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Biodiversity-focused post-fire ecosystem restoration guidelines

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Glossary

Abiotic components: Non-living components of the ecosystem (for example nitrogen elements, light, soil texture).
Mediterranean-type ecosystems: Ecosystems with a Mediterranean climate and similar vegetation physiognomy located on five continents worldwide. Mediterranean-type ecosystems are found in California, the Mediterranean basin, Chile, South Africa, and southern and western Australia.

Active restoration: Conducting activities during ecosystem restoration (seeding after fire, planting seedlings, mechanized operations).

Succession: Changes in the composition and structure of vegetation and other living groups in an area after any ecological intervention.

Biodiversity: It is the diversity of living organisms, the ecological environments (terrestrial, aquatic, marine) in which those organisms live, and the ecological processes supported by those environments and organisms. It includes intraspecific, interspecific, and interecosystem diversity.

Biotic components: Living components of the ecosystem (herbivores, carnivores, predators).

Resilience: The capacity of species, communities or ecosystems to recover after a disturbance such as fire, drought, grazing.

Ecosystem restoration: Attempting to restore an area that has been destroyed for any reason reaches its potential in terms of species composition, structural features, ecosystem dynamics, and ecosystem services.

Mega fires: Large fires that deviate from traditional or historical fire regimes in terms of size, damage and magnitude, damaging human socioeconomics and having the potential to slow the restoration of ecosystems.

Surface fire: A low-size fire that burns living and dead cover at the grass and shrub layer of the forest, but does not damage the trees at the crown of the forest.

Passive restoration: Restoration without engaging in activities during ecosystem restoration (for example, laying down branches after a fire, leaving alone tree groups).

Crown fire: Moderate or high-intensity fire burning trees in the upper part of the forest.

Fire-prone environments: Ecosystems on Earth that have enough temperature and precipitation to accumulate a sufficient fuel load and have dry periods during the year; hence, ecosystems where fires can occur.

Fire frequency: A measure of how often fires occur in an area over time.

Fire intensity: A measure of the magnitude of a fire in an area.

Executive summary

Our world is facing two major crises: the climate crisis, and the biodiversity crisis. We are experiencing the negative impacts of the climate crisis with increasing intensity – drought, flooding, an energy crisis caused by heat waves, health problems, and forest fires. Biodiversity plays a crucial role in combating these negative factors. Biodiversity and ecosystem services, and nature-based solutions provided by ecosystems, play a critical role in overcoming many problems. Forest ecosystems have a vital role in terms of these services and solutions. However, climate change negatively affects forest ecosystems, within the framework of different dynamics. It is imperative to reduce this impact and increase the resilience of forest ecosystems. Therefore, protecting and strengthening forest biodiversity should be one of the main objectives of forest management. This guideline has been prepared in cooperation with Doğa Koruma Merkezi (DKM), the Food and Agriculture Organization of the United Nations (FAO), and the General Directorate of Forestry (OGM) of Türkiye, to carry out forestry practices by considering forest biodiversity after wildfires and thus creating more resilient forests to climate change.

The Mediterranean region of Türkiye has been experiencing frequent wildfires, primarily caused by a combination of dry summer periods and human activities – 2021 witnessed devastating mega fires, resulting in significant economic, societal, and ecological impacts. While wildfires can cause immediate damage, they also play a crucial role in shaping ecosystems and promoting biodiversity.

The effects of wildfires on Mediterranean ecosystems are diverse. They can include vegetation consumption, the mortality of animals, and alterations in landscape structure and resource availability. While wildfires can cause significant damage, they are also a natural part of many ecosystems and can promote biodiversity by creating mosaic landscapes and facilitating the lifecycles of certain species. However, mega fires can push ecosystems beyond their resilience limits, resulting in biodiversity loss and disruptions to ecological processes.

The recovery of Mediterranean ecosystems after a fire is influenced by various factors, including fire intensity, frequency, pre-fire conditions, and climate. While these ecosystems generally possess strong resilience and the ability to regenerate naturally, some may require human intervention for effective restoration. Post-fire management strategies in Mediterranean countries vary based on ecological dynamics, local regulations, and economic considerations. Examples from Spain, Greece and Türkiye demonstrate a balance between financial concerns and ecological knowledge. Techniques such as soil stabilization, natural regeneration, and reseeding and replanting are commonly employed to aid ecosystem recovery. While some interventions can negatively impact biodiversity, passive restoration techniques often yield the best results for promoting biodiversity and ecosystem recovery.

The areas burnt in Marmaris and Köyceğiz forest management directorates in Muğla province in 2021 were selected as pilot sites for post-fire management evaluation. In both places, passive restoration techniques – including natural regeneration and additional seeding – proved to be the most effective approach for ecosystem regeneration, particularly in burnt Turkish red pine forests. Active restoration methods such as mechanized land preparation and planting were found to be expensive, and challenging to implement, due to the rugged topography of the pilot sites.

Overall, post-fire management decisions in Mediterranean ecosystems should consider the ecological basis of the region, emphasizing passive restoration techniques to ensure successful ecosystem recovery and preservation of biodiversity. Collaborative efforts involving local communities and a thorough understanding of ecological dynamics are essential for effectively conserving and managing fire risk areas. It is important to address all post-fire processes holistically. This can be achieved through a post-fire ecosystem restoration plan (post-fire restoration plan). A team of experts should prepare such a plan, and all implementation processes should be carried out under the supervision of this team.

These guidelines have been discussed in draft form during the workshop conducted within the scope of the Restoration of Post-Fire Forest and Maquis Ecosystems in Muğla Province (TCP/TUR/3902/C2) Project – with the participation of the OGM Ecosystem Services Department, relevant branch managers from Muğla Regional Directorate of Forestry, Köyceğiz and Marmaris forest management directorates, and DKM experts – and finalized on the back of the comments and decisions taken. It is the first comprehensive study on biodiversity-based post-fire restoration in our country. It is possible that new information may emerge and the guidelines enriched with new information based on further studies.

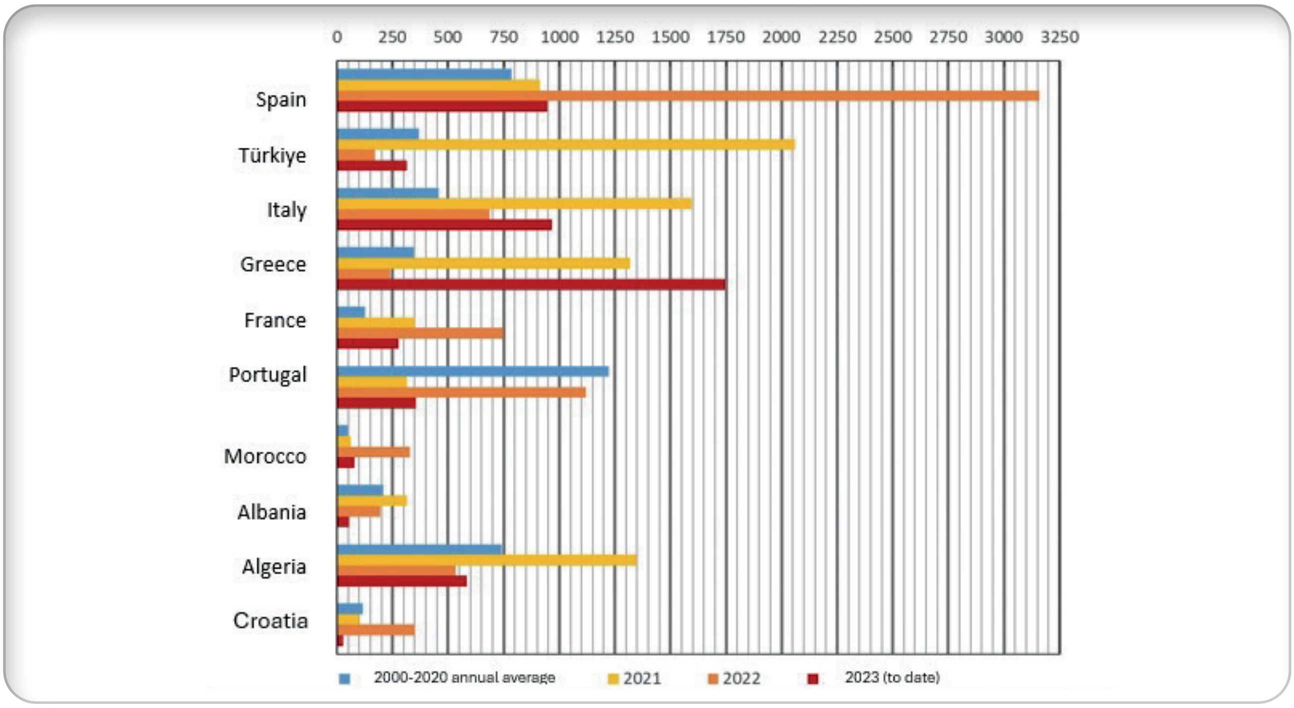
Introduction

Mediterranean Türkiye has been subjected to frequent wildfires, the prevalence of which is due to a combination of long, dry summer periods and an abundance of both natural and human-made ignition sources. These fires occur predominantly due to human activity (more than 80 percent), with common sources including discarded cigarettes, power lines, and agricultural burnings, although some fire events occur due to lightning. Wildfires in the Mediterranean region affect both forests and scrublands. Turkish red pine (*Pinus brutia*) forests are often subject to large fires, whereas scrublands vegetation, such as scrub and phrygana, experience more frequent, localized fires.

