N., Janssens, I. A., Falge, E., Ciais, P., Grünwald, T., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Facini, O., Grassi, G., Heinesch, B., Ilvesniemi, H., Keronen, P., Knohl, A., Köstner, B., Lagergren, F., Lindroth, A., Longdoz, B., Loustau, D., Mateus, J., Montagnani, L., Nys, C., Moors, E., Papale, D., Peiffer, M., Pilegaard, K., Pita, G., Pumpanen, J., Rambal, S., Rebmann, C., Rodrigues, A., Seufert, G., Tenhunen, J., Vesala, T. and Wang, Q. (2007) "Evidence for soil water control on carbon and water dynamics in European forests during the extremely dry year: 2003," *Agricultural and Forest Meteorology*, 143(1–2), pp. 123–145. doi: 10.1016/j.agrformet.2006.12.004.

- Hiers, J. K., O'Brien, J. J., Mitchell, R. J., Grego, J. M. and Loudermilk, E. L. (2009) "The wildland fuel cell concept: an approach to characterize fine-scale variation in fuels and fire in frequently burned longleaf pine forests," *International Journal of Wildland Fire*. CSIRO PUBLISHING, 18(3), pp. 315–325. doi: 10.1071/WF08084.

- Hódar, J. A., Zamora, R. and Peñuelas, J. (2004) "El efecto del cambio global en las interacciones planta-animal," *Ecología del bosque mediterráneo en un mundo cambiante*. Edited by F. Valladares. Madrid: EGRAFSA., Ministerio de Medio Ambiente, pp. 461–478.

- Johnson, M., Peterson, D. and Raymond, C. (2007) *Guide to fuel treatments in dry forests of the Western United States: assessing forest structure and fire hazard. General Technical Report PNW-686*. USDA Forest Service. Portland, USA.

- Kaufmann, M. R., Graham, R. T., Boyce, D. A., J., Moir, W. H., Perry, L., Reynolds, R. T., Bassett, R. L., Mehlhop, P., Edminster, C. B., Block, W. M. and Corn, P. S. (1994) *An ecological basis for ecosystem management. General Technical Report RM-GTR-246.* USDA Forest Service. Fort Collins, USA.

- Kaufmann, M. R., Moir, W. H. and Covington, W. W. (1992) "Oldgrowth forests: what do we know about their ecology and management in the Southwest and Rocky Mountain Regions?," *Old-Growth Forest in the Southwest and Rocky Mountain Regions. General Technical Report RM-213.* Edited by M. R. Kaufmann, W. H. Moir, and R. L. Basset. USDA Forest Service. Portal, USA, pp. 1–11.

- Keane, R. E., Hessburg, P. F., Landres, P. B. and Swanson, F. J. (2009) "The use of historical range and variability (HRV) in landscape management," *Forest Ecology and Management*, pp. 1025–1037. doi: 10.1016/j.foreco.2009.05.035.

- Kelly, L. T. and Brotons, L. (2017) "Using fire to promote biodiversity.," *Science*. American Association for the Advancement of Science, 355(6331), pp. 1264–1265. doi: 10.1126/science.aam7672.

- Landres, P. B., Morgan, P. and Swanson, F. J. (1999) "Overview of the use of natural variability concepts managing ecologycal systems," *Ecological Applications*. Wiley-Blackwell, 9(4), pp. 1179–1188. doi: 10.1890/1051-0761(1999)009[1179:OOTUON]2.0.CO;2.

- Larson, A. J. and Churchill, D. (2012) "Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments," *Forest Ecology and Management*, pp. 74–92. doi: 10.1016/j.foreco.2011.11.038.

- Lázaro, A. and Montiel, C. (2010) "Overview of prescribed burning policies and practices in Europe and other countries.," *Towards Integrated Fire Management-Outcomes of the European Project Fire Paradox*. European Forest Institut Research Report 23, pp. 137–150.

