



Integrating spatial indicators to evaluate fire risk and impacts on Mediterranean forests

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StrategyMedFor



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Glossary of terms, concepts, and abbreviations

AMSL	Above Mean Sea Level
BFI	Basic Fire Impact. A quantitative score derived from the proportion of burnt forest area within a grid cell, representing the baseline ecological impact of fire before accounting for forest typology and fire recurrence.
Burnt Area	Area affected by fire at least once during the analysed period (2008-2025), as mapped by EFFIS.
EFFIS	European Forest Fire Information System. A Copernicus-supported system providing harmonised information on forest fires across Europe, including burnt area extent and fire severity indicators.
FAO	Food and Agriculture Organization.
Fire recurrence	The number of times a forest area has burnt within a defined time period, classified as single-, double- or multiple-burnt.
FFIS	Forest Fire Impact Score. A composite categorical indicator integrating burnt forest impact, biodiversity sensitivity and overlap with Protected Areas.
Forest typology	Classification of Mediterranean forests based on dominant vegetation type and elevation, including broadleaved, mixed, and low, mid and high elevation conifer forests.
GBIF	Global Biodiversity Information Facility.
GIS	Geographic Information Systems.
Grid cell (1×1 km)	The spatial analysis unit used throughout the assessment.
IUCN Red List	The global inventory of species conservation status maintained by the International Union for Conservation of Nature.
PA	Protected Area. Legally designated terrestrial areas managed for biodiversity conservation, as defined by the World Database on Protected Areas.
PBA	Proportion of Burnt Area. The ratio of the burnt forest area to the total forest area within a grid cell.
SSMMF	Strategy for the Sustainable Management of Mediterranean Forests.
WDPA	World Database on Protected Areas. The global database of Protected Areas managed by UNEP-WCMC and IUCN.



1. Executive Summary



Mediterranean forests are under increasing pressure from wildfires as climate change, land-use change and human activities intensify across the region. Although fire is a natural and historically embedded process in Mediterranean ecosystems, recent decades have seen a rise in fire frequency, extent and recurrence that exceeds the regenerative capacity of many forest habitats. This trend threatens forest biodiversity, ecosystem services, livelihoods and the long-term sustainability of forest landscapes.

Responding effectively to this challenge requires robust, spatially explicit and comparable information that can support prevention, preparedness, post-fire restoration and visionary conservation planning.

This deliverable presents an integrated assessment of fire impacts on Mediterranean forests over the period 2008–2025, intending to support the implementation and monitoring of the Strategy for the Sustainable Management of Mediterranean Forests (SSMMF).

The assessment introduces a harmonised, Mediterranean-wide approach to evaluate fire impacts using readily available and operational spatial data. It builds on information from the European Forest Fire Information System (EFFIS), combined with forest typology data, spatial information on forest species for which fire represents a primary threat, and the distribution of protected areas (PAs). All analyses are conducted on a 1×1 km grid, allowing consistent comparison across the Mediterranean terrestrial ecoregion.

Forest Fire impacts are assessed through a multicriteria framework structured around three key factors. The first factor captures the ecological impact of burnt forests, integrating the proportion of forest area burnt, fire recurrence over the study period, and differences in post-fire regeneration capacity among major Mediterranean forest types. This approach recognises that large, continuous and recurrent fires have disproportionately higher ecological impacts, particularly in conifer forests and at higher elevations. The second factor accounts for biodiversity sensitivity by identifying forest areas that host species for which fire is a primary threat, based on IUCN Red List assessments. The third factor considers the overlap of Mediterranean forests with legally designated Protected Areas, reflecting their higher ecological and societal value and the additional management implications of fire within these sites.

These three factors are combined into a single operational indicator, the Forest Fire Impact Score (FFIS), which classifies forest areas into six impact categories ranging from not impacted to extremely impacted. While the core impact value is derived from quantitative fire and forest data, the presence of fire-threatened species and/or protected areas acts as categorical amplifiers, ensuring that areas of high conservation importance are appropriately highlighted.

The results reveal clear spatial patterns of fire impacts across the Mediterranean terrestrial ecoregion. Extensive areas of forest have been affected by fire at least once during the analysed period, with significant concentrations of double- and multiple-burnt forests indicating reduced resilience and increased risk of long-term degradation. Conifer forests, particularly those at mid and high elevations, emerge as the most vulnerable to repeated fires. The assessment also identifies areas where high fire impacts coincide with concentrations of threatened species and



protected forests, pointing to hotspots where fire management, restoration and conservation objectives need to be closely aligned.

By combining information on fire history, forest vulnerability, biodiversity sensitivity and protection status, the FFIS provides a practical tool for prioritising management actions. It supports decision-makers and practitioners in identifying areas where fire prevention and suppression should be strengthened, where post-fire rehabilitation is most urgently needed, and where conservation measures should focus on safeguarding vulnerable species and high-value forest ecosystems. The indicator is designed to be repeatable over time, enabling the monitoring of trends and the evaluation of progress in forest fire management under changing climatic conditions.

Overall, this deliverable demonstrates the value of harmonised geospatial information and integrated assessment approaches founded by expert knowledge and rules for supporting sustainable forest management in the Mediterranean terrestrial ecoregion. The methodology is transferable, scalable and aligned with the objectives of the SSMMF, offering a robust evidence base to inform policy, guide management actions and strengthen regional cooperation on forest fire management in the Mediterranean region.

2. Introduction



The Mediterranean basin is recognised as a biodiversity hotspot, but it is also facing rapid anthropogenic changes. The key drivers of forest degradation and loss include climate and land-use changes, wildfires, pest outbreaks, grazing, and the spread of alien species, significantly threatening the region's unique biodiversity (FAO 2025). The main threats on the rich and unique biodiversity in the region being agricultural development, biological resource use, residential and commercial expansion, pollution, wildfires, invasive species, climate change, and transportation corridors (IUCN, 2025). As the impacts of global change intensify, managing Mediterranean forests in a sustainable and multi-objective manner presents significant challenges. Effective forest management requires a deep understanding of how these threats evolve spatially and temporally, alongside the expertise to respond swiftly and appropriately (Gritti et al. 2006, Fried et al. 2014, Crosti et al. 2016). A comprehensive knowledge of forest resources and their condition is critical to planning and implementing suitable management practices, such as silviculture, harvesting, and reforestation. Among the many threats to Mediterranean forests, wildfires stand out as a particularly significant concern. While fire is a natural and necessary component of Mediterranean ecosystems, the frequency and severity of wildfires have increased in the last decades due to human activities, climate change, and changing fuel dynamics. Mediterranean forests, which are adapted to fire, can withstand a certain level of fire frequency and intensity; however, escalating fire severity due to human influence jeopardizes their survival. With predictions of reduced rainfall and rising temperatures, wildfire frequency and intensity are expected to increase, underscoring the importance of proactive forest fire management.

Effective fire management requires forest managers to have access to the relevant information that allows them to prioritise prevention efforts, allocate firefighting resources strategically, and identify areas needing post-fire rehabilitation. Modern technologies, particularly Earth Observation and Geographic Information Systems (GIS), together with advanced computing capacities, when guided by expert knowledge and rules, can assist in long-term planning, providing efficient knowledge and tools to monitor forest ecosystems and supporting the sustainability of forest management. These tools can clearly support efforts in threat detection, and the assessment of management actions, land-use changes, pest outbreaks, and the spread of invasive species across large areas, offering managers a broader view of threats and their spatial extent (Gao et al. 2020). Developing this knowledge involves integrating proxies on forest condition with data on human presence and neighbouring activities, including agriculture, and urban activities. The StrategyMedFor project has developed the Supplementary Indicator 2.4.1 to assess and monitor forest fire management effectiveness in the Mediterranean region. This indicator, alongside associated spatial layers, supports managers in evaluating fire risks and impacts on forests while contributing to the conservation and restoration of Mediterranean forests.

The impact of wildfires on Mediterranean forests is shaped by various factors such as vegetation type, topography, and meteorological conditions. Environmental and socioeconomic damages result from these fires, with the loss of natural regeneration capacity being a primary concern. The severity of fire damage is also linked to the adaptability of tree species to fire, with larger, high-severity fires generally leading to more significant ecological and economic losses (Rábade and Aragonese 2008, Marcos et al. 2024). While predicting fire severity at broad scales remains



challenging due to the complexity of influencing factors, it is widely accepted that large, high-severity fires cause the greatest damage to both the environment and local communities (Buonanduci et al. 2024).

This deliverable provides a spatially explicit, integrative assessment of fire impacts on Mediterranean forests, combining fire extent, recurrence, forest vulnerability, biodiversity sensitivity, and area protection status into a single operational indicator to support forest management and policy decision-making.

3. Data and methodology



The spatially explicit assessment developed by StrategyMedFor to evaluate **fire risk and its impacts of fires on Mediterranean forest ecosystems** covers the period 2008-2025. It builds on available, accessible, and reliable regional spatial data sources (see 3.1) and quantifies fire-related pressures by considering fire recurrence in forests, differentiated by major forest typologies and is expanded further to incorporate the impacts on threatened species and on forests within protected areas (PAs) (see 3.2).