In recent years, more extreme wildfire events – commonly referred to as mega fires (Kavgacı *et al.*, 2023) – have been occurring with increased frequency (Figure 1). This escalation can be attributed to a variety of factors, including climate change, longstanding forestry policies, and socioeconomic changes that have occurred over recent decades (Viedma *et al.*, 2017; Atmış, Tolunay and Erdönmez, 2023; Türkeş and Tolunay, 2023). The year 2021 proved to be the most devastating fire season in the history of Türkiye, with more than 150 000 ha of forest and scrublands being consumed by flames (Figure 1). Several villages and parts of larger human settlements were destroyed, making the 2021 mega fires the costliest in terms of economic damage in Türkiye's history.

The ecosystems of the Mediterranean basin have been shaped by human influence for thousands of years; natural landscapes and anthropogenic rural landscapes often coexist in these regions. Natural succession and accompanying afforestation activities, due to changes like rural–urban migration – which have taken and are taking place in many Mediterranean countries – have transformed relatively open Mediterranean habitats that humans have shaped for thousands of years into more closed habitats (Chergui *et al.*, 2018). Therefore, habitat homogenization and forest areas have increased in these landscapes. This has led to more uniform and continuous forest areas, eliminating habitat breaks in the horizontal plane in landscapes shaped by humans in the past. Wildfires, which could previously spread over relatively limited areas, can now spread over more expansive areas, leading to mega fires. In addition to the changes in landscape structure, climate change-induced factors such as temperature increase

Figure 1. Size of areas (km^2) affected by fires in Mediterranean countries since 2000



Source: EFFIS, Data and services. (n.d.), Retrieved 9 October 2023, https://forest-fire.emergency.copernicus.eu/applications/data-and-services

and the prolonged and intensified dry period, have also contributed to the growth of wildfires in the Mediterranean basin. Thus, in relatively economically developed Mediterranean countries over recent decades, there has been a shift from fire regimes limited by combustible material to those controlled by climatic conditions (Pausas and Fernández-Muñoz, 2012). This has occurred in different Mediterranean countries over different periods (Chergui *et al.*, 2018). In addition, fire suppression activities, which have been practised in Mediterranean countries for nearly a century, have led to the accumulation of combustible material in the long term, creating the conditions for the occurrence of larger fires (Moreira *et al.*, 2020). Land-use changes that make larger and uniform forest areas through afforestation activities, and fire management policies focused on fire suppression and the accompanying climate change, are the leading causes of mega fires in the Mediterranean basin today (Tavşanoğlu, 2021a).

The significant economic, societal and ecological consequences of the mega fires of 2021 have caused widespread concern among the public, leaders, media outlets, and the scientific community. These concerns about the impacts of the fires are natural. However, to rationalize post-fire actions, forest fires should be evaluated from a dual perspective (Pausas *et al.*, 2008). First, the immediate aftermath can be devastating, leading to an apparent loss of flora and fauna; these events can also initiate an ecological renewal period. Second, wildfires should not only be considered catastrophic despite the immediate visual devastation. Fires are a natural part of life in many ecosystems, including in the Mediterranean region of Türkiye. Therefore, the approach should balance the immediate damage caused with the integral role of fire in shaping these ecosystems over time.

In many ways, fire is a critical component of Mediterranean ecosystems, which have co-evolved with fire over millennia (Keeley *et al.*, 2012). Fires can facilitate biodiversity by creating mosaic landscapes and breaking up uniform vegetation, allowing for greater species richness. Some species are specifically adapted to fire-prone environments, utilizing fire to facilitate their life cycles; for example, certain plant species require the heat of and smoke from a fire to trigger seed germination (Paula *et al.*,, 2009; Moreira *et al.*, 2010; Tavşanoğlu *et al.*, 2017).

Despite these fire–ecosystem interactions, mega fires can push ecosystems past their resilience limits, especially when combined with other factors such as climate change and human interventions (Linley *et al.*, 2022). These intense fires can threaten species, disrupt ecological processes, and cause significant biodiversity loss (Geary *et al.*, 2022). The patches of burnt and unburnt areas in the landscape left after a fire can profoundly affect the recovery and recolonization of species. Understanding this dual nature of fire is crucial for developing balanced perspectives and effective post-fire management strategies.

Mediterranean ecosystems generally have a strong resilience against fire due to their evolutionary history (Lavorel, 1999). Post-fire landscapes can quickly recover as native species begin the regeneration process. In the short term, this can manifest itself in the rapid emergence of plant species that profit from the post-fire conditions to reproduce, and the re-appearance of several shrubs resprouting below-ground organs that are not affected by fire (Keeley *et al.*, 2012; Kavgacı *et al.*, 2016; Ergan, 2017). Over the long term, fire can set the stage for successional processes that lead to ecosystem recovery (Kavgacı *et al.*, 2010; Tavşanoğlu and Gürkan, 2014) or, in some cases, to a new ecological (or vegetation) state (Pausas, 2015). These successional vegetation changes can lead to different animal species utilizing the recovering forest ecosystem to accompany the successional change (Kaynaş *et al.*, 2002). Therefore, vegetation regeneration after a fire provides a basic infrastructure for re-establishing animal communities (Arnan *et al.*, 2006). In particular, although the withdrawal of forest habitat-dependent species (such as some bird and large mammal species) from the area after the forest fire may be seen as a habitat loss, with the forest regenerating over time, these species may re-enter the burnt area from unburnt regions where they have taken refuge in the vicinity (van Mantgem *et al.*, 2015; Soyumert *et al.*, 2020). At this point, it is essential to note the importance of the plant species that dominated the area before the fire to return to the site and regenerate after the fire. This is the only way the ecosystem can regain its pre-fire structure over time. Otherwise, a change in the vegetation structure occurs. For example, Turkish red pine forests turn into scrub.

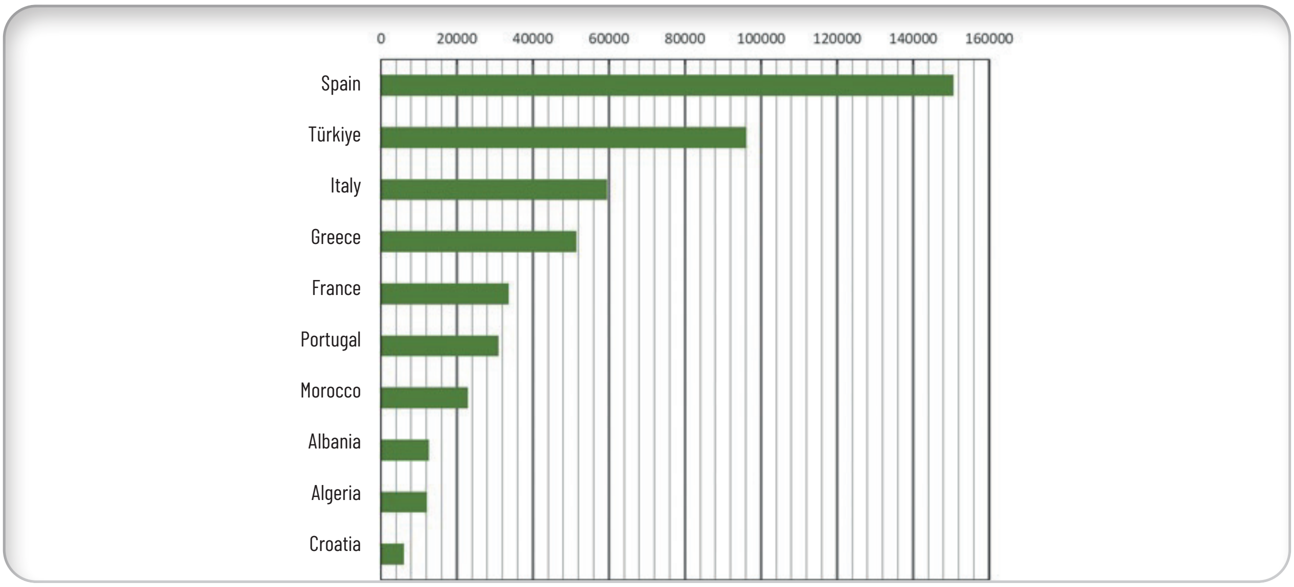
Post-fire recovery depends on several factors, including the size and frequency of the fire, the pre-fire state of the ecosystem, and ongoing climatic conditions (De Las Heras *et al.*, 2012; Vallejo *et al.*, 2012; Kavgacı *et al.*, 2016). Some ecosystems may require human intervention to aid their recovery, especially after severe or frequent fires. These interventions may include seeding and planting native plant species, controlling invasive species, and allowing rare and threatened species to repopulate the area. However, before any human intervention in fire-prone areas following a fire, the capacity of these ecosystems to regenerate naturally after a fire needs to be considered.