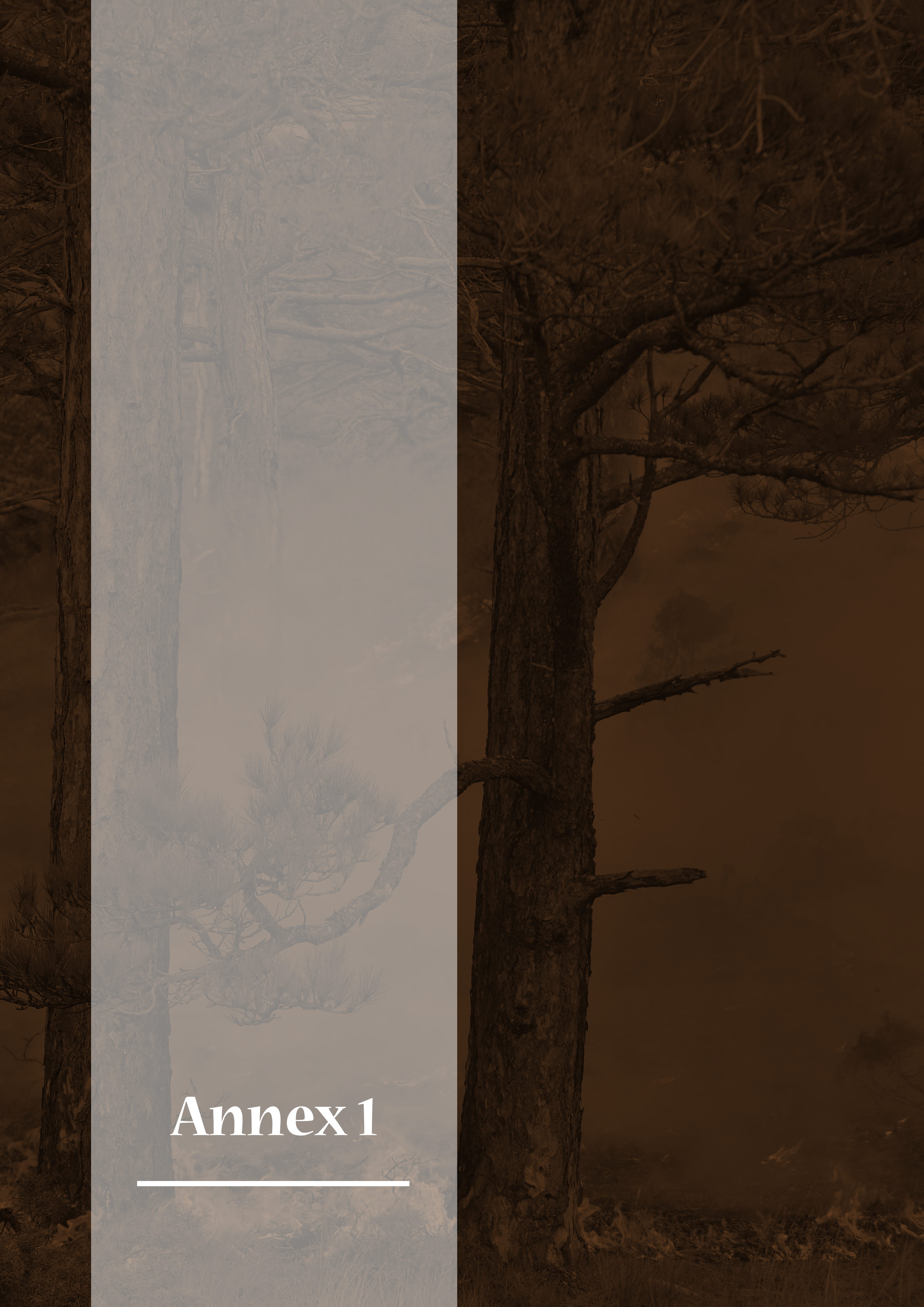
- Loustau, D., Bosc, A., Colin, A., Davi, H., François, C., Dufrêne, E., Déqué, M., Cloppet, E., Arrouays, D., Le Bas, C., Saby, N., Pignard, G., Hamza, N., Granier, A., Breda, N., Ciais, P., Viovy, N., Ogée, J. and Delage, J. (2005) "Modelling the climate change effects on the potential production of French plains forests at the sub regional level.," *Tree Physiology*, 25(7), pp. 813–823.