3.1 Spatial data sources and supporting layers

To develop this assessment, a variety of data sources and derived supporting layers has been used including a selected database from the European Forest Fire Information System (EFFIS), several supporting layers on the forest biodiversity and their proneness to risks due to fire, and an information layer on management efforts (Table 1).

A key spatial layer for forest fire risk and fire impact assessment is the burnt area map. The European Forest Fire Information System (EFFIS) provides harmonized burnt area mapping across Europe since 2008 (in this assessment, we used the data available until December 2025) and represents a reliable, freely available, and operationally sustainable data source (San-Miguel-Ayanz et al., 2012). Despite its underrepresentation of small fire events - being a limitation for localised fires and local assessments - EFFIS maps fires larger than 30 ha, capturing the majority of large burnt forest areas and being useful for broad scale mapping and assessments.

EFFIS also provides fire severity information based on the delta Normalized Burn Ratio (dNBR), classifying burnt areas into five severity classes: Unburnt/Very Low, Low, Moderate, High, and Very High. While severity mapping is useful for post-fire management, it may underestimate impact in areas affected by recurrent fires, particularly where forests are still in early regeneration stages.

Table 1. Data sources and supporting layers

Data source	Use of the thematic information	Temporal resolution	Spatial resolution
Copernicus European Forest Fire Information System (EFFIS)	Burnt area; Start and end of the fire event; Yearly spatial overlaps from 2008 to 2025	Twice daily (starting 2008)	10 m/px
Mediterranean forest area - 2020 (ETC-UMA, 2025)	Presence of Mediterranean forests	2020	10 m/px
Mediterranean forest type - 2020 (ETC-UMA, 2025)	Presence of each typology of Mediterranean forest (broadleaf, coniferous, mixed)	2020	10 m/px
Forest species primarily at risk due to fire (ETC-UMA, 2025)	Richness of forest species for which fire is the primary threat	2025	Not applicable
World Database on Protected Areas (WDPA)	Identification of Protected Areas within Mediterranean forests	January 2026	Not applicable

Building on the EFFIS database, and considering some defined limitations, StrategyMedFor derived additional spatial layers (SL) on a 1×1 km grid to represent the ecological impact of burnt areas, as listed below:

- SL1:** Forest distribution and dominant typology map, distinguishing broadleaved, mixed, and conifer forests, with conifers further classified by elevation (<500 m, 500–900 m, >900 m above sea level (AMSL));
- SL2:** Completeness of burn per grid cell, expressed as the percentage of forest area burnt;
- SL3:** Composition of the burnt areas, including forest and non-forest land areas;
- SL4:** Recurrence of forest fires, distinguishing single-burnt, double-burnt, and multiple-burnt areas (from 2008 to 2025);
- SL5:** Distribution and number of forest species at-risk for which fires are a primary threat;
- SL6:** Mediterranean forests covered by PAs;

The forest typologies defined by StrategyMedFor, when linked with their corresponding ecoregions, habitats, and dominant species, can support this effort by providing a structured basis for assessing fire-adaptive traits. These layers are used combined to estimate the fire impact (see methodology section for more details).

3.2 Methodological design

The Mediterranean-wide assessment of fire risk and impacts on Mediterranean forest ecosystems was developed to provide a proof of concept and spatially explicit evidence base of mapping one of the Supplementary indicators developed for the SSMMF. The approach builds on a multicriteria



analysis implemented on a 1x1 km grid covering the Mediterranean biome and ecoregions, combining fire recurrence and severity, forest typology, biodiversity sensitivity, and protection status. The methodology integrates harmonised spatial datasets and expert-based scoring rules to capture both the extent and vulnerability of burnt forests.

The assessment workflow, shown in figure 1, relies on three main factors:

Factor 1: Fire impact. Considers the fire extent, fire recurrence, and the vulnerability based on dominant forest typology;

Factor 2: Fire-threatened species. Forest species that are at risk, with fire being a primary threat. Taxonomy: amphibians, arthropods, mammals, and trees and tall shrubs. Red List categories: Critically Endangered, Endangered, Vulnerable, and Near Threatened;

Factor 3: Mediterranean forests covered by PAs. A selection of terrestrial PAs that overlap with Mediterranean forests.

Factor 1 generates a continuous impact value, while **Factors 2 and 3** act as categorical amplifiers, not proportional weights, increasing the final Forest Fire Impact Score (FFIS) by one category for each factor.

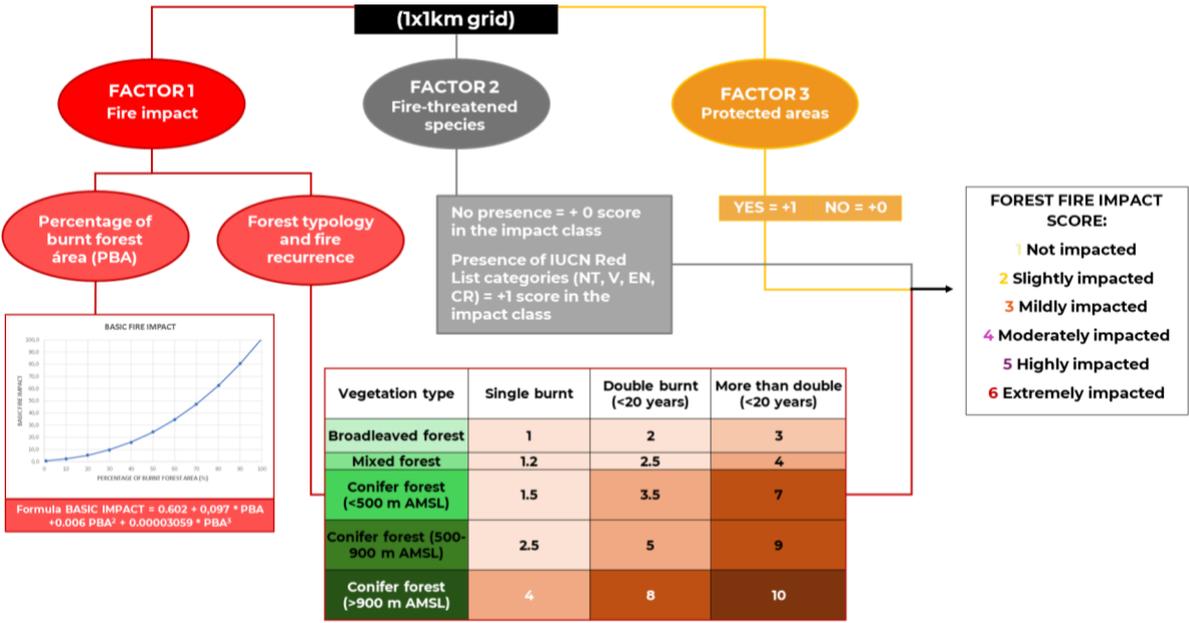


Figure 1. Workflow showing the methodology of the Forest Fire Impact Score (FFIS) assessment

3.3 Factor 1: Fire impact

For the study period, between 2008 and 2025, Factor 1 considers the fire extent, fire recurrence, and the vulnerability based on dominant forest typology and generates a continuous impact value.



3.3.1 Basic fire impact (BFI)

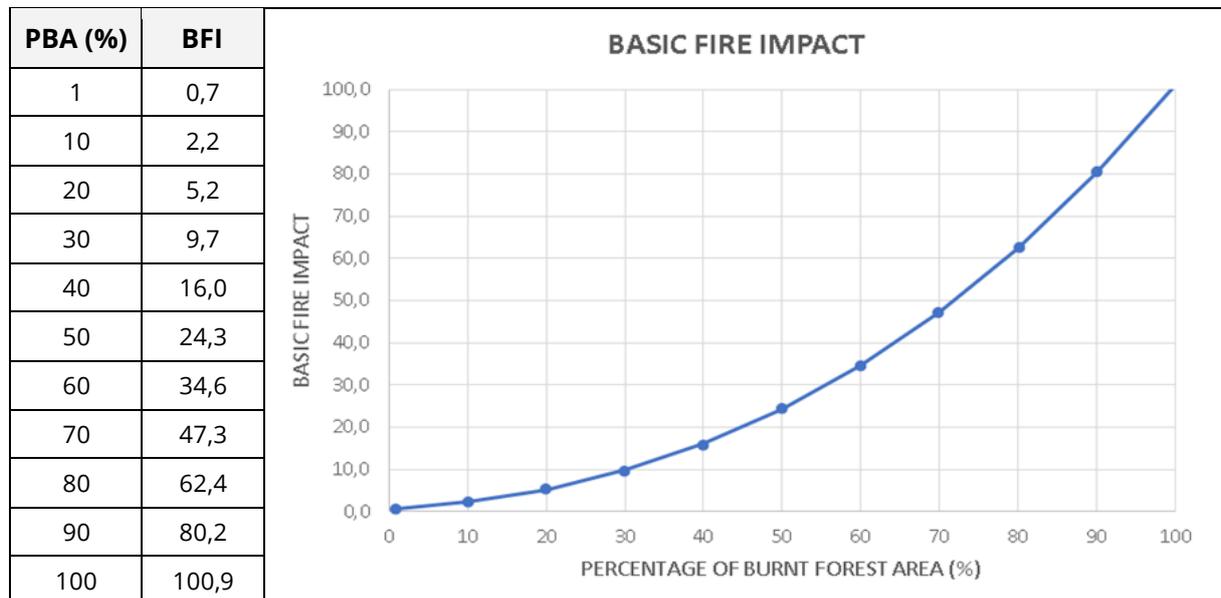
At the grid-cell level, the Proportion of Burnt Area (PBA) is used as a proxy for fire size, completeness of burn, and overall severity in forest ecosystems. A high PBA indicates extensive and continuous burning, which is typically associated with higher ecological and socioeconomic impacts, including soil degradation, erosion, and reduced regeneration potential. The relationship between PBA and fire impact is non-linear. Large, fully burnt areas tend to produce disproportionately higher impacts than smaller or patchy burns, as demonstrated by extreme wildfire events recorded in the region during the last decades, e.g., in the regions of Ilia (2007), Northern Evia (2021) and Evros (2025) in Greece. To capture this effect, a cubic empirical equation was developed to calculate a basic fire impact (BFI) score:

$$BFI = 0.602 + 0.097 * PBA + 0.006 * PBA^2 + 0.00003059 * PBA^3$$

where PBA is the Proportion of Burnt Area, defined as the ratio of the burnt forest area to the total forest area within a grid cell, reflecting the extent of ecological damage within forest ecosystems.