In summary, wildfires can play a critical role in the natural processes of ecosystems. The interplay of fire within an ecosystem is complex and multifaceted. Therefore, post-fire interventions and management decisions should be given by acknowledging this reality.

Effects of fires on Mediterranean ecosystems

Wildfires are an essential component of Mediterranean-type vegetation, which covers significant areas in many countries in the Mediterranean basin. These areas also affect millions of hectares of forest land under Mediterranean climatic regimes (Figure 2). Fire impacts Mediterranean ecosystems at multiple levels, affecting these systems' biotic and abiotic components. These impacts can be immediate or long term, direct or indirect. The most immediate and visible effects of fire include the consumption of vegetation, ranging from herbaceous plants to shrubs and trees. The extent of this destruction varies across Mediterranean basin ecosystems, depending on the intensity of the fire and the nature of the vegetation (Keeley *et al.,* 2012). For example, almost all above-ground biomass is affected in forest areas subjected to a high-intensity crown fire. In contrast, in forests subjected to low intensity surface fires, the tops of the trees in the higher layer are not damaged or partially damaged, while the shrub and grass layer can burn completely. Wildfires have direct effects on Mediterranean forests but also indirect effects, such as changing the habitat structure. Since burnt forest areas undergo a recovery process that lasts for many years (that is, successional change), different plant species become dominant in the forest area as time passes after the fire, allowing the forest to have other vegetation structures following the event. This temporal change also leads to different habitat structures for various plant and animal species. However, the recovery of areas with Mediterranean vegetation after fire depends on the dominant plant component of the vegetation exposed to fire, the type and intensity of the fire, and some other factors (aspect, rainfall, human intervention, and so on) that may affect natural regeneration in the area (Kavgacı *et al.,* 2016). For example, it takes at least 40 years for a Turkish red pine forest subjected to a crown fire to regenerate, while a scrub area reaches its pre-fire vegetation structure in less than ten years. This variability in the regeneration response of different Mediterranean vegetation to fire shows the importance of combining various approaches and plans specific to each situation, rather than a uniform approach in the post-fire management of these ecosystems.

Figure 2. Forest area of Mediterranean basin countries (km^2), 2021



Source: EFFIS, Data and services. (n.d.), Retrieved 9 October 2023, https://forest-fire.emergency.copernicus.eu/applications/data-and-services.

Bontemps *et al.*, 2009, 'GlobCorine – A joint EEA-ESA Project for Operational Change Detection at Pan-European Scale', Italy, https://land.copernicus.eu/en/products/corine-land-cover/clc2018

In ecosystems dominated by species with late-opening cones (serotiny), such as the Turkish red pine (*Pinus brutia*), the mass germination of seeds scattered from fire-triggered cones leads to the emergence of youth, which eventually dominates the ecosystem (Thanos, 2000; Kazancı, 2021). Similarly, many species that comprise the hard-leaved forests and scrub in the Mediterranean basin have resprouting abilities that allow them to regenerate rapidly after the fire (Tavşanoğlu and Gürkan, 2014). However, species that are not adapted to fire can suffer extensive losses. Since the natural selection pressure of fire on plant species in the region has persisted for millions of years, plant species without post-fire regeneration traits in Mediterranean-type ecosystems are relatively more uncommon.

Fire can cause sudden mortality, especially for species with little or no mobility, or for animals that cannot escape due to the speed and intensity of a fire. For birds and mobile mammals, however, displacement can be a significant issue, as they must find new habitats that may already be at carrying capacity. Some rodents and reptiles survive by taking shelter below the ground until the flames pass (Pausas and Parr, 2018; Ensbey *et al.*, 2023).

Wildfires also impact the chemical properties of soils in Mediterranean ecosystems. Although the strong heat effect of even the most intense crown fires only penetrates a few centimetres below the ground, wildfires can cause significant changes in the chemical composition of the topsoil (0–5 cm). This is because fire causes some organic matter accumulated in the above-ground biomass to evaporate during combustion. In contrast, a large part of the biomass is incorporated into the soil as inorganic matter. In recent years, increased fire frequency in the Mediterranean basin has led to soil loss and some regeneration problems in fire-prone pine forests (Eugenio *et al.*, 2006; Pausas *et al.*, 2008). Consequently, the post-fire recovery of Mediterranean pine species, such as Turkish red pine, may be contingent upon soil chemistry. Moreover, post-fire changes in the chemical and physical properties of the soil can affect the recovery of even those species that can resprout after fire (Ferran *et al.*, 2005). Therefore, it is essential to examine the soil properties of burnt areas before making post-fire management decisions (Thomas, Walsh and Shakesby, 2000; Providoli, Elsenbeer and Conedera, 2002). It is known that the recovery of the chemical properties of soil in Turkish red pine forests usually occurs within three years after the fire (Eron and Gürbüzer, 1988; Neyişçi, 1989; Tavşanoğlu and Gürkan, 2002; Tavşanoğlu and Gürkan, 2010). In these forests, soil organic matter content, pH value, and exchangeable cation concentration, which increase immediately after the fire, return to pre-fire levels three years post-fire (Eron and Gürbüzer, 1988; Neyişçi, 1989). Similar results were obtained in a Canary Island pine (Pinus canariensis) forest, five years after the fire (Durán *et al.*,2008) and in a Kermes Oak (Quercus coccifera) thicket, one year after the fire (Trabaud, 1983). Changes in soil properties after a wildfire mainly depend on the land use history of burnt areas (Pardini, Gispert and Dunjó., 2004), the intensity and frequency of fires, and post-fire climatic conditions (Certini, 2005). Thus, soil temperatures during wildfires affect the soil properties of forests and their spatial pattern in different ways (Gimeno-García, Andreu and Rubio, 2004; Terefe *et al.*, 2008). Therefore, spatial variation in fire intensity impacts the spatial heterogeneity of post-fire conditions (Pausas *et al.*, 2003).

Besides the direct mortality effects of fire, there are also indirect effects on Mediterranean ecosystems. Fire rapidly alters the structure of these ecosystems, transforming the landscape into a mosaic of burnt and unburnt areas. This heterogeneity can create new habitats for some species but also lead to habitat loss for others. For example, certain bird species in the Mediterranean region, such as the Woodlark (Lullula arborea) and European Nightjar (Caprimulgus europaeus), are known to thrive in the heterogeneous vegetation structure that emerges after fire (Pons and Bas, 2005). In the immediate post-fire environment, the availability of resources (light, nutrients, prey, and so on) for plant and animal species also changes. The loss of the tree and shrub layer, which restricts light transmission to the lower layers of vegetation, may benefit plant species with high light demand. The burning of vegetation also releases many nutrients from the present biomass back into the soil, providing an additional source of nutrients to newly germinating seedlings and sprouts, often for a short period. This may benefit some plant species, but the subsequent loss of nutrients (for example, cations) through leaching from the soil may delay long-term recovery for these species. The post-fire environment can also influence animal behaviour and community dynamics. Predators may take advantage of prey disoriented or exposed by the fire, leading to shifts in predation rates (Pausas and Parr, 2018). Similarly, post-fire changes in vegetation used as a food source can lead to changes in the feeding patterns of herbivores (Pausas and Parr, 2018).

Wildfires have contributed significantly to the current level of biodiversity on Earth (Pausas and Riberio, 2017; He, Lamont and Pausas, 2019), and their effects on biodiversity vary depending on the type of biome and ecosystem affected by the fire (Pausas and Riberio, 2017). In ecosystems where wildfires have been effective for millions of years and where plants in the environment have adaptations that allow them to survive or regenerate quickly after fire, they generally boost biodiversity. Examples of such ecosystems include South American savannas and Mediterranean-type ecosystems in California, the Mediterranean basin, and Australia (Paula *et al.*, 2009; Keeley *et al.*, 2012; Pilon *et al.*, 2021). Fires favourably impact biodiversity in such ecosystems by delaying the competitive displacement of species, creating landscape diversity, creating new niches, and thus providing new opportunities for a wide range of species (Pausas and Riberio, 2017). The adaptations of plants and animals resulting from millions of years of evolutionary processes are the main reason why forests, scrublands and grasslands in fire-prone ecosystems have more species diversity after fire than before (Kazanis and Arianoutsou, 2004; Kavgacı *et al.*, 2010; Ergan, 2017; Pilon *et al.*, 2021).

