D*6.1* - Review of Ecological Resilience Programme

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101037247

Project Acronym	SILVANUS
Grant Agreement number	101037247 (H2020-LC-GD-2020-3)
Project Full Title	Integrated Technological and Information Platform for Wildfire Management
Funding Scheme	IA – Innovation action

DELIVERABLE INFORMATION

Deliverable Number:	D6.1
Deliverable Name:	SILVANUS Review of Ecological Resilience Programme
Dissemination level:	PU
Type of Document:	R
Contractual date of delivery:	31/03/2023 (M18)
Date of submission:	31/03/2023
Deliverable Leader:	AMIKOM
Status:	Final
Version number:	V0.5
WP Leader/ Task Leader:	WP6 – AMIKOM
Keywords:	Ecological resilience, wildfire adaptation, restoration
Abstract:	The document reviews the current adaptation of ecological resilience programs across five (5) EU member states and one (1) non-EU region, including the related literature reviews. Furthermore, the deliverable discusses biodiversity and ecological resilience measurement. In conclusion, natural regeneration become a priority of post-wildfire restoration in most European Pilot Areas. The ecological resilience shows that even though the threat to the ecosystem has a higher value, the forest reveals a different response. Some forests under observation, such as Gargano, Tepilora, Sterea Ellada, Cova de Beira, and Podpol'anie, are considered more robust in facing the threat that shows the robustness of the forest. Some pilots need shorter periods to recover due to many factors, such as the magnitude of wildfires and the programs implemented in the pilot. In contrast, some observed pilots hardly recover their condition due to the recurrent wildfire.

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Document History			
Version	**Date**	**Contributor(s)**	**Description**
V0.1	10/02/2023	AMIKOM	Initial table of contents has been distributed
V0.2	14/02/2023	WP6 contributors	First round of input contributions consolidated
V0.3	10/03/2023	WP6 contributors	Second round of input contributions consolidated
V0.4	21/03/2023	TP, PNRT, ASSET	Internal review feedback collected
V0.5	28/03/2023	AMIKOM	Final version released for submission after integrating feedback from internal review
V0.6	18/09/2023	AMIKOM, IST, AUA, Z&P, LETS, KEMEA, PNRT, Other WP6 contributors	Version after addressing reviewer's feedback

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List of acronyms and abbreviations

ACRONYM	Description
ADD	Aeolian Dust Deposition
AGB	Above Ground Biomass
AIB	Anticendi Boschivi (Forest Fire Fighting, Italy)
AVI	Advance Vegetation Index
AWC	Available Water Capacity
BI	Bare Soil Index
BMG	Badan Meteorologi dan Geofisika (Meteorologu and Geophysics Agency, Indonesia)
CITES	Convention on International Trade of Endangered Species
DBH	Diameter at Breast Height
DTM	Digital Terrain Model
EEC	European Economic Community
EFFIS	European Forest Fire Information System
EU	European Union
ER	Ecological Resilience
FCD	Forest Canopy Density
FES	Forest Ecosystem Services
FHD	Foliage Height Difference Index
FoReSTAS	Agenzia Forestale Regionale per lo Sviluppo del Territorio e l'Ambiente della Sardegna (Regional Forestry Agency for the Development of the Territory and the Environment of Sardinia, Italy)
GDP	Gross Domestic Product
GIS	Geographic Information System
HNMS	Hellenic National Meteorological Service
HP	Hutan Produksi (Production Forest, Indonesia)
HPC	Hutan Produski Convertible (Convertible Production Forest, Indonesia)
IBA	Important Bird Areas
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
LAI	Leaf Area Index
LiDAR	Light Detection And Ranging
Logframe	Logical framework
MODIS	Moderate Resolution Imaging Spectroradiometer
MSAVI2	Modified Soil Adjustment Vegetation Index

ACRONYM	**Description**
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NIR	Near-InfraRed band
PLA	Protected Landscape Area
R	Red band
SAAD	Sensitive, Avoiders, Adaptive, Dependent
SAC	Special Area of Conservation
SAR	Synthetic Aperture Radar
SAVI	Soil Adjustment Vegetation Index
SI	Shadow Index
SPTN	Seksi Pengelolaan Taman Nasional (National Park Management Section, Indonesia)
Sb	Shrub Biomass
SSI	Scaled Shadow Index
SWIR	Short-Wave InfraRed band
TI	Thermal Index
USDA	United States Department of Agriculture
VD	Vegetation Density
WWF	World Wide Fund Nature
NDMI	Normalized Difference Moisture Index
NBR	Net Burn Ratio

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Executive Summary

The purpose of this deliverable is to review ecological resilience programme across five (5) EU member states and one (1) non-EU region. Pilot partners contributes to this deliverable are Gargano Park and Tepilora Park (Italy), Sterea Ellada (Greece), Cova da Beira (Portugal), Podpol’anie (Slovakia), and Sebangau National Park (Indonesia).

Ecological resilience programs along with biodiversity and its related variables being reviewed with the consideration of fire disturbance. The programs arrange by the pilot area analysed with the related references. The goals of the ecological resilience programs are the return to initial forest condition, including the biodiversity state.

In this deliverable, biodiversity is elaborated further in structure, function, and composition, which have detail indicators to be measured. Ecological resilience monitoring is explained and measured respectively in the deliverable.

As a result, the main discussion of the rehabilitation and restoration programs in the pilot area, biodiversity monitoring, ecological resilience monitoring are presented in the last chapter.

1 Introduction

This deliverable reports the work in Task 6.1 about ecological resilience programme. The main activities in the task are:

a. To propose the concept of resilience that provides a framework for assessing the response of ecosystems to changing pressures.
b. The task is aimed at developing a regional programme for each of the stakeholder represented in the consortium to adopt a resilience programme strategy.
c. The resilience programme proposed in the task will focus on the ecological balance that includes factors such as spatial resilience, pattern and process interactions and their variability and relationships among ecological and spatial resilience to support the natural habitat and species.

The deliverable reports on the activities carried out leading to the proposal on the ecological resilience programme to be adopted by SILVANUS consortium to evaluate the effectiveness of rehabilitation and restoration of forests. The study has considered the impact of wildfires upon natural resources and methodologies to be adopted for the restoration of ecological balance within burnt area.

The aim of the study is to review the current adaptation of ecological resilience programme across pilot areas in Phase C. Allocated pilot area focus in 5 sites across Europe (Gargano Park Italy, Tepilora Park Italy, Sterea Ellada Greece, Cova da Beira Portugal, Podpoľanie Slovakia) and 1 non europe pilot (Sebangau National Park Indonesia).

The review focused on the ecological resilience programs that were currently adopted by respective regional authorities towards rehabilitation and restoration of forests. Forest fires are one of the main causes of forest ecosystem degradation and destruction. Therefore, the restoration programs are essential to learn as it can rebuild the condition eventually into the initial state. Therefore, the study has considered the impact of wildfires upon natural resources to reach ecological balance.

According to the work package's objectives, this report's primary outcome is to review the rehabilitation and restoration programs in the pilot areas, including the related literature reviews. Furthermore, this deliverable discusses biodiversity and the measuring methods of the indicators. The deliverable focuses on the biodiversity measurement along with the ecological resilience calculation. Various indicators and methods are elaborated. However, in line with the SILVANUS Project, the selected indicators are measured in landscape scope and calculated by remote sensing.

2 Biodiversity

The connection between wildfires and ecological resilience has been known for a long time as reported in the literature. The fact that wildfires can potentially affect full forest communities, from soil to flora and wildlife, is increasingly a concern in forest management. Every forest area has its own biodiversity composition which influences the ecological resilience in facing the disturbance. Certain compositions of biodiversity elements will create an amount of resilience that will support a forest integrity and promote its recovery. Ecological resilience defines as the capacity of ecosystems to absorb the disturbance (resistance) and recover to the equilibrium pre-disturbance state after being subjected to damage caused by an ecological disturbance (Holling, 1973; Levin, 2023; Oliver et al., 2015)

Biodiversity or biological diversity is species, genetic, and ecosystem diversity in an area. Biodiversity comprises both the biotic component (from genes to species populations and biotic communities) (Noss, 1990; Swingland, 2013; Thompson et al., 2009; Wilson, 1994) and abiotic component of ecosystems (Swingland, 2013). Every area has its own biodiversity, which is consist of living biotic component and the other abiotic component such as environment and climate that support the living. Pressures constantly threaten the sustainability of biodiversity. Meanwhile, ecological resilience helps biodiversity sustain itself with short- and long-term stress.

The **Figure 1** illustrates the relation of biodiversity, disturbance (pressure), and ecological resilience. They are influence one and another. All kind of disturbances in the forest suppress the stability of biodiversity. The capacity of the forest to combat the disturbance, is called ecological resilience, meaning, supporting the forest to its initial condition once the pressure goes.

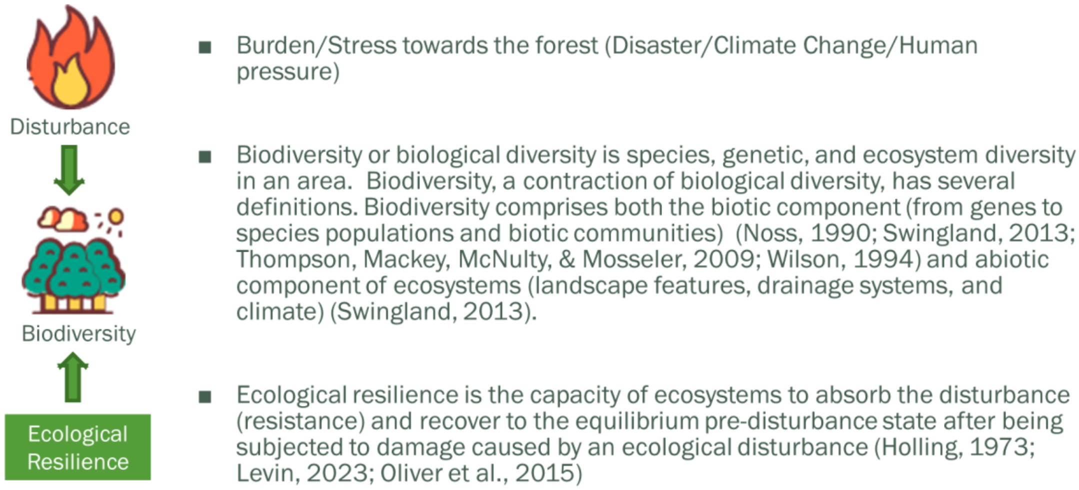


Figure 1. Relation of Biodiversity, Disturbance, and Ecological Resilience

2.1 Biodiversity

Biodiversity, a contraction of biological diversity, has several definitions as reported in the literature. Biodiversity comprises both the biotic component (from genes to species populations and biotic communities) (Noss, 1990; Swingland, 2013; Thompson et al., 2009; Wilson, 1994) and abiotic component of ecosystems (landscape features, drainage systems, and climate) (Swingland, 2013). Ecological systems, including forest ecosystems, are defined by their composition, structure, and function (Franklin et al., 1981; Noss, 1990). Moreover, ecological systems, encompass diverse organizational levels, including genetic, species population, community-ecosystem, and regional landscape (Noss, 1990). Every organization level can be described indicators of composition, structure, and function. This organization level of biodiversity that is further elaborated in this deliverable also related and in line with Ch. 3.1 in Deliverable 7.1.

2.1.1 Composition

Composition refers to the elements present in a certain organisational level, be it alleles, species, or the habitats in a landscape. Composition can be defined by the presence and amount of those elements. elements). The amount can be defined by abundance, cover, biomass, density, among other variables. The richness of habitat types or species, their abundance distribution (which defines evenness) and their diversity are examples of composition indicators. At the community level, community similarity (or dissimilarity) is also an important indicator relevant to monitor community composition.

2.1.1.1 Tree, understory, and animal composition

Trees play a crucial role in maintaining ecological balance, carbon sequestration, and providing habitat for numerous species (Lutz et al., 2012), and as the main element of a forest, trees help increase forest resilience from fires in the future (van Mantgem et al., 2012). However, trees and forests are susceptible to various disturbances and face increasing challenges due to climate change, human activities, and other factors. With climate change, more extreme events such as intense storms, and wildfires (Brando et al., 2019; Zelazowski et al., 2011) are expected. Storms are recognized as significant contributors to forest damage, particularly in regions like Central Europe, where they can lead to extensive tree falls. However, it's important to note that the impact of storms on forests can vary depending on geographical location.

When considering the impact of fire on forests, the extent of damage is influenced by multiple factors, including the intensity of the fire (the amount of energy released), which is determined by various variables. Moreover, the forest's susceptibility to fire progression is pivotal, influenced by factors such as moisture levels and the presence of fine fuels. Additionally, the capacity for post-fire recovery varies among forest ecosystems and depends on the presence of specific traits that enable a swift response to fire-induced disturbances. For example, species like *Quercus suber* (cork oak) exhibit remarkable resilience through vegetative sprouting, while others rely on seed regeneration, with their seed banks stimulated by fire for germination. It's also worth emphasizing that the forest's characteristics also play a significant role in determining the intensity of a fire, alongside external factors like meteorological conditions and topography.

Forests serve as complex ecosystems, providing habitat for millions of animal species. These forests are not merely landscapes of trees, the coexistence between animals and plants fundamentally shapes the ecological structure and dynamics of forests (G. Peterson et al., 1998). However, forests are not static entities. They are subject to various natural disturbances, with wildfires being particularly significant. When a forest is struck by wildfire, there can be devastating effects on the entire ecosystem, including the animal species that are part of it. The impact of disturbances, such as wildfires, on animal populations can be severe, as the loss of vegetation and habitat can disrupt the balance of predator-prey relationships and alter the availability of food and shelter for forest-dwelling creatures. Those that rely on specific forest conditions or are unable to adapt to post-fire landscapes may find their populations declining.

a. Species richness

Species richness (i.e., the number of species present in each area) is a widely used indicator of forest community composition. It can be applied to the full forest community, or more often to specific communities such as tree community, the understory community, or an animal community (e.g., birds, butterflies, etc.). The indicator can be applied at the forest level, considering the species locally present (α diversity), or at the landscape level (γ diversity), considering all the species present across the landscape, in forest and non-forest ecosystems (Vellend, 2001; Whittaker et al., 2001). Data are collected in situ, using monitoring protocols adjusted to the taxa being monitored and to the scale of the assessment. According to the theory of ecological resilience, a higher species richness is indicative of a more complex ecological system, with higher redundancy in species traits and functions, and more interactions, which contribute to a higher resilience to disturbance (Cardinale et al., 2006). Hence, in comparative terms, a richer forest ecosystem is potentially more resilient to fire, since it hosts species with different responses to fire disturbance, which contributes to sustain ecological functions and to faster recovery of the ecological system. This indicator has also been used to monitor post-fire recovery (González et al., 2022; Lindenmayer et al., 2014; Proença et al., 2010), by comparing the richness of pre- and post-fire communities, or by comparing burned and unburned areas. However, the response of species richness after a disturbance is variable, and often not linear, which means that it can suffer fluctuations as the community recovers (Lindenmayer et al., 2014; Tessler et al., 2016). Furthermore, the pool of species found within a forest also depends on the conditions of the surrounding matrix, especially for mobile organisms, which makes more difficult to establish an association between species richness and local forest recovery. Hence, while sensitive to community change, this interpretation of changes in species richness should consider the natural fluctuations from community dynamics and the influence of the surrounding matrix. Its use can be complemented with other indicators, such as community similarity indexes (see community similarity).

b. Species diversity

Species diversity is an indicator of community composition, it considers both the richness, and the relative abundance of the species present in the forest ecosystem (McCarthy & Magurran, 2004; Whittaker et al., 2001) More specifically, it quantifies the number of species present (species richness) and how evenly the individuals are distributed among those species (species evenness). Species diversity is often used to compare communities in different habitats.

As for species richness, a high species diversity is generally indicative of a more resilient ecosystem, composed by a rich and functionally redundant biotic community, with a higher capacity to endure and recover from disturbance (Cardinale et al., 2006). Conversely, low species diversity may indicate a more simplified or disturbed community, such as a recently burned community, with a few dominating (overabundant) species. For instance, that is the case of post-fire Mediterranean communities where pyrophytic shrubs, with fire adaptation traits, become more competitive and dominant (Vasques et al., 2023).

The quantification of species diversity often involves using composite indices such as the Shannon-Wiener Diversity Index or the Simpson's Diversity Index (McCarthy & Magurran, 2004). These indices consider the number of species, the abundance of each species, and the distribution of individuals among species to provide a numerical value that reflects the community's diversity.

Species diversity can be applied to specific communities (trees, understory, animal taxa, etc.) at the forest or at the landscape scale. Species diversity indices are widely used to compare communities, and can be used to assess, in comparative terms, the potential resilience of a forest ecosystem to fire and to monitor post-fire recovery. However, recent research advises against the use, or at least the single use, of this type of indicators (i.e., composite indices) for monitoring biodiversity change, due to the limitation in linking changes in the value of the indicator to specific changes in species richness or evenness, and because these indicators may exhibit counter-intuitive trends and non-linear responses (Santini et al., 2017).

c. Community Similarity

Community similarity is an indicator of community composition, which measures the degree of similarity, or compositional overlap, between two or more communities (McCarthy & Magurran, 2004; Vellend, 2001). It can be applied to compare the composition in terms of the species present, of the species present and their abundance (taxonomic similarity) or in terms of the functional traits present and their abundance (functional similarity). It can be applied to monitor post-fire recovery, by comparing the similarity between burned communities, as they recovered, and the pre-fire or unburned communities. Similarity is expected to gradually increase as the community recovers to its pre-fire state, which will be a signal of community resilience. However, if similarity remains low or fluctuates it may suggest a low degree of resilience, possibly caused by severe changes due to fire, or the maintenance of disturbance factors that hinder recovery.

The quantification of community similarity often involves using similarity indices such as the Sorensen Index or Jaccard index (Chao et al., 2006). Overall, these indices assess the proportion of species shared by the communities being compared. Indices may use presence data to assess the number of species shared between two communities and the number of species exclusive to each community or may also add relative abundance as an additional information layer. The computation of similarity indices, to monitor the recovery of post-fire communities, requires data collected in situ, using monitoring protocols adjusted to the taxa being monitored and to the scale of the sites being compared. The use of similarity indices, and particularly of the Sorensen index, has been recommended to monitor community response to disturbance due its sensitivity and consistent response to biodiversity change (Santini et al., 2017).

Community similarity is a concept closely associated with beta diversity (McCarthy & Magurran, 2004; Vellend, 2001). Beta diversity quantifies the turnover of species across different spatial or temporal scales, essentially measuring the degree of similarity between communities as they spatially or temporally replace one another. A relevant feature of beta diversity its partition in two components of species replacement and differences in species richness (Baselga, 2010), which enables a more detailed understanding of the processes underpinning differences in community similarity. That is, if they are driven by changes in species richness, due to community impoverishment after species loss, or in shifts in the species present, which could be associated to changes in the type of species present (e.g., forest species replaced by species more adapted to open areas (Ribeiro et al., 2019)).

2.1.1.2 Soil composition

The soil is the upper layer of the unsaturated zone of the earth and contains approximately 45% solid material, 5% organic matter, and 50% pore spaces, which are occupied by an equal proportion of water and air (Kalev & Toor, 2018). They are formed by the physical and chemical weathering of parent rocks. Parent materials are one of the main factors that influence soil formation and create different types of soils related to their mineralogical composition, texture, and stratification. So, minerals are the main soil elements as they produced from weathering or erosion of parent rocks (inorganic) mixed with organic matter.

As an essential to all life on earth, soil supports plant life with nutrients and water as well as root support. Soil with cavities is a suitable location for roots for breathing and growing. The soil is also a living habitat for various microorganisms, animals, and plants (Bohn et al., 2001; Brady & Weil, 2008). The effect of fire on soil varies with soil type. Some soils such as sand, silt, and clay exhibit higher heat tolerance and are usually unaffected by combustion unless directly exposed to temperatures greater than 400 degrees at the surface of the mineral soil. The most sensitive textural fraction is clay, which starts to change from 400 ^{o}C when clay hydration and clay lattice structure begin to collapse (DeBano et al., 2005). Complete destruction of the internal clay structure can occur at higher temperatures between 700 and 800 ^{o}C. In addition, irreversible damage to living organisms (seeds and microorganisms) near the soil surface can occur when temperatures exceed 60 ^{o}C (DeBano et al., 2005).

2.1.2 Structure

Structure regards the arrangement of the elements, including the age structure of populations, the horizontal and vertical arrangement vegetation, or the patch structure at the regional landscape scale. Examples of indicators include the proportion of saplings in a tree population, the structure of the canopy (its density or openness), the layering of vegetation in a forest, or the number of forest patches and their connectivity in the landscape.

2.1.2.1 Canopy structure

a. Forest Canopy Density

Forest canopy density (i.e., density or percentage of tree cover) is an indicator of forest canopy structure. This is a critical indicator to assess forest resilience to fire and to monitor post-fire recovery. Forest canopy density refers to the extent of tree cover in a forested area or landscape (Rikimaru et al., 2002). Forest canopy density is one of the indicators to monitor forest condition. Forest canopy density indicates percentage of vegetation cover (Rikimaru et al., 2002).

In general terms, a denser tree canopy will provide more shade, maintaining soil and vegetation moisture, which contributes to a higher resistance to fire progression and damage and to a faster recovery to pre-fire conditions. However, in some forest systems, such as coniferous plantations in Mediterranean systems, a higher tree canopy density may elevate the risk of crown fires, thus reducing overall resilience to wildfire events (Fernandes, 2009; Silva et al., 2009). Hence, the dominant tree species and additional structural aspects of the forest system should be considered when assessing the relationship between forest canopy density and fire resilience.

The assessment of forest canopy density can be conducted through in situ methods, such as hemispherical photography, or by employing land cover maps derived from aerial or satellite imagery. Forest canopy density may also be estimated using the workflow described by Rikimaru et al., 2002 for tropical forests. This indicator is typically quantified by measuring the percentage of canopy cover within a specified area. It represents the proportion of the ground covered by the vertical projection of the tree canopy.

Four indexes related to vegetation indices was used to determine forest canopy density (FCD) which are Advanced Vegetation Index (AVI), shadow index (SI), Bare soil index (BI) and Termal Index (TI) . Canopy density is the ratio of vegetation to ground as seen from the air that is covered by the crown of trees (expressed in percentage of the total area). Calculation of forest canopy density was described using the following formulas:

Advanced Vegetation Index (AVI)

The AVI formula is in the following [1]:

$$AVI = \sqrt[3]{NIR(1-RED)(NIR-RED)} \qquad \textbf{[1]}$$

This formula is applied to the specific spectral band include red, near infrared, shortwave infrared, blue, green, and thermal band. Bands and wavelengths depend on the specific type of satellite images.

Bare Soil Index (BI)

The BI formula is in the following [2]:

$$BI = \frac{(SWIR+RED)-(NIR+BLUE)}{(SWIR+RED)+(NIR+BLUE)}\, X\, 100+100 \qquad \textbf{[2]}$$

Shadow Index (SI)

The SI formula is in the following [3]:

$$SI = \sqrt[3]{(256-BLUE)(256-GREEN)(256-RED)} \qquad \textbf{[3]}$$

Thermal Index (TI)

The TI formula is in the following [4]:

$$TI = \frac{K2}{\ln\left(\frac{K1}{L\lambda}\right)} \qquad \textbf{[4]}$$

Vegetation Density (VD)

The VD formula is in the following [5]:

$$VD = \frac{(PCA1 - min)(max' - \min')}{(max - \min)} \quad [5]$$

Scaled Shadow Index (SSI)

The SSI formula is in the following [6]:

$$SSI = \frac{(PCA2 - min)(max' - \min')}{(max - \min)} \quad [6]$$

Forest Canopy Density (FCD)

The FCD formula is in the following [7]:

$$FCD = \sqrt[3]{SSI\ X\ VD + 1} + 1 \quad [7]$$

Where:

NIR is near infrared band; RED is red band; BLUE is blue band; GREEN is green band, SWIR is shortwave infrared band; PCA1 is digital value of principal component analysis between AVI and BI; PCA2 is digital value of principal component analysis between SI and TI; min is minimum value, max is maximum value; K1 is constant for thermal conversion band from metadata (K2_CONSTANT_BAND_x); K2 is constant for thermal conversion band from metadata (K2_CONSTANT_BAND_x); and Lλ is top of atmosphere spectral radiance.

b. Canopy base height

Forest canopy base height, or crown base height, is an indicator of forest canopy structure. This indicator informs on the vertical structure of the forest ecosystem and is relevant to assess a forest's resilience to fire. Forests characterized by taller canopies tend to be more secured from crown fire hazard, being associated to lower crowning potential (Fernandes, 2009). Taller canopies act as natural firebreaks by reducing the likelihood of contact with the understory, thus mitigating the formation of ladder fuels that can facilitate fire progression to the higher canopy. This vertical separation acts as a deterrent of crown fires that are typically more destructive and difficult to control. Hence, forests with taller canopies show higher resistance to fire progression and, by avoiding severe damage, are faster to recover. Moreover, forests with a taller canopy are often more mature, with developed tree cover, with larger stems, and thicker barks which also contributes to their higher resistance to fire disturbance.

The assessment of forest canopy base height can be obtained from in-situ measurement or using LiDAR (Light Detection and Ranging) technology (ground based or airborne).

This indicator is typically measured in meters and represents the distance between the ground layer and the base of the canopy.

2.1.2.2 Stand Structure

a. Tree density (n trees/ha)

The density of trees within a forest can significantly impact its resilience to fires and is one of the forest resilience indicators (Bryant et al., 2019; Stoddart, 2021; Waltz et al., 2014). Tree density refers to the percentage area covered by trees and can be measured by using the percentage of canopy cover (United States Departement of Agriculture, 2022). Canopy cover can be generated using satellite imagery (Crowther et al., 2015).

Effective forest management should consider tree population dynamics, such as promoting sustainable land practices by strategically planting large trees to increase tree population numbers (Crowther et al., 2015). This would significantly influence the long-term sustainability of the forest ecosystem. Furthermore, we can consider the tree population structure as a crucial variable. Tree population structure refers to the arrangement of trees based on their diameter at breast height (DBH). An analysis of population structure typically involves categorizing trees into seven DBH classes: 5.0–9.9, 10.0–19.9, 20.0–29.9, 30.0–39.9, 40.0–49.9, 50.0–59.9, and ≥60.0 cm (de Andrade et al., 2020). Notably, older and larger trees exhibit greater resilience to fire disturbances compared to younger and smaller trees (de Andrade et al., 2020). This underscores the significance of large trees in enhancing forest ecosystem resilience, as they contribute substantially to the provision of essential ecosystem services and biological legacies for future development (Stoddart, 2021) .

The escalation of tree density raises concerns regarding the lack of forest resilience because dense forests are associated with higher fuel loads and a decrease in the presence of large trees (Bryant et al., 2019). Therefore, decreasing tree density might be an effective strategy for enhancing resilience as it may reduce the intensity of a fire with less fuel available to burn. Reducing tree density also helps tree growth even during extended drought (Stoddart, 2021). However, overly sparse forests may also be more vulnerable to invasive species and other disturbances. Tree density generally increases with temperature (mean annual temperature and temperature seasonality) and moisture availability (precipitation regimes, evapotranspiration, or aridity) (Crowther et al., 2015). These variables are valuable for modelling broad-scale biological and biogeochemical processes because tree density is a prominent component of ecosystem structure, governing elemental processing and retention rates, competitive dynamics, and habitat suitability for many plant and animal species (Crowther et al., 2015).

b. Tree height

The average tree height within forest stands is a key component in forest management, monitoring, and inventory(Jurjević et al., 2020). The height of trees can be a crucial indicator of resilience. Taller and older trees often indicate a mature and well-established forest ecosystem and can act as firebreaks by reducing the continuity of fuel on the forest floor. Moreover, tall trees can offer better protection to understory vegetation and seedlings during disturbances like wildfires. Depending on the species, they may also have thicker bark, which provides protection against low-intensity fires. Tree high and dimension, depending on the species, can be measured using remote sensing methods such as LiDAR ((Ganz et al., 2019) as well from the above mentioned DBH (Buba, 2013).

2.1.2.3 Understory structure

a. Understory cover

The distribution of understory cover is a key indicator of forest understory structure. When combined with compositional data, it can help assessing the level of resilience of a forest to fire or the fire hazard on a landscape scale. The presence and dominance of flammable species in the understory is an indicator of higher fire hazard. Flammable species in the understory have the potential to increase fire intensity, particularly when they also feature fire adaptive traits that promote their fast recovery. This combination of traits may foster a cycle of frequent fires, which can impair the natural regeneration and recovery of the forest ecosystem (see Fire Adaptive Traits). Moreover, the presence of large and interconnected patches of fire-prone understory species in the landscape, such as pyrophytic shrubs and tall grasses, can further elevate the fire hazard (Fernandes, 2013). Contrastingly, an understory composed of species resistant to fire (e.g., thick bark, high leaf moisture content) can act as a natural barrier, slowing down the spread of flames and reducing the risk of crown fires. Thus, positively contributing to the forest's overall resilience.

In closed forest environments, evaluating forest understory cover can be achieved through on-site measurements or by using LiDAR (Light Detection and Ranging) technology, which can be deployed both on the ground and from airborne platforms. In more open settings, such as recently burned areas or forest clearings, the assessment and mapping of understory cover can be done through the utilization of airborne and satellite imagery.

This indicator can be measured in terms of the surface area occupied by the understory, or in terms of fractional cover within a defined area unit.

b. Understory biomass

On Earth, the higher percentage of biomass is covered by plants (especially land plants, embryophytes) with ≈ 80%, the second major component is bacteria), constituting ≈15% of the global biomass. Other groups, in descending order, are fungi, archaea, protists, animals, and viruses, which together account for the remaining<10% (Bar-On et al., 2018).

The biomass of understory vegetation is an indicator of forest understory structure. This indicator is key to assess pre-fire resilience, as it provides information about the available fuel load, which, in turn, is useful for the prediction of fire behavior (Rego et al., 1994; Zuazo & Pleguezuelo, 2009). The understory vegetation plays an essential role in forest functioning and stability, as it can have a direct effect on ecosystem processes. Shrub vegetation, in particular, influence water fluxes and help prevent soil desiccation and erosion (Zuazo, V.H.D. et al, 2008) , also contributing to the recruitment of other species and the increase in biodiversity (Gómez-Aparicio et al., 2004). However, when unmanaged, the accumulation of understory biomass, especially in conditions of dry and warm weather, considerably aggravates the risk of wildfires. Therefore, higher values of fire-prone understory vegetation are generally associated with a higher risk of wildfires (Kazanis et al., 2012).

The assessment of understory biomass can be performed through field biomass harvesting, to determine the volume of biomass dry weight in each area (T. Vashum, 2012). This is a precise but resource demanding approach. A cost-effective alternative is the use of calibrated allometric equations tailored to the specific vegetation type under assessment, relying on easily measurable variables for biomass estimation (Aranha et al., 2020) or the application of remote sensing techniques, including satellite and LiDAR data, for extensive-scale assessments. The selection of the method depends on factors such as the scale of assessment, the availability of time and labour resources, and the desired level of accuracy.

2.1.2.4 Landscape structure

a. Mean patch size

The mean patch size of fire prone vegetation or fire deterrent vegetation is an informative indicator of landscape structure, when assessing landscape susceptibility to fire. This metric is used in landscape ecology to characterize the size of patches of similar land cover or vegetation types within a landscape. It can be a valuable tool for monitoring forest resilience to fire, both for pre-fire assessment and post-fire assessment by using remote sensing data, such as satellite imagery or aerial photographs. In a baseline assessment (pre-fire), Mean Patch Size can be used to identify areas with high fire risk. In this context, the presence of large vegetation patches, particularly of pyrophytic shrubs, indicates a more homogeneous landscape, which can be a potential indicator of elevated fire risk, especially in fire-prone ecosystems ((Calviño-Cancela et al., 2016). Additionally, landscape homogenization may lead to less diverse communities and therefore, to less resilient ecosystems (Gámez-Virués et al., 2015).

On the other hand, in a post-fire scenario, and for certain vegetation types, a significant decrease in Mean Patch Size may indicate that the fire has fragmented larger patches, which can be detrimental to species that require larger contiguous habitat areas and may suggest a decrease in forest resilience (Maxwald et al., 2022).

This indicator is calculated by the sum of the areas (xij) of all patches corresponding to a certain land cover class, divided by the number of patches of the same land cover class (ni). It is expressed in hectares. This calculation can be performed using dedicated software such as Fragstats (McGarigal 2012).

$$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}\left(\frac{1}{10000}\right) \quad \textbf{[8]}$$

b. Clumpiness/Connectivity

The connectivity of potentially fire-prone vegetation, namely tree or shrub or tall grasses, is an indicator of landscape structure and quantifies the degree of aggregation or clumping of similar land cover or vegetation types within a landscape. Connectivity measures, like the Clumpiness Index (McGarigal 20125), inform how often different types of vegetation patches are adjacent to each other in the landscape. It can be used as an indicator of fuel connectivity in the landscape mosaic, which is key to assess wildfire risk. In this context, a high level of fuel connectivity means that there are contiguous and interconnected fuel sources, which can facilitate the rapid spread of wildfire (Sá et al., 2022). When applied to shrub cover, higher values of clumpiness indicate that shrub patches are closely connected throughout the landscape, suggesting an increase in the risk of wildfire, especially in fire-prone landscapes (Aparício, Pereira, et al., 2022). Identifying areas with high Clumpiness Index values can help prioritize fire prevention and mitigation efforts.

The Clumpiness Index can be determined for different vegetation cover classes (i) within a landscape, using land cover maps generated from remote sensing data, such as satellite imagery or aerial photographs. This metric is calculated by using a matrix (adjacency matrix) representing the spatial relationship between different pixels of the land cover maps. From the adjacency matrix, it can be quantified how often pixels of the same class are adjacent to each other, i.e., the proportion of adjacencies (Gi) between pixels of the class i, as well as the proportion of the landscape that is occupied by class i, i.e., the overall coverage of that class within the entire landscape (Pi). This calculation can be performed using dedicated software such as Fragstats (McGarigal et al., 2012).

$$CLUMPY = \left(\frac{\frac{Gi-Pi}{Pi}\ for\ Gi < Pi\ \&Pi < 5, else}{\frac{Gi-Pi}{1-Pi}}\right) \quad \textbf{[9]}$$

c. Edge density

Edge density is an indicator of landscape structure and informs on the level of land cover heterogeneity. This metric quantifies the number of edges or boundaries between different land cover or vegetation types in each area and is widely used in landscape ecology to assess the impacts of land use changes and habitat fragmentation (Laurance et al., 2007). For instance, shrubland encroachment after fires or afforestation can impact landscape patterns by increasing the continuity of flammable vegetation patches and leading to landscape simplification. Landscape heterogeneity may help delay the spread of wildfires across different vegetation cover patches (Lloret et al., 2002). Higher values of Edge Density are generally associated with more complex landscapes, with higher heterogeneity and can be associated with lower risk of large fires (Fernandes et al., 2016). However, as some vegetation types may be more flammable than other, the presence of multiple edges between different fuel types can create conditions for erratic fire behaviour, including rapid spread (Beverly et al., 2021). Therefore, this metric should be used in conjunction with other ecological metrics, such as vegetation cover type and patch size, to provide a comprehensive assessment of forest health and resilience.

Edge density can be measured using land cover maps, derived from aerial and satellite imagery, by summing the lengths of all edge segments in the landscape (E), divided by the total landscape area (A). This landscape metric is given in meters per hectare. This calculation can be performed using dedicated software such as Fragstats (McGarigal et al., 2012).

$$ED = \frac{E}{A}(10000) \quad \textbf{[10]}$$

d. Shannon's Diversity Index

The ShDI has been widely used to measure the Biodiversity index in landscape level due to its ability to measure the plane level diversity by using patches variety that constitutes the landscape area (Dušek & Popelková, 2012). The forest biodiversity can be captured by remote sensing tools that can be characterize into different patches in landscape plane level (Torresani et al., 2023). The heterogeneity of landscape pattern or structure reveals the biodiversity of the forest.

The advantage of numerical values of Shannon's diversity index for evaluating purpose is due to it is easily comparable. The index was inventing by Claude Elwood Shannon (1916 – 2001) in *A Mathematical Theory of Communication* published 1948. Shannon index originally could be used for any diversity index calculation. Here, the Shannon Biodiversity Index was used to calculate landscape biodiversity index based on landscape variety probabilities value. Shannon's diversity index used in landscape assessment is defined as follows (Dušek & Popelková, 2012) (Spellerberg & Fedor, 2003):

$$\text{Shannon's Diversity Index} = -\sum_{i=1}^{m} P_i Ln\ P_i \quad \textbf{[11]}$$

2.1.2.5 Soil structure

Soil structure and texture are two important soil properties that affect soil biological activity. Soil structure refers to the arrangement and organization of soil particles and aggregates, including their size, shape, and stability.

Healthy soils are capable of harboring great biodiversity. Soils and their components constitute complex ecosystems with multifaceted tissues of flora, wildlife and other organisms that respond dynamically to external influences. It is estimated that each gram of soil contains 1×10^9 microorganisms and about 4000 species (Pouyat et al., 2020) such as microbes (bacteria and fungi), microfauna (nematodes and protozoa), mesofauna (microarthropods and enchytraeids), and macrofauna (including earthworms, woodlice, and millipedes). These diverse organisms interact with each other and with various plants and animals to create a complex web of biological activity. Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems such as nutrient cycling, water filtration, pest control, carbon storage, organic matter decomposition, pollutant degradation, and soil stabilization. Countless microorganisms and soil animals crush and recycle leaves and other dead plant material to form humus, which is rich in nutrients, stores water and stabilizes the soil structure.

Soil structure depends on the stable aggregates of soil particles and aggregate stability is used as an indicator of soil structure (Six et al., 2000). Aggregate results from the particle rearrangement, flocculation, and cementation and its formation is related to soil organic matter, fungal hyphae, exudate, earthworm, casts, roots, clay, and ionic bridging by metal ions (Bronick & Lal, 2005). That is, soil organic carbon, living organisms, ionic bridges, clay, carbonates, and hydroxides of amorphous metals act as a binding agent and in the formation of aggregates. Microaggregates (20–50 µm) protect soil C from decomposition and microbial biomass from predation (Li et al., 2016), and they support greater microbial diversity (Bach et al., 2018). Microaggregates are also physically stable due to strong binding and cementing properties, which make them resistant to disruption from natural and anthropogenic disturbance. Macroaggregates (>250 µm) are more loosely arranged and offer organisms less protection. They are also more easily disrupted by forest and rangeland disturbances (Li et al., 2016). The role of microaggregates (20–50 µm) in soil is to protect soil C from decomposition and microbial biomass from predation (Li et al., 2016) and they support greater microbial diversity (Bach et al., 2018). Microaggregates are resistant to various natural or anthropogenic disturbances due to strong bonds and cementing properties. Macroaggregates (>250 µm) offer less protection to organisms and are looser and more vulnerable during forest and rangeland disturbances (Li et al., 2016).

a. Soil Texture

Soil texture refers to the relative proportions of sand, silt, and clay particles in the soil, which primarily determine its textural class.

Soil texture plays an important role in various soil processes such as structure development, carbon sequestration, nutrient and water retention, infiltration, etc. (Bronick & Lal, 2005). However, its effects on the diversity and composition of the soil microbial community are being investigated. In general, coarse-textured sandy soils support organisms that are best adapted to moisture- and nutrient-limiting stresses. Finer-textured soils (silty - clayey) provide a greater variety of structural habitat, leading to comparatively high diversity of soil organisms.

Soil texture is associated with the distribution of pores of different morphologies. Soil pore spaces play an important role in the livelihood of various microorganisms. Micropores (<0.15 µm) exclude almost all organisms and retain water not available for root absorption. Mesopores (0.15–30 µm) provide habitat for bacteria, fungi and microfauna (eg protozoa, nematodes) and contain available water for plants. Macropores (>30 µm) are critical for gravity water flow and provide habitat for fungal hyphae and mesofauna. Larger soil organisms (e.g., earthworms, ants, termites) serve as soil engineers because their movement requires setting aside and mixing soil particles. Pore size distribution regulates how water, gases, nutrients, heat, and organisms move—and thrive—in soil.

b. Bulk Density

Bulk density depends on soil texture, soil organic matter content and arrangement of soil minerals (sand, silt, and clay). Soils dominated by the sand fraction have a high bulk density and soils dominated by silt and clay have a low bulk density. When the bulk density is high then there is poor passage of water through the soil, poor gas or air exchange and poor root penetration at depth.

Bulk density plays an important role in infiltration, available water capacity, soil porosity, rooting depth, soil microorganism activity, root proliferation and nutrient availability. An increase in bulk density leads to a decrease in macropores and an increase in meso- and micropores, resulting in an effect on hydraulic conductivity (Horn & Smucker, 2005). Thus, bulk density affects pore diameter and its distribution and consequently influences soil hydraulic properties (Dec et al., 2008).

Bulk density is determined mainly by soil compaction. Soil compaction increases bulk density and decreases soil porosity and pore continuity (Jensen et al., 1996). The associated shift in pore size distribution modifies microbial community structure, the microhabitats of microorganisms and their distribution, and affects soil functions and ecosystem processes. Thus, soil compaction since it affects the size and activity of microorganisms may affect the bioavailability of nutrients required for plant growth.

2.1.3 Function

Function regards the processes that occur in ecological systems, including demography processes affecting species populations (e.g., mortality, survival, recruitment), ecological processes such as vegetation productivity, nutrient cycling, or ecological succession occurring at the community-ecosystem scale, and disturbance regimes at the landscape scale.

2.1.3.1 Forest moisture

Forest moisture refers to the amount of water present in the forest ecosystem, including throughfall water, forest floor water content, and soil moisture which is influenced by various factors such as precipitation, drainage dynamics, forest structure, and climate conditions (Andrews et al., 2020; Kreye et al., 2018). Forest moisture can be measured using in situ observations and remote sensing technologies (Albergel et al., 2012). Remote sensing technologies, such as satellite-based sensors and aerial imagery, can also be used to estimate forest moisture. The Normalized Difference Moisture Index (NDMI) is a spectral index that is used to measure forest moisture. It is particularly effective in detecting forest disturbances and changes in moisture levels (Otero et al., 2019; Veraverbeke et al., 2011). The NDMI is determined by comparing the refracted radiations in the NIR and SWIR regions which are sensitive to changes in moisture levels (Taloor et al., 2021). This information is crucial for understanding the health and dynamics of forest ecosystems, as changes in moisture levels can indicate stress or disturbances (Zhang et al., 2016). NDMI calculate using this equation (Bo-Cai, 1996):

$$NDMI = \frac{(NIR - SWIR)}{(NIR + SWIR)} \quad \textbf{[12]}$$

Where NIR is near infrared band and SWIR is shortwave infrared band

2.1.3.2 Forest productivity

Forest productivity is defined as the standing forest volume at a given time *t*, *Vt* (Volume at time), which is the cumulative increase of stand volume since the stand was initiated (at *t*=*t*0). It is referred to as yield in studies of forest growth and yield (Avery & Burkhart, 2019; Edition & Part, 2005)

Conventionally, forest inventory data has been collected primarily by means of field surveys, which is both expensive and time-consuming (Hyyppä et al., 2000). Currently with the availability of remote sensing data, more effective methods of calculating the forest productivity carried out by utilized derived index from multispectral data (Baldo et al., 2023; Coops, 2015; Hyyppä et al., 2000). Some indexes such as VTI, NDVI, Forest canopy density in spatial temporal domain has been explored and tested their accuracy compared to in situ study.

There are several diverse techniques available for assessing the productivity of forested ecosystems. These techniques can be categorized into three overarching approaches: productivity assessed through physiological measurements, dimension analysis, or the examination of growth in relation to foliage concentrations and light (Coops, 2015). Summary of approach for forest productivity using remote sensing analysis was described in **Table 1.**

Table 1. Approach for forest productivity using remote sensing analysis.

Variable	Spatial scale	Typical sensor	Reference
Physiology - Gross Primary prductivity (GPP)/Net Primary productivity (NPP)	Regional to global	TERRA MODIS, AQUA MODIS, SPOT VEGETATION	Running et al., 2004; Heinsch et al., 2006
Dimension analysis - Height/diameter - Volume/biomass - Stocking/crown dimension	Regional to local Regional to local Local	Landsat, LiDAR LiDAR, Radar RapidEye, DigitalGlobe, LiDAR	Ganz et al., 2019 Lefsky et al., 2002 Geugeon and Leckie, 2001
Productivity via light and foliar concentrations - Chlorophyl - Nitrogen - LAI (Leaf Area Index)	Regional to local Regional to local Global to local	CASI, AVIRIS, HYPERION CASI, AVIRIS, HYPERION Landsat, MODIS	Coops et al., 2002 Oliver and Smith, 2005 Fang & Liang, 2014; Xu et al., 2017

Silvanus' report focuses on assessing biodiversity at the regional to local level. Hence, for this analysis, it is feasible to explore the utilization of variables like GPP/NPP or LAI (Leaf Area Index), with the availability of data from MODIS imagery.

Leaf area index (LAI), one half the total green leaf area per unit horizontal ground surface, is an important structural property of vegetation. LAI is defined as the total one-sided green leaf area per unit of ground surface. The effective LAI (Le) is calculated from the canopy gap fraction assuming the foliage spatial distribution is random (Fang & Liang, 2014).

Measuring LAI can be conducted in 2 methods, through direct and indirect (Fang et al., 2019; Fang & Liang, 2014). Direct method needs a direct observation in the field or in laboratory. Meanwhile, one method of the indirect LAI measurement, is from remote sensing than can cover large area (Fang et al., 2019; Fang & Liang, 2014; Y. Wang & Fang, 2020) Studies shows that LAI derived LiDAR through remote sensing techniques provided an effective result.

2.1.3.3 Tree mortality

Successive forest disturbances are mainly caused by human activities such as logging and fire (de Andrade et al., 2020), which are the primary causes of tree mortality rates (Brando et al., 2014; De Andrade et al., 2019). The mortality of trees carries significant implications for the future of forests, particularly concerning their long-term adaptation to climate change, aiming to enhance their resilience(Stephens et al., 2018) Observing patterns of forest adaptation following successive disturbances, such as logging and fire, can help protect and manage forest ecosystems (de Andrade et al., 2020). Tree mortality is a natural process in forest ecosystem that indicated forest health, due to the forest disturbance such as widespread insect, severe drought, or wildfire (Ambrose, 2021)

Another disturbance such as storm, are a common phenomenon in Europe. Most storms occur in winter, especially along the Atlantic coast. According to (Gardiner et al., 2010) storm responsible for more than 50% forest damage during 1950 to 2010 in European forest. Tree height increase the risk of snow (Nykanen1997) and storm (Canham et al., 2011; Díaz-Yáñez et al., 2019; Gardiner, 2021). Tree mortality caused by storm due to the fact that the lever arm exerted by wind on the crown of taller trees is higher (Gardiner,2021). Moreover (Furniss2020) report that tree mortality processes have been quantitatively described at a range of spatial scales disturbance including insect epidemics, drought, and storm events (e.g., windthrow, ice storms).

While fire induced tree mortality has been poorly documented in the literature, some studies suggest that mortality due to fire has been increasing in recent years (Malhi et al., 2014; Brando et al., 2019). In the short term, smaller trees (DBH < 20 cm) are more vulnerable to fire than larger trees (DBH > 40 cm) (de Andrade et al., 2020). Larger trees are usually less affected by fire than smaller trees, contributing significantly to the forest's overall resilience. However, in severe fires, the larger trees also have high mortality rates (de Andrade et al., 2020).

The mortality rate function (de Andrade et al., 2020) is:

$$MR= (\ln N0 - \ln St)/t \quad \textbf{[13]}$$

where ln = natural logarithm; St = number of survivors at time "t"; N0 = initial population size.

Tree mortality also can be estimated using remote sensing techniques such as using UAV imagery (Furniss et al., 2020) or Landsat imagery (Bergmüller & Vanderwel, 2022). Estimation of tree mortality can be carried out by comparing current NDVI and base NDVI map as proposed and analysed in (Pascual et al., 2022), while in (Van Gunst et al., 2016) tree mortality calculated based on NDVI and dNDWI (difference normalized wetness index). Several spectral indices can be used to estimate tree mortality, one of which is using NBR (Normalized Burnt Ratio) (Furniss et al., 2020; Liang et al., 2014). The formula that can be used is:

$$NBR = \frac{(NIR - SWIR2)}{(NIR + SWIR2)} \ X\ 1000 \ \text{(Key \& Benson, 2006)} \quad \textbf{[14]}$$

$$dNBR = NBRpost - NBRpre \quad \textbf{[15]}$$

$$RdNBR = \frac{dNBR}{\left(\frac{|NBRpre|}{1000}\right)^{0.5}} \ X\ 1000 \quad \textbf{[16]}$$

Figure 2. The Discrepancy or Variability in Spectral Indices Obtained Through Remote Sensing Compared to Actual Fire Damage Data

(Furniss et al., 2020) detected tree mortality by utilizing various spectral indices. **Figure 2** shows the relationship between Normalized Burnt Ratio and Basal Area (BA) mortality in lower-montane-mixed-coniferous forest. However, in this Silvanus report, tree mortality identification cannot be done because it requires in situ measurements. Apart from that, the relationship between spectral indices is not always linear with tree mortality.

2.1.3.4 Tree regeneration

Tree regeneration is the process that allows a forest sustainability through the growth and survival of seedlings and saplings that replace large forest trees as they die. Tree regeneration starts with the production of seeds on the mother tree as a result of flowering and pollination. Following the dispersal of seeds, germination, seedling establishment and sapling development are largely determined by site and weather conditions (Käber et al., 2021; Price et al., 2001). Tree regeneration can also occur vegetatively, sprouting from roots or stumps - which is relevant for assessing post-fire resilience.

The monitoring of tree regeneration carried out by utilizing the satellite image monitoring in landscape scale. According to (Caughlin et al., 2021) they compared the NDMI, NBR, NDVI to predict the forest canopy height compared to the LIDAR derived data and they conclude that NDVI produce the best estimation. They monitor the canopy recovery of their burnt area under observation during 15 years through NDVI.

NDVI (Normalized Difference Vegetation Index) is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the R and NIR values with a soil brightness correction factor (L) defined as 0.5 to accommodate most land cover types. The NDVI formula is in the following [17]:

$$NDVI = \frac{NIR - R}{NIR + R} \quad \textbf{[17]}$$

NDVI has been widely used as an indicator of several factors such as canopy density, biomass, plant health, and vegetation productivity (Rezaei & Ghaffarian, 2021; Turubanova et al., 2015; Verbesselt et al., 2016) Furthermore, NDVI is also effective to assess vegetation damage, stress, recovery (Rezaei & Ghaffarian, 2021). NDVI cannot directly assess tree regeneration, but it can indirectly monitor the growth of canopy cover, which is associated with tree regeneration. NDVI can be strongly correlated with the regeneration of non-woody herbaceous vegetation cover, but poorly correlated with tree seedling density in some cases (Buma & Wessman, 2011). NDVI is the ratio of the difference between the near-infrared band (NIR) and the red band (R) and the sum of these two bands (Rouse et al., 1974; Yengoh et al., 2015).

For Landsat 8, Red band and Near Infrared (NIR) band include in Band 4 and Band 5. Otherwise for Sentinel 2A, Band 4 is represented red band and Band 8 is represented Infrared Band.

2.1.3.5 Adaptation to fire disturbance

The presence or absence of plant functional traits related to fire is a key indicator of a forest's resilience to fire. It reflects the plant community's capacity to withstand fire and recover from fire impact, but also its contribution to fire hazard by stimulating fire progression. Fire adaptive traits are characteristic of ecosystems that have evolved under the influence of fire disturbance and provide adaptation to natural fire regimes (Keeley et al., 2011). These ecosystems depend on natural fire regimes to maintain their structural integrity, species composition, and ecological function (Pereira & Navarro, 2015). In contrast, fire-sensitive systems lack these fire adaptation traits, rendering them more vulnerable to fire disturbance. The pace of recovery in a forest community will be influenced by the combination of traits it possesses. Some traits help withstand fire damage, reducing its impact, while others aid in post-fire recovery, whether in the short-term or over the medium to long-term. Additionally, certain traits, often found in species that benefit from fire for regeneration and competitiveness, play a role in fire progression and may exacerbate fire severity.

Data obtained from field surveys of plant communities can be utilized to evaluate the presence of fire adaptation traits within these communities. More precisely, the identification of fire-related traits associated with species can be accomplished by referring to plant trait databases, such as the TRY database (Kattge et al., 2020) and the BROT database ((Tavşanoğlu & Pausas, 2018), to characterize the dominant species within the community.

Examples of fire adaptation traits, relevant to assess forest resilience, include:

Bark thickness: Some tree species, such as the cork oak (*Quercus suber*), have thick, fire-resistant bark that can insulate the inner tissues from high temperatures. The presence of such trait, in a mature stand, may indicate a higher resistance to fire damage, and higher tree survival.

Resprouting capacity: Some species, such as the Pyrenean oak (Quercus pyrenaica) or the shrub brooms (*Cytisus* sp.), have the capacity to resprout from root or trunk following a fire, even when the canopy has been burned. The presence of these resprouting species indicates a rapid recovery capacity, which takes advantage of the underground root system to facilitate regrowth and the reestablishment of the plant structure. On the other hand, some of these species, shrubs in particular, can be highly competitive, and due to their fast recovery and flammable structure contribute to maintain frequent fires, which hinder the natural regeneration of the forest and keep the system in an alternative stable state, dominated by shrubs.

Fire stimulated seed bank: Some species, such as the maritime pine (*Pinus pinaster*) or the Aleppo pine (*Pinus halepensis*), produce canopy seed banks that germinate after being exposed to the high temperatures during the fire. These species show considerable resilience, although their recovery to their original structure is slower when compared to resprouting species, given their growth from seed. Additionally, some invasive species, such as Acacia species (*Acacia* sp.) or Hackea species (*Hackea* sp.), possess this trait and have the capacity to form dense seed banks that often germinate more rapidly than native species, potentially allowing them to dominate post-fire environments.

Presence of resin and flammable oils: Some plants produce flammable resins and oils that, if ignited, can amplify the intensity of a fire. For instance, many pine species contain flammable resin. These flammable traits are often coupled with other fire adaptation traits to increase the species' resistance to fire or its germination or regenerative capacity. These combined attributes confer a competitive advantage to the species in a post-fire environment.

2.1.3.6 Soil functions: Soil pH

Soil pH indicates soil acidity and alkalinity. Neutral soils have a pH between 6.5-7.5, acidic soils have a pH ≤6.5 and basic soils have a soil pH≥7.5 with most soils exhibiting a pH between 3 and 9.

Soil pH influences the biological, chemical, and physical properties of the soil and affects plant nutrition and growth (Brosofske et al. 2001). It also correlates with the stability of minerals in soil, clay and organic matter, the assimilability of the various soil nutrients and, generally, the concentrations of trace elements. Most trace elements become more available to plants and microbes in neutral or slightly acidic soils, favoring plant growth. Leaching of various ions such as Ca, Mg and K results in a more acidic pH. So, in soils with a low pH the presence of these elements will be limited and their assimilable forms will have been removed by leaching. The trace elements Fe, Mn, Zn, Cu, and Co as well as Al show high solubility at low pH to the point where they become toxic to plants (Londo et al., 2006). At high pH their presence decreases, a lack of them is observed, and their lower levels can adversely affect plant growth (Jiang et al., 2017).

Soil pH can change based on many abiotic factors and plants growing in the soil can also have an impact on soil pH. The pH is affected in the rhizosphere or the area of soil immediately adjacent to the root network of a plant and can change dramatically over time due to the activity of plant roots (Niena, 2019). Soil pH has complex effect on plant growth leading to the variation in the distribution of plant species in acidic or calcareous soils (Soti et al., 2020).

External factors such as forest fires can affect soil pH. During forest fires there are losses in biomass and soil organic layers with simultaneous deposition of nutrient-rich ash on the soil surface resulting in an increase in soil pH (Agbeshie et al., 2022). A significant increase in soil pH is observed at higher temperatures (450-5000 ^{o}C) (Certini, 2005) and where high amounts of ash are deposited on the soil as it has alkaline pH due to the presence of metal oxides and carbonates. Based on the above, the growth of young plants after the fire may be affected due to the increase in pH.

Soils develop from geological parent materials in various topographic positions interacting with climates and organisms. The parent material plays an important role in the physical and chemical properties of the soil as it influences soil texture, structure, porosity, nutrient availability, and pH (Gökbulak & Özcan, 2008; Delgado and Gomez, 2016). The spatial distribution of soil pH is highly dependent on the nature of the parent material (Reuter et al., 2008). Soils originating from acid igneous rocks (e.g., granites) generally exhibit low pH levels due to their high content of silicate minerals that release hydrogen ions into the soil during weathering processes, making them acidic. Conversely, alkaline soils usually derived from sedimentary rocks rich in carbonate minerals (e.g., limestones) or basic igneous rocks with a low content of silicates (e.g., basalts,) that do not release hydrogen ions during weathering processes but neutralize them through chemical reactions with carbonates present in soils. The pH of basaltic material soils according to Singer (1987) usually ranges between 5.0 and 7.5 and high pH values may be maintained even under tropical conditions (Isbell et al., 1976, 1977), except following intensive weathering (Gillman and Sumpter, 1986). In contrast, soils on granitic material are usually acidic (< 5.0–5.5) (Glentworth and Muir, 1963). According to literature data (Dimopoulos et al., 2013, Tsiripidis et al., 2012, Fotiadis et al., 2012), there are species that prefer specific rocks. From the available data it appears that Quercus petraea, Quercus frainetto species prefer acidic soils, while Quercus trojana subsp. trojana and Quercus cerris prefer alkaline soils. The species Pinus nigra, like Quercus pubescens and Buxus sempervirens, do not have a particular preference for the geological substrate, but are among the few woody species that form bushes and forests on serpentine rocks.

Most trees can live in a wide range of soil pH values, provided there is an appropriate balance of essential nutrients. However, it has been observed that conifers grow best in acid soils while hardwoods prefer slightly acidic to neutral soils (Londo et al., 2006).

2.2 Biodiversity Framework

Referring to the previous chapter, ecological systems encompassing biodiversity can be characterized by their composition, structure, and function, which should be considered in biodiversity monitoring.
On the other hand, biodiversity could be observed based on several organizational levels, from genes to species populations, communities/ecosystems, and the entire landscape. All these levels can be described by considering composition, structure, and function. Figure 3 described the alfa, beta, and gamma indicators as a common scope in biodiversity monitoring.

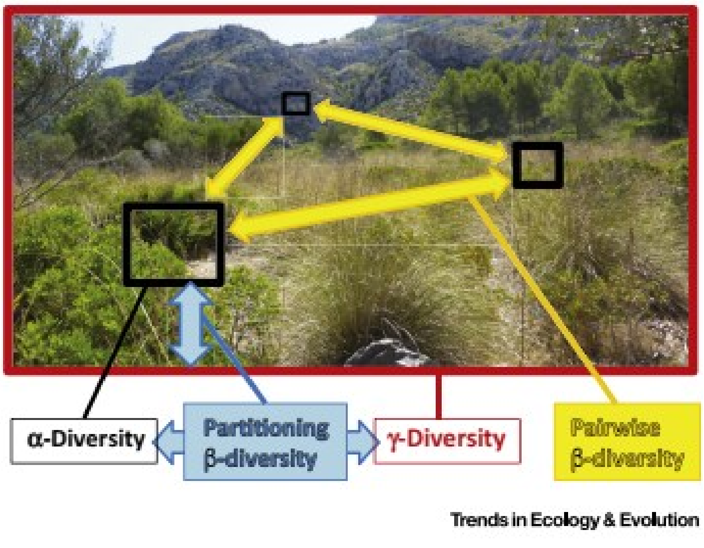


Figure 3. Biodiversity Level: alfa, beta, and gamma
Source: (Socolar et al., 2016)

Whittaker (1972) in (Socolar et al., 2016) classified diversity at the three levels: within habitat (species or alpha level), inter-habitat (beta level), and landscape diversity (gamma level). Alpha diversity is the within habitat or intracommunity diversity. Alpha diversity has two components: species richness and species evenness. Beta diversity is the between two habitats or inter community diversity. It is the change in species composition along environmental gradients. Gamma diversity is the landscape level diversity.

Alpha diversity

This is the most widely studied in diversity calculations method. It has two aspects: richness and equitability or evenness. Species richness is a measurement of the species content of the area presented in terms of several individuals or unit area or some other parameter. More the number of species, the higher will be the species richness index. Species richness indices are also known as variety indices. Equitability indices represent the relative abundance of different species of the area in terms of their evenness of distribution. A community having species with equal number of individuals for each species will have a higher evenness index as compared to a community in which dominance is concentrated in one or few species. Indices that combine both these components are known as heterogeneity indices. Some of the methods for finding the alpha diversity presented as follows (Thukral et al., 2006):

Chao's index: Chao's index for estimation of total species richness is given by the equation:

$$S_{max} = S_{obs} + (a^2 + 2b) \quad \textbf{[18]}$$

Where:

S_{max} = Maximum no. of species,

S_{obs} = Actual number of species observed in different samples,

a = Number of species represented by one individual each (Singletons),

b = Number of species represented by two individuals each (Doubletons).

1. Fisher's α: Fisher suggested that number of individuals representing different species follow a logarithmic series.

$$S = \alpha \log (1+ N/ \alpha) \quad \textbf{[19]}$$

   Where α is a constant. The value of Fisher's α is computed by iteration

2. Menhinick's biodiversity index: This index implies that number of species is directly proportional to square root of number of individuals.

$$R_{MENHINICK} = S / N^{½} \quad \textbf{[20]}$$

3. Margalef's index: This index assumes that number of species vary logarithmically as the number of individuals.

$$R_{MARGALEF} = (S-1)/ \log N \quad \textbf{[21]}$$

4. Odum's index: Odums's index (Odum et. al., 1960) is like the Margalef's index.

$$R_{ODUM} = S/ \log N \quad \textbf{[22]}$$

Beta diversity

Beta diversity is a measure of the change in diversity along a gradient. The simplest index for this measure is species turnover rate defined as the number of unique species for two habitats per species. Some of the indices of β - Diversity that widely used are given as follows:

1. Whittaker's Beta diversity

$$\beta_w = S/ (\alpha - 1) \qquad \textbf{[23]}$$

S = Total number of species,

α = The average species richness at the two habitats.

2. Cody's Beta diversity

$$\beta_c = [g(H) + l(H)] / 2 \qquad \textbf{[24]}$$

g (H) = The number of species gained,

l (H) = The number of species lost moving along a transect.

3. Routledge's Beta diversity

$$\beta_R = \frac{S^2}{2r + S} + 1 \qquad \textbf{[25]}$$

S = Total number of species,

r = Number of species with overlapping positions

4. Wilson & Schimida's Beta diversity

$$B_{W\&S} = [g(H) + l(H)] / 2\alpha \qquad \textbf{[26]}$$

g (H) = The number of species gained,

l (H) = The number of species lost moving along a transect,

α = The average richness of species at the two habitats

Gamma diversity

Gamma diversity is the diversity of pooled communities. An example for the computation for the richness contents of diversities at different levels is given as follows (**Table 2**):

Table 2. The Computation for The Richness Contents of Diversities at Different Levels

Species #	Habitat A	Habitat B	Habitat C
1	+	+	
2	+	+	+
3	+		
4	+	+	
5	+	+	
6	+		
7	+		
8	+		
9	+	+	
10	+		
Alpha Diversity	5	6	5
Beta Diversity	Beta AB = 7	Beta BC= 5	Beta AC= 4
Gamma Diversity		Gamma ABC=10	

After combining all the references above, a tentative framework of biodiversity components and indicators has been made. The following figure shows the biodiversity components assembled from the indicators. Biodiversity component can be seen in **Figure 4**.

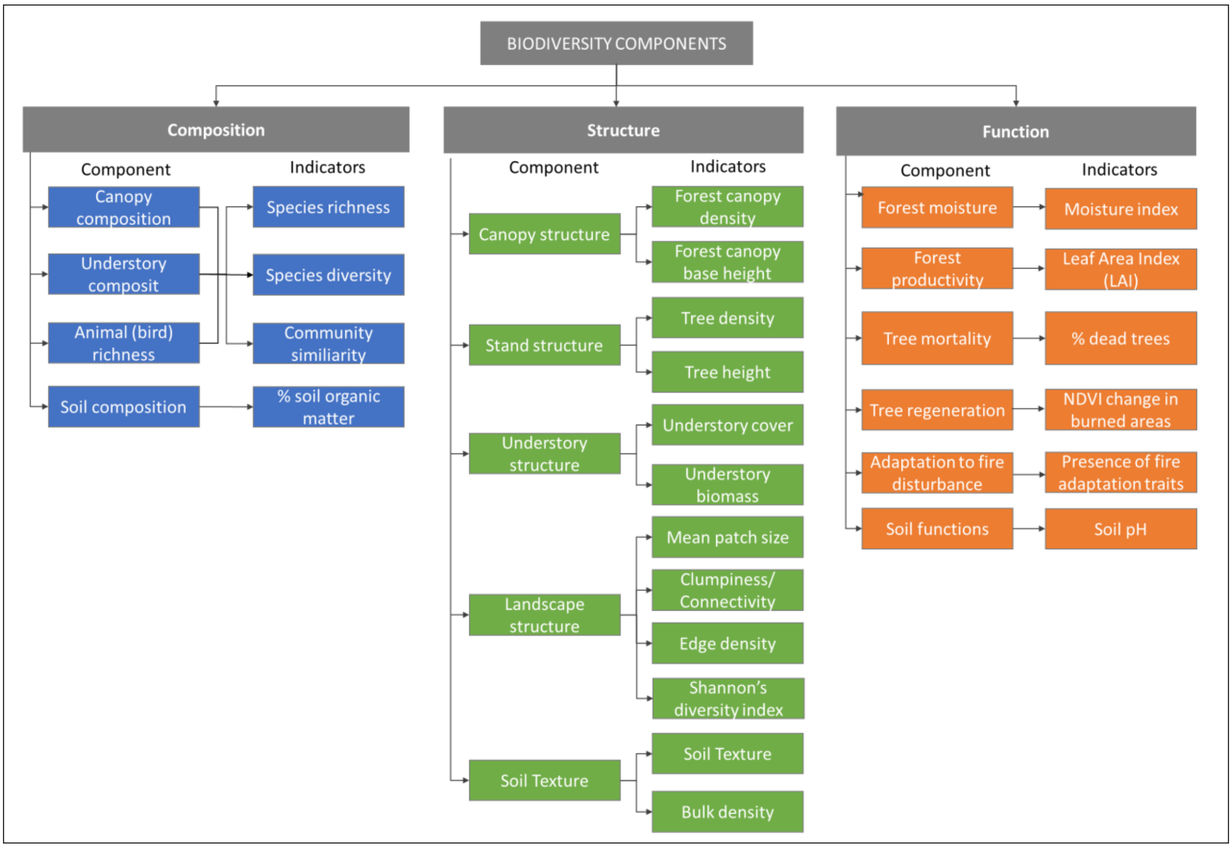


Figure 4. Biodiversity Component

Table 3. Components, Indicators, Data Source, and Scale of Biodiversity

	Component	Indicators	Data source	Scale	Pre-fire or post-fire use
Composition	Canopy composition	Species richness Species diversity Community similarity	In situ measurement	Forest ecosystem, landscape	Pre-fire, post-fire
	Understory composit.		In situ measurement	Forest ecosystem, landscape	Pre-fire, post-fire
	Animal composition		In situ measurement	Forest ecosystem	Post-fire
	Soil composition	% soil organic matter	In situ measurement	Forest ecosystem	Post-fire
Structure	Canopy structure	Forest canopy density Forest canopy base height	Land cover data from aerial imagery (e.g. drone) or satellite imagery; In situ measurements	Forest ecosystem, landscape	Pre and post-fire
	Stand structure	Tree density (n trees/ha) Tree height	In situ measurement or LIDAR	Forest ecosystem	Pre-fire, may also be use to assess post-fire recovery
	Understory structure	Understory cover Understory biomass	In situ measurement, LIDAR, satellite (in open areas and forest clearings)	Forest ecosystem	Pre-fire, may also be use to assess post-fire recovery
	Landscape structure	Mean patch size Clumpiness/ Connectivity Edge density Shannon's Diversity Index	Land cover data from aerial imagery (e.g., drone) or satellite imagery	Landscape	Pre-fire, may also be use to assess post-fire recovery
	Soil structure	Soil texture; Bulk density Etc.	In situ measurement	Forest ecosystem	Pre-fire, post-fire
Function	Forest moisture	Moisture index	Satellite imagery	Forest ecosystem	Pre-fire, post-fire
	Forest productivity	Max NDVI; small integral of NDVI, etc.	Satellite imagery	Forest ecosystem	Post-fire
	Tree mortality	% dead trees (loss of photosynthetic activity – NDVI)	Satellite imagery	Forest ecosystem	Post-fire
	Tree regeneration	NDVI change in burned areas; Density of seedlings and saplings	Satellite imagery; in situ	Forest ecosystem	Post-fire
	Adaptation to fire disturbance	Presence of fire adaptive traits	In situ data (from species composition)	Forest ecosystem	Pre-fire
	Soil functions	Soil pH Etc.	In situ measurement	Forest ecosystem	Pre-fire, post-fire

Table 3 shows the components and indicators along with the data source, the scale of biodiversity, and when the data should be retrieved. In this deliverable, we focus on satellite imagery data source and landscape scale.

Satellite image (remote sensing) is a methodology which integrates geographical information systems (GIS), environmental variables, and landscape ecology was used to evaluate the European biodiversity landscape (Martínez et al., 2010). The study area was Terras do Mino, the Iberian Peninsula. Two satellite images were used in the project. A Landsat TM (Thematic Mapper) image acquired in July 1990 (Path/row 204/030), and a Landsat ETM+ (Enhanced Thematic Mapper). Total landscape level indices that were used 14 (Number of patches, Patch density, Area mean, Area median, Area standard deviation, Area coefficient of variation, Perimeter-area fractal dimension, Patch richness, Shannon's diversity index, Shannon's evenness index, Total edge, Edge density, Contagion). The indices used have shown to be appropriate for the evaluation of fragmentation processes in the study area. The consistency in classification accuracy, spatial resolution, data processing, seasonality, and minimum mapping unit between 1990 and 2002 analysis prove the reliability of the results of landscape indices. The results indicate that although the traditional landscape is still predominant in the Biosphere Reserve of Terras do Mi˜ no, it is in a clearly regressive phase (passing from 65.27% in 1990 to 57.33% in 2002), which implies a generic process of landscape openness and low connectivity.

Biodiversity characterization at landscape level using geospatial modelling technique was used to evaluate the ecology in Meghalaya, North India (Roy & Tomar, 2000). A geographic information system has been used to spatially model the disturbance regimes and to integrate the ground based nonspatial data with the spatial characters of the landscape. The various parameters (viz. patch shape, patch size, number of patches, porosity, fragmentation, and juxtaposition) have been analysed on the most recent landcover map to spatially present the disturbance regimes.

A supervised classification of specifying seven landscape element types (Casuarina, Paddy, Grass, Acacia, Evergreen, Savana and Moist deciduous) were used to study the species diversity in Karnataka, India (Nagendra & Gadgil, 1999). This area was covered by Indian Remote Sensing Satellite (IRS) 1B LISS 2 imagery of 3 March 1993 at the height of the dry season. The accuracy of supervised classification using 57 randomly distributed points in the landscape was 88.8%.

High resolution images from satellite remote sensing not always give advantages for biodiversity measurement purposes. Hyperspatial data with their increased pixel resolution are possibly best suited at facilitating the accurate location of features such as tree canopies, but less suited to the identification of aspects such as species identity, particularly when spatial resolution becomes too fine and pixels are smaller than the size of the object (e.g., tree canopy) being identified (Nagendra & Rocchini, 2008).