The equation yields values close to 0 when PBA is 0% and approximately 100 when PBA reaches 100%, reflecting the accelerating impact of large and complete burns (Table 2). This formulation explicitly accounts for the presence of unburnt forest patches, which enhance seed availability, facilitate natural regeneration, and reduce overall impact (Christopoulou et al. 2014).

Table 2. Behaviour of the Basic Fire Impact equation based on the percentage of burnt forest per total burnt area on a cell basis (PBA)



3.3.2 Fire recurrence

Fire recurrence is incorporated as an additional impact factor, recognizing that repeated burning within short time intervals (<20 years) can severely limit forest recovery and resilience. In this analysis, we covered the last 17 years (period 2008-2025), which constitutes the whole time series available by the European Forest Fire Information System (EFFIS). Burnt areas are classified as:

- **Single-burnt areas:** relatively high regeneration potential;



- **Double-burnt areas** (<20 years): increased ecological stress and reduced seed sources;
- **More than double-burnt areas** (<20 years): high risk of ecosystem degradation and potential long-term forest loss.

3.3.3 Forest typology and regeneration capacity

Forest impact is strongly influenced by vegetation type and post-fire regeneration strategies. Mediterranean forests are generally fire-adapted, but resilience varies substantially among forest types and elevations:

- **Broadleaved forests** typically resprout and show lower long-term impacts after fire (compared to other forest types) (Espelta et al. 2012);
- **Mixed forests** are resilient but may shift toward broadleaved dominance after fire (Quevedo et al. 2007; Retana et al. 2002);
- **Low-elevation conifers** regenerate from serotinous cones but are highly vulnerable to repeated fires (Moreno et al. 2021; Marziliano et al. 2025);
- **Mid-elevation conifers** (e.g. *Pinus nigra*, *Pinus pinaster*) have variable post-fire response (Fernandes and Rigolot 2007, Arianoutsou et al. 2010).
- **High-elevation conifers** (e.g. *Abies* spp., *Picea abies*, *Pinus sylvestris*) have limited post-fire regeneration capacity, and repeated fires can lead to local extinction (Retana et al. 2002, Arianoutsou et al. 2010, Ganatsas et al. 2012, Christopoulou et al. 2018).

To reflect these differences, multiplicative coefficients are applied to the BFI score based on forest type and fire recurrence (table 3).

Table 3. Multiplicative coefficient values for assessing the influence of forest type to fire impact

Vegetation type	Single burnt	Double burnt (<20 years)	More than double (<20 years)
Broadleaved forest	1	2	3
Mixed forest	1,2	2,5	4
Low-elevation conifer forest (<500 m AMSL)	1,5	3,5	7
Mid-elevation conifer forest (500-900 m AMSL)	2,5	5	9
High-elevation conifer forest (>900 m AMSL)	4	8	10

This results in a final Factor 1 impact value that can reach a theoretical maximum of 1000 for highly vulnerable forests affected by repeated, complete burns.

Example

$$\text{Basic Fire Impact value} \times \text{vegetation type multiplicative coefficient} = \text{Fire impact value}$$

A broadleaved forest area burnt once at 50 %, will have a grid cell value of $24,3 \times 1 = 24,3$

A conifer forest at high elevation that burned once at 20 % will have a cell value of $5,2 \times 4 = 20,8$

A conifer forest at high elevation that burned more than two times at 100 % of the cell grid will have a value of $100 \times 10 = 1000$, which is the maximum possible impact value.

The impact values are reclassified into 6 classes using the natural breaks method and coded into numerical classes and descriptive categories (table 4).

Table 4. Class relation between fire impact values and impact categories

Fire impact (range of values)	Numerical class	Category
0	1	Not impacted
1 - 79	2	Slightly impacted
80 - 232	3	Mildly impacted
233 - 409	4	Moderately impacted
410 - 619	5	Highly impacted
620 - 1000	6	Extremely impacted

3.4 Factor 2: Fire-threatened species

The fire-threatened species factor accounts for biodiversity sensitivity, focusing on forest species for which fire is identified as a primary threat. As a preliminary step, a list of species with assessments published in the [IUCN Red List](#) (Version 2025-1, extracted on May 16th, 2025) was extracted based on their habitat preferences (Mediterranean forest and shrubland), confirmed native presence, category of threat (including Critically Endangered, Endangered, Vulnerable or Near Threatened), and the fact that forest fires was mentioned in their assessments as a primary threat, whether in the coding or the text. The resulting list included four taxonomic groups: 5 amphibians, 30 arthropods (Order Coleoptera and Order Lepidoptera), 2 mammals, and 9 big trees and tall shrubs (table 5). Species that are not linked to Mediterranean forest ecosystems, their presence in the region is unclear, or are vagrants, were excluded from the analysis; freshwater species that occasionally enter terrestrial ecosystems were also excluded, as well as species that settled or were introduced to the Mediterranean basin after 1500 CE.

Table 5. Forest species that are primarily at risk from forest fire by taxonomic group, Red List category and country of occurrence

Taxonomic group	Species	Red List Category	Country of occurrence
Amphibians	<i>Lyciasalamandra antalyana</i>	Endangered	Türkiye
	<i>Lyciasalamandra atifi</i>	Endangered	Türkiye
	<i>Lyciasalamandra fazilae</i>	Endangered	Türkiye
	<i>Speleomantes imperialis</i>	Near Threatened	Italy (Sardegna)
	<i>Speleomantes supramontis</i>	Endangered	Italy (Sardegna)
Arthropods	<i>Alphitophagus xaxarsi</i>	Vulnerable	Spain (Balears)
	<i>Ampedus assingi</i>	Endangered	Cyprus
	<i>Ampedus rifensis</i>	Endangered	Morocco
	<i>Cephennium selenanum</i>	Vulnerable	Greece (Kriti)
	<i>Chromovalgus peyroni</i>	Vulnerable	Lebanon; Syrian Arab Republic; Türkiye
	<i>Clytus paradisiacus</i>	Vulnerable	Greece
	<i>Coelometopus cobosi</i>	Vulnerable	Spain
	<i>Dorcus alexisi</i>	Endangered	Cyprus
	<i>Dorcus musimon</i>	Vulnerable	Algeria; Italy (Sardegna); Tunisia
	<i>Esarcus baudii</i>	Vulnerable	France; Italy
	<i>Esarcus fiorii</i>	Vulnerable	Italy
	<i>Gnorimus baborensis</i>	Endangered	Algeria
	<i>Gnorimus decempunctatus</i>	Endangered	Italy (Sicilia)
	<i>Grammoptera viridipennis</i>	Vulnerable	Italy (Sicilia)
	<i>Heptaulacus gadetinus</i>	Endangered	Spain
	<i>Hipparchia christenseni</i>	Critically Endangered	Greece (East Aegean Is.)
	<i>Hymenorus baudii</i>	Near Threatened	Cyprus
	<i>Maniola chia</i>	Vulnerable	Greece (East Aegean Is.)
	<i>Nacerdes hesperica</i>	Near Threatened	Spain
	<i>Nosodomodes syriacus</i>	Vulnerable	Syrian Arab Republic; Türkiye
	<i>Opilo orocastaneus</i>	Endangered	France (Corsica); Italy (Sardegna)
	<i>Osmoderma brevipennis</i>	Endangered	Türkiye
	<i>Osmoderma cristinae</i>	Endangered	Italy (Sicilia)
	<i>Osmoderma italicum</i>	Endangered	Italy
	<i>Schurmannia sicula</i>	Critically Endangered	Italy (Sicilia)
	<i>Sparedrus lencinae</i>	Near Threatened	Spain
	<i>Stenagostus sardiniensis</i>	Endangered	Italy (Sardegna)
<i>Tarphius oulmesensis</i>	Vulnerable	Morocco	
<i>Thanasimodes dorsalis</i>	Vulnerable	Algeria; Morocco; Tunisia	
<i>Zerynthia cretica</i>	Near Threatened	Greece (Kriti)	
Mammals	<i>Plecotus sardus</i>	Critically Endangered	Italy (Sardegna)
	<i>Sciurus meridionalis</i>	Near Threatened	Italy
Trees and big shrubs	<i>Abies cilicica</i>	Near Threatened	Lebanon; Syrian Arab Republic; Türkiye
	<i>Abies nebrodensis</i>	Critically Endangered	Italy (Sicilia)
	<i>Abies numidica</i>	Critically Endangered	Algeria
	<i>Abies pinsapo</i>	Endangered	Morocco; Spain
	<i>Gonocyttis pterocladus</i>	Vulnerable	Israel; Lebanon; Syrian Arab Republic; Türkiye
	<i>Prunus ramburii</i>	Vulnerable	Spain
	<i>Rhamnus ludovici-salvatoris</i>	Endangered	Spain (Balears)
	<i>Salix ionica</i>	Near Threatened	Italy
	<i>Zelkova sicula</i>	Critically Endangered	Italy (Sicilia)

