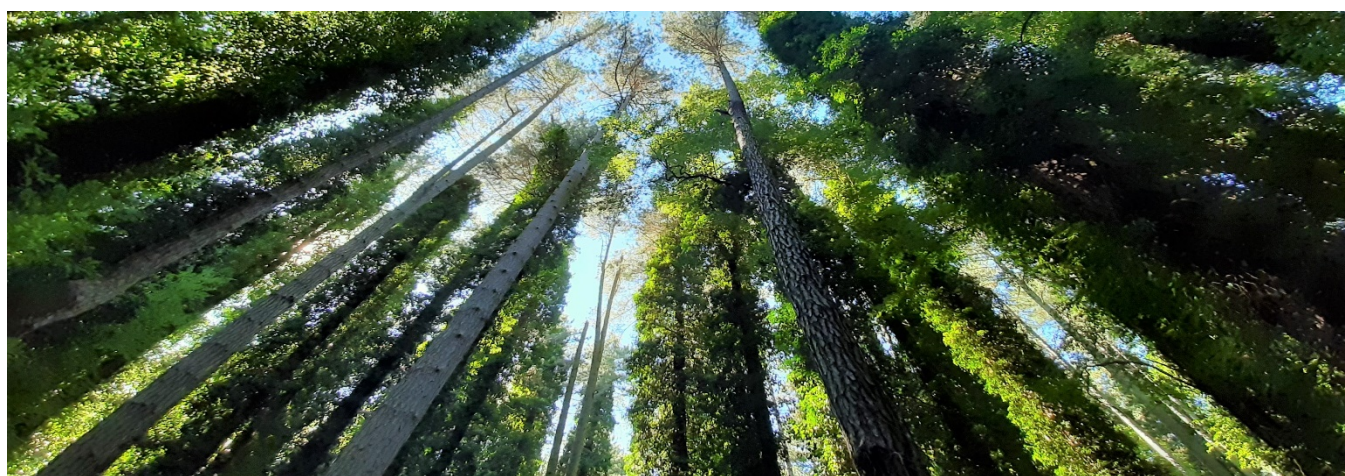


Primary and old-growth forests are more resilient to natural disturbances – Perspective on wildfires



HIGHLIGHTS

- In Europe, primary and old-growth forests are rare, small, and fragmented, representing less than 3% of the total forest area. However, they are critical for biodiversity and ecosystem services, including among others climate regulation and habitat for imperilled species.
- These forests are relatively rare in the Mediterranean region, which is a hotspot area for wildfires.
- Primary and old-growth forests are typically more resilient to disturbances than mono-specific or heavily modified forests.
- Primary and old-growth forests are likely to be less, not more, prone to fire hazard than human-modified forests due to their structural complexity, natural species composition, strong micro-climate effect, and the high moisture content of the decaying coarse wood debris.
- High amounts of fine woody debris are associated with increased probability of fire ignition and spread under fire-prone weather conditions, but are equally or even more present in harvested than in primary and old-growth forests.

This briefing describes the characteristics of primary and old-growth forests and evaluates their resilience to natural disturbances, in particular wildfires. Likewise, the role of primary and old-growth forests on wildfire risk is analysed with a view on the EU's policy aim of strictly protecting these

forests as called for in the EU's Biodiversity [1] and Forest [2] Strategies to 2030.

While this brief presents a general overview of the resilience of primary and old-growth forests, one should consider the variety

of forest types and forest ecosystems across Europe, where forests are distributed across 11 biogeographical regions [3], 14 forest categories, and 76 forest types [4]. Despite the fact that primary and old-growth forests are unevenly distributed in Europe, they occur across different forest types, and these forest types may have different degrees of resilience to disturbances.

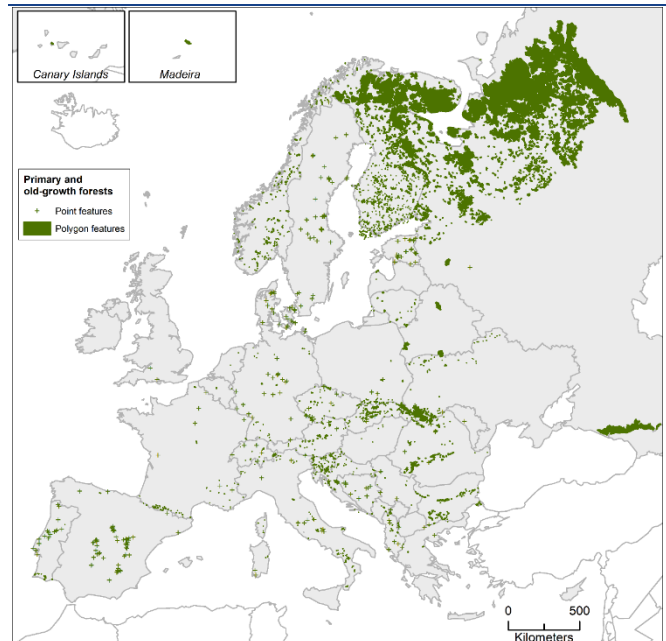
PRIMARY AND OLD-GROWTH FORESTS IN EUROPE