Across the world, the negative impacts of wildfires on biodiversity are evident, particularly in ecosystems where fire has not been an ecological factor for a long time. The most devastating effects of fire on biodiversity are seen in tropical rainforests, where fire has not been a vital ecosystem component for tens of millions of years. As these forests are naturally humid, even if lightning- or human-caused ignition occurs in the forest, a wildfire does not break out. However, as observed in recent years in the Amazon (Brazil) or Borneo (Indonesia), large amounts of tropical rainforests have been cut down, burnt and deforested by humans for conversion to farmland (Fearnside, 2005). A similar case exists for the Mediterranean-type ecosystems of Chile, where fire has not been a natural factor for tens of thousands of years despite having a Mediterranean climate. In the last century, large areas of pine plantations have been established in these regions for economic reasons. Today, these forests are subject to large fires and suffer from fire damage due to their low post-fire regeneration capacity (Gomez-Gonzalez *et al.*, 2017). In these areas, where wildfires are naturally non-existent, burnt forests have little chance to regenerate quickly. In such cases, fire leads to a significant loss of biodiversity. A similar problem exists in the temperate rainforests of the eastern Black Sea region of Türkiye. These forests, part of the Caucasian biodiversity hotspot, do not have fire-adapted flora as they have not been exposed to wildfires for long periods. Therefore, the possibility of increased fires due to climate change is of concern as these forests do not have the capacity to regenerate quickly after a fire. Post-fire regeneration of these forests is highly dependent on seed dispersal from neighbouring unburnt areas, and complete regeneration is likely to take hundreds of years.

Post-fire natural recovery in Mediterranean ecosystems

Mediterranean basin ecosystems exhibit similar patterns to other Mediterranean ecosystems around the world in terms of the fire–biodiversity relationship, and contain different survival and regeneration strategies of plants with different life forms after fire (Kazanis and Arianoutsou, 2004; Paula *et al.*, 2009; Keeley *et al.*, 2012; Tavşanoğlu and Gürkan, 2014). As a result, wildfires do not cause a significant loss in terms of plant diversity, except in some exceptional cases. On the contrary, many studies have drawn attention to increases in the number and abundance of plant species after fire (Kazanis and Arianoutsou, 2004; Kavgacı *et al.*, 2010, 2017; Ergan, 2017). The removal of the tree layer and increased plant diversity after the fire has an increasing effect on invertebrate diversity, particularly for pollinator insects (Prada, Marini-Filho and Price, 1995; Kaynaş and Gürkan, 2008; Carbone *et al.*, 2019). Many insect species not found in unburnt forests prefer newly burnt and regenerating forest habitats for feeding and breeding (Prada, Marini-Filho and Price, 1995; Kaynaş and Gürkan, 2007; Pausas and Parr, 2018). These habitat changes also impact vertebrate animal communities such as birds and mammals (Pausas and Parr, 2018; Soyumert, Ertürk and Tavşanoğlu, 2020; Stillman *et al.*, 2023).

Different plant groups in the Mediterranean basin have different strategies for post-fire survival and regeneration (Paula *et al.*, 2009; Kazanis and Arianoutsou, 2004; Tavşanoğlu and Gürkan, 2014; Tavşanoğlu and Pausas, 2018). For example, the seeds of many annual plants remain in the soil for years before the fire (soil seed bank) and germinate after the fire by removal of germination barriers with the heat and smoke generated during the fire (Moreira *et al.*, 2010; Tormo, Moreira and Pausas, 2014; Ergan, 2017; Tavşanoğlu *et al.*, 2017; Kazancı and Tavşanoğlu, 2019). After a few years, these plants rebuild the seed bank in the soil and remain dormant in the ground until the subsequent fire (Tavşanoğlu *et al.*,2017). The seeds of some light-demanding annual plants that can deliver their seeds from unburnt areas to the burnt site can germinate in the area due to the removal of the tree and shrub layer with the fire and become densely populated in the vegetation in the first few years after the fire. However, the abundance of these plants decreases with the formation of shrub and tree layers in the vegetation over time (Kavgacı and Tavşanoğlu, 2010). While some of the herbaceous perennial plants and shrubs in Mediterranean ecosystems can persist in the post-fire area (like annual plants) through seeds, others can resprout from buds on the soil surface or below the soil after the fire (Paula *et al.*, 2009; Tavşanoğlu and Pausas, 2018). Post-fire shoots are characteristic of many perennial grasses (Poaceae) and are also observed in many evergreens and phrygana and shrubs that make up hard-leaved forests and scrub. Post-fire resprouting is possible when plants survive the fire by protecting buds at or below the soil surface from the fire. Protection on the soil surface is provided by a special structure called lignotuber, and the soil cover offers protection of the subsoil organs, which prevents fire temperatures from reaching the buds (Paula *et al.*, 2016). Post-fire resprouting is the most critical feature that enables different vegetation types in the Mediterranean ecosystem to be resilient to fire and to recover quickly after fire. Fire induced germination in woody plants is also a common character in Mediterranean-type ecosystems of the Mediterranean basin and California (Keeley *et al.*, 2012). In general, seeds with a water-impermeable seed coat (physical dormancy) are mechanically injured by the heat energy generated during the fire and become water-permeable, whereas seeds with a water-permeable seed coat begin to germinate in the first rainy season after the fire as some chemicals in the smoke stimulate embryo development (physiological dormancy) (Moreira *et al.*, 2010; Çatav *et al.*, 2018; Kazancı and Tavşanoğlu, 2019). These two distinct strategies are generally conserved at the family level, with some plant families (Cistaceae, Fabaceae) having temperature-induced germination and others having smoke-induced germination (Paula *et al.*, 2009; Moreira *et al.*, 2010; Çatav *et al.*, 2014; Tavşanoğlu and Pausas, 2018). In some exceptional cases, both temperature shock and smoke stimulate germination (Tavşanoğlu *et al.*, 2017). Most geophytes in the Mediterranean basin and many other Mediterranean type ecosystems exhibit increased flowering after fire. This is a particular type of post fire shoot production, and it is thought that this adaptation in bulbous plants occurs in response to the increase in the amount of light reaching the soil, and changes in soil chemistry due to the removal of the tree and shrub layer after the fire.

Finally, in the Mediterranean basin, some tree species keep their cones closed for many years to ensure that the seeds inside the cones are not damaged in the event of a fire (serotiny adaptation). During a fire, the resin between the cone scales melts, and within a few weeks after the fire, the cones open, and the seeds are scattered on the ground. In this way, even though the trees may have died in the fire, mass germination produces young trees and regenerates the forest. Serotiny adaptation is only observed in a few conifer species in the Mediterranean basin: Aleppo pine (*Pinus halepensis*), Turkish red pine (*Pinus brutia*), Maritime pine (*Pinus pinaster*), and Mediterranean cypress (*Cupressus sempervirens*). Serotiny trait has been shown to vary among different populations of the same species, and this variability is related to fire regimes (Hernández-Serrano *et al.*, 2014; Kazancı, 2021). Since tree species with serotiny adaptation are light-demanding trees, this strategy allows for the rapid growth of youth and regeneration of the forest ecosystem. Studies have shown that Turkish red pine saplings after fire are healthier and have better growth performance than those growing under closed canopy (Eron and Gürbüzer, 1988; Neyişçi, 1989; Ganatsas *et al.*, 2012).

Post-fire forestry interventions and management approaches in Mediterranean ecosystems

In Mediterranean ecosystems, vegetation types exhibit varying responses to fire (Tüfekcioğlu and Tavşanoğlu, 2022). For example, in Turkish red pine (*Pinus brutia*) forests, fire can act as a trigger for regeneration (Boydak, Dirik and Çalıkoğlu, 2006). The closed cones of this species open and release seeds when exposed to the heat of fire. This allows tree cover to recover after a fire. Hard-leaved forests and scrub, native to Mediterranean regions, also have a remarkable capacity for regeneration after fire, thanks to the ability of plants to resprout from the subsoil or germinate seeds after exposure to fire (Paula *et al.*, 2009). Forests and scrublands at low altitudes can quickly recover from any crown fire, owing to their fire adaptations.

Unlike Turkish red pine, black pine (Pinus nigra), distributed at relatively higher altitudes in the Mediterranean, does not have closed cones (serotiny), so the recovery of the species after a crown fire is more challenging. If a crown fire occurs in black pine forests, regeneration depends only on trees that survived the fire or stands adjacent to the fire site (Sabuncu *et al.*, 2023). Therefore, post-fire regeneration in black pine forests is slower and can take hundreds of years, depending on the size of the fire and the presence of unburnt areas. Black pine naturally grows at relatively higher elevations in comparison to Turkish red pine, and is adapted to surface fire regimes of medium elevations in Mediterranean mountains (Şahan *et al.*, 2022). Consequently, black pine has adaptations to survive surface fires, such as thick bark and self-pruning (Akkemik, Kavgacı and Akarsu, 2023). This species has a thick bark to protect living tissues under the bark from the heat effect of surface fires, and prunes its lower branches over the years to create a gap between the surface fire zone and its canopy area. The latter adaptation reduces the risk of transforming a surface fire into a crown fire.

In summary, the effects of wildfires on Mediterranean ecosystems and the potential for forest regeneration vary greatly depending on the dominant species in the vegetation and the nature of the fire. Immediate and long-term post-fire management strategies must be adapted to these specific conditions to ensure effective restoration and maintenance of biodiversity.