3 Ecological Resilience (ER)

Ecological resilience has been defined in the literatures in different ways, each reflecting different aspects of stability. Ecological resilience has been focal points of research due to the importance of this aspect in ecosystem management including the forest. Perturbation or disturbance such as wildfire and storm bring a chalenge into an ecosystem and a resilience ecosystems can cope with it by maintaining its pre-disturbance state. The post disturbance speed of recovery also an indication of the resilience ecosystems.

3.1 Ecological Resilience Concept

The concept of resilience has been defined by Holling as the “buffer capacity of a system to absorb perturbations, or the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behaviour” (Holling, 1973).

Levin Simon defines ecological resilience, also called ecological robustness as “the ability of an ecosystem to maintain its normal patterns of nutrient cycling and biomass production after being subjected to damage caused by an ecological disturbance” (Levin, 2023). The term "resilience" is occasionally used interchangeably with "robustness" to characterize a system's capacity to both endure and rebound from a disruption while maintaining its functionality.

The notion of system resilience was initially introduced by the theoretical ecologist S. Holling (1973). In ecological literature, resilience has been defined in two distinct ways, each shedding light on different facets of stability. (Holling, 1973) originally emphasized these distinct aspects of stability to underscore the differences between efficiency and persistence, constancy, and change, as well as predictability and unpredictability. He characterised stability as the persistence of a system near or in proximity to an equilibrium state. Conversely, resilience was introduced to describe the behaviour of dynamic systems that exist far from equilibrium. It does so by quantifying resilience as the extent of disturbance that a system can withstand without undergoing a state change.

The resilience of an ecological system is tied to how well the system operates, rather than the stability of its individual populations or its capacity to sustain a consistent ecological condition.

Regarding the SILVANUS project, a glossary encompassing key concepts has been formulated and incorporated into the project's framework (**Table 4**).

Table 4. Key Concepts in SILVANUS Project

Concept	Definition
Resilience	The ability of an ecosystem to absorb changes of state variables, driving variables, and parameters, that is, to maintain its normal patterns of nutrient cycling and biomass production after disturbance (Holling, 1973). Also referred to as ‘ecological resilience’ or ‘Holling’s resilience’ and often confused with ‘resistance’. *Units of measurement*: intensity of disturbance associated with a switch between states (i.e., the threshold; Connell and Sousa, 1983) coupled with data to document the switch (e.g., ecosystem attributes such as species composition)
Resistance	The ability of an ecosystem to absorb changes of state variables, driving variables, and parameters, that is, to persist after disturbance (Holling, 1973). Also referred to as ‘ecological resilience’ or ‘Holling’s resilience’ and often confused with ‘resistance’. *Units of measurement*: measure of one or more ecosystem state variables (e.g., species composition) before and after disturbance. Measuring resistance does not require knowledge of system specific thresholds
Threshold	Point at which a small change environmental conditions, associated with disturbance, leads to a switch between ecosystem states (Suding and Hobbs, 2009)
Disturbance	Any process that effects ecosystem, community, or population structure, and/or individuals within a population either directly or indirectly via changes to the biophysical conditions (Hobbs and Huenneke, 1992 and references within). Short-term and longer-term disturbances are often referred to as ‘pulse’ and ‘press’ disturbances respectively (Bender et al., 1984) or ‘acute’ and ‘chronic’ disturbances (Connell, 1997)

Source: (Standish et al., 2014: 43-51)

Earlier research has shown that ecological resilience can be assessed by observing the pace, degree, and manner through which vegetation characteristics are restored following a disturbance (Westman, 1986).

In the SILVANUS project, ecological resilience is defined as the capacity of ecosystems to absorb the disturbance (resistance) and recover to the equilibrium pre-disturbance state after being subjected to damage caused by an ecological disturbance (Holling, 1973; Levin, 2023; Oliver et al., 2015)

Based on the definition that is used in SILVANUS Project, we are considering the ecological resilience indicators such as elasticity, malleability, and trends, drawing inspiration from the research conducted by (Liu et al., 2021) in their study on these metrics.

3.2 Forest Disturbance

Forests, as living ecosystems, endure natural disturbances primarily influenced by climate change. Recently, climate change has become a significant factor of disturbance, including fires, droughts, windstorms, as well as insect infestations and pathogen outbreaks (Seidl et al., 2017). Hence, human-induced disturbances have also become a major threat capable of altering the composition, structure, and the overall functioning of the forest. Activities such as land use changes and timber production, driven by human actions, pose risks to the to the long-term health of forests (Senf & Seidl, 2020).

The following **Figure 5** illustrates a fire event as a forest disturbance. This event occurred in Croatia in 2022.

Figure 5. Forest Fire in Croatia, 2022

This report primarily focuses on forest disturbances triggered by climate change. It is well-established that climate change disrupts forests in three distinct ways: direct, indirect, and through interactions (Seidl et al., 2017). One of the most damaging disturbances observed in forests is wildfires, which can result from both nature and human errors. The impact of wildfires extends to both the biotic and abiotic components of the ecosystem, causing soil degradation and creating open spaces devoid of tree canopy. The magnitude of a significant wildfire event can be measured in terms of its temporal duration and spatial extent.

In many areas, climate change and land-use change cause major natural forest disturbances, such as wildfires, windstorms, and insect outbreaks, and are becoming more frequent, intense, severe, and widespread (Viljur et al., 2022). In several forest ecosystems, fire is an important natural process and disturbance (Moretti et al., 2006; Myers, 2006). Along with herbivory, fire has an ecological role in shaping vegetation structure and composition, it promotes natural regeneration and the diversity of habitat mosaics in the landscape (Pereira & Navarro, 2015). The presence of plants with traits that enhance fire resistance (e.g., thick bark) or the recovery after fire (e.g., fire stimulated germination) is a key aspect affecting the resilience of the ecosystem. Fire-dependent systems cover about 53 % of the world's terrestrial surface (Shlisky et al., 2007). These systems have developed in response to natural fire regimes, which depending on the region differ in the frequency, intensity, and seasonality of fires. For instance, the natural fire regime of Mediterranean forests, includes large and intense crown fires, occurring in the warmer and dry season and with a frequency of decades or even more (Archibald et al., 2013). In these regions, forest species exhibit various adaptations, including the capacity to regenerate through resprouting after a fire, the development of seed banks that sprout upon fire stimulation, or the possession of insulating barks, such as cork. However, the composition and structure of forests has drastically changed in the recent past, with consequences for forest adaptation and resilience to fire. For instance, several native oak species (*Quercus sp.*) show a high resistance to fire damage when in mature stands (due to stand structure, humidity content, and a thick bark) but also the ability to resprout vegetatively after fire, a trait that is also shared with some shrub species in the understory. On the other, the plantations of maritime pine (*Pinus pinaster*), which were established during the 20th century, not only amass a substantial quantity of flammable biomass due to high tree density and the presence of fine fuels in the litter but also the trees lack fire resistance. Moreover, they are unable to resprout, and their recovery depends on a seed bank, thus being slow to recover. If subject to frequent fires, these forest systems tend to be replaced by other systems such as shrublands. In additions to changes in the forest composition and structure, the fire regime has also changed, driven by direct human activity, which is the dominant source of ignitions, and by climate change. Current fire regimes have become more frequent and larger in scale, posing a threat to the forest's capacity to recover following such disturbances, and moving away from a natural process to an anthropogenic process of disturbance.

The final vegetation of the Mediterranean region is described by different ecologists (e.g., Naveh, 1974) as fire-climax (i.e., a vegetation association that stabilises after frequent and repeated fires). In many areas, under natural conditions, an evergreen forest with holm oak (*Quercus ilex*) as the predominant species would be the climax stage of the region's vegetation community. On the other hand, repeated fires lead to a vegetation complex in which secondary vegetative stages, with shrubs adapted to the passage of fire, are prevalent and tree vegetation covers limited areas. Fire is undoubtedly a natural ecological factor, although human-caused fires increase its frequency, intensity and extent. The use of fire by humans has been documented for 250,000 years, but some evidence would take this date back just as many years; as a result, large portions of the landscape were profoundly transformed by human action aimed at obtaining, in forest areas, free land that could be used as pasture and for cultivation. The impact of fires would have been more serious if fire had not already played the role of filter in the development of Mediterranean ecosystems, whose species were already adapted to fire.

In these ecosystems, one finds many fire-resistant plant species such as the Cork Oak (*Quercus suber*) or even plants whose germination is stimulated by the passage of a fire. For example, plants of some endemic Mediterranean genera (*Cistus, Halimium, Fumana, Tuberaria*) germinate after the vegetation has burnt (Pyrophytes). Plants like the latter include those with a good capacity for rapid vegetative recovery after fires, among which are the Holm oak (*Quercus ilex*), the cocciferous oak (*Quercus coccifera*) and other evergreen oaks. In addition to morphological adaptations in response to the passage of fire, several plants possess the capacity for changes in phenology, growth rate, biomass, and nutrient transfer to different parts of the plant (references in Stamou, 1998)). For example, overgrazing or frequent fires cause fast-growing plants to predominate (Paraskevopoulos et al., 1994). Among animals, the predominance of species that can move away from fires and quickly recolonise recently burnt areas is characteristic of environments subject to frequent fires (Pantis et al., 1988). Generally, burnt areas are dominated by species adapted to living in a variety of habitats and climatic conditions. The recolonisation of burnt areas is often carried out by animals that can take refuge in the deeper layers of the soil (Athias-Binche et al., 1987).

Some aspects, however, must be highlighted regarding fire as an ecological factor.

- Fire is a natural factor in all Mediterranean ecosystems on the earth's surface, but plants in the Mediterranean basin do not seem to be as specifically tolerant to the impact of fire as in Western Australia or South Africa. After repeated fires, the vegetation of Mediterranean forest areas is severely damaged, and gaps remain (Pausas & Vallejo, 1999).
- 90% of the burnt areas in Europe are in the Mediterranean Biogeographical Region, within which 200,000 ha of forests burn each year (Hernandez et al., 2015).
- Natural or spontaneous fires are the cause of only 4 % of fires in the region (Hernández et al., 2019).
- Before the depopulation of rural areas, most fires were not overly dangerous as they were immediately controlled. In addition, fires did not find fuel in the form of the tree vegetation that is now reoccupying abandoned crops and pastures (Blondel & Aronson, 1999). The use of pine forests for timber and fuel has decreased dramatically, contributing to the phenomenon (Stamou, 1998).
- Reforestation with combustible species such as pine and eucalyptus are conducive to the development of higher intensity fires (Grove & Rackham, 201 C.E.).
- The use of aerial fire-fighting equipment only serves to limit the damage of small fires.

The number of fires is expected to increase in the coming years because of global warming (Kasischke & Stocks, 2000). Therefore, although fires are natural disturbances that contribute to the maintenance of landscape variability and, therefore, biodiversity, the use of fire as an ecological factor in the region (an intervention technique recently suggested by some ecologists) must be more carefully considered and managed. According to some authors (Grove & Rackham, 201 C.E.), small, controlled fires (as were carried out in the past by shepherds) could prevent the accumulation of combustible vegetation and the occurrence of disastrous fires. In addition, increased grazing in risk areas may reduce the possibility of such fires. The development of vegetation reconstruction techniques for the recovery of burnt land is also important to avoid fostering desertification phenomena in repeatedly burnt areas.

Since 1990, a pilot project to develop a forest fire information system has been developing in the European Union (Council Regulations EU 86/3529/EEC and 92/2158/EEC). Data were collected daily at regional level in France, Greece, Italy, Spain, and Portugal to establish a geographical database on forest fires. In the Mediterranean part of the EU, two thirds of fires occur in summer and are responsible for three quarters of the total burnt area. The area of fires also varies between these regions. The largest fires (> 30 ha) occur in northern Portugal and Spain, whereas in southern Italy almost all fires are smaller than 30 ha. Active fire protection measures include forecasting the risk of fires occurring, which involves analysing meteorological data on a reiterative basis to predict conditions potentially conducive to fires, and regular monitoring, using fixed installations (such as control towers) or mobile installations (land patrols and use of aircraft). Considering that the cost of putting out fires, and subsequently recovering burnt areas, varies between 1,000 and 5,000 euros per hectare burnt, the European Commission is funding some pilot projects. PROMETHEUS, for example, studies the effects of fires on vegetation and suggests management methods to limit the damage. The PROMETHEUS system is currently applied for validation in five European countries: Greece, Italy, Portugal, France, and Switzerland.

The related variation of resilience that succeeds the wildfire event is relevant to assess, because fires often lead to changes in environmental conditions, biomass, species diversity, and ecosystem function (G. D. Peterson, 2002). Three main disturbance factors are considered. Each of them will be evaluated in a classification (a value from 1 to 5), considering some influential factors described below in each category. The higher is the classification number, the lower and challenging will be the resilience process of the considered area.

- Disturbance intensity: including fire severity, deforestation intensity, exposure to disturbance, fire temperature.
- Disturbance regime: including fire frequency, fire history, fire recurrence, previous disturbance events.
- Disturbance timing: burn time in a specific area.

3.3 Ecological Resilience Framework

Ecological resilience can be seen as a combination of recovery and resistance (Oliver et al., 2015) Recovery is the ability of the ecology to recover to the equilibrium of the position before disturbance. Resilience is the ability of the ecology to resist its functions through adaptive capacity. The following variable on calculating ecological resilience also in line with Deliverable 7.1, Ch.5.1, page 70 which is mentioning vegetation monitoring to measure ecological resilience. In this deliverable, the following variable also considering vegetation as the main resource of measurement.

3.3.1 Elasticity

Elasticity, which considers both the rate and timing of recovery following a disturbance, has been devised to gauge ecological resilience. The timing (T) signifies the duration from the end of the disturbance to the end of the recovery process. R represents the extent of recovery from the end of the disturbance to the end of the recovery process. A shorter timing and a swifter rate of recovery indicate greater elasticity and high resilience.

The rate of recovery is articulated as follows:

$$Elasticity = \frac{R}{T} \quad \textbf{[27]}$$

Elasticity refers to the rapidity at which a system can return to a stable state after a disturbance (Westman, 1986). Some parameters to monitor to evaluate post-disturbance stable state may be the return period of species richness, beach width and elevation, percentage vegetation cover (Westman, 1978) and sorting of sand grain size and shape.

3.3.2 Malleability

Malleability is defined as the extent to which a system deviates, following a disturbance, from a reference equilibrium value or its initial state. Malleability (Mal), is derived from the difference between forest conditions before and after the disturbance; this difference is then divided by the pre-disturbance forest condition as follows:

$$Malleability = \frac{|R - D|}{D} x\ 100\ \% \quad \textbf{[28]}$$

R corresponds to the equation for elasticity, and D represents the change at the end of the disturbance. Malleability proves to be a valuable tool for assessing the impacts of disturbances on ecosystem characteristics. Lower malleability values are indicative of stronger malleability, a more stable forest ecosystem, and an enhanced level of forest resilience.

Malleability is the degree to which the stable state that is established after a disturbance differs from the original steady state (Westman, 1986).

3.3.3 Trend

Trend assessment involves examining the oscillations between post-recovery and pre-disturbance measurements of forest greenness and landscape metrics. Subsequently, the three fundamental trends—decreasing, increasing, or stable—during the transition from pre-disturbance to post-recovery stages are determined using Mann-Kendall (MK) non-parametric analysis at a significance level of p = 0.(Czerwinski et al., 2014).

The significance of identifying decreasing, increasing, or stable trends in forest resilience lies in their potential to indicate the degradation, improvement (evolution), or stability of the forest ecosystem's characteristics. These trends offer valuable insights into the ecosystem's overall health and capacity to withstand disturbances.

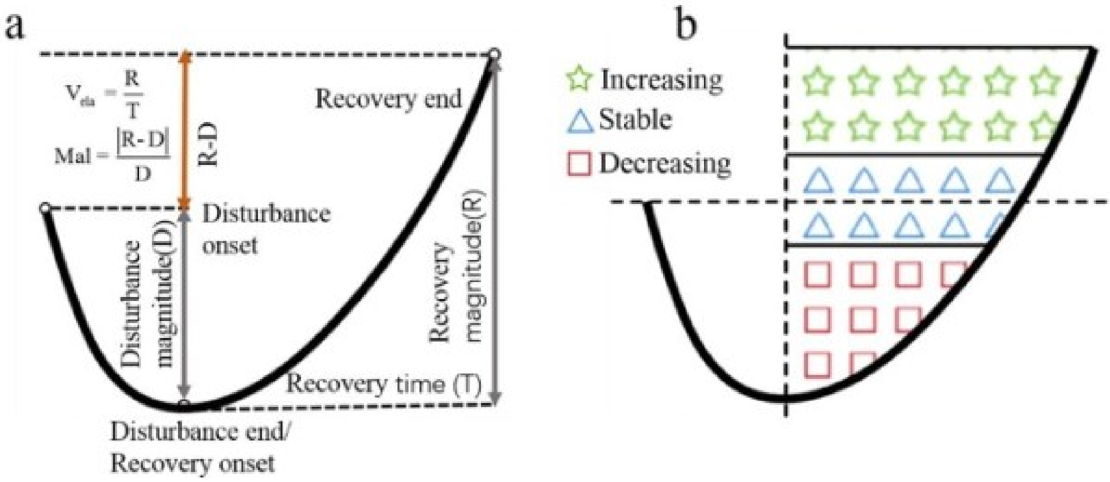


Figure 6. Indicators for ecology resilience: a) Elasticity and malleability; b) Trend

4 Method

4.1 Data Collection Method

This first task employs a qualitative and quantitative method. Data is mainly collected through secondary observation, such as gathering from satellite images, papers, and related documents. We collected Landsat 8 OLI (Operation Land Imager) satellite images for monitoring forest conditions from 2015 to 2023. The data was taken from USGS Earth Explorer. We filtered the clear-sky scenes with maximum of 20 % cloud cover. We applied radiometric and atmospheric correction before processing the images.

On the other hand, field observation was conducted in several pilot areas to observe the overall condition. Pilot observation is one of the ways to assemble data. Because all pilot areas have different characteristics, field observation is needed if it's possible to be done. Data from pilots assembled through data collection provided by pilot partners. A systematic literature review was also conducted to analyse the rest data that could not be collected from the pilot area.

4.2 Data Analysis

4.2.1 Logical Framework Analysis

A logical framework is a tool for monitoring and evaluating a project or a programme. Logical framework (logframe) can be used for defining and understanding project success (Baccarini, 1999). The logical framework is also known as logframe, logframe matrix, logic model, logical model, or programme logic (Uwizeyimana, 2020). Logframe is a matrix representing the hierarchy relationship of project objectives between the inputs, activities (processes), outputs, outcomes, and impacts (Auriacombe, 2011; Baccarini, 1999). The hierarchy of project objectives in logical framework is shown in **Figure 7**.

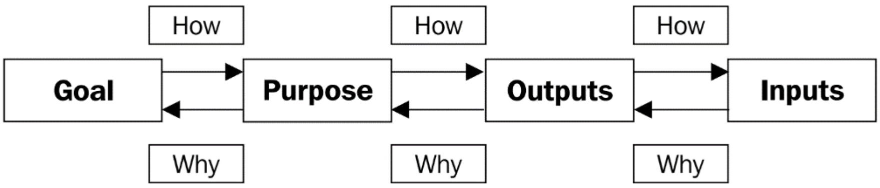


Figure 7. Hierarchy of Project Objectives in Logical Framework
Source: (Baccarini, 1999)

There are two components of project success: project management success and product success (Baccarini, 1999). Project management success is focuses on the project process and the successful accomplishment of cost, time, and quality objectives. It also considers the way the project management process was conducted. Product success is deals with the effects of the project's final product (Baccarini, 1999).

4.2.2 Impact Measurement: Biodiversity

All Ecological resilience programme have a goal. One of the goals of the programme is ecosystem recovery or biodiversity recovery. So, biodiversity needs to be assessed. This research uses multispectral derived indices to assess biodiversity such as NDVI, NDMI, Shanon Index diversity both pre-fire, post fire and after the rehabilitation and restoration programs carried out.

4.2.3 Resilience index calculations

In this report, we assessed ecological resilience by using parameters discussed in section 3.1, including malleability, elasticity, and trend analysis. The outcomes of these resilience assessments are presented in a qualitative and comparative analysis across the pilot project sites. The determination of resilience combines the evaluation of vegetation health, with the Normalized Difference Vegetation Index (NDVI) serving as a proxy (Cui et al., 2013). NDVI is a widely utilized vegetation index for quantifying forest resilience, as it offers valuable insights into vegetation structure and its relationship with plant characteristics and productivity (Pan et al., 2018). The process of calculating resilience involves several steps:

1. Disturbance magnitude calculations

The identification of the fire event location and timing relies on fire-related data extracted from the EFFIS report data for EU pilot projects and data provided by the government for non-EU pilot projects. Disturbance magnitude is determined by measuring the difference in NDVI values before the fire event and immediately after it.

$$Disturbance\ magnitude\ (D) = NDVIpre - NDVIpost \qquad \textbf{[29]}$$

2. Recovery time

Forests require a specific duration to return to their initial state prior to the occurrence of a fire event. The recovery time (T) is computed by tracking the period from the onset of the fire until the forest ecosystem regains at least 70% of its initial condition (Rezaei & Ghaffarian, 2021). This temporal assessment is carried out manually by monitoring the changes in NDVI monthly.

3. Recovery magnitude calculations

Recovery magnitude is the difference in NDVI values between the recovery period and the initial state. This measurement describes alterations in forest conditions both before the fire and upon its recovery. A higher recovery magnitude indicates a less stable forest ecosystem.

$$Recovery\ magnitude\ (R) = |NDVIrec - NDVIpre| \qquad \textbf{[30]}$$

4. Elasticity

Elasticity is an indicator of the recovery rate after experiencing disturbance. This elasticity metric is derived from the recovery magnitude and the recovery time. A higher elasticity value indicates faster recovery of the forest ecosystem.

$$Elasticity = \frac{R}{T} \qquad \textbf{[31]}$$

5. Malleability

Malleability reflects the extent of deviation from the initial state after a fire event. A greater malleability value indicates a less stable ecosystem, whereas a lower malleability value suggests a stable and more resilient ecosystem. The maximum malleability value is 100% or 1.

$$Malleability = \frac{|R - D|}{D} x\ 100\ \% \qquad \textbf{[32]}$$

6. Trends

Time series analysis is calculated based on the average NDVI value per month after a fire event. Trend analysis was carried out using the Mann Kendal method.

4.2.4 Fire Weather Index

The Fire Weather Index (FWI) is an internationally recognized meteorological metric used to assess the risk of fire. Originally developed by the Canadian Forestry Service, it measures conditions conducive to forest fire ignition and spread by considering various weather factors such as temperature, precipitation, relative humidity, and wind speed. This report utilized FWI data from the Copernicus Climate Change Services (C3S) using ERA5 reanalysis data. The fire weather index is classified into six categories as mentioned below:

1. Very low danger: FWI is less than 5.2.
2. Low danger: FWI ranges from 5.2 to 11.2.
3. Moderate danger: FWI ranges from 11.2 to 21.3.
4. High danger: FWI ranges from 21.3 to 38.0.
5. Very high danger: FWI ranges from 38.0 to 50.
6. Extreme danger: FWI is more than 50.

5 Pilot Area

5.1 Gargano Park – Italy

5.1.1 Location/ Administrative

Gargano is a historical and geographical sub-region in the province of Foggia, Apulia, southeast Italy, consisting of a wide isolated mountain massif made of highland and several peaks and forming the backbone of the Gargano Promontory projecting into the Adriatic Sea. Gargano is a historical and geographical sub-region in the province of Foggia, Apulia, southeast Italy, consisting of a wide isolated mountain massif made of highland and several peaks and forming the backbone of the Gargano Promontory projecting into the Adriatic Sea. The Gargano National Park, one of the Italian project pilots jointly with the Park of Tepilora in Sardinia, is a National Park established in 1991 (according to art. 19 of Law 394/91, the framework law on protected areas). The area of Gargano Park shown in **Figure 8**. The territory, located in the north-eastern part of Apulia, covers over 118,000 hectares, and includes 18 municipalities in the province of Foggia:

- insular: Tremiti Islands
- coastal: Mattinata, Peschici, Rodi Garganico, Manfredonia, Vieste
- inland with important coastal hamlets (indicated in brackets): Ischitella (Foce Varano), Vico del Gargano (San Menaio), Lesina (Marina di Lesina), San Nicandro Garganico (Torre Mileto), Cagnano Varano (Capojale)
- inland and piedmont areas: Apricena (piedmont area), Carpino (inland), Monte Sant'Angelo (inland), Rignano Garganico (inland but with part of the territory falling within the piedmont area), San Giovanni Rotondo (inland but with part of the territory falling within the piedmont area), San Marco in Lamis (inland but with part of the territory falling within the piedmont area), Serracapriola (piedmont area).

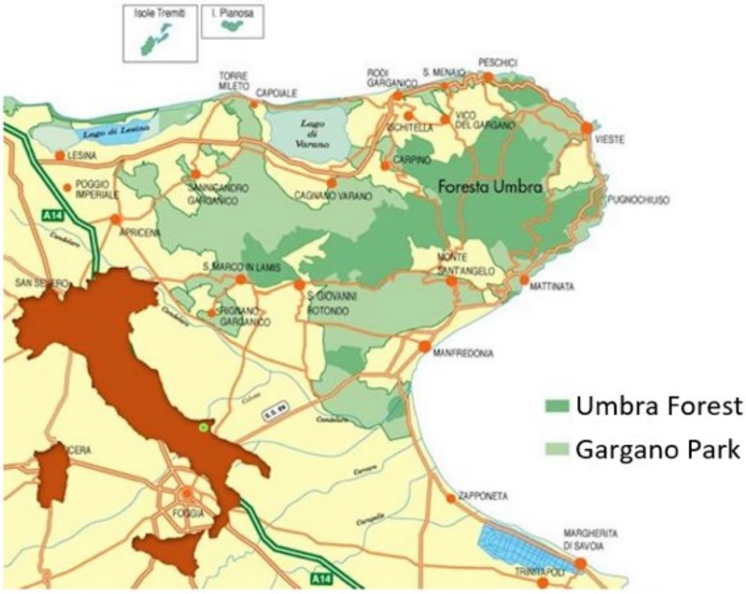


Figure 8. Map of the Gargano Park

The location of the park on the Mediterranean Sea lends to a climate of high temperatures and moist conditions with precipitation during every season. The temperature change throughout the year is gradual and moderate, with the warmest month of the year being July with an average high of 88.9 degrees Fahrenheit, and the coldest month being January with an average high of 52.9 degrees Fahrenheit.

5.1.2 Geomorphology

Karstification: Among the innumerable manifestations of karstification are the more than 4,000 dolines (In geomorphology, a doline is a closed basin, typical of plateaus made up of limestone rocks, formed because of the dissolution of the calcium carbonate constituting the rocks; it is a morphology typical of areas in which surface karst occurs) dotting the Gargano territory, closed hollows produced by the collapse of the vault of underground caves and the erosion action of water communicating with the underlying water table.

The Pozzatina doline, more than 100 metres deep and about 500 metres in diameter, is the largest in Europe (the doline is part of the municipality of San Nicandro Garganico). To the superficial karstification process are attributable the countless furrowed fields, outcropping rocks marked by rainwater runoff. The existence of more than 600 caves, many of which are of archaeological interest (inhabited from the Palaeolithic to the Bronze Age), can be traced back to the process of deep karstification.

5.1.3 Geology

The Gargano consists mainly of sedimentary rocks, limestone, and dolomite, dating back to the Cretaceous and Jurassic periods, mostly stratified, and affected by the phenomenon of karst dissolution. An exception is Punta Pietre Nere (so called because of the characteristic black rocks outcropping from the sand; it is the only autochthonous outcrop of magmatic rocks in southern and insular Italy), a mass of dark volcanic rocks dating back to the Triassic period, outcropping on Lesina beach. The karst phenomenon, produced by the action of water and carbon dioxide on the limestone rocks, has 'sculpted' the landscape in various ways.

Along the entire edge of the limestone block, there are large erosive furrows that radiate towards the sea or the Capitanata region. These are rocky ravines (related to the phenomenon of 'dry valleys' or 'gullies'), caused by mechanical and karst erosion.

Regarding permeability, a distinction is made between:

- Permeable rocks by karstification mainly due to the karst phenomenon initiated by cracks in irregularly stratified white organogenic limestones and sub-vertical fractures.
- Rocks with mixed permeability due to cracking and karstification that occurs in dolomites and grey dolomitic limestones with flints.

5.1.4 Soil

The Gargano soils, originating from the degradation of calcareous rocks, are:

- brown soils, with a high moisture content, on dolomitic substrate and paleogenic limestones (especially in the medium-high part of the forest).
- decalcified Mediterranean red soils with a thin A horizon and a powerful B horizon with a polyhedral structure, which are found in the lowest part.

5.1.5 Hydrograpy

From a hydrographic point of view, the torrential watercourses of the Gargano comprise all those hydrographic networks that, according to a roughly centripetal arrangement, descend from the heights of the promontory towards the coast or the Tavoliere plain, or in some cases flowing into the lakes of Lesina and Varano. The watercourses present, which take on 'mountainous' characteristics, are characterised by substantially limited catchment areas, which only in a few cases exceed 100 km^2 in extension, while from a morphological point of view the river networks show a good level of internal hierarchical organisation. The river valleys appear in many cases wide and deep, strongly modelled in the rocky substrate, and characterised by slopes of the bottom in places even high. From this it follows that the hydrological regime of these watercourses is typically 'torrential', characterised by short running times, and such that, in relation to the local rainfall regime, it gives rise to long periods of low water interspersed with short but intense flood events, which are also accompanied by abundant solid transport. The frequent flooding events that have affected the edaphic blind valleys present within the promontory have also given rise to interlaced basins in which the in which widespread fluvial and eluvial-colluvial deposition phenomena are prevalent (the most significant of these is the Pantano di S. Egidio).

5.1.6 Ecological Valence

The Ecological Valence is highest for the wooded and forested areas of the Foresta Umbra, and high for the natural pasture areas, grasslands, and non-irrigated stable meadows of the Karst plateau. It shown in **Figure 9**. In these areas, in fact, the agricultural matrix is always interspersed with or close to natural spaces, with frequent natural elements and refuge areas (hedges, walls and rows). There is a high contiguity with ecotones and biotopes. The agroecosystem is generally diversified and complex.

The hilly areas of the eastern, northern, and southern Gargano, cultivated mainly with olive groves, still have a medium to high ecological value due to the significant presence of woods, hedges, low walls and rows and the discrete contiguity with ecotones and biotopes. The agroecosystem is sufficiently diverse and complex.

On the other hand, low values of ecological value are associated with the intensive agricultural areas near the lakes of Lesina and Varano cultivated with irrigated crops such as vegetables, field grasses and protected crops. In these areas the agricultural matrix generates strong pressure on the agroecosystem, which is also poorly complex and diversified.

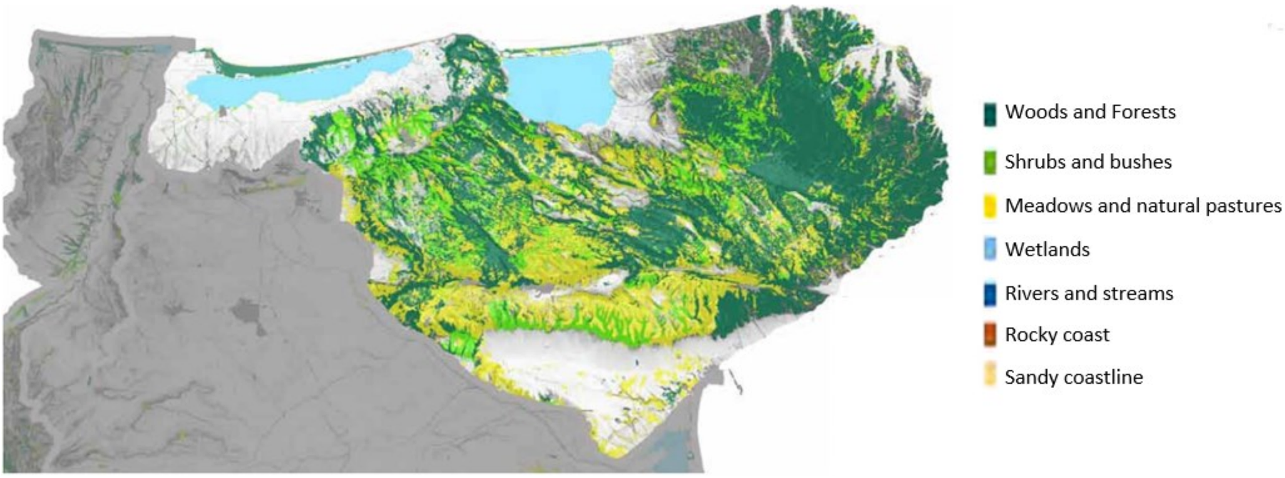


Figure 9. Ecological Valence in Gargano Park

5.1.7 Land use

The analysis of the rural morphological types in the Gargano area returns an image of the landscape that can be schematised into various rural landscapes of the area.

A first rural landscape can be identified around the lake of Lesina. This is characterised by the prevalence of arable crops, characterised by a broad plot in the flatter area that becomes thicker as the steepness of the land increases. Especially east of the coastal lake, the prevalence of arable crops leaves room for tree crops, especially the olive grove that rises on the hillsides; and for cultivation associations of vineyards alternating with thickly textured arable crops. Other tree crops are present to a much lesser extent within the arable extensions that dominate the valleys. This rural type, which is structured around the coastal lake of Lesina, tends to fade away as the geometry of the relief changes to the southeast, while the arable extensions to the west tend to structure themselves along the Torrente Fortore, a torrential basin outside the Gargano area. The coastal slopes are another mosaic of rural morphological types that identify a recognisable landscape that is structured from the coastal lake of Varano to Manfredonia, generally with a certain continuity. Travelling ideally along a section that goes from the coastline towards the mountain reliefs, one finds in the flat portion, sometimes the prevalence of agricultural mosaics, alternating with the peri-urban agricultural type in correspondence with the centres; sometimes the prevalence of dense weave tree crops, in particular olive groves and orchards (mainly in the northern part). If one goes up in altitude, along the slopes one encounters olive groves in various declinations, terraced olive groves, olive groves alternating with patches of woodland, hillside olive groves.

Except for a few small episodes of peri-urban agricultural mosaics and a few valleys dominated by the prevalence of thickly textured arable crops, the rural landscape is characterised by the fragmentation of the rural mosaic determined by arable crops interspersed sometimes with pasture, sometimes with woodland, sometimes with both. The hinterland is characterised by an agricultural mosaic fragmented by the peripheral urbanisations of the settlement, while as one moves further away from the coastline, one perceives the dominance of arable crops, characterised by a wide and very sparse weave, difficult to read, extending from the perifluvial mosaic of the Cervaro torrent to the Gargano foothills to the north; these are also characterised by the presence of hilly and terraced olive groves.

Among the critical elements of the landscape characteristic of the Gargano area are the different types of anthropic occupation of karst forms, those linked to surface hydrography and those of slopes. These occupations (dwellings, road infrastructures, facilities, service areas, tourist areas, etc.), contribute to fragmenting the natural morphological continuity of the forms and increase the conditions of both hydraulic risks, where the forms themselves play a primary role in regulating surface hydrography (valleys, sinkholes, chasms), and morphological impact on the complex landscape system. One of the most impactful forms of anthropic occupation is, for example, the opening of quarries, which create real wounds to the natural continuity of the territory.

Other critical elements are the transformations of coastal areas, especially for the purposes of tourism, which often take place in the absence of adequate assessments of the effects induced on the sea-weather balance (e.g., the construction of ports and jetties, with significant alteration of coastal solid transport). A further critical aspect is linked to the alteration of the balance between surface and underground hydrology, in the knowledge that the extensive underground water table present in the Gargano area depends, in its qualitative and quantitative characteristics, on the natural characteristics of the soils and surface forms that contribute to the collection and percolation of meteoric water (dolines, chasms, endoreic depressions).

5.1.8 Climate

As far as the general climatic characteristics of the Gargano are concerned, it should be noted that these are mainly due to the geographical location of the area, its orientation in the Adriatic Sea and the predominant arrangement of the main mountain ridges oriented along the East-West axis.

As far as temperature is concerned, annual averages range between 6° C in the winter months and 34° C in the summer months, with an annual range of approximately 16-18° C, while the period in which values below or slightly above 0° C are recorded is related to the altitude of the territory as well as the distance from the sea. Therefore, in coastal areas the thermometer rarely drops below zero, while in the high Gargano area temperatures of -10° C can be recorded, generally limited to short periods or, in some years, temperatures drop below zero even for periods of more than 40-50 days that are continuous. The average temperature and precipitation in August shown in **Figure 10**.

The distribution of rainfall over the year generally follows the typical Mediterranean rainfall regime, i.e., with abundant winter-spring rainfall and accentuated aridity in summer. Generally, there is modest rainfall along the coasts (600-700 mm/year) while, as the altitude increases, it becomes more and more accentuated, reaching 1,200 mm/year in the Foresta Umbra area. The northern slope of the promontory is very singular, as it enjoys, because of the humid currents coming from the north, not only a higher quantity of precipitation, on average, than that of the southern slope, but also a pronounced atmospheric humidity.

Rainfall directly influences the water content of plant fuels, both living and dead. In addition to the total amount of rainfall, its temporal distribution is particularly important; in fact, rainfall of limited intensity but evenly distributed over a summer season significantly lowers the fire risk because it keeps the moisture content of the fuels potentially affected sufficiently high.

Air temperature influences fires both directly and indirectly. The direct action is on the direct heating of the fuel and the water content of the vegetation, while the indirect action is on the air and soil moisture. Monthly maximum temperatures highlight the predisposition of an area to be affected by summer fires, as in the case of the Gargano.

Wind is a crucial factor in forest fires for various reasons: in addition to influencing air humidity, it plays a fundamental role in the ignition and development phases of fires, also conditioning the direction, height, and speed of the flame front. Also fundamental is the increased supply of comburent (oxygen) that the wind produces, favouring combustion processes.

Also, not to be overlooked are the transport actions of flaming fragments that the wind carries out, causing the ignition of new fires, even distant from the main front. It should also be remembered that sometimes the wind can hinder the spread of fires, both because of the strong gusts that can extinguish small fires and when it blows in the opposite direction to the slope.

Average temperature and precipitation in August (data from 1951 to 2001 - Apulia Region, Meteorological Service)

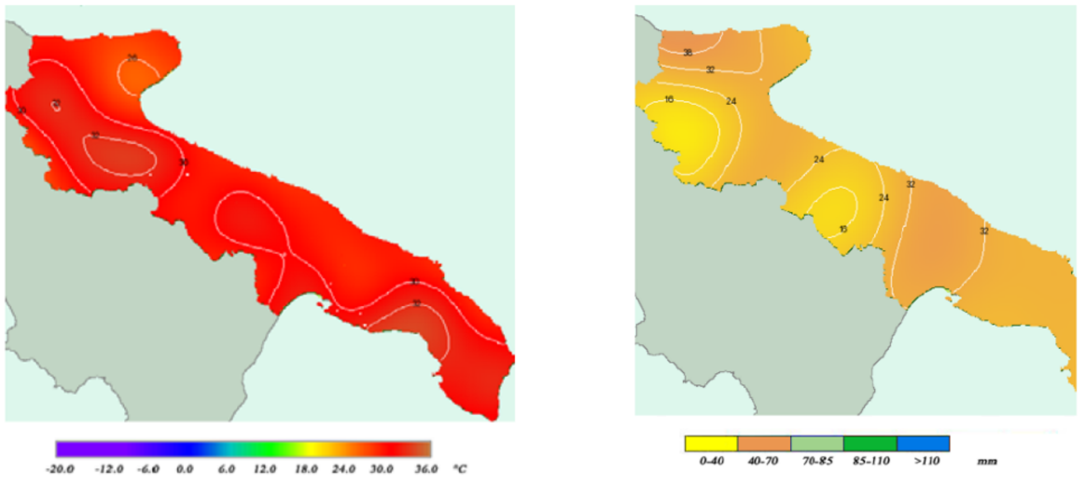


Figure 10. Average Temperature and Precipitation in Gargano Park in August (Data From 1951 to 2001 – Apulia Region, Meteorogical Service)

5.1.9 Forest Ownership

It is managed by the Gargano National Park Authority, covering nearly the entire promontory, and extends over an area of about 120,000 hectares, including totally or partially, 18 municipalities, including the Tremiti Islands.

5.1.10 Flora

The Gargano National Park is home to a variety of habitats: beech forests in the interior and on the northern slope, Aleppo pine forests along the coasts, large expanses of Mediterranean scrub, not to mention oak forests where turkey oaks and holm oaks abound, mixed forests rich in ornelli, ash trees, elms, hollies, chestnut trees, maples, oaks, beech trees, etc.

The undergrowth is populated by numerous essences: ferns, brambles, dog roses, cyclamens, edible and poisonous mushrooms, etc. On the slopes exposed to the sun, perasters, melasters, hawthorns grow surrounded by lentisk bushes, juniper, thyme, brambles, prickly pears and the peculiar 'devil tree' (carob). In the foothills, the vegetation changes radically and the steppe predominates, rich in prickly pears, asphodels, ferulas, euphorbias, irises; in which a very special mushroom, the Pleurotus eryngii, grows.

Everything is interrupted here and there by olive groves, almond groves, vineyards, and wheat fields. In the innermost areas of the promontory (Ischitella, Manatecco, Ginestra, Sfilzi, Umbra, Bosco Quarto, Umereta delle Ripe forests) are spread large forests of beech, holm-oak, turkey oak and, sometimes associated with farnettos, elms and ash trees. On the coast, pine forests of Aleppo pine dominate, about 7,000 hectares alternating with Mediterranean scrub, rich in formations of mastic trees, phillyrea, multiflora heather and strawberry trees.

5.1.11 Wildlife

The Gargano National Park encompasses a vast biodiversity in a small area, spanning the different habitats that make up the nature of the Mediterranean. These features outline a considerable diversity of wildlife. Birds: Around 170 bird species nests in the Gargano. Five species of woodpeckers live in the innermost forests: green, greater red, lesser, middle, and white-backed.

Other nesting birds are the buzzard, hen harrier, kestrel, peregrine falcon, sparrow hawk, lanner, marsh harrier and short-toed eagle. Ospreys and eagles are also present during the migration period. Nocturnal birds of prey include the eagle owl, the barn owl, the tawny owl, and the scops owl.

Mammals: Among the mammals known is the italic roe deer (Capreolus capreolus italicus), a subspecies subendemic to the Gargano. Also living in this area are deer and the more common wild boar, fallow deer, weasels, beech martens, wild cats (in the thicket of the Foresta Umbra), hares, hedgehogs, moles, badgers, foxes, dormice, dormice, porcupines, squirrels and various species of mice and voles. Not long ago, the wolf returned to the promontory after a long absence.

Reptiles and amphibians: Among the reptiles and amphibians, the land and marsh tortoise, the orbettino, the Aesculapian and smooth snake, the luscegnola, the verrucous gecko, the common viper, the cervone, the collared snake, the lizard, the field lizard, etc. are very present. Amphibians are present with the tree frog, the green and dalmatine frog, the common and emerald toad, and the italic and crested newt. These animals occupy the marshy areas, canals, lagoon banks and cutines in various wooded areas of the park.

5.1.12 History of Fires

For the analysis of the historical series of fires, the events referring to the ten-year period 2003-2012 provided by the Territorial Coordination for the Environment of the State Forestry Corps were considered, which also show that fires in the Gargano occur almost exclusively in summer (June, July, August, September). The data of historical series of fire shown in **Table 5**. The processing of the raw data made it possible to obtain the data summarised in the table, from which a total of 379 fires occurred in the period under investigation, but their number per year is extremely variable, ranging from a minimum of 13 in 2009 to a maximum of 72 in 2007. Even the annual extent is not constant, in fact in 2009 the total area burnt was 139.8 ha with an average area per fire of 7 ha. In 2007, following exceptional and extensive fires, the total area burnt was 5,762.4 ha with an average area per fire of 80 ha. The average fire area was 23.3 ha while the average annual number was 37.9.

In the same decade, the total area burned by fire was 8,836 ha, 7 of which 63% (ha 5,603.4) involved wooded areas, while the remaining 37% (ha 3,233.4) involved non-wooded areas (pastures, uncultivated land). It shown in **Figure 11**.

Table 5. Historical Series of Fire in Gargano Park

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	Tot.
Number of wildfires [ha]	55	40	21	13	24	72	23	27	33	71	379
Wooded area	258.32	297.66	55.04	27.82	380.16	4,189.48	42.31	55.54	44.94	252.20	5,603.38

	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	Tot.
[ha]											
Unforested area wooded. [ha]	128.98	390.03	84.72	63.16	531.11	1,572.95	63.40	109.44	133.73	155.86	3,233.38
Total area [ha]	387.30	687.68	139.76	90.98	911.28	5,762.43	105.71	164.89	178.67	408.06	8,836.76
Avg. fire area [ha]	7.04	17.19	6.66	7.00	788.08	80.03	4.60	6.11	5.41	6.75	927.87

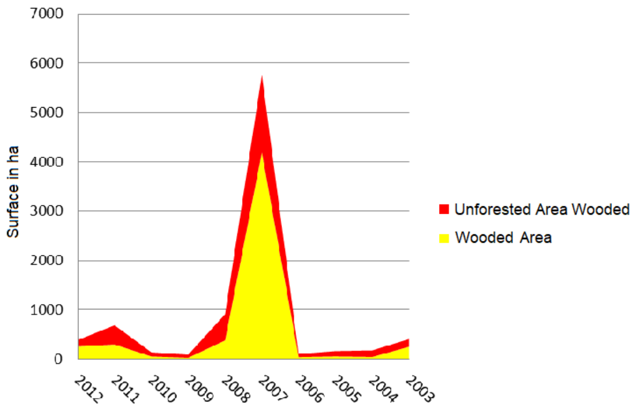


Figure 11. Wooded and Non-wooded Areas of Gargano Park Burned by Fire in 2003-2012

The historical analysis on wildfire has been carried out on fire events for the 2010-2019 decade, provided by the *Coordinamento Territoriale per l'Ambiente del Corpo Forestale dello Stato* (Territorial Coordination for the Environment of the State Forestry Corps). The analysis pointed out that wildfires in the Gargano occurs almost exclusively during the summer, especially in July and August. The **Table 6** shows that during the study period a total of 483 wildfires occurred with a high varying frequency during the years, from 20 in 2014 up to 106 in 2017. Annual extension is highly variable as well, 17,42 ha burned in 2018, with an average per wildfire of 0,6 ha, while in 2017, after many outbreaks and a particularly dry summer, the total burned area was 2149,04 ha, with an average per wildfire of 20,27 ha. The average burned area per year, during the 2010-2019 decade, was 23,3 ha, while the average number of wildfires was 48,3.

Table 6. Yearly Distribution of Wildfires in The Gargano Park in the 2010-2019 Decade

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Tot.
N° of wildfires [ha]	21	40	55	34	20	72	41	106	29	65	483
Wooded area [ha]	55.04	297.66	258.32	94.79	10.08	299.94	74.46	1378.07	10.08	155.45	2642.27
Non wooded area [ha]	84.72	390.03	128.98	14.07	39.66	324.21	51.98	770.97	7.33	418.47	2230.43
Total area [ha]	139.76	687.68	387.30	108.87	58.12	624.15	126.44	2149.03	17.42	573.92	4872.70
Avg. area per wildfire	6.66	17.19	7.04	3.20	2.91	8.67	3.08	20.27	0.6	8.83	10.1

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Tot.
[ha]											

During the same decade, the total area affected by wildfires was 4872,70 ha, of these 54,23% (2642,27 ha) affected wooded area, the remaining 45,77% (2230,42 ha), on the other hand, affected non wooded area (pastures, uncultivated areas). It shown in **Figure 12**.

The analysis of the number of wildfires confirms the exceptionality of 2017, with 106 wildfires. The municipalities that have been more affected by wildfires are San Giovanni Rotondo, Cagnano, Varano, San Marco in Lamis and Serracaptiola, as shown in **Figure 13**.

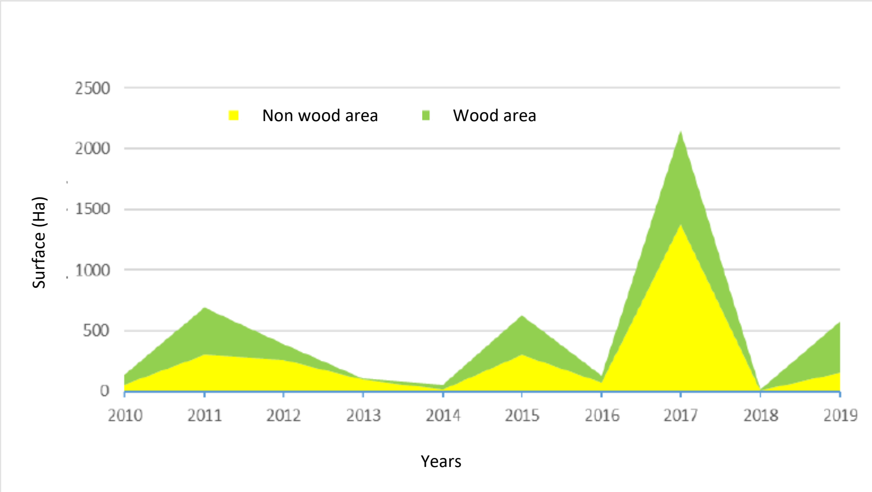


Figure 12. Wooded and Non-wooded Areas of Gargano Park Burned by Fire in 2010-2019

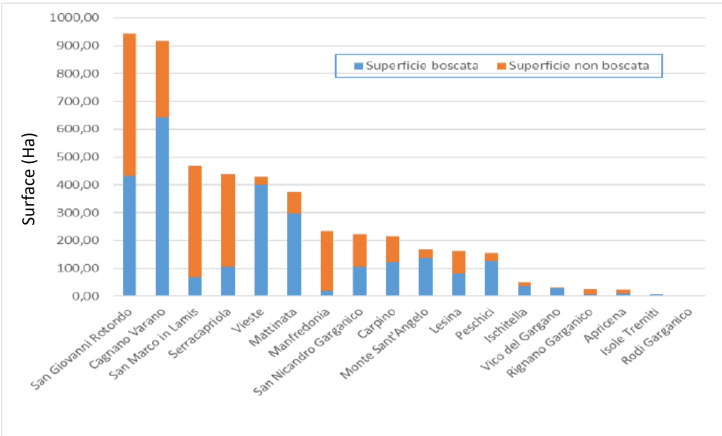


Figure 13. The Municipalities that Have Been Affected by Wildfires

5.1.13 Brief description of the fire risk

The perimeter of the park is delimited in the 1:50,000 cartography attached to the Presidential Decree of 18 May 2000; the territory is divided into zone 1 and zone 2, zone 1 is the area of significant naturalistic, landscape and cultural interest with limited or no degree of anthropisation. Zone 2 is the area of naturalistic, landscape and cultural value with a greater degree of anthropisation (see **Figure 14**).

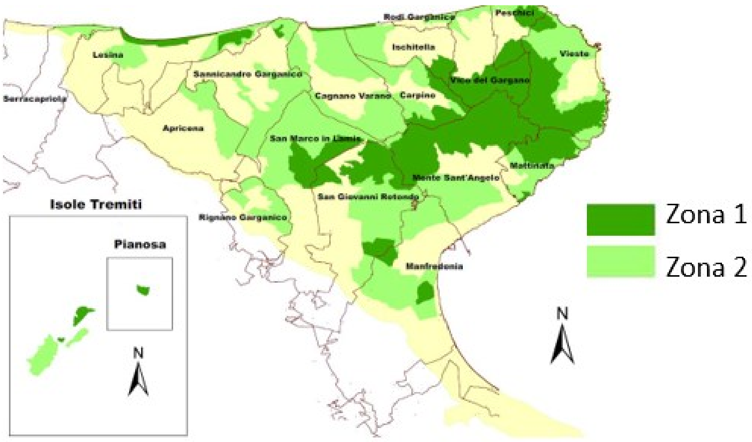


Figure 14. Zone of Gargano Park

The fire prevention plan was drawn up based on the level of land cover and land use, subdivided into different classes (see **Figure 15**), representing a first level of knowledge of the territory, with the characteristics and properties of a territorial database based on which to carry out the monitoring of the AIB (Forest Fire Fighting) plan. Land cover and land use were obtained, in turn, from the 2006 Corine Land Cover project, data suitably reworked in a GIS environment.

In particular, the surfaces appear as follows:

1) artificial surfaces (residential areas, industrial areas, etc.) 1,300 ha;
2) agricultural surfaces 29,000 ha;
3) woods and semi-natural environments 36,000 ha
4) pasture areas 18,000 ha
5) Mediterranean scrub area 6,000 ha
6) areas covered by sparse or absent vegetation (e.g. beaches) 80,000 ha
7) water courses, canals, etc. 10,000 ha

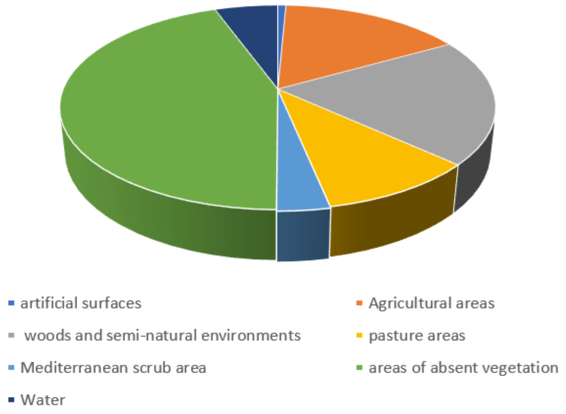


Figure 15. Classification of Land use for Fire Prevention

Throughout the territory covered by the plan, it is essential to know the type, load, and distribution of fuel, identified by forest types, which represent a fundamental tool for planning protection against forest fires and an important cognitive element for the use of fire behaviour prediction models.

For the fuel model maps, which provide an estimate of fire behaviour especially over vast areas, land cover classes were extrapolated based on the vegetation present (starting from the CLC 2000 cartography). Each one was associated with the relative fuel model according to the Fire Behaviour standard, which defines models classified into four main groups: grasslands, shrublands, forest litter and forest use residues; these groups are subdivided into 13 fuel models (see **Table 8**). Of these, in the Gargano National Park area, there are 9 models grouped into 3 groups below (see **Table 7**), for which the relative Linear Intensity value -which expresses the thermal emanation in the unit of time for the unit of length of the flame front- and the relative values of flame height and maximum speed have also been indicated.

Table 7. 9 Groups of Fuel Models

Group	Model	Description	Intensity KJ/(ms)	Height of flame (m)	Speed max m/min
Grasslands	1	Natural or artificial pastures and meadows consisting of fine grasses, with senescent or dead tissue, less than 30-40 cm in height, completely covering the ground. Very low shrubs or trees may be sporadically present, however, occupying less than one third of the surface area. Fields and stubble are also included in this model. Amount of fuel 1-2 t/ha.	250	1.8	150
	2	Natural or artificial pastures and meadows, consisting of fine grasses, with senescent or dead tissue, less than 30-40 cm in height, completely covering the ground. Woody species are present, occupying one to two thirds of the surface, but fire propagation is supported by the herbaceous layer. Quantity of fuel 5-10 t/ha.	400	2.4	60
	3	Natural or artificial pastures and meadows, consisting of dense grasses, with senescent or dead tissue, over one metre in height. This is the typical pattern of savannahs and wetlands with a warm-temperate climate. Unharvested cereal fields are representative of this pattern. Fires occurring in this pattern are the most violent in the grassland group. Amount of fuel 4-6 t/ha.	1900	4.9	150
Shrublands	4	Very dense young bush or planting, two metres or more in height. Dead branches inside contribute significantly to increasing the intensity of the flames. The fire spreads through the crowns. Amount of fuel 25-35 t/ha.	4400	4.9	150
	5	Dense, green scrub, less than one metre high; fire spread is mainly supported by the litter and herbaceous layer present. Amount of fuel 5-8 t/ha.	250	1.8	30
	6	Similar to model 5 but consisting of more flammable species. The fire is supported by the shrub layer but requires moderate to strong winds. A wide range of low scrub situations can be represented with this model. Amount of fuel 10-15 t/ha.	500	2.7	20

Group	Model	Description	Intensity KJ/(ms)	Height of flame (m)	Speed max m/min
	7	Scrub consisting of very flammable species that make up the shrubby lower floor of coniferous forests, varying in height between 0.5 and 2 m. Amount of fuel 10-15 t/ha.	330	2.1	40
Forest litter	8	Dense forest, devoid of shrubby undergrowth. Fire propagation supported by compact litter consisting of needles or small leaves. The undergrowth of dense Scots pine or holm oak forests are representative examples. Amount of fuel 10-12 t/ha.	20	0.6	8
	9	Dense woodland without shrubby undergrowth but with less compact litter than model 8, consisting of conifers with long, stiff needles or broadleaf trees with large leaves. Representative examples are the undergrowth of maritime pine or chestnut forests. Amount of fuel 7-9 t/ha.	160	1.5	30

Table 8. Fuel Model According to The Fire Behaviour Standard

Model	Average height m	Biomass burnable t/Ha	Dead (D) Alive (A)	Intensity KJ/(ms)	Flame height m	Max. speed m/min
M1	0,3	1 – 2	D	250	1.8	150
M2	0,45	5 – 10	D + A	400	2.4	60
M3	>1	4 – 6	D	1,900	4.9	150
M4	>2	25 – 30	D + A	4,400	7.6	125
M5	<1	5 – 8	D + A	250	1.8	30
M6	<1	10 – 15	D	500	2.7	20
M7	0,5 – 2	10 – 15	D + A	330	2.1	40
M8	Lettiera	10 – 12	D	20	0.6	8
M9	Lettiera	7 – 9	D	160	1.5	30
M10	Lettiera	30 – 35	D + A	330	2	20
M11	Detriti	50	D	250	1.8	20
M12	Detriti	80	D	1500	4	20
M13	Detriti	150	D	2400	5.5	50

This intersection of data shows that the fuel models characterised by a high linear Intensity value (model 3 and model 4) are natural or artificial pastures and meadows, consisting of dense grasses, with senescent or dead tissue, over one metre in height (Intensity of 1,900 KJ/(ms)) and areas of very dense young scrub or plantation, two metres or more in height (Intensity of 4,400 KJ/(ms)) that develop flame heights of 4.9 to 7.6 metres.

The fuel pattern map of the Gargano National Park, drawn up as part of the MATM fire project, provides an estimate of fire behaviour especially over large areas. This map was elaborated by extrapolating the land cover classes on the basis of the vegetation present (starting from the CLC 2000 cartography) and to each one was associated the relative fuel model according to the Fire Behavior standard, which, as mentioned above, defines the models classified into four main groups: grasslands, shrublands, forest litter and residues of forest use; the latter not considered for the Gargano.

This is a distribution map of fuel patterns, which provides an estimate of fire behaviour based on the description of the layer of vegetation closest to the ground that can be traversed by the fire.
Knowledge of the fuel models makes it possible to direct active control and preventive silviculture interventions, since knowing the fuel models makes it possible to estimate the expected fire behaviour.

5.2 Tepilora Park - Italy

5.2.1 Location/ Administrative

The Regional Natural Park of Tepilora is a Regional Park established in 2014 (pursuant to Regional Law No. 21 of 24 October 2014). It is managed by the Regional Natural Park Authority of Tepilora. The park is entirely part of the region of Sardinia, province of Nuoro and covers an area of about 7,877 hectares. It includes in part, 4 municipalities: Bitti, Lodè, Posada and Torpè. The following map (**Figure 16**) shows the map of the Tepilora Regional Natural Park.

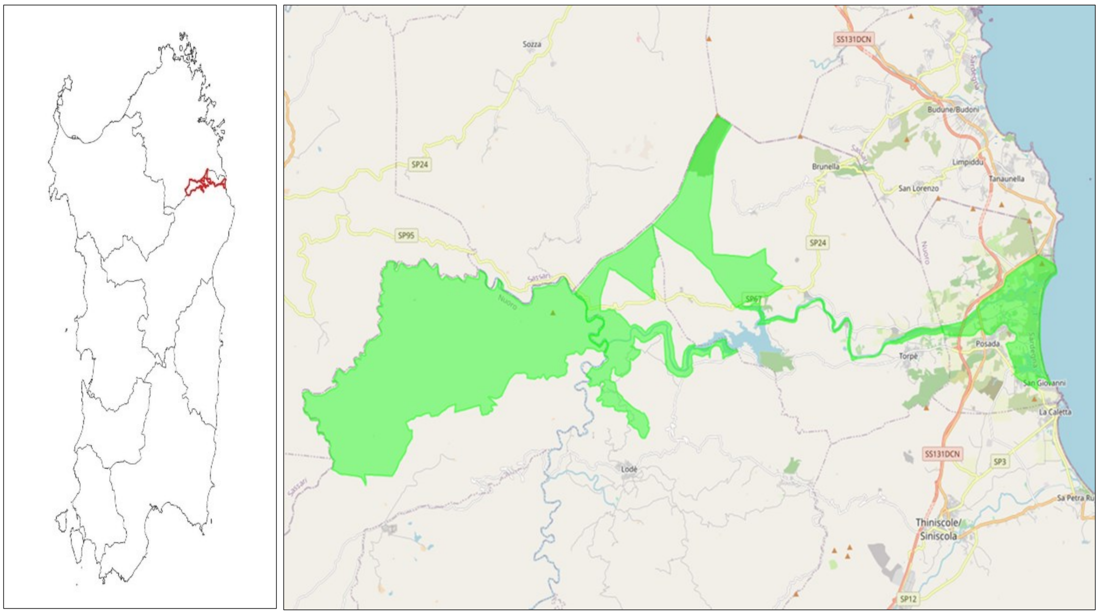


Figure 16. Map of the Tepilora Regional Natural Park.

Located in the north-west of Sardinia, the Tepilora Regional Natural Park includes a vast territory that insists on four municipalities: Torpè, Posada, Lodè and Bitti. The park extends from the Tepilora forest to the mouth of the Rio Posada; its fulcrum is Mount Tepilora (m.528 s.l.m.), a rocky tip with a triangular profile that stands out in the densely wooded area of Littos and Crastazza and looks towards Lake Posada. Once intended for grazing and cutting wood, in the 1980s the area was afforested for 16% of the total and was equipped for hiking and fire protection, becoming a nature reserve.

In the territory of the municipality of Bitti fall the state forests of Crastazza-Tepilora and Sos Littos-sas tumbas owned by the Autonomous Region of Sardinia and managed by the regional agency FORESTAS. In the territory of the municipality of Lodè falls the territory bordered by the forest yard of Sant'anna, owned by the municipality of Lodè and managed by the regional agency FORESTAS. In the territory of the municipality of Torpè falls the territory bordered by the forest yard of Usinavà state-owned and managed by the regional agency FORESTAS.

The practice of establishing the Park was started in 2005 at the impulse of the Municipality of Bitti, in agreement with the Sardinia Region, the Forestry Authority of Sardinia and the Province of Nuoro with the aim of protecting the natural resources of the area and encouraging the sustainable development of the territory. Today the Park, entirely passable, also thanks to its mild winters is an ideal destination for tourism in contact with nature even in low season, between breathtaking views, fresh spring waters and florofaunistic typicality: vigorous lyceums, strawberry trees, junipers, corks are the habitat of animal species typical of the Mediterranean scrub, such as the Sardinian hare, wild boar, fox; there are also donkeys and mouflons and, near the Tepilora tip, with a little luck it is possible to spot specimens of golden eagle. There is no shortage of cultural attractions, linked to a rich historical-archaeological heritage, ancient traditions, crafts and food and wine.

5.2.2 Geomorphology

Paleozoic intrusive granite-related rocks generally make up the basic rocky apparatus on which the area insists. The most significant morphological aspect is given by greenhouses, a characteristic succession of conical ridges reminiscent of the teeth of a saw. Particular are also the tafoni that is the concaveities and recesses (small and large) present in the rock or boulders. These recesses, of different shapes and sizes, sometimes model themselves as gigantic sculptures, and take on bizarre shapes that somehow recall silhouettes of animals or birds of prey. The stems, largely shallow or medium-deep, are permeable and have marked characteristics of subacidal to acid reaction erodibility.

The area where the Park extends is characterized by a system of low mountains with irregular morphology, marked by deep valleys. From an altimetric point of view it ranges from 68 m above sea level .m Rio Posada to 979 m of Nodu Pedra Orteddu. The whole territory of the park is rich in natural springs: some clearly visible along the roads and paths and therefore usable to visitors, others, now disappeared in the thick forest vegetation, remain alive only in the historical memory of the inhabitants of the area. Many of the waterways present, despite the prevailing torrential regime, manage with their reach to sufficiently withstand the fish fauna.

The Posada River and the Rio Santa Caterina, together with other smaller waterways, feed the ponds that develop parallel to the strip of coastal dunes that characterize the Posada coastline. With the abundant transport of debris, the Posada River formed deposits of considerable thickness and built the coastal plain where the river digresses and forks.

5.2.3 Geology

From a geological point of view in the area emerge essentially rocks of the crystalline basement varisic and late-varisic (Paleozoic) and sediments of the Quaternary. The crystalline basement consists of metamorphic rocks of high and medium metamorphic degree connected with the varisic continetal collision event, which are in turn intruded by granitoid rocks linked to a long ensialic relaxation phase.

The high-grade metamorphic complex is represented by migmatites and eclogite lenses. The medium-grade metamorphic complex consists of micaschists (partly transformed into phyllonites) with amphibolites and paragneiss, original magmatic rocks that have produced ortogneiss and gneiss occhiadini, and rare strips of marble deriving from carbonate rocks.

The late variscan intrusive complex is formed by plutonic rocks distinguished into two intrusive units, in turn subdivided into five litofacies. The intrusive unit of Sos Canales is characterized by the distinctly peralluminous character of all lithofacies; cordierite granites and muscovite (Sos Sonorcolos facies), garnet leucogranites (Loelle facies), garnet leucogranites and muscovite (Punta Tepilora facies) have been distinguished. The intrusive unit of Monte Nieddu includes garnet and muscovite leucogranites (Concas facies), biotitic leucogranites (Monte Nieddu facies).

Associated with late-orogenic magmatism are the intrusions of Philonian bodies, which in the park area cross the granitoids and have prevailing directions of about E-W. The Late Varisan Philonian Procession includes acid veins, quartz veins and basaltic veins.

The Quaternary deposits fill the valley and the plain of F. Posada and discontinuously cover the previous formations. These deposits are attributed to the Late Pleistocene (Cedar Synthema) and Holocene evolution. The Cedrino syntheme is divided into Cala Luna subsynthema consisting of coastal clastic deposits (Tyrrhenian bench auct.), Abba Meica subsyntheme consisting of gravel and sand of fan and alluvial plain, and slope debris. The Holocene deposits are represented terraced alluvial deposits, slope deposits and eluvio-colluvial coltri, landslide deposits, alluvial deposits, tin deposits, beach deposits and coastal cordons. This unit includes deposits of anthropic origin.

The tectonic structuring linked to varisic orogeny originated the Paleozoic crystalline basement, according to a ductile evolution typical during the collisional orogenic phases. These phases produced several generations of tectonic folds and foliations in a medium-high grade metamorphic environment in which the primary structures were completely obliterated. In the crystalline basement of northern Sardinia were recognized the wrecks of a first deformation event of high pressure and high temperature, at the eclogitic stage typical of the collisional orogenic phases (up to a maximum of 700 ° C and 2.1 GPa), followed by a second event in the granulitic state of pressure and lower temperature. The most significant feature of this area is the Posada-Asinara Line, a fragile-ductile cutting area of regional importance, which separates the high-grade metamorphic complex from the medium-grade one, oriented around E-W. The interpretation on the tectonic meaning and evolution of this structure has changed over time, first considered a late-Paleozoic cutting area, then a varisic oceanic suture area because it separates two different metamorphic complexes and due to the presence of eclogitic amphibolites; other authors attribute instead a role linked to a late-Paleozoic transpressive tectonics, intracontinental parallel to the limits of the varisic orogen. It is currently considered a transcurrent structure with right kinematics. The same feature was reactivated as a right transcurrent fault during the Tertiary, as well as the faults present in the western sector. The most important system has E-W orientation and is evidenced by three parallel main faults, which cross the western and central area of the park.

The very morphology of the relief is clearly conditioned by these structures, as indicated by the three straight and parallel valleys of Sos Trainos, Valle del Rimedio and Riu sas Praneddas, and the clear change in slope of the slopes that can be observed to the N of Lake Posada and along the SP 67. These faults are partly dislocated by some minor NW-SE-oriented structures, and by others of NNW-SSE direction that reject both the main faults and the late-varisic veins. These fragile tectonics, both late Paleozoic and Tertiary, have also originated different fracturing systems of different orders that constitute preferential surfaces of weakness and can be reactivated in gravitational processes on the slopes.

Soil Properties

The entire territory under study has been defined by dividing it into landscape units, as indicated by the guidelines of the Sardinia Region. The area is, therefore, composed of the following units:

-Landscapes on Metamorphites (shales, arenaceous schists, clay schists, etc.) of the Paleozoic and on the relative slope deposits (unit B).
-Landscapes on intrusive rocks (granites, granodiorites, leucogranites, etc.) of the Paleozoic and on the relative slope deposits (unit C).
-Alluvial deposits of the Pliocene and Pleistocene and cemented aeolian sandstones of the Pleistocene (unit I).
-Recent and current alluvial sediments and slope deposits derived from substrates consisting of marl and volcanic tuffs (L unit).
-Holocene wind sands (unit M).
-Coastal sediments (swamps, coastal lagoons, etc.) of the Holocene (N unit).

For each of the landscape units identified, the main types of soil have been defined also through direct surveys in the field, to characterize in detail the soils and define the limits of the land units.

5.2.4 Hydrography

Territorial framework
With resolution dated 30/10/1990 n. 45/57, the Regional Council divides the Single Regional Basin into Sub - Basins, already identified in the Plan for the Rational Use of Water Resources of Sardinia (Water Plan) drawn up in 1987. The entire territory of Sardinia is divided into seven sub-basins, each of which is characterized by general geomorphological, geographical, hydrological homogeneities but also by strong differences in territorial extension. The area is limited to within the Hydrographic Basin n. 5 - Posada Cedrino, only a small portion to the north falls within the Hydrographic Basin n. 4 - Liscia. The following map (**Figure 17**) shows the area of Basin n. 5 - Posada Cedrino in The Park Area.