Subsequently, maps were compiled and curated to keep only relevant codes for presence, origin, and seasonality, and polygons were merged into one per species. Finally, data were analyzed using a grid composed of individual units (cells) that retain their shape and area of 10×10 km per cell. When spatial data was not available in the Global IUCN Red List assessment, this information was extracted from the Global Biodiversity Information Facility (GBIF, 2025), following the geographic range described in the Red List. The species distributions represent an approximation of known ranges building on expert assessment, and do not represent confirmed local presence. An assessment of richness patterns was performed by intersecting the species distribution polygon layers with the 10×10 km grid layer. Then, the number of species per polygon was counted and joined with the 1×1 km fire-threatened species proxy reference grid.

At the grid-cell level, the number of overlapping species distribution ranges present is registered. A binary attribute indicates their presence or absence at the cell level, and this is used to increase the final Forest Fire Impact Score (see 3.6 Forest Fire Impact Score) by one category, reflecting increased ecological importance and potential long-term consequences of fire.

3.5 Factor 3: Mediterranean forests covered by Protected Areas

The Mediterranean forests covered by PAs factor integrate legal and conservation status, using the terrestrial PAs from the UNEP-WCMC Protected Planet dataset. PA overlap with Mediterranean forests is treated as a binary at grid cell level and PA category or designation type is not differentiated. Overlapping areas receive an increase of category in the final score, reflecting the higher ecological and societal importance of these locations and evidence that fire impact can be higher within protected Mediterranean landscapes (de Dios et al. 2025).

3.6 Forest Fire Impact Score

The Forest Fire Impact Score (FFIS) is calculated based on the Factor 1 continuous impact values, while Factors 2 and 3 act as categorical amplifiers; the presence of fire-threatened species (Factor 2) and Mediterranean forests in PAs (Factor 3) within the grid cell increase the impact category by one each, as shown in the following example:

Example

$$FFIS = F1 + F2 + F3$$

where:

FFIS = Forest Fire Impact Score;

F1 = Factor 1 = Fire impact;

F2 = Factor 2 = Fire-threatened species;

F3 = Factor 3 = Mediterranean forests covered by Protected Areas.

A grid cell with an fire impact (F1) value of 4 (*Moderately impacted*) that does not contain fire-threatened species (F2) nor Mediterranean forests covered by Protected Areas (F3) will have a Forest Fire Impact Score (FFIS) of: $4 + 0 + 0 = 4$

A grid cell with an F1 = 5 that contains a forest covered by PA (F3) but no presence of fire-threatened species: $5 + 0 + 1 = 6$; will go from *Highly impacted* to *Extremely impacted*.



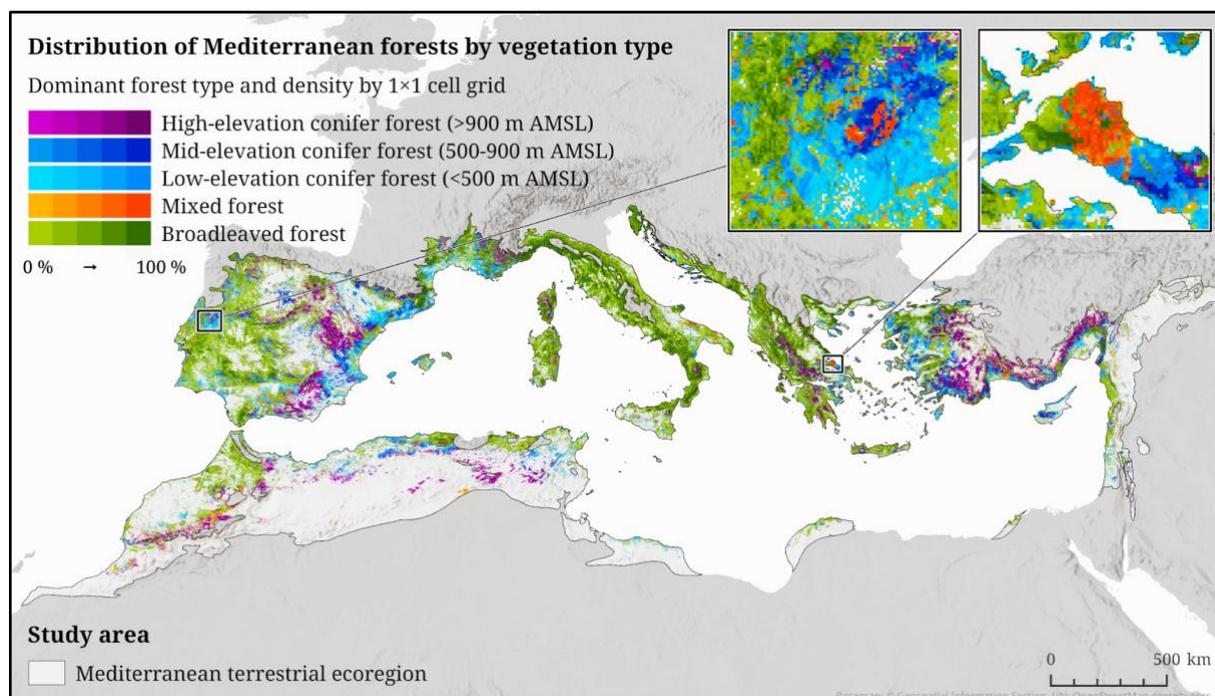
4. Results



This section presents the spatial analysis done and the results achieved through this assessment. All the spatial data shown can be explored and downloaded from the [Mediterranean Biodiversity Protection Knowledge Platform](#).

4.1 Forests distribution and density (1×1 km grid)

The map of distribution and density of Mediterranean forests (Map 1) shows the forest density (percentage of forest) and the broad dominant forest types at the 1×1 km cell grid level. The map synthesises the presence and distribution of the five forest types that were considered to assess the impacts of the forest fires. The underlying spatial data contains, at the cell grid level, information regarding the total forest area, as well as the relative area of the following five broad typologies: broadleaf forests, mixed forests, and low, mid, and high-elevation conifer forests.



Map 1. Distribution and density of Mediterranean forest by dominant forest type (reference year: 2020)

4.2 Factor 1: Fire impact

4.2.1 Burnt Mediterranean forests

Wildfire frequency and severity have increased over the past decades. We have quantified it by calculating the total burnt area of Mediterranean forests by year between 2008 and 2025 (Figure 2), disaggregated by major forest type –broadleaf forest, mixed forest, and conifer forest (including low-, med- and high-elevation conifers) in Figure 3.