The effects of fires in Mediterranean basin ecosystems vary according to many factors. Variables such as fire intensity, frequency, local capacity, and post-fire management, can significantly influence the trajectory of post-fire recovery in Mediterranean ecosystems. Understanding these factors is crucial for implementing effective conservation and management strategies in fire-prone areas such as Türkiye and other Mediterranean countries.

Although most Mediterranean-type ecosystems can recover quickly after a fire, post-fire management decisions can significantly influence this process. In particular, decisions that prioritize economic objectives can negatively affect biodiversity and ecosystem services. Therefore, post-fire management techniques can vary greatly depending on each location's specific conditions and context (De Las Heras *et al.*, 2012).

While post-fire management decisions may, in some cases, include an economic dimension (such as future timber production in managed forests), post-fire management strategies also have an important dimension of soil resource conservation and restoration of other economically valuable ecosystem services (Mavsar *et al.*, 2012). Moreover, these strategies are based on a good understanding of the ecological dynamics of Mediterranean ecosystems, especially their resilience capacity for natural regeneration after fire (Vallejo and Alloza, 2012). These restoration techniques demonstrate that a balance between economic concerns and ecological knowledge can ensure successful post-fire management and recovery (Vallejo, Arianoutsou and Moreira, 2012). Indeed, post-fire management strategies and restoration techniques are vital tools to promote and maintain ecosystem recovery in Mediterranean ecosystems. These strategies can be applied both reactively, by directly responding to wildfires, and proactively, by helping to reduce the risks and impacts of future wildfires.

Post-fire management in Spain has improved significantly in recent years. Emergency interventions generally aim to protect the soil by preventing erosion and landslides in mountainous terrains, common in the Mediterranean. Techniques include mulching, creating contour terraces with logs, and planting with native species (Fernández and Vega, 2016). These activities not only protect the soil but also ensure a rapid recovery of vegetation. They also support the restoration of ecosystem services, such as regulating the hydrological regime and sequestering carbon. This approach has been shown to be more cost-effective and ecologically sound than large-scale planting efforts based on a single species (monoculture) (Castro *et al.*, 2002).

In Greece, a comprehensive post-fire management plan has been developed that includes both short term and long-term measures. Following a fire, the priority is to ensure soil stabilization and to restore burnt areas by afforestation with native species through reseeding or planting (Spanos, Ganatsas and Tsakaldimi, 2010). Several factors, including fire intensity, natural regeneration conditions, and economic constraints, influence post-fire reseeding. Local people are often involved in these efforts, which increases employment opportunities and revitalizes the local economy. This participatory approach also helps local people to take ownership of restored landscapes (WWF Greece, 2023). To reduce the risk and impact of fire, practices such as fire buffer zones around settlements, prescribed burning, and community-based fire management, are implemented.

In Türkiye, post-fire efforts are based on the regeneration of fire-exposed forests and scrub dominated by native species (GDF, 2014). The General Directorate of Forestry strives to control the process immediately after fires by implementing emergency measures to stabilize the soil. After that, a comprehensive assessment is made to determine the need for reforestation. In areas where natural regeneration is deemed insufficient, supplemental reseeding is carried out. Local people are usually involved in the post-fire work, and the resulting employment provides economic benefits. In the long term, post-fire restoration contributes to the local and national economy by providing different ecosystem services such as timber, non-timber forest products, carbon sequestration, and recreation.

The following list provides an overview of post-fire forestry practices in Mediterranean countries, including Türkiye:

Soil stabilization measures: Employed in Spain, these measures aim to prevent soil erosion and landslides after fire. This includes using mulch to protect the soil surface and the creation of contour log terraces to slow water runoff and reduce soil erosion. In Türkiye, laying branches from post-fire salvage logging on the burnt soil to support the natural regeneration of Turkish red pine is used as mulching, and is actively used to prevent soil loss and erosion.

Allowing for natural regeneration after fire: This is the practice of letting the ecosystem recover naturally from a fire without human intervention, such as reseeding or planting. This technique relies on the inherent resilience and adaptation of the ecosystem and its species to fire, where many plant species have seeds that germinate and grow better after a fire or have other adaptations like the ability to resprout from roots or stems. This is the result of many years of selection and survival of species with this characteristic. This technique is widely used in Mediterranean countries due to the high natural recovery potential of Mediterranean vegetation and the financial cost of any active management activities (Vallejo, Arianoutsou and Moreira, 2012). In Türkiye, this technique is generally applied in phrygana, scrub, and Turkish red pine forests, where intervention is impossible due to the rugged terrain.

Reseeding: Several countries, including Spain, Greece, and Türkiye, employ these techniques as part of their post-fire management. This practice, which involves the scattering of seeds of native species, especially the primary tree species of the forest (such as Turkish red pine), or planting them by line planting, aims to help the intended trees and plants settle in the area through seed germination. Local seed sources are used to supply seeds, or seed transfer zoning is considered.

Active reforestation (sapling planting): This technique is frequently used in Türkiye when natural regeneration is deemed insufficient. It involves planting native species, especially Turkish red pine (*Pinus brutia*), to speed up the recovery process and restore the ecosystem. Afforestation, as part of artificial regeneration after fire, can be carried out by manpower or mechanized tillage (mechanization), depending on the topographic structure of the area. Saplings produced from local seed sources or from seed sources suitable for seed transfer zoning, are used as sapling material.

Invasive species management: Post-fire environments can be particularly susceptible to invasion by non-native species. Therefore, monitoring and managing against potential invasive species is a standard part of post-fire management in many Mediterranean countries, especially Spain.

Prescribed burnings: Mediterranean countries also use several techniques to reduce future fire intensity and spread, both before and after wildfires. These techniques include prescribed burnings and firebreaks (buffer zones). This practice reduces the risk of high-intensity fires by reducing the fuel load in the environment. This technique requires careful planning and implementation to be carried out safely and effectively. Prescribed burning can also be considered as part of forest management to re-establish the natural fire regime in Mediterranean forests. In this way, prescribed fires can control wildfire frequency and prevent extreme climatic events like heatwaves from turning fires into mega fires. In addition, this method is also used to prevent fires from negatively impacting human settlements and economic activities (agricultural areas, rural buildings, and so on). Prescribed burning, used by many countries worldwide, has become widespread in some countries in the Mediterranean basin, such as France and Spain, in the past decade. However, in places such as Greece, Türkiye, and North African countries, prescribed burning is only used for experimental purposes and is not included as part of fire management in forestry.

Firebreaks: Firebreaks are used as another measure to prevent the spread of fire, involving strip lines in which vegetation is cleared or significantly reduced. Greece, Spain, and Türkiye are among the countries that use this technique.

Community-based fire management: Community involvement in fire management, especially in risk reduction efforts, has been an essential part of fire management as a preventive measure in Mediterranean countries. Greece, for example, has a community-based fire management approach that involves training and empowering local people to manage fire risks and respond effectively when fires occur (Papaspiliou, Skanavis and Giannoulis, 2014). The General Directorate of Forestry (OGM) of Türkiye has also taken necessary steps in this regard after the mega fires of 2021. This approach can be particularly effective around settlements at risk of fire.

Each of these techniques has its own merits and challenges. The choice of method depends on management objectives and social, economic, and natural constraints. For example, for any given point, the decision for post-fire treatment between leaving it unmanaged or reseeding and planting depends on a variety of factors, such as the intensity of the fire, the natural regeneration potential of the stand, and the ecological conditions of the site. An in-depth understanding of ecological dynamics, local knowledge, and long-term monitoring, should be considered in determining post-fire management strategies. The post-fire recovery potential of Mediterranean vegetation is naturally very high. Therefore, this ecological characteristic should be the basis for successful and cost-effective post fire management. In this context, post-fire management, including post-fire production and marketing processes, should be addressed holistically through a restoration plan.

Post-fire restoration practices of the General Directorate of Forestry

The General Directorate of Forestry (OGM), established in 1839 and operating under the Ministry of Agriculture and Forestry (MoAF), is responsible for managing Türkiye's forests. The overall objective of the OGM is to protect, enhance, and sustainably manage forests and forest resources. Post-fire forest management in Türkiye typically involves a series of actions aimed at rehabilitating and restoring forest ecosystems affected by wildfires. The primary approach of the OGM's post-fire management is to intervene in the area with minimal damage and to ensure the continuity of the ecosystem structure by protecting the ecological, biological (flora, fauna), landscape, and cultural resource values of the area (OGM, 2017). However, post-fire forest management practices in Türkiye may vary depending on factors such as fire intensity, ecological characteristics of the affected area, legislation, and available resources.