- van Mantgem, P. and Schwartz, M. (2003) "Bark heat resistance of small trees in Californian mixed conifer forests: testing some model assumptions," *Forest Ecology and Management*, 178(3), pp. 341–352. doi: 10.1016/S0378-1127(02)00554-6.

- Martin, R. E. and Sapsis, D. B. (1991) "Fires as agents of biodiversity: pyrodiversity promotes biodiversity," *Biodiversity of Northwestern California.* Edited by J. LeBlance. Santa Rosa ,USA, pp. 150–157.

- Miralles, M. (2016) “Las quemas prescritas como herramienta forestal sostenible,” *Seminario Cambio climático y global, incendios y uso del fuego en ecosistemas Mediterráneos.* Almeria, Espanya.
- Mitchell, S. R., Harmon, M. E. and O’Connell, K. E. B. (2009) “Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems.,” *Ecological applications*, 19(3), pp. 643–655.
- Pausas, J. G. and Keeley, J. E. (2009) “A Burning Story: The Role of Fire in the History of Life,” *BioScience*. Oxford University Press, 59(7), pp. 593–601. doi: 10.1525/bio.2009.59.7.10.
- Pellisa, O. (2003) *Ecologia del foc del Pinus Nigra Arn. a la Serra de Cardó. Treball pràctic tutorat, Enginyeria Forestal*. Universitat de Lleida.
- Peñuelas, J. and Boada, M. (2003) “A global change-induced biome shift in the Montseny mountains (NE Spain),” *Global Change Biology*, 9(2), pp. 131–140. doi: 10.1046/j.1365-2486.2003.00566.x.
- Piqué, M., Castellnou, M., Valor, T., Pagés, J., Larrañaga, A., Miralles, M. and Cervera, T. (2011) *Integració del risc de grans incendis forestals (GIF) en la gestió forestal: Incendis tipus i vulnerabilitat de les estructures forestals al foc de capçades. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST).* Centre de la Propietat Forestal. Departament d’Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural. Generalitat de Catalunya, Barcelona.
- Piqué, M. and Domènech, R. (2018) “Effectiveness of mechanical thinning and prescribed burning on fire behavior in Pinus nigra forests in NE Spain,” *Science of the Total Environment*. Elsevier B.V., 618, pp. 1539–1546. doi: 10.1016/j.scitotenv.2017.09.316.
- Piqué, M., Vericat, P., Cervera, T., Baiges, T. and Farriol, R. (2014) *Tipologies forestals arbrades. Sèrie: Orientacions de gestió forestal sostenible per a Catalunya (ORGEST).* Centre de la Propietat Forestal. Departament d’Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural. Generalitat de Catalunya, Barcelona.
- Plana, E. (ed.) (2004) *Incendis forestals, dimensió socioambiental, gestió del risc i ecologia del foc.* Xarxa ALINFO XCT2001-00061, Solsona.
- Pons, P., Lambert, B. and Rigolot, E. (2003) “The effects of grassland management using fire on habitat occupancy and conservation of birds in a mosaic landscape,” *Biodiversity and Conservation*, 12, pp. 1843–1860.
- Reynolds, R. T., Meador Sánchez, A. J., Youtz, J. A., Nicolet, T., Matonis, M. S., Jackson, P. L., DeLorenzo, D. G. and Graves, A. D. (2013) *Restoring composition and structure in southwestern firequent-fire forests: A science-based framework for improving ecosystem resiliency. General Technical Report RMRS-GTR-310*. USDA Forest Service. Fort Collins, USA.
- Rothermel, R. C. (1983) *How to predict the spread and intensity of forest and range fires. General Technical Report INT-143*. USDA Forest Service. Ogden, USA
- Scott, J. H. and Burgan, R. E. (2005) *Standard fire behavior fuel models: a comprehensive set for use with Rothermel’s surface fire spread model. General Technical Report RMRS-GTR-153.* USDA Forest Service. Fort Collins, USA.
- Scott, J. H. and Reinhardt, E. D. (2007) “Effects of alternative treatments on canopy fuel characteristics in five conifer stands.,” *Restoring fire-adapted ecosystems: proceedings of the 2005 national silviculture workshop. General Technical Report PSW-GTR-203.* Edited by R. F. Powers. USDA Forest Service. Albany, USA, pp. 193–209.
- Tapias, R., Climent, J., Pardos, J. A. and Gil, L. (2004) “Life Histories of Mediterranean Pines Life histories of Mediterranean pines,” *Plant Ecology*, 171(1), pp. 53–68.
- Taylor, D. L. (1971) “Biotic succession of lodgepole pine forests of fire origin in Yellowstone National Park.,” *National Geographic Research Reports*, 12, pp. 693–702.
- Taylor, D. L. (1973) “Some ecological implications of forest fire control in Yellowstone National Park, Wyoming.,” *Ecology*, 54, pp. 1394–1396.
- Terradas, J. (ed.) (1996) *Ecologia del foc*. Edicions Proa, Barcelona.
- Tingley, M., Ruiz-Gutiérrez, V., Wilkerson, R., Howell, C. and Siegel, R. (2016) “Pyrodiversity promotes avian diversity over the decade following forest fire,” *Proceedings of the Royal Society B*, 283(1840), p. 9.
- Tíscar, P. A. and Linares, J. C. (2014) “Large-Scale Regeneration Patterns of Pinus nigra Subsp. salzmannii: Poor Evidence of Increasing Facilitation Across a Drought Gradient,” *Forests*, 5, pp. 1–20. doi: 10.3390/f5010001.