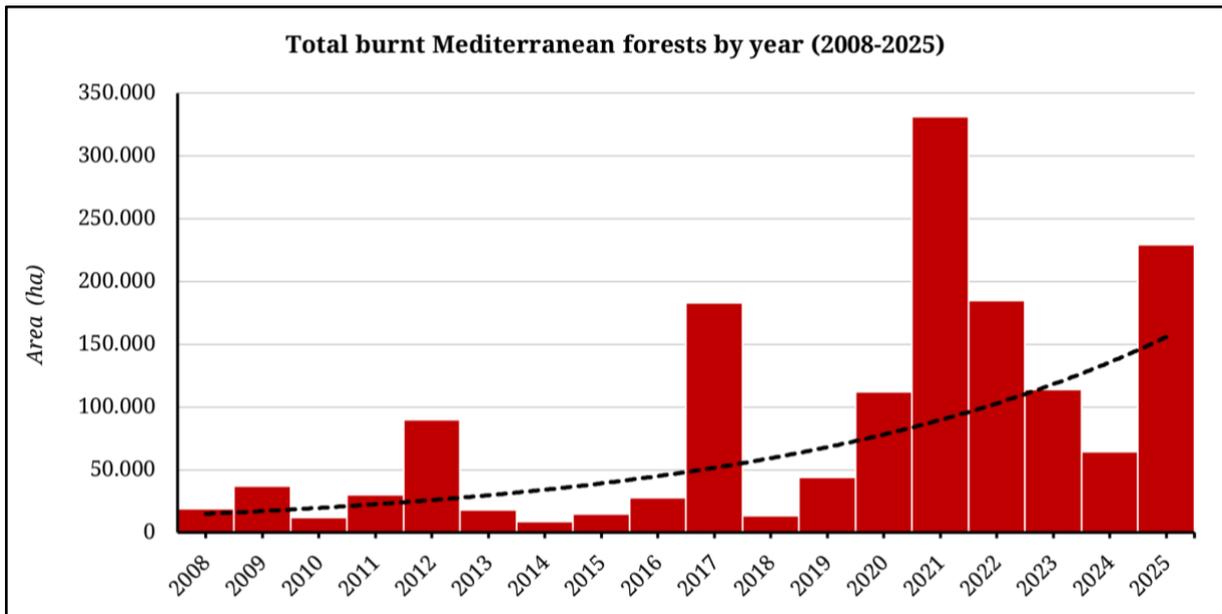


Figure 2. Burnt Mediterranean forest area by year, between 2008 and 2025

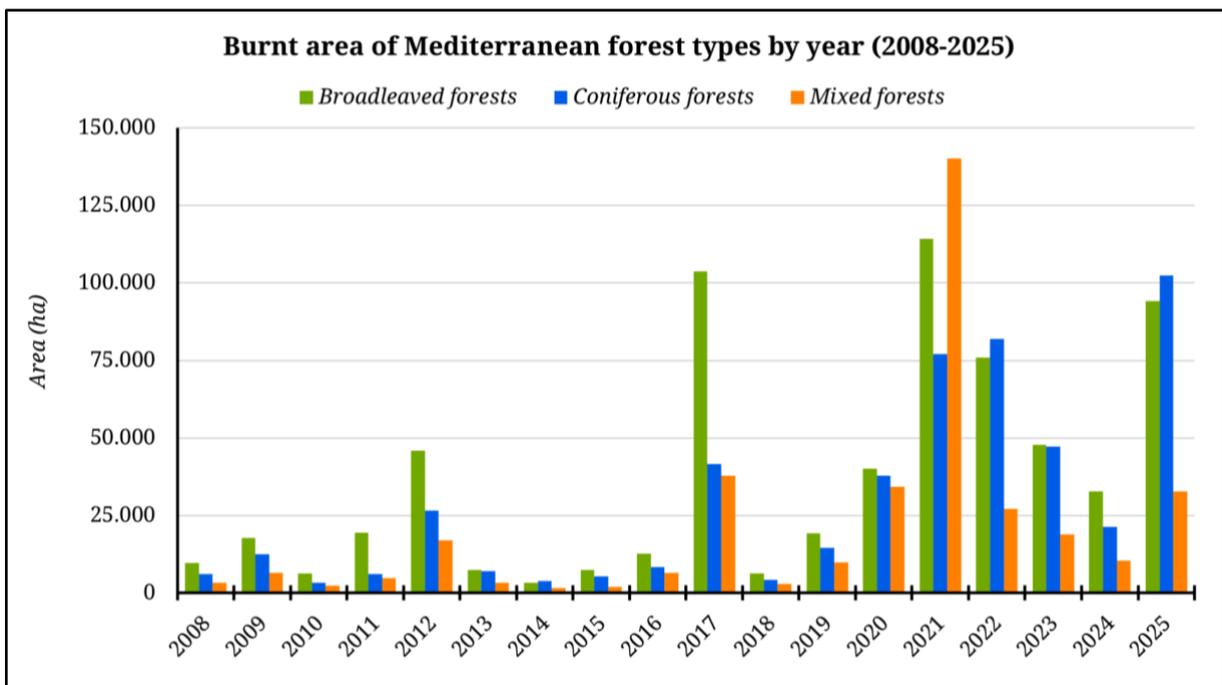
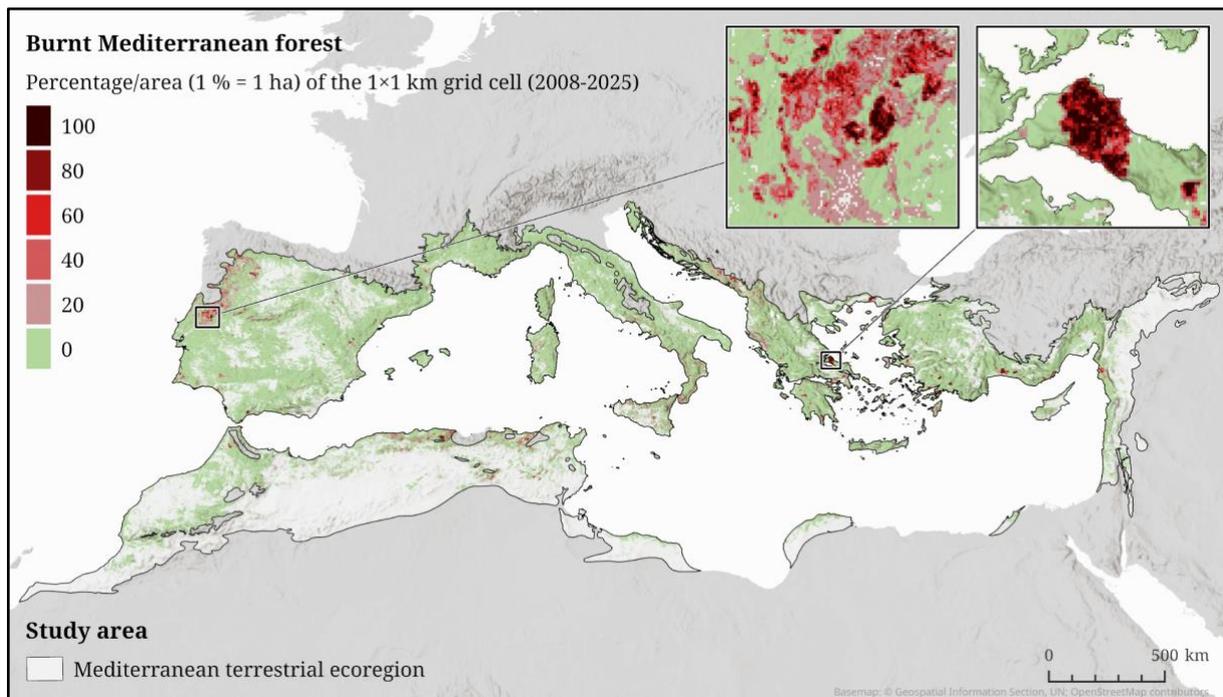


Figure 3. Burnt area of Mediterranean forest types by year, between 2008 and 2025

The total Mediterranean forest areas burnt between 2008 and 2025 are represented in Map 2 as area (in ha) and percentage of burnt Mediterranean forests per grid cell (1 % equals to 1 ha). This map features the spatial distribution and relative extent of burnt forest within each grid cell affected by fire. It indicates whether forest areas were burnt at any time during the analysed period (2008-2025), regardless of fire recurrence. The underlying spatial data has additional attributes at the grid cell level, namely the total land area affected by fires, the total burnt forest, the relative area of burnt forest by vegetation type (broadleaf, mixed, and low-, mid- and high-elevation conifers).

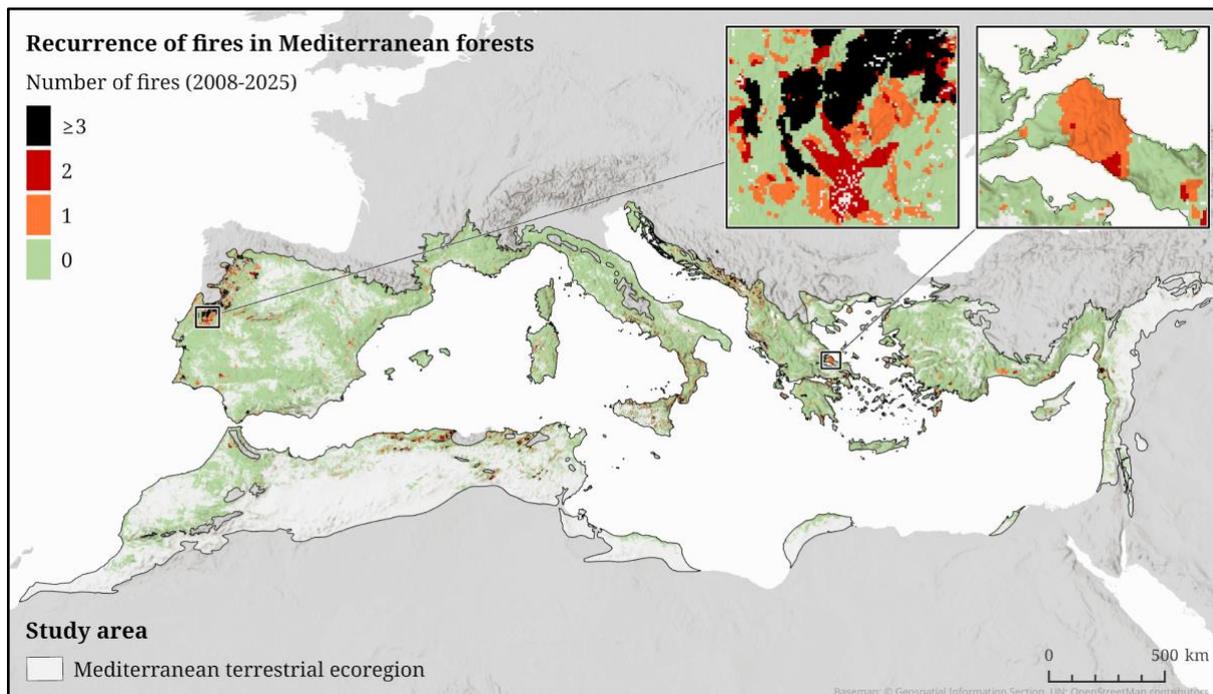




Map 2. Area and percentage of the burnt Mediterranean forests (2008-2025)