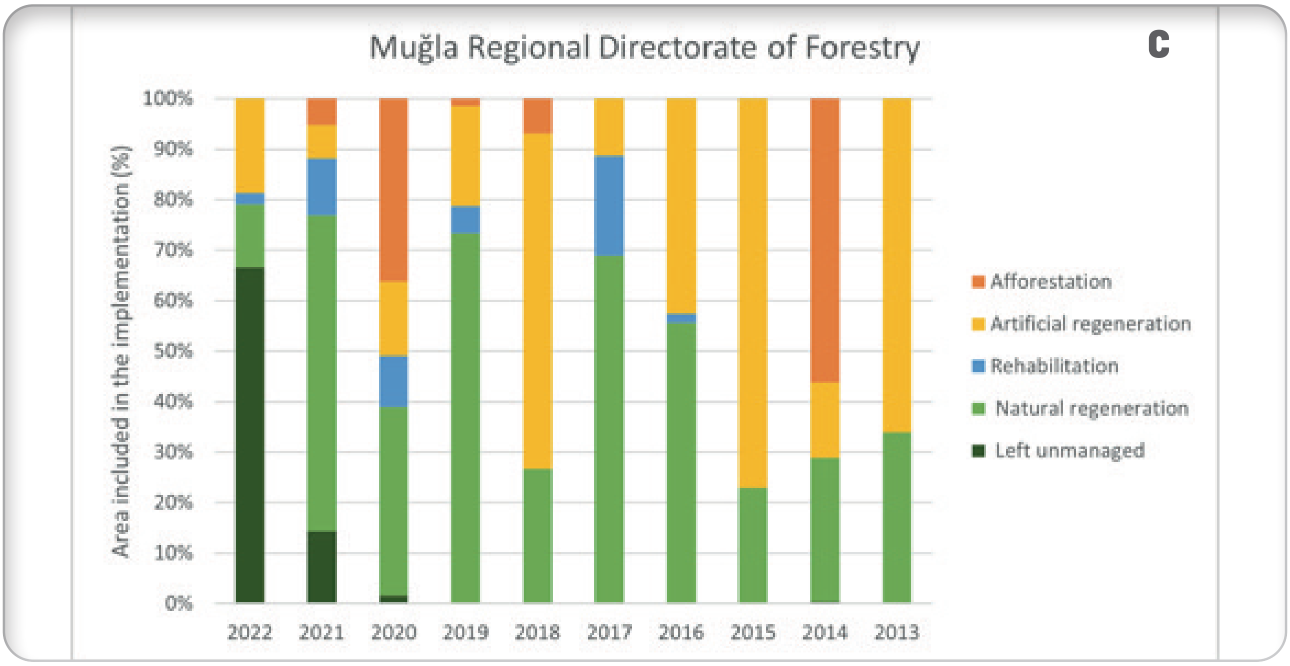
Regarding the forestry works carried out after the fire, they are carried out within the scope of silvicultural operations terminologically named natural regeneration, artificial regeneration, rehabilitation, afforestation, conservation (left unmanaged, allowing natural recovery), and leaving to the subsequent years (OGM, 2022) (Table 1). The practices within the scope of the preferred intervention types differ on the basis of management units according to the ecological and topographic structure of the area and the current resource status. Before these applications, it is a common practice to cut and remove burnt trees for economic purposes (post-fire production logging) and to deliver them to the timber industry.

Table 1. Forestry practices for post-fire ecosystem regeneration in Türkiye (definitions based on Communiqué No. 298 on Technical Principles of Silvicultural Practices (OGM, 2017).

Forestry practice	Definition
Natural regeneration	The work carried out to bring the seed from natural sources to the site naturally and ensure germination. In the regeneration of forests, natural regeneration methods must be applied first.
Artificial regeneration	Reseeding or planting activities carried out in areas that have been included in the regeneration period but do not have natural regeneration conditions or where it is deemed necessary to make a species change. In some cases (such as fire), artificial regeneration may be mandatory in productive grove forests.
Afforestation	Reseeding or planting activities carried out in open groves and coppice areas with 0–10 percent canopy cover in the management plans.
Rehabilitation	In closed-canopy and open-canopy forests, the aim is to make maximum use of the growth dynamism and growth energy of existing stands and to improve the forest with the least effort and expense to preserve the appropriate natural species in the area without disrupting the forest ecosystem. It is carried out in closed forests without planned annual yield, closed forests with a canopy cover of 11–40 percent or, open canopy forests with a canopy cover of less than 10 percent, and openings in forests with degraded vegetation cover.
Leaving unmanaged (allowing natural recovery)	Leaving the area as it is without considering any management function due to terrain conditions or because there is no action to be taken or in places with nature conservation function.

According to the wildfire data, Muğla, Antalya and Izmir stand out as the provinces that suffer the most from wildfires (OGM, 2022). When the post-fire silvicultural techniques applied by the regional directorates of these cities since 2013 are compared, Izmir Regional Directorate of Forestry mostly prefers active restoration methods such as artificial regeneration and afforestation, while the remaining areas are mostly left unmanaged for passive restoration, or natural regeneration is adopted (Figure 3, a). Antalya Regional Directorate of Forestry has generally applied the natural regeneration technique, which is one of the passive restoration methods, in the burnt areas since 2013, and afforestation as active restoration was carried out only in a small area in the 2018 fires (Figure 3, b). On the other hand, Muğla Regional Directorate of Forestry mainly preferred natural regeneration practices in burnt areas, as well as artificial regeneration, afforestation, and rehabilitation processes, and there has been an increase in the areas left unmanaged since the 2020 fires (Figure 3, c).

Figure 3. Preferred post-fire silvicultural practices of regions most exposed to fire in Türkiye

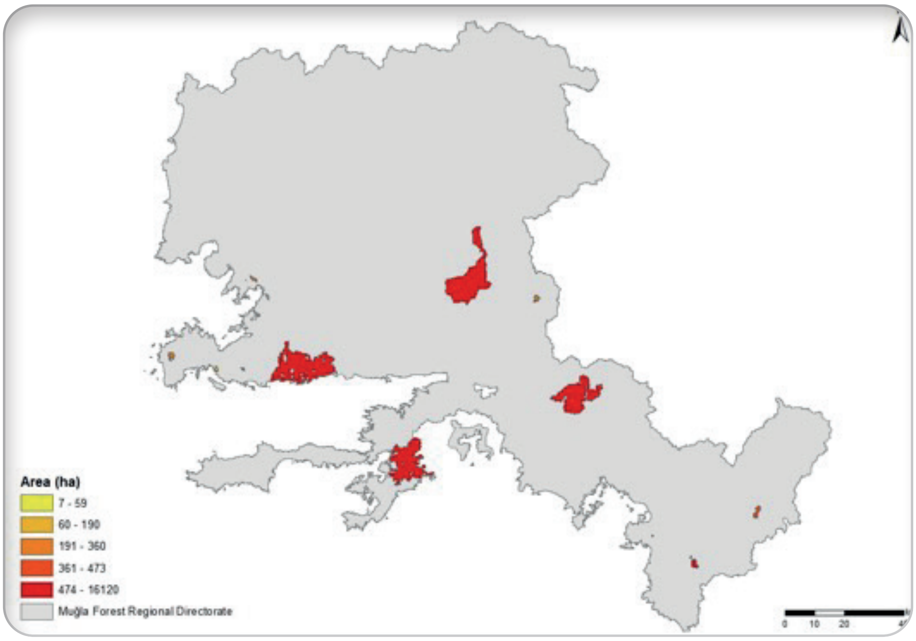


Source: OGM, 2022, General Directorate of Forestry Official Statistics for 2022, Ankara, https://www.ogm.gov.tr/tr/e-kutuphane/resmi-istatistikler

Examples of post-fire restoration practices in two pilot sites in Türkiye

Between 28 July and 10 August 2021, large-scale wildfires occurred in various parts of the Mediterranean region of Türkiye. Some of these fires fall within the definition of mega fires. Two of the largest forest fires in Muğla occurred in Marmaris and Köyceğiz districts (Figure 4), corresponding to approximately 22 000 ha of the total area of 55 764 ha burnt in Muğla province (Figure 5).