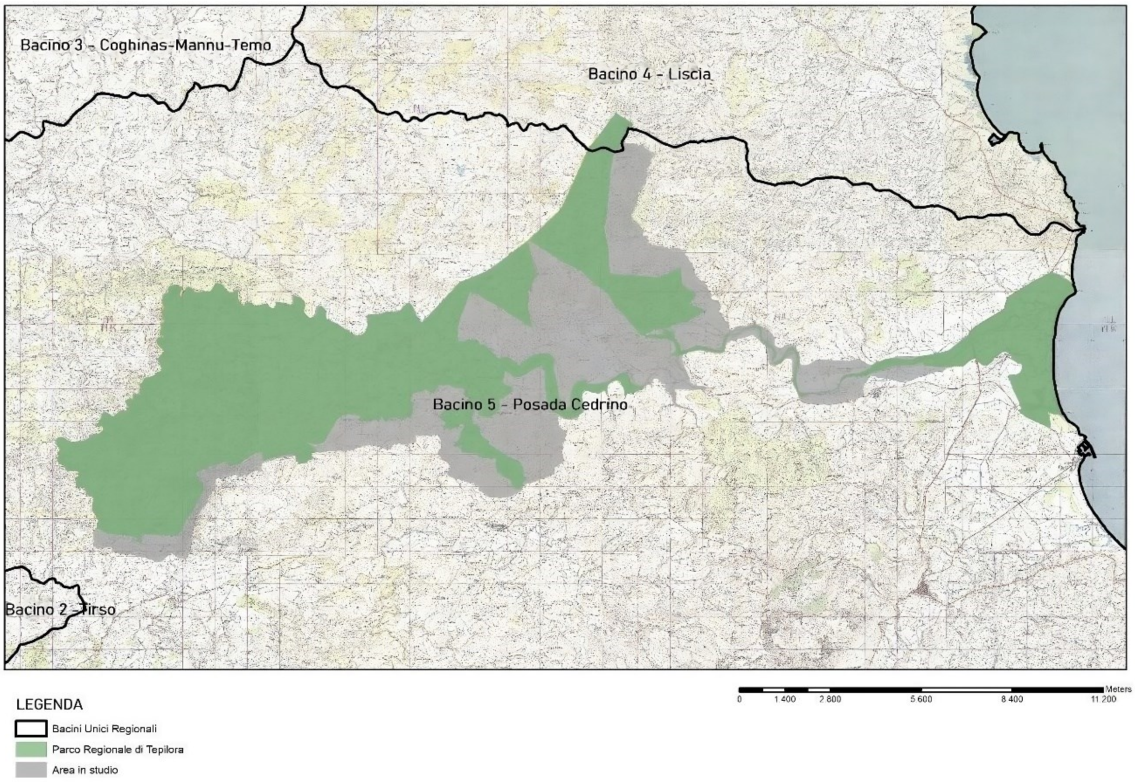


Figure 17. The Area of Basin n. 5 - Posada Cedrino in The Park Area

The main watercourse of the basin is the Posada River, divided into two main stretches: the first between the confluence with the riu Mannu and the Posada Lake and the second between the Maccheronis dam and the outlet to the sea. The secondary watercourses (up to the order of Strahler n. 3), inside the catchment area and therefore to the Park area, are represented in the following image and listed below by attributing to them the toponyms indicated in the graph of the hydrographic network of Sardinia approved by Resolution of the C.I. n. 3 of 30.07.2015: Riu Santa Caterina, Riu Mannu, Riu Lacc'umbresu, Riu Sas Praneddas, Fiume 10652, Fiume 102368, Fiume 87036, Riu Nieddu, Fosso Giorgia, Riu Solianu, Riu S'Astore, Riu Sa Sumedda, Riu Calistru, Fiume 87003.

The remaining part of the territory is crossed by the Posada River, which rises on the slopes of the tip of Senalonga, in the municipal territory of Alà dei Sardi, and flows into the Iscraios beach, in the municipality of Posada, separating into two branches and constituting the Stagno Longo. The river of Posada, which crosses all four municipalities of the Tepilora Park, has a basin of 675 km^2, is bordered to the west and north by the mountains of Bitti and the mountains of Alà dei Sardi and to the south by Monte Albo and to the east by the sea. The main hydrographic network within the park is shown in **Figure 18**.

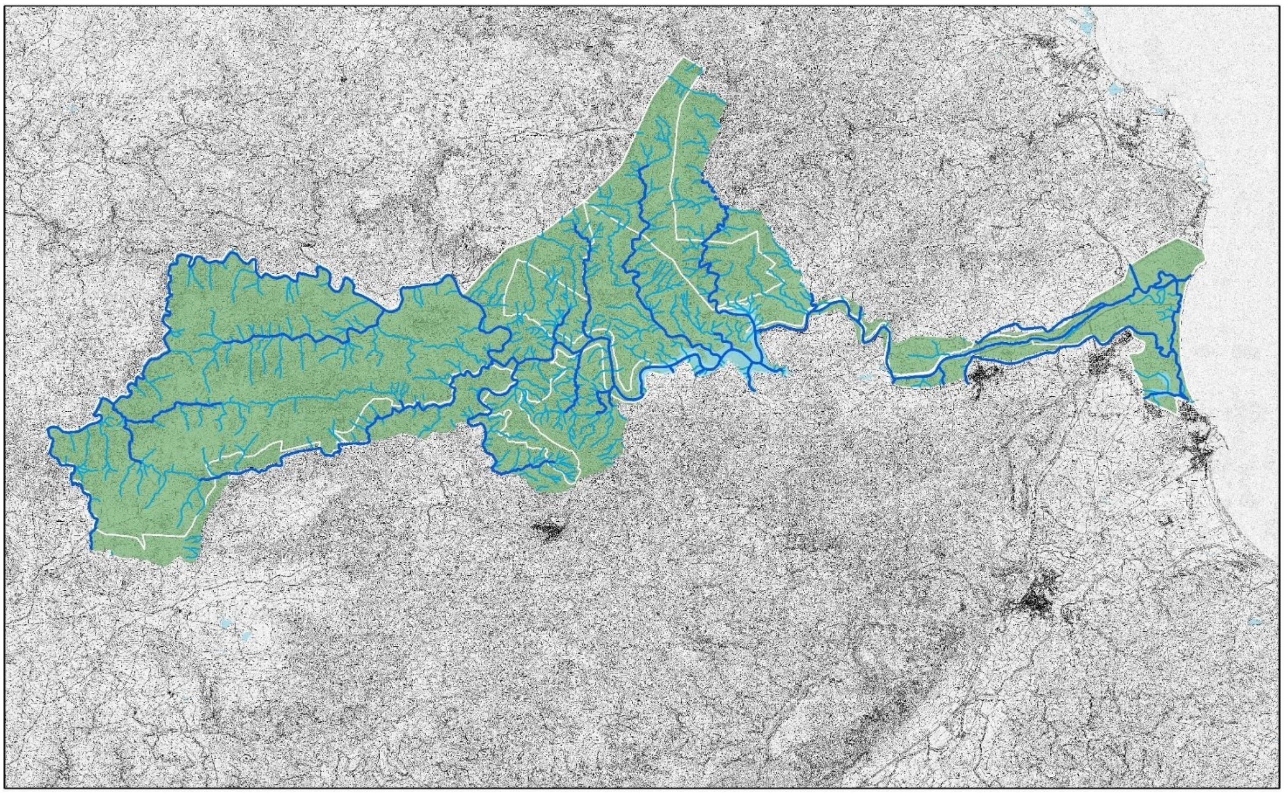


Figure 18. Main hydrographic network within the park.

5.2.5 Ecological Valence

The Park is characterized by different environments that, for the purpose of describing the vegetal landscape, can be aggregated into three large macrosystems (see **Figure 19**):

a. Macrosystem of the margins of the Bitti, Alà and Buddusò plateau.

The macro-system is characterized by the plateau and the granite hills, bordered by the narrow-recessed valleys of the tributaries of the Rio Posada; inside there are the forest complexes of Crastazza, Sos Littos and Usinavà, where the dominant vegetation is holm oak (Forest Complex "Oasi di Tepilora" - PFP 2014-2023). In the Forest of Sos Littos, there is mainly a mesophilic holm oak vegetation (*Quercus ilex*), pure or with sporadic penetration of cork oak (*Quercus suber*). In the cooler and more humid areas there are more advanced structures with almost exclusive dominance of holm oak with phyllyrea (*Phillyrea latifolia*). In the slopes with warm exposure, species with heliophilous and xerothermophilic temperament predominate: the mesophilic holm oak scrub hosts heliophilous species, such as juniper (Juniperus sp.pl.), strawberry tree (Arbutus *unedo*), tree heather (*Erica arborea*) and other species typical of the thermoxerophilous scrub such as mastic (*Pistacia lentiscus*), olive (*Olea europaea var. sylvestris*) and myrtle (M*yrtus communis*).

Cork formations are, for the most part, of secondary origin and not very widespread. Holm oak and cork oak are attributable to the sub-alliance Clematido cirrhosae-Quercenion ilicis. The regressive stages of holm oak are mainly represented by the strawberry tree scrub and arboreal heather with phillyrea angustifolia (*Phillyrea angustifolia*), spiny spartium (*Calicotome sp.pl.*) and myrtle and mastic. In situations of greater degradation there are cyst phytocoenoses (*Cistus sp.pl.*), lavender (*Lavandula stoechas*), helichrysum (*Helichrysum italicum ssp. micr*ophyllum), and *Stachys glutinosa*. More sporadic and localized in the rockiest aspects are the garrigues with Corsican broom (*Genista corsica*).

Near Crastazza and in the complex of Usinavà we find mainly reforestation of conifers (*Pinus sp.pl.*). In the other areas the absence of grazing and fires has allowed the development of a scrub of heather and strawberry tree, and small strips of holm oak and heath cysts with the presence of cork oak (*Quercus suber*). On vast areas the anthropic intervention has determined the presence of degradation phenomena and the subsequent settlement of xerophilous plant species, with the appearance of formations first of garrigue or heath and subsequently of Mediterranean scrub with strawberry tree, mastic, juniper, alaterno (*Rhamnus alaternus*), heather, myrtle, phillyrea, olive (*Olea europaea var. sylvestris*), lavender (*Lavandula stoechas*), thorny brooms (*Genista corsica*), as well as cyst heaths.

b. Middle and lower course of the Rio Posada.

Along the river prevails the azonal vegetation typical of watercourses, riverbeds, temporary Mediterranean pools and lake environments, near the basin of the Maccheronis Dam and the presence of some artificial lakes deriving from quarry activities. The main tree species are represented by willows (*Salix spp*) and tamarisk formations *(Tamarix africana*) and oleanders (*Nerium oleander*). There are chaste trees (*Vitex agnus-castus*), black alder (*Alnus glutinosa*), black poplars (*Populus nigra*) and, rarely, white poplars (*Populus alba*). Among the trees, along the banks and / or in the bars and limited to some stretches, it is important to underline that there are populations of eucalyptus trees that show signs of invasiveness. Along the watercourse, there is an aquatic vegetation consisting of helophytes and referable to the class *Phragmito-Magnocaricetea* and *Potamogetonetaea*.

c. Macrosystem of the coastal plain and coastal habitats.

The contribution of continental and marine waters in the coastal plain allows, in a relatively small area, the presence of different plant formations: large extensions of reeds in Phragmites australis and valuable riparian formations in *Tamarix* and *Salix* along the banks of the Rio Posada and the Rio Santa Caterina, while, in the terminal sections, closer to the sandy cordon, and in the Stagno Longo, halophytic formations prevail with salicornie *(Sarcocornia spp*.), sueda (*Sueda sp*.) and obione (*Obione portulacoides*); In areas subject to grazing, grass meadows and annual plants are found, partly subject to temporary flooding, which are configured as Mediterranean steppe habitats. In the small internal ponds, there are riparian formations in *Tamarix sp.* and *Typha angustifolia* (RIS, 2017).

Of particular interest is the halophilic vegetation dominated by succulent Chenopodiaceae, with large halophyte meadows in the coastal portions and some small ponds in the inner part that are often flooded even in the summer months as they are fed by the superficial aquifer. The sand dunes host a mosaic of types of vegetation of interest (see habitat section), some present as small flaps, others more represented (e.g., *helichrysum psammophilous meadows*).

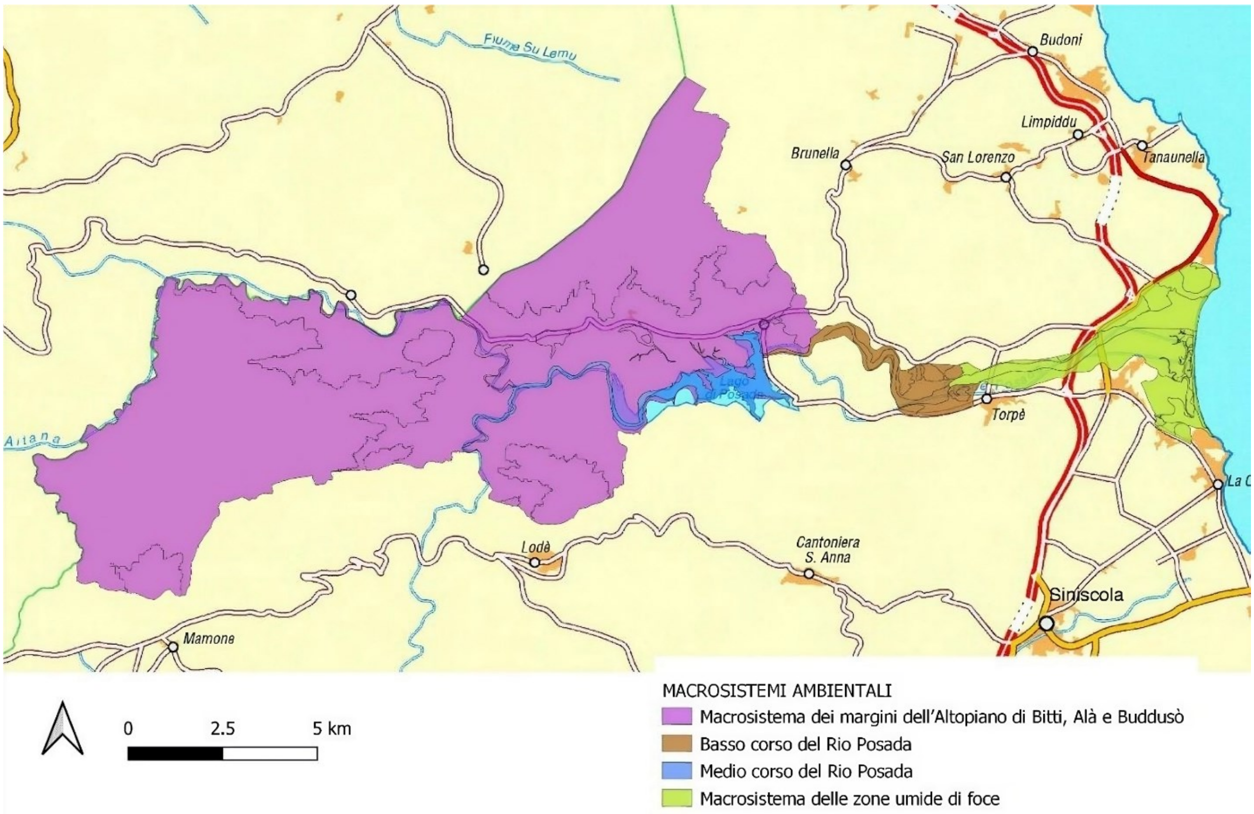


Figure 19. The environmental macrosystems of the Tepilora Park.

5.2.6 Land use

Below is the breakdown of the park territory in the different types of land use identified (see **Figure 20**):

a. Agricultural land

Arable crops

- Arable land in non-irrigated areas (699.74 hectares): Cultivated areas regularly ploughed and generally subject to a rotation system (e.g., cereals, legumes in the open field, crops, temporary meadows, herbaceous industrial crops, edible roots, and fallows). Channels or pumping structures are not identified by photointerpretation. This includes simple arable land, including plants to produce medicinal, aromatic, and culinary plants.
- Simple arable land and open field horticultural crops (101.05 hectares).
- Greenhouse crops (1.79 hectares).

Permanent Crops

Non-rotational crops that provide more crops and occupy the ground for a long period of time: these are mostly woody crops.

- Vineyards (23.12 hectares): areas planted with vines, including mixed cultivation of olive trees and vines, with a prevalence of vines.
- Orchards and minor fruits (98.72 hectares): planting of fruit trees or shrubs. Pure or mixed crops of fruit producing species or fruit trees in association with permanently grassed surfaces. They are mainly represented by citrus groves.
- Olive groves (10.79 hectares): Areas planted with olive trees, including mixed cultivation of olive trees and vines, with a prevalence of olive trees.

Heterogeneous agricultural areas

- Temporary crops associated with other permanent crops (15.47 hectares): pastures and arable land planted with cork cover from 5 to 25%.
- Complex cropping and parcel systems (91.18 hectares): mosaic of individually unchartable plots with various temporary crops, stable grassland, and permanent crops each occupying less than 50% of the area of the mapped element. They include family gardens.
- Areas mainly occupied by agricultural crops with the presence of important natural spaces (36.43 hectares).
- Agroforestry areas (312.73 hectares): Temporary crops or pastures under tree cover of forest species less than 20%.

b. Wooded areas and semi-natural environments

Wooded areas are the areas with tree cover consisting of forest species with a density of more than 20%.

- Deciduous forests (1665.69 hectares): plant formations consisting mainly of trees, but also of bushes and shrubs, in which deciduous forest species dominate.
- Coniferous forests (497.04 hectares): plant formations consisting mainly of trees, but also of bushes and shrubs, in which coniferous forest species dominate. The coniferous area constitutes at least 75% of the forest tree component.
- Poplars, willows, eucalyptus, etc. Also, in mixed formations (99.58 hectares).
- Arboriculture with coniferous forest species (1821.09 hectares). They are areas planted with trees of forest species mostly fast-growing to produce wood or intended for different productions, but subject to agricultural cultivation operations.
- Mixed coniferous and deciduous forests (376.18 hectares).
- Natural pasture areas (423.66 hectares): forage areas located in less productive areas sometimes with rock outcrops that cannot be converted to arable land. They are often located in rugged and/or mountainous areas. Particle boundaries (hedges, walls, fences) may also be present to circumscribe and localize their use.
- Non-arboreal ripa formations (41.78 hectares): stable formations composed mainly of bushes, shrubs and herbaceous plants located in wetlands.
- Mediterranean scrub (4441.50 hectares): dense plant associations composed of numerous shrub species, but also trees mainly with persistent leaves, in the Mediterranean environment.
- Garrigue (171.81 hectares): low and discontinuous bushy associations on calcareous or siliceous substrate. They are often composed of lavender, cysts, thyme, rosemary etc. It may include isolated trees.
- Areas with artificial recolonization (1.58 hectares): areas where interventions and preparatory works are evident for the plants such as tiering, holes, etc. even if sometimes, currently, spontaneous vegetation may have taken over the planted species.
- Areas with sparse vegetation (408.07 hectares): outcrops with vegetation cover > 5% and < 40%. It includes xerophilous steppes, halophilic steppes, and gully areas with partial vegetation cover.
- Stretches of sand (18.59 hectares): expanses of sand and pebbles of continental environments, including stony beds of torrential watercourses.
- Beaches over 25 meters wide (31.36 hectares).

c. Artificially modeled territories

- Compact and dense residential fabric (0.46 hectares): historical, twentieth-century fabrics and in any case, those structured in closed, continuous blocks. The fabrics are composed of buildings and cottages with open spaces interspersed with buildings.
- Sparse residential fabric (3.22 hectares): discontinuous urban areas with large open spaces where buildings, roads and artificially covered surfaces cover more than 50% of the total area.
- Sparse and nucleiform residential fabric (1.73 hectares): areas occupied by distinct residential buildings but grouped into nuclei that form widespread settlement areas of an extensive nature.
- Rural buildings (25.98 hectares): areas occupied by rural buildings, agricultural buildings, and their appurtenances – stables, warehouses, dairies, wineries, oil mills, etc., forming settlement areas dispersed in semi-natural or agricultural areas.
- Mining areas (23.88 hectares): extraction of inert materials in the open pit, also in the riverbed (sand, gravel, and stone quarries) or other materials (open-cast mines). This includes associated buildings and industrial installations as well as areas pertaining to abandoned and unrecovered quarries or mines.
- Construction sites (11.45 hectares): spaces under construction, excavations, and remodeled soils.
- Landfills (0.33 hectares).

d. Water bodies

- Watercourses, canals, and waterways (242.80 hectares): natural or artificial waterways that serve for the outflow of water – rivers, streams, and ditches.
- Reservoirs (231.32 hectares): artificial areas covered by water, whether intended for agricultural or fishing use.
- Inland marshes (0.71 hectares). They are lowlands generally flooded in winter and occasionally soaked in water during all seasons, sometimes with vegetation cover consisting of reeds, rushes, and sedges.
- Brackish marshes (152.27 hectares) They are lowlands with vegetation, located below the high tide level, therefore susceptible to flooding by the waters of the sea. Often in the process of filling, colonized little by little by halophilic plants.
- Lagoons, lakes, and coastal ponds with natural fish production (78.52 hectares).
- Estuaries and deltas (11.83 hectares).

The units of land describe portions of territory within which it is possible to insert an association of different soils, united by homogeneous physical parameters, such as lithological substrate, vegetation cover, land use, altitude, slope, type and intensity of erosion. Within each unit there are sufficiently homogeneous substrates both for natural aptitudes and in the responses to the uses to which these areas are subjected.

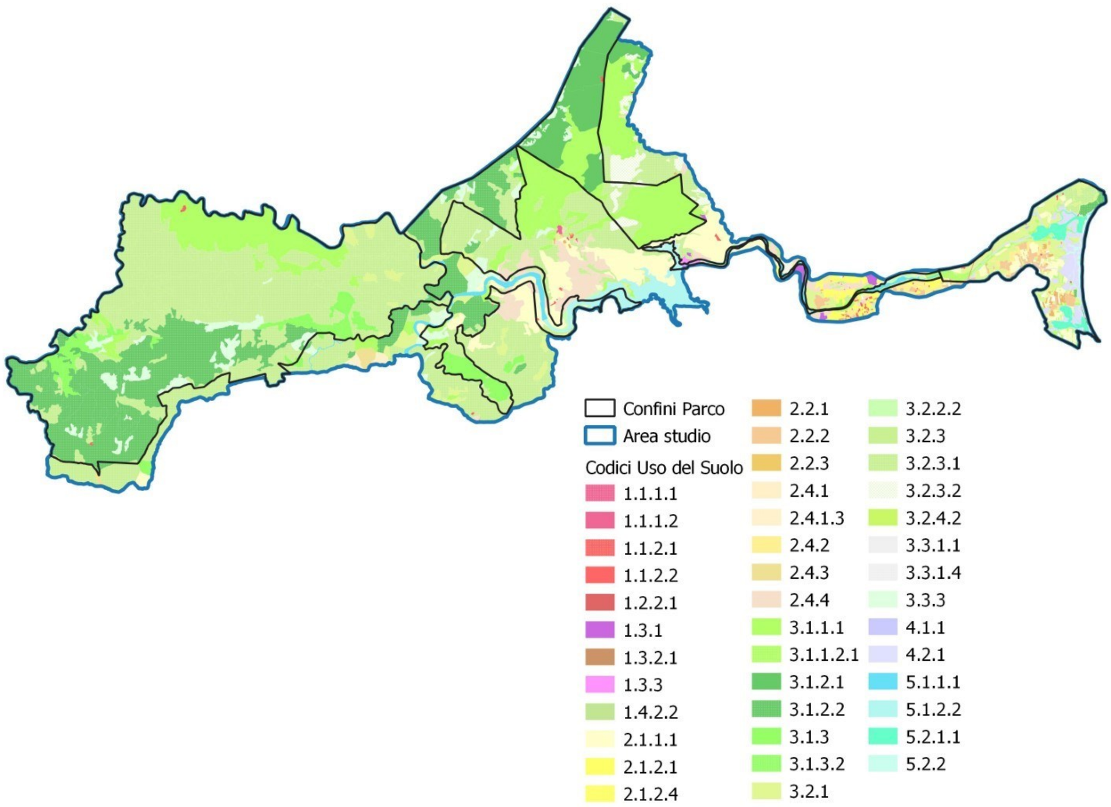


Figure 20. Land Use Map of Tepilora Park

Landscapes on metamorphites (shales, shales, clay schists, etc.) of the Paleozoic and relative slope deposits (2050.55 hectares)

The landscape on metamorphites is distinguished by different shapes and characteristics, depending on the slope and the vegetation cover, which also determines different thicknesses of the substrate. On the top of the hills, on the slopes and in the valley floors there are portions of territory where the outcropping rock is covered with a layer of soils with weak thickness and rich in skeleton. Where vegetation grows more continuously, even if in the presence of a rugged substrate or steep slopes, the soils are deeper and with more developed horizons.

Predominant soils: Typic and Lithic Xerorthents, Typic and Lithic Haploxerepts.

Main characteristics of the soils: shallow soils, variable texture from loam-sandy to loam-sandy-clayey, angular and subangular polyhedral structure, soil from permeable to little

permeable, moderate to high erodibility depending on the slope, poor organic matter, medium-low cation exchange capacity.

Limitations of use: moderate to high risk of erosion, often excess skeleton.

Attitude: grazing, reforestation, or protection of natural vegetation cover. Limited to some areas tree crops.

Landscapes on intrusive rocks (granites, granodiorites, leucogranites etc.) of the Paleozoic and related slope deposits (8604.06 hectares)

The landscape on intrusive rocks is distinguished by different shapes and characteristics, depending on the slope and vegetation cover, which also determines different thicknesses of the substrate. The soils found on granite rocks show an evolutionary pattern quite like those present on metamorphites.

Predominant soils: Typic and Lithic Xerorthents, Typic and Lithic Haploxerepts.

Main characteristics of the soils: shallow depth, variable texture from loam-sandy to loam-sandy-clayey, angular, and subangular polyhedral structure, permeable to slightly permeable soil, moderate to high erodibility depending on the slope, poor organic matter, medium-low cation exchange capacity.

Limitations of use: moderate to high risk of erosion, often excess skeleton.

Attitude: grazing, reforestation, or protection of natural vegetation cover. Limited

to some areas tree crops.

Alluvial deposits of the Pliocene and Pleistocene and cemented aeolian sandstones of the Pleistocene (174.70 hectares)

These are landscapes characterized by soils set both on ancient Quaternary substrates and on coastal plains and which generally have a strong evolution, with the formation of profiles A-Bt-C and A-Bw-C. Despite having different geolithological matrix, they can be merged with regard to use. They derive from floods and aeolian sandstones of the Pleistocene and as landscape forms lie on areas from flat to sub-flat. The current use is mainly agricultural.

Predominant soils: Typic Haploxerepts, Typic Palexeralfs.

Main characteristics of the soils: deep soils, variable texture from loam-sandy to loam-

sandy-clayey on the surface and from loam-sandy-clayey to clayey in depth, angular and subangular polyhedral structure, permeable to slightly permeable soil, moderate erodibility, scarce organic substance, medium-low cation exchange capacity.

Limitations of use: slow to very slow drainage, moderate risk of erosion, sometimes excess

of skeleton.

Attitude: herbaceous crops and, in the most drained areas, arboreal crops also irrigated.

Recent and current alluvial sediments and slope deposits derived from substrates consisting of marl and volcanic tuffs (848.94 hectares)

The soils of the L1 landscape unit are found on flat or slightly depressed morphologies. The soils have profiles A-C and subordinately A-Bw-C, they are deep, with texture from sandy franca to clayey loam, from permeable to little permeable, neutral, saturated.

They are entities classified as Typic Xerofluvents; At times they have limitations (excess skeleton, slow drainage, flood danger) that reduce the choice of crops and require special practices for the conservation of soil and production potential. The good pedo-agronomic characteristics of these substrates are mainly limited by problems related to situations of fine texture and therefore to any water stagnation also possible due to rising groundwater or flooding.

Holocene wind sands (28.39 hectares)

The soils of the M1 Landscape Unit are found morphologically in the dune field areas. They are found in open areas with sparse and absent vegetation.

The soils have profiles A-C and subordinately A-Bw-C, deep, sandy to sandy frank, from permeable to very permeable, sometimes not very permeable in depth, from neutral to subalkaline, saturated. They are classified as Typic Xeropsamments, Aquic Xeropsamments, Typic Xerorthents subordinately Xerochrepts, Quartzipsamments Fluvaquents. Main characteristics of soils: deep soils, clayey or clayey-silty texture, massive or columnar structure, poorly permeable soil with poor erodibility, poor-medium organic substance cation exchange capacity.

Limitations of use: slow drainage, high salinity, flood hazard.

Attitude: conservation of the natural environment.

Coastal sediments (marshes, coastal lagoons, etc.) of the Holocene (213.34 hectares)

The soils of the N1 Landscape Unit are found morphologically in flat or depressed areas. They are found in open areas with sparse and absent vegetation.

The soils of the peristagnal areas are characterized by a high percentage in soluble salts. These soils, with a predominance of Typic Salorthids and subordinately Fluvaquents, of light gray color, have a very slow or absent drainage, and often have accumulations of salt (sodium chloride and calcium bicarbonate) which in the dry period are found in the form of pockets or lenses. The excessive salt concentration and the almost absent drainage make them unsuitable for agricultural use and are instead colonized by halophilic vegetation.

The soils have A-C profiles, deep, clayey or loamy loamy, little permeable, from subalkaline to alkaline, saturated.They are classified as Typic Salorthids, subordinately Fluvaquents. The limitations of use: slow drainage, high salinity, flood hazard. The attitude: conservation of the natural environment.

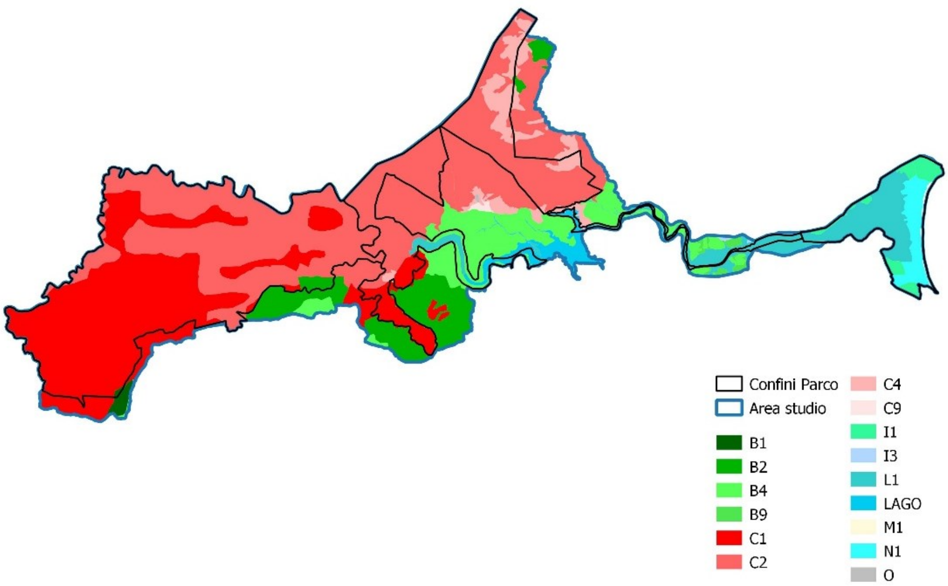


Figure 21. Map of land units

5.2.7 Climate

a. Crastazza

The climatic description of this area is compared through the analysis of precipitation and temperatures in their most significant parameters taken from the Alà Dei Sardi observatory. The data are quite reliable because they are taken in an observatory of the plateau and therefore very similar to bitti station. Climatic phenomena will be analyzed by examining precipitation and thermal data in their annual and seasonal values. The thermal and rainfall data are compared with each other through the Wolth and Leith diagram to immediately render the main climatic characteristics of the station. The average annual precipitation for 42 years of observation is mm. 1,079. The average seasonal precipitation is Inv. 415, Prim. 276, East. 54, Aut. 334; rainy days 79 (source – P.V. Arrigoni-Phytoclimatology of Sardinia). A maximum of winter precipitation and a minimum during the summer period are immediately noticeable. Through the seasonal relative rainfall coefficients, a rain regime winter-autumn-spring-summer (IAPE) is determined, which is the most common for the island. It was also intended to calculate the Fournier index, the value of which (25.8) expresses a considerable eroded capacity of the climate, contributing greatly to the pedological degradation, accentuated in the case of the Bitti Forest station by the previous poor protection offered by vegetation, slope and soil deriving from a granite substrate, rather loose. The thermal character of the station emerges from the following data: - Average annual max 18.2 °C - Average annual min 7.7 °C - Annual average 12.9 °C - Average maximum warmer month (July) 29.7 °C - Average min colder month (January) 1.1.6 °C - Average of the hottest month 22.8 °C - Average of the coldest month 3.9 °C - Average annual lows 4.6 °C - Average annual highs 36.3 °C - Annual thermal excursion 18.9 °C These values , in particular the annual average (12.9 °C) the average of the coldest month (3.9 °C) and the average of the annual minimums (- 4.6 °C), supplemented by the rainfall values for the annual precipitation (1,079 mm.) and summer (54 mm.) frame the station under examination in the lauretum-cold undersea area of the phytoclimatic classification of the Pavari. The examination of the Wolth and Leith climatogram shows a physiologically significant drought of about 72-80 which, while not taking pathological aspects on vegetation, causes a sharp slowdown in vegetative activity resulting in a lower biomass production of the ecosystem.

b. Tepilora

The climate of this area is characterized by high spring-summer temperatures and irregularity of precipitation so, also considering the building characteristics, the conditions are not ideal for a rapid recovery and reintegration of the tree cover. Also, in the Tepilora area there is no thermo-rain station, so, for the purpose of phytoclimatic classification, reference was made to the nearby thermo-violent station of Torpè. Precipitation is variable from one year to the next, so rainy years alternate with extremely dry years with dry periods that last for over five to six months. From the phytoclimatic point of view the area can be ascribed to the area of the Lauretum hot and medium subarea.

5.2.8 Demographic

In the 4 municipalities that make up the park (Bitti, Lodè Posada, Torpè) live about 10,000 people. From a demographic point of view there has been a progressive depopulation of inland areas (Bitti, Lodè) for decades, while in coastal areas there has been a slight increase in the resident population (Posada, Torpè)

The population is divided as of December 31, 2021:
Municipality of Bitti: 2,610 residents;
Municipality of Lodè: 1,529 residents;
Municipality of Posada: 3,020 residents;
Municipality of Torpè: 2,720 residents;

The production activities in the territory are divided as follows:
In the municipality of Bitti are active in February 2021:
• 549 production activities;
• 337 (61%) are productive activities related to agriculture, forestry and fishing;
• 68 (12%) are wholesale and retail trade, and repair of motor vehicles;
• 38 (7%) are activities related to the construction sector;
• 31 (6%) are manufacturing activities;
• 21 (4%) accommodation and food service activities.

In the municipality of Lodè are active, in February 2021:
• 153 production activities;
• 85 (56%) are productive activities related to agriculture, forestry and fishing;
• 25 (16%) are wholesale and retail trade, and repair of motor vehicles and motorcycles;
• 16 (10%) are activities related to the construction sector;
• 12 (8%) accommodation and food service activities;

In the municipality of Torpè are active, in February 2021:
• 324 production activities;
• 85 (26%) are activities related to the construction sector;
• 83 (25%) are productive activities related to agriculture, forestry and fishing;
• 78 (24%) are wholesale and retail trade and repair of motor vehicles;
• 28 (9%) manufacturing;
• 22 (7%) accommodation and food service activities;

In the municipality of Posada are active in February 2021:
• 238 production activities;
• 58 (24%) are wholesale and retail trade, and repair of motor vehicles and motorcycles;
• 54 (23%) are activities related to the construction sector;
• 48 (20%) accommodation and food service activities;
• 45 (19%) are productive activities related to agriculture, forestry and fishing;
• 11 (5%) are manufacturing activities;

5.2.9 Forest Ownership

There are several public properties in the Tepilora Park, which see the Regione Sardegna as the main public entity owner of assets in the three-state property of Sos Littos, Crastazza and Usinavà, especially if we consider that the assets currently still registered to the FoReSTAS Agency will fall within the regional state property. The municipalities of Lodè, Torpè and Posada, the State Property for water, but also the Tepilora Park for the property of the Longu Pond are also important public entities holding assets in the park.

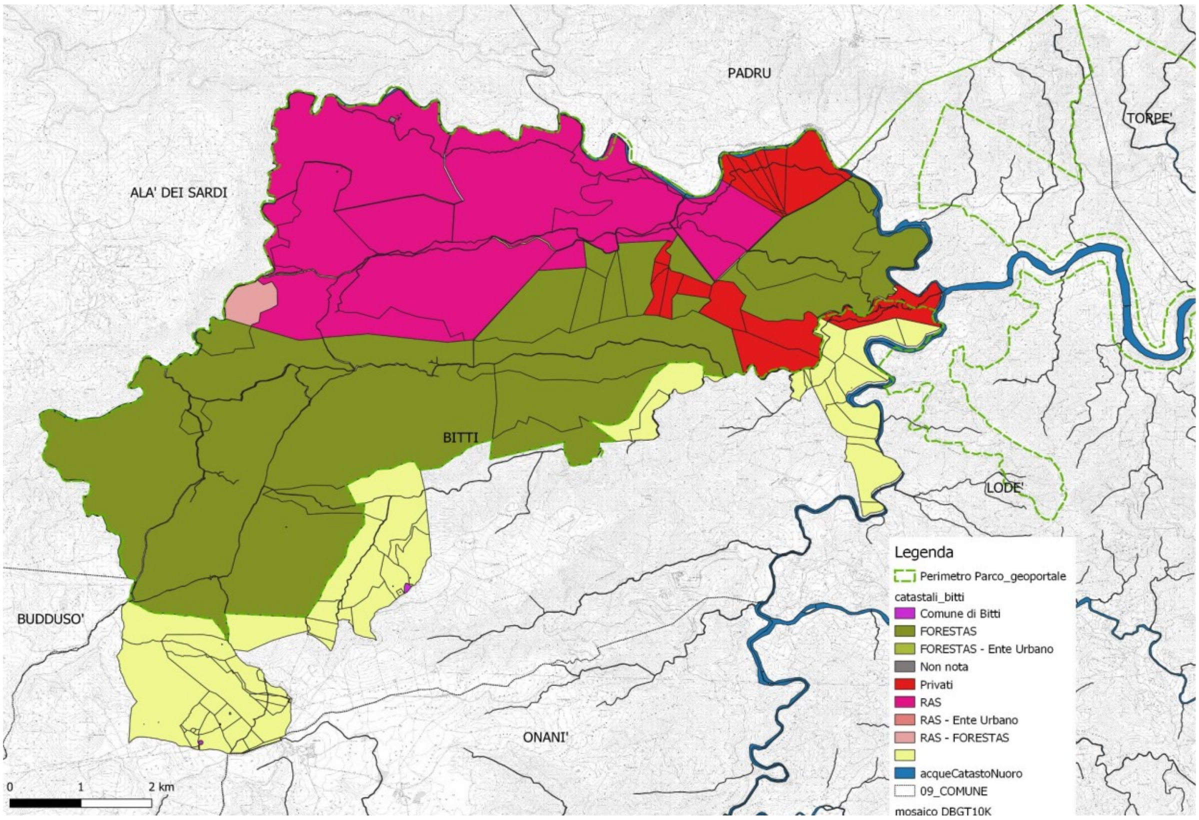


Figure 22. Forest ownership

5.2.10 Flora

In the Forest of Sos Littos, there is mainly a mesophilic holm oak vegetation (*Quercus ilex*), pure or with sporadic penetration of cork oak (*Quercus suber*). In the cooler and more humid areas there are more advanced structures with almost exclusive dominance of holm oak with phyllyrea (*Phillyrea latifolia)*. In the slopes with warm exposure, species with heliophilous and xerothermophilic temperament predominate: the mesophilic holm oak scrub hosts heliophilous species, such as juniper (*Juniperus sp.pl*.), strawberry tree (*Arbutus unedo)*, tree heather (*Erica arborea*) and other species typical of the thermoxerophilous scrub such as mastic (*Pistacia lentiscus*), olive (*Olea europaea var. sylvestris*) and myrtle (*Myrtus communis*).

Cork formations are, for the most part, of secondary origin and not very widespread. Holm oak and cork oak are attributable to the sub-alliance Clematido cirrhosae-Quercenion ilicis. The regressive stages of holm oak are mainly represented by the strawberry tree scrub and arboreal heather with phillyrea angustifolia (*Phillyrea angustifolia*), spiny spartium (*Calicotome sp.pl*.) and myrtle and mastic. In situations of greater degradation there are cyst phytocoenoses (*Cistus sp.pl.*), lavender (*Lavandula stoechas*), helichrysum (*Helichrysum italicum ssp. microphyllum*), and Stachys glutinosa. More sporadic and localized in the rockiest aspects are the garrigues with Corsican broom (*Genista corsica*).

Near Crastazza and in the complex of Usinavà we find mainly reforestation of conifers (*Pinus sp.pl.*). In the other areas the absence of grazing and fires has allowed the development of a scrub of heather and strawberry tree, and small strips of holm oak and heath cysts with the presence of cork oak (*Quercus suber*). On vast areas the anthropic intervention has determined the presence of degradation phenomena and the subsequent settlement of xerophilous plant species, with the appearance of formations first of garrigue or heath and subsequently of Mediterranean scrub with strawberry tree, mastic, juniper, alaterno (*Rhamnus alaternus*), heather, myrtle, phillyrea, olive (*Olea europaea var. sylvestris*), lavender (*Lavandula stoechas*), thorny brooms (*Genista corsica*), as well as cyst heaths.

Along the river prevails the azonal vegetation typical of watercourses, riverbeds, temporary Mediterranean pools and lake environments, near the basin of the Maccheronis Dam and the presence of some artificial lakes deriving from quarry activities. The main tree species are represented by willows (*Salix spp*) and tamarisk formations (*Tamarix africana*) and oleanders (*Nerium oleander*). There is chaste tree (*Vitex agnus-castus*), black alder (*Alnus glutinosa*), black poplar (*Populus nigra*) and, rarely, white poplar (*Populus alba*). Among the trees, along the banks and / or in the bars and limited to some stretches, it is important to underline that there are populations of eucalyptus trees that show signs of invasiveness. Along the watercourse, there is an aquatic vegetation consisting of helophytes and referable to the class Phragmito-Magnocaricetea and Potamogetonetaea.

The contribution of continental and marine waters in the coastal plain allows, in a relatively small area, the presence of different plant formations: large extensions of reeds in Phragmites australis and valuable riparian formations in Tamarix and Salix along the banks of the Rio Posada and the Rio Santa Caterina, while, in the terminal sections, closer to the sandy cordon, and in the Stagno Longo, halophytic formations prevail with salicornie (S*arcocornia spp*.), sueda (*Sueda sp.*) and obione (O*bione portulacoides*); In areas subject to grazing, grass meadows and annual plants are found, partly subject to temporary flooding, which are configured as Mediterranean steppe habitats. In the small internal ponds, there are riparian formations in Tamarix sp. and Typha angustifolia (RIS, 2017).

Of particular interest is the halophilic vegetation dominated by succulent Chenopodiaceae, with large halophyte meadows in the coastal portions and some small ponds in the inner part that are often flooded even in the summer months as they are fed by the superficial aquifer. The sand dunes host a mosaic of types of vegetation of interest (see habitat section), some present as small flaps, others more represented (e.g., *helichrysum psammophilous* meadows).

5.2.11 Wildlife

The Park area has been divided into four macro-systems within which the possibility of finding the different species has been indicated, based on the environmental characteristics of the system and the ecological needs of the species.

a. Macrosystem of the margins of the Bitti, Alà and Buddusò plateau

The macro-system, characterized by a high naturalness, consists of plateau and granite reliefs, within which extend the forest complexes of Crastazza, Sos Littos and Usinavà. The area represents a site of valuable wildlife value and is mainly associated with the presence of macro mammals such as wild cats (180), martens (183) and mouflon (186), species included in Annexes IV, III and II-IV of the Habitats Directive, respectively. The Sardinian deer (184) reported within the GIREPAM, at the moment is not present within the perimeter of the park but is present in contiguous areas is therefore not to be excluded a reoccupation of the area in the medium term. In addition, within the system was reported the presence of the fallow deer (185), extinct in Sardinia in the late 60s and reintroduced in the regional territory from the second half of the years "70.

Among the most important species of birds of note is the presence of nesting birds of prey (goshawk (50), sparrow hawk (51), buzzard (52), golden eagle (53), kestrel (55) and peregrine falcon (57)) and a large number of passerines, some of which are mainly linked to forest and mountain environments or to habitats located on the margins of these, consisting of open areas, with low scrub, cliffs or rocky outcrops (great spotted woodpecker (96), tottavilla (98), wren (109), robin (111), saltimpalo (115), solitary sparrow (117), collared nurse (119), bottaccio thrush (121), tordela (122), Sardinian magnanina (127), common magnanina (128), sterpazzolina (131), blackcap (133), fiorrancino (136), blackberry (137), blue (138), great (139), raven

(145), Chaffinch (150), Venturone Corso (152), Lucherino (155) and Black Bunting (157)). Among the species listed, 8 are considered endemic species, (50, 51, 96, 109, 127, 137, 139 and 152) and 9 others are included in the Annexes of the Birds Directive (50, 53, 57, 98, 119, 121, 122, 127 and 128) and therefore considerable of greater attention.

Furthermore, as regards reptiles, the presence of the dwarf algyroid (23), endemic to Sardinia and Corsica and of the tarantuline (20), both present in the annexes of the Habitats Directive, has been reported. Among the most valuable invertebrates is the presence of the oak cerambyx (189), included in Annexes II and IV of Directive 43/92 / EEC and the endemic species Uromanes annae (191) and Papilio hospiton (192).

b. Half Corsican of the Posada River

The macro-system includes the stretch of the Rio Posada upstream of the Maccheronis Dam and its reservoir. The river, in this sector, is characterized by the presence of fish species characteristic of mountain stretches, with fresh and well-oxygenated waters, such as Sardinian trout (13), classified as critically endangered by the IUCN and the dog (8). Along the course, moreover, the presence of the Sardinian eupult (18) is reported, an endemic species, considered endangered by the IUCN and included in Annex IV of the Habitats Directive, to be considered also present in the mountain tributaries of the course. While, in the waters of the reservoir there is the cuttlefish (5), included in Annexes II and IV of Directive 43/92 / EEC. Within the area has been detected the presence of numerous species of birds related to freshwater environments, both river and lake, and riparian (mallard (45), moorhen (61), nightjar (88), kingfisher (92), bee-eater (93), yellow wagtail (108), river nightingale (123)), some of which are included in the Annexes of the Birds Directive.

As far as mammals are concerned, the presence of bodies of water recalls some species of bats, particularly linked to humid environments, such as the vespertilio smarginato (160), the dwarf bat (163) and the Savi's bat (164), all species included in the Annexes of the Habitats Directive. However, these do not appear, together with the other species of bat’s present (vespertilio maghrebino (161), bat albilobato (162), minioptera (165), plecotus sp. (166) and Cestoni molosso (167)), exclusive of the macrosystem, but can also be found in the other macrosystems.

Among the invertebrates it is reported the presence of divalve molluscs dulciacquicoli, uninionids of the genus Unio, probably attributable to the species Unio mancus, species indicated in the IUCN red lists as NT, almost threatened.

c. Lower course of the Rio Posada

The lower section of the Rio Posada is between the lower limit of the Maccheronis Dam and its reservoir and the wet system of the terminal section of the river. The most valuable and critical fish species, present both in this macro-system and in that of the wetlands, is the eel (1), classified as critically endangered by the IUCN and included in Annex II of CITES. The area is characterized by the presence of open spaces in which numerous agricultural areas fall, in its easternmost limit, which are an optimal habitat for some species of birds of considerable environmental and community value (lesser kestrel (54), cuckoo hawk (56), lark (99), calandro (103), nightingale (112) and shrike (141). Finally, the presence of the aquaculture system is relevant for a large number of amphibians and reptiles (emerald toad (14), Sardinian discoglossus (15), Sardinian tree frog (16), European marsh turtle (15), snake (28), biscia (29) and viper snake (30)), all linked to the presence of water and to be considered present also in the macrosystems of the middle course of the Rio Posada and in that of the wetlands of the mouth as well as in the tributaries of the Posada present in the macrosystem of the Plateau of Bitti, Alà and Buddusò.

d. Macrosystem of mouth wetlands

The macrosystem has a high degree of naturalness and includes the terminal stretch of the Rio Posada, its alluvial plain and the sandy coastal cordon. This area is a favorable habitat for numerous species of birds, linked to the presence of wetlands, included in Annex I of the Birds Directive (bittern (33), night heron (34), squacco heron (35), egret (37), great white heron (38), purple heron (40), flamingo (42), ferruginous duck (47), marsh harrier (49), sultan chicken (62), big eye (64), knight of Italy (65), fratino (68), Sandpiper Sandpiper (73), Rosegull (76), Corsican Gull (77), Fishbill (79), Calanrella (97)), for which special conservation measures are laid down, and in Annexes II and III (teal (44), pochards (46), water rails (60), coot (63), snipe (70), marsh (71) and common gull(75).

5.2.12 History of Fires

For the analysis of the historical series of fires were considered the events referring to the period 2012-2019 elaborated by the Forestry and Environmental Surveillance Corps of the Autonomous Region of Sardinia, from which it also emerges that the fires in the Territory of the four Municipalities that make up the Tepilora Park. **Table 9** shows the detail of forest fires data in the Tepilora Park. They occur almost exclusively in the summer period (June, July, August, September). The processing of the raw data made it possible to obtain the data summarized in the table, which shows that a total of 78 fires occurred in the period under review, but their annual number is extremely variable, going from a minimum of 4 in 2018 to a maximum of 18 in 2019. The annual extension is also not constant. In 2019, because of exceptional and extensive fires, the total area burned was 595.80 hectares with an average area per fire of 33.1 hectares.

In the same period, the total area burned by the fire was 898.95 Ha, of which 58% (Ha 539.12) concerned wooded areas, while the remaining 37% (Ha 359.83) involved non-wooded areas (pastures, uncultivated land).

Table 9. Forest Fires in the Tepilora Park

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Tot.**
Number of fires	6	8	10	10	10	12	4	18	78
Wooded area (Ha)	23.64	7.31	12.59	18.6	10.41	139.28	1.12	326.15	539.12
Total area (Ha)	**49.70**	**27.08**	**19.99**	**38.86**	**25.01**	**139.58**	**2.93**	**595.80**	**898.95**
Average fire area (Ha)	8.28	3.38	1.99	3.88	2.50	11.63	0.73	33.10	65.49

2016: Fire that caused the destruction of about 3 hectares of forest. The extinguishing operations were conducted by the Forestry and Environmental Surveillance Corps of the Sardinian Region, supported by Forestas Agency workers and volunteers.

5.2.13 Brief description of the fire risk

The perimeter of the park (See **Figure 23**) is delimited in the 1:20,000 cartography attached to the Regional Law No. 21 of 24/10/2014.

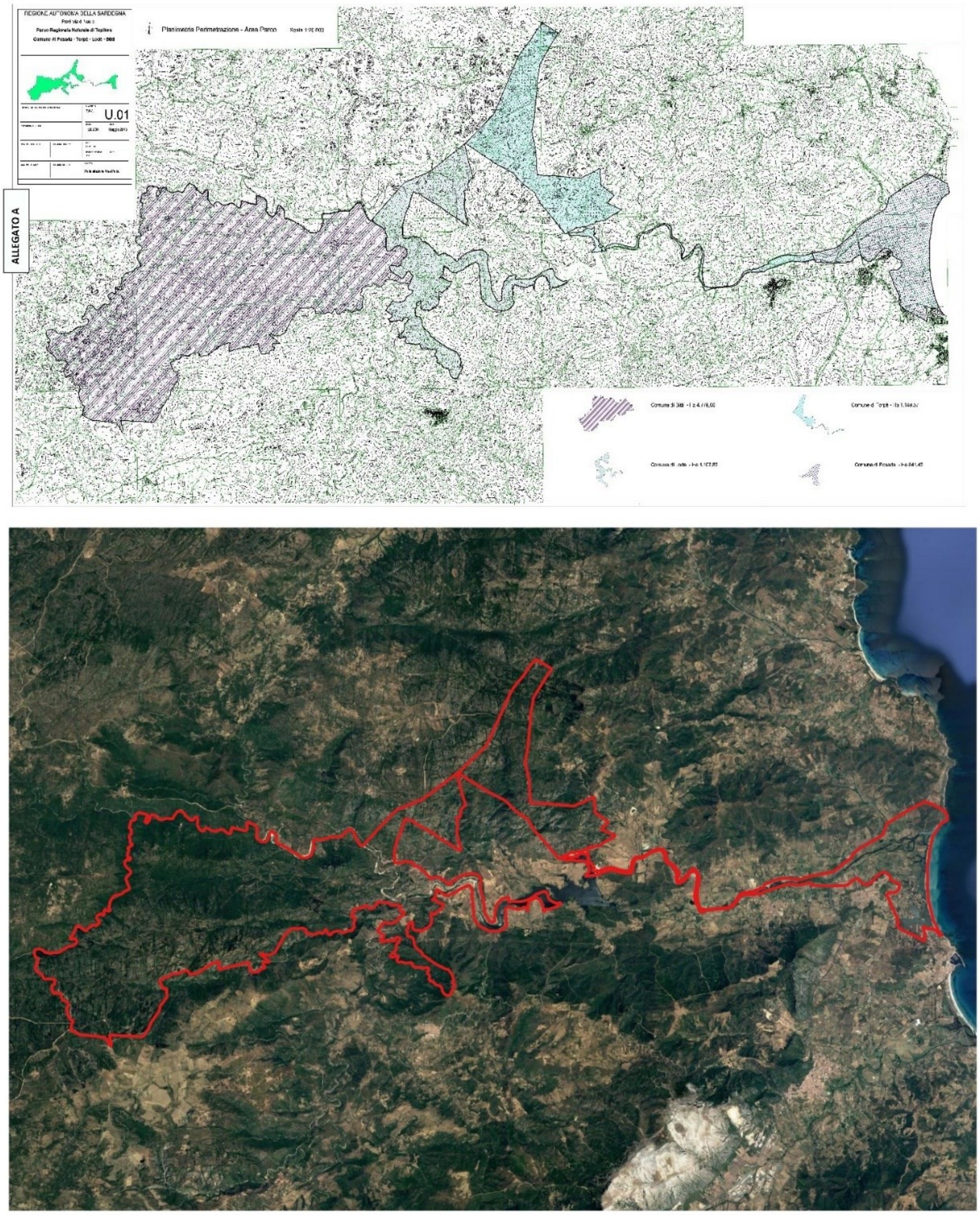


Figure 23. Perimeter of the Tepilora Regional Natural Park.

The following information has been taken from the Detailed Forest Plan - 2014-2023 of the Crastazza- Littos - Usinavà Forest Complex.

The following zoning aims to provide useful reference indications to define and size fire protection interventions, identifying, based on risk spatialization, the areas where a priority of prevention intervention is required.

The fire risk map (**Figure 24**) is derived from a weighted spatial superposition operation of the ignition potential map and the linear intensity map with reclassification into 4 priority levels (see legend). The zoning has highlighted the areas that present the greatest risk of fire and from the analysis of the map emerge the critical issues relating to the most sensitive areas in which it is a priority to concentrate prevention interventions.

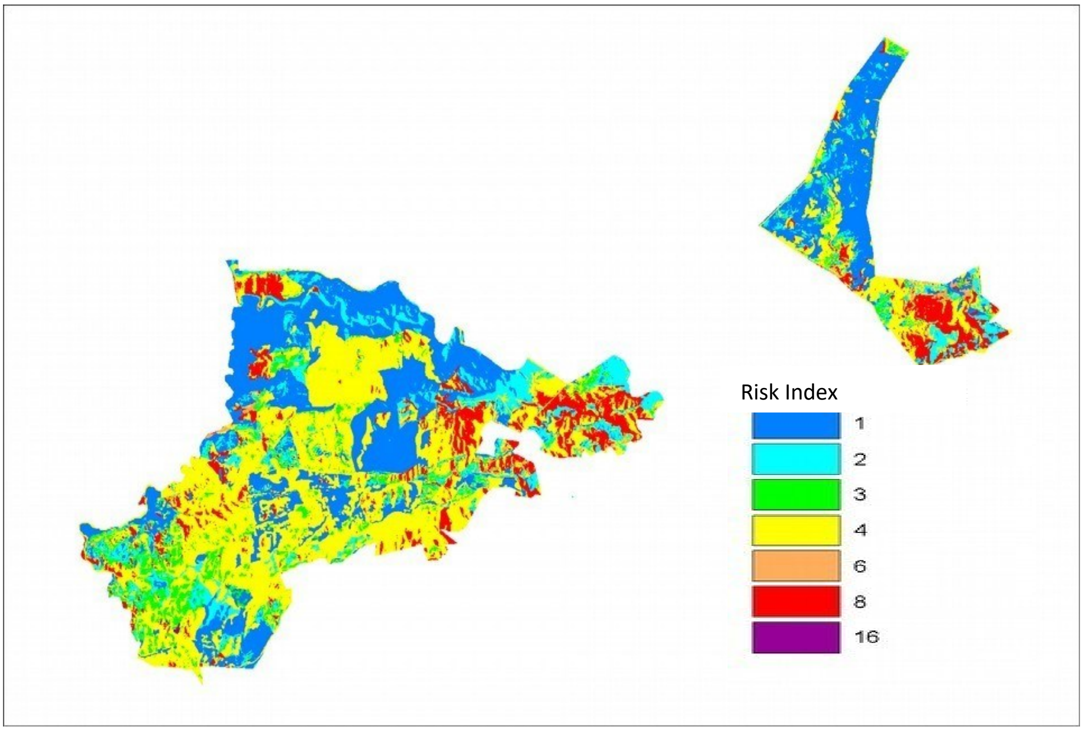


Figure 24. Fire Risk Map

Figure 25 shows the surface distribution by fire risk class. The areas at high risk are more than 10% of the surface; it is clear from the map that the high-risk areas are concentrated above all in the southern part of Usinavà and another area of high risk is represented by the southern slopes of Punta Tepilora (falling within the Crastazza forest but the area also extends into the neighboring areas of Sos Littos). However, relatively large areas are also found in other areas of Sos Littos Sas Tumbas (in the northwest and southeast corners, in the Prammas area and along the road leading to Crastazza).

The data presented are derived from a processing model that takes into account climatic, topographical and silvicultural parameters; However, it is equally important to carefully evaluate the presence of accommodation facilities, the areas accessible to visitors (areas accessible by car and areas near the paths) and the areas with exclusive access to the staff of the FORESTAS Agency, especially in the portions of the complex qualified by a high-risk class.

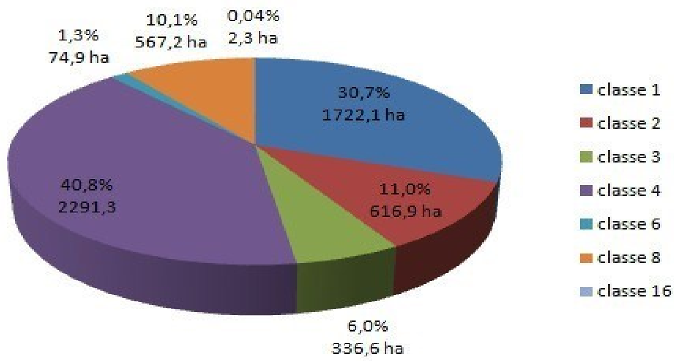


Figure 25. Distribution of the surface area by fire risk class

The predisposing factors are those variables that directly affect the conditions that favor the spread of fire, i.e., type of burnable fuel (fuel models), topographical conditions (altitude, slope, exposure) and meteorological conditions (air temperature, air humidity, precipitation, wind speed and direction). The fuel model map displays data that constitutes a fundamental input variable, which allows you to implement the static component of the simulation model to be placed in relation to the weather scenario.

The spatialization of the types of fuel present contributes to the definition of the risk and can be used to respond to the need to plan and allocate resources for the extinction or reconstitution of areas covered by fire. The map was made from the characteristics of the fuel present in the different types of vegetation, observed in the various survey campaigns (**Table 10**).

The classification was based on the main models described by the Northern Forest Fire Laboratory, catalogued in four main groups and 13 types in relation to the component of phytomass, dead and alive, which supports the spread of fire. The **Table 10** shows the spatial distribution of fuel models within the forest complex. As can be seen, the most represented model is that relating to sub particles in which the fire spreads mainly on the green fuel of the component and shrub in formations characterized by an almost uniform horizontal continuity (40.4%). These are all the degradation formations of the evergreen holm oak evolved and stable (spots and garrigues).

Table 10. List of Fuel Models Used in Field Surveys.

Brief description of the model	Model encoding	Component that supports propagation
Low and continuous grassland	1	Herbaceous layer
Grassland with scattered trees and/or shrubs	2	
High prairie	3	
High and continuous shrubby vegetation	4	Shrub layer
vegetation low	5	
Shrubby vegetation with intermediate characters between the mod. 4 and 5	6	
Vegetation characterized by very flammable species	7	
Compact litter	8	Litter
Non-compact litter	9	
Litter with undergrowth	10	
Light residues of use	11	Residues
Average residues of use	12	
Heavy residues of use	13	

Table 11. Surface distribution for fuel models.

Fuel model	Ha	%
0	155.2	2.7
1	14.9	0.3
2	323.2	5.6
4	733.8	12.8
5	2,313.9	40.4
6	961.9	16.8
7	28.8	0.5

Fuel model	Ha	%
8	846.0	14.8
9	94.6	1.7
11	261.7	4.6
TOTAL	*5,734.1*	*100.0*

Among the other categories, there are models no. 4 and 6, different from 5 for the average amount of fuel present but always concerning formations with a prevalent shrub character, which cover a total of almost 30% of the total area. Finally, there is a certain number of hectares where a fuel model can be envisaged for which the pyrological event can be triggered starting from the undecomposed litter of conifers or broad-leaved trees (model attributable to reforestation of conifers and holm oaks).

The implementation of the mathematical model of fire propagation requires, in addition to the data depicted in the map of fuel models, also the drafting of the following information layers: Tree cover (divided into 4 classes: < 20%, 20 – 50 %, 50 – 80 %, > 80 %), Slope exposure, Slope of the land, and Altitude. The meteorological and climatic factors (temperature, humidity, precipitation, wind speed and direction), necessary for the definition of the meteorological scenario, were derived from the data collected by the meteorological stations located in the geographical area of localization of the Forest and from bibliographic data valid for the entire regional territory.

5.2.14 The ignition probability map

The ignition probability map (**Figure 26**) is closely linked to the variation in the moisture content of the dead-end fuel in the different sectors of the complex, in relation to the topography and therefore to the parameters of exposure, slope and altitude.

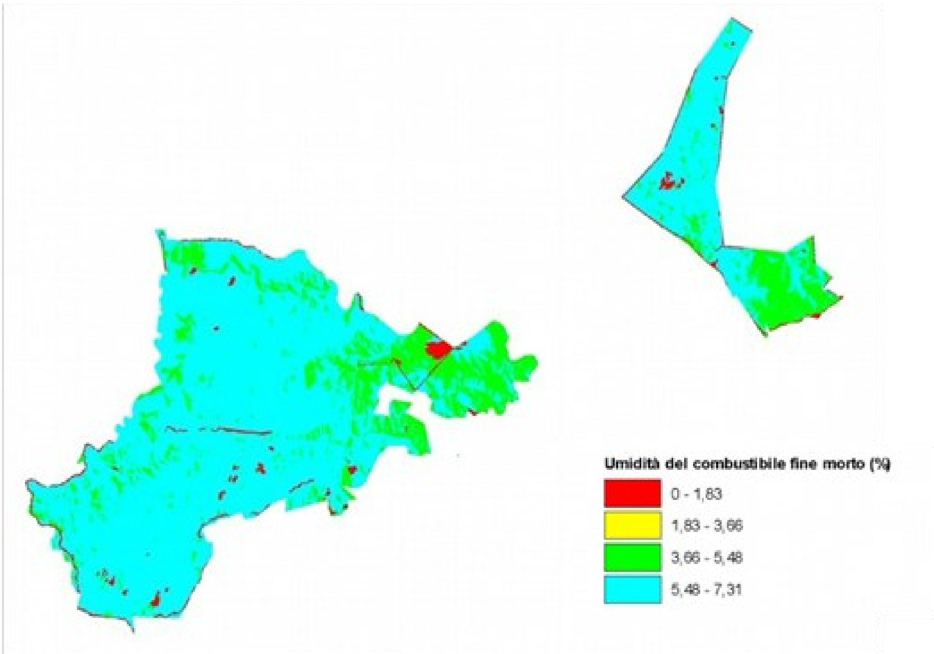


Figure 26. Ignition Probability Map

To quantify the value of this parameter, the incidence of solar radiation, at each point of the territory, was examined, in relation to the amount of dead-end fuel present. Exposure is an element of great importance in forest fires and especially in their initial phase of ignition and immediate propagation. In the graph in **Figure 27** (Campbell Prediction System graph) you can see how fuel temperatures vary according to the time of day and slope exposure. The flammability of the fuel is closely linked to its temperature, so it is noted that for the southern and western exposures and the central hours of the day there is a greater probability of ignition because, evidently, the temperature of the fuel is higher.

The trigger risk map therefore expresses the probability that an event will develop in the presence of a determining factor which, in this hypothesis, is presumed to be uniform throughout the territory under investigation.

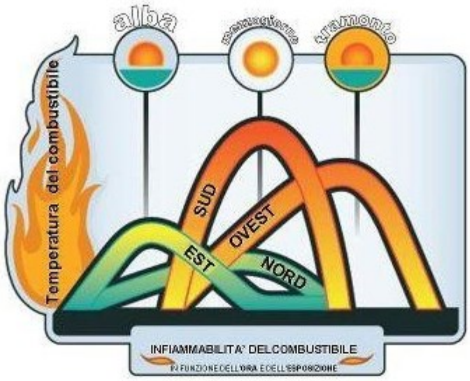


Figure 27. Campbell Prediction System chart.

5.2.15 The linear intensity of the fire

The fire parameters that allow to characterize the event are the following:

1. Linear intensity: heat developed in the length unit (Kw/m);
2. Flame length: (m);
3. Propagation speed: (m/min).

The linear intensity turns out to be a fundamental quantity to understand the characteristics of the fire and allows to estimate the probable effects of the fire on the vegetation and the possibilities of intervention of the firefighting teams: low values of linear intensity of the fire indicate the possibility of intervening with manual means; on the contrary.

High linear intensity values indicate scenarios that are increasingly difficult to control even by mechanical means. Below is the linear intensity ma, in which the expected values have been grouped into classes in relation to the extinction difficulty, parameterizing the 4 classes (Figure 28) based on the 3 parameters above:

a. CLASS 1: up to 400 KW/m (flame length of about 1 m), the flame front can be attached directly to the head portion and sides by manual means.
b. CLASS 2: from 400 to 800 KW/m (flame length between 1 and 2 m), the direct connection can be done only by mechanical means.

c. CLASS 3: from 800 to 1600 KW/m (flame length between 2 and 3 m), fire can only be attacked with indirect attack and by air.

d. CLASS 4: over 1600 KW/m (flame length over 3 m), the fire is difficult to control in which spotting phenomena and jumps of sparks are predictable (Bovio, 1996).

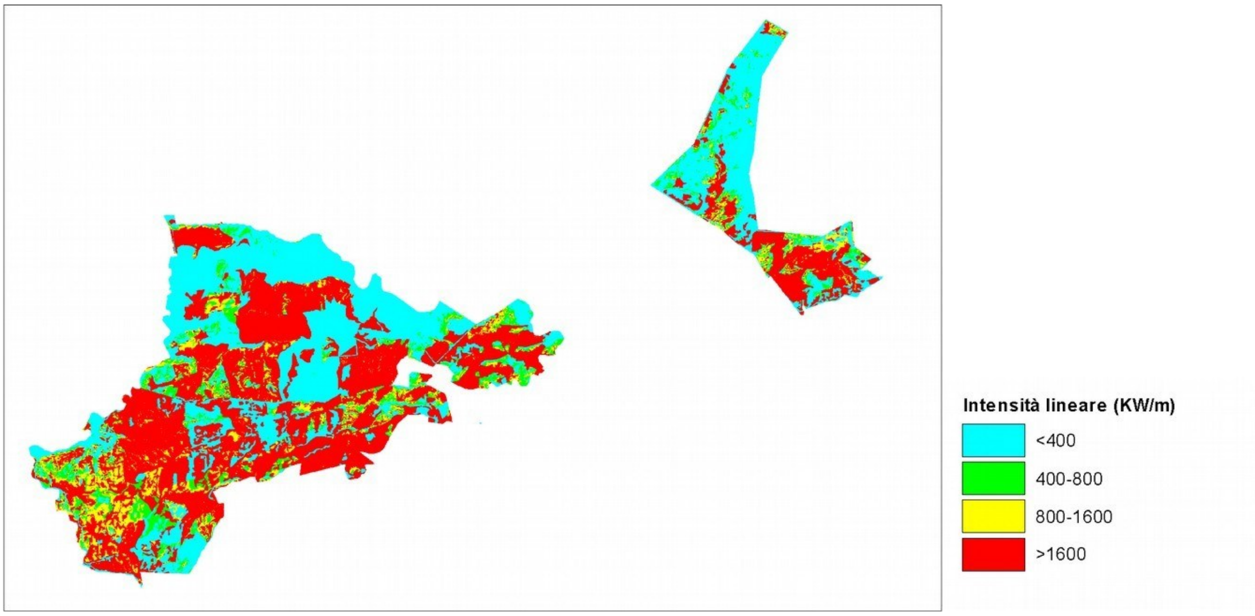


Figure 28. Map of linear fire intensity

As can be seen in **Figure 28**, the 4 classes are all represented with prevalence of class 1 and 4. It is possible to foresee a class 1 fire (400 Kw / m) with flames up to 1 meter high and therefore can be faced with the ground teams with the use of manual and mechanical tools (flabelli, tapes, atomizers) without difficulties.

There are also several areas where class 2 fire behavior can be expected. In this case it is possible to foresee fires with flames of 1-2 meters that can no longer be faced only with manual tools, but which instead require AIB vehicles (pick up, Tsk) set up with AIB modules.

The areas in which a greater linear intensity is expected (Class 3 and 4), and therefore those most sensitive from the point of view of pyrological phenomena due to the type of fire and the consequent difficulty in its extinction, can be expected especially in correspondence of bushy and open wooded areas, which could bring fires very difficult to control and repress. These areas have shrub layers, degradation formations of the evergreen holm oak evolved and stable (spots and garrigues) in which violent behavior of the fire fronts, high propagation speeds and very high flames (even above 10 meters) can be expected. In these types of fires there are frequent spotting phenomena, jumps of sparks in combustion with relative danger of multiple ignitions, doubling of the fire front and loss of control of extinguishing operations. In these situations, the ground teams must be careful and follow protocols to operate safely and heavy land vehicles with water, air vehicles and indirect attack of the front must be used.

Forest Firefighting Intervention Module "Main urbanized areas" within the Regional Natural Park of Tepilora

The urban-rural interface areas identified above are subjected to periodic silvicultural maintenance (buffer 200 m). In these areas, constantly frequented by the staff of the FORESTAS Agency and by tourists staying in the accommodation facilities, it is important to intervene both by reducing the fuel load (biomass and necromass) and by directing the forest vegetation towards more natural structures and therefore more resilient to the disturbances created by fires, at least in the areas of greatest frequentation. At least as far as housing and tourist facilities are concerned, it is important, within the perimeter band of interface, to assess the danger and risk.

Figure 29. Urban/rural interface area of the Gianni Stuppa barracks of Sos Littos (left) and of the service building of Punta Pedra Niedda (right).

Figure 30. Urban/rural interface area of Crastazza barracks (left) and renovated building in Su burgu

However, these are assessments that should be deepened in the individual municipal and / or inter-municipal Civil Protection plans, whose preparation and updating are regulated by Law 100/12, which converts Decree 59/2012 into law.

However, a complete cleaning of the undergrowth in the first 10 meters and a careful and punctual evaluation of the wooded component is prescribed when the foliage is in direct contact with the structure. In this case, it is prescribed the elimination or, possibly, the pruning of the branches in contact.

As for the rest of the interface area, the rationale that must move the planner must be to create both horizontal and vertical continuity solutions of the shrubs and tree components, making cuts with a progressively decreasing intensity with the departure from the infrastructure and the approach to the boundaries of the interface area.

Figure 31. Urban/rural interface area of the Usinavà barracks.

Forest Firefighting Intervention Form "Houses, sheds, garages, deposits"

Also, in this case the interface area is 200 meters, and the intervention module is the same as that for the main urbanized areas.

Particular attention must be paid to agricultural sheds, sheds with tools and more generally all sites where fuel can be stored.

In the case of mobile sheds used during cutting and then moved to the next silvicultural site, the concept of an interface area of 200 meters can be postponed, but it is good to maintain a 10-meter buffer zone in which to clean up the undergrowth and create discontinuity between the tree foliage and the infrastructure.