The majority of Europe was covered by natural forests in the pre-agricultural era. The advent of agricultural societies marked the beginning of a period of severe forest use and degradation across the continent. Severe deforestation and degradation were the norm since before AD 1000 [5]. Then, a shift was initiated about AD 1712 from broadleaved forests to more productive conifers, transforming an area equivalent to around one third of the current extent of forests in the EU. After the timber shortage of the 2nd World War, reforestation and afforestation actions were significant across much of the European continent, increasing the forest area to 38% of the land area of the EU today. One of the consequences of the history of forest use and degradation in Europe is that today primary and old-growth forests represent less than 3% of the total forest area (excluding Russia) [6].

What makes primary and old-growth forests unique?

Primary forests are defined as naturally regenerated forests of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed [7]. That means that they are ecosystems where natural disturbances have governed evolutionary processes across millennia with no direct human intervention. In turn, old-growth forests have been defined as forests consisting of native tree species that have developed, predominantly through natural processes, structures and dynamics normally associated with late-seral developmental phases in primary or undisturbed forests of the same type. Signs of former human activities may be visible, but they are gradually disappearing or too limited to significantly disturb natural processes [7]. Primary and old-growth forests often coexist in landscape mosaics of successional patches, representing all stages of the natural range of disturbance and recovery. In Europe, these forests are rare, small and fragmented (Figure 1). However, they are critical for biodiversity and ecosystem services, including among others climate regulation, due to the large amounts of carbon stocked in their living biomass, deadwood, and soils, and the habitat provided for imperilled species.

Figure 1 – Documented primary and old-growth forests in Europe according to the European Primary Forest Database (EPFD v2.0) of Sabatini et al. [8] and UNESCO's Primeval Beech Forests of the Carpathians and Other Regions of Europe [9]. Note that the boundary of the polygons is highlighted for better readability. Point features represent small patches of these forests.



Source of the figure: [6].

Why are primary and old-growth forests more resilient to natural disturbances?

It is widely recognised that primary and old-growth forests are typically more resilient and resistant than mono-specific (i.e. a single tree species) or more even-aged forests [10, 11]. In practice, this means that primary and old-growth forests have greater capability to absorb and overcome stressors than heavily modified forest ecosystems due to the inherent properties and evolutionary legacies that enable them to cope and recover from natural disturbances, i.e. wildfires, drought, windthrow, insect and pathogen outbreaks [10-12].

Resilience is defined as the capacity of an ecosystem to withstand (absorb) external pressures and return, over time, to its pre-disturbance state. When viewed over an appropriate time span, a resilient forest ecosystem is able to maintain its principal characteristics in terms of composition, structure, and functions [11, 13]. Resilience is an emergent property of ecosystems that is underpinned by genes and species diversity, functional groups of species at multiple scales, and processes within the system [14, 15]. While resistance is the capacity of an ecosystem to absorb disturbances and remain largely unchanged [11, 13].

Primary and old-growth forests present a range of differential characteristics in relation to e.g. mono-specific even-aged forests. Among the characteristics of primary and old-growth forests underpinning increased resilience and resistance the more relevant are summarised as follows:

- Primary and old-growth forests exhibit natural structural, functional and compositional traits, which describe forests in the upper range of naturalness, hosting myriads on natural processes, and large structural, taxonomic and functional diversity. This translates into biodiverse forest ecosystems (beta diversity) delivering the full range of ecosystems functions and services. These types of forests are in general more resilient and adapted to natural disturbance regimes [16, 17], including fire regimes in regions where fire is a dominant disturbance, such as the Mediterranean biome and, to some extent, Boreal Fenoscandinavia [18].
- Primary and old-growth forests have higher functional diversity and redundancy of functional species, which are key features of resilient forest [19, 20]. In contrast, ecological resilience is unlikely in forests having low redundancy such as mono-specific planted forest. Redundancy describes the overlap and duplication of ecological functions implemented by diverse genomes and species in an ecosystem [21]. In summary, redundancy is an attribute supporting ecosystem stability and resilience. In contrast, the lack of diversity (at all levels) found in mono-specific planted forests reduces resilience. Making them more vulnerable to disturbances.
- Primary and old-growth forests are more structurally diverse than intensively managed forests, in particular even-aged forests. This implies a more heterogeneous intra-patch structure, including both vertical and horizontal heterogeneity, which is one key trait of resilient forest ecosystems. This patchiness might reduce spread (contagion) in case of widespread disturbances. In fact, old-growth characteristics normally associated with forest ecosystems driven by natural succession and dynamics are often reduced in managed forests [22], and therefore their resilience to disturbances.
- Structural and functional traits of primary and old-growth forests contributes to create microclimatic conditions underpinning ecosystem functions and increased resilience and resistance during extremes due to the insulating effect [23]. The canopy of old-growth forests is often taller and denser than managed forests, which can lead to more shade and cooler temperatures at the forest floor. The litter layer is often thicker and more diverse, supporting a higher diversity of ground vegetation, which can help to retain moisture and create a humid microclimate. These conditions include lower mean temperature in spring and summer months, increased amounts of humidity between the forest floor and the canopy roof, and increased moisture in the forest floor. Which in turn is associated with soils rich in organic carbon, as it is the case in primary and old-growth forests. All these factors contribute to reduced wildfire hazard.
- Forest size is an important component of resilience because ecosystems are exposed to disturbances regimes that occur across a range of temporal and spatial scales. This should be considered for the creation of buffer zones around small-sized patches of primary and old-growth forests and connecting corridors between them.

PRIMARY AND OLD-GROWTH FORESTS AND WILDFIRE

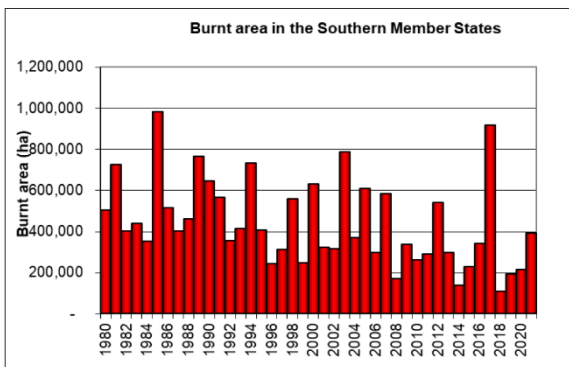
Wildfire is a context dependent disturbance. It occurs under specific dry and hot weather conditions, often combined with low humidity and strong winds. Other contributing factors of natural fire ignition and spread are the amount and type of fuel [24], for instance, the amount of fine woody debris and their moisture content, and topography [25]. The summary presented in this section provides a general overview of the relation between primary and old-growth forests and wildfire. However, a local focus would be necessary for assessing specific cases. In particular, local climate conditions and dominant tree species are of paramount relevance.

Wildfire occurrence in Europe is largely concentrated in the Mediterranean region [26]. According to the European Forest Fire Information System (EFFIS), Portugal, Spain, France, Italy, and Greece alone summed 78% (391 736 ha) of the 500 566 ha burnt in 2021 in the EU [27], with similar figures reported over the last few decades (Figure 2). It is interesting to note that these countries together host barely around 50 000 ha of primary and old-growth forests, which is equivalent to 0.1% of their total forest area. Indeed, these countries host only 1.6% of the total extent of the known primary and old-growth forests in the EU [6]. Even in the Mediterranean region most primary and old-growth forests are found in mountain areas where precipitation is substantially higher, summer water scarcity lower, and accessibility difficult. In short, the area of primary and old-growth forests in these countries is limited when compared to the total forest area. In addition, the amount of primary and old-growth forests they host is also low when compared with other regions of the EU.

Another aspect to be considered is that in the EU 96% of wildfires are caused by direct human action, among which are accidental, negligence and deliberate fire [25, 27]. Therefore, in this case, we can hardly talk of wildfires in the context of natural disturbances. This fact delineates the effects of wildfires outside the domain of natural disturbances occurrence and recovery. That is, fire regimes, which describe the type, frequency, intensity, seasonality, and spatial dimension of fire, are heavily influenced by direct human causality, as fires in the EU are mostly the result of direct human action [25]. For this reason, even natural forest ecosystems adapted to fire regimes, such as Mediterranean ecosystems, can experience degradation and ecosystem shifts

resulting from human-modified fire regimes and the concomitant effects of climate change [28].

Figure 2 – Burnt area in Portugal, Spain, France, Italy, and Greece, 1980-2021.



Source: EFFIS [27].