4.2.2 Fire recurrence

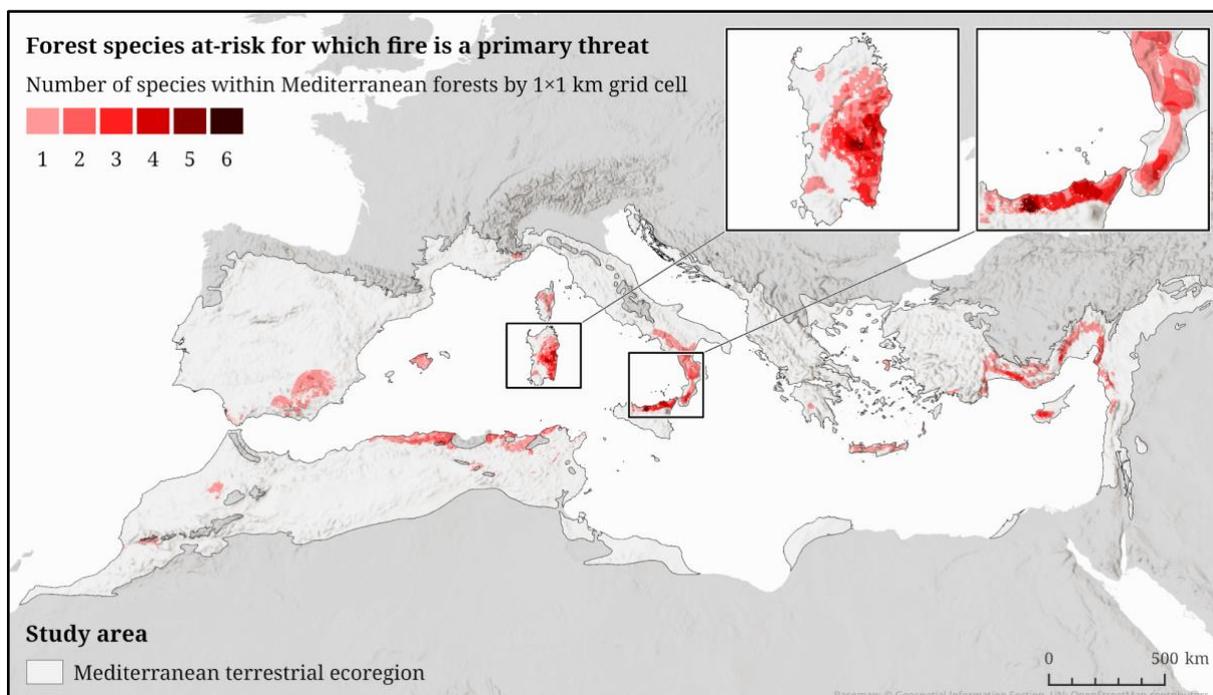
Map 3 illustrates the recurrence of forest fires in Mediterranean forests over the period 2008-2025, distinguishing areas affected by single (1), double (2) or multiple (≥ 3) fire events within the same grid cell. Fire recurrence is unevenly distributed across the Mediterranean terrestrial ecoregion, with clusters of multiple-burnt forest cells. The map highlights regions where repeated burning has occurred within relatively short time spans (< 20 years), an indicator associated with reduced forest resilience and a higher risk of long-term ecosystem degradation (especially in conifer forests). Recurrently burnt forests tend to show increased vulnerability to regeneration limitations, soil degradation processes, and potential shifts toward non-forest land covers. The analysis outcomes shall guide the identification of priority areas that could benefit from the integration of proactive strategies into forest and territorial management plans. Priority areas identified within those plans deserve emphasis on application of best forest management practices to control soil erosion, fuel management projects, including controlled burns and prescribed grazing, to reduce fuel hazard, and creation of fire breaks and fuel breaks, among others. These practices and preventive measures would ensure long-term forest health, sustainability of forest management, and safety to livelihoods around these areas.



Map 3. Recurrence of fires in Mediterranean forests (2008-2025)

4.3 Factor 2: Fire-threatened species

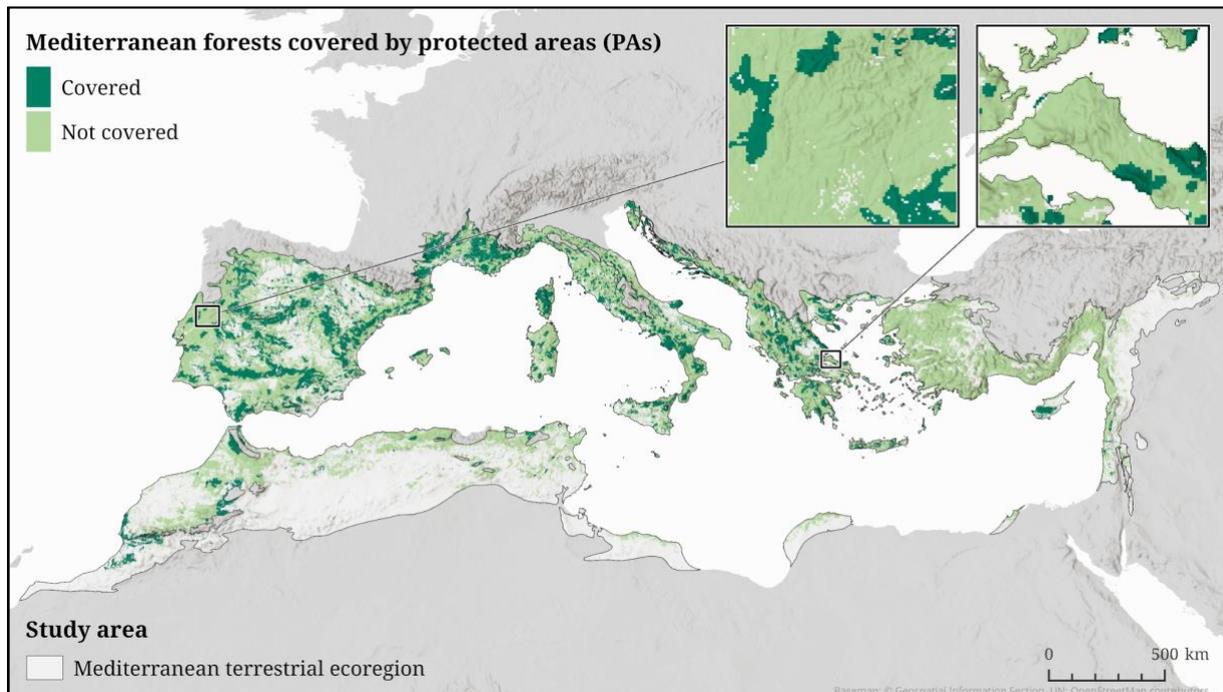
Map 4 presents the spatial distribution and richness of forest species for which fire is identified as the primary threat, based on the IUCN Red List assessments (as defined in section 3.4) For each 1×1 grid cell containing forests, the map reports the number of fire-threatened species present.



Map 4. Distribution and number of fire-threatened forest species

4.4 Factor 3: Mediterranean forests covered by PAs

The spatial overlap between Mediterranean forests and PAs is shown in Map 5. The map identifies forest areas that fall within legally protected sites, reflecting forest biodiversity of high value and importance. Fires occurring within PAs may have higher impacts due to conservation objectives, restrictions on post-fire interventions, and the presence of sensitive habitats and species. The inclusion of this factor acknowledges that fire impacts in protected forests carry additional management and policy implications, reinforcing the need for targeted prevention, preparedness and restoration strategies in these areas.