- Tíscar, P. A. and Lucas-Borja, M. E. (2010) "Seed mass variation, germination time and seedling performance in a population of Pinus nigra subsp. salzamannii," *Forest Systems*, 19(3), pp. 344–353. doi: 10.5424/fs/2010193-9094.
- Valor, T., González-Olabarria, J. R., Piqué, M. and Casals, P. (2017) "The effects of burning season and severity on the mortality over time of Pinus nigra spp. salzmannii (Dunal) Franco and P. sylvestris L.," *Forest Ecology and Management*, 406, pp. 172–183. doi: 10.1016/j.foreco.2017.08.027.
- Vigo, J., Carreras, J. and Ferré, A. (eds.) (2005) *Manual dels hàbitats de Catalunya.* Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona.
- Wagner, C. E. Van (1977) "Conditions for the start and spread of crown fire," *Canadian Journal of Forest Research*. NRC Research Press Ottawa, Canada , 7(1), pp. 23–34. doi: 10.1139/x77-004.
- Wirth, C., Messier, C., Bergeron, Y., Frank, D. and Fankhänel, A. (2009) "Old-Growth Forest Definitions: a Pragmatic View," *Old-Growth Forests*. Edited by C. Wirth, M. Heimann, and G. Gleixner. Berlin: Springer Verlag, pp. 11–33.
- Zimmermann, S. (2003) "Closing Comments: Fire, Fuel Treatments, and Ecological Restoration—Proper Place, Appropriate Time," *Fire, fuel treatments, and ecological restoration. Proceedings RMRS-P-29*. Edited by P. N. Omi and L. A. Joyce. USDA Forest Service. Fort Collins, USA, pp. 435–442.