Risk is described as the combination of hazard, exposure and vulnerability [29]. Risk has been defined as “the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems” [30]. While hazard is “the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources” [30]. Therefore, risk is associated with the consequences of a damaging event, while hazard refers to the probability of occurrence of the event, i.e. fire ignition, spread, and development.

Primary and old-growth forests have been evolving over centuries resulting in natural structural and compositional characteristics. In contrast, industrial logging and intensive forest management introduce changes in forests resulting often in increased fire hazard, severity and/or frequency [31-34]. In particular, these anthropogenic changes may affect:

- Forest microclimates toward dryer conditions resulting from changes in structural traits [35]. Clearing of trees by logging increases solar radiation in the forest floor, altering micro-climatic conditions, specifically increasing drying and a major effect of wind in evapotranspiration in forest areas around the cleared patches.
- Stand structure and species composition resulting from changes in stock and stem density, spatial patterns of trees, and plant species composition. Especially, the conversion of mixed and broadleaved forests to monocultures of species with higher flammability such as Eucalyptus or conifer (especially Pine) will strongly increase wildfire hazard [36], or to more homogenous stands, e.g. mono-specific or even-aged stands, which facilitate fire spread after ignition [33].

- Fuel characteristics by changing the amount, type, and moisture content of the litter biomass toward drier fuel [32].
- Change in the prevalence of ignition points resulting from an increased access to forest areas [37].
- Spatial pattern of stands and forest edges. This has the potential to change spatial contagion of fire when spreading through landscapes.

In summary, primary and old-growth forests are likely to be less prone, not more, to fire hazard than human-modified forests [31-33]. The case of plantation forests is illustrative of this fact. Mono-specific plantations are in general more susceptible to fire [33, 34]. Large mono-specific forests favour fire spread and host often more flammable fuel, depending on the planted tree species, e.g. conifers. Moreover, one option for reducing fire risk in managed forests is to mimic features of natural forests such as increased tree species diversity, e.g. mixed-species stands, and reduced biomass density [34, 38].

The views presented in this section are contingent to forestry practices, forest types under consideration, and the natural fire regime characteristic of that forest. We acknowledge this fact because not all forest ecosystems are equally resilient to disturbances. Therefore, local information would be necessary for addressing specific cases.

Deadwood in primary and old-growth forests

Large and diverse amounts of deadwood, or coarse woody debris, is one of the characteristics of primary and old-growth forests. Deadwood is defined as “all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country” [39].

Considering that primary and old-growth forests are typically richer in deadwood than managed forests, it is legitimate to ask whether deadwood in primary and old-growth forests is a contributing factor for wildfire. The answer to this question is context-dependent. First, the many different forest types and climatic gradients in Europe make it necessary to take into consideration other drivers of wildfire, e.g. the presence and duration of a dry period during the year such as in the Mediterranean region [40, 41]. Second, the contribution of deadwood (pieces with a diameter larger than or equal to 10 cm) to fire ignition and spread is small [42]. Decaying larger deadwood, especially if in contact with the soil, will contain much higher amounts of moisture [43-45]. However, the situation is different for fine woody debris (branches with a diameter from 1 to 10 cm), which are generally defined as forest litter. Fine woody debris are associated with increased fire ignition and spread potential under fire-prone weather

conditions, due to the fact that they dry faster than deadwood (a few hours), and that their high surface to volume ratio facilitates rapid heating, volatilization, and ignition, allowing therefore rapid fire spread [42, 46-48]. In turn, after spread, during the development phase of the fire, dry deadwood can also contribute significantly to the energy released at the fire front, because in this case deadwood may contribute to the fuel loading. Nevertheless, deadwood moisture should be also taken into consideration, as moisture determines significantly the amount of fuel available for combustion [42].

In summary, it is primarily the fine woody debris, which are common in primary and old-growth forests, but evenly present in harvested forests [49, 50], that tends to contribute to an increased probability of fire ignition and spread. Moreover, other factors should be considered, such as the amount, type, and moisture content of the debris, and the level of moisture of the forest patch and the forest floor, which is typically higher in primary and old-growth forests in relation to forest stands under intensive management. A discussion on the role of deadwood in the European Green Deal is available here¹.

OUTLOOK

Calls to log forests to 'save' them from stressors are an oversimplification of the complex processes and feedbacks within forest ecosystems underpinning their resilience and resistance to fire. Policy makers should be able to embed all this complexity in the decisions aimed to achieve healthy forest ecosystems in the EU. In particular, strict protection of primary and old-growth forests and the creation of protective buffer zones facilitating its expansion and conservation should be a policy priority [51], as mandated in the EU biodiversity strategy to 2030. The time for urgent and decided policy action is now, before there remains little left to protect.

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