Forest Firefighting Intervention Module "Roads"

The requirements of this intervention module apply to the most important road branches, i.e., the main and secondary trucks transited by EFS personnel, tourists, and visitors.

For those located in areas with a high risk of fire (sections generally rather localized only in some areas) progressive thinning should be carried out in a band of 300 meters both upstream and downstream of the road, with the scheme adopted for the intervention module "Main urbanized areas". We recommend, as far as possible, the total cleaning of the shrub and tree components in the first 5 meters upstream and downstream of the road. In medium and low risk areas the band is reduced to 100 m.

The interventions will be carried out at the same time as the ordinary maintenance of the roads.

5.3 Sterea Ellada - Central Greece

5.3.1 Location/Administrative

The SILVANUS pilot area for Greece is the island of Evia, and more specifically its northern part as well as parts from the centre of the island due to its characteristic mountainous area of Dirfys, which is the highest peak (1743m) of the island.

The island is the second in size after Crete largest island of Greece, it is in central Greece, and it belongs to the Region of Sterea Ellada. Extends along the northeastern shores of Attica, which is separated by Northen and Southern Evia Bays, which is narrowest near the central part of island. Here the island connected with the continent by a parament bridge leading directly into Chalkida town.The eastern coasts of the island are in the Aegean Sea, while the western coasts are in Evoikos gulf. In terms of geographical coordinates Evia spans from latitude of 39.00 N (northernmost part - Cape Artemision) to 37.95 N (southern part – Cape Mandili) and longitude of 22.81E (western part) to 24.59E (most eastern part). The total area of Evia Island is approximately 3.670 (3700) km^2, while the area of interest for SILVANUS is approximately 1.868 km^2 (**Figure 32**).

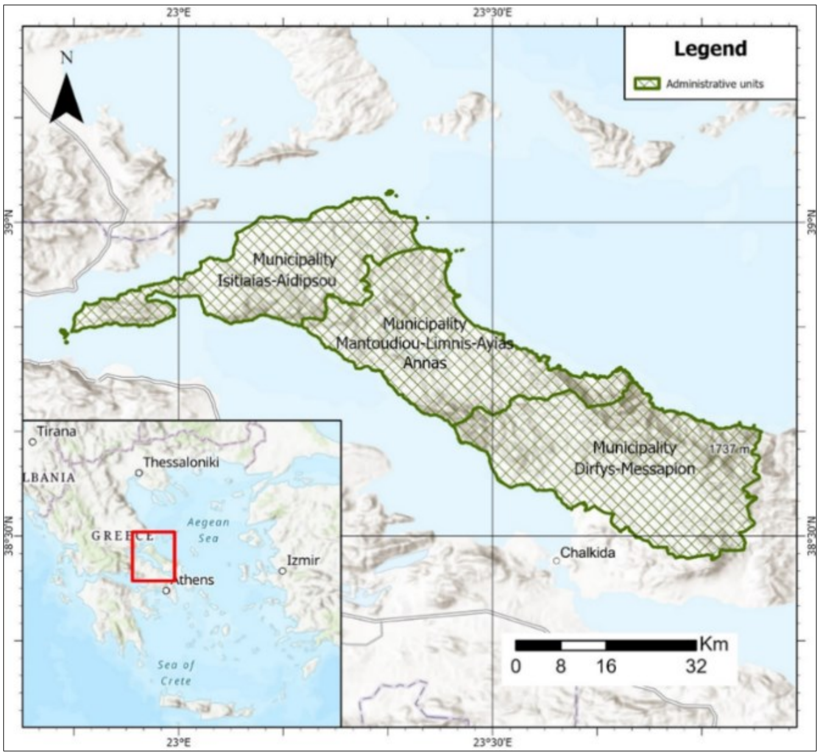


Figure 32. Administrative boundaries of the SILVANUS Hellenic pilot area (North Evia) and SILVANUS pilot interest area.

In terms of administrative borders, three municipalities are in the pilot area, the municipality of Istiaia-Aidipsos, the municipality of Limni-Mantoudi-Ayia Anna and the municipality of Dirfys-Messapion. The core of North Evia is the area that belongs to the municipalities of Istiaia-Aidipsos and Mantoudiou-Limnis-Ayias Annas. Due to the fact that inside the borders of the municipality of Dirfys-Messapion is located the mountain of Dirfys with a significant ecological value for the whole island Evia (protected forested area with dense forest and local species of flora and wildlife) with the fact that is still unburned, it was decided by the GR partners to extend the pilot area of North Evia by including the municipality of Dirfys-Messapion, especially the part of the mountain of Dirfy.

5.3.2 Geomorphology

Evia is located eastern of Sterea Ellada mainland, with an elongation in the direction NW-SE. The maximum length of the island reaches 180km with a varying width from 7km (south part) to 45 km (central part). At the narrowest point, at the center of the island, the largest city of Evia, the city of Chalkida, is located. Evia is characterized by a varied relief that presents alternations of plains, semi-mountains, and mountainous areas. The large area of the island combined with the morphological structure of its individual units allows the geographical division of the island into North, Central and South Evia.

Northern Evia includes the plain of Istiaia which is enclosed by the mountains Telethrion (997 m.) and Xiron (991 m.) to the south and south-west. Most of it is occupied by arable land, while woody vegetation begins to appear at the edges of the mountain formations. In the northern coastal area, remarkable wetlands of special ecological interest are formed, such as the large and small Livari lagoons. To the northwest you can see the Yaltron - Lihades peninsula with a maximum altitude of 600 m, as well as the Lihades volcanic islets with characteristic dense vegetation. The eastern coastal zone gathers gentle morphological gradients where the plain of Mantoudi is located.

In Central Evia the mountain range of Dirfy dominates which presents an arcuate arrangement along the eastern coastal areas, with the highest peak being Delphi at 1743 m. In the area of Dirfy, the characteristics of mountainous relief are noticeable, with strong and steep slopes, while there is also intense forest cover. To the east and south of the mountain range of Dirfy, stretches the unity of Kymi - Aliveri, a hilly area with the presence of lowlands mainly along the Manikiati and Avloneri streams. This unit connects the Aegean Sea with the South Euboean Gulf, with the presence of residential zones in its coastal areas. Along the western coastal zone, and south of Mount Kandyli (1246 m) lies the basin of Psakhni, which drains through numerous streams to the North Euboean Gulf, while further south is the wider region of Chalkida with developed urban construction.

The hydrographic network of Evia is presented with an almost transverse development along the island with the presence of streams that show mainly periodic flow (Arapis et al., 2022).

5.3.3 Geology

In terms of geology, North and Central Evia belong to the Internal Hellenides, and more specifcally to the Pelagonian and Sub-Pelagonian tectonic units. The bottom layer of the Pelagonian units consists of Paleozoic bedrock. The alpine structure of the upper layers of the stromatographic column is composed of Triassic-Jurassic limestones and dolomites, of fine-grained oceanic sediments accompanied by ophiolitic masses that are pushed onto the Triassic-Jurassic carbonate rocks and finally the upper Cretaceous limestones that were deposited unconformably on top of the previous rocks and cover in places ferro-nickel deposits. In the upper layer of the alpine formations Maastrichtian - Eocene age flysch deposits appear. The newer formations consist of Neogene lacustrine and marine deposits and Quaternary fluvial alluvial deposits. North and Central Evia are different geologically from South Evia, and this differentiation is documented by the different topographic relief and forests. In addition, thicker forests are present in Central and North Evia. Karst structures appear in Evia Island, although, the most significant ones are outside the SILVANUS pilot case area.

In addition, significant ferronickel deposits of significant economic value are in central Evia, while in North Evia, deposits of magnesite (leukolithos) are noteworthy with reserves of 40 million tons.

North Evia, and specifically the NW part, is an area of geothermal interest. The areas of Aidipsos and Lihades islands gather characteristics of a remarkable geothermal system. The intense tectonism that characterizes the area in combination with the recent volcanic activity (Lihadon volcano) and the existence of karst formations justify the existence of geothermal fluids near the surface. Temperatures of the geothermal fluids are greater than 80°C in Aidipsos, with an increase in temperature at greater depths (medium enthalpy hydrothermal system), while in Agios Georgios of Likhades. It was found that geothermal fluids reach 47°C at a depth of 270 m and in Gialtron 42, 3°C at depths from 100 to 170 m (Arapis et al., 2022).

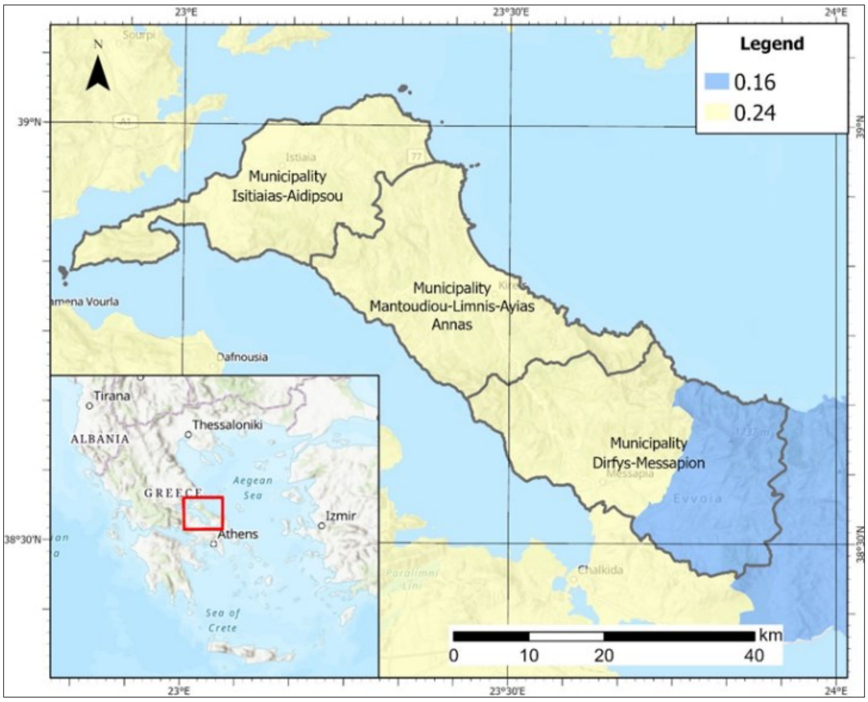


Figure 33. Seismic zones map according to EAK 2000 (amended in 2003) for the North Evia.

In terms of seismicity, Evia is characterized by low to moderate seismicity based on the Greek standards. The majority of Northern Evia belongs to second seismic hazard zone (ZONE II) with maximum expected Peak Ground Acceleration to rock sites equal to 0.24g. **Figure 33** shows the seismic zones map according to EAK 2000 (amended in 2003) for the North Evia.

5.3.4 Soil

The texture of the topsoil of North Evia Island consists mainly of loam and sandy clay loam as it can be seen from

Figure 34. In smaller portions other soil textures can be found such as sandy clay, sands, or silt loams. In **Figure 35**, the Available Water Capacity (AWC) for the topsoil of North Evia is presented. Data and maps are from Ballabio et al., 2016, and the ESDAC database (ESDAC, n.d.; Panagos et al., 2012, 2022). The AWC varies from 09.08 to 0.15 distributed across the study area.

In terms of soil horizons, most of the pilot area is covered by cambisols (moderately developed soil horizons) rich in Fe and Al (Alfisol equivalent to USDA classification). In the NW part, at Lihades peninsula and the southern parts of pilot area, at Dirfy mountain, Leptosols are met. In the North coasts (close to the GR2040004 and GR2420007) and in the middle of the study area Fluvisols are met. Luvisols are met in the southern part of the study area (northern part of the municipality of Dirfys-Messapion, in the borders with the municipality of Mantoudiou-Limnis-Ayias Annas(Arapis et al., 2022).

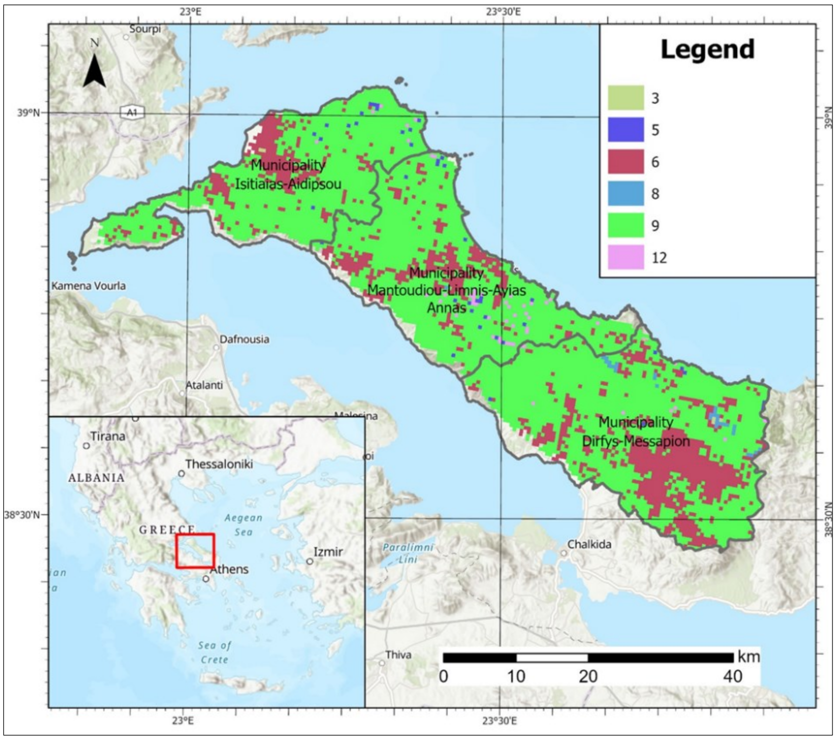


Figure 34. Soil USDA texture of North Evia based on JRC soil data maps (Source: Ballabio et al. 2016). Based on the USDA texture classification: 3= sandy clay, 5= clay loam, 6= sandy clay loam, 8= silt loam, 9= loam and 12= sand)

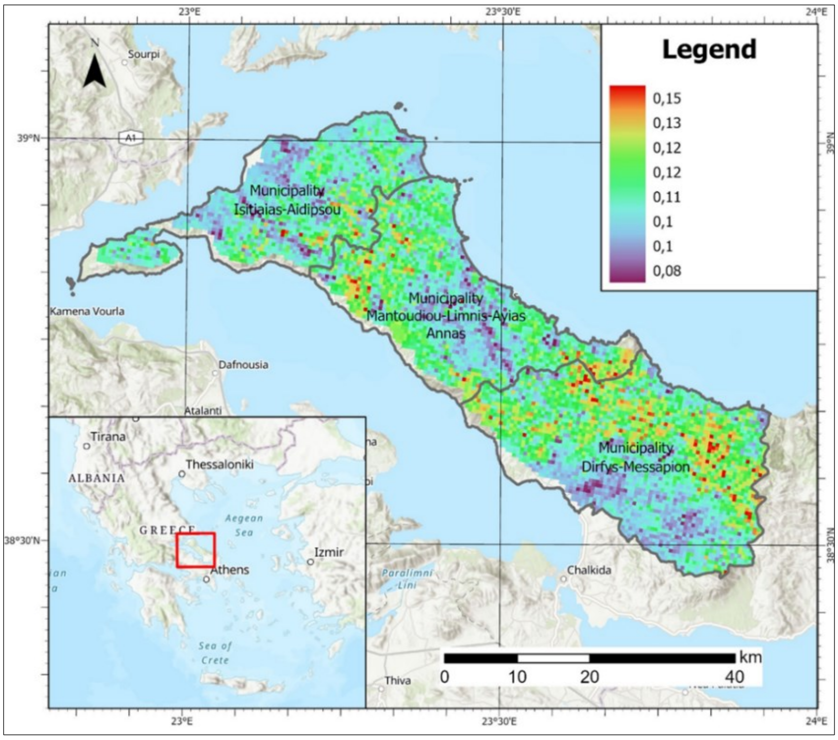


Figure 35. Available Water Capacity in North Evia Island (Sources: (Ballabio et al., 2016; ESDAC, n.d.; Panagos et al., 2012, 2022)**)**

5.3.5 Hydrology

The area can be characterized as semi-mountainous. Rivers are of moderate size (R-M2), strongly seasonal, frequently modified, with unknown water quality (ecological and chemical). Their length varies from 15 to

20km. Nevertheless, as the area is rural with specific economic activity it is not expected to be under extreme ecological pressure. The underground waters are in general of good quality and typical of karst systems, especially in the mountain of Dirfy (SE pilot area). Bad quality of underground water is monitored at the SW part of the administrative borders (municipality of Dirfys-Messapion) but in terms of interest this is outside the borders of the pilot SILVANUS area.

Figure 36 shows the hydrological data in the pilot area.

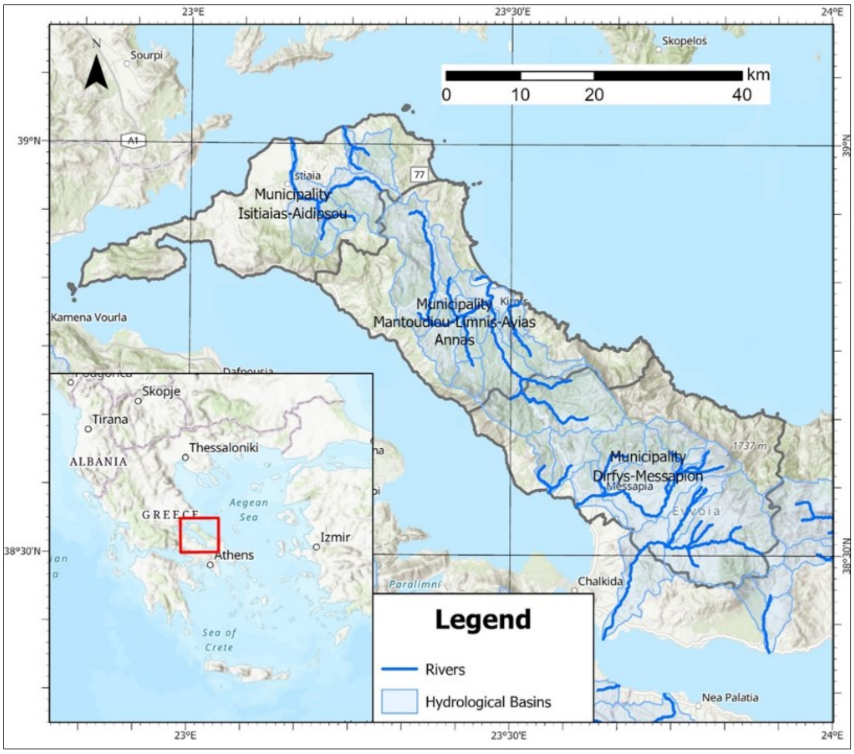


Figure 36. Hydrological data in the pilot area. Rivers and hydrological basins – EL07
(Source: Special Secretariat for Water, Ministry of Environment).

5.3.6 Ecological Valence

The study area is characterized as plain and hilly – submontane. The distribution of the land according to the altitude is given in Figure 26. The maximum altitude is 1600+ m above the sea level. More than half of the area (57.9%) is extended up to 250 m in height and the 99.1% is up to the zone of 1050 m. Only a small fraction of it, less than 1%, has altitude above the zone of 1050 m.

The study area is a typical mosaic of Greek lowland rural areas with some towns and many villages scattered in the landscape. The valleys are, mostly, used for agricultural cultivations such as maize, wheat and clover, as well as, for domestic animal grazing. In a lesser extent nomadic animal husbandry in the near forests is applied. Most of the cultivations are non-irrigated or semi-irrigated, usually early in the summer or late in the summer, depending on the type of cultivation. Olive trees are growth in extensive areas. In the rest of the landscape above valleys forests prevail. **Figure 37** distribution of the area according to the altitude in the Greek pilot area.

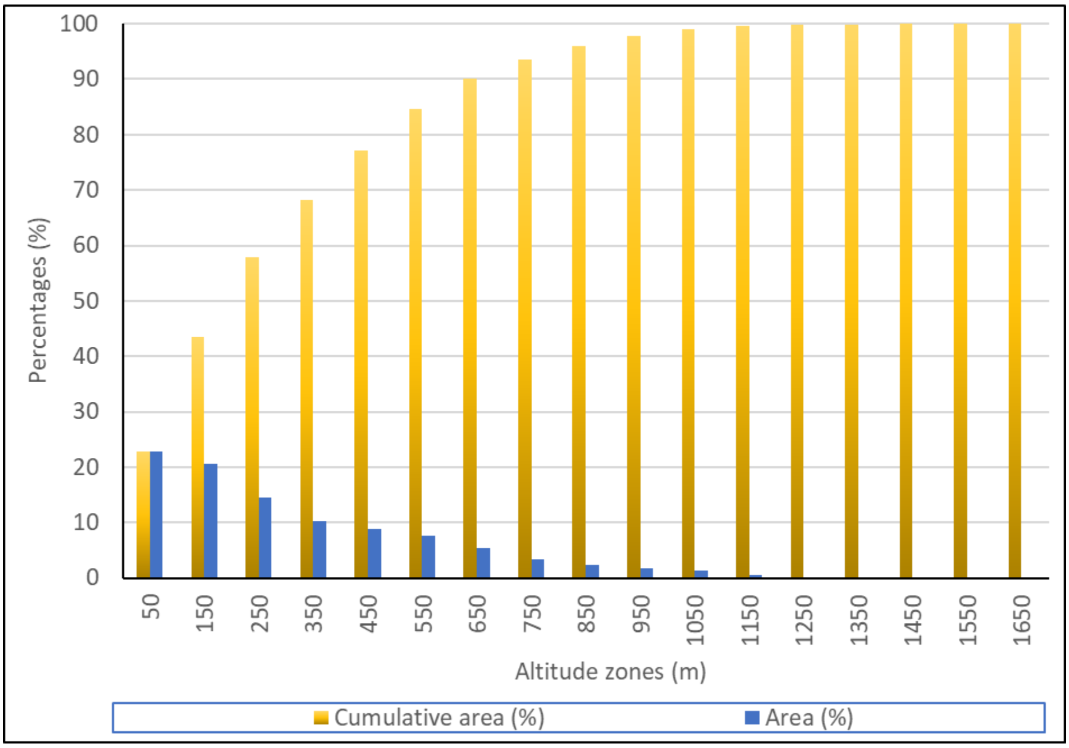


Figure 37. Distribution of the area according to the altitude in the Greek pilot area

The forest vegetation is mostly determined by the climate conditions that also change by the altitude and in a lesser extent by the exposure to the horizon.

More specifically, in the lower altitudes the forest vegetation zone Quercetalia ilicis prevails, where pines, Pinus halepensis and Pinus brutia, form large forests. Due to the climatic conditions with hot and dry summers that extended to a period of almost 5 to 6 months, these pine forests suffer from frequent and destructive fires, as it was, the last wildfire during the summer of the year 2021, that burned a big part of the study area. Fortunately, Pine species of the area have an excellent adaptation to fires and regenerate naturally with none or little human intervention.

Along the rivers, riparian forests are growth, mainly, consisted of Platanus orientalis and other broadleaved hydrophilic species. Most significant, in terms of the aesthetic and ecological value, are those riparian forest of Kirea and Nilea rivers.

Particularly important contribution to the conformation of the landscape in Evia is the wide variety of forest ecosystems, some of which are rare and very essential. These forests are identified as wood remains of old forests, such as the riparian forests of field elm (Ulmus minor) and narrow-leaved ash (Fraxinus angustifolia) in Krya Vrisi and English oak, (Quercus robur) also known as common or pedunculate oak, (Quercus robur ssp. pedunculiflora) in Agios Nikolaos Kanatadikon. Special importance has the forest stands of rare endemic subspecies, Quercus trojana subsp. euboica (Papaioannou) K.I. Chr., known exclusively from the island of Evia, the oak forest of Mount Telethrio.

As the altitude increases the agricultural activities decreasing significantly and the climate becomes more humid. In these areas the typical Quercetalia pubescensis zone prevails. In this zone Quercus forests are common.

Over the Quercetalia pubescentis the Fagetalia zone is extended where cold and wet conditions prevail during the most part of the year except to the limited summer period. In this zone fir makes reach forest on Mount Xiro, Kavalari, Pyxaria and Kantili. Due to climatic conditions these forests considered more resilient to wildfires and have special ecological value for the whole area, since they are less accessible to the people and offer shelter to many species of wildlife.

5.3.7 Land use

In **Table 12**, the surface (ha) of the various land use types in North Evia are presented. In **Figure 38**, the land cover map for North Evia is presented. As a basis, CORINE (2018-2021) is used, to support interoperability with other pilot areas in Europe and keep a consistent format. A significant part of North Evia is occupied either by forests or by agricultural land.

Table 12. Land cover type and area in North Evia Island based on Corine land use classification schema.

COVER DESCRIPTION	CORINE CODE	AREA (ha)
Discontinuous urban fabric	112	1,680.38
Industrial or commercial units	121	178.41
Mineral extraction sites	131	1,991.33
Sport and leisure facilities	142	24.50
Non-irrigated arable land	211	12,483.22
Fruit trees and berry plantations	222	703.63
Olive groves	223	12,190.50
Pastures	231	172.01
Complex cultivation patterns	242	14,411.20
Land principally occupied by agriculture, with significant areas of natural vegetation	243	17,171.99
Broad-leaved forest	311	7,773.80
Coniferous forest	312	43,859.51
Mixed forest	313	16,697.97
Natural grassland	321	4,430.82
Moors and heathland	322	960.28
Sclerophyllous vegetation	323	15,885.01
Transitional woodland/shrub	324	32,390.24
Beaches, dunes, sands	331	239.19
Moors and heathland	332	32.17
Sparsely vegetated areas	333	2,800.10
Inland marshes	411	50.66
Salt marshes	421	129.67
Coastal lagoons	521	45.02
	Grand Total	186,301.6

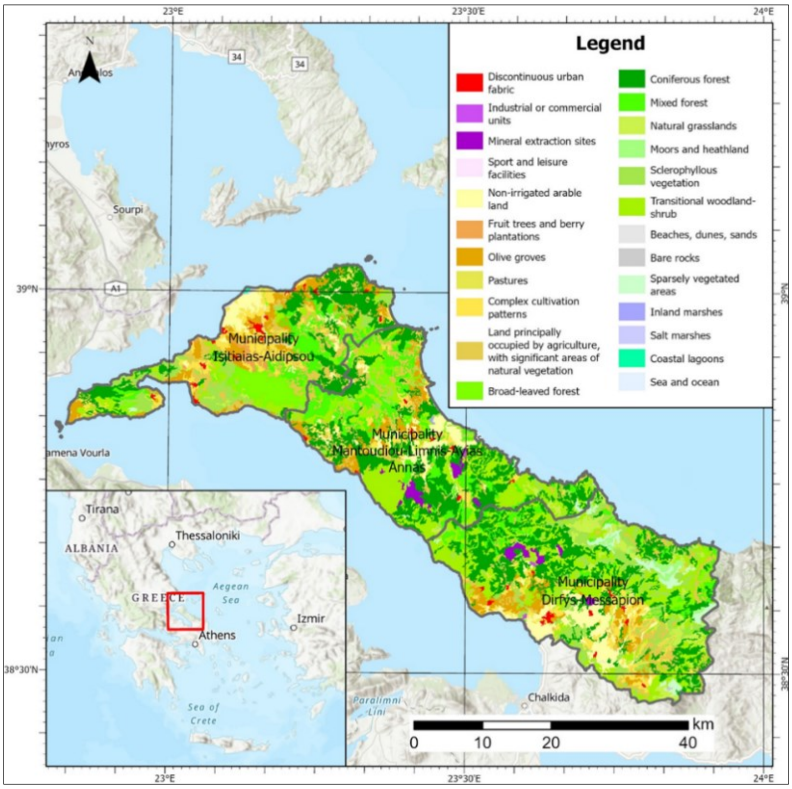


Figure 38. Land cover for North Evia based on the CORINE land cover 2018-2021. The recent wildfire of 2021 is not included.

5.3.8 Forest ownership

Evia is one of the areas in Greece, in which a significant percentage of private forests exist. In the municipality of Istiaia-Aidipsos (same administrative borders with the local forest office) 90% of the forests/forested areas are private and only 10% belong to the state. In the municipality of Mantoudiou-Limnis-Agias Annas (same administrative borders with the local forest office) 74% of forests/forested areas are private and only 26% belong to the state. Forests in Istiaias-Aidipsou covered 47.4% of the municipality/forest office surface while in Mantoudi-Limnis-Ayias Annas forests were approximately 79.5% of the municipality/forest office surface (Apostolidis et al., 2022).

5.3.9 Flora

North Evia has a unique natural environment with rich flora and wildlife. Moreover, land and sea areas have been characterized as Natura 2000 protected areas. The combination of local geology, topography and climate is responsible that North Evia is among the richest in flora diversity areas in the Aegean with 1,663 recorded native plant species. Among those are the local oak trees (Quercus trojana sbsp. euboica) which have been identified since 1940 (Apostolidis et al., 2022). We classify four (4) vegetation zones (Apostolidis et al., 2022): Eumediterranean vegetation zone, Submediterranean vegetation zone, Mediterranean montane conifers zone, and Azonal riparian forests.

a. Eumediterranean vegetation zone (*Quercetalia ilicis*), which grows at an altitude of - up to 1,000m. In Northern Evia appears with the subzone *Quercion ilicis*, where extensive aleppo pine forests (*Pinus halepensis*) appear, with shrubs, as well as formations of evergreen broadleaves, but also phrygana.
b. Submediterranean vegetation zone (*Quercetalia pubescentis*). This zone extends in small areas on Mount Telethrio with the sub-zone Quercion confertae, with forests of hungarian Oak (*Quercus*

frainetto) at an altitude of 500-900 m, where in places appear - in form of niche and chestnut stands (*Castanea sativa*).

c. Zone of Mediterranean montane conifers (Abietion cephalonicae). In this zone, forests of Greek fir (*Abies cephalonica*) is mainly formed of pure or mixed forests with Black Pine (Pinus nigra), as in Xero Oros, Kavalari and Ayios Konstantinos (Kerasia).
d. Azonal riparian forests. It mainly found along the banks of rivers or lakes. The vegetation of these subareas consists mainly of sycamore or oriental plane forests (*Platanus orientalis*). Also, in the wetland of Almirorema appears an area of wetland forest with the field elm (*Ulmus minor*) and narrow-leaved ash (*Fraxinus angustifolia subsp. oxycarpa*).

In more detail:

The forest species that dominate in the forests of Evia are Aleppo pine (*Pinus halepensis*), Firs (*Abies cephalonicae*), Black pine (*Pinus nigra*) and from the broadleaf, Chestnut (*Castanea sativa*), Oak (*Quercus sp*) and, sporadically, in small areas, other species, such as *Platanus orientalis* and *Accer sp.*

- *Pinus halepensis* occupies a significant area, especially in the northern part of the Evia and forms pure clusters up to 500 m by altitude.
- *Abies cephalonica occupies* areas above 500m in altitude and is found either pure or mixed by person, groups, and lochs with black Pine (*Pinus nigra*).
- *Pinus nigra* occupies a small area, shows good growth and where there is a mix with Greek Fir forms dense clusters.
- *Platanus sp.* develops on the banks of rivers and in the large streams that exist in the study area.
- *Pinus pinea* is found sporadically in the low zone of the forest per tree and groups of trees.
- The broadleaf leaves shrubs form a particularly dense understory under *Pinus halepensis* forests where offer additional protection from soil erosion and provides shelter to the wildlife.

In addition to the main forest species mentioned above, many secondary species are found, the most important of which are: *Arbutus Unedo*, *Arbutus Adrachnae*, *Erica Arborea*, *Erica Verticalata*, *Myrtus Communis*, *Quercus Coccistera*, *Spartium Junceum*, *Dactylis glomerata*, *Nerium Oleander*, *Paliurus Australis*, *Festuca sp.*, *Bromus Molis*, *Lolium Perene*, *Juniperus communis*, *Juniperus oxycedrus*.

Besides the forests, various significant plants are met, characterized according to the Natura classification system.

5.3.10 Wildlife

Wildlife consists of mammals, birds, reprtiles, ambpibia, and chiroptera. The birds that live in the wider area are various eagle species (*Aquila chrysaetos*, Aquila fasciata, Circaetus gallicus), hawks (*Buteo buteo, Falco peregrinus, Falco tinnunculus, Accipiter nisus*). Other bird species that are met are the *Emberiza caesia*, the *Streptopelia turtor*, the *Soclopax rusticola*, the *Columba palumbus*, the *Turdus philomelus*, the *Turdus merula*, the rock partridge (*Alectoris Graeca*), the blackbird and passing bird species, such as woodcock (*Scolopax rusticola*). Significant species of birds live or pass by in the Natura 2000 protected areas. Mammals, such as *Martes foina*, Vulpes vulpes, *Meles meles*, *Lepus europaeus, Carpeolus carpeolus, Sus scrofa* and *Mustella nivallis* and arthropods, such as, ants are found in competent populations.

In the **Table 13**, the Natura 2000 protected areas in North Evia are presented. The biggest one (GR2420011) extends beyond the limits of SILVANUS main pilot area for Greece. It has also to be noted that North Evia is one the limited areas in the Mediterranean that hosts the Mediterranean monk seal *Monachus monachus,* which is one of the threatened species worldwide.

Table 13. Natura 2000 Protected in North Evia

Natura 2000 Area Code	Natura 2000 Area Name	Type
GR2420004	MEGALO KAI MIKRO LIVARI - DELTA XERIA - YDROCHARES DASOS AG. NIKOLAOU - PARAKTIA THALASSIA ZONI	Special Areas of Conservation (pSCI, SCI or SAC)
GR2420007	MEGALO KAI MIKRO LIVARI - DELTA XERIA	SPA (Special Protection Areas)
GR2420010	OROS KANTILI	SPA (Special Protection Areas)
GR2420013	NISIDES LICHADES KAI THALASSIA PERIOCHI	Sites of Community Importance (pSCI, SCI or SAC)
GR2420011	ORI KENTRIKIS EVVOIAS, PARAKTIA ZONI KAI NISIDES	SPA (Special Protection Areas)
GR2420002	DIRFYS: DASOS STENIS - DELFI	Special Areas of Conservation (pSCI, SCI or SAC)
GR2420014	THALASSIA PERIOCHI KAI YFALOI VOREIOANATOLIKIS EVVOIAS	Sites of Community Importance (pSCI, SCI or SAC)

Important Plant species

GR2420002 hosts one species (*Nepeta argolica ssp. Dirphya*) characterized as “very important” of Annex II of the directive 92/43/EEC on the conservation of natural habitats and of wildlife and flora. Moreover 58 plants are characterized as “other important” out of which 49 will be characterized as “important” and 13 of these species or sub-species meet the conditions to be included in the “very important”.

Important Wildlife species

- In the GR2420002 one reptile species (*Testudo hermanni*) is hosted (very important species). Also, 13 species (2 mammals, 4 reptiles, 3 amphibia and 4 invertebrates) leave there among the “important” species.
- In the GR2420004, 9 very important species of wildlife are met. In addition, 12 “important” species/sub-spieces are hosted, 9 reptiles, 2 amphibia and one sea invertebrate.
- In the GR2420014, the *Monachus monachus* seal is met with a significant concentration as a place of reproduction. Also, 12 more sea invertebrate species are hosted in the area.
- Finally, the GR2420013 hosts the *Monachus monachus* seal and is one the most important feeding place in Greece and five “important” species of sea invertebrates.

The location of important wildlife species in Natura areas are shown in **Figure 39**.

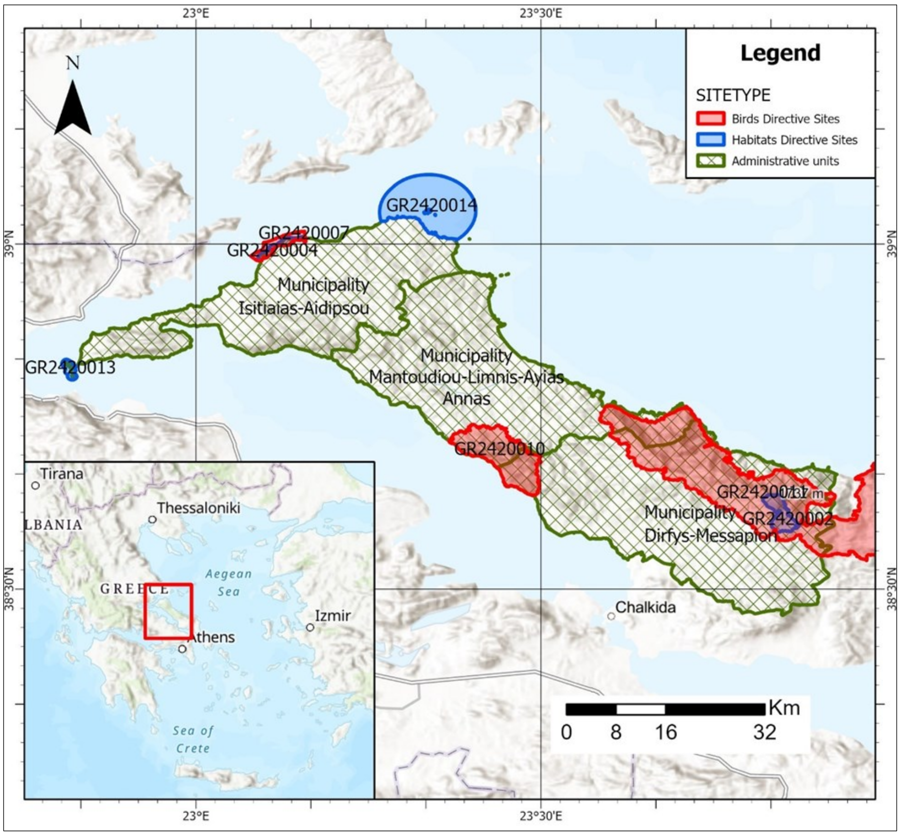


Figure 39. Natura areas in North Evia along with the administrative NUTS III (municipalities) borders.

5.3.11 Climate

According to the HNMS (2016) the following climate variables for the period 1971-2000 have been recorded in North Evia (**Table 14**).

Table 14. Climatic variables for North Evia

Variable	Value
Average low temperature	varies from 7°C to the mountain of Telethrion up to 13°C (Telethrion and high altitudes of North Evia)
Average high temperature	varies from 17°C to 21°C (Telethrion and high altitudes of North Evia).
Mean temperature	varies from 13°C to 17°C in North Evia
Annual precipitation	varies from 375mm (a few kilometers south of Limni) to 830mm (Telethrion mount). Average, approximately equal to 600mm
Yearly sunshine	varies from 2150 to 2700 hours
Wind	Winds (prevailing) N-NE

(Source: Climatic Atlas of Greece for the period 1971-2000 – (Hellenic National Meteorological Service, 2016))

In general, the climate differentiates between the areas of high altitudes compared to the lower altitude areas, and more importantly between the western and the eastern part. In the Eastern part winds are stronger and last for more days. Precipitation is also usually more intense in the western part.

The bioclimate in the study area has the following characteristics (Arapis et al., 2022; Mavromatis, 1980).

Existing bioclimatic storeys (based on Emberger's climate diagram) are:

- Semi-arid with mild winter (3-7ºC) on the western coasts of Evia and the coasts of Boeotia,
- the Hyphygros with mild winter in most of Evia and Skyros,
- Hyphygros with cold winter (0-3ºC) inland of Boeotia and northern Evia and
- Hygros with mild or cold winter (depending on the altitude) in the mountains of central Evia.

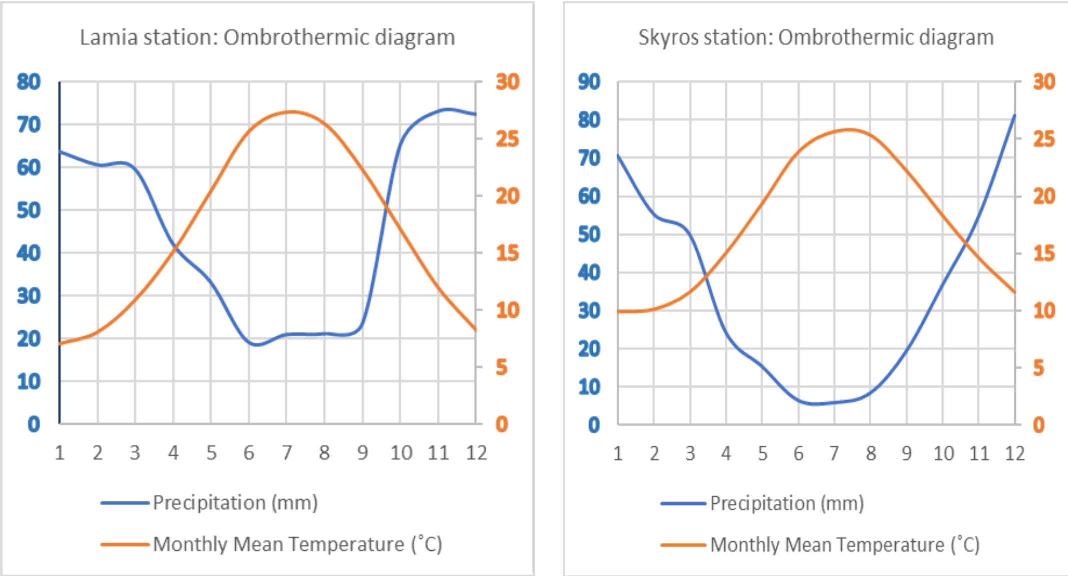


Figure 40. Ombrothermic diagram for North Evia. (Source: (Hellenic National Meteorological Service, 2016)**).**

Existing Mediterranean bioclimate characters are:

- the Intense thermo-Mediterranean (125-150 biologically dry days during the warm season of the year) on the western coast of Evia,
- the Weak thermo-Mediterranean (100-125 dry days) in southern and western Evia, Skyros, and coasts of Boeotia,
- the intense mid-Mediterranean (75-100 dry days) in central Evia and the Boeotia,
- the mild mid-Mediterranean (40-75 dry days) in the north and mountainous central Evia and
- the Sub-Mediterranean on the peaks of central Evia.

5.3.12 Demographics / Social / Economy

<u>Evia island</u>

Evia is the second largest island of Greece with a population of 210,815 people. 31% of the population are young people of the age 0-29 years old, 29% of the age 30-49 years old, 24% of the age 50-69% and 16% higher than 70 years old. What is interesting is the fact that only 13% of the permanent population of Evia is highly educated (university degree and/or higher) when approximately 42% are not educated at all or they are educated only until the primary school level. In Evia, 91.5% of the population are Greeks, while 1.4% come from EU member states, 4.8% from other countries in Europe and 2% from countries in Asia and for 0.27% it could not be specified. What is also interesting is the family status of the permanent population. The population that comes from EU member states has similar figures compared to the Hellenic population (married, divorced, widowed, unmarried). Those that come from other countries the ratio is a bit different as the majority are married (54%) which is like the Hellenic population while the unmarried are 44%, compared to 37% of unmarried of Greeks or 36% of EU unmarried population. This high percentage of unmarried is also recorded to those people that the country origin could not be specified. This high percentage for non-Greeks most probably belongs to manpower that has migrated to Greece, considering as well that 0.5% of those hold a university degree (Hellenic Statistical Authority, 2011).

Pilot area

The population of the pilot area of SILVANUS (North Evia) and more specifically of the municipalities of Dirfys-Messapion, Istiaias-Aidipsou and Mantoudiou-Limnis-Ayias Annas is 51,920 people, in total, while 50.7% of them are men and 49.4% are women. In North Evia, 8% of the permanent population holds a university degree (or higher than that), while more than 50% are either primary school graduates or have stopped their education at some point during the primary school. For the municipality of Mantoudiou-Limnis-Ayias Annas this percentage is equal to 55%. See **Table 15** and **Table 16** for the detail of number population and education level.

Extremely interesting is the fact that according to the 2021 population census of Greece, the residents in the municipality of Istiaias-Aidipsou reduced by 14.21%, while in the municipality of Mantoudiou-Limnis-Ayias Annas reduced only by 0.4%. It is also worth to note that these results are not the final one, but it is not expected that these will change significantly.

Table 15. Permanent population in SILVANUS GR pilot

Municipality	Population	Men	% Of total	Women	% Of total
Dirfys-Messapion	18,800	9,912	52.72%	8,888	47.28%
Isitiais-Aidipsou	21,083	10,396	49.31%	10,687	50.69%
Mantoudiou-Limnis-Ayias Annas	12,045	6,024	50.01%	6,021	49.99%
Total	51,928	26,332	50.71%	25,596	49.29%

Source: (Hellenic Statistical Authority, 2011)

Table 16. Education level of the population in the SILVANUS GR pilot area

Municipality	Total	University graduates including Master or PhD)	Graduates of post-secondary education level	Lyceum graduates	College (gymnasium) graduates	Elementary scholl graduates	Illiterate	People born after 1/1/2005
Dirfys-Messapion	18,800	1,475	524	3,885	2,558	5,747	3,629	982
		7.8%	2.8%	20.7%	13.6%	30.6%	19.3%	5.2%
Isitiais-Aidipsou	21,083	2,004	610	3,592	2,915	7,200	3,699	1,063
		9.5%	2.9%	17.0%	13.8%	34.2%	17.5%	5.0%
Mantoudiou-Limnis-Ayias Annas	12,045	1,009	414	1,904	1,585	4,682	1,990	461
		8.4%	3.4%	15.8%	13.2%	38.9%	16.5%	3.8%

Source: (Hellenic Statistical Authority, 2011)

Another important, for SILVANUS, statistic is the fact that in the municipality of Istiaias-Aidipsou only 12% of the residents work in other municipalities, regions or countries, a percentage significantly less than the ones of the other two municipalities or the regional unit of Evia. The number of unemployed people in the three municipalities is close the percentage of the regional unit of Evia (7-8%) with the municipality of Mantoudiou-Limnis-Ayias Annas being a bit higher at 10% (see **Table 17**).

Table 17. Economically active and inactive population in the SILVANUS GR pilot area

	Total	Economically active						Economically inactive			
		Emplo-yed	**Primary sector**	**Second-ary sector**	**Terti-ary sector**	**Unempl-oyed**	**Sub-total**	**Students**	**Retired**	**Other**	**Sub-total**
Regional district of Evia	**210,815**	**67,990**	**8,373**	**18,227**	**41,390**	**16,801**	**84,791**	**31,688**	**50,490**	**43,846**	**126,024**
Men	106,648	43,882				10,020		16,420	27,425	8,901	
Women	104,167	24,108				6,781		15,268	23,065	34,945	
Municipality of Dirfys-Messapion	**18,800**	**6,067**	**1,600**	**1,700**	**2,767**	**1,456**	**7,523**	**2,845**	**5,083**	**3,349**	**11,277**
Men	9,912	4,181				913		1,484	2,572	762	
Women	8,888	1,886				543		1,361	2,511	2,587	
Municipality of Istiaias-Adipsou	**21,083**	**6,242**	**1,440**	**1,085**	**3,717**	**1,497**	**7,739**	**2,674**	**6,446**	**4,224**	**13,344**
Men	10,396	4,038				904		1,398	3,286	770	
Women	10,687	2,204				593		1,276	3,160	3,454	
Municipality of Mantoudiou-Limnis-Ayias Annas	**12,045**	**3,032**	**602**	**709**	**1,721**	**1,205**	**4,237**	**1,359**	**3,993**	**2,456**	**7,808**
Men	6,024	1,977				804		687	2,169	387	
Women	6,021	1,055				401		672	1,824	2,069	

Source: (Hellenic Statistical Authority, 2011)

Approximately 24% of the population in North Evia works in the agricultural sector, 10% in construction, 10% in tourism, 10% in catering services and 15% in services around the car industry. Also, mining activity is among the characteristics of local economy (magnesite in Mantoudi and Limni, iron and nickel in Dirfys). The cultural identity of the population in Evia is like that of the people in the rest of Central Greece. In the following tables (**Table 18, Table 19, and Table 20**) various statistics regarding the population, the economic activities, the profession, and the location of work of the North Evia area are presented.

Forests in North Evia is an important factor of the economy. The local population works on the agricultural sector such as beekeeping, resin farming, logging, charcoal production, animal husbandry, olive trees, figs, and vines. In addition, mining activities are important nevertheless not so extensive as the previous years (see **Table 21**). Tourism and catering services are an additional important economic activity of the area.

The 2021 mega-fire caused significant problems to the economic activities of North Evia, as the forests were the core of many of the activities. Even tourists were combining sea and mountains for the summer vacations.

Table 18. Economic activities based on NACE Rev. 2 classification system in the SILVANUS GR pilot area

Administrative level	Total	Economic activities (NACE Rev.2)									
		Agriculture, forestry and fishing	Construction	Wholesale and retail trade; repair of motor vehicles and motorcycles	Transportation and storage	Accommodation and food service activities	Administrative and support service activities	Public administration and defence; compulsory social security	Education	Human health and social work activities	Other professional activities
Regional district of Evia	**67,990**	**8,373**	**6,001**	**11,708**	**3,649**	**5,005**	**1,302**	**5,528**	**4,743**	**2,646**	**19,035**
Municipality of Dirfys-Messapion	6,067	1,600	444	891	286	349	162	326	236	145	1,628
Municipality of Istiaias-Adipsou	6,242	1,440	697	1.074	239	868	100	392	370	164	898
Municipality of Mantoudiou-Limnis-Ayias Annas	3,032	602	347	428	128	291	61	269	191	97	618

Source: (Hellenic Statistical Authority, 2011)

Table 19. Professions in the three municipalities of the SILVANUS GR pilot area

Administrative level	Total	Profession								
		1. Senior management and administrative staff	2. Professionals	3. Technicians and practitioners of related professions	4. Office clerks	5. Service Providers and Vendors	6. Skilled farmers, breeders, foresters, and fishermen	7. Skilled craftsmen and practitioners of related professions	8. Industrial plant, machinery and equipment operators and assemblers (fitters)	9. Unskilled workers, manual workers, and small-scale professionals
Regional district of Evia	**67,990**	**3,992**	**8,862**	**4,879**	**4,286**	**13,407**	**6,099**	**10,942**	**6,429**	**9,094**
Municipality of Dirfys-Messapion	6,067	286	376	278	332	936	938	836	706	1,379
Municipality of Istiaias-Adipsou	6,242	440	653	291	292	1,306	1,197	972	316	775
Municipality of Mantoudiou-Limnis-Ayias Annas	3,032	233	319	171	136	593	498	462	193	427

Source: (Hellenic Statistical Authority, 2011)

Table 20. Location of work of the economically active population in the three municipalities of the SILVANUS GR pilot area

Administrative level	Total economically active	Work location		
		In the municipality of residence	Outside the municipality of residence (other municipality/region/ country)	Outside % of total working
Regional district of Evia	**67,990**	**50,131**	**17,859**	**26%**
Municipality of Dirfys-Messapion	6,067	3,881	2,186	**36%**
Municipality of Istiaias-Adipsou	6,242	5,515	727	**12%**
Municipality of Mantoudiou-Limnis-Ayias Annas	3,032	2,387	645	**21%**

Source: (Hellenic Statistical Authority, 2011)

Table 21. Mining activities in North and central Evia Island

Municipality	Type of mining activity	Material	Area (m^2)
Mantoudi-Limni-Ayia Anna	Mine	Leukolithos	1,102,281
Mantoudi-Limni-Ayia Anna	Mine	Leukolithos	5,644,710
Mantoudi-Limni-Ayia Anna	Mine	Leukolithos	2,493,223
Mantoudi-Limni-Ayia Anna	Mine	Leukolithos	280,065
Mantoudi-Limni-Ayia Anna	Quarry	Inert materials	
Dirfys-Messapion	Mine	Iron-nickel	2,154,860
Dirfys-Messapion	Mine	Iron-nickel	2,403,797
Dirfys-Messapion	Mine	Iron-nickel	2,728,193
Dirfys-Messapion	Mine	Iron-nickel	2,196,302
Dirfys-Messapion	Mine	Iron-nickel	2,742,594
Dirfys-Messapion	Mine	Iron-nickel	535,112

source: (Arapis et al., 2022)

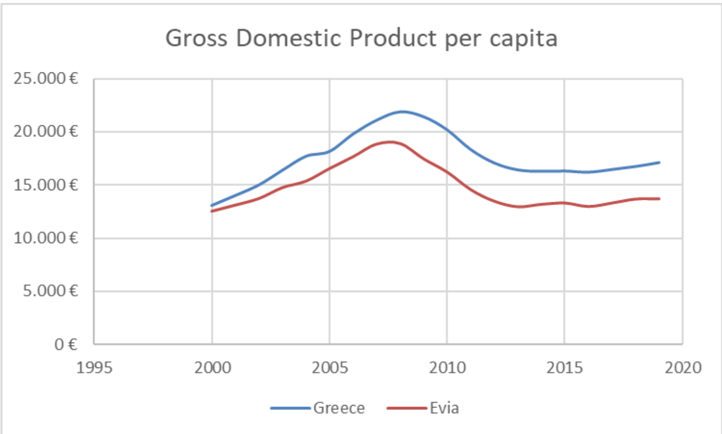


Figure 41. Per capita GDP of Greece and regional unit of Evia Island
source: (Hellenic Statistical Authority, 2011)

5.3.13 History of Fires

Evia is one of the most wildfire prone areas in Greece. Since 1980, with the Presidential Decree 575/1980 the forests of Evia are included to the ones that are vulnerable to forest and landscape fires (**Figure 42**). Considering the climate change and the expansion of human activity towards the forests, this map **(Figure 42**) could be considered as outdated, as more areas have vulnerable forests in Greece, but it shows the need of the state to protect more its vulnerable forests.

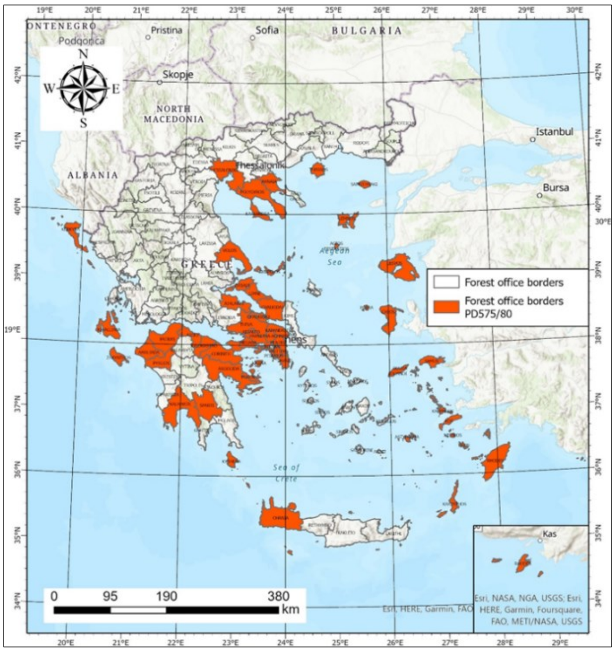


Figure 42. Forest areas vulnerable to forest and landscape fires (Source: Presidential Decree 575/1980, 1980)

Colin C. Hardy (2005) defines as "Fire risk the chance that a fire might start, as affected by the nature and incidence of causative agents". He highlighted also that there is general agreement on this definition between numerous U.S. and international organizations, including the National Wildfire Coordinating Group (NWCG, 2003), the Society of American Foresters (1990, 1998), the Food and Agriculture Organization (FAO, 1986), and the Canadian Committee on Forest Fire Management (National Research Council Canada, 1987).

Furthermore, fire danger maps prediction is created to be the possibility of a forest fire ignition even more intelligible, providing information about the areas, which are prone to fires. In case of Greece, the Ministry for Climate Crisis and Civil Protection, Secretary General for Civil Protection publishes every day (at around 12:30 am) a map that shows the fire danger for next day (Source: https://www.civilprotection.gr/en/daily-fire-prediction-map). The map displays a five colours scale that corresponds to five fire danger levels (very low, low, medium, high and alarm).

To produce these maps is considered data of meteorology/weather forecast, satellite data for vegetation/fuel and soil status as well as any other available information that contributes to determine the danger of an area at given time (e.g., historical records of fire events, ground morphology, land use/land cover, location related data). The high accuracy of the map prediction depends on the high accuracy of weather forecast.

As presented in the following daily fire map prediction **(Figure 43)** Evia, when the fire was ignited (Tuesday 03/08/2021), was included in the high fire risk areas (fire danger class 3).

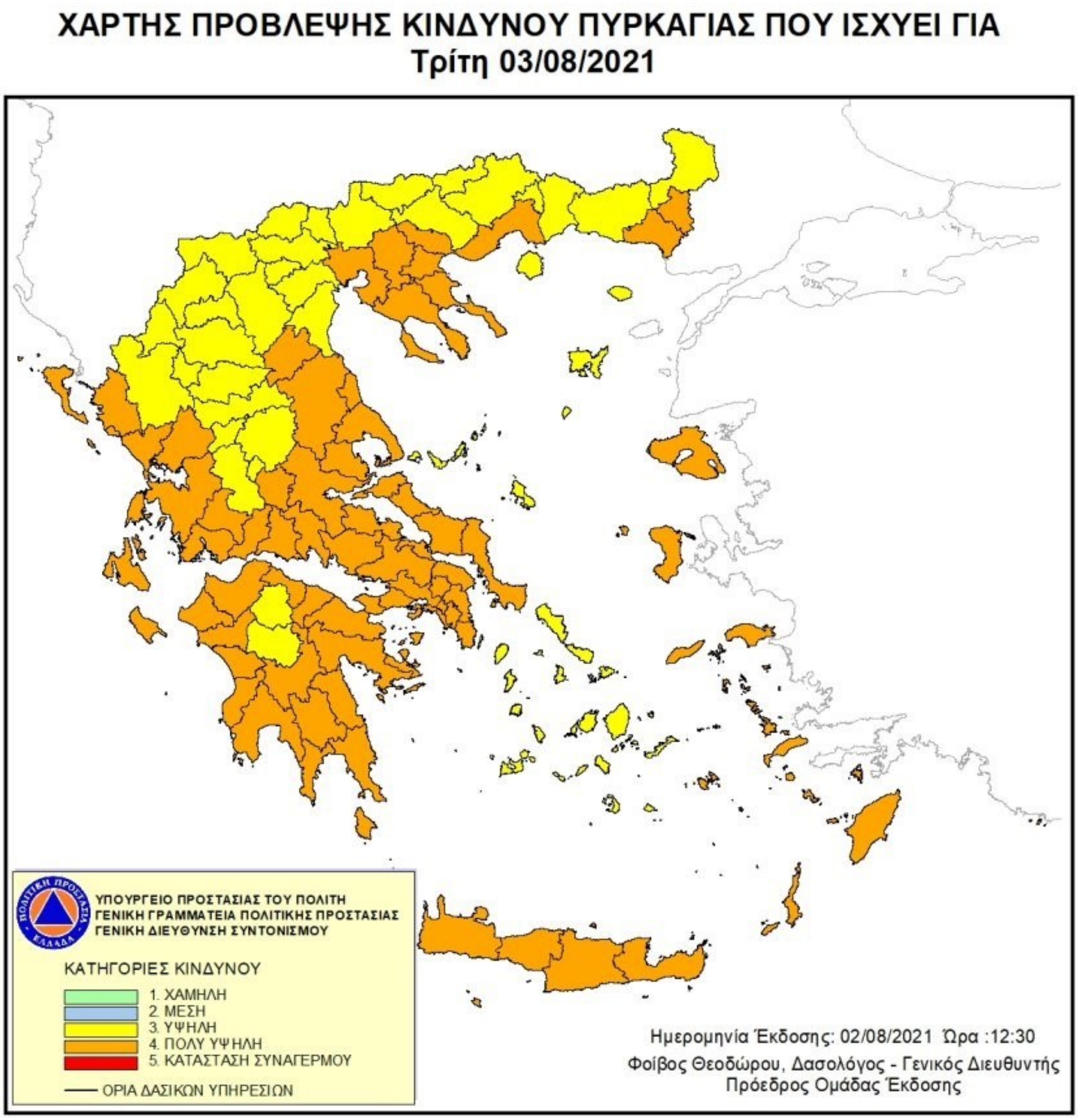


Figure 43. Daily fire danger map for Tuesday 03/08/2021 (The image is published in Greek).

During the fire season, for the creation and publishing of the daily fire danger map, since 2003 the Secretary General for Civil Protection, to monitor, evaluate and mapping of Greek vegetation condition uses satellite imagery of MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard NASA's TERRA satellite (Source: https://terra.nasa.gov/about/terra-instruments/modis). The method of map data assessment is based on Normalized Difference Vegetation Index (NDVI). These NDVI maps are robust, empirical measures of vegetation activity at the land surface. The colour on these maps depicts a measure of the "greenness" of Earth landscape, also known as relative biomass (Source: https://modis.gsfc.nasa.gov/data/dataprod/mod13.php). During the fire season, these maps are updated every 10 days.

In North Evia, since 2012 multiple landscape fires have been recorded, in total 886 landscape fires have been recorded based on the data logs of the Hellenic Fire Service (See **Table 22**). On average 89 landscape fires are being recorded in North Evia (three municipalities) every year (See **Table 23**). Many of these landscape fires are very small but some of them are extremely significant and large. Since 2012 seven large fires have been recorded with the largest one being that of the year 2021 that burnt for 8 days and destroyed more than 50,000 ha. It must be noted that some differences exist in the burnt area between

EFFIS and the Hellenic Fire Service, but these are not that significant and do not change the overall picture. In addition, in **Figure 44** the ignition points for the fires of 2020 and 2021, inside the limits of the three municipalities that constitute the pilot area, are presented (source: Hellenic Fire Service). Moreover, the burnt areas from the significant fires are presented based on the data form EFFIS in **Figure 45**.

Table 22. Main statistics data on landscape fires in North Evia based on the Hellenic Fire Service data logs.

Year	Landscape Fire occurrences	Forest (incl. forested) area burnt (ha)	Other areas burnt (ha)	Total area burnt
2012	114	108.28	29.15	137.43
2013	105	9.17	19.34	28.51
2014	110	19.70	68.49	88.19
2015	78	178.41	18.42	196.83
2016	83	2,195.46	45.16	2,240.61
2017	75	105.19	6.04	111.23
2018	81	388.94	260.91	649.85
2019	76	2,177.63	20.41	2,198.04
2020	86	6.52	10.50	17.03
2021	78	33,805.47	17,399.52	51,204.98
Total	886	38,994.77	17,877.94	56,872.70
Average per year	88.6			

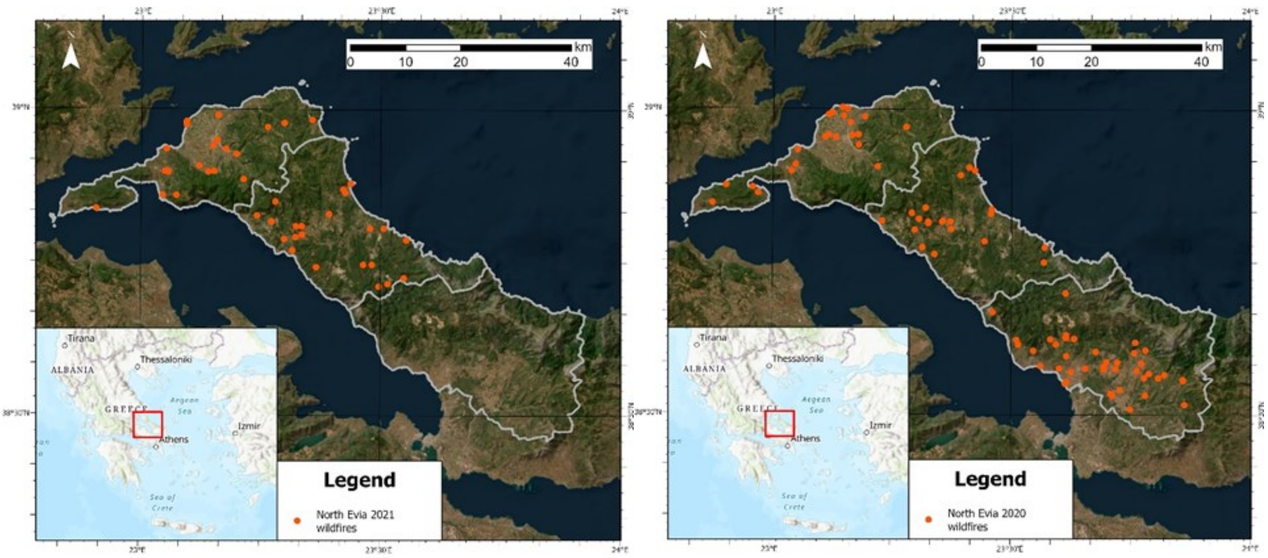


Figure 44. Left: Wildfire initiation points for the pilot area in 2021. Right: Wildfire initiation points for the pilot area in 2020 *(Source: Hellenic Fire Service).*

Figure 45: Significant wildfires in the pilot area for the period 2009-2021 (Source: polygons from EFFIS).

Table 23. Burned land cover type and area, per fire event (from Corine 2018-2021).

LAND COVER		FIRE EVENT-DAY (DD/MM/YY)/AREA BURNED (ha)								Grand Total
Description	**Corine Code**	**13-10-09**	**10-07-11**	**05-07-12**	**23-07-15**	**30-07-16**	**12-08-18**	**12-08-19**	**03-08-21**	
Discontinuous urban fabric	112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	136.7	136.7
Mineral extraction sites (Abandoned)	131	0.0	0.0	0.0	0.0	27.8	0.0	0.0	151.4	179.3
Sport and leisure facilities	142	0.0	0.0	0.0	0.0	0.1	0.0	0.0	13.6	13.7
Non-irrigated arable land	211	0.0	49.5	0.0	0.0	1.0	0.0	34.2	2,188.1	2,272.9
Fruit trees and berry plantations	222	0.0	31.2	0.0	0.0	0.0	0.0	0.0	0.0	31.2
Olive groves	223	24.3	88.8	0.0	40.5	0.0	171.1	137.7	3,509.6	3,972.0
Complex cultivation patterns	242	5.8	143.9	0.0	0.0	0.0	37.3	53.7	2,932.7	3,173.4
Land principally occupied by agriculture, with	243	0.0	75.6	26.7	0.0	2.3	31.2	79.7	8,389.9	8,605.4

LAND COVER		FIRE EVENT-DAY (DD/MM/YY)/AREA BURNED (ha)								Grand Total
Description	**Corine Code**	**13-10-09**	**10-07-11**	**05-07-12**	**23-07-15**	**30-07-16**	**12-08-18**	**12-08-19**	**03-08-21**	
significant areas of natural vegetation										
Broad-leaved forest	311	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,446.2	2,446.2
Coniferous forest	312	0.0	0.0	0.0	3.1	39.8	238.1	1,257.3	14,855.1	16,393.3
Mixed forest	313	0.0	0.0	37.3	0.0	0.0	0.0	15.4	10,223.8	10,276.5
Natural grassland	321	0.0	58.5	0.0	0.0	0.0	0.0	0,0	0.0	58.5
Sclerophyllous vegetation	323	70.9	66.5	0.0	0.0	0.0	33.6	162.8	1,314.0	1,647.7
Transitional woodland/shrub	324	105.1	0.0	0.0	60.5	2,530.7	53.3	1,146.1	4,925.8	8,821.5
Beaches, dunes, sands	331	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	36.3
Sparsely vegetated areas	333	13.9	0.0	0.0	0.0	0.0	0.0	0.0	25.3	39.2
Inland marshes	411	0,0	0.0	0.0	0.0	0.0	0.0	0.0	48.2	48.2
Grand Total		220.1	513.9	64.0	104.1	2,601.7	564.6	2,886.9	51,196.6	58,151.8

In **Figure 46**, soil erosion maps of the burnt area due to the 2021 megafire, before and after the wildfire, are presented, based on the study of (Valkanou et al., 2022) By comparing the two images, it is evident, that erosion of soil has been increased significantly after the 2021 megafire, and apparent that the area suffers from high erosion to most of the area.

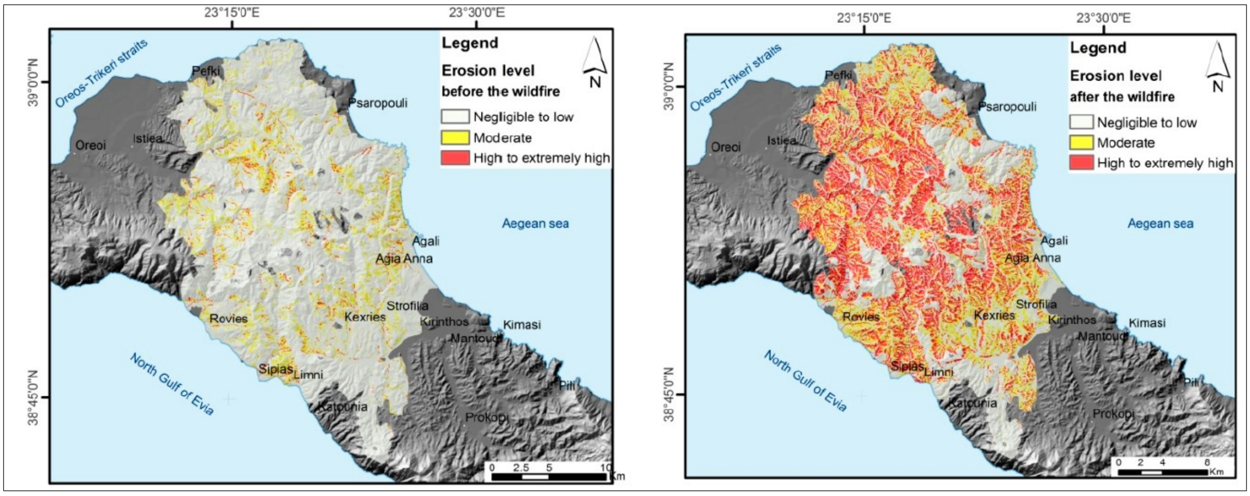


Figure 46: Soil erosion maps of the burnt area due to the 2021 megafire in Evia. Left: before the fire. Right: after the fire
source: (Valkanou et al., 2022)

5.3.14 Causes of wildfires in Evia

The study area is a mosaic of forests, agricultural lands, and other secondary land uses such as grasslands and, to a lesser extent, lands with past mining activity that are now largely abandoned. In the area about 52,000 people **(Table 15)** live and work in small villages and towns. Residential areas are scattered in the study area and spread into the neighbouring forests and/or agricultural lands. Residents' activities at the boundaries of settlements, such as outdoor cooking, construction and repair work, and the operation of machinery, are a cause of increased fire risk. These fires directly threaten the flammable forests of the region since there are no fire protection zones between the settlements and the surrounding forest and rural areas. Accordingly, work carried out in rural areas related to the burning of agricultural crop residues, construction work, or from the operation of agricultural machinery, as well as work in the forests such as smoking bees, increase the risk of starting a fire. These fires threaten both rural areas and forests as well as residential areas. The forests of the area are highly flammable due to the type and composition of the vegetation and the dry-thermal climate conditions that prevail during the summer season. Furthermore, the spatial continuity of the vegetation and the insufficient removal of the dead biomass, through forest management, increase the risk of fire spreading in the wider area. The big fire of the year 2021, which burned more than 50,000 ha of forest and agricultural land, spread over such a large area due to the above reasons in combination with the prevailing weather conditions.