Figure 4. Areas burnt in wildfires in Muğla province, 2021

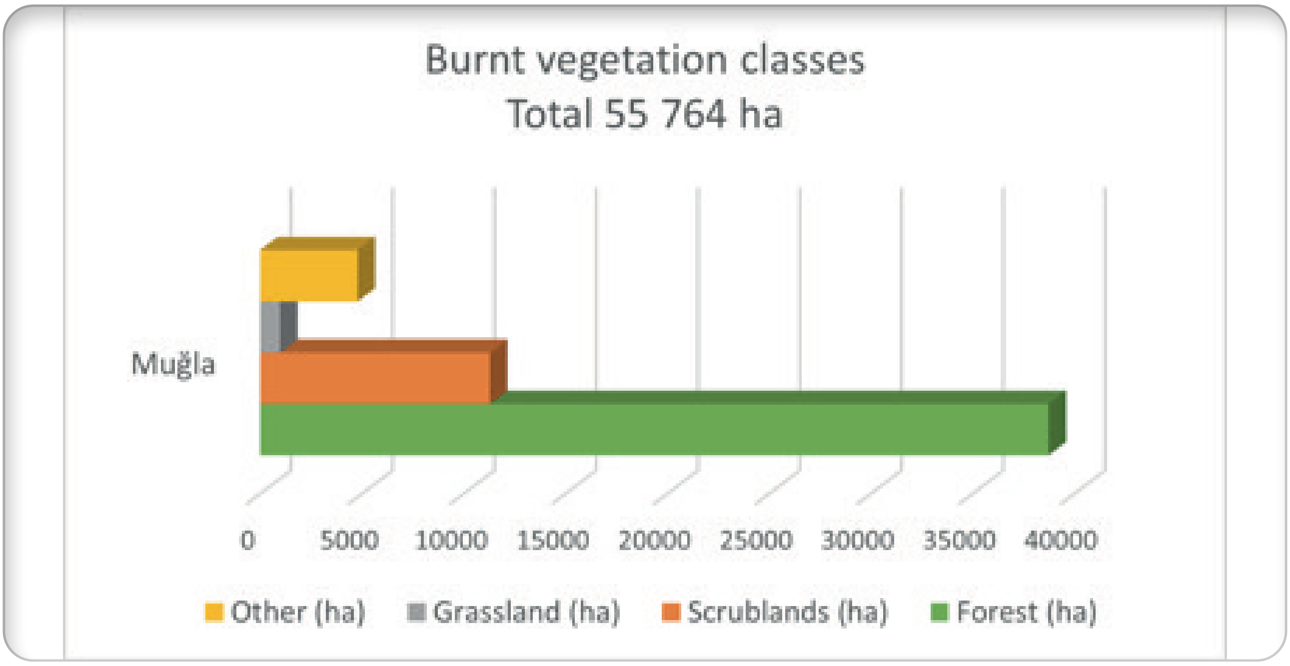


Note: Refer to the disclaimer page for the names and boundaries used in this map

Source: EFFIS, Data and services. (n.d.), Retrieved 9 October 2023, https://forest-fire.emergency.copernicus.eu/applications/data-and-services

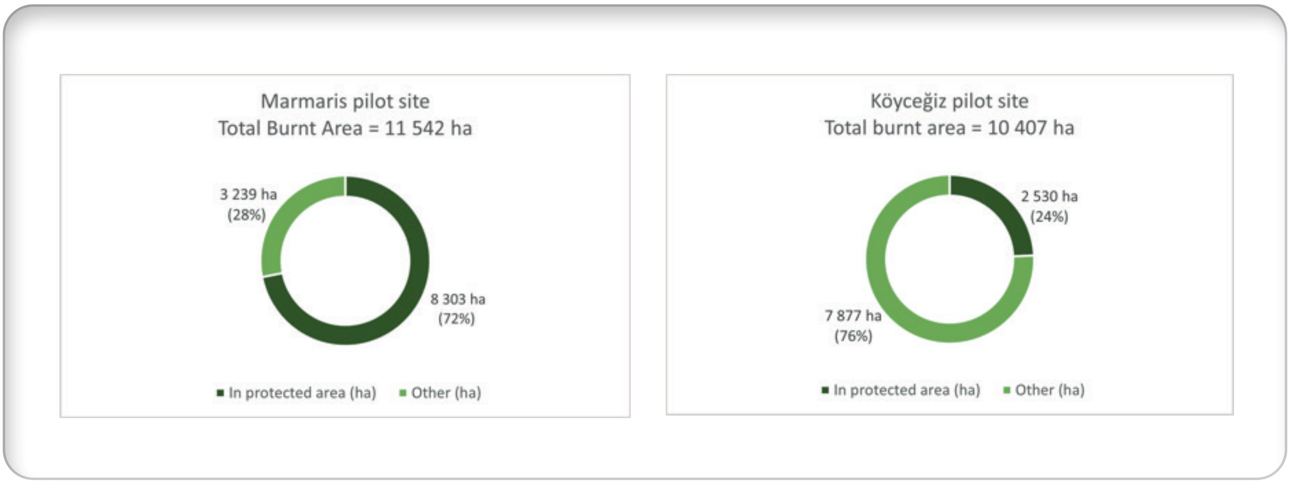
About a quarter (24 percent) of the total area burnt in Köyceğiz (10 407 ha) was within protected areas, while the majority (72 percent) of fires in Marmaris (11 542 ha) occurred in protected areas (Figure 6). Both pilot sites are known for their high biodiversity, with numerous rare and narrowly distributed endemic species of conservation importance, notably many plant species. The wildfire areas in Marmaris have dense scrub vegetation and Turkish red pine forests. The wildfire areas in Köyceğiz are predominantly Turkish red pine forests, with black pine forests at higher altitudes.

Figure 5. Total burnt area according to vegetation classes in Muğla wildfires, 2021



Source: EFFIS, Data and services. (n.d.), Retrieved 9 October 2023, https://forest-fire.emergency.copernicus.eu/applications/data-and-services

Figure 6. Areas burned per hectare in Marmaris and Köyceğiz pilot sites in 2021.



Source: EFFIS, Data and services. (n.d.), Retrieved 9 October 2023, https://forest-fire.emergency.copernicus.eu/applications/data-and-services

In 2021, the wildfire areas within the borders of Köyceğiz and Marmaris forest management directorates were determined as pilot sites for evaluating post-fire forestry practices and monitoring the recovery of biodiversity. The burnt areas were assessed on the government production programme, and the necessary actions were planned according to the silvicultural calendar.

According to the evaluation reports of the management directorates, the burnt areas in the Bayır Forest Management Unit of the Marmaris Management Directorate within the boundaries of the Marmaris pilot site were included in the natural regeneration programme. After removing burnt trees from the site (salvage), the cutting and skidding process was carried out for the damaged trees. Natural regeneration was supported by reseeding. In this context, reseeding was carried out using broadcast, line, and spot planting methods with seeds obtained from suitable origin before the germination period. In the areas where the regeneration was successfully achieved, as of April, measures were taken to prevent suffocation risks and control shoot growth. In addition to the natural regeneration programme, an artificial regeneration programme, including sapling planting, has been implemented in the Hisarönü Forest Management Unit. After removing burnt trees from the site, reseeding was carried out per the natural regeneration programme using broadcast, line, and spot planting methods. Within the scope of sapling care, prevention of suffocation risk, control of shoot growth, cleaning of weeds, and hoeing are carried out.

In Beyobası, Çayhisar, Köyceğiz, and Otmanlar forestry management units of Köyceğiz Forest Management Directorate, a significant portion of the burnt areas, which are located within the borders of the Köyceğiz pilot area, were included in the natural regeneration programme. In these areas, regeneration was conducted with line and spot planting and reseeding methods after the clear-cutting and removing burnt Turkish red pine and black pine trees. In the Köyceğiz pilot area, most of the burnt areas were left unmanaged due to the rugged terrain. The fire sites within the borders of Akköprü Forest Management Unit are the most important of these areas. A small area within this unit was included in the artificial regeneration programme, and in this context, reseeding was implemented after mechanical tillage. In the Otmanlar Forestry Management Unit, half of the burnt areas were included in the natural regeneration programme, most of the rest were left unmanaged due to accessibility issues, and some were included in the rehabilitation programme.

According to our observations in the field, and data obtained from the relevant forest management units, passive restoration and natural regeneration techniques are the best solution for our pilot sites. In the Marmaris pilot site, natural regeneration was practised in Bayır Forest Management Unit, and artificial regeneration was practised in Hisarönü Forest Management Unit. In the Köyceğiz pilot area, the majority of forest management units implemented natural regeneration or left the burnt areas to natural processes due to topographical constraints. In this pilot area, the Akköprü Forest Management Unit is the only unit in the pilot site where mechanical tillage, which is an active restoration practice, is implemented.

Habitat needs of different species groups

Every species thrives in specific habitats, providing resources for feeding, reproduction, and predator evasion. A species can achieve the highest survival success and the highest population density in the most favourable, or optimal, habitat. As it moves away from the optimal habitat type, that is when it is forced to live in marginal environments, and the negative impacts of factors such as competition, predator pressure, and disease acting on the population gradually increase. If these adverse effects manifest themselves in the form of significant declines in reproductive and survival success, it can lead to the complete extinction of the species from the area in question.

A habitat is considered to be made up of four different elements. These are space, food, water, and cover. The size of the habitat required is different for each species and can vary according to the age and sex of the individual. For example, for carnivorous mammals (Carnivora), males generally require larger areas than females. If the habitat size falls below the critical value, the individual(s) will either leave to find a suitable habitat elsewhere, or perish. Beyond individual space requirements, there is also the concept of the space required for a population to survive. For a population – which we can define as a collection of individuals that interact and exchange genes even if they do not live together – the need for a suitable habitat is undoubtedly much greater than the needs of individual organisms. For demographic and genetic reasons, it is unlikely that a population that does not exist in a large enough habitat, especially if its relationship with other neighbouring populations is limited, can survive for a long time. One example of this is felines.

Each species may have different food sources; however, the habitat of the species should provide these sources. The habitat requirements of herbivores and the plants they feed on, or of predators and prey species, overlap to a large extent. Similarly, water – both for consumption to meet physiological needs and as an environment in which to live – is an important habitat element. Cover, in terms of the structure formed by vegetation and topography, is a determinant for providing shelter from predators, concealment from prey, and as a nesting place. For example, wild goats prefer steep, inaccessible areas with expansive views. This type of habitat is favoured primarily because it allows them to escape from their enemies. In addition, other herbivore species that can compete with them rarely occupy these environments.