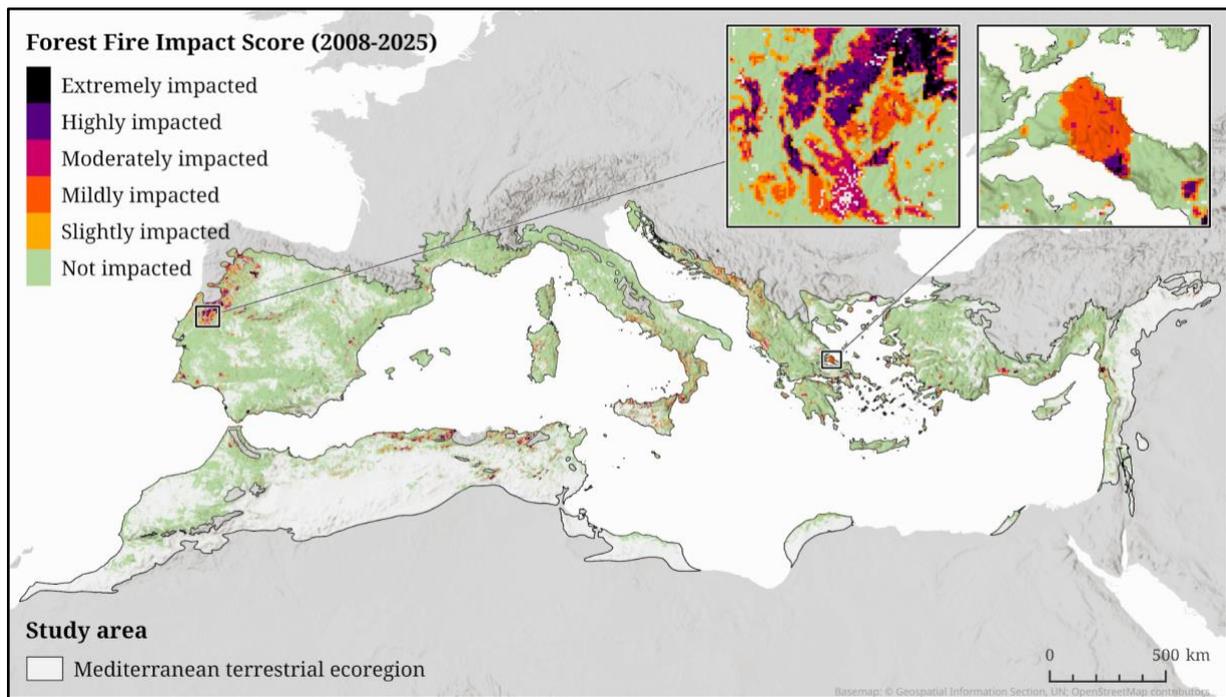


Map 5. Mediterranean forests covered by PAs

4.5 Forest Fire Impact Score

Map 6 presents the Forest Fire Impact Score (FFIS), which integrates the three assessment factors: fire impact (Factor 1), fire-threatened species (Factor 2), and Mediterranean forests covered by PAs (Factor 3) into a single spatial proxy to describe the impact of fires on Mediterranean forest biodiversity. The map classifies Mediterranean forest areas (at 1x1 Km grid level) into impact categories ranging from not impacted to extremely impacted.

The FFIS provides a synthetic overview of fire-related ecological impacts across the Mediterranean region, highlighting hotspots where extensive or recurrent fires coincide with vulnerable forest types, key biodiversity sensitivity, and areas under protection measures. This integrative approach supports strategic decision-making by enabling comparisons across regions and by identifying areas where combined pressures may compromise long-term forest resilience and the provision of ecosystem services.



Map 6. Forest Fire Impact Score (2008-2025)

4.6 Applicability: guidance for action prioritisation based on forest fire impact assessment

The aim of the fire impact assessment is to provide decision-makers and local stakeholders with key information needed to prioritise local actions that support sustainable and integrated forest management. Actions should be informed by forest condition, exposure, sensitivity and territorial needs and prioritised according to the conceptual scheme represented in Figure 4. Depending on the local circumstances, priority actions may include targeted restoration, prevention, and/or conservation measures. These priorities should reflect both the biological sensitivity of forest areas and the need to maintain ecosystem integrity and proper function.

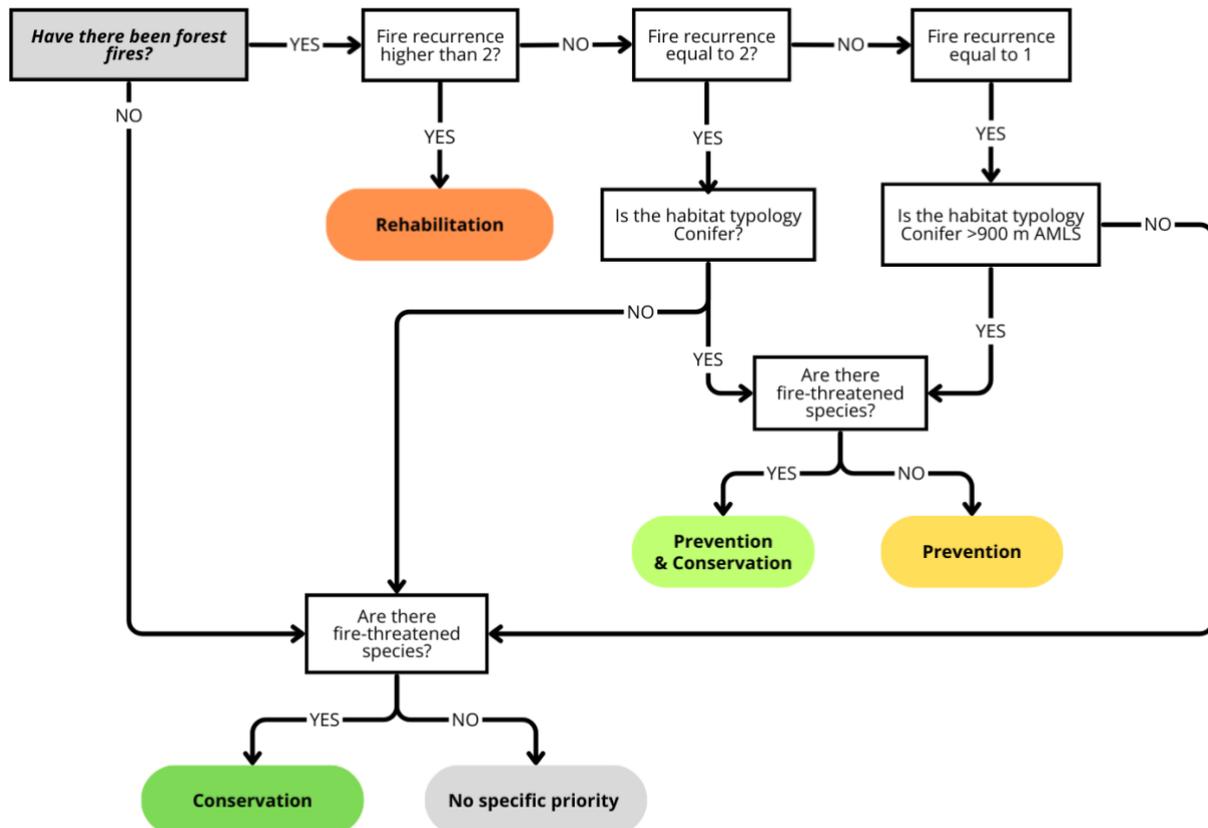


Figure 4. Conceptual scheme of the question-guided procedure to guide the prioritisation of local action

Priority areas for fire prevention and suppression

Forests that have been subject to the highest level of impacts (at least one single or double-burnt forest event) face degradation and difficulty for natural regeneration (with a particular severity for conifer forests growing above 500 m AMSL), making **prevention and fire suppression** a priority.

Priority areas for rehabilitation

The higher the impact score, the more likely that reforestation is needed. **Rehabilitation** would be recommended for highly impacted forests, which are less likely to regenerate naturally, with the highest need for conifer forests that have been affected by at least two fire events. Additional restoration works may be needed, depending on the potential for soil erosion and for triggering of flooding, which should be prioritized based on the proportion of burnt forest area (PBA), the topography (slope), the erodibility of the soil, and the potential for damage to settlements, properties, and cultivations due to flooding and landslides.

Priority areas for conservation of at-risk biodiversity

Finally, the presence of species at risk, which are categorized as Critically Endangered, Endangered, Vulnerable, and Near Threatened, based on their restricted range and fire being a primary threat that increases the likelihood of becoming more threatened or extinct in the future, triggers the prioritization for **conservation**.

Other questions aimed at supporting the assessment of trends and supporting policy decisions

1. What percentage of Mediterranean forest areas have been impacted by fire in the last 20 years?
2. What percentage of Mediterranean forest areas has been impacted more than twice in this period?
3. What percentage of each forest typology has been impacted, and how many times, during this period?
4. What percentage of burnt areas (single, double, or more) were located within PAs when the fire event occurred?
5. Where will future fires be relatively easier to control in the first 4-10 years after the fires?

5. Recommendations for uptake



5.1 Recommendations for practitioners / forest managers

- Use harmonized fire history and recurrence maps (including single-, double- and multiple-burnt areas) to prioritize fire prevention, preparedness, and suppression efforts.
- Integrate burn completeness, fire recurrence, and forest typology to guide post-fire management, recognizing differences in regeneration capacity among forest types.
- Prioritise assessment of natural regeneration before initiating reforestation in fire-adapted Mediterranean forests; focusing active restoration efforts on repeatedly burnt areas and on forest types with low regeneration potential.
- Give special attention to double- and multiple-burnt forests, where fire recurrence threatens long-term forest persistence, biodiversity, and ecosystem services.
- Incorporate information on threatened and near-threatened forest species into fire prevention and post-fire rehabilitation planning.
- Apply severity maps for short-term operational decisions (i.e. erosion control, flood mitigation), while complementing them with recurrence-based indicators for long-term impact assessment.
- Use repeated spatial assessments - using similar approaches to allow accurate monitoring in time - to support adaptive forest fire management under changing climatic conditions.



5.2 Recommendations for decision makers

- Ensure sustained support for harmonized, long-term fire monitoring across the Mediterranean, with enhanced detection of small fires.
- Integrate spatial indicators of fire impacts into national and regional strategies for forest management, biodiversity conservation, and climate adaptation.
- Prioritise fire prevention policies, particularly in areas with high fire recurrence, high ecological impact, and expanding wildland–urban interfaces.
- Allocate targeted resources for fire management in PAs, recognizing their high ecological value and vulnerability.
- Invest in research and operational tools to enhance the mapping of fire severity, recurrence, forest composition, and post-fire regeneration.
- Promote cross-border coordination and data sharing on forest fires across the Mediterranean region.
- Include adaptive fire management explicitly within climate change adaptation and forest resilience policies.