According to Camia et al., (2013), in Greece, 56% of the landscape fires are of unknown reason, while 21% are set due to negligence. 11% are deliberately set by humans while only 3% are due to an accident and 4.5% to natural causes for the period 1983-2010 (**Figure 47- Top**). According to GFMC (2019), for the period 1984-2009, 57.24% of the landscape fires in Greece are of unknown reason, 11.26% have been set due to negligence, 4.1% due to natural causes, 11.49% due to arsons, while two sub-categories have been added, as these have found to be important for Greece. The category of” burning of fields” (8.25%) which belongs to negligence, and the category of “creation of pastures” (7.67%) which belongs to arsons (**Figure 47 - middle**). The independent committee of fire experts (GFMC, 2019) that was established to study the causes of fires in Greece, after the catastrophic fire of Mati-Attica in 2018, pointed out the categories as a reality for Greece that should be considered in prevention and recovery measures. In this aspect, landscape fires can be considered, in Greece, as a “social phenomenon “(GFMC, 2019). Based on GFMC (2019), the burned land based on the cause of fire ignition is 18% fuel to negligence, 13% due to arsons, 52% for unknown causes, almost 9% sets for burning of fields, 7.5% for the creation of pastures and 1% is related to natural causes **Figure 47 - Bottom**. **Figure 47** Overall, these statistics can also be considered valid for the case of Evia Island. The differences between Camia et al., (2013) and GFMC (2019) are not significantly different (differences range between 1% and 3%, depending on the class) mainly because due to the slightly different study period.

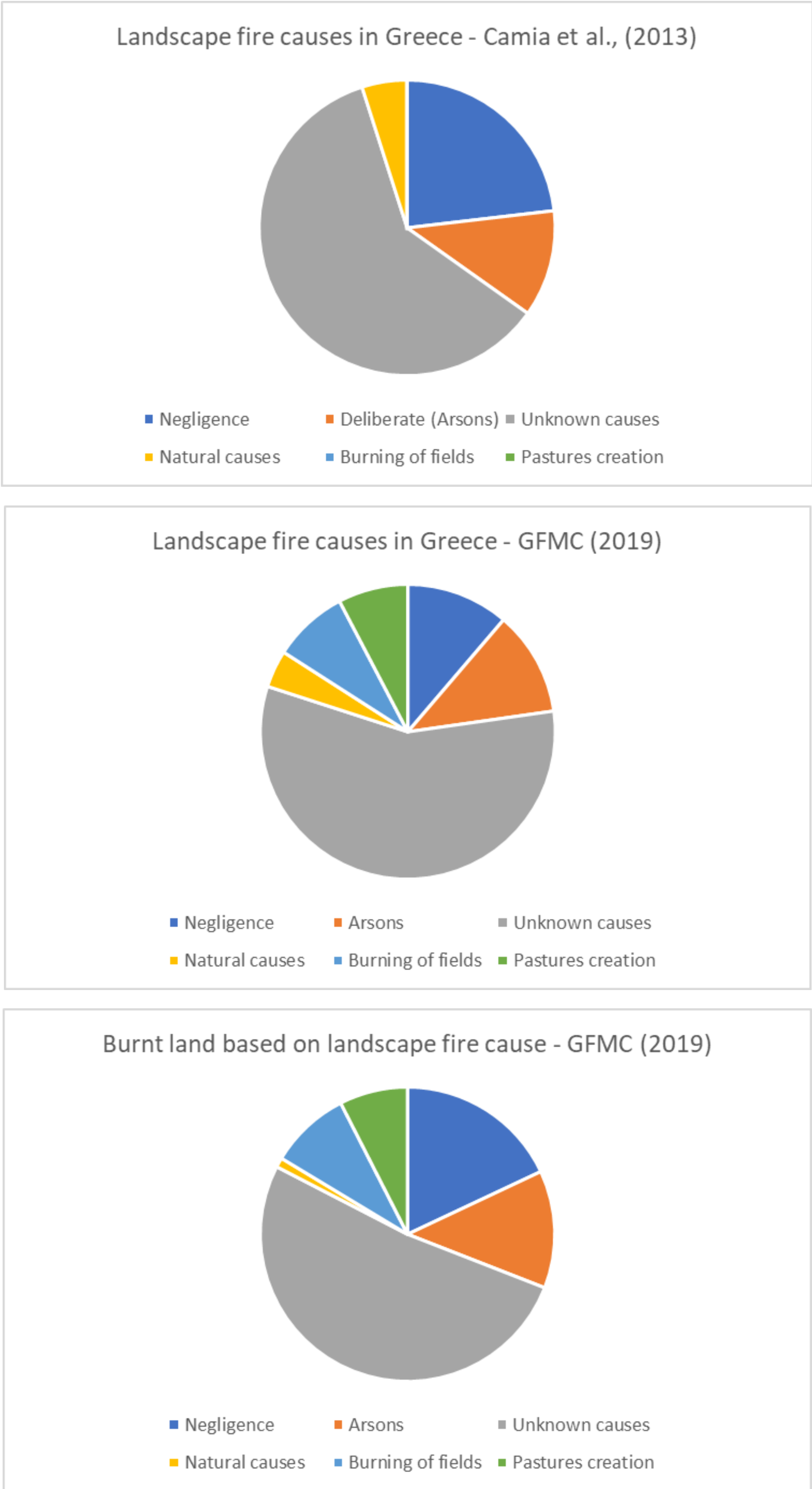


Figure 47: Top: Landscape fire causes in Greece for the time period 1983-2010 (Source: Camia et al., 2013)**. Middle: Landscape fire causes in Greece for the time period 1984-2009 (Source:** GFMC, 2019)**. Bottom: Relation of burnt landscape to the fire causes for the time period 1984-2009 (Source:** GFMC, 2019)**.**

5.4 Cova da Beira - Portugal

5.4.1 Location/ Administrative

Cova da Beira is located in the interior east part of Portugal. It comprises 4 counties: Belmonte; Covilhã, Fundão and some parishes of Castelo Branco. In addition to some industry, the region has strong traditions in the agriculture and forestry sectors, and it is much known for its top-quality agriculture products. The landscape at Cova da Beira is characterized by two main altitudinal zones: a large relatively flat valley at the centre, which is surrounded by mountain ranges. **Figure 48** shows the Cova da Beira Region and landscape.

The flat area is composed by a mosaic of agricultural land uses, including pastures, cropland, and orchards, but also forest patches, including native oak forests and pine plantations. The mountain areas overlap two important Nature 2000 sites, the Special Area of Conservation (SAC) of Serra da Gardunha (PTCON0028) and the SAC of Serra da Estrela (PTCON0014), the latter also classified as Natural Park. The valley is crossed, from northeast to southwest, by the river Zêzere. The Zêzere has its source in the Serra da Estrela Mountain range and is an important tributary of the Tagus. The river margins host riverine habitats of high ecological value, with alder (*Alnus glutinosa*) and ash (*Fraxinus excelsior*) populations. The mountain areas surrounding the valley are characterized by forest habitats, listed in the Habitats Directive, of chestnut (*Castanea sativa*, habitat 9260) and deciduous oaks (*Quercus robur* and *Q. pyrenaica*, habitat 9230).

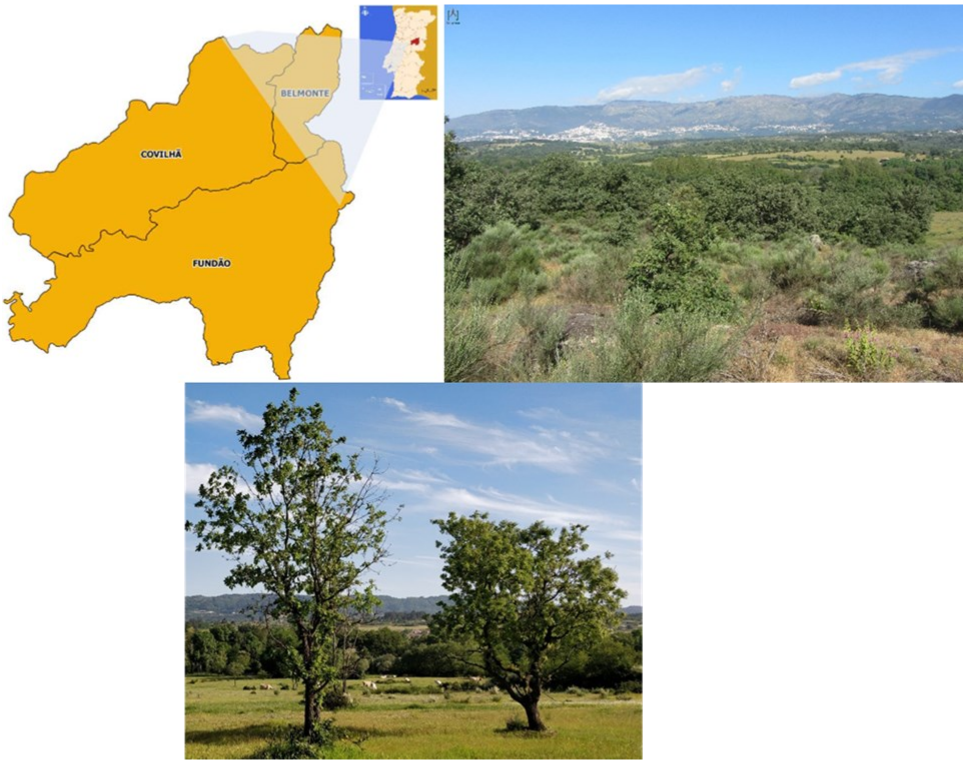


Figure 48. Cova da Beira, Portuguese Pilot region, and landscape

Cova da Beira combines a strong implantation of industry in an area with a strong rural influence, resulting in a rural region of high population density (57,6 residents/km^2; source: INE 2022). The asymmetry in land distribution is revealed by the presence of large side-by-side properties with a generalized smallholding. The landscape is very diverse, due to the hydrographic network that influences land use and their distribution. Today most of the area is occupied with intensive agriculture and fruit farming (apple, peach, cherry). The landscape is strongly compartmentalized, marked by the agricultural land uses and the granitic

outcrops with oak woodland patches. This is a region of abundant water resources, characterized by a great interannual irregularity.
Recent fires have had an important impact in large tracts of the mountain ecosystems, calling for preventive measures to regulate future fire damage and restoration measures to recover the native habitats, their biodiversity, and the ecosystems services they provide, including water flow regulation, control of soil erosion, and habitats for wildlife, namely wild pollinators.

5.4.2 Geomorphology

From a geological point of view, the territory is integrated into the Central-Iberian Zone of the Hesperian Massif, mainly composed of ancient, Paleozoic and pre-Paleozoic rocks that have undergone deformations during different tectonic cycles of the Hercynian and Alpine orogenies. These deformations led to "NE-SW or ENE-WSW directional faults that mark the great horst of the Central Range and are responsible for Serra da Estrela and Gardunha and the Cova da Beira trench.

The Cova da Beira corresponds to a subsidence basin, approximately 30km long and 12km wide, located between Serra da Estrela and Gardunha, and is crossed longitudinally by the Zêzere River (**Figure 49**). It is predominantly flat, with some peaks corresponding to harder rock outcrops, such as in Belmonte. This basin owes its fertility to deep soils from granitic formations, the presence of water, and the protection conferred by the massifs of Serra da Estrela and Gardunha, which determine a continental climate with a cold and dry winter and a hot summer.

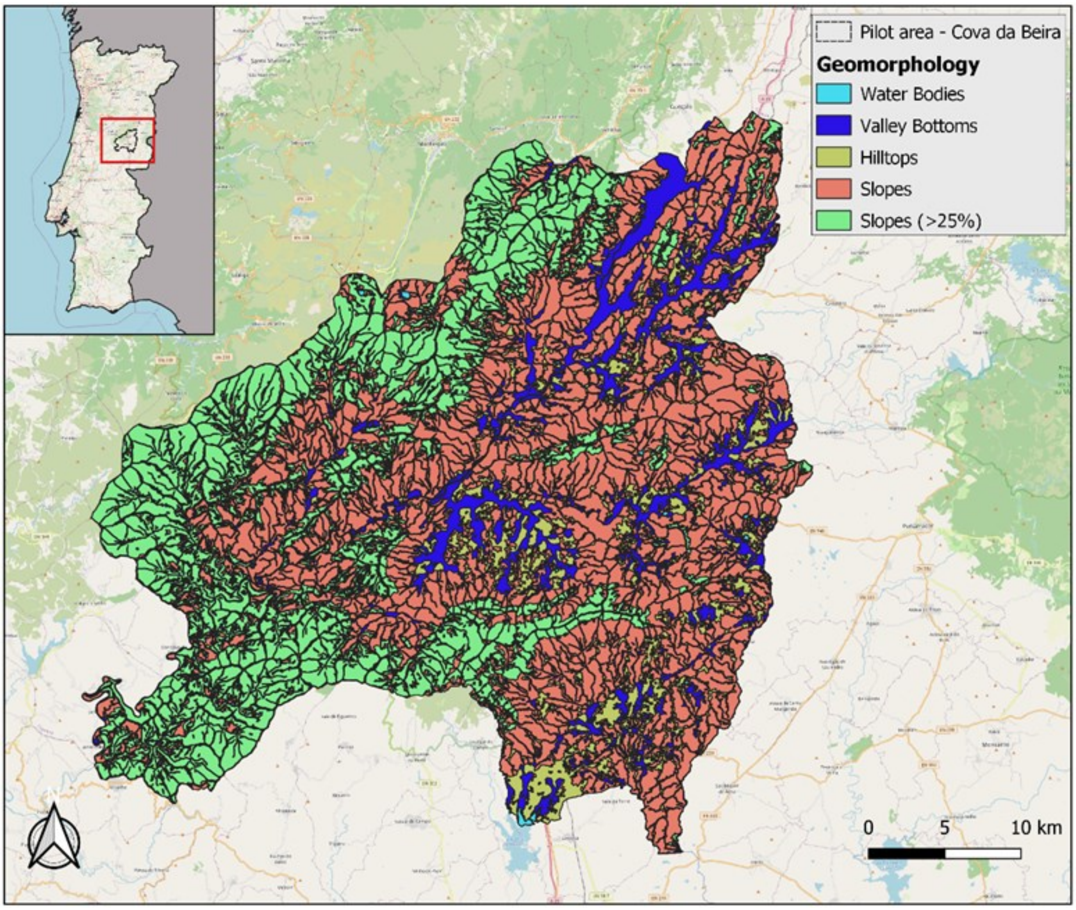


Figure 49. Geomorphology of Cova da Beira Portuguese Pilot in Portugal (Source: Epic-webgis-portugal, ISA).

5.4.3 Geology

The area is mainly composed by granitic rocks corresponding to two-mica monzonitic granites, predominantly biotitic and with a uniform mineralogical composition. The granodiorite is limited to the pluton of Fundão and outcrops in a northern area of this city. These granite and granodiorite outcrops are highly altered on the surface, resulting in a weathering mantle known as granitic saprolite. The veins of igneous material are fundamentally constituted by quartz and pegmatites, whose distribution can be observed on the geological map (**Figure 50**)

Although NE-SW and E-W directions predominate, the orientation of these veins is variable. These veins are the most representative and are distributed throughout the Cova da Beira area. In general, the composition of the alluvium along the Zêzere River is essentially sandy with varying grain size, intercalating sandy-silty or sandy-clayey materials and gravel mantles.

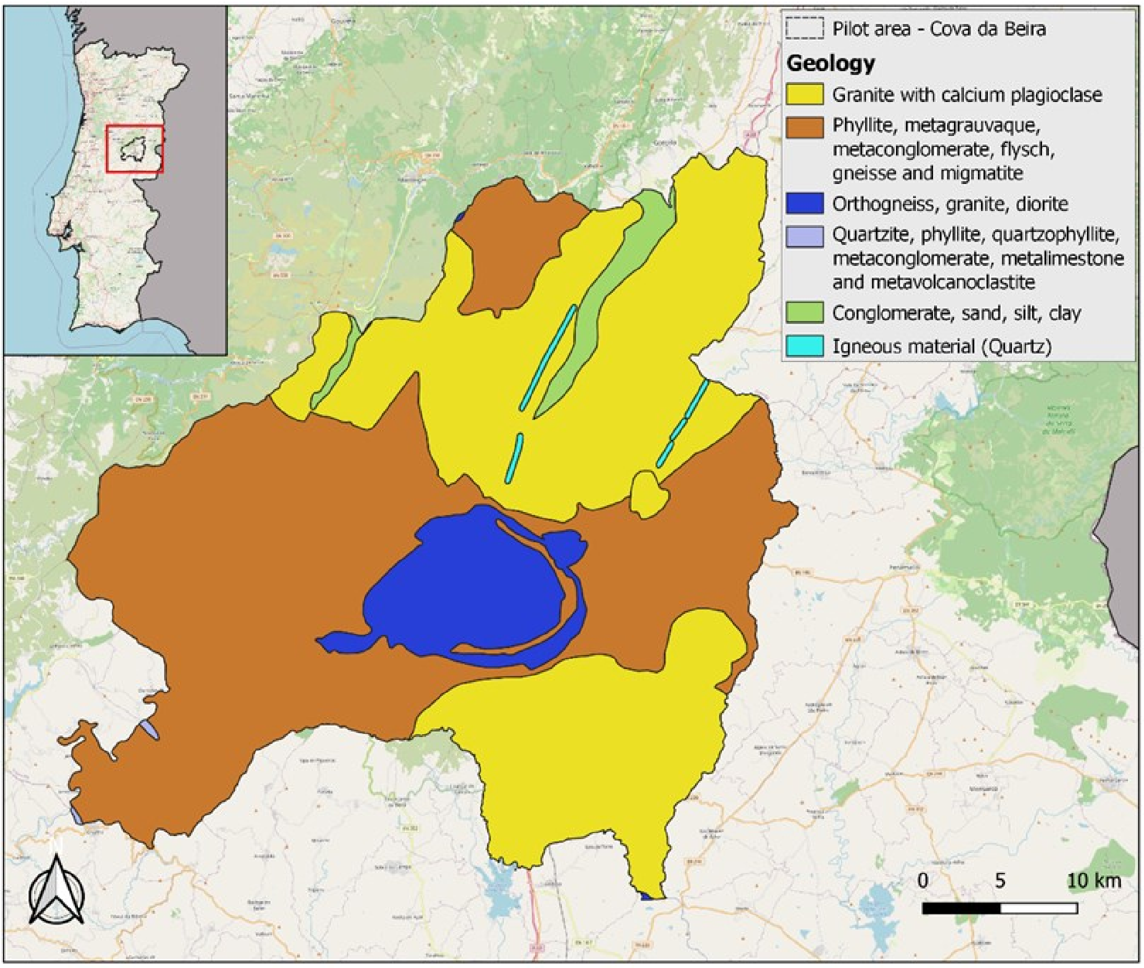


Figure 50. Geology of Cova da Beira Pilot site (Source: Epig-webgis-portugal, ISA)

5.4.4 Soil

Regarding the soil properties of Cova da Beira, as seen in **Figure 51**, the texture is mainly medium to coarse, with the coarser areas corresponding to moderate to high permeability. Except from the Zêzere River gallery area, the soil pH is less than 5.5. The area is mainly characterized by shallow soils, up to 50cm depth. Moreover, the areas with more than 100cm of depth, are coincident with the more permeable soils.

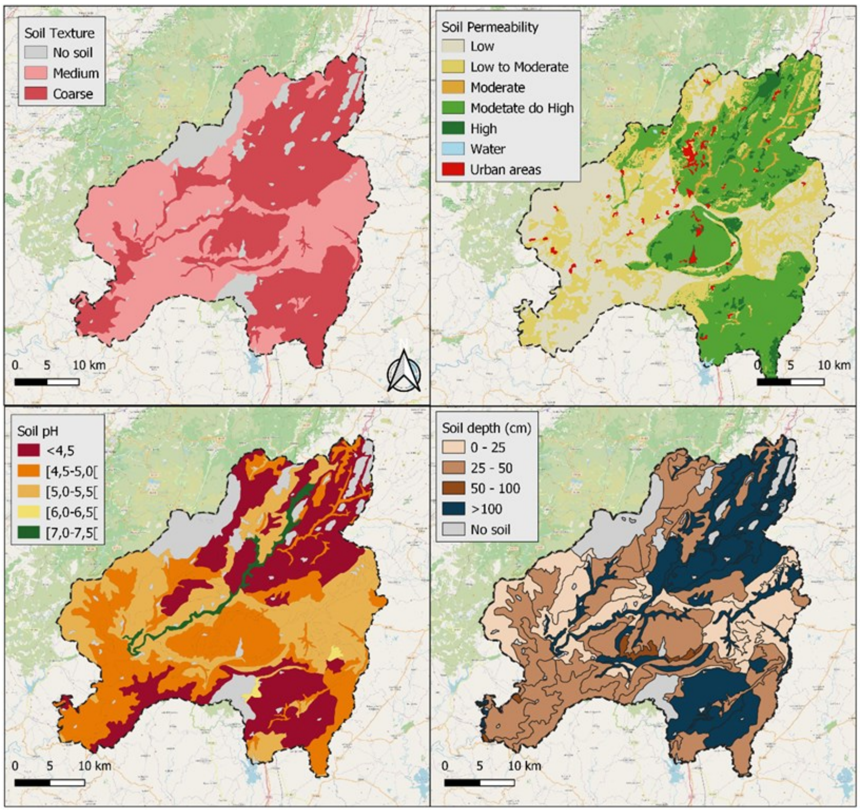


Figure 51. Soil properties of Cova da Beira Pilot region. Soil texture (top left), soil permeability (top right), soil pH (bottom left) and soil depth (bottom right). (Source: Epig-webgis-portugal, ISA)

5.4.5 Hydrology

Cova da Beira region is rich in water resources, characterized by the spring and watershed of the Zêzere River with its tributary streams (**Figure 52**). The river is the most important watershed in the area. The morphological feature of Cova da Beira corresponds to a large depression with a flat bottom, where the Zêzere River occupies a wide valley. In addition to the Zêzere, Caria and Meimoa streams are also important waterways that drain Cova da Beira, with elevations ranging from 400 to 600m.

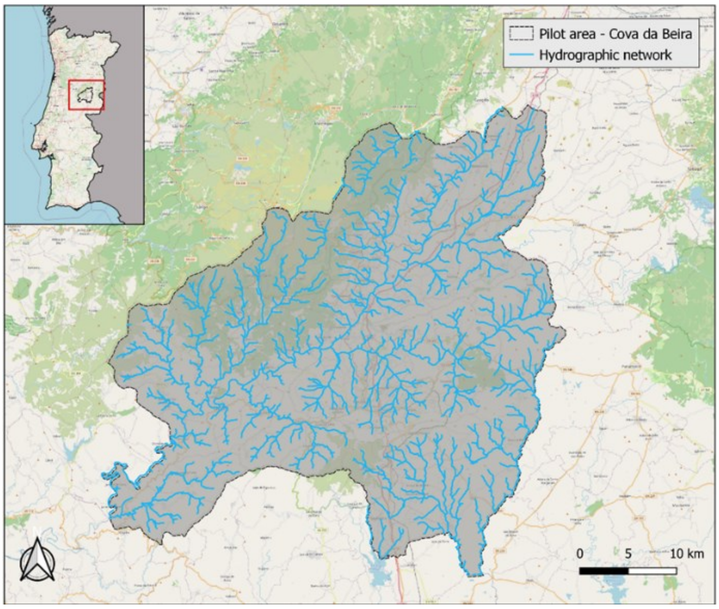


Figure 52. Hydrographic network of Cova da Beira Pilot region (Source: Epig-webgis-portugal, ISA)

5.4.6 Land use

The landscape of Cova da Beira reflects the fertility of the soil through small-scale parcel division and intensive agricultural exploitation, ranging from pine or oak forests to olive groves, orchards, vineyards, vegetable gardens, etc... (**Figure 53**). Hedgerows are not very common, but their presence adds to the diversity of the landscape, such as those along roads. In general, there is coherence between land use and biophysical characteristics in the Cova da Beira region. However, there are significant exceptions, particularly near the main urban centres of Covilhã and Fundão, where there is the uncontrolled development of various types of industries.

The most representative land uses of the area are:

• Dryland agricultural land;

• Agricultural land densely wooded with fruit trees (olive, cherry, apple, peach, and vine) (predominant near settlements);

• Agricultural land used for irrigated crops (corn, potato, sunflower, and tobacco);

• Pine forests typically composed of maritime pine.

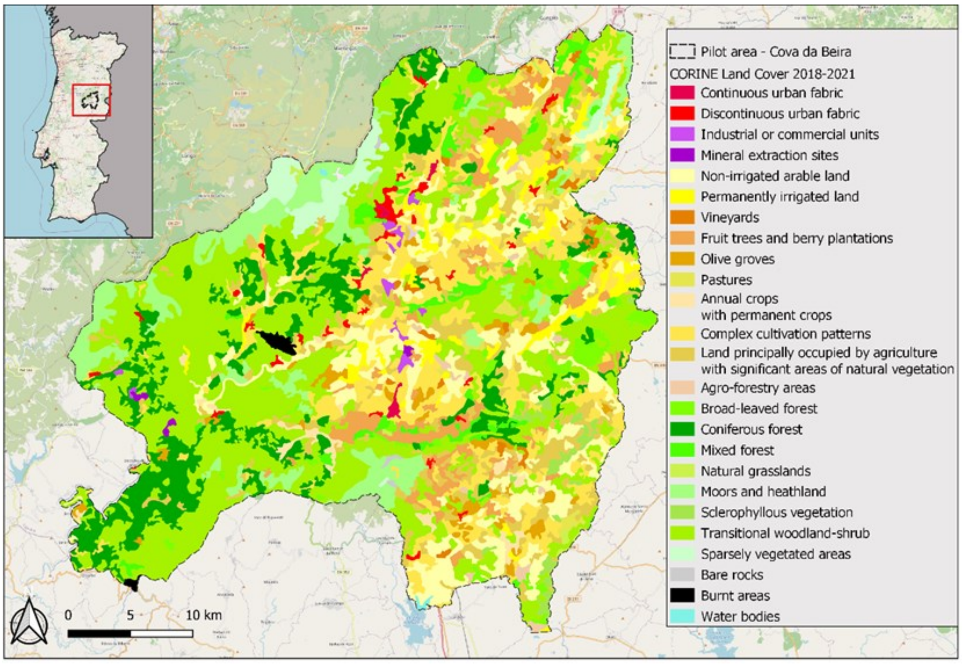


Figure 53. Land cover for Cova da Beira Pilot region based on the CORINE land cover 2018-2021. Recent wildfires are not included.

5.4.7 Flora

On the banks of the Zêzere River and the Meimoa and Caria streams, it is worth noting the agricultural use of alluvial soils due to their fertility. However, on the hillsides, it is worth highlighting the existence of vineyards and olive groves, and on the northern hills and hilltops, the dominant occupation is pine forests and cherry orchards.

The most representative flora is:

• Querco-Fagetea vegetation class, along the riparian galleries of the Zêzere River, with value as ecological corridors;

• Oak forests, of *Quercus robur* and of *Quercus pyrenaica*, where *Asphodelus bento-rainhae* (endemism of Serra da Gardunha) is noteworthy;

• Cork oak forests (*Quercus suber*), corresponding to small patches of mixed stands;

• Shrublands that correspond to mixed vegetation formations associated with secondary succession after forest fires or field abandonment.

5.4.8 Wildlife

The wildlife in the Cova da Beira region is diverse and is associated with the vegetation cover and land use. The various existing habitats provide the region with a high faunal richness. Worth mentioning is the otter (*Lutra lutra*), the Iberian water lizard (*Lacerta scheriberi*), the Portuguese salamander (*Chioglossa lusitanica*), the Iberian nase (*Chrondrostoma polypepis*) and the marsh fritillary butterfly (*Euphydryas aurinia*), as well as various protected bird species such as the Montagu's harrier (*Circus pygargus*) and the booted eagle (*Hieraaetus pennatus*).

This area is composed of diverse habitats where representative elements of different biodiversity zones are found **(Figure 54**). It has 250 species of vertebrates and 2,100 species of invertebrates. It also has a high diversity of amphibians and reptiles.

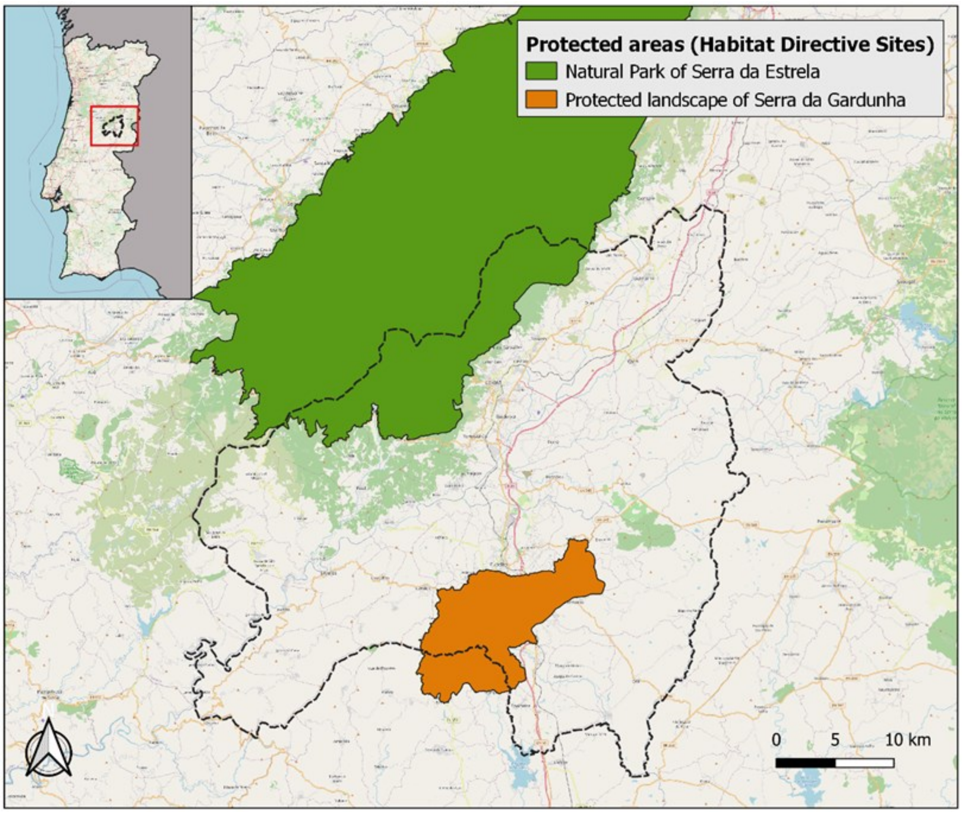


Figure 54. Protected areas (Habitat directive sites) included in the pilot region of Cova da Beira. (Source: https://geocatalogo.icnf.pt/catalogo_tema2.html)

5.4.9 Climate

From a climatic point of view, Cova da Beira region is classified as Mediterranean climate, with hot and dry summers and mild and rainy winters (Köppen climate classification), with sone continental characteristics. **Figure 55** shows the variation of the mean annual temperature and accumulated annual precipitation between 2000 and 2021, for Cova da Beira region.

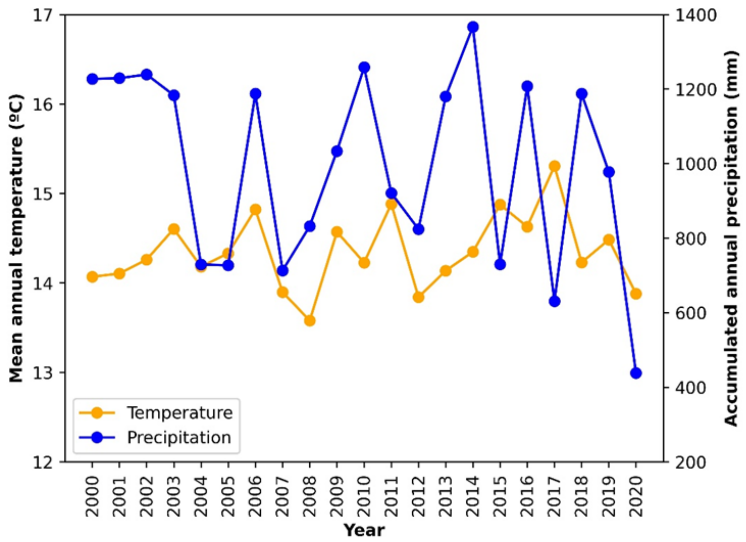


Figure 55. Variation of the mean annual temperature and accumulated annual precipitation between 2000 and 2021, for Cova da Beira region (Source: Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), https://cds.climate.copernicus.eu/cdsapp#!/home)

5.4.10 Demographics / Social / Economy

Cova da Beira is characterized by mixed settlements, concentrated mainly in urban areas, and quite dispersed in some rural areas, notably through numerous small farms. Cova da Beira has been a region marked by rural exodos, despite the development of industrial activity and proximity services (**Figure 56**). The population density shows some social disparity that accentuates the demographic pressure on urban centres to the detriment of the surrounding rural areas. In addition to the diversity of agricultural uses and some forest patches, this landscape is also characterized by the density and dispersion of settlements, accompanied by a dense network of communication routes and, in general, by signs of relative vigour of economic activities, especially related to agriculture but also to industry and services (Covilhã and Fundão).

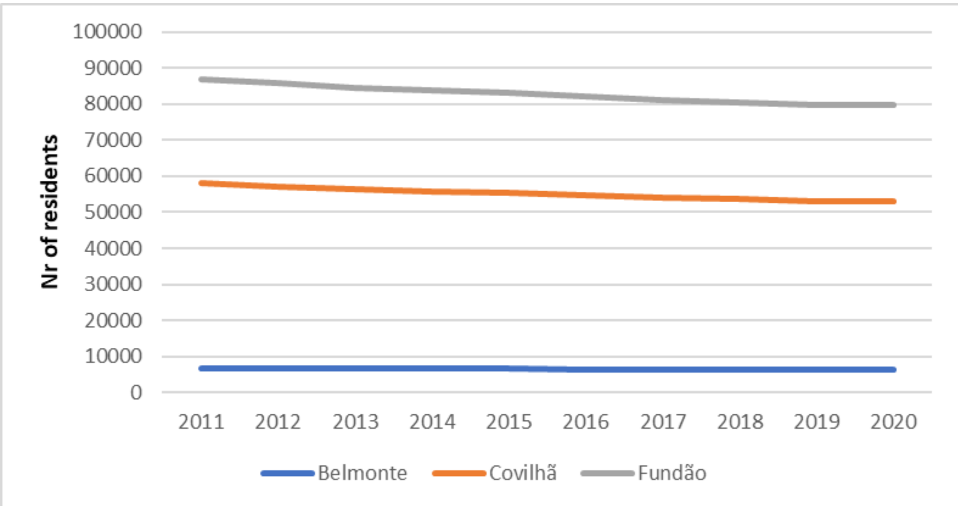


Figure 56. Annual estimates of the resident population in Cova da Beira by local of residence (municipalities, NUTS) (Source: INE, 2022)

Some regional products, directly or indirectly related to the landscape, have been classified as of great quality by the Ministry of Agriculture, such as: Olive oil, goat and lamb meat, Cova da Beira cherries, peaches, and apples, a variety of cheeses, and wine with the Cova da Beira Designation of Origin.

5.4.11 History of Fires

Portugal ranks among the European countries that are more vulnerable to the impacts of climate change and is witnessing an intensification of phenomena such as drought, desertification, and coastal erosion, along with increased risks of flooding and wildfires. The forest fire hazard Map of Portugal is shown in **Figure 57**. Almost all parishes from the Cova da Beira region (case study area) have been classified as priority areas for monitoring fuel management in the context of rural fire prevention by the Portuguese fire management authorities. This context underlies the importance of Cova da Beira region regarding fire vulnerability.

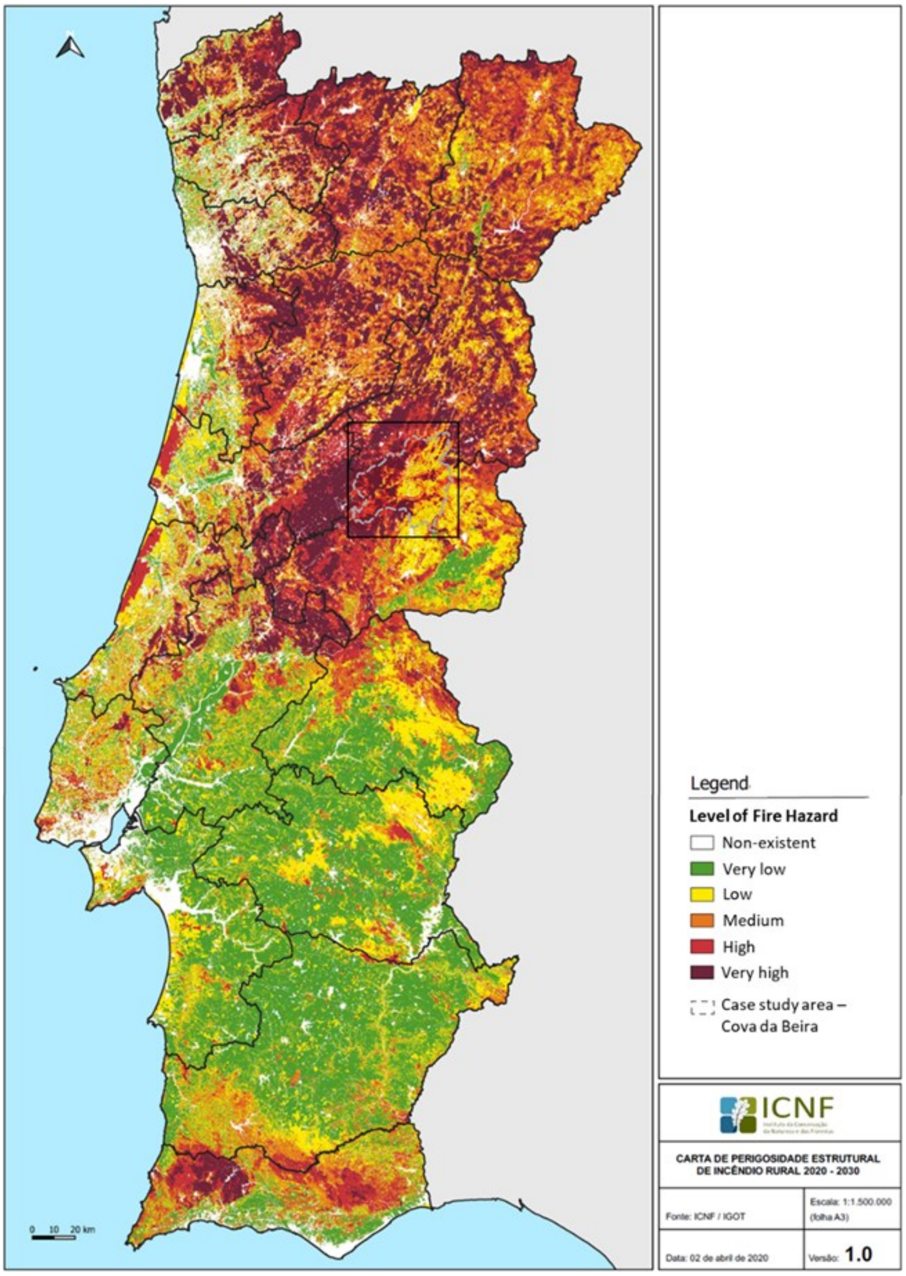


Figure 57. Forest fire hazard Map (Portugal) 2020-2030 (Source: ICNF)

For the analysis of the historical series of fires we considered the events occurring in the case study area, referring to the period 1975-2021, elaborated by the Portuguese Nature and Forestry Conservation Institute (ICNF) (**Figure 58**). Since 2000 a total of 452 fire occurrences were reported in the pilot area by the ICNF, with a total burnt area of more than 50,000 ha (**Table 24**). Many of these might be considered small fires, but most of them significantly affected the burnt areas. In 2017, a major fire occurred in Portugal, destroying more than 12,000 ha in the pilot area, and more than 60 people have died. Since then, according to the Portuguese Law n. 76/2017 owners, tenants, or entities that, for whatever reason, hold land adjacent to buildings in rural spaces, are obliged to proceed with fuel management.

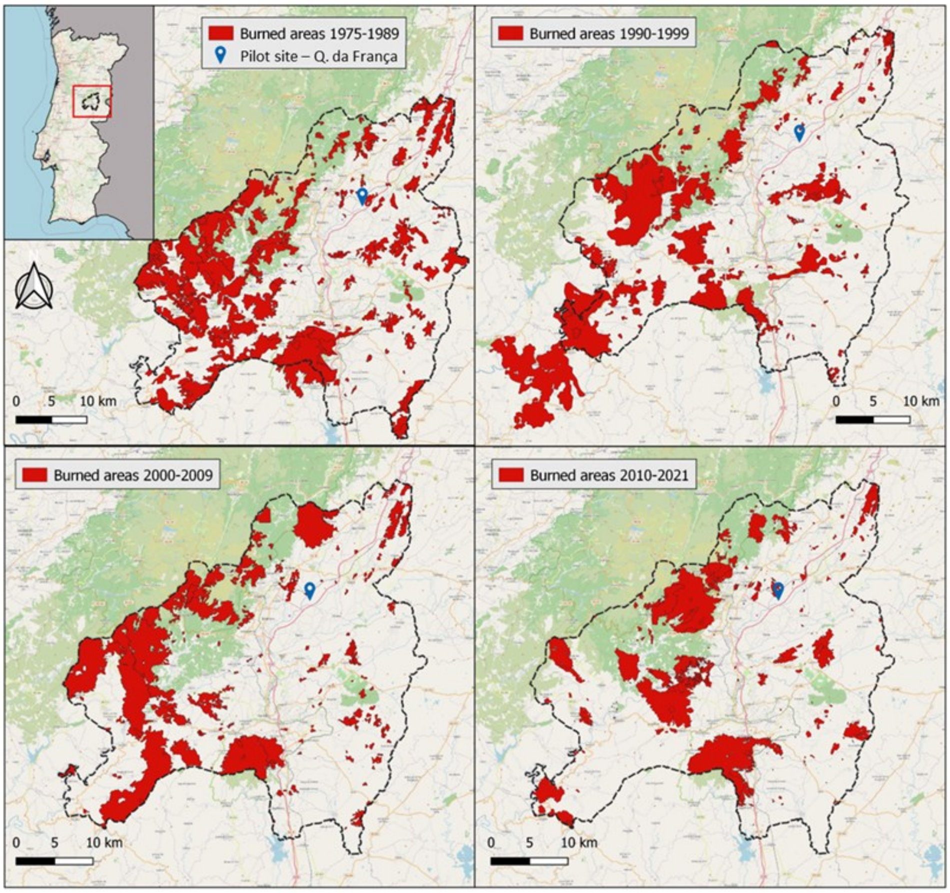


Figure 58. Wildfires map in the case Pilot region for the periods 1975 to 2021 (Source: ICNF).

Table 24. Fire occurrences and total burnt area per year in the case pilot region, from 2000 to 2021 (Source: ICNF).

Year	Fire occurrences	Total forested area burnt (ha)
2000	41	8,254.74
2001	43	5,915.24
2002	16	1,912.92
2003	21	6,181.47
2004	5	352.70
2005	13	8,204.61
2006	6	92.29
2007	5	63.09
2008	10	245.32

Year	Fire occurrences	Total forested area burnt (ha)
2009	36	625.76
2010	41	1,384.31
2011	35	487.92
2012	35	825.33
2013	42	2,651.75
2014	4	34.94
2015	40	1,469.48
2016	6	226.05
2017	22	12,676.86
2018	5	311.15
2019	8	748.22
2020	15	2,675.26
2021	3	29.07
Total	452	55,368.48

5.4.12 Causes of wildfires in Portugal

The rural exodus that occurred in Portugal mainly in the second half of the twenty-century contributed to land abandonment and widespread afforestation, especially in the interior North and Centre of the country, contributing to an increase not only in the amount of flammable biomass but also of its spatial continuity. These changes in land cover increase the susceptibility of the landscape to fire, contributing to more severe wildfires. Moreover, fire frequency has also increased, partially due to more frequent extreme climate conditions, especially heatwaves, drought periods, and strong winds.

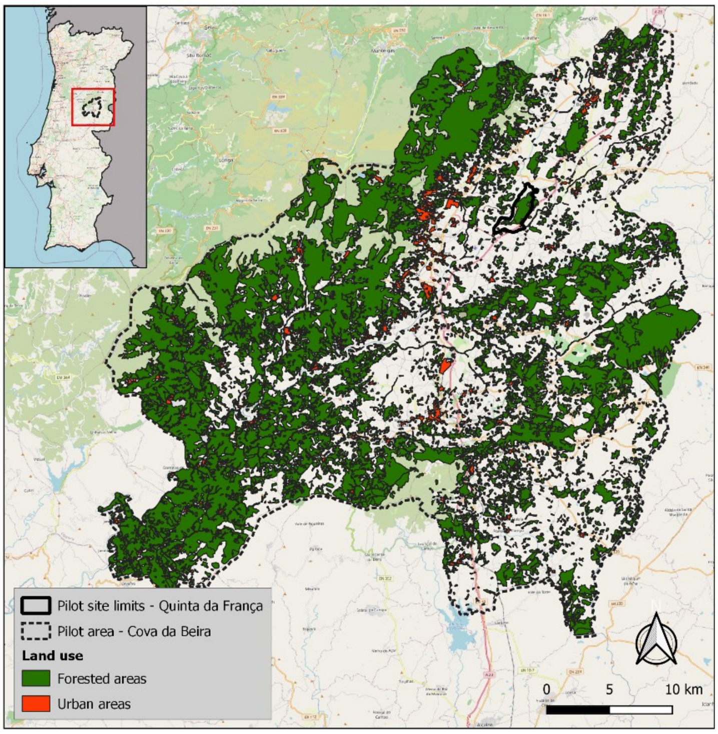


Figure 59. Urban-rural interface areas in Cova da Beira Pilot region, Portugal. (Source: COS2018, https://snig.dgterritorio.gov.pt)

Cova da Beira combines a predominantly rural influence with a strong presence of industry. The main urban-rural interface areas are shown in **Figure 59**.

Between 2012 and 2021, out of a total of 158,210 rural fires, 122,514 were investigated (77% of the total number of fires). Of these, the investigation allowed for the attribution of a cause for 80,063 fires (65% of the investigated fires). Only 1% of the fires occurred from natural causes (**Figure 60**). Negligent use of fire (41%) and arson (28%) were the most frequent causes of fires between 2012 and 2021. Reignition of fires accounted for 13% of the total identified causes, which is lower than the average of the previous 10 years (17%).

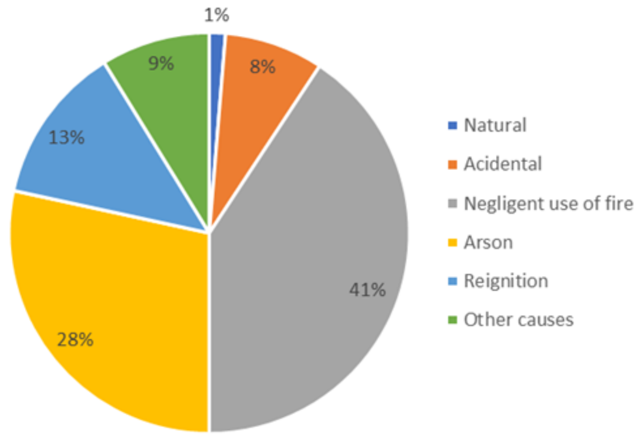


Figure 60. Percentage distribution of rural fires by most frequent causes between 2012 and 2021 (Source: https://www.icnf.pt/florestas/gfr/gfrgestaoinformacao/grfrelatorios/areasardidaseocorrencias)

5.5 Podpoľanie - Slovakia

5.5.1 Location/ Administrative

Approximate location of case study area: Podpolanie is in the central part of Slovakia (**Figure 61**), particularly within region of Banská Bystrica and its district Detva. Within case study area are situated two towns (Detva and Hriňová) and 13 municipalities. In 2021 the population of Detva district was almost 33,700 residents and population density 74 persons per square km.

The location of the Podpolanie case study area within NUTS classification is as follows:
NUTS1 SK0 - The Slovak Republic (republic = republika)
NUTS2 SK03 - Central Slovakia (area = oblasť)
NUTS3 SK032 - Banská Bystrica Region (region = kraj)
LAU 1 604 - Detva District (district = okres)

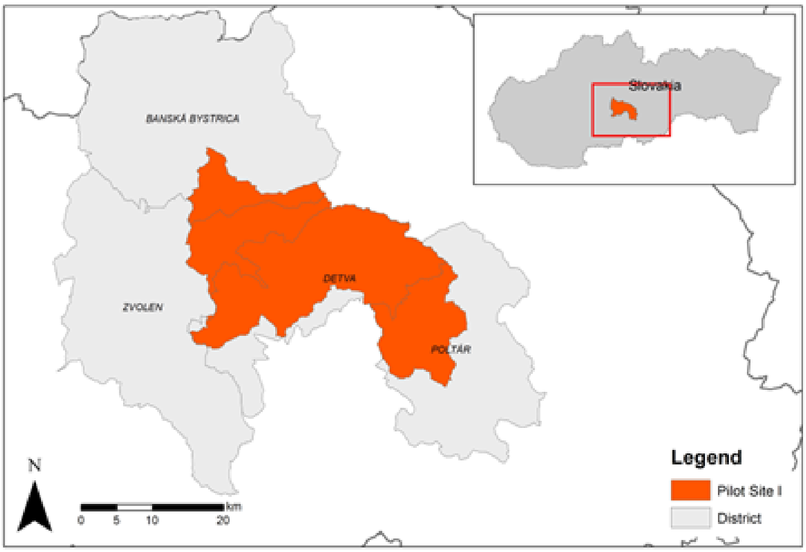


Figure 61. Pilot study area of Podpolanie

5.5.2 Geomorphology

In terms of the geomorphological subdivision of Slovakia, the Poľana Mountains belong to the Slovak Central Mountains, which are mainly made up of andesite stratovolcanoes and the intermountain basins surrounded by them. The basins, except for the higher Horehronské sub-valley, belong to the so-called middle basins, which have a bottom at an altitude of 300-700 m above sea level.

Polana Mountains is of a volcanic structure, with the best-preserved features of the original volcanic morphostructure. The dominant geomorphological unit is Vysoká Poľana with its central depression (the erosive caldera of Kyslinky). The caldera is strongly indented with a flat bottom, the slopes of which with valleys and watercourses have a centripetal orientation.

The geological structure of most of the area is dominated by the neovolcanics of the Poľana stratovolcano, built up by lava flows, breccias and epiclastic rocks of andesitic composition of Lower-Central Sarmatian age. The most varied and complex part is in the Kyslinky area, which is an erosive caldera. The Detvian foothills are built by less resistant pyroclastics.

The sediments of the intra-mountain basins and basins are mainly built up by deluvial sediments. From the north and east, bedrock belonging to the Veporské vrchy (Veporské vrchy Mountains) unit is submerged beneath the stratovolcanic rocks of the stratovolcano. They are built up by Palaeozoic rocks of the Veporik crystalline, mainly metamorphosed rocks and granitoids.

The Poľana is a strongly individual unit of almost circular plan with a diameter of about 18 km. This plan is only significantly disturbed on the northern side by the Ľubietovské Vepro escarpment. A specific physiognomic feature of Poľana is that the maximum altitudes are not related to the central part of the mountain range. The core of Poľana is a depression, a depressed form of a basin-like shape - Kyslinky. The sub-unit of the Detvian foothills flanks the high Poľana along its entire western and southern perimeter and is partly characterized by lower to irregularly spaced groups of spines. The Veporské vrchy Mountains are characterized by different morphographical features compared to Poľana. There are two types of relief here, namely the plain and the dissected plain. The typical floodplain is linked to the source area of the Kamenistý potok (Kamenistý brook). The dissected plain is characterized by broad flat-topped ridges and relatively deeply incised valleys.

Polana is divided into sub-regions (See **Figure 62**):

a. Vysoká Poľana occupies the main ridge of the mountain range and the Vepra escarpment. The Vysoká Poľana also includes a part called the Kyslinky, representing an erosively depressed depression with upland relief - the bottom of a caldera drained by the Hučava river.
b. The area around the highest peak of the mountain range (Poľana, 1,458 m above sea level) and the opposite Bukovina (1,294 m above sea level) has a relief of strongly rugged higher mountainous terrain, the rest of the High Polana is strongly to very strongly rugged lower mountainous terrain. Most of the main ridge is located at an altitude above 1,000 m, the lowest saddleback is the saddleback of Príslopy (956 m above sea level). On the ridge, and especially on its inner edge, there are rock formations on the outflows of andesitic lava. To a limited extent, reefs are also found on the thick pyroclastics, e.g., on the ridge between Hájny Grun and Vepro. On the outer slope of the mountain range, the scarps are formed by selective erosion on the faces of andesite lava flows, but also scoured along cracks in the pyroclastics.
c. The Detvian Predhorie (foothills) is a transitional sub-unit connecting the Poľana and the Zvolen basin. It has the relief of a moderately to strongly dissected highland, in the deeply incised Hučava valley, in places also very strongly dissected. It is formed on mainly volcanoclastic rocks of the lower part of the stratovolcanic slope.

Figure 62. Poľana orographic sub-regions

The specific geomorphological structure of the area is also reflected in the unique watercourse network of the area. The central part of the Poľana caldera is drained by the Hučava stream, which tributaries form a centripetal network of watercourses. On the other hand, a centrifugal - radial network of watercourses has formed on the periphery of the caldera, which flow out of the territory to all sides of the world. The total reported length of watercourses in Poľana is 357.12 km. The most important watercourses of the territory, apart from the Hučava mentioned above, are the Hukava and Slatina in the south-east of the territory, the Kamenistý potok in the north-east, the Hutná in the north-west and the Zolná in the west. All streams belong to the Hron river basin.

In the south-eastern part of the territory, on the upper reaches of the Slatina, there is the Hriňová water reservoir. The south-eastern part of the territory of the protected landscape area is therefore subject to restrictions resulting from the relevant sanitary protection zones.

The territory of the PLA-BR Poľana overlaps with several areas of water management importance. The most significant is the already mentioned Hriňová water reservoir with a sanitary protection zone of 71.04 square km, as well as sanitary protection zones of smaller water sources, and several water streams and their catchment areas. Hygienic protection zones serve for stricter protection of water resources and are designated for all exploited sources of groundwater and surface water, as well as medicinal and mineral waters. They also include the protection of areas within watercourses and their catchment areas, as well as the protection of areas of interest for prospective water works. The catchment area of a watercourse is the area from which surface water flows into the catchment area to the profile defining the termination of the watercourse, as well as the area from which surface water is artificially transferred into the catchment area of a watercourse to increase its capacity. Enhanced and special protection shall apply in the catchment area of watercourses. In addition to the constructions, installations or activities listed under the Water Act, the consent of the competent water authority is required for all constructions, installations and activities in a watercourse basin which may adversely affect the quality, formation, circulation, and quantity of water resources.

5.5.3 Soils

The dominant soil type of the PLA is cambisols, especially typical cambisols. These are mostly medium to deep soils (0.4 - 1.2 m). The soil reaction is acidic 4.5 to 5.0 pH/KCl.

In the higher altitudes of the volcanic part of the PLA they are followed by andosols. They are characterized by a high content of volcanic glass and humus in the soil profile. The specific properties of these soils are attributed to the remarkable dimensions of some trees (e.g., fir species at the end of the Hrochot valley) or the occurrence of thermophytic habitats at unusually high altitudes (oak-hornbeam at Kalamarka at around 800 m). It is the second most widespread soil type in the PLA. The other soil types are less widespread in area and occur only locally in smaller islands.

5.5.4 Land use

The case study area is agricultural – forest land with forests in the north and agricultural land in the south (**Figure 63**). For an upper part of the forest area are typical beech and fir-beech forests, in contrast to lower part where do prevail the Carpathian oak-hornbeam forests. Agricultural land is characterized by middle to low productive. The region is considered rather as region with specific cultural landscape development. In particular, the surrounding of Hriňová town is characterized by dispersed rural settlements and by traditional land use (e.g., small private owners). The region has never undergone collectivization in the 20th century; therefore, it represents a unique opportunity to study relations between the man and the landscape. Moreover, region could be characterized as highland territory with different land-use patterns. There are grown commercial deciduous and mixed coniferous-deciduous forests, meadows, pastures, arable land, and areas with non-forest woody vegetation. Some parts of the mountain pastures and meadows are abandoned and overgrown.

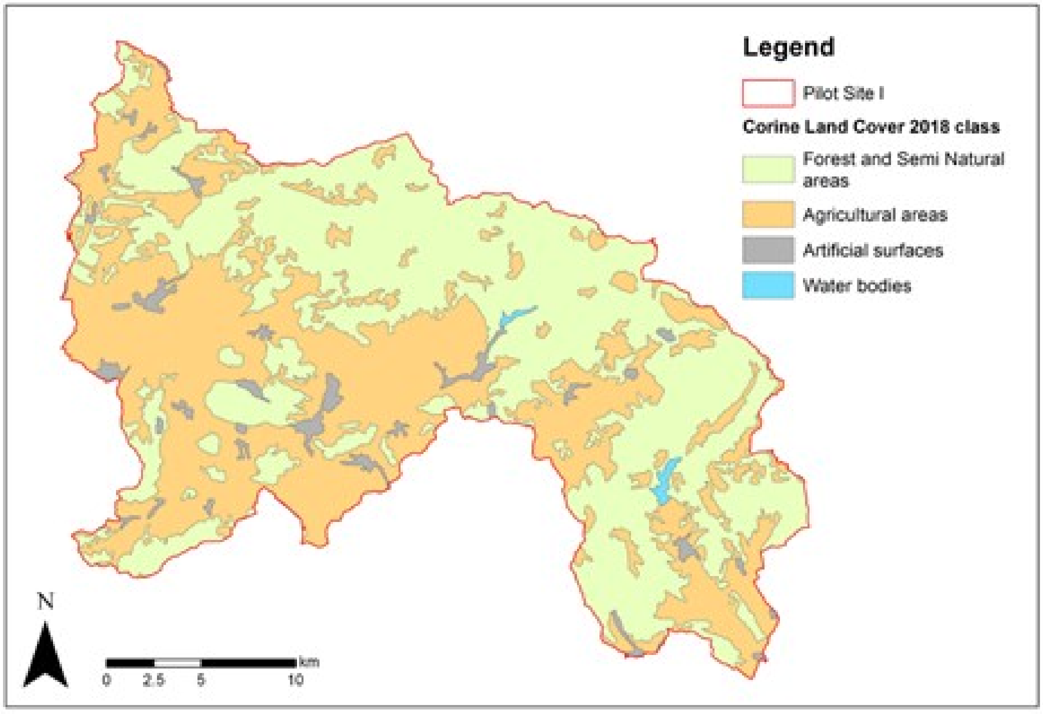


Figure 63. Land use structure of Polana

5.5.5 Ecological Valence

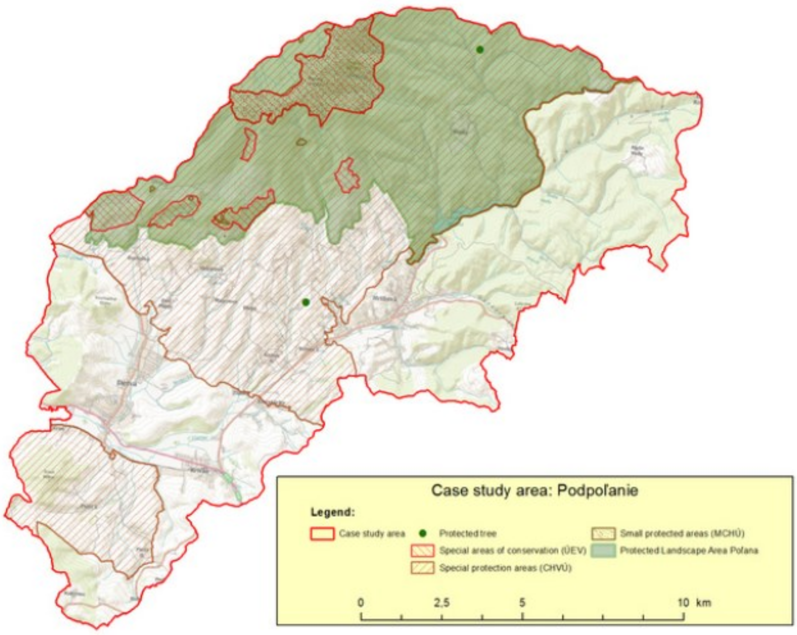


Figure 64. Protected Landscape Area Poľana - the Poľana Biosphere Reserve

North part of the pilot study area (almost forest) is under nature protection (**Table 25**), particularly it belongs to Protected Landscape Area Poľana - the Poľana Biosphere Reserve (**Figure 64**). Protected Landscape Area (PLA) Poľana was launched in 1981 for the protection of inanimate nature, plant, and animal communities as well as a special landscape character. Agricultural land as the mountain meadows and pastures is either mowed or grazed by cattle and sheep. Re-cultivation in recent past, to some degree has changed the original floristic composition of the grasslands. Despite this, enough natural plant and animal communities is still present. The area is dominated by the massif of Poľana Mountain that is the highest extinct volcano in Central Europe with its altitude of 1458 m. Elevation range is about 1000 m (the lowest point of 460 m. above sea level and the highest of 1458 m. above sea level). The whole mountain is part of the Carpathian arc. In a relatively small area exists a presence of mountain thermophile species of plants and animals.

Table 25. Proportion of protected areas in Podpolanie Pilot study area

Protected areas within Podpolanie pilot study area	**Area (ha)**	**%-share**
Protected Landscape Area (acronym CHKO)	6,795	32
Special areas of conservation (acronym ÚEV)	12,085	57
Small, protected areas (acronym MCHÚ)	749	3.5

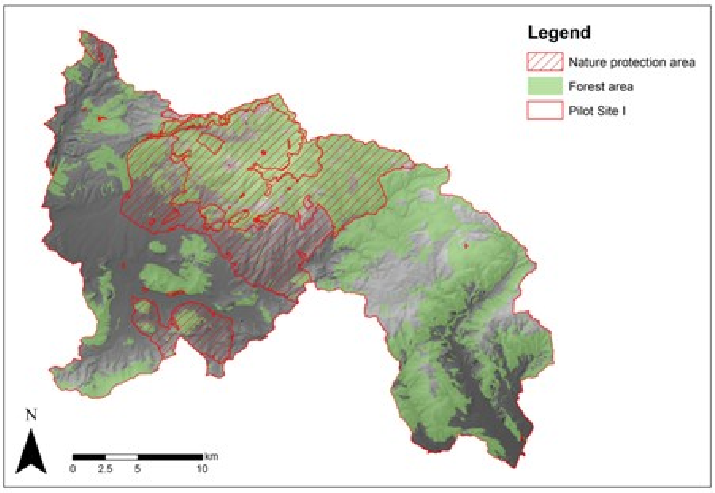


Figure 65. Protected areas within Podpolanie pilot study area

The forest land in the area has important protection functions concerning the water, soil, and biodiversity. Within the territory is located a water reservoir Hriňová, which is an important source of drinking water for the surrounding region. Moreover, the recreational function of the area is also significant. Due to Protected game area of Poľana is Podpolanie pilot study area well known for its hunting. On the area of more than 20,000 ha is provided a coordinated ecological and large-scale management of game, especially of red deer population of Carpathian deer. Additionally, the forest is also intensively used for mushrooms, forests' fruits, and nuts picking. To the outdoor activities mainly belong summer activities as tourism, ecotourism, and various sports.

The Protected Landscape Area (PLA) Poľana was declared on the territory of 20 360.4804 ha. Of these, there are 3 001.4072 ha of agricultural land, 17 102.3626 ha of forest land, 102.4992 ha of water areas, 48.6161 ha of urban areas and 105.5953 ha of other areas. The landscape of Protected Landscape area Poľana is shown in **Figure 66**.

Figure 66. Protected Landscape area Poľana

5.5.6 Climate

The territory of the PLA is characterized by the dominance of a cold mountain climate in the higher parts of the mountains, which changes to a cool and slightly cool climate in the lower parts. The average annual air temperature ranges from 3-5°C. The coldest months are January and February, while the warmest months are July and August. Average rainfall ranges from 600-900 mm, rising to 1,100 mm in the highest parts of the area.

The specific geomorphological structure of the area is also reflected in the unique river network of the area. The central part of the Poľana caldera is drained by the Hučava river, the tributaries of which form a centripetal network of watercourses. On the other hand, a centrifugal - radial network of watercourses has formed on the periphery of the caldera, which flow out of the territory to all sides of the world. The total reported length of watercourses in Poľana is 357.12 km. The most important watercourses of the territory, apart from the Hučava mentioned above, are the Hukava and Slatina in the south-east of the territory, the Kamenistý potok in the north-east, the Hutná in the north-west and the Zolná in the west. All the streams belong to the Hron river basin.

In the south-eastern part of the territory, on the upper reaches of the Slatina, there is the Hriňová water reservoir. The south-eastern part of the territory of the protected landscape area is therefore subject to the restrictions resulting from the relevant sanitary protection zones.

5.5.7 Forest Ownership

In terms of forest land ownership in Podpolanie pilot study area (**Figure 67**), the state forest proportion is 84.7 %. This area is administered by the State Enterprise Forest’s branch plant Kriváň, which is the largest forest subject in the region. Forest land whose owners are unknown (3.7 %) is also managed by this forest holding. From non-state owners the biggest share is in communal ownership (8.3 %). Private owners own 3.2 % and church only 0.1 % of forest land. Very small part of forest land is in municipal and agricultural cooperatives ownership.

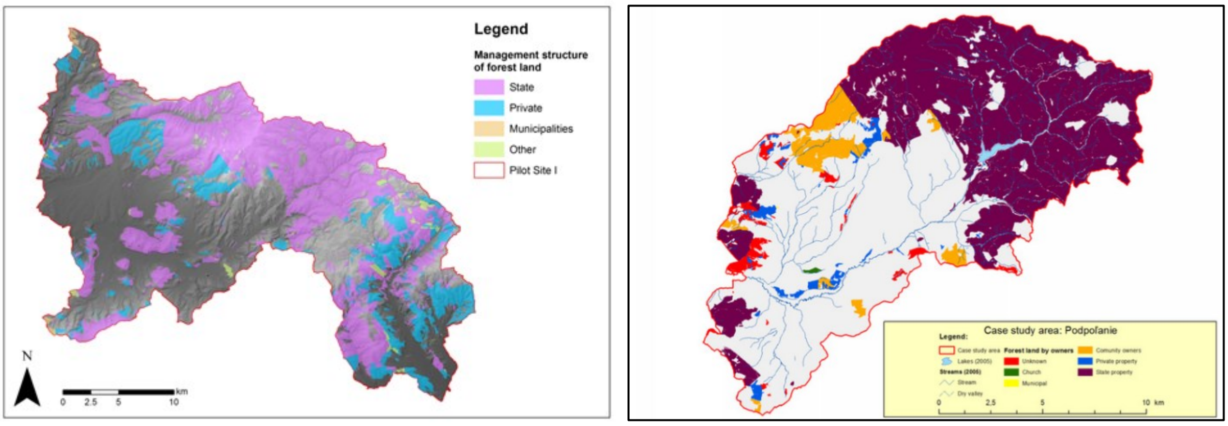


Figure 67. Ownership structure in the pilot study area Podpolanie

5.5.8 Flora

In terms of the phytogeographical division of Slovakia, the territory of Poľana belongs to the area of the West Carpathian flora (Carpaticum occidentale), to the perimeter of the Precarpathian flora (Praecarpaticum) and to the district of the Slovak Central Mountains.

In the past, a large part of this tertiary stratovolcano was covered by an extensive forest cover, which even today occupies about 85% of the area. The original species composition of their stands has been altered in many places by intensive human activity, particularly since the 17th century. At present, forest communities of forest vegetation stages 2 to 7 are present.

Only fragmentary oak-beech and beech-oak forests can be found in the south-western parts. In these forests, in addition to oak (*Quercus cerris L.*), winter oak (*Quercus petraea* L.), summer oak (*Quercus robur* L.) and beech (Fagus sylvatica L.), hornbeam (*Carpinus betulus* L.), small-leaved and large-leaved lime (*Tilia cordata L.*, *Tilia platyphyllos* L.) are also present. They are followed by the most widespread beech and fir-beech forests. In addition to the main tree species, these forests are mixed with Norway spruce (*Picea abies L*) and, in the valley bottoms with damp, stony scree, maple (*Acer pseudoplatanus L.*), elm (*Ulmus glabra L.*) and ash (*Fraxinus excelsior l.*). Beech stands are dominant on more or less open southern slopes with warm air currents up to the ridge positions.

The highest positions of the Protected Landscape Area Poľana are occupied by the original mountain spruce forest, which is ringed by a narrow belt of spruce-beech-fir forests. It represents the southernmost occurrence of native spruce forests on volcanites in the Western Carpathians. In addition to spruce, its tree species composition is dominated by *Sorbus aucuparia*, which forms an organic complement in the development of stands of *Acer pseudoplanus,* while the shrub floor is made up of *Lonicera nigra*, *Salix silesiaca*, *Ribes alpinum*, *Daphne mezereum*, *Rosa pendulina*, etc. In the two-layered herbaceous undergrowth, mainly mountain and subalpine species such as *Doronicum austriacum, Cicerbita alpina*, *Adenostyles alliariae*, *Ranunculus platanifolius*, *Soldanella hungarica*, *Veratrum lobelianum*, *Luzula sylvatica*, *Calamagrostis villos*a, can be found.

In many locations, larger areas have been deforested and replacement communities of meadows, pastures and fields have been created. Species-rich meadow communities with many threatened and rare plant species, together with other non-forest and forest communities, increase the overall biodiversity of the PLA Poľana. Field communities can be found mainly at the southern foot of the massif, near typical dispersed settlements and farm buildings - "lazy".

5.5.9 Wildlife

The entire southern part of the Poľana Mountains is under the influence of a warmer climate, and therefore some characteristic xerothermophilic species, some of which reach the northeastern limit of their distribution here, such as *Lychnis coronaria*, *Artemisia absinthium*, *Calamintha clinopodium*, *Achillea nobilis*, *Potentilla argentea*. In contrast, cool-temperate montane species occur in the lower inversion valleys. The extremely valuable, most endangered and at the same time declining communities include the vegetation of peat bogs, springs, and waterlogged mountain meadows with the occurrence of the *Parnassia palustris*, *Drosera rotundifolia*, *Trollius altissimus*, *Iris sibirica*.

Poľana is also characterized by a richness of animal species, mainly due to the high diversity of the territory and the influence of the relief and the location of the mountains themselves. This is also reflected in the occurrence of thermophilic as well as mountain species. The area is largely made up of forests, with approximately 2,000 ha of meadows and pastures.

Of the invertebrates, many species are endemic, relict, rare and endangered. Several of them are protected species of European and national importance. Invertebrates are very abundant, many of which are rare and endemic. The wildlife of molluscs is interesting, which are mainly associated with preserved forest ecosystems, with several Carpathian endemics, e.g., *Trichia bakowski*i, *Vestia elata*, *Vestia turgida*, *Vitrea transylvanica*, *Biezia coerulans*, and the wildlife of spiders, shepherd's spiders, millipedes and centipedes.

The richest class of invertebrates is represented by insects. In the meadows with isolated hills and rocks, straight-winged insects can be found, e.g. In some localities there are also the *Chorthippus biguttulus, Chorthippus mollis, Decticus verrucivorus, Tettigonia cantans*, and in some localities also the rare *Arcyptera fusca* and *Pholidoptera frivaldskyi*. Recently, however, the meadows have gradually become overgrown due to their lack of use. This is gradually leading to the destruction of undeniably interesting biotopes and the species that live in them.

The beetles of relatively preserved forest communities are represented by, e.g., Carabus variolosus, Carabus auronitens, Carabus irregularis, Eurythyrea austriaca, Cucujus haematodes, Rosalia alpina, etc.

The group of mountains, boreomontane relicts is represented by the *Carabus arcensis*, *Lacon fasciatu*s, *Aphodius alpinus*. Some sites with south-facing slopes create conditions for thermophilic species such as *Ephippigera ephippiger*, *Mantis religioza*, *Carabus scabriusculus,* and *Eurythyrea quercus*, *Anthaxia funerul*a, which are characteristic for the Pannonian zoogeographical region.