Annex 1

Annex 1

Data sheets with applied examples

PRESCRIBED BURNING IN AN UNEVEN-AGED BLACK PINE FOREST

Location

Municipality: Llobera (Solsonès)	SAC: ES5130027 Shady areas of the Madrona stream	Surface area: 9.9 ha

Burning date: May 2016

Objectives: Understory clearing and low thinning. To eliminate the shrub and regenerate the grasses to reduce the fuel load, break the vertical continuity of the vegetation layers to reduce the risk of crown fires (plot located in a strategic management area with regards to extinguishing forest fires) and to regulate the competition for resources and improve tree vitality.

Main objectives

- To prevent forest fires
- Silvicultural (improve the forest's growth and vitality)
- Training and transfer

Specific objectives

- To reduce fuel load
- To rejuvenate grasses
- To eliminate slash on the ground
- To eliminate dominated and supressed trees

Characteristics of action area

Uneven-aged black pine structure with variable cover, in general, and underlayer of patches of oak and holm-oak, and an understory varying in density, but with a clear trend towards becoming denser. Understory made up of grasses, dead leaves, *Genista*, box, kermes oak, sprouting oak and holm-oak. The area's slope would make passive crown fire spread more easily.

Stand tree dimension characteristics

Site quality	Cover	Tree density (>7.5 cm)	Average diameter	Basal area	Average height	Volume with bark	Age	TVFoC[1]
	%	trees/ha	cm	m^2/ha	m	m^3/ha	years	
Medium	89	1,341	15.9	2.9	9.1	135	60-80	A1

[1] Crown Fire Vulnerability Typologies (TVFoC): Type A structures are more vulnerable to generating crown fires, type B are averagely vulnerable, and type C, the least vulnerable.

Stand understory characteristics

Main shrub species	Shrub cover	Average shrub height	Non-shrub cover		
			Grasses	Moss	Dead downed wood
	%	cm	%	%	%
Buxus sempervirens	72	117	10	6	12

Description of action performed

Prior work

- Preparation of stand. Control lines are created to limit both flanks and the top of the plot with a total of around 950 m. The bottom of the plot shares a border with a tertiary forest path.

- Communication with population. Notifications to affected town halls and press.

Burning execution

Meteorology
Average temperature: 19.5°C
Average relative humidity: 44.9%
Average wind speed: 2.8 km/h

Burning execution parameters
Height of flame: <1.5 m, Mortality: 0%
Max-min leaf scorch height: 0.79-0.37 m
Height of first live branch: 4.35 m

Results

Stand tree dimension characteristics 2 years after treatment

Site quality	Cover	Tree density (>7.5 cm)	Average diameter	Basal area	Average height	Volume with bark	Age	TVFoC
	%	trees/ha	cm	m^2/ha	m	m^3/ha	years	
Medium	78	1,178	16.6	25.4	9.8	136	60-80	C10/B7

Stand understory characteristics 2 years after treatment

Main shrub species	Shrub cover	Average shrub height	Non-shrub cover		
			Grasses	Moss	Dead downed wood
	%	cm	%	%	%
Quercus coccifera	14	34	28	2	19

Burning assessment

The effect of the set of burning days has been varied depending on the meteorological window during which fire was applied. In almost half of the surface area, the vulnerability to crown fires has been reduced from very high to low (from structure type A to C) and in the other half, from very high to mild (from A to B). The plot's diversity and the meteorological variety of the burning days have been key factors to explain the variety of effects and have allowed us to reach conclusions regarding how and when to apply fire to this kind of forest structure.

Photos before burning and 11 months after

a)

b)

Performance estimation of burning execution

For burning performed in these kinds of structures and with the aim to emulate clearing of undergrowth and affecting the dominant tree layer the least possible, teams of around 15 – 20 operators per day are employed, with performances of between 1.5 to 4 ha/day. This data reports performances of time dedicated per hectare worked that oscillate between 50 – 110 hours/ha. The performance variation is largely due to the plot's own elements such as:

- Shape of plot to be burnt; this kind of understory burning is performed following a descending direction down the slope with progression rates of 7 to 10 meters per hour, plots with less than 100 linear meters wide require burning days that will hardly surpass 1 ha.
- The characteristics of the plot boundaries condition the size of the control team. In this sense, burning anchors in narrow paths or small fuel discontinuities require stronger control teams than when it can be anchored in fields, wider paths or established natural boundaries. In many cases the boundaries of the burning can lean on previously burnt areas, which simplifies the control tasks and reduces the burn teams.
- Working burning hours per day are also a significant constraint of burn team performances. When fuel availability is conditioned by solar radiation, such as shady areas or flat areas with fog in winter, working burning hours are few from November to January, greatly reducing burn team performance. In contrast, during periods of high fuel availability, it has to be assessed whether the interval of hours within the behaviour window is enough to justify the deployment of resources to perform the burning.

Lessons learnt/recommendations

When using direct fire to treat this kind of structures, which are complex with regards to fuel accumulation and vertical continuity between vegetation layers, it is complicated to reduce the vulnerability to crown fires generally in the whole stand (evolution from A type structures to C type structures) in a single intervention. Diversity within the stand makes finding a burning window where the effects will be uniform difficult, especially when care must be taken to not affect the dominant trees.

In structures made up of abundant ladder fuel and continuity between vegetation layers, selective clearing of undergrowth that only affects vegetation that is difficult to burn or that could jeopardise the vitality of the tree layer can be suggested.

Contrary to what it may seem at first glance, the most stable burning windows with an availability that is more in tune with the desired effects in this kind of structure, will be found in advanced spring and summer, preferably at night.

Prediction of expected evolution

The main effect of burning is the changes that it applies to live fuels that make up the surface and ladder layers, composed mainly of grasses, shrubs and pine and oak sprouts.

The decrease of ladder fuel cover below 25% guarantees C type structures (less vulnerable to crown fires), taking into account the distance between the surface layer and the crowns is >4 m. The dead shrubs and burnt leaves can mean an increase in dead fuel from 1 to 100 hours transitionally, but that in absolute terms is compensated by consumption in this range of dead fuels, as the effect of the fire that has burnt the surface fuel.

In those areas where ladder fuel has not been reduced to a cover of 25%, the resulting structure will be type B (mildly vulnerable) and its evolution towards a type A structure will depend on the cover of surface fuel.

The natural entry of herbivores or subsequent pasture is considered a good practice to maintain and consolidate less vulnerable structures. The pasture effect consists of inhibiting the proliferation of surface fuel and the shrubs towards becoming ladder fuel.

PRESCRIBED BURNING IN A MATURE BLACK PINE FOREST

Location

Municipality: Margalef and Cabacés (Priorat)	SAC: ES5140017 Serra de Montsant-Pas de l'Ase	Surface area: 3.2 ha

Burning date: September 2015

Objectives: Burning to emulate the natural action of lightning strike fires in this area to maintain fire-resistant black pine structures. Eliminate shrubs and grass regeneration to reduce the fuel load and improve fuel vertical and horizontal continuity.

Main objectives:	Specific objectives:
- To prevent forest fires	- To reduce fuel load
- Training and transfer	- To rejuvenate grasses

Characteristics of action area

Adult black pine stand with signs of fire scares. In general, this structure occupies a space along the main crest line alternating open shrub and grass areas with isolated individual trees or small groves. Very recurrent lightning strike area where different density shrub patches can be observed due to the effects of lightning strike fires . Black pine regeneration is distributed in patches of 0.5 to 1.5 m high with understory consisting of grasses, rosemary, *Genista*, common juniper and rock rose, with a variable cover of between 20 to 75%. In 1982 there was a forest fire that affected the whole stand.

Stand tree dimension characteristics

Site quality	Cover	Tree density (7.5 cm)	Average diameter	Basal area	Average height	Volume with bark	Age	TVFoC[1]
	%	trees/ha	cm	m^2/ha	m	m^3/ha	years	
Low	60	565	22.3	22.0	9.1	103	80-100	B8

[1] TVFoC: Type A structures are more vulnerable to generating crown fires and type B are averagely vulnerable.