6. Conclusions



This methodology set is transferable and can be integrated into the assessment and monitoring efforts to be pursued under the Strategy for Sustainable Management of Mediterranean Forests (SSMMF).

The assessment developed and tested through StrategyMedFor has proven to be a useful tool for guiding the Strategy and should be applied every 10 years to track progress against established targets. At each grid cell, the value of fire repetitions within a 20-year period will evolve over time, and the resulting maps will reflect the success or failure of forest fire management, including the influence of climate change.

In summary, effective management of Mediterranean forests requires not only a solid understanding of the drivers of forest degradation, but also the integration of advanced technologies to monitor, plan, and respond to these evolving threats. Wildfires, in particular, require focused and adaptive management strategies to mitigate their impacts and to ensure the resilience of these vital ecosystems.

While geotechnologies are invaluable for generating spatial data, ensuring that this information is sufficiently precise and aligned with the operational needs of forest managers remains a key challenge. Continued efforts are needed to develop accurate and validated thematic information layers that support threat detection, effective planning, monitoring, and assessment.

Although significant progress has been made in developing an approach to assess the impacts of wildfires on Mediterranean forest ecosystems, forest fire environmental damage severity metrics still face important limitations. These include the lack of consistent, high-resolution data on forest composition and fire severity, difficulties in accurately mapping stand-replacement events, and incomplete historical fire records, all of which constrain reliable assessment of long-term fire recurrence and ecosystem vulnerability.



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Annexes

What is the [StrategyMedFor](#) project?

The StrategyMedFor project aims **to develop a robust and adaptable strategy for sustainable management of Mediterranean forests, considering future climate scenarios**. It focuses on the Balkan region. Testing sites are located in the Dinaric Alps of Bosnia and Herzegovina, Galičica National Park in North Macedonia, and Samaria National Park in Greece. In each of them, stewardship and locally grounded planning and prioritisation were key to identifying and prioritizing restoration actions. Its innovative approach resides in its **integration of geotechnologies, in-depth research, and collaborative partnerships**.

Through a comprehensive literature review and a highly consultative process along with key stakeholders, the StrategyMedFor partnership has developed eleven **supplementary policy indicators tailored to Mediterranean forests**, which complement the Forest Europe framework by adapting it to the Mediterranean context.

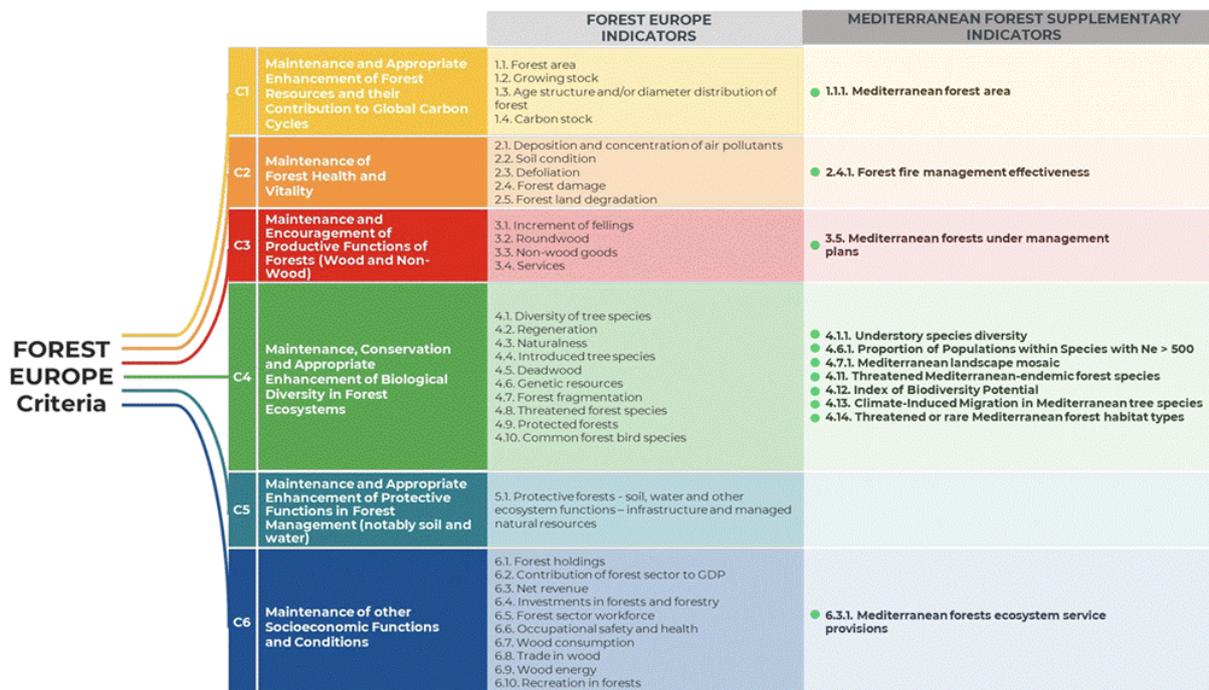


Figure 1: Diagram illustrating the final set of 11 Mediterranean forest SIs aligned with the Forest Europe criteria framework (StrategyMedFor 2025). As a relevant example, see below the factsheet of *Supplementary Indicator 2.41. Forest fire management effectiveness*.

StrategyMedFor took a step forward, translating some of these indicators into information layers and geodata, and making them publicly available via an interactive tool hosted in the [Mediterranean Biodiversity Protection Knowledge Platform](#) to support the assessment and progress monitoring of these indicators against set targets at different scales, and guide restoration planning at regional and local scales.

In addition to developing spatial proxies for the supplementary indicators, other spatial products produced by the project to support decision making include a map of **Mediterranean forest area**, categorized by typologies, **assessments of the impact of fire** in Mediterranean forest ecosystems and **priority areas for protection, restoration, and resilient management**, and maps of predicted **changes in habitat suitability** for selected tree species based on future climate change scenarios.

SUPPLEMENTARY INDICATOR

2.4.1 FOREST FIRE MANAGEMENT EFFECTIVENESS

Full text: Burned forest area as main benchmark of forest fire management effectiveness, further linked to environmental damage and socioeconomic footprint, and assessed for efficiency through the overall cost and the effort on fire prevention.

Rationale:

Forest fires are a major threat to Mediterranean forests. They have a natural role, they cannot be eliminated, but due to their importance they need to be explicitly managed, with the objective to ensure people safety and to minimize environmental and socioeconomic damages, without ever-increasing costs.

Data sources:

National fire statistics database; National forest maps; Burned area maps and satellite-based severity assessment (EFFIS Copernicus); country fire management authorities; Classification of forest species according to adaptation to fire, and their spatial distribution (forest maps) (Pyrogeography); fuel treatment records/mapping from authorities or via satellite images (e.g. Aubard et al. 2020).

Measurement units:

Forest fire suppression

- Burned forest area/total forest area (unitless ratio or %);
- Average fire response time (minutes or hours from detection to first suppression action)

Forest fire environmental damage severity:

- Burned forest area with stand replacement fire /Total burned forest area (%)
- Burned area of non-fire-adapted forest/Total area of non-fire-adapted forest (%)
- Annual double-burned forest area in the last 20 years / Total forest area (%)

Forest fire prevention assessment:

- Number of fires per year
- Total length of firebreaks in the FMU/Total FMU area (km/km²)
- Area that received mechanical fuel treatment/Total FMU area (%)
- Area that received prescribed burning (fuel) treatment/Total FMU area (%)
- Area with planted/restored slow-burning vegetation/Total FMU area (km/km²)

- Area under fire management plan/Total FMU area (km/km²)

Socioeconomic footprint:

2. Permanent and seasonal personnel in forest fire management (numbers)
3. Cost per total protected area (€/km²)

Current periodicity of data availability:

Yearly

Reporting notes:

Keeley (2009) suggested that fire (or burn) severity should focus on the loss or decomposition of organic matter, both aboveground and belowground. Ecosystem responses should be evaluated separately to avoid confusion. However, most managers are not specifically interested in severity measures per se, but rather the extent to which they reflect potential ecosystem responses.

EFFIS has focused on manager needs providing a practical product that should best be used after some field-based validation through the Composite Burn Index (CBI) (Key & Benson 2006).

Fire cause (natural, human-induced, unknown).

Fire response efficiency (time taken for detection, suppression, and containment).

Related definitions:

Fire severity is a measure of the magnitude of the immediate fire impacts on vegetation (aboveground) and soils (belowground) through the loss or decomposition of organic matter (EFFIS Copernicus, adapted from Keeley, 2009). It is assessed over large areas by EFFIS using Sentinel-2 data. NIR and SWIR bands of Sentinel-2 (Bands 8A and 12) to calculate the Normalized Burn Ratio (NBR) for the pre and post-fire images. The Delta NBR (dNBR) is then determined through the difference between the pre and post-fire NBR composites (20 m resolution). Finally, dNBR is classified according to the severity thresholds adopted by Key & Benson (2006). Fieldwork assessment using the CBI can be used for validation of dNBR, because there can be differences between ecosystems.

[EFFIS - Fire Severity](#)



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