The flowering meadows attract a variety of colourful butterflies, e.g., Parnassius mnemosyne, Papilio machaon, Erynnis tages, Pyrgus malvae, Melitaea cinxia, M. didyma, Lycarna tityrus, L. alciphro and others. The meadow is also rich in watercourses. Their purity is also evidenced by the occurrence of some bipterans, especially the Chironomidae and the Salmo trutta morpha fario.

In PLA Poľana, which is also Biospheric Reserve, there are 11 species of amphibians. The most endangered are the *Triturus vulgaris, Triturus alpestris, Triturus montandoni* and *Salamandra salamandra.* In recent years, the number of sites and the population density of the Hyla arborea have decreased significantly.

Reptiles are represented by 9 species. The avifauna of Poľana is extremely rich. So far, 174 species of birds have been found on its territory and in the vicinity, 128 of which are breeding birds. The exceptional importance of this area is underlined by the inclusion of Poľana among the Important Bird Areas (IBA) of Europe. The wildlife of Poľana also includes 56 species of mammals. The mountain species of micromammals include *Sorex alpinus*, *Sicista betulina* and *Microtus agrestis*. *Microtus arvalis* and *Crocidura leucodon* are associated with woodland sites.

The decaying trees, rock crevices, haylofts and old buildings are home to several species of bats such as *Rhinolophus hipposideros*, *Myotis myotis*, *Plecotus auritus*, *Barbaslella barbaslella*, *Nyctalus leisleri* and others. The critically endangered *Lutra lutra* occurs on watercourses. *Ursus arctos* lives in the quiet forest corners of Poľana, *Lynx lynx* and *Canis lupus* are also present. Deer are the most widespread game species in Poľana.

5.5.10 History of Fires and Prevention

Data on wildfires in 2021 from the Pilot study area are introduced in **Table 26**.

Table 26. Wildfires of Poľana in 2021

No.	Date of fire announcement	Municipality	Vegetation type	Ignition source	Fire reason	Direct damage [eur]	Fire site area [m²]	Fire season
1	3.3.2021	Detva	grass and fallow land	matchstick; lighter	burning of grass and dry stands	0	30	winter
2	4.3.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	15	3,391	winter
3	9.3.2021	Korytárky	veldt	matchstick; lighter	burning of grass and dry stands	20	5,000	winter
4	10.3.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	5	1,300	winter
5	19.3.2021	Stožok	grass and fallow land	not known	other negligence and carelessness of adults	50	6,750	winter
6	26.3.2021	Vígľaš	veldt	matchstick; lighter	burning of grass and dry stands	10	10	spring
7	26.3.2021	Látky	grass and fallow land	matchstick; lighter	waste incineration (non-landfill)	30	900	spring
8	26.3.2021	Vígľaš	veldt	matchstick; lighter	waste incineration (non-landfill)	10	600	spring
9	26.3.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	10	80	spring
10	27.3.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	10	1,500	spring
11	29.3.2021	Vígľaš	veldt	matchstick; lighter	burning of grass and dry stands	20	5,000	spring
12	28.3.2021	Vígľaš	veldt	matchstick; lighter	burning of grass and dry stands	0	750	spring
13	30.3.2021	Hriňová	veldt	matchstick; lighter	burning of grass and dry stands	0	1,400	spring

No.	Date of fire announcement	Municipality	Vegetation type	Ignition source	Fire reason	Direct damage [eur]	Fire site area [m²]	Fire season
14	27.3.2021	Stará Huta	veldt	matchstick; lighter	burning of grass and dry stands	0	10,000	spring
15	31.3.2021	Hriňová	veldt	matchstick; lighter	waste incineration (non-landfill)	10	1,800	spring
16	1.4.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	10	10,000	spring
17	2.4.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	0	3,420	spring
18	1.4.2021	Detva	veldt	matchstick; lighter	burning of grass and dry stands	5	1,000	spring
19	10.4.2021	Detva	another wildland	matchstick; lighter	burning of grass and dry stands	100	20,000	spring
20	10.4.2021	Slatinské Lazy	veldt	cigarette butt	smoking	0	200	spring
21	10.4.2021	Hriňová	veldt	hot ash; glowing particles	hot ash handling	0	450	spring
22	12.5.2021	Stožok	other forests	not classified	lightning	20	100	spring
23	10.6.2021	Podkriváň	grass and fallow land	matchstick; lighter	burning of grass and dry stands	10	20	spring
24	10.6.2021	Podkriváň	grass and fallow land	matchstick; lighter	burning of grass and dry stands	0	5	spring
25	14.6.2021	Látky	grass and fallow land	matchstick; lighter	burning of grass and dry stands	10	185	spring
26	19.6.2021	Detva	grass and fallow land	matchstick; lighter	burning of grass and dry stands	15	2,500	spring
27	5.7.2021	Detva	grass and fallow land	other parts of transport mean and working machines	failure of exhaust, brake system, etc.	10	24	summer
28	6.7.2021	Korytárky	grass and fallow land	matchstick; lighter	burning of grass and dry stands	10	40	summer
29	22.7.2021	Stará Huta	grass and fallow land	matchstick; lighter	burning of grass and dry stands	0	1,000	summer
30	29.7.2021	Vígľaš	grass and fallow land	cigarette butt	smoking	10	1,500	summer
31	12.8.2021	Detva	grass and fallow land	external low voltage distribution - bare power line	electrical short circuit	15	3	summer

No.	Date of fire announcement	Municipality	Vegetation type	Ignition source	Fire reason	Direct damage [eur]	Fire site area [m²]	Fire season
32	11.9.2021	Detva	veldt	matchstick; lighter	setting fires at landfills and rubbish	20	2	summer

In general, the wildfires are caused mostly by human activities. Most often, it is a deliberate human activity associated with the burning of agricultural and grassland areas close to the forest. This activity is typical throughout the territory, particularly in the spring and autumn seasons. It is most pronounced in the period of the survey of meadows and pastures in the territory of the Slovak Republic, which is carried out by the Ministry of Agriculture of the Slovak Republic and the outputs of which are used for redistribution of subsidies for haying of meadows and pastures to their owners or users. This is carried out at 10-yearly intervals. The last survey was carried out in 2022. The fire statistics for 2022 confirmed this fact.

When want to effectively combat with the wildfire, fire prevention phase is the most important. Foresters carry out patrolling activities in the forests of the territory at the time of increased fire danger after the declaration of the competent District Directorate of the Fire and Rescue Service on forest land or in its protective zone (50 m from the boundary of the forest land) on the entire territory of the district or only in the part of it. Often after the situation has been assessed by the director of the relevant forest administration office and the fire protection technician, even outside the declared time of increased fire danger. Usually, it used to be some time before the declaration of the District Directorate of the Fire and Rescue Service during the spring dry season, when the number of tourists in the forests is higher. Patrolling activity is one of the integral parts of the fire protection and fire prevention. During patrolling, the patrol service moves along the prescribed route of the patrol, or stays at a specified observation point, according to a fixed time schedule. During the working week, forest rangers patrol during non-working hours from 3 PM to 7 PM, and on weekends and public holidays they patrol from 10 AM to 6 PM.

It is the duty of every owner, administrator, or manager of a forest to have mapping documents elaborated, resulting from the Fire Prevention Ordinance. Each forest administration office has elaborated maps and placed in a visible place. This includes a text part and a graphic part with a text part indicating the location of water sources suitable for firefighting. Water sources suitable for aerial firefighting, firebreaks, and forest road network that can be used for access by firefighting vehicles and providing the intervention activities.

The Decree also specifies the exact number and type of fire-fighting tools depending on the area of forest under management.

5.6 Sebangau National Park, Borneo - Indonesia

5.6.1 Location/ Administrative

Sebangau National Park, administratively in Central Kalimantan Province. It is located accros three regencies: Katingan Regency, Pulang Pisau Regency, and Palangka Raya City. The wide area of Sebangau National Park is ± 542,141 ha; meanwhile, the forest land area in Central Kalimantan Province is ± 12,561,867.57 ha. Regarding the management, Sebangau National Park is divided into 3 (three) areas of the National Park Management Section (SPTN), namely SPTN I in Palangka Raya, Region II SPTN in Pulang Pisau, and Region III SPTN in Kasongan. Sebangau National Park Position is shown in **Figure 68.**

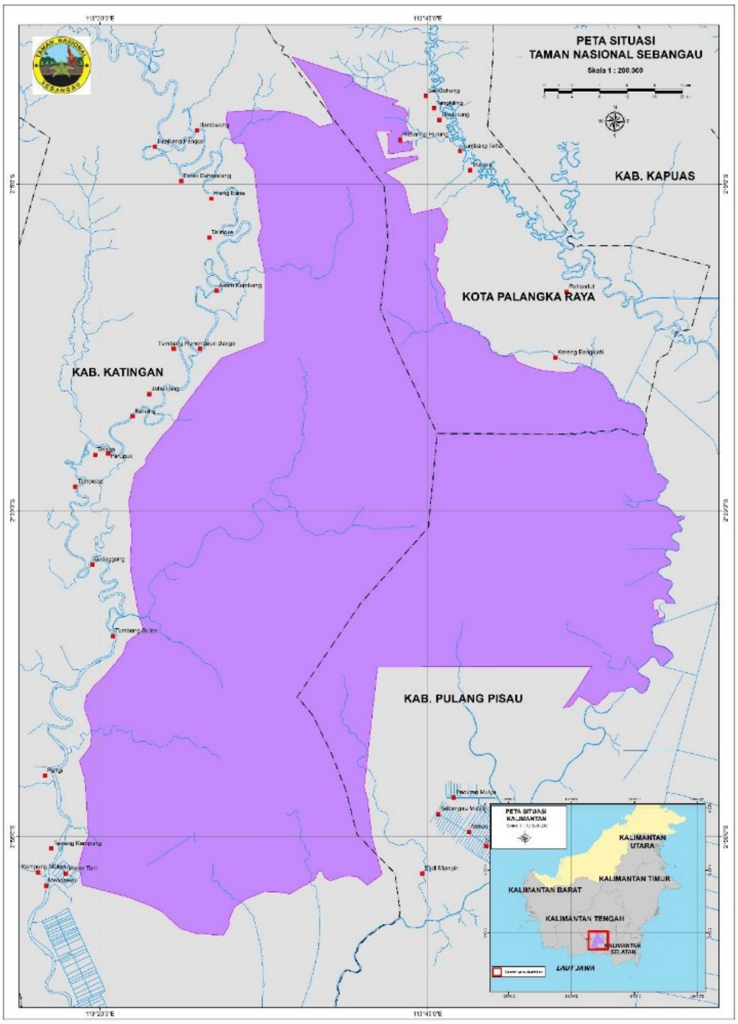


Figure 68. Sebangau National Park Position
Source: (Balai Taman Nasional Sebangau, 2022)

Sebangau National Park is the largest tropical peat forest conservation area in Indonesia (more than 90% of its area is a peat ecosystem). Variations in peat depth between 1 meter to 12 meters and up to 14 meters at some points. Sebangau National Park main functions according to Law no. 5 of 1990 is concerning Conservation of Biological Natural Resources and Their Ecosystems, namely: Preservation of biodiversity and their ecosystems. The Sebangau National Park area is a haven for orangutans, proboscis monkeys, and hornbills. Sebangau's important role can be seen in its reputation as a conservation area with the densest orangutan population in the world. The Sebangau National Park landscape is shown in **Figure 69**.

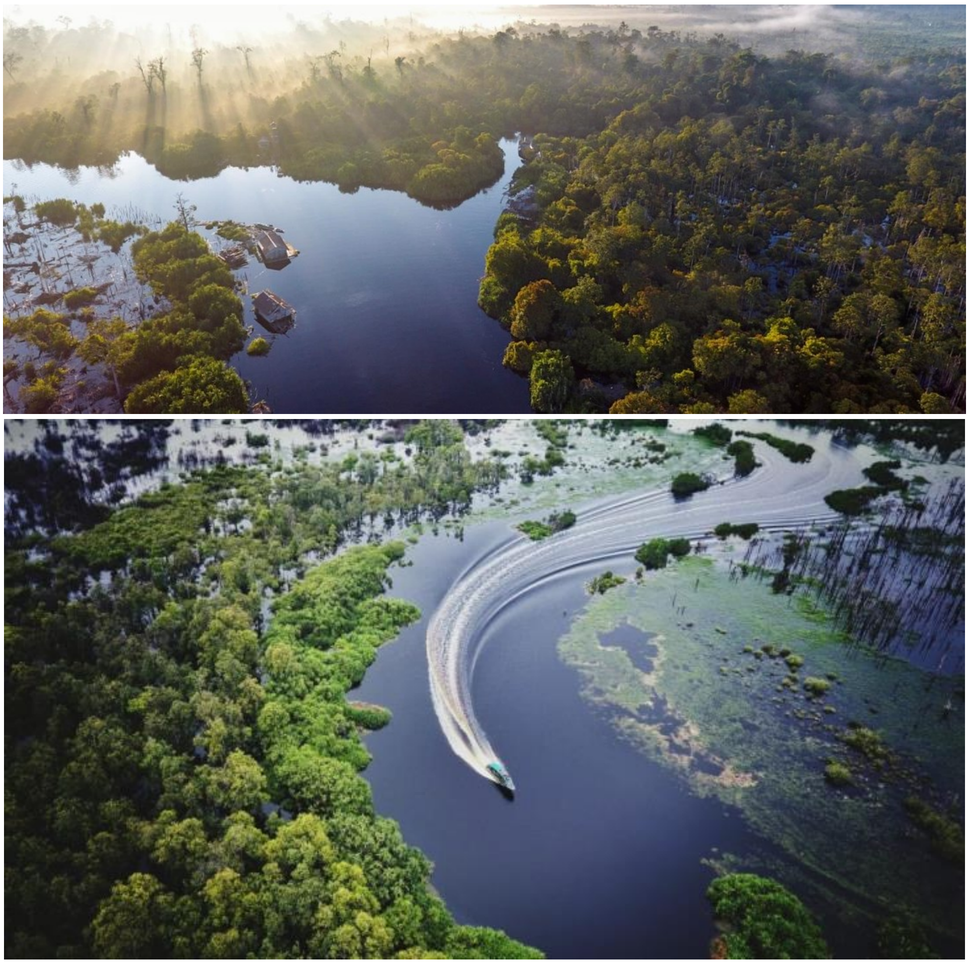


Figure 69. Sebangau National Park landscape
Source: (Balai Taman Nasional Sebangau, 2022)

5.6.2 Geomorphology

Generally, Sebangau National Park is a fluvial landform. The development of geomorphology in this area has been influenced by Kahayan River activities. This area consists of several landforms that are alluvial plain, floodplain, and waterlogged floodplain. The most area of Sebangau National Park includes in alluvial plain area. Some areas near Kahayan River were classified as floodplain and waterlogged floodplain area which has been temporarily or permanently inundated. Based on the Land System Map of Regional Planning Programme for Transmigration, most of the area were classified as peatland. This area is categorized as terrace, basin/domed peatland, riverine and marginal peatland (Rieley et al., 1993).

5.6.3 Geology

Sebangau National Park lies on Barito tertiary sedimentary basin (**Figure 70**). Barito basin is one of the oil and gas resources site in Indonesia (Mirnanda, 2020). This basin consists of 5 km thick of Old-Tertiary sedimentary rock and 6 km thick of Young-Tertiary sediment above the Old-Tertiary sedimentary rock (van Gorsel, 2018). The bedrock of Barito basin contains Pre-Tertiary granitic and andesitic igneous rock and metamorphic rock interspersed by siltstone and sandstone with inserting breccia and conglomerate (Heryanto & Sanyoto, 1994). Tertiary sedimentary rock was deposited above the Pre-Tertiary layer. Quaternary alluvium deposit fills top of the layer surface. Most of Sebangau National Park consist of alluvium deposits in the surface layer.

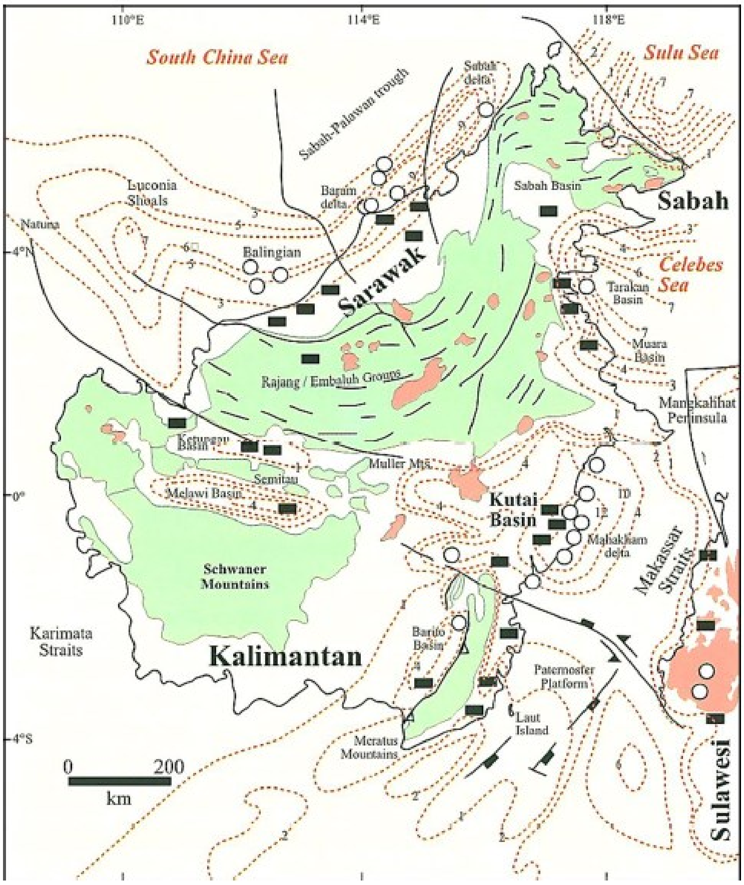


Figure 70. Geological map of Borneo (Moss & Chambers, 1999)

Sebangau National Park has a generally flat topography, with a slope between 0 and 2%. The altitude ranges from 0 to 35 m asl. The stratigraphic structure of the Sebangau National Park is composed of two main formations, surface sediments (Q) and frontal sedimentary rocks (Tq) (Balai Taman Nasional Sebangau, 2022).

5.6.4 Soil

Sebangau National Park area consists of 2 (two) soil types, fluvaquents, and Tropaquents (Balai Taman Nasional Sebangau, 2022). Fluvaquents are undeveloped soil, have sulfidic material at a depth of 50 cm, and are constantly saturated with water in all soil horizons at some time of the year. Tropaquents are undeveloped soil, have sulfidic material at a depth of 50 cm, and are constantly saturated with water in all soil horizons at some time of the year. Specifically, Tropaquents are characterized by the average difference in soil temperature of less than 5˚C.

5.6.5 Hydrography

Sebangau National Park is flanked by two large natural hydrological systems: the Sebangau River and the Katingan River. This hydrological component includes river discharge and groundwater fluctuations in areas with good vegetation and in degraded peat areas. The condition of the water system in the area or swamp forest currently varies relatively according to the season, the land typology condition, and the forest cover condition. Relatively open swamp areas, such as between the Kahayan and Sebangau Rivers, provide high fluctuations. This area generally spills water during the rainy season, and it experiences high drought during the dry season.

5.6.6 Climate

The climate of the Sebangau National Park area, according to the Koppen system, is mainly included in the wet tropical climate (A), namely the tropical climate type, with the driest wet season being type Aw. This type indicates an area with an annual rainfall of <2,500 mm, rain in the driest month of <60 mm, and the coldest monthly average air temperature of >18 ˚C. Based on climate data obtained from a micrometeorological tower located in the peat swamp forest of the Sebangau Sub-watershed, Central Kalimantan, that area is climate type A according to the Schmidt and Ferguson climate classification, with a Q value = 8.8% with an average monthly rainfall of 164 .61mm. According to data from the Meteorology and Geophysics Agency (BMG) Region III Palangka Raya Q value = 13.32% with an average monthly rainfall of 173.96 mm. In general, it can be described that the Sebangau area includes a wet climate.

5.6.7 Demography

The Sebangau National Park area is administratively located in eight districts in one city and two regencies, namely Palangka Raya City, Pulang Pisau Regency, and Katingan Regency. There are 42 villages located in and adjacent to the area with 95,924 residents. The villages and the number of populations surrounding Sebangau National Park shown in **Table 27**.

Table 27. Villages and Number of Population Surrounding Sebangau National Park

SPTN	Resort	District	Village	Number of Population
SPTN I	Sebangau Hulu	Sebangau	1. Kereng Bangkirai	7,963
			2. Sabaru	3,626
	Habaring Hurung	Jekan Raya	3. Bukit Tunggal	43,612
		Bukit Batu	4. Habaring Hurung	932
			5. Banturung	4,357
			6. Tangkiling	3,412
			7. Marang	986
SPTN II	Sebangau Kuala Mangkok dan Bangah	Sebangau Kuala	8. Paduran Sebangau	1,948
	Sebangau Kuala	Sebangau Kuala	9. Sebangau Mulya	769
			10. Paduran Mulya	643
			11. Mekar Jaya	1,060
			12. Sebangau Jaya	435
			13. Sebangau Permai	1,405
SPTN III	Baun Bango	Tasik Payawan	14. Handiwung	743
			15. Tumbang Panggo	774
			16. Petak Bahandang	1,632
			17. Hiyang Bana	1,934
			18. Talingke	510
			19. Tewang Tampang	946
			20. Luwuk Kanan	1,669
			21. Asem Kumbang	1,329

SPTN	Resort	District	Village	Number of Population
		Kamipang	22. Tumbang Runen	356
			23. Jahanjang	640
			24. Keruing	454
			25. Baun Bango	676
			26. Perupuk	111
			27. Telaga	1,442
			28. Tampelas	410
			29. Galinggang	1,310
	Muara Bulan dan Mendawai	Mendawai	30. Teluk Sebulu	219
			31. Mendawai	1,024
			32. Mekar Tani	748
			33. Parigi	492
			34. Tewang Kampung	498
			35. Tumbang Bulan	528
		Katingan Kuala	36. Kampung Baru	1,585
			37. Setia Mulia	664
			38. Singam Raya	614
			39. Sungai Kaki	272
			40. Bakung Raya	651
			41. Sebangau Jaya	779
			42. Bangun Jaya	1,766
			Amount	95,924

Souce: (Balai Taman Nasional Sebangau, 2022)

5.6.8 Forest Ownership

Prior to the appointment of Sebangau National Park in 2004, this area was a Permanent Production Forest, based on the Decree of the Ministry of Agriculture Number 759/KptsUm/10/1982 dated 12 October 1982 concerning Designation of Forest Areas in the Province of Central Kalimantan with an area of 15,300,000 Ha. The status of the Sebangau forest area is production forest (HP) and convertible production forest (HPK) managed by 13 production forest companies around the early 1970s to the mid-1990s.

After the companies stopped operating, the activities were illegal logging rife in the Sebangau area. As a result, the hydrological function of the Sebangau forest area was damaged, and its function as a water catchment area was also disrupted. The impact is that if there is drought during the dry season, it will easily cause forest fires.

In 2004 the Sebangau area was designated as the Sebangau National Park based on the Decree of the Minister of Forestry No.SK.423/MenhutII/2004 dated 19 October 2004 with an area of ± 568,700 Ha.

5.6.9 Flora

The Sebangau National Park area has seven forest types: 1) riparian forest, 2) riparian transition–mixed swamp, 3) mixed swamp, 4) transitional mixed swamp-low pole forest, 5) low pole forest, 6) high interior forest, and 7) shallow canopy forest (Balai Taman Nasional Sebangau, 2022). Riparian forests lie between freshwater swamp forests and peat swamp forests. It is located close to the river (± to one km from the riverbank), and this area is always flooded during the rainy season. Generally, the peat depth in this area is very thin (± to a depth of 1.5 meters). The main plant species in this forest type are Shorea balangeran. The plant species in this forest are *Calophyllum* spp., *Campnosperma coriaceum* and *Combretocarpus rotundus*, and *Thorachostachyum bancanum*.

Riparian transition–mixed swamp forests generally have a very narrow area (± 1 – 1.5 km from the riverbank) with peat depths generally up to 2 meters. The type of plant that generally dominates this type is *Shorea balangeran*.

Mixed Swamp Forest can be found from the edge of the peat dome to 4 km inland. Peat depth generally ranges from 2-6 meters. Abundant plants also characterize this forest type with stilt or *buttres* roots; pneumatophores are also frequently found. The plant species commonly found in this mixed forest type are *Aglaia rubuginosa, Calophyllum hosei, C. lowii, C. sclerophyllum, Combretocarpus rotundatus, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera costulata, Ganua mottleyana, Gonystylus bancanus, Mezzetia leptopoda, Neoscortechinia kingii, Palaquium coclearifolium, P. Leiocarpum, Shorea balangeran, S. teysmanniana,* and *Xylopiafusca*.

Transition Forest (Mixed Swamp Forest – Low Pole Forest) is generally found in areas 4 – 6 km from the riverbank. The composition of the upper and middle canopy layers is generally relatively the same as that of mixed swamp forests. However, the density of *Calophyllum spp., Combretocarpus rotundatus, and Palaquium cochlearifolium* is higher than that of mixed swamp forest. Very few plants have stilt or buttressing roots; pneumatophores are abundant on the forest floor. Pandan formations *(Pandanus and Freycinetia* spp.) are often extensive, continuous formations covering the ground surface.

Low pole forests are generally found between 6 – 11 km from the riverbank, with peat depths ranging from 7 – 10 meters. The water table is usually permanently high, and the forest floor is highly erratic. The trees grow in island-like hummocks separated by water depths which generally disappear during the dry season. Pneumatophores are abundant and very dense on the peat floor. The plants commonly found in this forest type are *Combretocarpus rotundus, Calophyllum fragrans, C. hosei,* rarely found *Campnosperma coriaceum*, and *Dactylocladus stenostachys*. Pandan formation is very dense, and *Nephentes spp*., the amount is very abundant.

Tall Interior Forest is located on the sloping side of a peat dome, from 12 km to over 24.5 km. The water level is always below the peat level throughout the year. Common plant species in this community include *Agathis damara, Calophyllum hosei, C. Lowii, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera costulata, Eugenia havelandii, Gonystylus bancanus, Gymnostoma sumatrana, Koompassia malaccensis, Mezzetia leptopoda, Palaquium coclearifolium , P. leiocarpum, Shorea teysmanniana, S. platycarpa, Tristania grandifolia, Vatica mangachopai, Xanthophyllum* spp., and *Xylopia* spp.

This Very Low Canopy Forest is relatively open and is located at the highest point between the two river systems. The plant species commonly found in this area are *Calophyllum* spp., *Combretocarpus rotundatus, Cratoxylum* spp., *Dactylocladus stenostachys, Litsea* spp., *Ploiarium alternativeolium, Tristania* spp, and *Pneumatophores*.

5.6.10 Wildlife

Sebangau National Park is an essential habitat for Bornean orangutans. Many studies have been conducted to determine the orangutan population (*Pongo pygmaeus wurmbii*) in Sebangau. Based on the 2016 PHVA (Population Habitat and Viability Analysis) report, it is estimated that the population of Bornean orangutans in Sebangau National Park is 6,080 individuals (Balai Taman Nasional Sebangau, 2022) and is one of the large metapopulations and has high prospects for sustainability.

Apart from the orangutan, another endangered and protected primate is the probosci's monkey (*Nasalis larvatus*). Even though the area is concentrated in the Bulan and Musang Rivers, the threat is relatively high. The total population of probosci's monkeys at the Sungai Bulan and Sungai Musang sites was found to be 187 individuals (Balai Taman Nasional Sebangau, 2022). The population of gibbons (*Hylobates agilis albibarbis*) is estimated at 19,000 individuals (Balai Taman Nasional Sebangau, 2022). Apart from orangutans and probosci's monkeys, several types of wild animals encountered include long-tailed monkeys (*Macaca fascicularis*), sun bears (*Helarctos malayanus*), wild boar (*Sus barbatus*), deer (*Cervus unicolor*), deer (*Muntiacus muntja*k), mouse deer (*tragulus javanicus*), clouded leopard (*Neofelis nebulosa*), squirrel (*Tupaia* spp.), *Nycticebus coucang* and tarsiers (*Tarsius bancanus*).

There are 176 species of bird diversity in the Sebangau National Park area (Balai Taman Nasional Sebangau, 2022). From the ethnic composition, birds in Sebangau National Park are dominated by frugivores, insectivores, and fruit and insect eaters. Examples of frugivores are the *Bucerotidae*, Columbidae, and Psittacidae; insectivores are *Timaliidae, Cuculidae,* and *Muscicapidae*; and the fruit and insect-eating groups are *Pycnonotidae*, *Chloropseidae, Dicaeidae*, and *Aegithinidae.*

Many fruit eaters are essential to forest communities because they disperse plant seeds throughout the forest. Types of nectar eaters (*Nectariniidae*), such as birds from the *Nectariniidae* tribe, play a vital role here, considering their presence can help pollinate flowers in the forest.

Some of the species that are easy to find are the tong tong stork (*Leptoptilus javanicus*), bondol eagle (Haliastur indus), gray-headed eagle (*Ichtyopaga ichtyaetus*), bido snake eagle (*Spilornis cheela*), brontok eagle (*Spizaetus spirhatus*), golden pekaka (*Pelargopsis capensis*), black hornbill (*Antrachoceros malayanus*), white-bellied hornbill (*Antrachoceros albirostris*), bush sunbird (*Chalcoparia singalensis assamensis*), sea stork (*Ardea sumatrana*), and the great cuckoo (*Centropus chinensis*), swamp forest heron (*Ciconia stormi*), hornbill (*Aceros corrugatos*), rhinoceros hornbill (*Rhinoceros hornbil*l) and fire kite (*Hirundo rustica*).

Apart from birds, the types of reptiles in Sebangau National Park include pythons (*Phyton reticulatus*), water snakes (*Homalopsis buccata*), red-tailed pipe snakes (*Cylindropsis rufus*), cobras (*Naja sumatrana*), green snakes (*Ahaetulla prasina*), brown snakes Malayan (*Xenelophis hexagonatus*), monitor lizard (*Varanus salvator*), and box turtle.

5.6.11 History of Fire

Previously, Sebangau National Park was an area of production forest and convertible production forest. It provided commercial opportunities for forestry companies. Unsurprisingly, from the 1970s to the mid-1990s, the Sebangau production forest area was managed by companies holding forest concession rights. During that period, there were 13 large companies entrenched in the Sebangau production forest area. After the forest company stopped operating, illegal logging hit the Sebangau area. As a result, the hydrological function of Sebangau is increasingly in disarray. Its function as a water catchment area is also disturbed. As a result, during the dry season, Sebangau is prone to forest fires.

Forest fire indicators that have been used so far are hotspots. Number of hotspots in Sebangau National Park 2015-2020 shown in **Figure 71**. Sebangau National Park distribution of hotspot in 2019 and 2020 is shown in **Figure 72** and **Figure 73.**

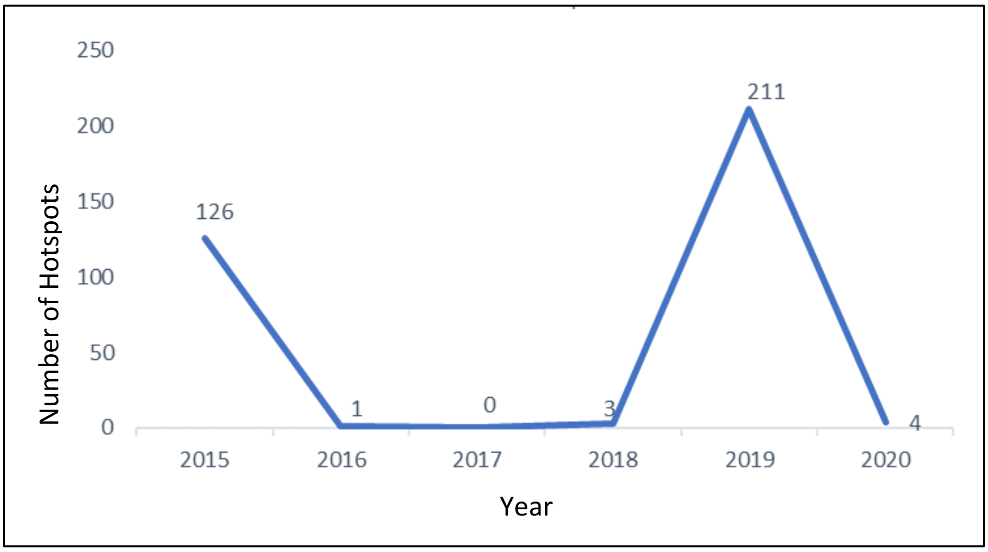


Figure 71. Number of hotspots in Sebangau National Park 2015-2020

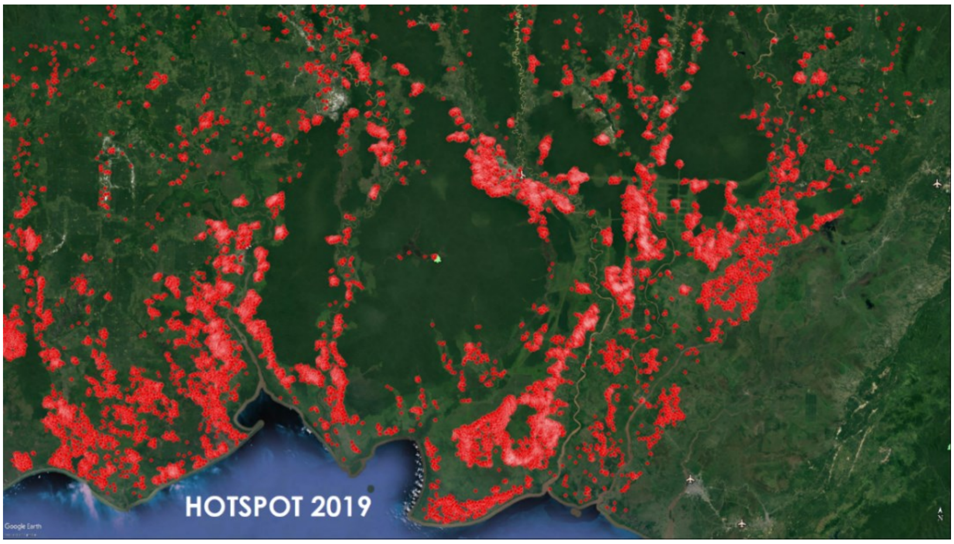


Figure 72. Sebangau National Park distribution of hotspot in 2019
Source: (Balai Taman Nasional Sebangau, 2022)

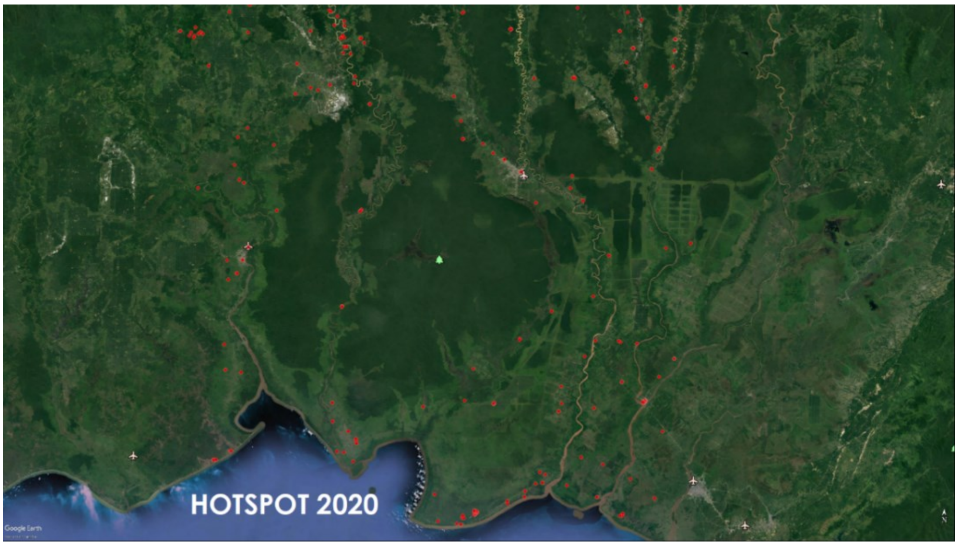


Figure 73. Sebangau National Park distribution of hotspot in 2020
Source: (Balai Taman Nasional Sebangau, 2022)

Forest fires are a problem faced by Sebangau National Park during the dry season. Based on data from the Sebangau National Park Office, it is known that from 2011 to 2020, the area of fires reached ± 54,236.87 ha. Area of Forest Fires in Sebangau National Park 2011-2020 shown in **Figure 74**.

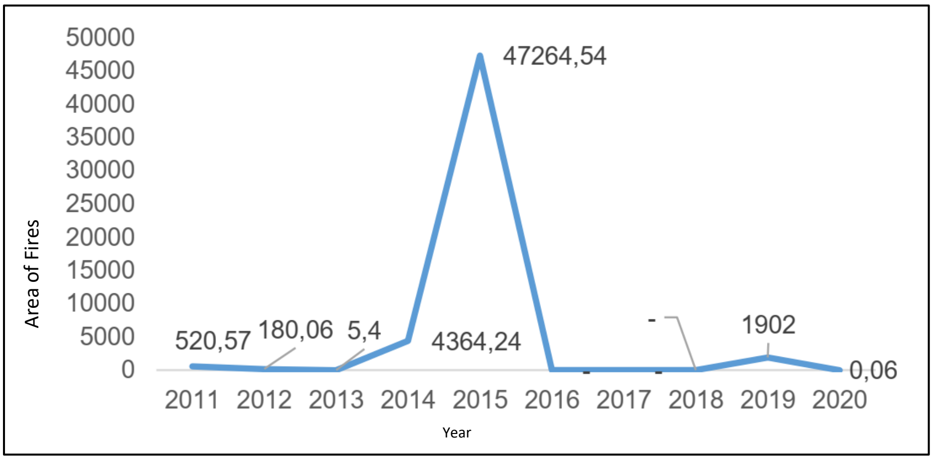


Figure 74. Area of Forest Fires in Sebangau National Park 2011-2020

6 Result and Discussion

6.1 Rehabilitation and Restoration Programs in Pilot Areas

6.1.1 Gargano Park – Italy

6.1.1.1 Need for recovery – post fire reconstitution.

According to AIB Plan of Gargano National Park, forest cover recovery intervention after a fire must be based on retracing, completely, the evolutionary stages of the secondary succession of the vegetation type involved. This evolution can take place naturally or with the contribution of silvicultural intervention coherent in floristic and cenelogical terms with the series of native vegetation. This is not compatible with the passage of another fire event. Adaptions to the passage of fire that the forest vegetation has developed over time are not sufficient for the maintenance of a forest ecosystem if wildfires increase their intensity and frequency. Fire, in fact, can change from being a simple ecological disturb factor to a catastrophic one if the events repeat with some frequency (phenomenon of recurrence), or if the recovery time or the amount of damage becomes so high to have a strong impact to the ecosystem. In this case, forest areas may regress to a bushy, spot, or prairie formation because the ecosystem is not able to react through the establishment of natural renewal, also due to the destruction of seed-bearing plants in that area. Additionally, the consequent lack of vegetation cover may favour the trigger of erosion with additional damage to the affected habitats.

In such cases, a more direct and active restoration intervention of the forest ecosystem (active reconstitution) is useful and/or necessary. This allows the reconstitution in short time of the forest stand that will, hopefully, keep the structure and the function of the destroyed one. The scope of Active reconstitution is, de facto, to bring back the above ground to the pre-disturbance conditions.

The most adopted strategy takes as a model the natural processes of secondary succession considering the critical parameters that regulate the ecosystem using restoration techniques. Such techniques involve the introduction of some indicator species (e.g., tree or shrub pioneer species) that speed up the succession and then let nature take its course until the ecosystem becomes self-sufficient.

In an area with high naturalistic and landscape value like the Gargano Park it is appropriate to evaluate case by case the need to intervene to restore the forest cover damaged by the wildfire or to let nature take its course (natural restoration). In the first case, silvicultural operation must be defined in relation to the traits of the pre-existing forest and to the evolutionary dynamics of the vegetation in the intervention area. Whenever possible, natural restoration should be favoured. For sure, in the pine forest of the Aleppo pine post-fire natural restoration is secured by the auto ecology of the species itself. Nonetheless, it is necessary to evaluate the possibility of removing dead plants or to interfere, if possible, with naturalistic engineering technique to prevent dangerous events of soil “decapitation” that take place during summer rainstorms or trying to curb the “sorren” phenomena in sandy coastal areas. Cultivation care (hoeing and mechanical weeding) is necessary in the following years to speed up the growth of forest plants and “mend” faster the landscape and ecological wound caused by the wildfire. In the coppices, the consolidated techniques of copying and trimming, carried out immediately after the fire, provide always excellent results if grazing can be regulated. For degraded coppices, it may be necessary to intervene with thickening and then with all the other silvicultural techniques typical of reforestation always referring to the series of vegetation in which the intervention is carried out.

6.1.1.2 Reconstitution of forest vegetation damaged by wildfires.

Before addressing the reconstitution of forest vegetation damaged by wildfires, it is appropriate to understand the adaptation to the passage of fire that the vegetation has developed over time. Acknowledging that, it cannot be considered sufficient to the maintenance of a forest ecosystem if, as mentioned before, the intensity and frequency of wildfires drastically increases.

Knowing the effect of fire to vegetation and about the various possibility and different dynamics of natural reconstitution of forest stands, which may allow to detect the cases that require active intervention, represents an essential informative level in integrated forest fire prevention planning. This foresees the harmonization and the balance between forecasting, prevention, active fight, and environmental restoration.

The size of the wildfire and the location needs to be considered as well. In fact, all other factors held constant the damage is proportional to the affected area. It is therefore a priority to carry out the reconstitution after large fires, even with just limited intervention to part of the damaged areas.

Reconstitution must increase the resistance and resilience of a forest to wildfire. Furthermore, it must also increase the prevention capabilities, ensuring that the probability of additional fires to happen decreases.

The intervention to carry out is very delicate. At time, during the reconstitution of coniferous forests, deciduous trees have been used to guarantee recovery in the event of another fire. Most of the time this leads to a failure as deciduous trees are not adapted to the environmental conditions after a large fire. In many cases, cutting and removal of dead plants are questionable and are justified only for the landscape appearance. Sometimes, the removal of burned trees does not foster spontaneous renewal, which benefits from the covering brought by standing dead trees. In many cases, renewal has been more abundant where no intervention was carried out.

Sometimes, some colonizing species prevail over the original coverage. Where no artificial renewal is carried out, natural renewal prevails, especially around residues of seed trays. In canopy fires with pulsating behaviour, there are often area where the fire does not affect part of the forest that remain intact. From these areas, active or artificial reconstitution may be started. These facts suggest intervention that respects natural evolution, able to support secondary succession in one hand and limit costs on the other.

Respecting natural evolution, focusing in areas differentiated with respect to damage and encouraging seedlings allows to avoid more extensive and traumatic interventions. Such aspects highlight how reconstitution forces a delicate analysis of the environment.

Additional problems arise also from the provision of laws that it burned area, for 5 years after the fire, reforestation and environmental engineering with public funding is forbidden (L 353/2000 art. 10). This overly restrictive rule prevents the reconstitution to be properly allocated over time. In fact, both the actual mortality of plants and the resumption of the renewal needs to be evaluated, not much time has to pass. The intervention, carried out at the proper time, encourages secondary succession, a delayed one disturbs it.

As illustrated above, the lines of intervention to be carried out for the forest reconstitution in the Gargano National Park, can be summarizes as follows:

a. Low intensity wildfires and/or on small areas:
    1. No intervention
b. Low intensity wildfires on large areas:
    1. Pine forest of Aleppo pine: dead tree removal interventions only along the roads and the paths, without logging but with the reuse of woods for the contextual realization of micro intervention (palisades, gratings) of natural engineering on sloping land above the road;
    2. Reforestation of conifers: encourage with interventions the progressive substitution of conifers by indigenous hardwoods;
    3. Mediterranean bush: dead tree removal interventions only along the roads and the paths, without logging but with the reuse of woods for the contextual realization of micro intervention (palisades, gratings) of natural engineering on sloping land above the road.
    4. Coppice: quick intervention of coppicing with safeguarding of all still vital matrices;
    5. Deciduous high forests (<20% mortality): dead tree removal interventions only along the roads and the paths, without logging but with the reuse of woods for the contextual realization of micro intervention of natural engineering on sloping land above the road.
c. High intensity wildfires on large areas:
    1. Pine forest of Aleppo pine
        - dead tree removal interventions only along the roads and the paths, without logging but with the reuse of woods for the contextual realization of micro intervention of natural engineering on sloping land above the road.
        - Recurring fire on stands < 20 years old: dead tree removal intervention with logging and partial reuse of the wood for the contextual realization of micro intervention of natural engineering on the slopes. It is necessary to evaluate natural renewal after 5 years for any restocking.
    2. Reforestation of conifers: encourage with interventions the progressive substitution of conifers by indigenous hardwoods.
    3. Mediterranean bush: dead tree removal interventions only along the roads and the paths, without logging but with the reuse of woods for the contextual realization of micro intervention of natural engineering on sloping land above the road.
    4. Coppice: quick intervention of coppicing, considering succession and transurethral, safeguarding all still vital matrices; micro intervention of natural engineering on slopping land above the road.
    5. Deciduous high forests (>20% mortality): interventions to remove dead trees with logging and chipping of waste material, with partial reuse of wood for the contextual realization of micro intervention of natural engineering on slopping land above the road; release of perishable subjects, release of 20% of the stem on the ground. It is necessary to evaluate natural renewal after 5 years for any restocking with shrub elements typical of the affected series of vegetation.

The climate and forest type of a region are not the only element to consider for wildfire prevention and for post-fire intervention. Essential point to consider are:

a. Study of the spatial form of the cenosis;

b. Study of the temporal dynamics (sucession): realization of potential vegetation maps, real vegetation maps, dynamic series cards (sigmeti), cartography of the pyrogenic attitude of the different areas.
c. Knowledge about the ecological niches of syntaxa (altimetric bands, substrates, soils, exposures, inclination);
d. Pyrological attitude of woodland formations.
e. Detection of the more suitable herbaceous and woody species for post-fire recovery.

For reasons related to the safeguard of the genetic integrity of flora, it is advisable that the proposed species for the different areas are taken from nurseries that area able to provide certified native species produced with seeds collected in the Gargano Park.

6.1.2 Tepilora Park – Italy

Restriction on areas covered by fire
Rehabilitation strategies in wooded areas covered by fires are essentially due to constraints. The Law 21/11/2000 n. 353, "Framework law on forest fires", which contains prohibitions and requirements deriving from the occurrence of forest fires, provides for the obligation for municipalities to census the areas covered by fires, also making use of the surveys carried out by the Forestry Corps, in order to apply the constraints that limit the use of the land only for those areas that are identified as wooded or intended for pasture, with different time frames, namely:

Fifteen-year constraints: the intended use of wooded areas and pastures whose stands have been crossed by fire cannot be changed compared to the pre-existing fire for at least fifteen years. In these areas it is allowed only the realization of public works that are necessary for the protection of public safety and the environment. It follows the obligation to insert on the aforementioned areas an explicit constraint to be transferred in all the deeds of sale stipulated within fifteen years of the event.

Ten-year constraints: in wooded areas and pastures whose stands have been crossed by fire, the construction of buildings as well as structures and infrastructures aimed at civil settlements and production activities is prohibited for ten years, except in cases where municipal authorization acts have already been issued for this realization on a date prior to the fire based on the urban planning instruments in force on that date. Grazing and hunting are prohibited in such areas.

Five-year constraints: on the aforementioned stands it is forbidden to carry out reforestation and environmental engineering activities supported with public financial resources, except in the case of specific authorization granted either by the Minister of the Environment, for state protected natural areas, or by the competent region, for documented situations of hydrogeological instability or for particular situations in which an intervention to protect environmental and landscape values is urgent.

6.1.3 Sterea Ellada - Central Greece

NDVI in Greece is used mainly on a research land experimental level and not by the official authorities to decide on future actions and decisions regarding the status of a burnt forest, level of regeneration and restoration in general. The monitoring of restoration and success, or no-success, is usually examined by *in situ* measurements and observations.

Nevertheless, NDVI has been in various areas of Greece as an index for the measurement of regeneration of a forest and its ”health” with interesting results. For example, In Peloponnese (Southern Western) Gemitzi and Koutsias (2021) have analyzed 20 years of satellite images of Peloponnese studying NDVI related to pre-fire and post-fire of the 2007 large wildfire in the area(Gemitzi & Koutsias, 2021). They concluded that through NDVI monitoring of regeneration is of course possible and in good relation with *in* *situ* measurements and observations. In the case of the 2007 wildfire in Peloponnese regeneration lasted for about 7 to 10 years, as this was the time for NDVI index to come back to pre-fires values. In Northern Greece Kassandra (Gitas, 2012) and sites in the Mediterranean (Katagis et al., 2011) that NDVI is a measure that provides promising results for post-fire monitoring. In addition, NDVI was used as a tool for identifying vegetation classes that dominated the burnt areas in the post-fire period (Palandjian et al., 2009). In the island of Karpathos at Dodecanese islands (SE Greece) NDVI has been used to monitor post-fire recovery (Nioti et al., 2015) and at Tzoumerka-Arta (Central-Western Greece, mountain range of Pindos) NDVI was used as an indicator for the evaluation of grasslands agri-environmental programs (Roukos et al., 2013).

In the pilot area, at Evia Island, the recent study of (Gemitzi & Koutsias, 2022) makes use of NDVI satellite series images through a dedicated tool for Google Earth, not only to define the affected area but also to point out prone areas to future fire events. Since the megafire it is only one year, nevertheless, in situ observations show a natural regeneration. The tool developed by the could be used for the study of success of restoration measures as well.

Restoration processes

a. General framework for restoration in Greece:

In Greece, the following processes take place for restoration as a post-fire action:

The objective of post-fire rehabilitation aims at restoring problems and damage caused by fires, preventing secondary disasters, and restoring burned areas to their previous status or to an improved condition. These measures are short-term and long-term, and mainly include:

1. the management of burnt tree trunks,
2. the protection of soil stripped of vegetation from erosion until it is recovered by vegetation,
3. the parallel protection of settlements and infrastructure from floods and landslides and
4. the recovery of vegetation by seeding or reforestation, as a rule only where natural regeneration is not assured,
5. protection of the burnt area from grazing, land use changes and encroachments.

In the case of reforestation, the natural regeneration is the first option. Artificial reforestation is made in cases that natural regeneration has not given specific results, or the area is burnt again with a result of the regenerated trees to burn again.

The first step that precedes every protective action is the assessment and recording of burnt areas as it provides the necessary data for:

1. Addressing erosion and potential soil degradation.
2. The planning of rehabilitation interventions.
3. The management of flora and human activities (e.g., grazing).
4. The management of surface runoff to prevent flooding.
5. The reduction of the quantity and quality of water resources (drinking water and water for irrigation).
6. The prevention of land use changes (encroachments, illegal residential development).

Additional measures that take place in the restoration phase after a wildfire are the following:

1. Ensure the continuity of the economic activity.
2. Reconstruction of the affected, by landscape fires, areas
3. Ensure that all the functions of the local society are back in normal situation.

The main legal and regulatory framework that is related to restoration in Greece after landscape fires is described in the following laws and regulations:

1. Law 998/1979 (OGG 298/A/1979) – On the protection of forests and forest areas in the country
2. Presidential Decree 1157/1980 (OGG 293/A/1980) - On the leasing of public lands for reforestation
3. Presidential Decree 437/1981 (OGG 120/A/1981) - On the study and execution of forestry works.
4. Presidential Decree 135/1987 (OGG 74/A/1987) – Forest reproductive material
5. Common Ministerial Decision 12030F.109.1/10-5-1999 (OGG 713/B/1999) on Regulating issues of cooperation between the Hellenic Fire Service and the Hellenic Armed Forces, the Hellenic Police, the Forestry Service, the Local Authorities, the Health Services and other bodies and persons who provide their services for the prevention and suppression of forest fires.
6. Law 3208/2003 (OGG 303/A/2003) - Protection of forest ecosystems, preparation of forest taxonomy, regulation of rights in rem over forests and forest lands in general and other provisions
7. Law 3818/2010 (OGG 17/A/2010) - Protection of forests and forest lands of the Prefecture of Attica, establishment of a Special Secretariat for the Environment and Energy Inspection and other provisions.
8. Law 4280/2014 (OGG 159/A/2014) - Environmental upgrading and private urban development – Sustainable development of settlements, Forest law regulations and other provisions
9. Law 4342/2015 (OGG 143/A/2015) - Article 32 Amendments to provisions of Law 4280/2014 (Α΄ 159)
10. Law 4467/2017 (OGG 56/A/2017) - Amendments to provisions of forestry legislation and other provisions
11. Law 4685/2020 (OGG 92/A/2020) - Modernization of environmental legislation, incorporation into Greek legislation of Directives 2018/844 and 2019/692 of the European Parliament and of the Council and other provisions.

Main responsible for managing the restoration and rehabilitation of a burned forest area is the local forest service. The main steps for the restoration are:

1. The local forest service will identify through in situ measurements and observations and satellite/aerial imagery the burnt area.
2. A special decision will be issued and made public that declares the burnt area as to reforested.
3. A special decision will be issued and made public that prohibits the majority of the activities and especially grazing.
4. Individual studies for assessing short-term measures such as the protection of soils in the forest and the mitigation of potential floods and landslides.
5. Contracting for the implementation of short measures for the minimization of soil erosion, mitigation of floods and landslides.
6. Special studies for artificial reforestation, if necessary.

Depending on the damage caused by the wildfire, other public administration services may be engaged in the restoration and, especially the return to the pre-fire situation of the local society and economy. It must also be noted that even though in burnt areas there is a general prohibition of activities, exceptions do exist, and these exceptions may act as a drawback to any type of reforestation (natural or artificial regeneration) thus leading to the destruction of the forest.

b. Restoration framework after the 2021 megafire in Evia:

The mega-fire of Evia in 2021 was a wildfire that burnt not only forests or agricultural areas but destroyed infrastructures, and settlements. The measures for recovery and restoration focused on the following pillars:

1. Restoration of the burnt areas and protection from (secondary disturbances) other external factors
2. Restoration of the affected infrastructures
3. Economic support and restoration of the affected businesses
4. Support, economic and psychological of the local population

In addition, a special independent committee following the work of the Goldammer committee that was established with the aim to assess and record the damages and recommend a new Master plan(Apostolidis et al., 2022) for the "re-birth" and future development of the area and will provide the axes for the future. The results are expected to be publicly available in the first semester of 2023, when the Master plan will be approved by the national and European authorities.

The measures for restoration, recovery and support are described in more detail is shown in **Table 28**.

Table 28: Measures for restoration and support of local society after the 2021 mega-fire.

Sector	Measures
Restoration of the burnt area	- Burnt areas have been declared as reforested (according to the Law 998/1979) - All new activities to the burnt areas have been prohibited - Soil protection and erosion measures - Prevention of flooding projects - Cleaning of the forests from burnt logging - Restoration of burnt villages and infrastructures - Recovery, restoration and maintenance of forest road network - Wildfire prevention measures in the area that did not burn
Strategic measures for the future development	- Appointment of a new committee to create a strategic master plan for the future development of the area
Economic measures for residents and businesses	- Pending of payment of taxes, suspension of social security payments, extension of deadlines related to taxes, social security and loans. - Emergency funding for recovery of the main networks. - Additional funding to regional and local authorities in order to restore the damages to critical infrastructures networks and improve the networks, as well as to carry out large-scale projects to prevent flooding. - Direct economic support to the population that has been affected by the fire - Housing subsidies to the residents - Direct economic support to the businesses that have been affected by the fire - Support of all the primary sector businesses in North Evia (e.g., provision of food for animals, special plans for the figs agricultural businesses, etc) - Additional measures to support the secondary and tertiary sector businesses (e.g. attracting tourist, issue of tourist passes, etc) - Creation of targeted funding through the LEADER program - Creation of programs to support the resin cultivators

6.1.4 Cova da Beira - Portugal

The Portuguese Pilot at Cova da Beira will focus its demonstration activities on a pilot farm - Quinta da França, more specifically, in a natural oak forest of about 200 ha, which is managed for biodiversity conservation and delivery of ecosystem services, namely carbon sequestration and storage and soil protection. The forest suffered two large fires in 1983 and 1995 and has been under natural regeneration since. Forest management practices in Quinta da França after these events were mainly financed by national funds and were focused on promoting the natural regeneration of *Quercus pyrenaica*, which is a resprouting species able to naturally regenerate (from the root system) after fires. The first restoration activities were co-financed under the Forestry Development Plan AGRO, between 2003 and 2006, and covered the total forested area (200 ha). This program consisted in the control of shrub biomass with mechanized shrub clearing to allow the regeneration of *Quercus pyrenaica* (Pyrenean oak) and included planting groves of *Pinus pinaster*, *Cupressus lusitanica*, *Prunus avium*, *Tilia spp.* and *Betula spp*. in the clearings of the existing oak forest, which showed variable survival success (species dependent). The following rehabilitation project was co-financed by the RURIS program and took place between 2007 and 2011, consisting of new plantations of Pinus pinaster in an area of 33ha.

More recently, around 2017, a preliminary study was developed to select the areas suitable for the implementation of a silvo-pastoral mosaic. This study was first based on the characterization and mapping of the main ecological components of the landscape, which then allowed the selection of the areas suitable for grazing, without compromising the proper functioning of ecosystems and the resilience of the landscape. In 2018, a fence was installed to divide the oak forest in two: one area open to cattle (a herd of approximately 60 cows), under free grazing on one side of the fence, and one area without grazing on the other side. Since then, the herd has had permanent access to the forest while also grazing on rainfed and irrigated pastures in the vicinity (total grazing area, including forest and pastures, of about 180 ha). The implementation of livestock grazing in half of the forest area as a natural-based solution aims to promote the restoration of Pyrenean oak forest and contribute to the control of the risk of fire, by regulating biomass growth, creating horizontal and vertical fuel discontinuity, and maintaining open-habitats (herbaceous dominated patches within the forest – silvo-pastoral mosaic). To evaluate the effects of cattle grazing, data on the vegetation structure and composition was collected in both grazed and non-grazed sites, between 2018 and 2021.

Extensive grazing cattle (in natural pastures in the oak forest) was implemented at Quinta da França, in June 2018, as a natural-based solution to promote the restoration of Pyrenean oak forest and contribute to the control of the risk of fire. Since then, data on vegetation structure has been collected, in both grazed and ungrazed areas of the oak forest, to assess the effects of grazing on biomass regulation and control of fire risk. At every sampling plot (10 m x 10 m), data on vegetation type (grasses, forbs, shrubs, trees) and height class (0-0.25 m; 0.25-0.50 m; 0.5 -1.3 m; 1.3 - 2m; 2 - 4m; >4m), or bare soil, were registered. Then, vegetation structure is characterized using two indicators of vertical vegetation structure, foliage height diversity index (FHD) and mean shrub height, and two indicators of horizontal vegetation structure, percentage of shrub cover and percentage of tree cover. Also, three indicators of fire risk were used to assess the amount, structure and connectivity of shrub cover and the fuel vertical continuity.

Indicators of vertical vegetation structure:

- FHD – Applies the Shannon-Weiner diversity index to the proportion of vegetation cover in each vertical (height) class.
- Mean shrub height – Mean height of shrub cover in 10 m x 10 m plots, assessed from the highest shrub hit in each of the registering points.

Indicators of horizontal vegetation structure:

- % Tree cover – Percentage of tree cover calculated from the proportion of registering points in 10 m x 10 m plots with tree cover above 2 meters height
- % Shrub cover – Percentage of shrub cover calculated from the proportion of registering points in 10 m x 10 m plots with shrub cover

Indicators of fire risk:

- Aboveground shrub biomass (Sb) – Calculated from the Mean shrub height and the percentage of Shrub cover (Enes et al. 2020), where higher values of shrub biomass are associated with a higher risk of wildfire.
- FHD – Higher values of FHD would be associated with stratified plant cover, with more complex vertical structure and potentially with the existence of ladder fuels that connect ground to canopy levels.
- Vertical vegetation profile – Visual analysis of plots showing the vertical stratification of plant cover, disaggregated by main life forms. A relatively high cover of shrubs or tall grasses in the intermediate vertical layers (0.5 m - 2 m height) contributes to a higher risk of wildfire.

Moreover, data on vascular plant communities' composition was collected. The presence and percentage cover of understory plant species (excluding adult trees) was registered in 1m2 plots (1 m x 1 m), within the sampling plots (10 m x 10 m), using the Braun Blanquet's cover scale.

Species richness and the Sorensen dissimilarity index were used to assess understory plant composition in the grazed and ungrazed areas:

- Species richness – Provides a measure of local diversity (alfa diversity)
- Sorensen dissimilarity index – Provides a measure of change (turnover) in community composition between sites (beta diversity).

6.1.4.1 Results for vegetation structure

The results (**Figure 75**) reveal different trajectories of vegetation structure depending on the grazing regime. Between 2018 and 2021, the vegetation structure in the non-grazed plots evolved towards greater structural complexity, characterized by an increase in coverage of the various vertical strata, and, consequently, an increase in vertical continuity and vulnerability to fire progression. An increase in herbaceous cover (grasses and forbs) was observed in the lower strata (< 0.5 m), also an increase of tall grasses was observed in the intermediate strata (0.5m - 2m) as well as of shrub cover, including shrubs with height greater than 2 meters. In the grazed parcel, vegetation growth was more moderate. There was a simplification of the vertical structure of the understory, associated with a decrease in the cover of oak saplings and by the thinning of low branches of trees (<2 m), as well as a decrease in tall grasses and shrub cover. In the last year (2021) there was an increase in grasses and forbs in the lower to medium height classes, between (0 m to 1.3 m), as well as a slight increase in shrub cover, between 0.5 m and 1.3 m. At ground level (< 0.25 cm), an increase in herbaceous cover and density was observed. Furthermore, an increase in the proportion of bare soil was recorded (higher than that recorded in the non-grazed parcel), which may indicate a negative impact of the cattle presence.

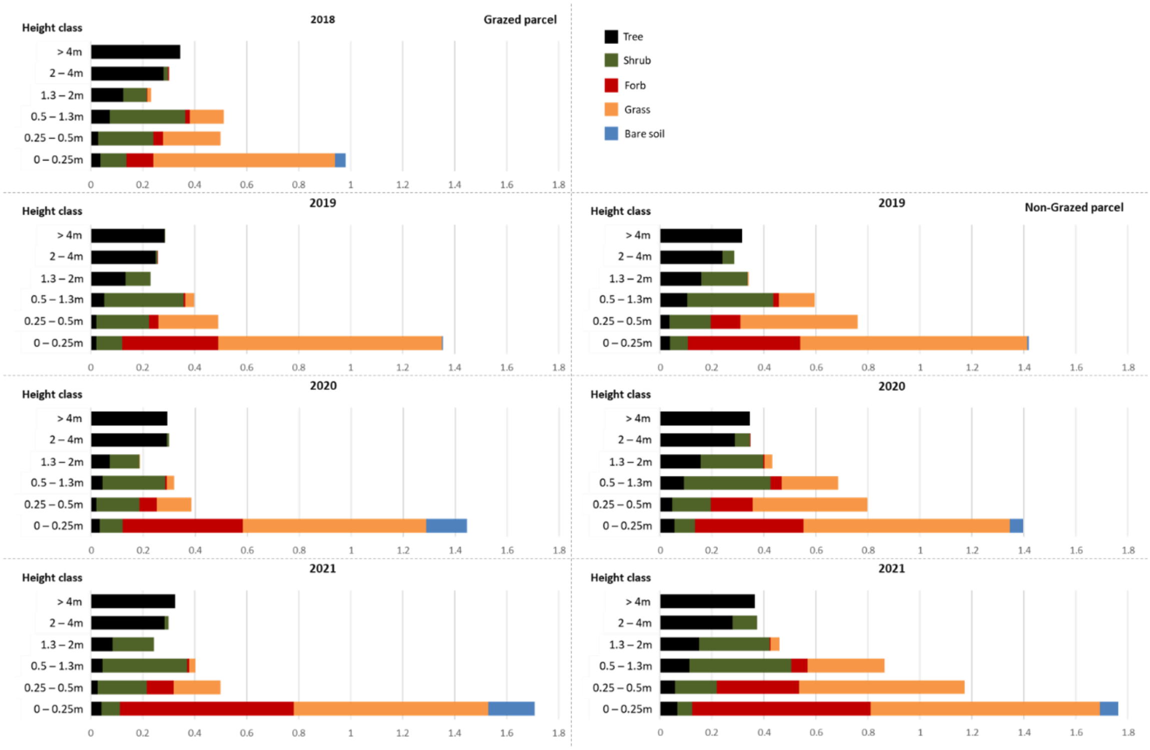


Figure 75. Changes in the relative coverage of the vegetation functional groups in different vertical strata, in the monitoring areas. The cumulative coverage value can be greater than 1.

6.1.4.2 Results for plant community composition

The assessment of plant species composition targeted the understory communities. At Quinta da França we recorded a total of 130 species (109 species in non-grazed parcels and 112 species in grazed sites; **Table 29**). On average, 10 species were observed in the 1m^2 sampling plots, in both grazing regimes. Shannon-Wiener diversity was slightly higher in the grazed area (**Figure 76**). Moreover, species richness levels were equivalent for both grazing regimes, without significant statistical differences. Brooms (*Cytisus sp*.), regenerating oaks, and grasses (*Anthoxanthum aristatum*, *Arrhenatherum elatius*, *Bromus sterilis*, *Micopyrum tenellum*) were the dominant species in the ungrazed forest area. In the grazed forest, the dominant species were the brooms and grasses (*Anthoxanthum aristatum*, *Briza maxima*, *Bromus sterilis*), but also two forbs (*Tolpis barbata*, *Campanula lusitanica*). From the total 130 species, 18 were only observed in non-grazed areas and 16 in grazed areas.

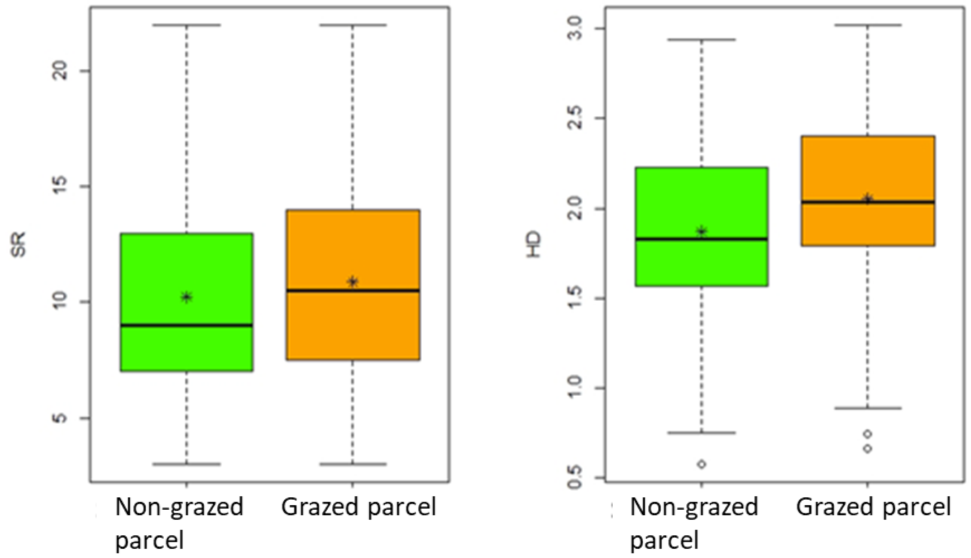


Figure 76. Plant species richness (SR, left) and Shannon-Wiener diversity index (HD, right) for both grazing regimes. Boxplots show the distribution of observed richness and diversity in 1m² plots (mean: asterisk, median: line). Species richness values are not statistically different between grazing regimes (Kruskal-Wallis, p > 0.05). Shannon-Wiener diversity index is higher in the grazed area (Kruskal-Wallis, p = 0.0015).

Table 29. Species richness of vascular plants at different scales. Average values for 1 m x 1 m and 10 m x 10 m plots, and total species richness observed in the 40 m x 40 m survey sites and in all sites with the same grazing regime.

	Non-grazed parcel	Grazed parcel
	Average species richness	
1 m x 1 m	10	11
10 m x 10 m	23	24
	Total species richness	
40 m x 40 m	41 to 59	37 to 62
All sites	109	112

Moreover, forest management activities to control the risk of fire include the mechanical control of woody biomass and the regular maintenance of forest roads (unpaved) and safety corridors (firebreaks). These activities should occur preferably on an annual frequency, between autumn and spring (outside the season with higher fire risk).

6.1.5 Podpoľanie - Slovakia

In terms of the Slovak forestry legislation concerning forest management, it is required to reforest the deforested forest area within 2 years at the latest. So, any deforested area in Slovakia must be reforested in this interval. To do it, there are criteria specified.

Since in 2022 forest management in the national parks and protected areas in Slovakia was transferred from the hands of foresters to the State Nature Conservancy organization, increased attention is being paid to nature conservation in this area over traditional forest management.

Here we present the main principles for forest management/forest restoration under

1. Maintain no-deforestation zones, especially in areas with natural forests (primaeval forests) and in areas of existing reserves with the potential for natural conversion of stands to natural forests.
2. Not to spread non-native tree species (e.g., acacia but also spruce on sites outside its natural range). Non-native tree species should be removed as a matter of priority during reforestation and regeneration.
3. Species missing from the natural species composition should be introduced into the forest stands, including species that will only be represented individually.
4. The possibilities of natural regeneration of forest stands and the associated nature-friendly management methods should be consistently exploited.
5. Priority should be given to a more structured spatial structure of forest stands, which can be achieved by a more varied natural species composition, a longer regeneration period and appropriate educational interventions. It is recommended to apply level coppicing during educational harvesting. If there are older precocious individuals from the original stands in the stand, it is recommended to keep them.
6. Small-scale forms of understory management, especially group and group-covered coppice, should be used for restoration in managed forests. Depending on the possibilities of the terrain, the forest road network, and the condition of the stands, it is recommended to introduce selective management.

There are no special requirements related to forest restoration after the fire from the fire protection legislation or practice. Fire prevention is not a criterium for selection of restoration program.

6.1.6 Sebangau National Park, Borneo, Indonesia

6.1.6.1 Replanting

Forest fires in the Sebangau National Park area occur almost every year. Based on data from the Sebangau National Park, from 2011 to 2015, the burned area reached ±21,576.710 ha. The disaster in 2015 was the largest in the last eight years, with a burned area of ±16,506.44 ha. Replanting activities were one of the rehabilitation efforts in the Sebangau National Park during 2008-2017. It already covered an area of 10,944.62 ha.

In consequence, the rehabilitation activities need funding to run the programs. All budgets allocated by Nasional Sebangau Park Bureau, local and national government, as well as the NGO (Non-Governmental Organization). Replanting process in Sebangau National Park is shown in **Figure 77**.

The desired condition is maintaining moisture and high water on the peat surface to reduce greenhouse gas emissions from peat decomposition. In addition to reducing greenhouse gas emissions, restoration of natural hydrological conditions is expected to restore natural peat swamp forest ecosystems, support vegetation growth, and allow restoration and increase in wildlife populations, especially the Bornean orangutan. Meanwhile, for revegetation, it is expected that artificial succession will accelerate with the following criteria:

1. Forest Canopy Density (FCD) between 41% -< 60%.
2. Type of sub-natural swamp area, which is generally dominated by dense forest structure which is a mixture of.
3. It has 2–3 canopy layers with a height of 15-25 m, a high level of species diversity with several tree vegetation types between 15-20 species.

4. Low standing forest is the home range of the flagship species, namely orangutans and can ensure the availability of food so that the population increases.

Figure 77. Replanting process in Sebangau National Park

To analyse the program, we use logical framework analysis. Resume of Logical Framework Analysis of Replanting Program in Sebangau National Park is shown in **Table 30**.