Stand understory characteristics

Main shrub species	Shrub cover	Average shrub height	Non-shrub cover		
			Grasses	Moss	Dead downed wood
	%	cm	%	%	%
Rosmarinus officinalis	37	105	59	14	52

Description of action performed:

Prior work:

- Preparation of stand. A total of 1000 m of control lines are made and clearing of undergrowth around the perimeter of selected regenerated black pine trees that could suffer irreversible damage that puts their vitality at risk.
- Communication with population. Notifications to affected town halls and press.

Burning execution:

Meteorology	*Burning execution parameters*
Average temperature: 15.3°C	Height of flame: <2 m, Mortality: 0%
Average relative humidity: 57.33%	Max-min leaf scorch height: below 1.5 m
Average wind speed: 6.9 km/h	Height of first live branch: 4.5 m

Results

Stand tree dimension characteristics 2 years after treatment

Site quality	Cover	Tree density (7.5 cm)	Average diameter	Basal area	Average height	Volume with bark	Age	TVFoC[1]
	%	peus/ha	cm	m^2/ha	m	m^3/ha	years	
Low	55	552	22.4	21.7	9.3	104	80-100	C9/C10

Stand understory characteristics 2 years after treatment

Main shrub species	Shrub cover	Average shrub height	Non-shrub cover		
			Grasses	Moss	Dead downed wood
	%	cm	%	%	%
Rosmarinus officinalis	12	30	44	9	28

Burning assessment

The goals have been achieved in a large percentage of the treated plot, eliminating the vegetation layer that could jeopardise the vitality of the adult black pine crowns in the case of a potential fire. In more open areas where the implantation of black pine sprouts of < 3 m, the percentage of vital trees after the burn will be sufficient and a notable increase of the likelihood of survival in the case of a potential fire is observed.

Photos before, during burning and 11 months after

a)

b)

Performance estimation of burning execution

In the case of Catalonia, adult black pine structure burns are mostly located in areas which are difficult to access with vehicles, which makes the deployment of burn teams more difficult and therefore conditions costs and performances. The plot preparation work and standby crew after the burning are more complex because they involve more hours only dedicated to accessing the plot. The deployment requires more careful planning, involves transporting the materials during the days before to the burn and collecting them afterwards on subsequent days to make the most of the windows.

In this case, 50 hours were dedicated to the execution of burning 3.2 ha and 60 hours more to preparation and standby, which gives an idea of the effort distribution percentages typical of these kinds of plots with difficult access routes.

Lessons learnt/recommendations

This kind of burning requires considerable commitment, both from the point of view of the safety of the burning and of the value of the treated habitat. The difficulty of access involves a different control team to that usually used in accessible burning, which is generally made up of fire engine and 25 mm hose installation resources. The remote control of plots must be carried out based on manual tool teams. Therefore, the team responsible must predict very stable scenarios and a comprehensive ignition pattern direction to minimise the possibility of fire behaviour changes.

The choice of burning window is more restricted than in other scenarios to ensure a certain fire behaviour and in accordance with the desired goals, and the control of effects on the habitat requires a superior degree of precision since it involves mature stands with feet that can be older than 200 years of age.

In contrast, guiding the burning and the ignition pattern can be simpler than in younger multi-layered structures due to them being forests with little ladder fuel and a surface cover generally below 50%.

Nevertheless, special attention must be paid to the standby phases which can go on for days if the conditions of organic matter thickness availability is high, as is the case of conditions at the end of summer when it is usual to accumulate high drought values that make the subsoil burn slowly more easily.

Prediction of expected evolution

Eliminating ladder fuel and reducing the surface fuel will have a positive effect to preserve the vitality of adult black pine in the case of a potential fire. Ladder fuel cover will be kept under 25% for a few years in this location, because the shrub species that make up the understory need time to exceed 130 cm in height.

The presence of new grass could also attract natural herbivores to the area and ease the maintenance of a surface layer with small shrub loads.

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