Table 30. Logical Framework Analysis of Replanting Program in Sebangau National Park

STAGE	RESULTS
GOAL (IMPACT)	- Ecosystem recovery
PURPOSE (OUTCOME)	- Vegetation growth in the burn area
OUTPUT	- Several areas start to growth
PROCESS (ACTIVITY)	- Replanting processes start in 3-5 years after the fire. - The Sebangau National Park office decide the most suitable replanting area. - Several areas fully controlled in the first 3 years
INPUT	- Planning documents are available. - Activities funded by the bureau and NGO. - Supervised by Sebangau National Park Bureau.

INPUT

Sebangau National Park Bureau has annual planning documents specifically to arrange the rehabilitation activities. This document consists of background history of the fire, budgeting, rehabilitation location, area, and the allocated program. The National Sebangau Park bureau supervised the programs by themself and supported by another bureau. So that they could monitor the programs from the beginning.

PROCESS

Land preparation starts with providing suitable growing habitats for plants concerning ecological, physical, management, and social factors. Land preparation includes making sure that the programs are implemented effectively and efficiently and do not cause major environmental change.

1. Preparation

1) Coordination with related institutions
2) Prepare plant design documents for planting locations block/area/location.

3) Prepare implementing organizations such as implementing leaders, supervisors/foremen and labour
4) Develop a timetable for activities and a rational division of labour.
5) Prepare areas for conflict and prevent conflicts between residents and workers by socializing.
6) Preparing materials and equipment
7) Re-measurement of location boundaries and erection of plot boundary stakes.

2. Create land preparation work units.

1) The land unit work unit consists of at least five people.
2) The head of the work team oversees determining the location of the plant path and concurrently as an activity recorder.
3) Two team members in charge of making and opening trails
4) Two team members oversee making stakes and installing markers in planting holes along the path.

3. Preparation of work equipment

1) Preparation of land preparation work map 1: 10,000
2) Preparation of work equipment, including machetes/machetes, hoes, sign boards and
3) other logistics equipment

4. Planning

1) Determine the location of blocks and work plots.
2) Make a detailed work map of land preparation.
3) Planning the workforce and budget required
4) Make a schedule for the implementation of land preparation work.

5. Implementation

1) Look for markings for planting paths that will be made.
2) Make a stub of a clean/plant path 1 meter wide.
3) At each end of the path are marked with wooden stakes with a minimum diameter of 2 cm with a height minimum 130 cm
4) Determine the location of 40,000 holes or 800 holes/ha and
5) Mark the planting hole with a stake

6. Recording and reporting

1) Name of block location and work tile
2) Number of planting paths in intensive cultivation - Planned type and number of plants in each plot
3) Number of working days that have been used, work performance, and quality profession.
4) The register book is filled out every day of the activity.
5) Records of monitoring and evaluation of work by the person in charge of the work unit
6) land preparation
7) Activity reports and land preparation work maps must provide relevant information complete.
8) In monitoring and evaluating activities, a plot is declared complete land preparation.

The rehabilitation process of planting activities in Sebangau National Park includes various activities with the following stages:
1) Socialization (pre, monitoring, and evaluation)

2) Survey of planting sites
3) Preparation of technical plans
4) Survey of seed abundance (natural extraction)
5) Training in nurseries and planting
6) Procurement seeds
7) Procurement of stakes
8) Planting
9) Procurement and installation of boreholes
10) Monitoring and evaluation
11) Maintenance

However, when deciding rehabilitation area, the bureau must make sure that the burned area was 3-5 years since the disaster. By doing so, the soil will be ready to plan again.

OUTPUT

Total area that is successfully recover around 111 ha in 2020-2021.Seeds distribution for the intensive planning in Sebangau National Park Block 1 around 50 ha with total 40,000 seeds. All the seeds use land and water transportation with the intensive location in Block 1, Sebangau Kuala Resort, Pulang Pisau.

PURPOSE

There are 2 types of replanting programs, which are fully controlled and without controlled programs. Both activities successfully regrow the vegetation in certain ways. **Table 31** and **Table 32** are examples of rehabilitation programs in Paduran Sebangau Village.

Table 31. The Plan, The Realization, and The Justification of Replanting in Paduran Sebangau Village

No	Block	Re-planting Area			Justification
		Plan	Realization		
			Ha	%	
1	1	25	25	100	Success
2	2	25	25	100	Success
3	3	25	25	100	Success
4	4	25	25	100	Success
5	5	25	25	100	Success
6	6	25	25	100	Success

Table 32. Healthy Trees Percentage and Justification of Success of Replanting Program

No	Block	Total PU	Number of Tree in every PU	Healthy Trees	Healthy Trees Percentage	Justification
1	1	13	40	30	76%	Success
2	2	13	40	31	76%	Success
3	3	13	40	31	77%	Success
4	4	13	40	30	76%	Success
5	5	13	40	31	77%	Success
6	6	13	40	31	77%	Success
Healthy Tree Average				31	76%	Success

GOAL

The goals of the program are biodiversity recovery. By planting the local trees, forest ecosystem hopefully will flourish back as the trees grows. Although there are a lot of measurement, in this first stage of deliverable, the successful growing trees was measured by NDVI value.

6.1.6.2 Canal Blocking

Sebangau National Park has a history of degradation. Sebangau National Park ecosystem degradation due to canal construction and forest fire. the canals in Sebangau National Park reached 465 pieces made by companies and the community (Balai Taman Nasional Sebangau, 2017). If unraveled, the length of the canal in Sebangau will reach 919,213 kilometers. This condition makes peat as easy as possible water loss, drought, and prone to fire. The threat of repeated peat fires in Sebangau National Park occurred in the period 2005-present. Interventions were carried out by constructing canal blocking, fire prevention patrols, security patrols, outreach to the community, and planting efforts.

Sebangau National Park seeks to restore the peat ecosystem by constructing the canal blocking. Canal blocking project in Sebangau National Park that has been going on since 2006 (Balai Taman Nasional Sebangau, 2017). By 2020, the number of canal-blocking units built in the Sebangau National Park area will reach 1,831 units. Restoring the peat ecosystem takes a long time and costs a lot of money. The number of Canal Blocking Constructions and the process of construction in Sebangau National Park 2005-2016 is shown in **Figure 78**.

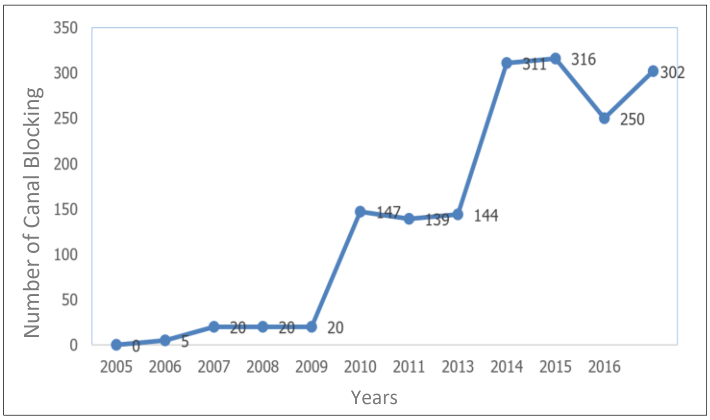


Figure 78. Number of Canal Blocking Construction in Sebangau National Park 2005-2016
Source: (Balai Taman Nasional Sebangau, 2017)

Figure 79. Canal-blocking construction process in Sebangau National Park.
Source: (Balai Taman Nasional Sebangau, 2017)

To analyze the program, we use logical framework analysis. Resume of Logical Framework Analysis of Canal-blocking Construction Program in Sebangau National Park is shown in **Table 33**.

Table 33. Logical Framework Analysis of Canal-blocking Construction Program in Sebangau National Park

STAGE	RESULTS
GOAL (IMPACT)	- Ecosystem recovery
PURPOSE (OUTCOME)	- Blocking the black water running outside the Sebangau National Park. If the water stays in the peat area, it won't get drained.
OUTPUT	- 2010 numbers of canal blocking were built
PROCESS (ACTIVITY)	- Deciding which canal should be blocked - Reconstruction process
INPUT	- Planning documents are available. - Activities funded by the bureau and NGO. - Supervised by Sebangau National Park Bureau

INPUT

Sebangau National Park Bureau has annual planning documents. This document includes about the plan, implementation, result, and impact of this programme.

Quantity and Location.

In 2020, Sebangau National Park has planned to build 176 canal blocking ((Balai Taman Nasional Sebangau, 2021). Detail of Canal Blocking Number by Types is shown in **Table 34**.

Table 34. The Plan of Canal Blocking Construction in Sebangau National Park

Location	Number of Canal Blocking	Detail of Canal Blocking Number by Types	
		Type of Canal Blocking	Number
Resort Sebangau Hulu SPTN I Palangka Raya	83	Type-1	27 units
		Type-2	35 units
		Type-3	21 units
Resort Mangkok SPTN II Pulang Pisau	68	Type-1	38 units
		Type-2	25 units
		Type-3	5 units
Resort Bangah SPTN II Pulang Pisau	25	Type-1	10 units
		Type-2	15 units
		Type-3	-

Source: (Balai Taman Nasional Sebangau, 2021)

Time plan.

The canal blocking should be built within 30 days (1-31 December 2020).

Cost plan

Rp. 3,000,000,000 (Three Billion Rupiah) or (1842 EUR) in Fiscal Year 2020.

Quality plan

The design and construction of canal blocking are made entirely using boards and beams without slats (Galam wood), with the recommended type of substitute wood being the resak type (Vatica resak) with a construction consisting of 3 (three) types based on the dimensions of the canal, namely; (1) Type-120 canals with a width of 150 cm, (2) Type-2 canals with a width of > 151 cm - ≤200 cm and (3) Type-3 for a canal width of > 201 cm - 300 cm. The illustration and design of canal type is shown in **Figure 80** and **Figure 81**.

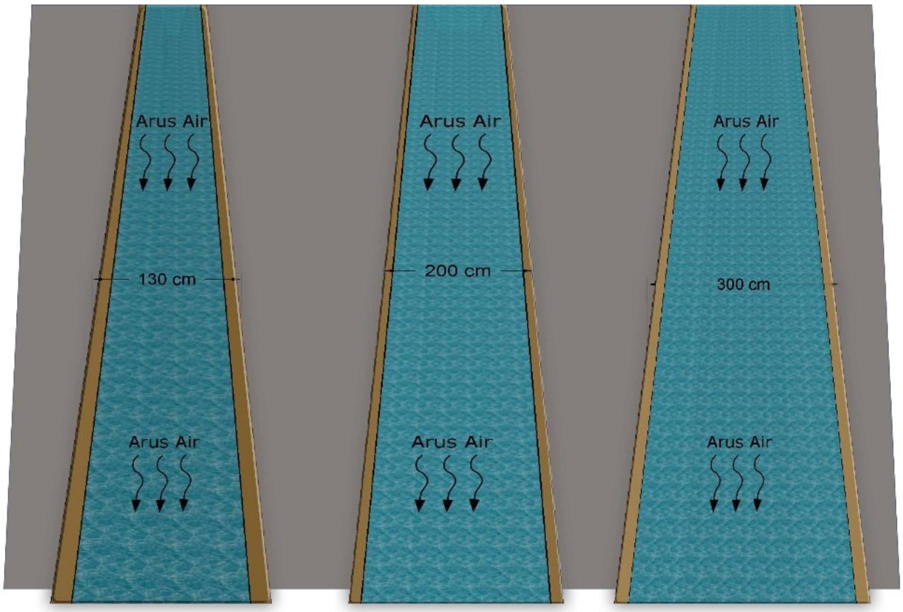


Figure 80. Canal width in determining Bulkhead Type
Source: (Balai Taman Nasional Sebangau, 2021)

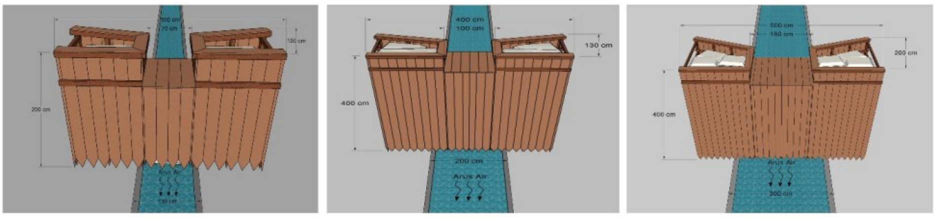


Figure 81. Canal Blocking Design
Source: (Balai Taman Nasional Sebangau, 2021)

PROCESS

The construction of canal blocks consists of three main stages (Balai Taman Nasional Sebangau, 2017) that is; pre-construction, construction, and post-construction.

1. Pre-construction

1) Initial socialization of peat rewetting program as FPIC process chain.
2) Field survey.
3) Determination of the number of canals blocking and selection of block/block design along with its technical specifications; PE Plan for TN Sebangau 2018-2022 36
4) FPIC (Consent on an initial basis without any coercion).
5) Analysis of the need for human resources and canal blocking materials.
6) Determination of canal blocking time and material mobilization time.
7) Estimating the cost of insulation.
8) The process of forming a group to carry out the construction.
9) Cooperation agreements with construction implementing groups.
10) Technical training; and
11) Procurement and mobilization of materials, equipment, and labor

2. Construction

1) Determination of the location and number of blocks/blocks to be built.
2) Measuring the location of the block/block
3) Construction of bulkhead structures
4) Installation of waterproof coatings (tarpaulins, geotextiles, etc.)
5) Entry and stockpiling of infill soil.
6) Installation of the overflow cover (spillway)
7) Tidying job

3. Post-construction

1) Checking, monitoring, and evaluating the canal blocks that have been built.
2) Demobilization of labour and equipment
3) Installation of water level monitoring instruments (if needed)
4) Block/bulk/dam maintenance work

OUTPUT

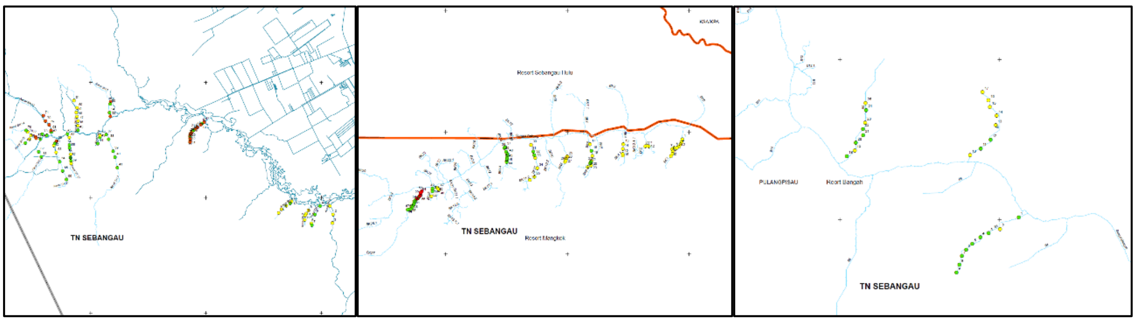
Quantity and Location.

The quantity and the location of canal blocking have accordance with the plan, in total 176 units. The detail of the number and the location can be seen in **Table 35**. The distribution of the result of canal blocking by the type is shown in **Figure 82**.

Table 35. The Realization of Canal Blocking Construction in Sebangau National Park

Location	Number of Canal Blocking	Detail of Canal Blocking Number by Types	
		Type of Canal Blocking	Number
Resort Sebangau Hulu SPTN I Palangka Raya	83	Type-1	27 units
		Type-2	35 units
		Type-3	21 units
Resort Mangkok-SPTN II Pulang Pisau	68	Type-1	38 units
		Type-2	25 units
		Type-3	5 units
Resort Bangah SPTN II Pulang Pisau	25	Type-1	10 units
		Type-2	15 units
		Type-3	-

Source: (Balai Taman Nasional Sebangau, 2021)



a). b). c).

Figure 82. Distribution of the Result of Canal Blocking by the Type (Yellow: Type-1, Green: Type-2 and Red Type-3). a). Resort Sebangau Hulu SPTN Wilayah I Palangka Raya; b). Resort Mangkok-SPTN Wilayah II Pulang Pisau; c). Resort Bangah- SPTN Wilayah II Pulang Pisau

Source: (Balai Taman Nasional Sebangau, 2021)

Time realization

The canal blocking should have been built within 22 days (1-22 December 2020).

Cost realization

The realization of the implementation budget for the construction of canal blocking in Sebangau National Park is Rp.2,922,289,024 (1793 EUR). It is 97.41% of the planned budget allocation of Rp. 3,000,000,000 (1842 EUR).

Quality realization

The realization of canal blocking quality has accordance with the plan.

PURPOSE

Canal blocking is one of rewetting peat methods. Peat rewetting is used on peatlands that have experienced degradation and excessive dryness due to the construction of a network of drainage canals. In general, the goal is to restore peat hydrology. It can be seen from the stabilization of the peatland's water table and the peat's increasing level of wetness and humidity.

The canal blocks function to restrain the rate of groundwater loss in peatlands. As an effort to maintain the hydrological balance, water is sought to settle for longer on peatlands. The hope is that the peatlands will get wet again to reduce the risk of forest fires. Restoring hydrological conditions also can reduce greenhouse gas emissions from peat decomposition. In addition, restoration of natural hydrological conditions to restore natural peat swamp forest ecosystems, so the forest ecosystems will grow again to support the life of humans, flora, and wildlife, especially to increase the orangutans' population.

GOAL

The construction of canal blocks has had a positive impact, namely ecosystem recovery.

Figure 83. Photo of the success of canal blocking construction in Sebangau National Park
Source:(Balai Taman Nasional Sebangau, 2017)

This ecosystem recovery includes increasing forest cover, maintaining humidity and water level to reduce greenhouse gas emissions from peat decomposition, and restoring natural forest ecosystems that can support vegetation growth and provide a food source for wildlife. The photo of the success of canal blocking construction in Sebangau National Park is shown in **Figure 83**.

6.1.6.3 Well Construction

One of the efforts to restore peat is to rewet peat material that has dried up due to the lowering of the peat soil surface. Drilling wells are one of the infrastructures for restoring the hydrological function of peatlands. It consists of a series of tools in the form of pipes or serial connections PVC pipe installed/planted into peat soil drain/discharge water sources located underground in the peat (aquifer layer).

The purpose of drilling well construction is to overcome the scarcity of surface water sources which generally occurs during the dry season. Under these conditions, the peat groundwater level naturally drops dramatically. Natural surface water sources found in canals/ditches, creeks, rivers, and lakes experience dryness, and their reach is very far. The function of drilled wells in peat restoration efforts is a water source for wetting peat, so it doesn't dry out and is easy to burn, especially during the dry season. However, it can be used also as a source of water for early fire suppression. Each well can cover the surrounding land up to 300 meters. Drilling wells are built with community groups. Drilling well that has been built in Sebangau National Park is shown in **Figure 84** and **Figure 85**.

Figure 84. Drilling well that has been built in Sebangau National Park

Figure 85. Drilling well construction process.

Previously, there were 112 drilling well spots that were built in Sebangau National Park. Subsequently, due to improving the protection, the Peat Restoration Bureau supported building 625 drilling wells in Sebangau National Park. Now, there are 737 drilling wells that have been built in this area.

To analyse the program, we use logical framework analysis. Resume of Logical Framework Analysis of Well Construction Program in Sebangau National Park is shown in **Table 36**.

Table 36. Logical Framework Analysis of Well Construction Program in Sebangau National Park

STAGE	RESULTS
GOAL (IMPACT)	- to overcome the scarcity of surface water sources which generally occurs in the dry season. (Hydrology protection)
PURPOSE (OUTCOME)	- Drilled wells for peat restoration efforts at BRG are a water source for peat wetting, especially during the dry season. However, drilled wells can also be used as a source of water for early fire suppression
OUTPUT	- 2017 numbers of well were built
PROCESS (ACTIVITY)	- Deciding well location - Reconstruction process
INPUT	- Planning documents are available. - Activities funded by the bureau and NGO. - Supervised by Sebangau National Park Bureau

INPUT

Sebangau National Park Bureau has annual planning documents. In the 2017 Peat Contingency Plan compiled by the Peat Restoration Bureau, Sebangau National Park is included in the Katingan-Sebangau Peat Hydrological Unit. The Sebangau National Park Center is the Sebangau National Park Center which is the Peat Restoration Implementing Unit under the Directorate General of Nature Resources and Ecosystem Conservation. Meanwhile, in its development, Sebangau National Park made an Ecosystem Restoration Plan in 2018. According to the plan, the Sebangau National Park Center plans to construct 1.788-unit drilled wells built from 2018 to 2022 to restore the forest.

Quantity and Location.

In 2022, Sebangau National Park Through Peat Restoration Bureau, as a part of the peat restoration program, has built 625 drilled along with supporting equipment for peat wetting, totaling 62 machines and 236 hoses. The distribution based on the management work area includes in **Table 37**.

Table 37. The Plan for Well Construction in Sebangau National Park

Location	Number of Well	Detail of Well Number by Types
Area II		
1. Resort Bangah	50	5 units of wetting machines and 25 units of hose
2. Resort Sebangau Kuala	275	26 units of wetting machines and 106 units of hose
Area III		
1. Resort Muara Bulan	100	10 units of wetting machines and 50 units of hose
2. Resort Mendawai	200	21 units of wetting machines and 55 units of hose

Time plan.

The drilled well construction takes 90 – 120 minutes to be built with 5-6 people working on it.

Cost plan

Rp. 4,000,000,000 (Four Billion Rupiah) or 2455 EUR in Fiscal Year 2020.

Quality plan

The design and construction of drilled well starts with determining the point, digging a 1x1 meter hole to collect water, drilling to pipe installation, and experimenting with machines. Generally, peatland water will still be available even during the dry season if drilling is carried out correctly and reaches a stable water source. Drilling wells in practice uses about four iron Piva rods and reaches a water source at a depth of about 12 meters. Drilling is stopped when the drill bit has passed the sand layer as a sign that it has reached the water source. Then proceed with inserting the 1.5-inch paralon that has been prepared. The process of entering the paralon into the drilled well must be done quickly to avoid sand collapsing. Because if there is sand collapse, the drilled well that has been made will fail and have to repeat from the initial stage. The last stage is an experiment using a water machine to operate a drilled well. The water that comes out of the drilled well is quite clear, with a water discharge of 2 liters per second. Thus, the practice of making boreholes can be said to be successful because they have met the eligibility criteria for drilled wells.

PROCESS

The construction of well consists of three main stages that is: pre-construction, construction, and post-construction.

1. **Pre-construction**
   1) Initial socialization of peat rewetting program as FPIC process chain.
   2) Field survey, for determining the location of wells and the number of simple bore wells as well as selecting a simple borehole design along with its technical specifications.
   3) Formation of drill well construction groups and teams.
   4) Cooperation agreement.
   5) Technical training; and
   6) Procurement and mobilization of materials, equipment, and labor
2. **Construction**
   1) Determination of the point and cleaning of the location plan for the placement of the borehole.
   2) Preparation of borehole tools and materials.
   3) Preparation of borehole injection water pool.
   4) Drilling process.
   5) Installation of well pipes.
   6) Trial of the use of installed bore wells; and
   7) Foundation casting, marking installation, and taking coordinates.
3. **Post-construction**
   1) Demobilization of tools and labor;
   2) Monitoring and evaluation; and
   3) Drilling well maintenance work.

OUTPUT

In its development, according to the 2017 BRG Contingency Plan, the construction of drilled wells in the Sebangau National Park has an impact on restoration efforts in an area of 456,018 Ha. It is because the existence of drilled wells can overcome the scarcity of surface water sources. It generally occurs during the dry season when the peat groundwater level drops drastically several meters below the peat soil surface. Natural surface water sources in canals, creeks, rivers and lakes experience drought, and the range is very far.

PURPOSE

Drilling well is another method of peat rewetting. In general, the purpose of rewetting peat that has experienced degradation and excessive dryness due to the construction of a drainage canal network is to restore the hydrological function of peat, which is reflected in stabilizing the water table on peatlands, increasing the peat wetness and humidity. The construction of drilled wells for peat restoration efforts at Sebangau National Park is a water source for peat wetting, especially during the dry season. Furthermore, drilled wells can also be used as a water source for early fire suppression.

GOAL

The benefit of drilled well is restoration of the hydrological function of peatlands and accelerates the process of peat restoration and recovery. The use of drilled well construction in peat restoration and recovery is shown in **Figure 86**.

Figure 86. The use of drilled well construction in peat restoration and recovery.

Beside the rehabilitation and restoration program in pilot area, we conduct some literature review related to the rehabilitation and restoration program in Europe. To create the resilience of a forest ecosystem, the need for an approach to managing forests is urgent. There are five steps for managing Europe's forests (Silvano Fares, 2015):

(1) Plant resilient species. Managers should plant species that tolerate a variety of climates, such as those that can grow over a range of latitudes and altitudes. Mixed stands are more resistant to pests and disturbances than single species, which succumb easily to such threats. They also shelter sensitive species such as beech that become vulnerable in warm, dry conditions.

(2) Promote carbon storage. The timing of harvests needs to be optimized. Commercial pressures dictate frequent harvests and thus, short rotations (the time between timber establishment and harvest). But longer rotation cycles are needed to promote carbon storage. The win–win strategy6 lies in between.

(3) Manage disturbances. In pure stands, selecting resistant families and clones could reduce the risk of damage by pests and diseases. Scientists need to understand why different diseases and pests become problematic by studying specific forest communities affected by pathogens or insects.

(4) Consider renewable energy. Policy makers need to provide incentives for investment across the supply chain, and the impacts of such policies should be considered carefully. For example, subsidizing biodiesel production would increase the price of forest biomass and thus lessen its use in generating heat and power. To ensure that bioenergy production is environmentally and economically sustainable, researchers.

(5) Quantify and market other benefits. Non wood products and services from forests — related to conservation, water and soil protection, recreation or climate-change mitigation and adaptation — are now excluded from the market. Introducing payments for them would encourage private landowners to manage their forests sustainably (about half of European forests are in private hands). A water company, for example, might pay foresters to protect a catchment; citizens might pay to enter a woodland for recreation.

Vegetation planting after the fire become a method to foster the tree growth. Many approaches have been developed to enhance the planting process. Direct seeding is one of it, as a technique of planting that is resilience to the climatic condition. This approach gives better result on combating pressure (Villalobos et al., 2020). Another is planting specific tree species that provide more benefit to the process. Native tree species is more tough to cope with climate change disturbance (Bowditch et al., 2022).

Another method of forest conservation is timber plantation. Timber plantations can support the conservation of natural forests (Pirard et al., 2016). Timber plantation has benefits and shortages. The benefit is reducing the degradation of natural forests. The shortage of timber plantation is potential increasing the deforestation due to either lower market value of natural forests in the absence of logging, or displacement effects.

If we talk about conservation, we also talk about restoration. There are four forest restoration strategies: rehabilitation, reconstruction, reclamation, and replacement (Stanturf et al., 2014). Rehabilitation restores desired species composition, structure, or processes to a degraded ecosystem. Reconstruction restores native plant communities on land recently in other resource uses, such as agriculture. Reclamation restores severely degraded land generally devoid of vegetation, often the result of resource extraction, such as mining. Replacement of species (or their locally - adapted genotypes) with new species (or new genotypes) is a response to climate change. (Stanturf et al., 2014) reviewed many papers and conduct restoration programs according to objective, present forest condition, strategy, and method. In this deliverable, present forest condition is about degradation forest caused by fire disturbance. So, these programs are (1) Clear fell and plant all desired species, (2) "Enrichment planting; framework species method", (3) "Assisted natural regeneration; farmer assisted natural regeneration", (4) Blowdown; with or without salvage logging; plant desired species, (5) Agroforestry methods, (6) Partial overstory removal; underplanting; natural regeneration, (7) "Erosion control (re-seed native understory; mulching); with or without salvage logging; plant desired species", (8) "Fuel reduction by mechanical or chemical means; re-introduce prescribed fire; fire surrogates", (9) "Fuel reduction by mechanical or chemical means; re-introduce prescribed fire; fire surrogates".

In Central European Forest that forest decline' attributed to industrial emissions, there are several programs to rehabilitate the degraded forests (Fanta, 1997), such are (1) colonization of degraded sites by pioneer tree species that more have benefit to restore the soil; (2) succession (spontaneous regeneration) which can supports biological diversity and facilitates natural regeneration of forest trees (especially pioneers); (3) delaying the replanting of clearings; (4) adaptive planting; (5) mowing the grass around young trees; (6) the combination of spontaneous regeneration and adaptive planting.

Further on mowing method, it is proven to be an efficient method to increase the vegetation richness. Mowing had a statistically significant effect on species composition except for the shortest (3-year) experiment. cessation of mowing significantly reduced the richness of species, especially those of conservation importance. In contrast, any mowing of abandoned fens increased species richness.

Natural regeneration often is mentioned in many papers as restoration programs in the forest that are degraded. (Jonášová et al., 2006) explain that natural regeneration can transform the plant in the forest into more diverse stands with a higher participation of target indigenous tree species. it happens in Dwingeloo and Smilde, Drenthe Province in The Netherlands. The most important factors influencing the regeneration of indigenous species in that location were: numbers of seed trees within a 50 m distance from the plot, the type of plot (gap or canopy), canopy cover and age and size of gaps.

While tree growth and survival have long been quantifiable using traditional methods, they cannot be used to anticipate reforestation potential without knowledge of fecundity (Qiu et al., 2022). **Seed limitation** takes on new urgency, as highlighted by fires of uncommon severity in fuels cured by multi-year drought that leave only remnants of reproductive trees. The global relationships quantified from this synthesis bring not only a previously unmeasured dimension of forest response; they also will allow us to leverage existing knowledge of growth and survival with the missing link to regeneration, that of tree fecundity.

Forest land use also exists in peatland areas. Peatland area has ecological services such as influencing in global climate and having a high potential for water quality improvement (Trepel, 2007). The importance of their service to the global, the rehabilitation of peatland areas become essential too. One of the peatland rehabilitation programs is rewetted peatlands. In Schleswig-Holstein, Northern Germany, the rewetted plan was used for the reduction of non-point source pollution entering surface water bodies (Trepel, 2007). In Northern Germany, the rewetting program rehabilitates the water quality improvement potential of degraded peatlands.

Developing solutions is not only about programs created to restore and rehabilitate the forest but also some solutions relating to the disturbance that causes degradation, such as fires. Study of unraveling the effect of climate change on fire danger and fire behavior in the Transboundary Biosphere Reserve of Meseta Ibérica (Portugal-Spain) (Aparício et al., 2022). In this study, quantified the effect of climate change on fire danger and wildfire behavior characteristics for the four major Mediterranean forest ecosystems located in the Transboundary Biosphere Reserve of Meseta Ibérica. The results show that the meteorological fire season will start earlier and end later, leading to a significant increase in the number of days with weather conditions that promote high-intensity wildfires. The most relevant changes are projected to occur in pine forests, where a wildfire with median fireline intensity will offer serious resistance to control from spring to autumn. The severity of fire behavior in shrublands also increases substantially when considering climate change, with high-intensity wildfires potentially occurring in any time of the year. Both deciduous and evergreen broadleaf forests are predicted to typically generate wildfires with low enough intensity to remain within suppression capability.

The complex relationships between climate, vegetation, and fires hamper the applicability of fire impact models to conditions that are very different from the current ones (Turco et al., 2018. For these reasons, the estimation of fire response should be considered more robust for a few decades, when climatic conditions should not be dramatically different from the current ones. This model does not consider future changes in fire management policies, land-use, and land-cover change, or in ignition patterns mainly because reliable projections for these drivers are not available. In summary, the results support the statement of the Paris Agreement that reports that limiting the temperature increase to 1.5 °C would significantly reduce the risks and impacts of climate change. seasonal climate forecasts may enable a more effective and dynamic adaptation to climate variability and change, offering an under-exploited opportunity to reduce the fire impact of adverse climate conditions.

Forest resilient using **fire-smart management of forest landscapes** in the Mediterranean basin under global change were proposed (Fernandes, 2013). Uncertainty in the outcomes of fire-smart management arises mainly from insufficient understanding of the relative weights of fuel and weather -drought on the fire regime. Likewise, linkage between global change processes and the fire regime is not straightforward. The fire regime will be largely driven by weather, advising concentration of fuel management efforts in wildland – urban interfaces and in forests and their vicinity. The decrease of landscape fire severity rather than area burned as the objective; prescribed burning as the treatment of choice, except in the wildland-urban interface; and focus on forest types that are fire-resilient irrespective of flammability.

A biomimicry idea that helps humans to coexist sustainably with fire (Smith et al., 2018) The evolutionary adaptations of organisms for survival (and flourish) in the fire regimes were discussed. Floristic representation of the **Sensitive, Avoiders, Adaptive, Dependent (SAAD)** model. **Fire-sensitive** species have no evolutionary adaptations and are killed by fire; they fill niches in places with minimal fire or very long fire-return intervals. **Fire-avoiding** wildlife species generally focus on escaping by fleeing or hiding in safe places, whereas fire-avoiding flora species invest heavily in protecting themselves against immolation by translocating critical resources (for example, carbon, nitrogen) to their roots to create reserves for post-fire resprouting, seeding, regeneration and recovery. **Fire-adaptive** flora developed protective morphological features such as 'armour' (for example, thick insulative bark or sheaths around reproductive organs) and self-pruning of lower branches to reduce fire jumping to the canopy. **Fire-dependent** flora have evolved to require fire to reproduce (for example, serotinous cones, cued flowering, seed germination by heat or smoke), with the added benefit of killing their competition in the process. The suggestions are that for humans to live sustainably with fire, collaborations between urban planners, architects, engineers, and ecologists should adopt the principles of biomimicry and follow the lead of organisms and indigenous peoples that have evolved to thrive in flammable environments.

According to the literature reviews, we conclude that there are 3 main programs of forest restoration conducted in Europe. Planting, natural regeneration, and the combination of both programs has the most benefit for the forest. The same goes to the observation on the pilot areas. Most of the programs are in the same line as mentioned in the literature reviews.

Natural regeneration

Natural regeneration refers to the renewal process of forest ecosystem growth that appears by natural processes. The terminology of natural regeneration varies from one and another studies. Either natural regeneration, natural succession, or spontaneous regeneration, they have the same meaning. In a natural succession process, recovery occurs gradually as the composition, structure, and function of an ecosystem progress towards the forest's climax state or an alternative stable state, particularly when ecological constraints hinder the attainment of the climax state. The successful regeneration includes all processes, such as seed production, seed dispersal, seed predation, germination, emergence, seedling survival, and seeding initial growth (Calama et al., 2017).

This restoration process has been studied for decades, showing that natural regeneration provides better results on the forest ecosystem (Chazdon & Uriarte, 2016). Natural regeneration is more successful in restoring the native forest community, including trees, understory plants and wildlife, as well as in restoring the native structure and ecological processes, which results in more resilient forests to climate change and other disturbances (García et al., 2020).

In forest ecosystems where fire is a natural disturbance, fires promote vegetation renewal and the maintenance of areas of discontinuity, thereby enhancing habitat diversity (Pausas & Keeley, 2019). Natural regeneration is facilitated by the presence of fire-adapted traits that support vegetation recovery (Pausas, 1999). This includes the ability to resprout from stumps, bulbs, or roots, as well as the capacity to form seed banks that germinate after a fire event (in many cases, seeds are stimulated by fire). The speed of recovery also hinges on the strategies employed by keystone species, particularly dominant trees, with vegetative regeneration leading to a faster recovery compared to seed-based regeneration. While both contribute to restoring the ecological system, the slower process has implications for the restoration of ecosystem services within a timeframe that aligns with human needs and may necessitate assisted regeneration measures. This system becomes the first option in Sterea Ellada, because the results provide the best composition of forest which is more resilient than artificial reforestation. On the other side, in Cova da Beira, natural regeneration has also been the main option in the forest pilot site, with successful results in oak forest reestablishment. Furthermore, to mitigate the threat of severe wildfires, which could impede the progress of natural regeneration, it is essential to manage shrub biomass and prevent excessive sapling density during the initial stages of tree regeneration. This has been accomplished through mechanized shrub control and, since the pilot site is situated within a farming area, by fostering synergies with cattle grazing to regulate fuel loads and maintain open areas that create fuel discontinuity. Another case was in Sebangau National Park, the installation of canal blocking in the peat forest restores the hydrological condition. Forests become wetter and support the change of forest to regrow naturally.

Natural regeneration hence facing many obstacles and needs more time to recover. Several activities to boost the performance of the growing trees are weeding, fire protection, grazing protection, enhancing natural seed dispersed, and enrichment planting with desired tree species (Chazdon & Uriarte, 2016).

Planting

Planting programs start from the seedling process to renew the new forest ecosystem. This system has become one of the forest management methods in responding to post-fire events. For instance, this method is commanded to every year's programs in Indonesian forests. Not only in the National Sebangau Park, but across all forests since it is stated in the regulation. In Sterea Ellada, restoration through seeding became an option when natural regeneration is not reassured.

Several studies proved that the consideration of choosing specific tree species is essential in tree planting. It is to make sure that the chosen tree species are resilient enough to cope with climate change and fire. Normally, the management of the forest chooses the native tree or tree species that is more resilient in adjusting to climate change, fire, and able to sprout in the allocated latitude and longitude. The process of handling the seeds also becomes an essential process of planting new trees. Several tree species need extra action on the seed before the planting process.

To some extent, an intervention from the stakeholder should be done in the planting processes more than just planting the trees. For instance, mowing the grass surrounding the young trees gives a good impact on the tree's growth. Similarly, clearing the fire fuel as biomass and the remnant of burned woods surpass the growing tree.

Studies that support restoration of forests mentioned that timber plantation supports natural forest. However, it is vulnerable to logging both legal and illegal. Another planting shortage is the results of even-age and monoculture trees, which are vulnerable to fire events.

The combination of Planting and Natural Regeneration

The combination of both programs refers to the process of both natural regeneration and active restoration combine in certain ways. In Podpol'anie, reforestation and regeneration are considered together as the non-native tree being removed when the natural regeneration starts.

In fact, the combination of natural regeneration gives a benefit that is lacking in both methods. There are certain ways of combining both methods to give the most benefit. Mixed restoration conducted in several places, combining natural regeneration that is managed by the farmer, forest manager, or surrounding communities. They will try to return tree cover on cultivated or grazed farmland without tree planting.

6.2 Biodiversity Monitoring in Pilot Areas

An ecological resilience program supposes to become forest ecosystem recovery after the forest fire. The outcome of the ecological resilience program needs to be evaluated by implementing biodiversity monitoring. Remote sensing is an essential tool for earth observation, including resilience assessment, disaster monitoring, and vegetation monitoring (Cui et al., 2013; Lee et al., 2008; Rezaei & Ghaffarian, 2021; W. Wang et al., 2010). Previously, researchers utilized remote sensing to monitor vegetation cover, forest productivity, and vegetation stability (De Keersmaecker et al., 2017; Donohue et al., 2009; Zeng et al., 2013).

In the regional scale, where the biodiversity cover in a wide range of area, the most approachable measurement is through satellite images so far. Several tools used to monitor the parameters are UAVs, cameras, observatories, rectified aerial photographs (e.g., orthophotos), drone-based aerial imagery, hyperspectral sensors, remote sensing technologies.

Biodiversity components, indicators, and some method to assess it has been mentioned in Chapter 2. Although they are essential to monitoring biodiversity, in this deliverable, we are monitoring using the Normalized Vegetation Difference Index (NDVI) as an indicator of tree regeneration, NDMI as an indicator of forest moisture, Forest Canopy Density (FCD) as an indicator of canopy structure, and Shannon's Diversity Index as an indicator of landscape structure. Furthermore, the development of other methods will be applied in the next deliverable 6.4.

6.2.1 NDVI Monitoring

These deliverable covers 6 pilot areas, Gargano Park (Italy), Tepilora Park (Italy), Cova da Beira (Portugal), Podpol'anie (Slovakia), Sterea Ellada (Greece), and National Sebangau Park (Indonesia). NDVI calculation being used to all the pilot area to measure part of the biodiversity measurement. In the following table (**Table 38)** shows the coordinate of the area which is measured by NDVI.

Table 38. Pilot Location

No.	Pilot Location	Longitude	Latitude
1	Gargano Park	41.772592°	15.758710°
2	Tepilora Park	40.591833°	9.416415°
3	Sterea Ellada	23.323°	38.872°
4	Cova da Beira	40.274550°	-7.432178°
5	Podpol'anie	19.44672°	48.649644°
6	National Sebangau Park	-2.598°	113.994°

1. NDVI Measurement in Gargano Park

The following graph (**Figure 87**) shows the series of NDVI value in 2009, 2010, 2015, 2020 and 2022 in Gargano Park, Italy pilot area.

The graph (**Figure 87**) illustrates the NDVI value in Gargano Park, Italy. The observation conducted in 5 years, which are in 2009, 2010, 2015, 2020, and 2022. From the observation, the least value touch 0.236 and the higher value is 0.855. In 2009, the NDVI value shows 0.669 mean value showing that the vegetation condition is moderately healthy. However, in the next year (2010), the vegetation condition remains the same, but decreasing mean value into 0.493. In 2015 and 2020 the value gradually increases into 0.644 (2015) and become a very healthy plant in 0.717 in 2020. In the last year of observation (2022), the value score on 0.689 and the vegetation condition in very healthy condition.

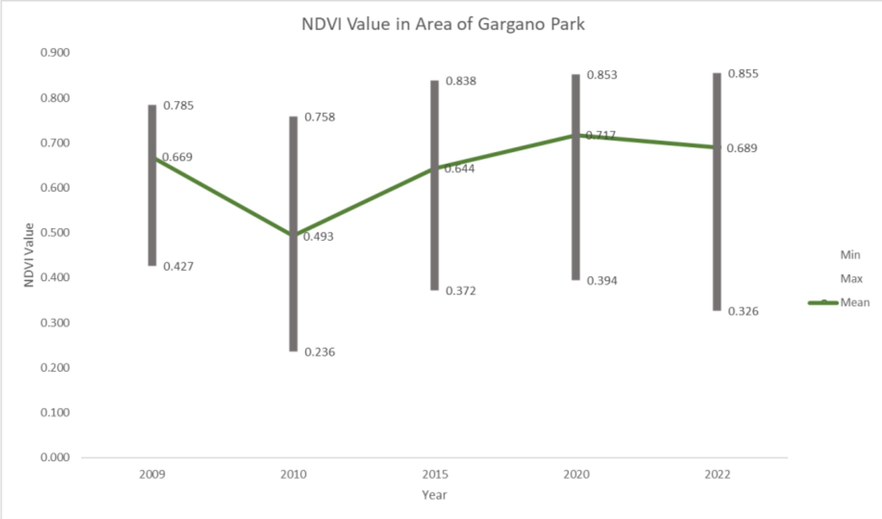


Figure 87. NDVI Value in Sample Area of Gargano Park

2. NDVI Measurement in Tepilora Park

The following graph (**Figure 88**) shows the series of NDVI value in 2017 and 2022 in Tepilora Park, Italy pilot area.

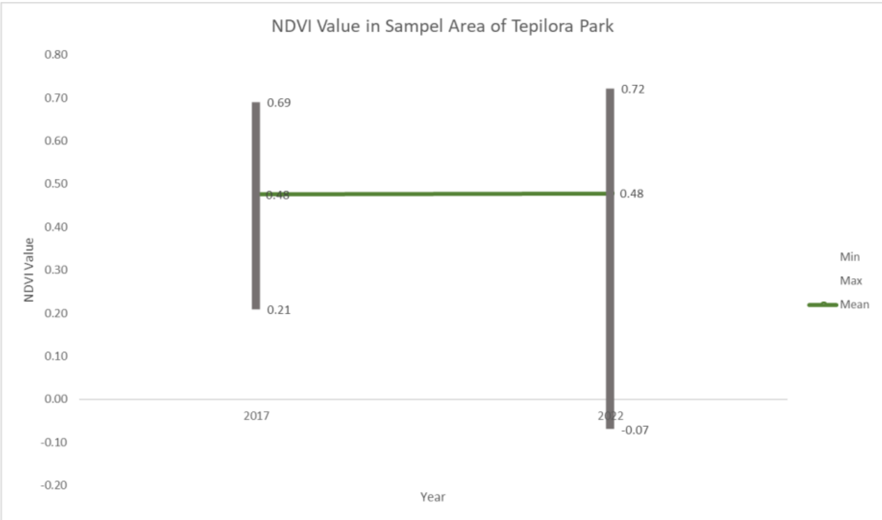


Figure 88. NDVI Value in Sample Area of Tepilora Park

The graph (**Figure 88**) illustrates the NDVI value in Tepilora Park, Italy. The observation conducted in 2 years, which are in 2017 and 2022. In 2017 and 2022, the mean of NDVI value is the same, a moderately healthy plant condition in 0.48. From the 2 years of observation, the least value is 0.07, considering as an unhealty plant in certain area. The highest value is 0.72, considering as the healthy plant.

3. NDVI Measurement in Sterea Ellada

The following graph (**Figure 89**) shows the series of NDVI value in 2011, 2013, 2017 and 2022 in Sterea Ellada, Greece pilot area.

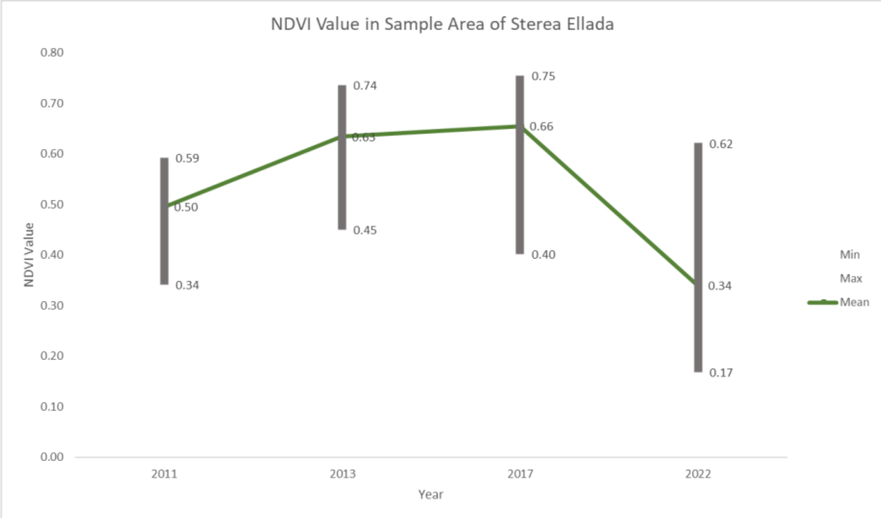


Figure 89. NDVI Value in Sample Area of Sterea Ellada.

The graph (**Figure 89**) illustrates the NDVI value in Sterea Ellada, Greece. The observation was conducted in 2011, 2013, 2017, and 2022. The mean of NDVI value gradually increasing in 2011, 2013, and 2017. All values in moderately healthy condition of 0.50, 0.63, 0.66 mean. The NDVI value in 2011 shows moderately healthy condition with 0.50 score. In 2013 and 2017 the value gradually increases into a healthy plant. However, the last observations are in 2022, illustrating the NDVI number decreasing into moderately healthy plant, perhaps because of the massive fire in 2021.

4. *NDVI Measurement in Cova da Beira*

The following graph (**Figure 90**) shows the series of NDVI value in 2015, 2020, and 2022 in Cova da Beira, Portugal. The graph (**Figure 90**) illustrates the NDVI value in Cova da Beira. The observation conducted in 2016, 2017, and 2022. Mean of the NDVI value gradually decreasing from 0,48, 0,44, and the last is 0.43. However, the range of NDVI value still in a range of moderately healthy plant condition

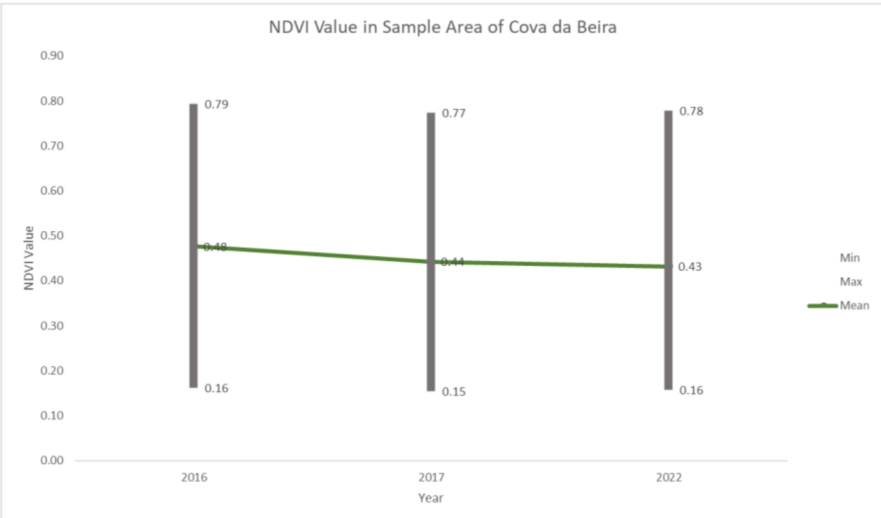


Figure 90. NDVI Value in Sample Area of Cova da Beira.

5. *NDVI Measurement in Polpol’anie.*

The following graph (**Figure 91**) shows the series of NDVI value in 2013 and 2022 in Polpol’anie, Slovakia.

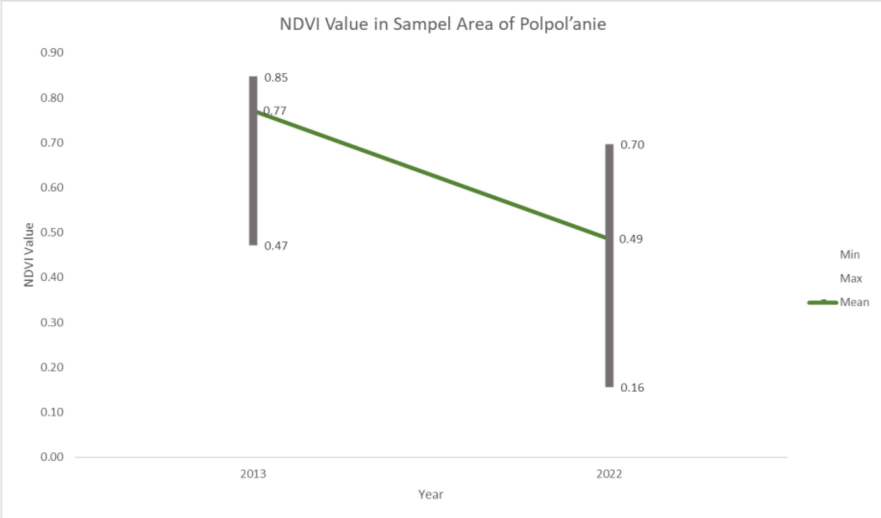


Figure 91. NDVI Value in Sample Area of Polpol'anie.

The graph (**Figure 91**) illustrates the NDVI value in Podpol'anie. The observation conducted in 2013 and 2022. The mean of NDVI value decreasing from 2013 (0.77) to 2022 (0.49). So, the average plant condition in the area went from very healthy plant to moderately healthy plant.

6. NDVI Measurement in National Sebangau Park, Indonesia.

The following graph (**Figure 92**) shows the series of NDVI value in 2015, 2020, and 2022 in Indonesia pilot area, Mangkok, National Sebangau Park.

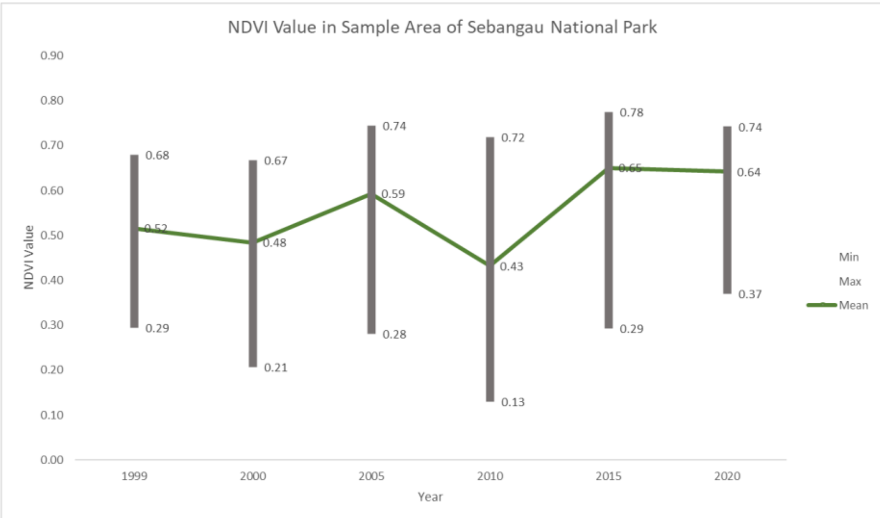


Figure 92. NDVI Value in National Sebangau Park

The graph (**Figure 92**) illustrates the NDVI value in areas of Mangkok, National Sebangau Park, Indonesia. The observation conducted in 1999, 2000, 2005, 2010, 2015, and 2020, showing a fluctuate value of NDVI. Starting in 1999 with a mean value of 0.52 and then went up and down until 0.64 in 2020. Nevertheless, from all range of the observation year, the plant is in a range of moderately healthy condition.

6.2.2 Forest Moisture Monitoring

Forest moisture levels are assessed using the NDMI (Normalized Difference Moisture Index) derived from Landsat 8 satellite data. This assessment involves calculating forest moisture both before and after fire event. **Figure 93** displays the forest moisture values before the fire for the six pilot projects. This assessment involves calculating forest moisture both before and after fire event for single fire event for six pilot projects. Figure x displays the forest moisture values before the fire which was occurred in the six pilot projects as follows: Cova de Beira in September 2017, Sterrea Ellada in May 2017, Sterrea Ellada in May 2017, Gargano in March 2019, Podpol'anie in April 2019 and Sebangau in August 2015. Particularly, Podpolanie, Sterea Ellada, and Sebangau exhibit relatively higher NDMI value compared to the other pilot projects. NDMI values within this range indicate a moderate to high canopy cover with low water stress. Conversely, Cova de Beira, Gargano, and Tepilora tend to display lower NDMI values, signifying a moderate to low canopy cover with low water stress.

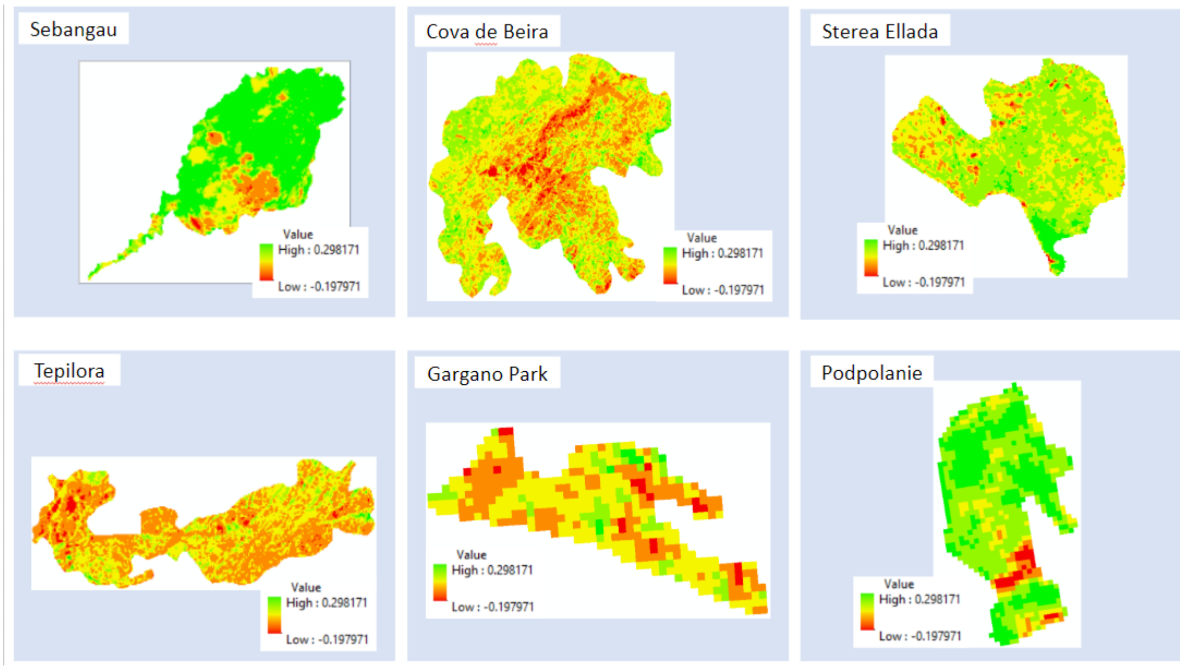


Figure 93. NDMI value before the fire event

Figure 94 illustrates the NDMI values for the six pilot projects after the fire event. Following the fire incident, a notable decline in the NDMI value of the pilot projects was observed. This decline can be attributed to the increased water stress experienced by the forest because of the fire. Gargano and Podpol'anie displayed relatively smaller changes in their NDMI values compared to the other pilot projects, indicating that the severity of the fire in these two areas was relatively lower. Conversely, the Sebangau pilot project exhibited a more substantial change in its NDMI value, indicating a higher level of fire severity in that region.

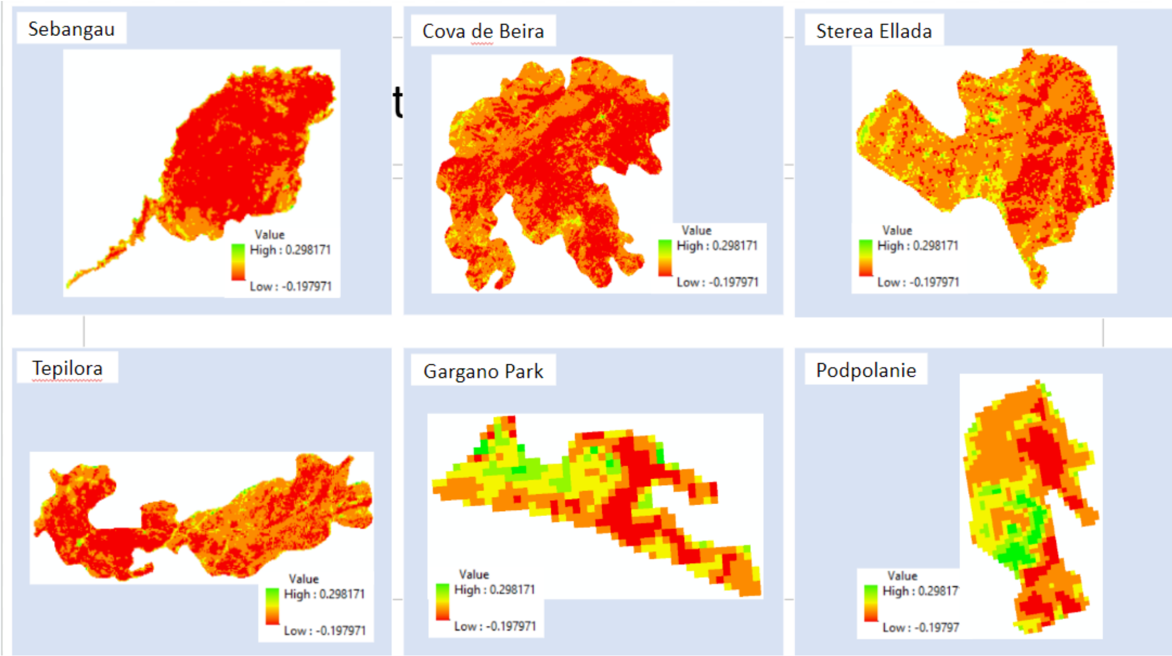


Figure 94. NDMI value after the fire event

6.2.3 Canopy Structure Monitoring

One method to assess canopy structure is forest canopy density. Forest canopy density refers to the amount of foliage and vegetation cover in the uppermost layer of a forest. It is a measure of how dense or thick the canopy is, which can have significant implications for various ecological processes and functions within the forest ecosystem. Within this report, we calculated Forest Canopy Density (FCD) for a specific pilot project, Sebangau National Park. FCD calculations were carried out for the years 2015 and 2020. Over this five-year timeframe, several alterations in FCD were observed. In 2015, a fire event in Sebangau National Park was occured, evident from the low FCD value displayed in bright white. Conversely, by 2020, the previously burned area showed an increased FCD, now displayed in yellow. **Figure 95** illustrates the gradual post-fire recovery of the Sebangau forest.

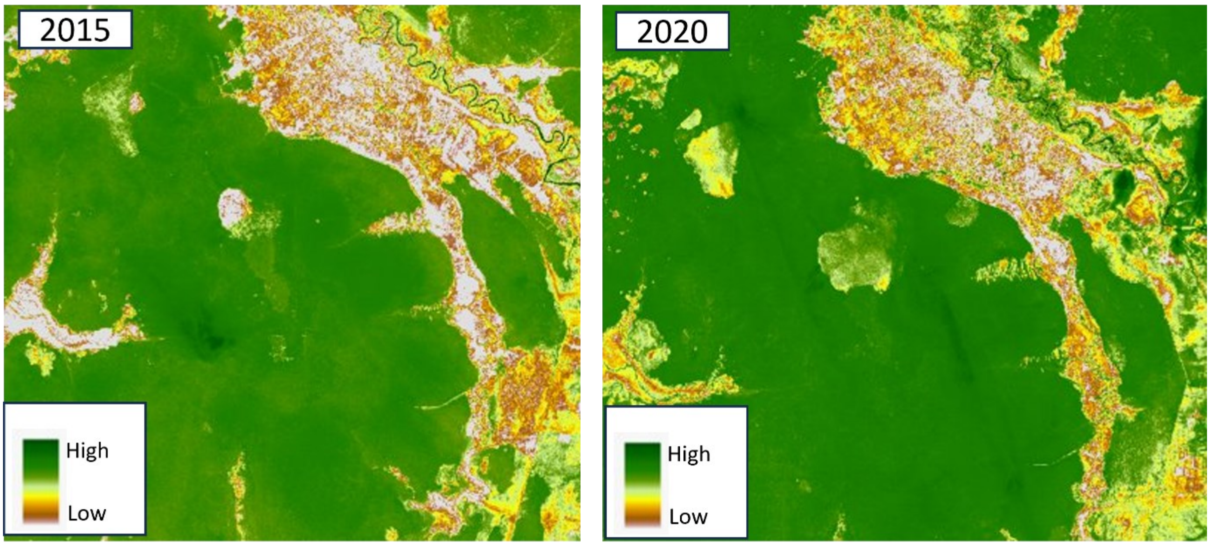


Figure 95. The Gradual Post-Fire Recovery of The Sebangau Forest

6.2.4 Landscape Structure Monitoring

The Shannon Biodiversity Index, also known as the Shannon-Wiener Index or Shannon-Weaver Index, is a measure used to quantify the diversity of species within a given ecosystem or community (Spellerberg & Fedor, 2003). It also assesses the plane level diversity by using patches variety that constitutes the landscape area. In this report, we calculated biodiversity index at the landscape level.

In this report, the biodiversity index calculation is demonstrated using examples from two locations: Sterea Ellada and Podpol'anie. Sterea Ellada represents a subtropical dry forest, while Podpol'anie represents a temperate continental forest. The calculation of landscape biodiversity necessitates the use of landscape classification. In this report, the CORINE land cover classification is utilized, focusing on vegetation cover (**Figure 96** and **Figure 97**). Sterea Ellada shows a Shannon Biodiversity Index value of 2.24, whereas Podpol'anie has a Shannon value of 1.79. A higher index value indicates greater landscape biodiversity. Consequently, Sterea Ellada displays a higher level of biodiversity compared to Podpol'anie.

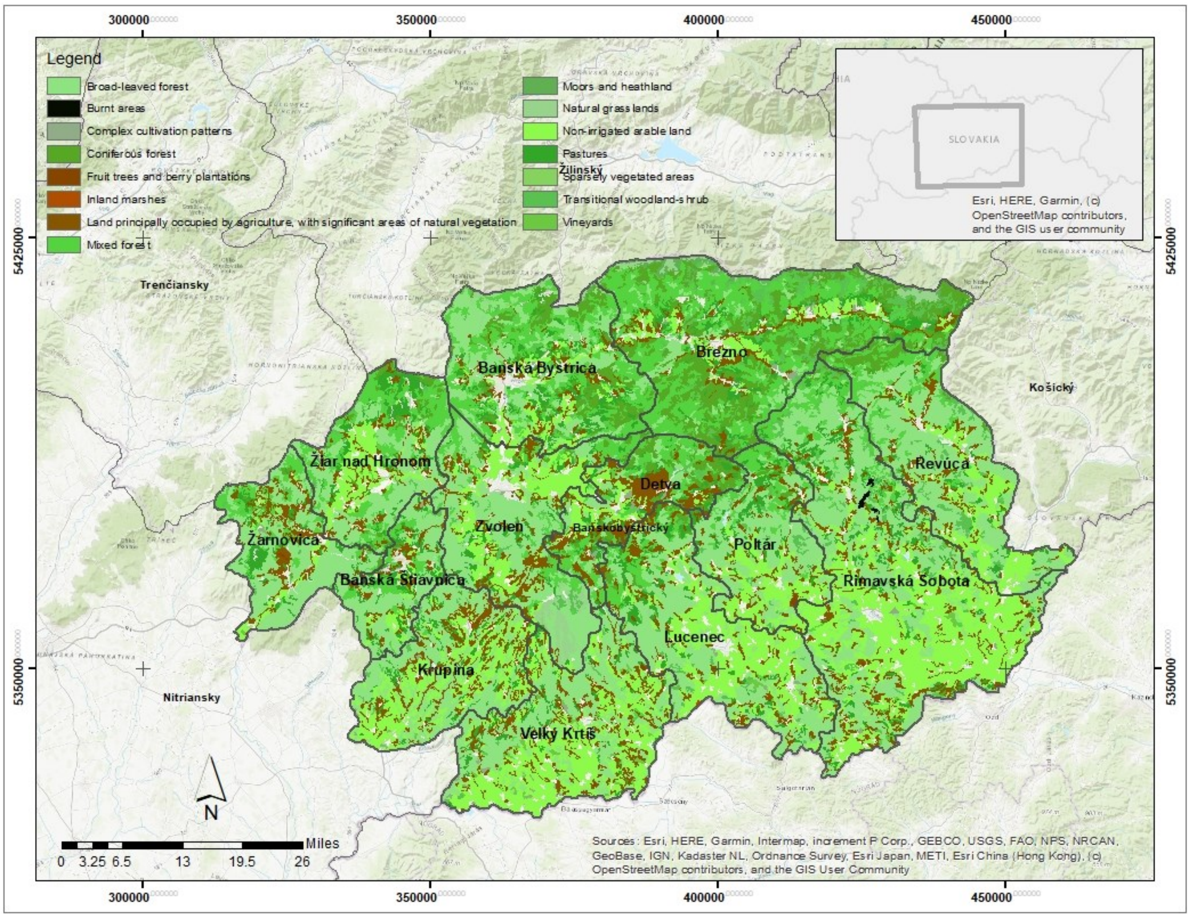


Figure 96. Landcover map of Podpol'anie

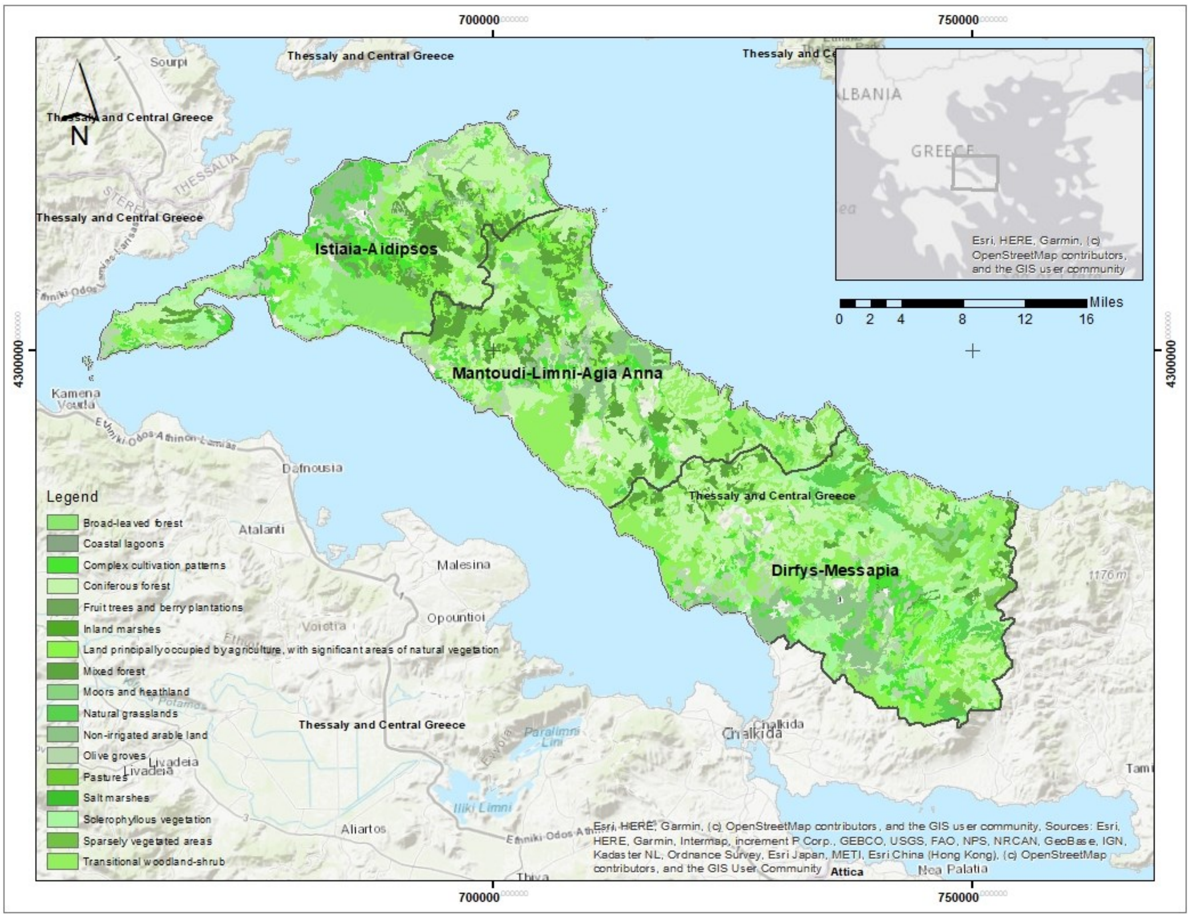


Figure 97. Landcover map of Sterea Ellada

6.3 Ecological Resilience Monitoring in Pilot Areas

6.3.1 Fire Weather Index Monitoring

In this report, we displayed fire weather index for the sample of fire events of six pilot projects (**Table 39**). The peak Fire Weather Index (FWI) value was observed in Sterea Ellada in August 2021, which is 38.7, which is categorized as very high danger. Sterea Ellada recorded the largest forest fire of 2021, spanning 8 days and resulting in the burning of nearly 34,000 hectares of forest (as detailed in the Pilot Description). It implies that the weather conditions significantly influence the occurrence of fires in Sterea Ellada. In 2017, Cova de Beira also experienced a high danger level. The forest fire incident that year led to extensive damage, affecting an area of almost 13,000 hectares. Conversely, Sebangau showed lower FWI value at 5.91. Despite this, it experienced severe forest fires, highlighting that these fires are not solely attributable to weather conditions but can also be triggered by human activities.

Table 39. Fire Weather Index for sample fire events for pilot projects

Pilot	Fire Events	Fire weather index
Sebangau	October 2015	5.91
Cova de Beira	September 2017	30.43
Gargano	March 2019	5.61
Sterrea Ellada	August 2021	38.7
Tepilora	July 2017	17.27
Popdol'anie	Apr 2019	8.03

6.3.2 Ecological Resilience Monitoring

6.3.2.1 Gargano Park - Italy

The remaining pilot area within Italy is the Gargano National Park, which has experienced very infrequent fire incidents. A relatively significant fire event occurred in March 2019, which is illustrated in **Figure 98** through images captured before the fire, immediately after the fire, and during the recovery phase. The pre-fire image was taken in November 2018, while the recovery image was captured in November 2019. In the composite Landsat 654 image, it can be seen distinct dark tones and blackish-brown shades within the areas that were scorched by the fire, in stark contrast to the green and light green hues that characterized the forested regions prior to the fire. By November 2019, the image reflected a return to the original pre-fire coloration.

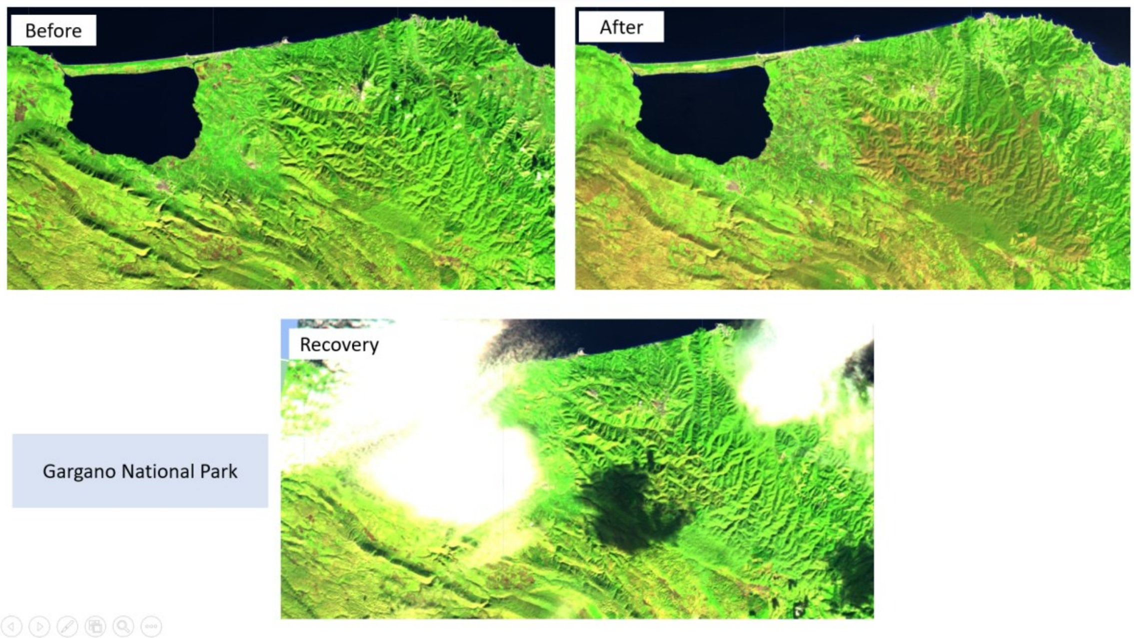


Figure 98. RGB 654 Landsat 8 Composite Image at Gargano National Park before forest fire, after forest fire and recovery phase

The NDVI values before the fire exhibited a range between 0.12 and 0.39, with an average of 0.22. Following the fire, the NDVI values declined to a range of 0.04 to 0.25, with an average of 0.08. To gauge the severity of the fire, we refer to a magnitude value of 0.05 (as seen in **Figure 99**). Particularly, this magnitude value is the lowest among all locations within the pilot area, signifying the lowest fire intensity. This value indicates that Gargano National Park experiences the least frequent occurrence of fires. The fire in Gargano National Park primarily spread in one direction, with its magnitude gradually declining toward the centre of the fire-affected region.

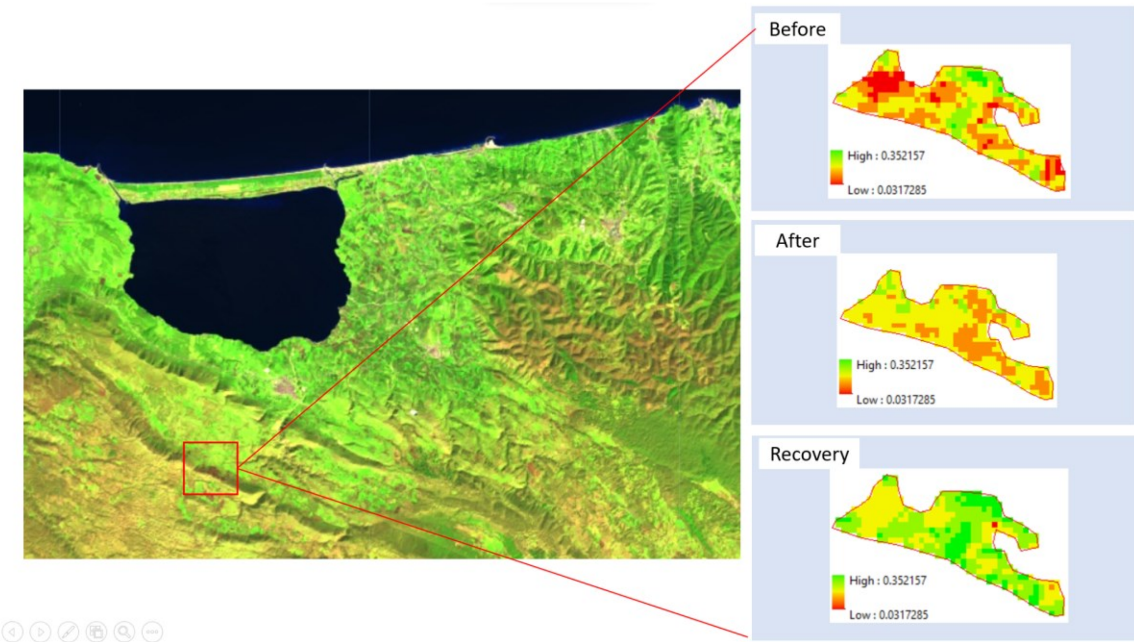


Figure 99. NDVI distribution in Gargano National Park before forest fire, after forest fire and recovery phase

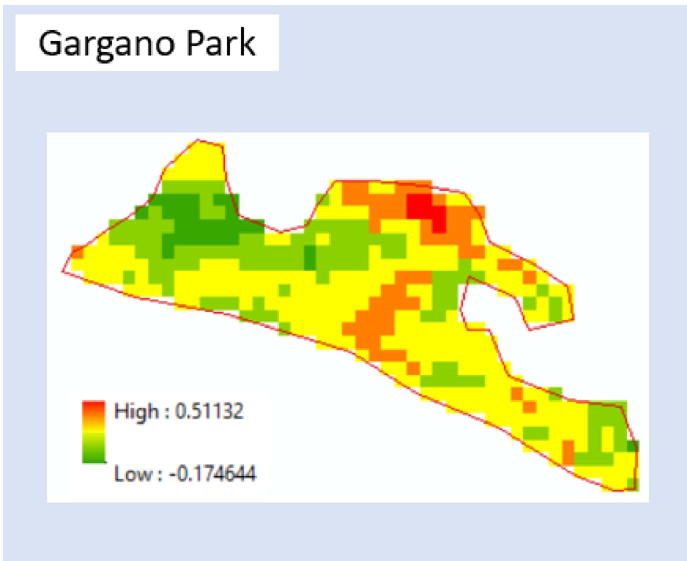


Figure 100. Spatial distribution of magnitude in Gargano National Park

Gargano National Park exhibits a malleability value of 0.2, signifying a relatively stable ecosystem within the park. The duration required for Gargano National Park to return to its initial state was determined using the elasticity indicator (refer to **Figure 101**). Impressively, Gargano National Park took recovery within just 8 months. The highest elasticity values were identified in the northwestern portion of the fire-affected area, while the fire's central zone displayed even higher elasticity values, indicating a faster pace of recovery.

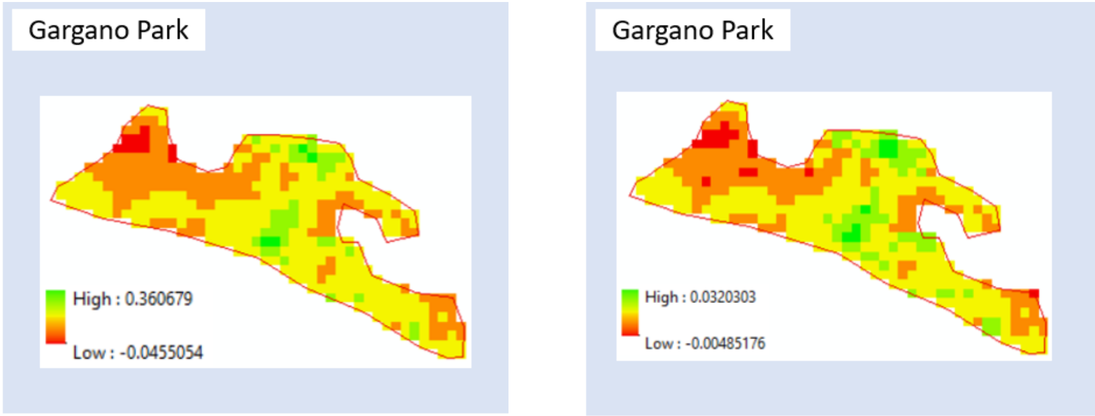


Figure 101. Recovery and elasticity distribution in Gargano National Park

Gargano Park has the fastest recovery time among the pilot projects. This graph showed the time series of NDVI from the initial state until the recovery. It was increasing and statistically significant at 0.01 confidence level. Gargano is the pilot project that experiences the least fires and has the lowest fire severity.

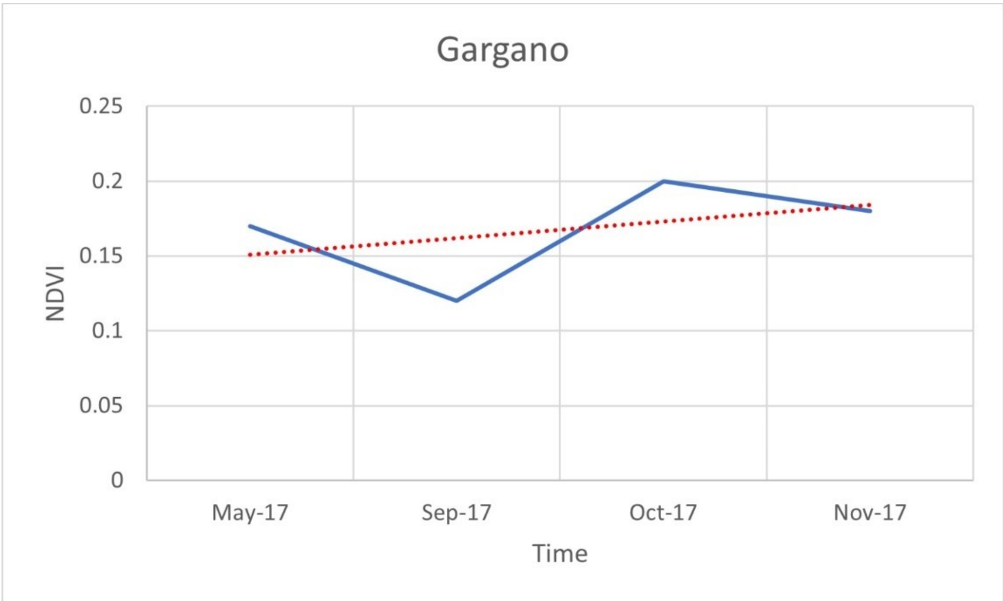


Figure 102. NDVI Trend Analysis in Gargano Park

6.3.2.2 Tepilora Park - Italy

Tepilora Park is still included in the subtropical dryforest type which is situated in the hot-summer Mediterranean climate characterized by dry and hot summer. In this report, the resilience assessment focuses on a single fire event that occurred in August 2017. **Figure 103** displayed a visual representation of the landscape before the fire, immediately after the fire, and during the recovery phase. The pre-fire image was captured in May 2017, while the recovery image was taken in October 2018. In the composite Landsat 654 image, starkly contrasting dark tones and blackish-brown hues are evident within the burned regions, presenting a sharp contrast to the colours of the surrounding arid terrain. Prior to the fire, the forested area displayed various shades of green and light green. By October 2018, the image discovered a return to the pre-fire coloration, even though certain parts of Tepilora Park were covered by cloud.

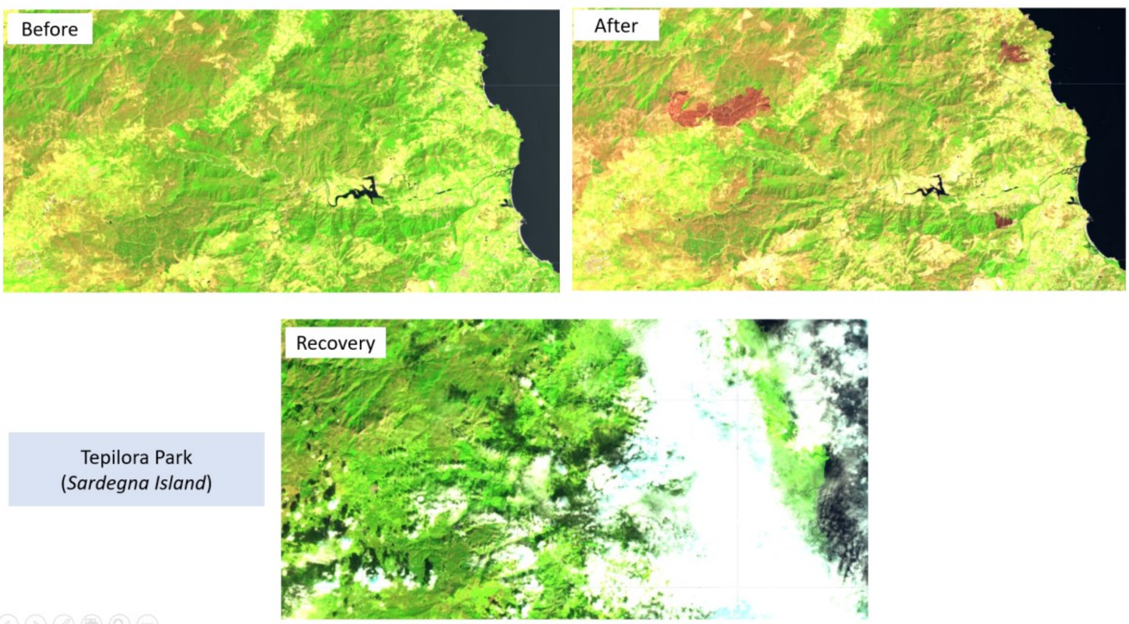


Figure 103. RGB 654 Landsat 8 Composite Image at Tepilora Park before forest fire, after forest fire and recovery phase

The fire sites represented sample locations for calculating the NDVI values at each phase. Before the fire, the NDVI values ranged from 0.12 to 0.39, averaging at 0.22. After the fire, the NDVI values decreased within the range of 0.04 to 0.25, with an average of 0.08. The degree of fire severity is reflected by the magnitude value, specifically at 0.14 (as depicted in **Figure 104**). The fire that occurred in Tepilora Park predominantly spread from its centre, with the magnitude value gradually weakening in the outer areas of the fire-affected zone. The locations exhibiting high magnitude values were primarily situated along the periphery of the affected area. In Tepilora Park, most of the areas displayed relatively low magnitude values. Despite the FWI data indicating a value of 17.27 during that period, signifying a moderate fire risk.

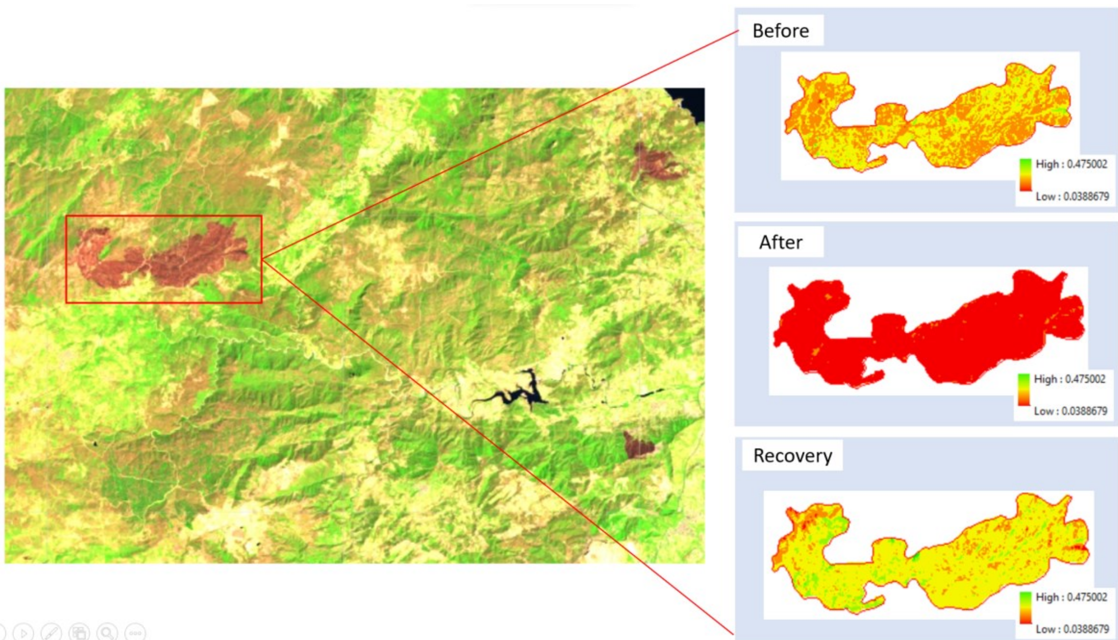


Figure 104. NDVI distribution in Tepilora Park before forest fire, after forest fire and recovery phase

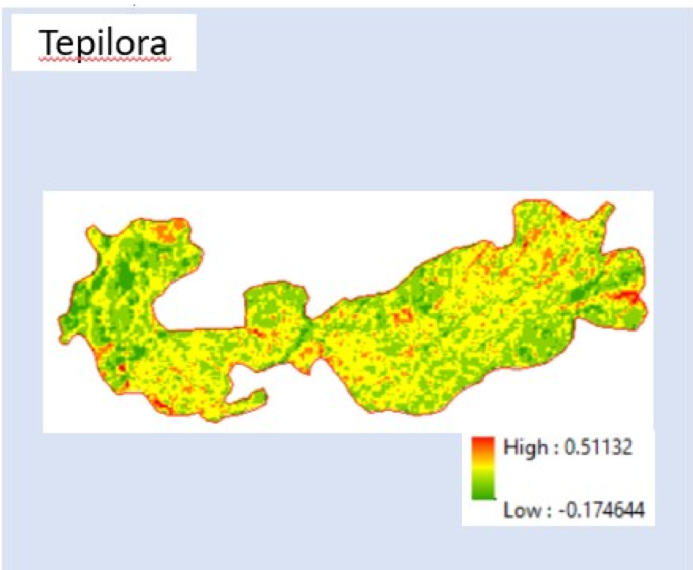


Figure 105. Spatial distribution of magnitude in Tepilora Park

Malleability value for Tepilora Park was at 0.21. This malleability value, although lower compared to other pilot area locations, signifies a stable ecosystem within Tepilora Park. Further analysis employing for elasticity indicator exposes that Tepilora Park requires a duration of 14 months to fully restore itself to its original state (see **Figure 106**). Particularly, the highest elasticity value is observed in the outermost region of the fire-affected area, suggesting a more rapid recovery in this zone. Conversely, as one moves towards the center of the fire, the elasticity value reduces, indicating a longer recovery process. Tepilora Park exhibits a relatively high resilience profile when compared to other pilot areas. This is evident from its lower malleability values and high elasticity. Despite facing moderate fire danger, Tepilora Park tends to manifest lower levels of fire severity, demonstrating a capacity to recover relatively faster in the event of a fire.

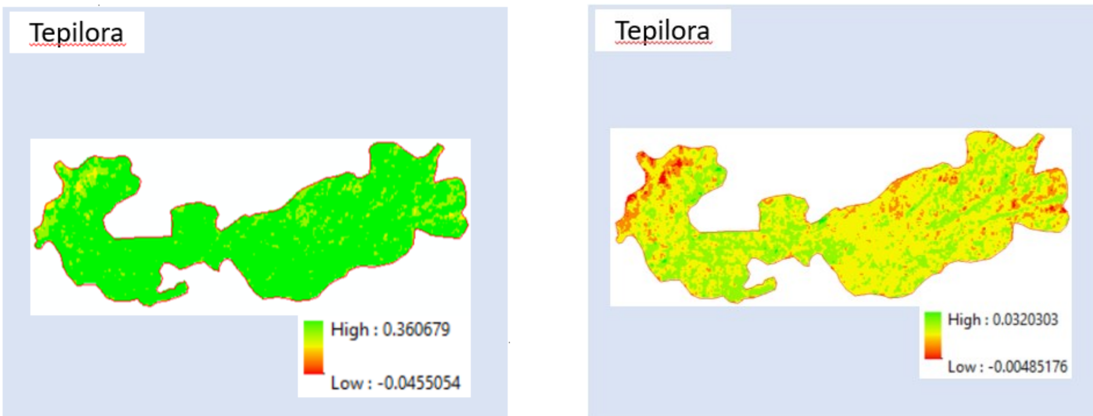


Figure 106. Recovery and elasticity distribution in Tepilora Park

In Tepilora, there is a increasing trend in NDVI, which is statistically significant at a confidence level of 0.1. Tepilora demonstrates periodic increases in NDVI values, contributing to an accelerated recovery process.

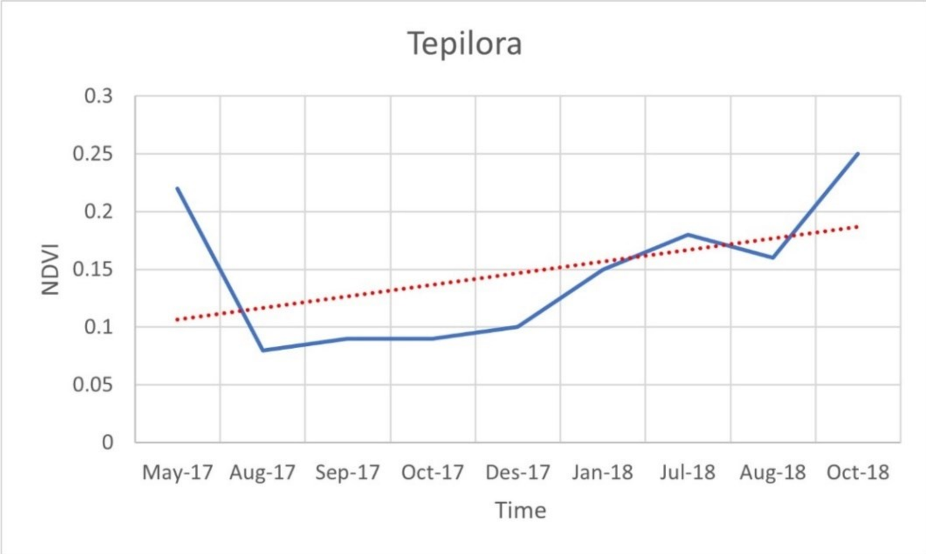


Figure 107. NDVI Trend Analysis in Tepilora Park

6.3.2.3 Sterea Ellada – Central Greece

Sterea Ellada is classified as subtropical dry climate. According to the annual report from EFFIS, there has been an increase in fire incidents in Greece over the past three years. The peak occurred during the summer of 2021, spanning from mid-June to the end of August, featuring exceptionally high temperatures that reached a maximum of 46 degrees Celsius (EFFIS, 2021). This period marked the most prolonged heatwave in the past 35 years. The most significant fire incident can be observed in satellite imagery, pinpointed in the northwestern section of Evia Island.

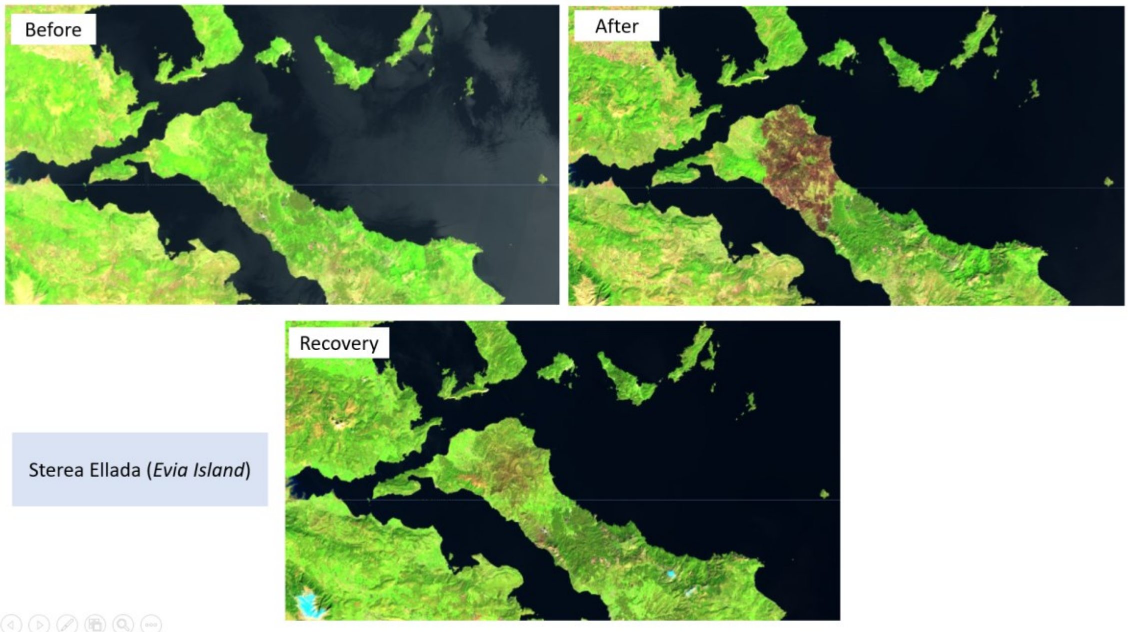


Figure 108. RGB 654 Landsat 8 Composite Image at Sterea Ellada before forest fire, after forest fire and recovery phase

Figure 108 illustrates the Landsat image before the fire, after the fire, and during the recovery process in 2021. The pre-fire image was captured in June 2021, while the recovery image was taken in March 2023. It is important to note that this image represents one of the samples from the fire-affected area on Evia Island. The composite Landsat 654 image displays dark tones and blackish-brown shades within the burnt regions.

Prior to the fire, the forested area displayed green and light green hues. In March 2023, the image reveals a greenish colour, though not entirely identical to its pre-fire state.

Prior to the fire, the NDVI value spanned from 0.09 to 0.46, with an average of 0.27. Following the fire, the NDVI value decreased within the range of 0.01 to 0.25, averaging at 0.04. During the recovery phase, the NDVI value ranged from 0.04 to 0.38, with an average of 0.17. These NDVI values indicate that ecological conditions at the fire site have not fully recovered. The fire's severity is quantified by its magnitude value, specifically at 0.21 (as depicted in **Figure 109**). This magnitude value stands as the highest among all fire locations within the pilot area. The fires on Evia Island were predominantly concentrated in the southern part of area, with their magnitude gradually decreasing towards the northwest part.

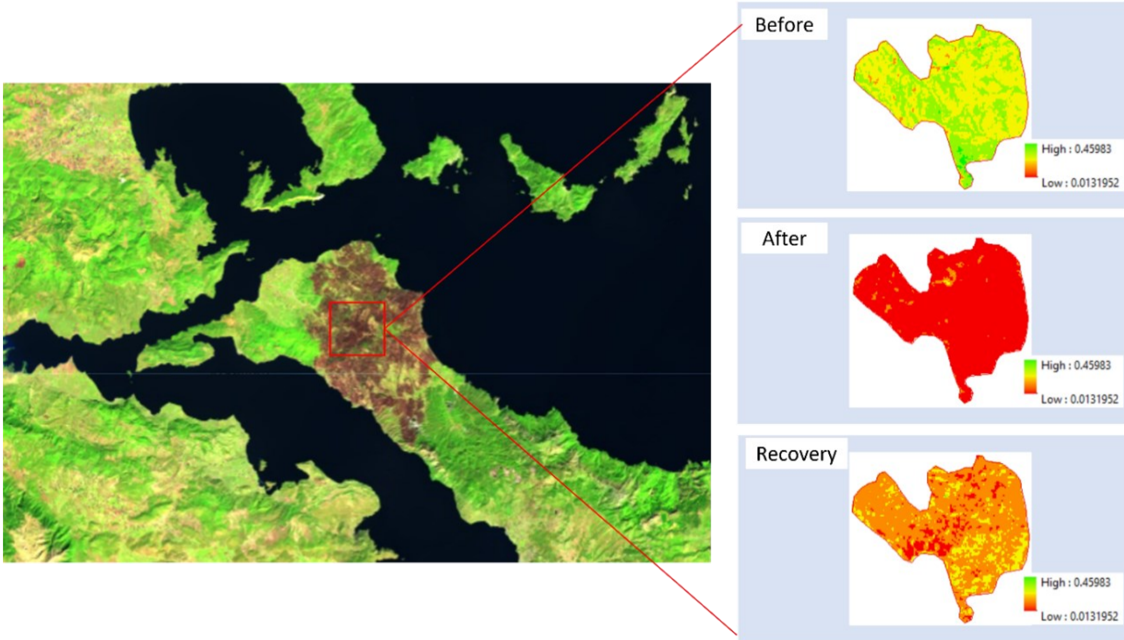


Figure 109. NDVI distribution in Sterea Ellada (Evia Island) before forest fire, after forest fire and recovery phase

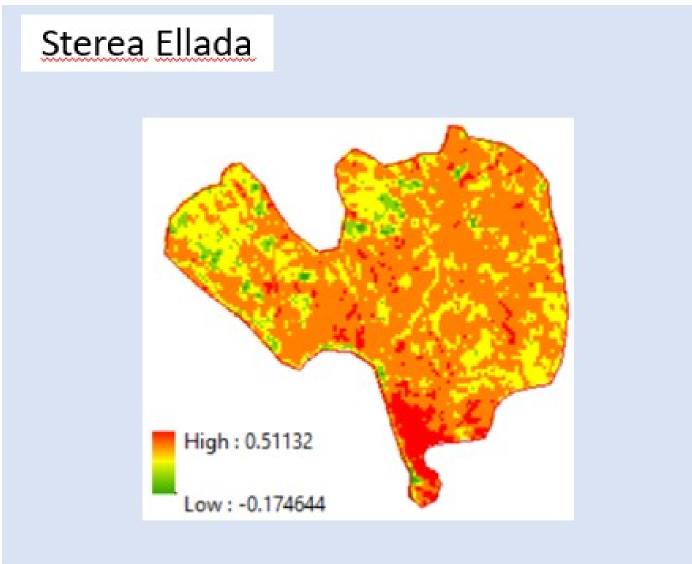


Figure 110. Spatial distribution of magnitude in Sterea Ellada (Evia Island)

It has been determined that the malleability value for Evia Island stands at 0.34. This value signifies a relatively stable ecosystem on Evia Island. To estimate the duration needed for Evia Island's full recovery, we used the elasticity indicator (refer to **Figure 111**). Evia Island experienced a recovery period spanning 19 months, and ongoing maintenance is necessary to facilitate the ecosystem's return to its normal state. Notably, the highest elasticity values are observed in the westernmost part of the fire-affected area, indicating a faster recovery in this region. Conversely, the central area of the fire site exhibits lower elasticity values, suggesting a more prolonged recovery process. In the southern part of the affected area experienced highest magnitude but relatively showed higher recovery and elasticity. It is indicated that the southern part of the affected area is more resilience than the northern part.

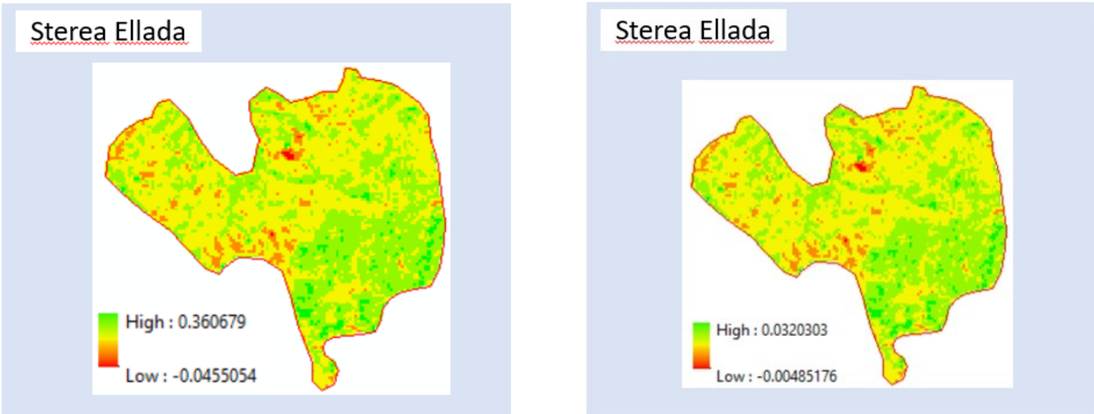


Figure 111. Recovery and elasticity distribution in Sterea Ellada (Evia Island)

Figure 112. NDVI Trend Analysis in Sterea Ellada

NDVI trend in Sterea Ellada was increasing from the initial state until the recovery. It was not statistically significant. NDVI in Sterea Ellada was fluctuated from time to time.

6.3.2.4 Cova Da Beira – Portugal

Cova de Beira represents a subtropical dry forest ecosystem within a region characterized by a hot-summer Mediterranean climate. The resilience assessment in this report focuses on a single fire event which occurred in September 2017. **Figure 113** provides visual documentation of the area's appearance before the fire, immediately after the fire, and during the recovery period. The pre-fire image was captured in May 2017, while the post-fire recovery image was taken in September 2019. It is important to note that this image serves as sample location on the Cova de Beira region. In the composite Landsat 654 image, the burned areas exhibit dark tones and blackish-brown hues, in contrast to the lush green and light green hues that characterized the forested areas before the fire. By September 2019, the image revealed a return to the pre-fire coloration, indicating signs of recovery in the ecosystem.

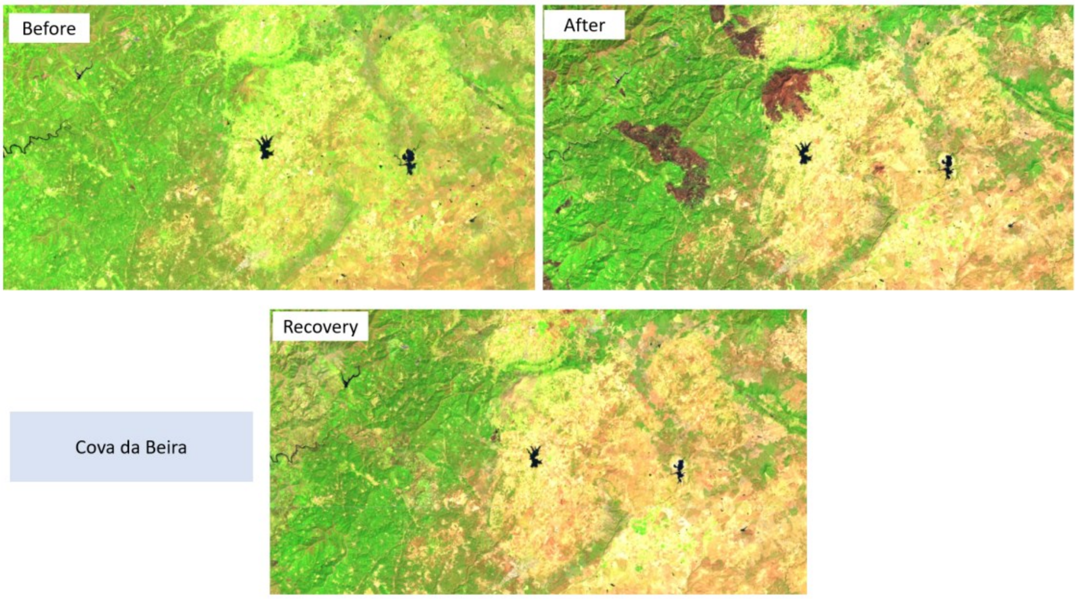


Figure 113. RGB 654 Landsat 8 Composite Image at Cova de Beira before forest fire, after forest fire and recovery phase

Prior to the fire, the NDVI value ranged from 0.02 to 0.51, with an average of 0.26. After the fire, the NDVI value dropped within the range of 0 to 0.47, with an average value of 0.06. The extent of fire severity is reflected in a magnitude value of 0.2 (**see Figure 115**). A higher magnitude value corresponds to a more intense level of fire severity. In the case of the Cova de Beira fire, it was primarily concentrated at the edge, and the magnitude value gradually decreased toward the centre of the fire-affected area.

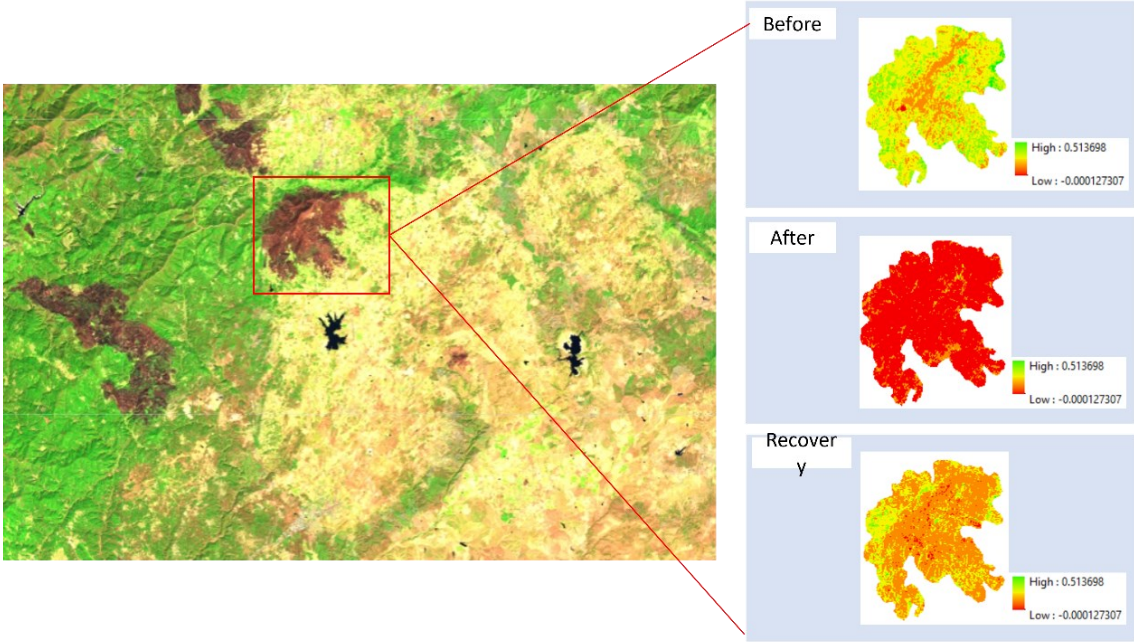


Figure 114. NDVI distribution in Cova de Beira before forest fire, after forest fire and recovery phase

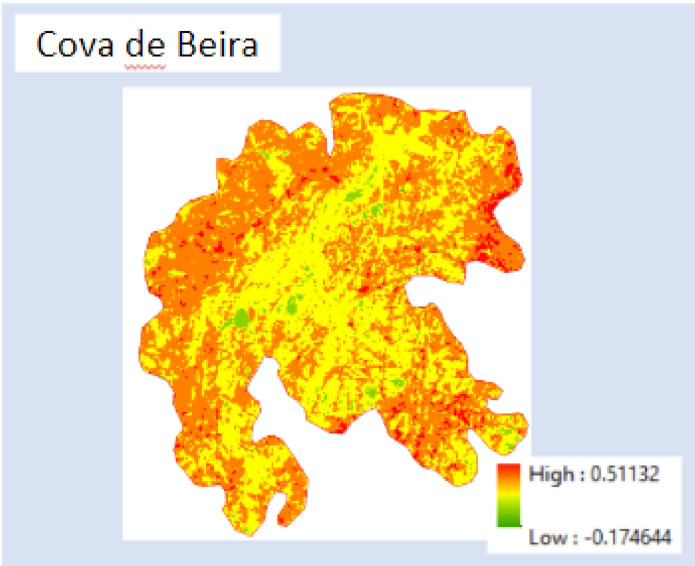


Figure 115. Spatial distribution of magnitude in Cova de Beira

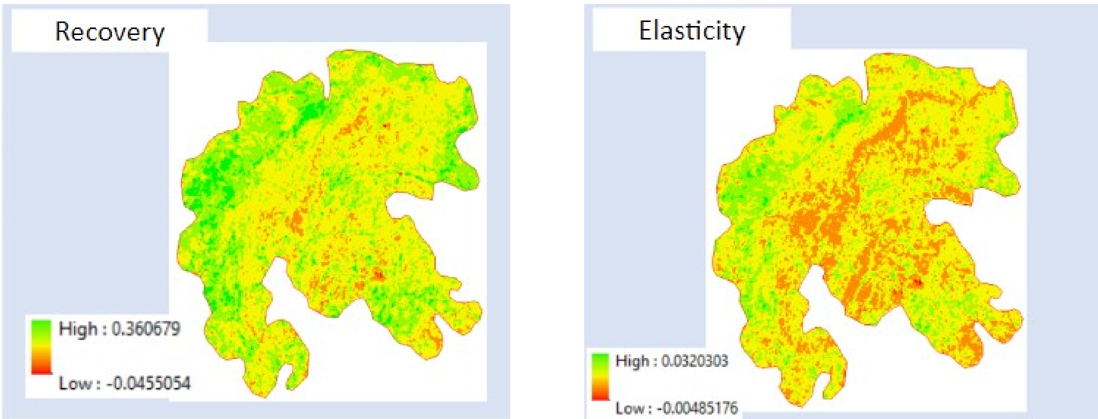


Figure 116. Recovery and elasticity distribution in Cova de Beira

Based on calculation, it was determined that Cova de Beira possesses a malleability value of 0.35. This malleability value represents as an indicator of the ecosystem's stability. In this context, a value of 0.35 indicates that Cova de Beira maintains a relatively stable ecosystem. To estimate the duration required for the forest to return to its normal state, we used the elasticity indicator (refer to **Figure 116**). Cova de Beira, in this regard, took a recovery period lasting 25 months. Notably, the highest elasticity values are observed in the westernmost part of the fire-affected area, implying a faster recovery in this region. Conversely, the centre area of the fire site exhibits lower elasticity values, signifying a slower pace of recovery. The western part of the fire-affected area tends to have higher magnitude, yet it results higher recovery and elasticity. In contrast, the central part experienced lower fire severity but resulted in lower recovery and elasticity. This observation highlights that the western part tends to be more prone to fire but faster to recover. Contrarily, the central area tends to be less prone to fire but need a longer duration to recover. It can be inferred that western part of the area has the higher resilience than the centre part. This result could be influenced by various factors that characterized each area.

Based on the Portugal forest fire hazard map, Cova de Beira region have been classified as the priority zone for fuel management in context of fire prevention by the government. In 2017 was a major fire occurred in Portugal, which destroying more than 12,000 ha in the pilot area, and more than 60 people have died. Since then, according to the Portuguese Law n. 76/2017 owners, tenants, or entities that, for whatever reason, hold land adjacent to buildings in rural spaces, are obliged to proceed with fuel management. Based on the climate data from ERA5 (see the description of pilot area), annual temperature in 2017 was the highest during 2000-2020. his has implications for a high FWI (Fire Weather Index) value of 30.4, which is classified as high danger.

NDVI trend in Cova de Beira was increasing from the initial state until the recovery. It was not statistically significant. NDVI in Cova de Beira was fluctuated from time to time.

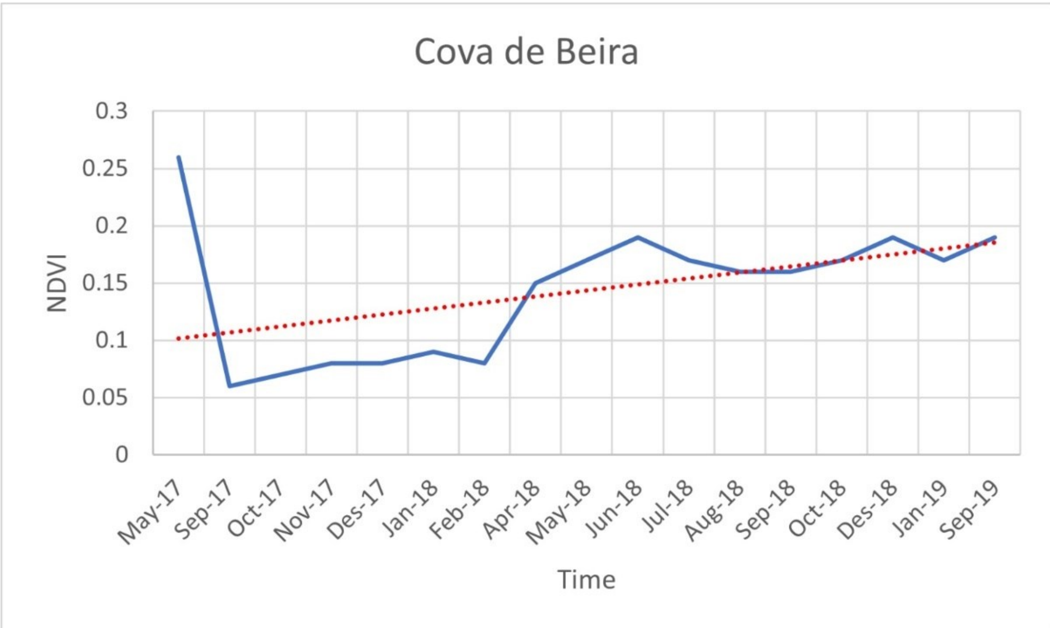


Figure 117. NDVI Trend Analysis in Cova de Beira

6.3.2.5 Podpolanie – Slovakia

Podpol'anie is a subregion located within Slovakia, characterized by temperate continental forests nestled in the Carpathian Mountains and Plains. A sample case of forest fire occurred in April 2019, and **Figure 118** provides a visual representation of the landscape before the fire, after the fire, and during the recovery phase. The image taken prior to the fire was in July 2018, while the image capturing the recovery process was in August 2022.

In the composite Landsat 654 image, the burned area is apparent through its dark tones and blackish-brown colors, clearly distinguishing it from other regions. The forested areas exhibited shades of green and light green prior to the fire, and by August 2022, the image displayed a return to the pre-fire condition.

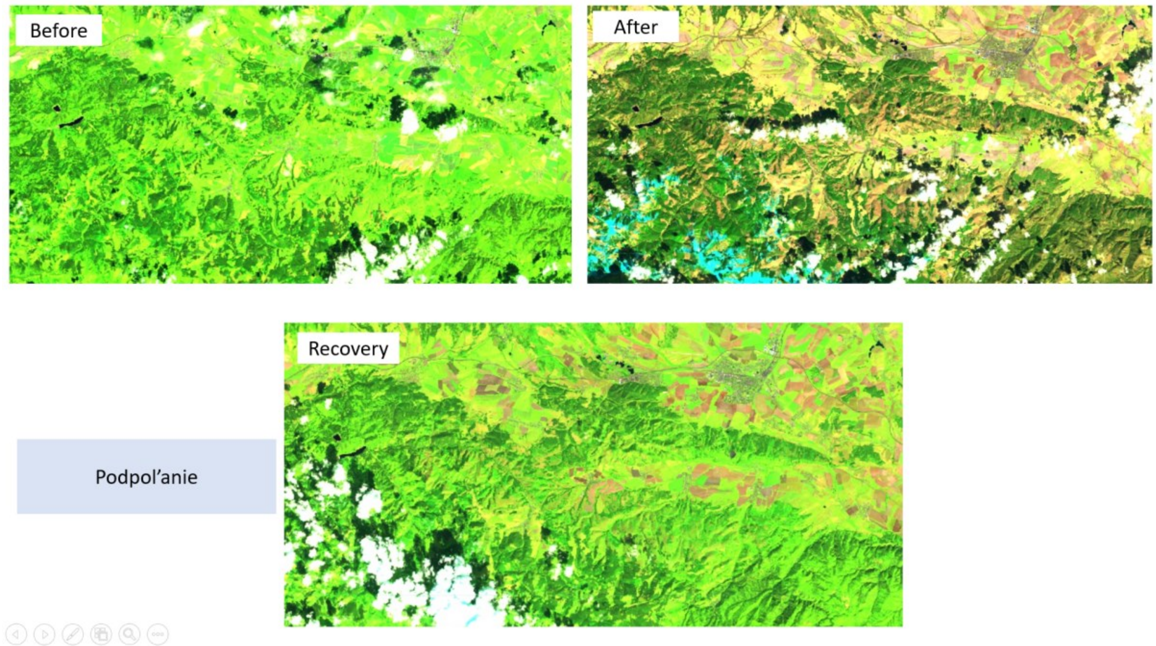


Figure 118. RGB 654 Landsat 8 Composite Image at Podpol'anie before forest fire, after forest fire and recovery phase

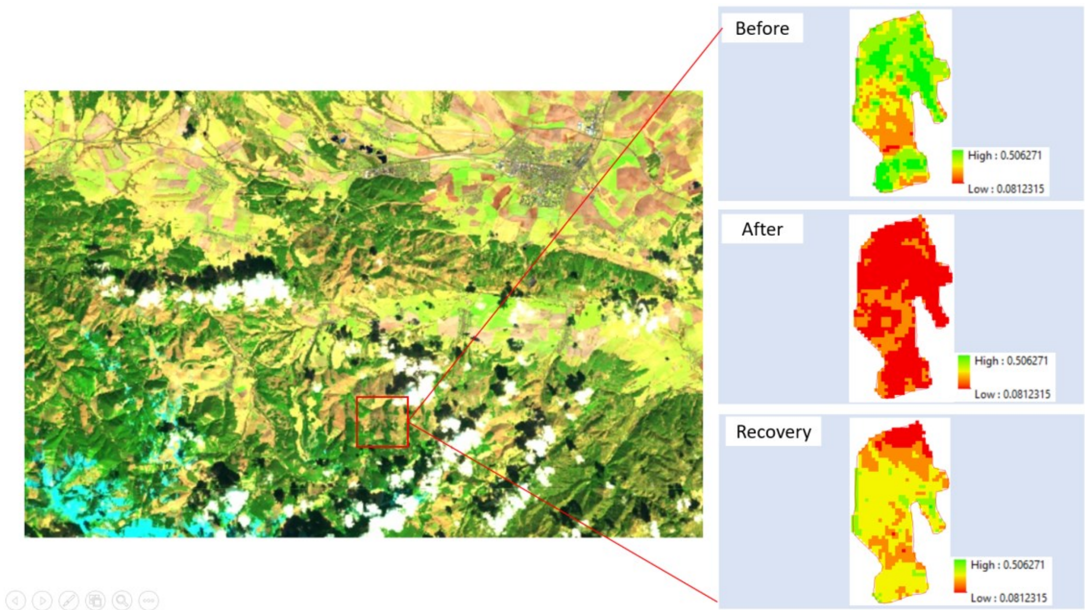


Figure 119. NDVI distribution in Podpol'anie before forest fire, after forest fire and recovery phase

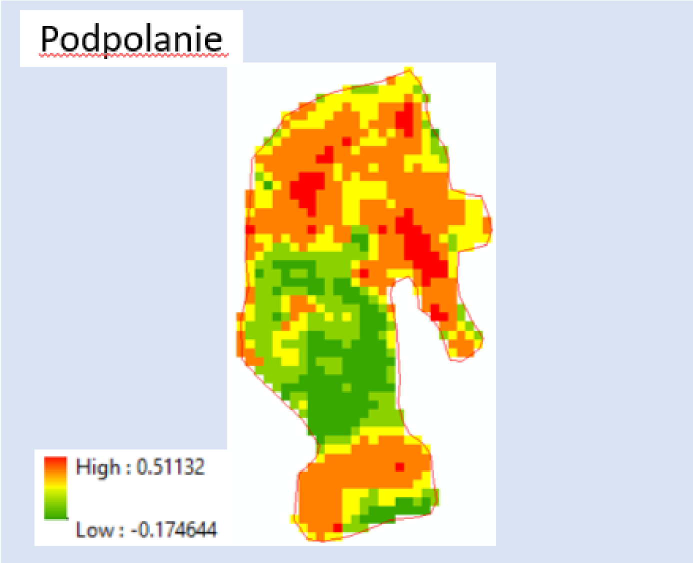


Figure 120. Spatial distribution of magnitude in Podpol'anie

The fire took place around Pol'ana, and the calculated NDVI value before the fire ranged from 0.15 to 0.51, with an average of 0.34. After the fire, the NDVI value decreased to a range of 0.08 to 0.23, with an average of 0.15. The fire's intensity is represented by a magnitude value, specifically at 0.19 (as depicted in **Figure 120**). When compared to other forested regions, this magnitude value is relatively high, indicating a more severe level of fire. A higher magnitude value corresponds to greater fire severity. The fires that occurred in Podpol'anie were primarily concentrated in the northern area, with the magnitude value gradually diminishing in the central part of the fire-affected area.

It has been determined that Podpol'anie possesses a malleability value of 0.19, indicative of a relatively stable ecosystem in this region. When estimating the duration required for the forests to return to their stable state, we used the elasticity indicator (as illustrated in **Figure 121**). Notably, Podpol'anie took a 41-month recovery process. The lowest elasticity values were observed in the northern direction, situated in the outermost part of the fire-affected area. This indicates that this area needs longer recovery period. Conversely, areas characterized by moderate to high elasticity values are situated in the southern part of the affected area.

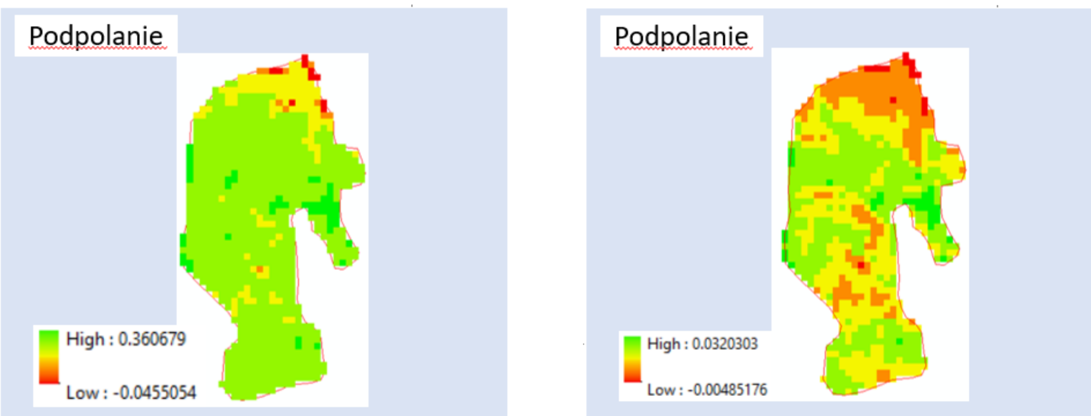


Figure 121. Recovery and elasticity distribution in Podpol'anie

Podpol'anie has a trend that tends to be stable and not statistically significant. The NDVI value appears to fluctuate from the initial state until recovery.

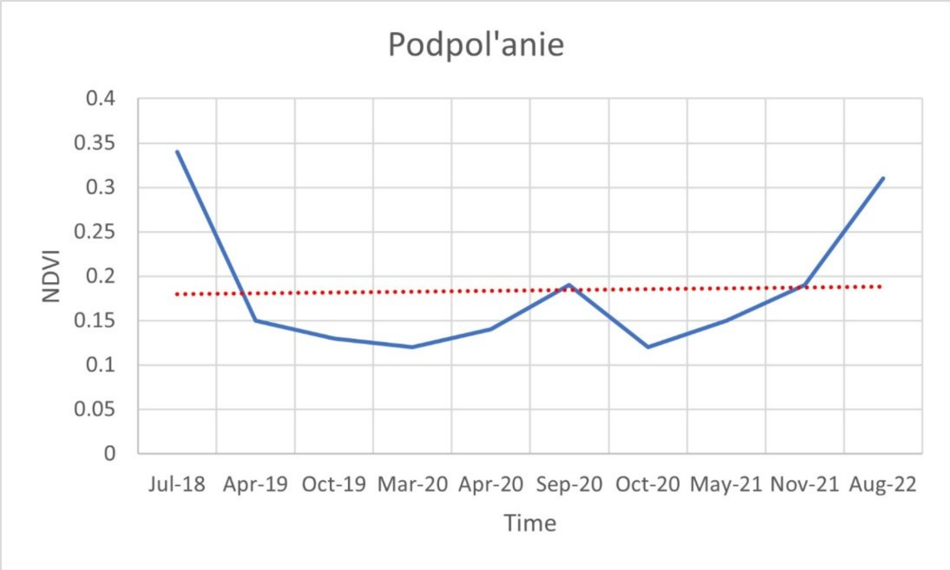


Figure 122. NDVI Trend Analysis in Podpol'anie

6.3.2.6 Sebangau National Park – Borneo, Indonesia

Sebangau National Park is situated within the Kalimantan tropical rainforest bioregion. This region comprises flat, low-lying alluvial floodplains, which are prone to periodic flooding, resulting in seasonal inundation. Sebangau National Park frequently experiences fire events, particularly surface fires with a high frequency. During the dry season of 2015, along with the El Niño phenomenon, Sebangau National Park suffered from quite severe fires. The unique nature of the peat soil around the Sebangau National Park makes it highly flammable, making firefighting challenging due to the sub-surface source of the fires.

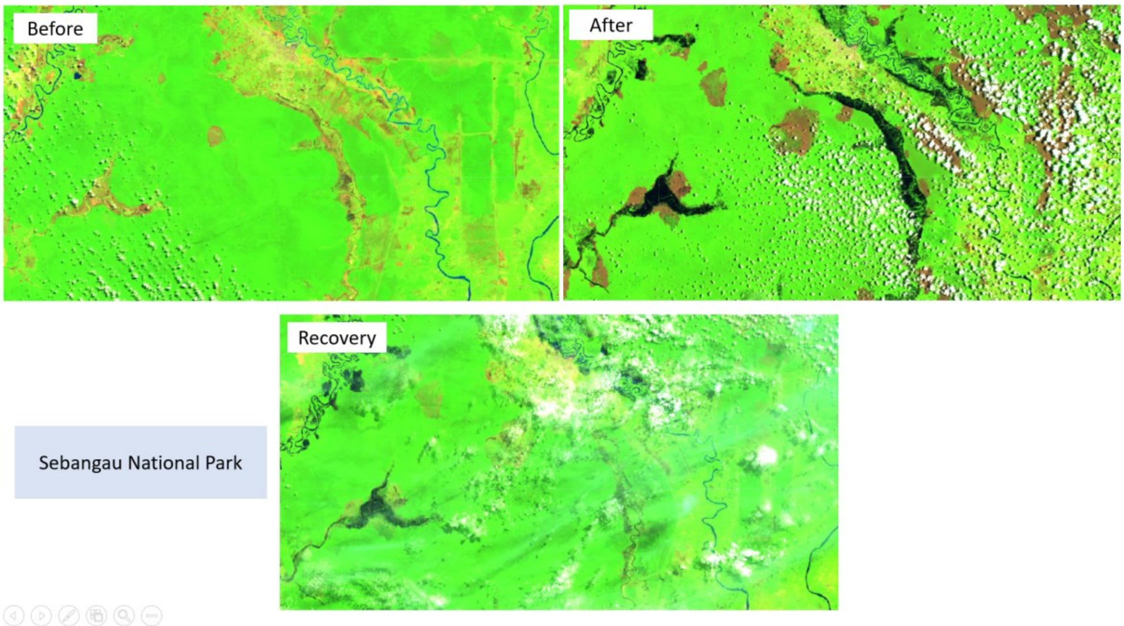


Figure 123. RGB 654 Landsat 8 Composite Image at Sebangau National Park before forest fire, after forest fire and recovery phase

The fires occurred at multiple locations within Sebangau National Park. **Figure 123** represents the visual landscape before the fire, after the fire, and during the recovery phase. The pre-fire image was captured in August 2015, while the image of recovery process was taken in July 2017. This location was a representative sample of a fire-affected location within Sebangau National Park. In the composite Landsat 654 image, it displayed that contrasting dark tones and blackish-brown colors within the burnt areas, in sharp contrast to the green and light green hues that characterized the forested regions before the fire. By July 2017, the forest recovered into the stable conditions.

Before the fire, the NDVI values exhibited a range of 0.04 to 0.65, averaging at 0.36. After the fire, the NDVI values declined within the range of 0.04 to 0.40, with an average of 0.18. The extent of fire severity is represented by the magnitude value, specifically at 0.19 (as depicted in **Figure 125**). Sebangau National Park displayed relatively high levels of fire severity and damage. The fires that occurred within Sebangau National Park showed high magnitude values that were uniform across most fire locations. Only in certain areas did the magnitude value gradually decline.

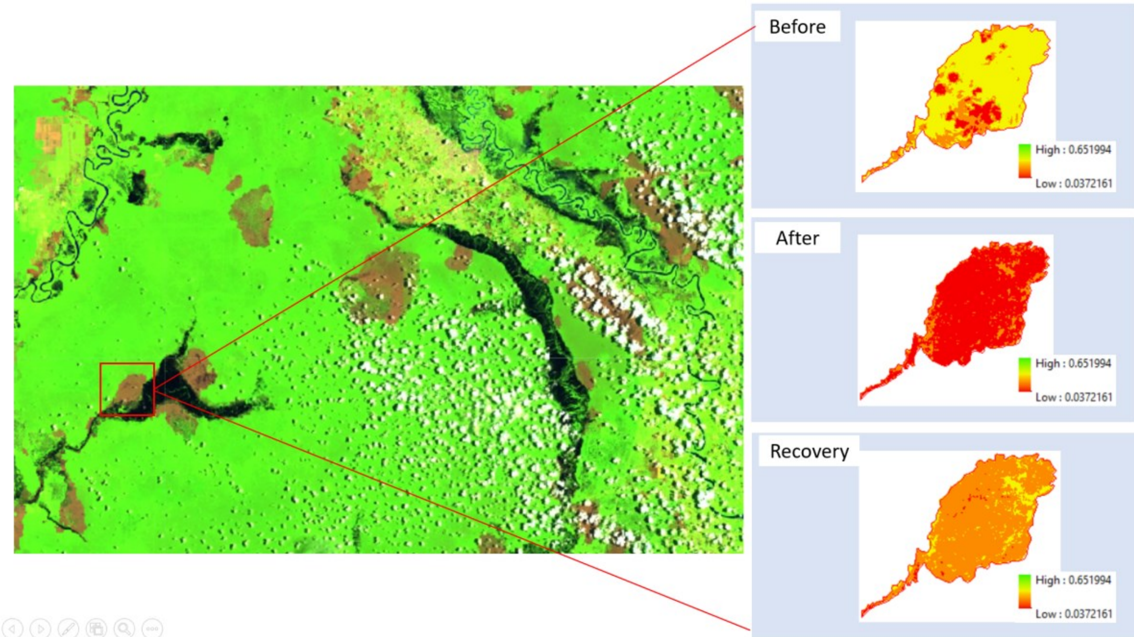


Figure 124. NDVI distribution in Sebangau National Park before forest fire, after forest fire and recovery phase

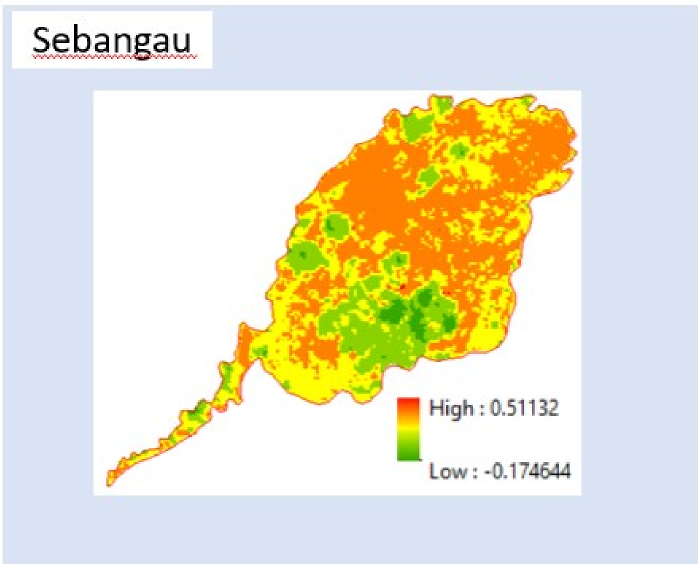


Figure 125. Spatial distribution of magnitude in Sebangau National Park

Based on calculations, the malleability value in Sebangau National Park is 0.42. In comparison to other pilot areas, this value is relatively high. A higher malleability value suggests that the forest ecosystem is less stable and prone to changes more easily by the disturbance. The recovery period for Sebangau National Park took 21 months. Sebangau National Park has lower elasticity value among various forest types, it reflects a limited capacity for adaptation and changes in ecosystem conditions following a fire event. Particularly, elasticity values are declined in the northern and southernmost outer regions of the fire-affected area. In contrast, the central area of the fire boasts a higher elasticity value, indicating a swifter pace of recovery.

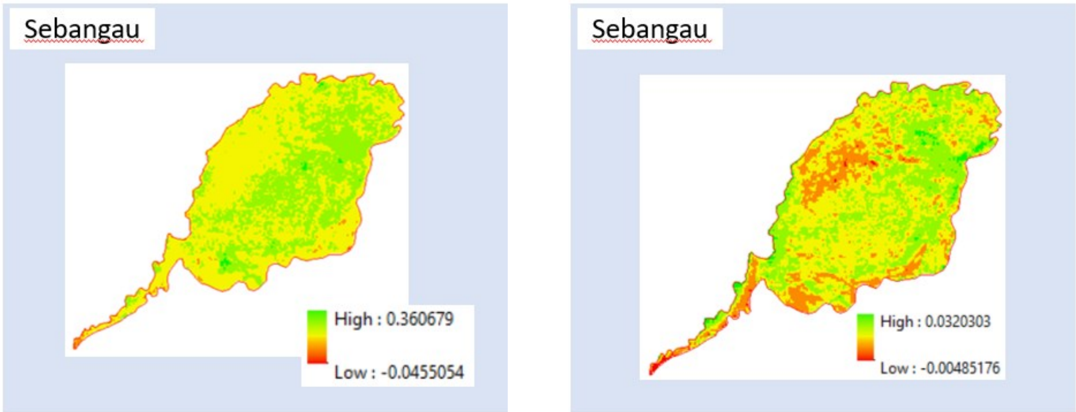


Figure 126. Recovery and elasticity distribution in Sebangau National Park

Trend analysis was conducted for NDVI time series data from the initial state until the recovery process. This data was obtained by Landsat satellite images with maximum 20 % cloud cover. Cloud cover become a problem in satellite image data acquisition in Indonesia as a tropical country with abundance rainfall. NDVI trend in Sebangau was stable during the initial state until the recovery. However, it was not statistically significant.

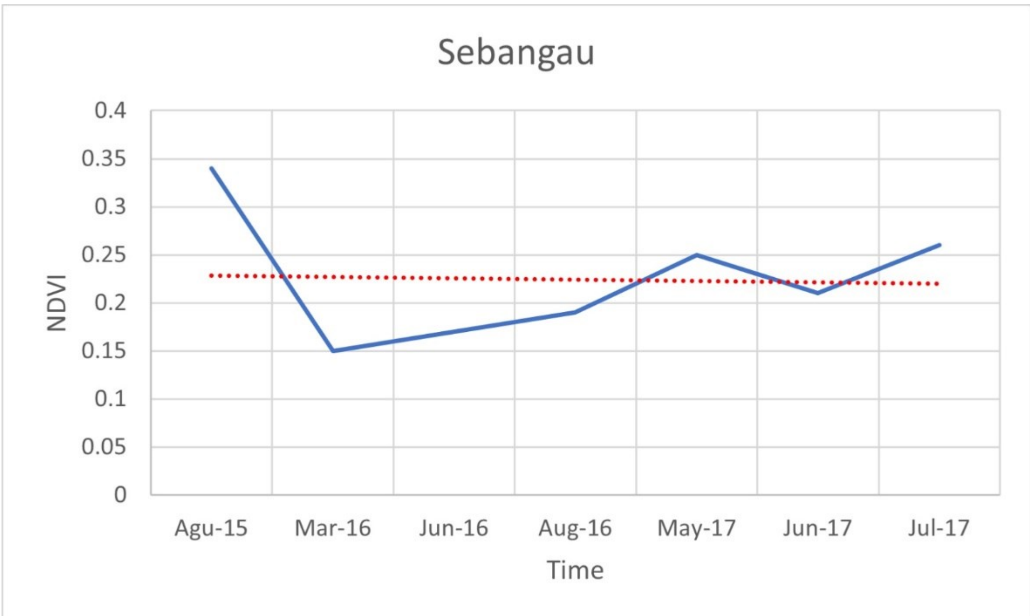


Figure 127. NDVI Trend Analysis in Sebangau National Park

7 Conclusion

Generally, in European pilot, natural regeneration becomes a priority of post-wildfire restoration. Natural regeneration needs more time to rebound to the forest's historical condition but presents a better possibility of a higher rate of biodiversity. Artificial (non-natural) regeneration is made in cases where natural regeneration has not given specific results, or the area is burnt again due to the regenerated trees burning again. The response of this artificial regeneration improves the speed of forest rehabilitation. It can be explained in the resilience monitoring. Maintaining native species and avoiding introducing non-native species has also become the focus of rehabilitation programs. European pilot, in general, prohibits land conversion for new activities after a wildfire. Only safety-related activity and protection of the land are allowed in burnt areas.

Besides the general approach, some variations of European pilots are identified. For example, Tepilora has three-time frames: 15, 10, and 5 years constraints. The first five years of artificial reforestation are prohibited, allowing five years of natural regeneration. In Podpoľanie, a 2-year time frame is given to reforest, focusing on keeping native species. There are no specific time frames in the Cova da Beira pilot; according to their wildfire rehabilitation history, the natural regeneration has been carried out since the wildfire event in 1983 and 1995, while the assisted rehabilitation was carried out in 2003 by shrub clearing and planting. Another approach presented in Gargano Pilot is the decision of rehabilitation based on the size and severity of the wildfire. For example, low intensity in small areas will be treated with fully natural regeneration. In contrast, low intensity in large areas needs tree removal along the road area only and assisted substitution of progressive substitution of conifers by indigenous hardwoods.

Non-European pilot in Sebangau National Park takes different activities for rehabilitation purposes. Natural and artificial regeneration is carried out, but those options have no specific priority due to the peatland condition where the amount of water contained in the canal blocking infrastructure is developed to keep the water wetting the peatland to avoid fire.

Biodiversity is an essential variable in forest management. Maintaining a rich level of biodiversity becomes one of the forest management goals. Biodiversity scope can be considered individual species, community, and landscape level. Wildfires affect most individual species in the forest and potentially affect the function of the forest. In monitoring the important variables of biodiversity, remote sensing provides an opportunity to assess the impact of wildfire on the landscape level over time. In all pilot areas, the ecological resilience has been evaluated employing vegetation parameters suitable to be measured through remote sensing.

The ecological resilience variables to be considered are malleability, elasticity, and trend. Malleability refers to ecological degradation after periods of restoration compared to that before the disturbance. The elasticity is also calculated as the capacity of the forest to soil rebound after being damaged by wildfire. The graph representation of ecological resilience shows that even though the threat to the ecosystem (represented by FWI) has a higher value, the forest shows a different response. Some forests under observation, such as Gargano, Tepilora, Sterea Ellada, Cova de Beira, and Podpol'anie, are considered more robust in facing the threat that shows the robustness of the forest. Each forest's recovery speed represents the capacity of forest response after the wildfire. Some pilots need shorter periods to recover due to many factors, such as the magnitude of wildfires and the programs implemented in the pilot. In contrast, some observed pilots find it hard to recover their conditions due to recurrent wildfires.

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