For some species, for example, nesting and feeding environments may differ. In such cases, these two different environments should be close or nested, and the habitat of the species should be defined as their totality. On the other hand, aquatic elements, in particular, may only provide temporary habitats for associated species. The concept of habitat includes these temporary elements (such as shallow lakes that dry up in summer). Apart from the tropical belt, all ecosystems show seasonal fluctuations. These fluctuations often result in significant changes between summer and winter. Such major changes lead to the temporary disappearance of a habitat. Many species have adapted to this through migration or hibernation.

Sweetgum forests have become increasingly fragmented due to agricultural clearing.

Today, many habitats show a discontinuous, fragmented character. Although there are ongoing scientific debates about the impacts of this discontinuous structure, which has been expanding for thousands of years due to human influence on biodiversity, these dynamics will certainly affect species' future. In large areas, habitat is often considered in a whole-part relationship. For example, for many species of diurnal butterflies, the forest openings they inhabit are considered habitat fragments within a forest area. On the contrary, for a woodpecker species, habitat fragments are the isolated patches of forest (groves) in a region converted for agricultural purposes. The placement of habitat fragments within the whole forest area, the width of each fragment, their distance from each other, and the extent to which they impede the mobility of the species, are decisive for the population's survival.

Beyond climatic constraints, the most important parameters determining species preferences in a forest habitat are cover and vertical structure (stratification). Other characteristics such as physiognomy (coniferous/leafy, evergreen/deciduous) and the age of the forest (diameter at breast height, dry standing ratio) can also be added. The degree of closure not only affects the access of sunlight to the lower layers (hence photosynthesis and plant growth), but also determines the emergence of new habitat types that can be characterized as "openings". Stratification is perhaps the most important determinant for many vertebrate species.

Figure 7. Different layers in a forest (not all forests have these layers)

Source: https://commons.wikimedia.org/ (drawn by Elke Freese)

Canopy cover is recorded on a spectrum ranging from very loose to fully closed (in forestry terminology, from "degraded" or "sparsely closed" to "3 closed"), depending on how close the tall species (trees or shrubs) grow to each other, the diameter of their crowns, and the branch and leaf structure. Canopy cover affects the ecosystem by preventing the sun's rays, nature's sole energy source, from reaching the lower layers. Although some plant species are adapted to live and even grow in the shade, many species, including the dominant species' saplings, may not survive under a tree canopy with high canopy closure. This can lead to reduced biomass production in the lower layers, with no or weak intermediate and lower tree, shrub, and herb layers. Therefore, fully closed forest ecosystems are generally unsuitable for species with high light demand, except for tall trees.

The leaf type and phenology of dominant species also influence many vital parameters and processes in the ecosystem, from the amount of light to nutrient cycles. For example, the leaves of coniferous and sclerophyllous species have qualities that minimize water loss but are consumed as food by very few vertebrate species. On the other hand, the broad leaves of deciduous species are good food for species such as roe deer (*Capreolus capreolus*). In certain seasons, the fruits of both scrub and deciduous shrubs and trees constitute an essential resource for wild animals. In deciduous forests, the dynamics of photosynthesis, carbon sequestration, and nitrogen accumulation vary significantly from season to season. In contrast, in evergreen forests, the process is carried out almost throughout the year.

The age of the forest and the presence of dead trees or shrubs in the ecosystem are also crucial factors for certain species of fungi and animals – mainly those found in old-growth forests. All these differences determine for which species an ecosystem is a potential habitat. Although each species has its specific habitat requirements, generalizations can be made for large groups of species (Table 2).

Table 2. Possible effects of forest characteristics on different species groups

	Herbaceous plants	Woody plants	Reptiles	Amphibians	Birds	Invertebrates	Small mammals	Large mammals	Bats
Stratification	0/-	+/0	0	+	++	+	+	+/-	+/-
Forest opening	++	+	++	+	++	+	++	++	+
High canopy closure	0/-	0/-	-	+	-	-	-	-	-
Existence of scrub communities	0/-	+	+	0	+	+	+	+/-	0
Diversity of stand developmental ages	0	0	0	0	++	+	+	+/-	0
Diversity of tree species	+/0	+/0	0	+	+	++	+	+	+

Note: + positive, - negative, 0 no effect.

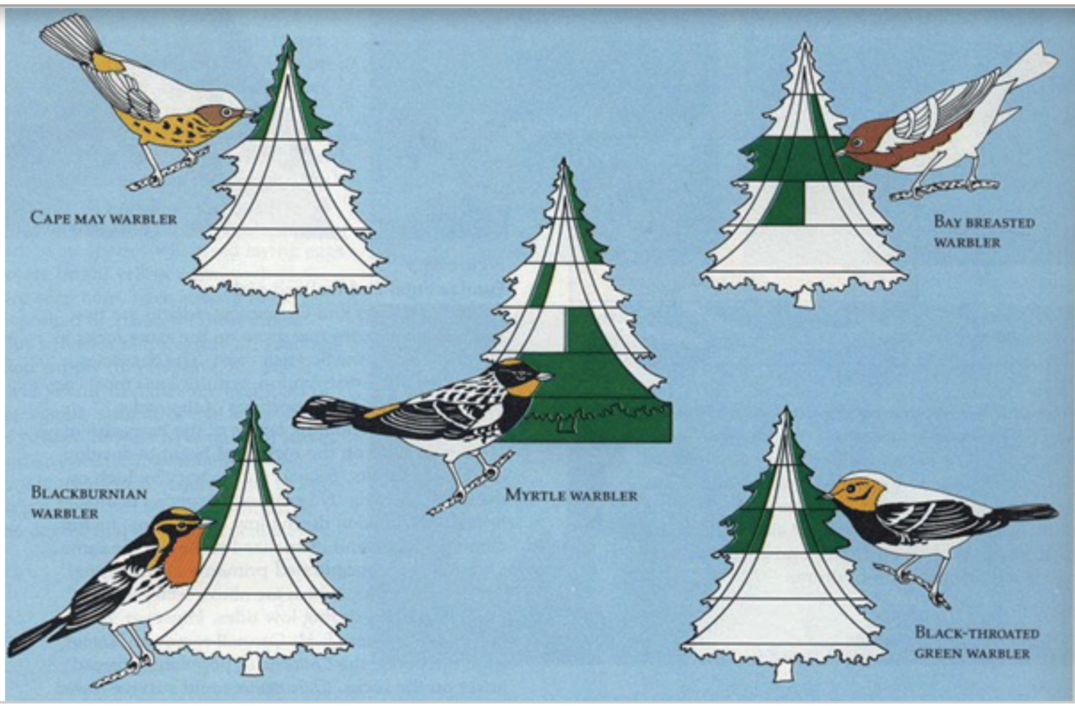
Source: Author's own elaboration

Important (forest) habitat features for major species groups are described in more detail below:

Mammals: This group of species is traditionally divided into three different subgroups – bats, small mammals, and large mammals. For bats, the only group of flying mammals, feeding usually occurs just above trees or over water. For many bat species in Türkiye, old trees are vital as breeding sites or hibernation shelters due to the hollows and cracks they provide (Yorulmaz, Ürker and Özmen, 2018). Most small mammals, such as rodents and insectivores, live in the ground layer, even below ground. Squirrels and tree shrews in this group prefer habitats with a strong vertical structure that is rich in trees and shrubs. Large mammals include species such as wild boar, which can impact forest ecosystems over time (Bongi *et al.*, 2017; Gray *et al.*, 2020). Many forest species, such as red deer, brown bear, and lynx, require large areas. On the other hand, almost all of these large mammal species benefit from fragmentation of the forest cover to create openings (Grodsky, Moorman and Russell, 2016).

Birds: This group uses vertical structures most effectively and depends more on forest physiognomy than other species groups. Many bird species prefer mainly coniferous or mainly broadleaved trees and shrubs. Many bird species with similar habitat requirements in physiognomy and even species composition feed predominantly on different parts of a tree to reduce competition with each other (MacArthur, 1958; Miller*et al.*, 2022).

Figure 8. Feeding behaviour of five warbler species native to the spruce forests of North America



Source: MacArthur, R. H. 1958. Population ecology of some warblers of northeastern coniferous forests. Ecology, 39(4), 599-619

Although the habitat requirements of many bird species are quite general, some species prefer only old-growth forests or habitats dominated by conifers. For example, the Eurasian siskin (*Spinus spinus*) or the Red crossbill (*Loxia curvirostra*) are found in conifer-dominated habitats, at least during the breeding season.

In the process of successional change, initially, common species are gradually replaced by other species. When habitat fragmentation or external interventions such as skidding or fire temporarily reverse this process, bird species are the fastest adapters to new conditions and, therefore, the most appropriate species group to be used as indicator species.

The main food of red crossbills (Loxia curvirostra) is the seeds of conifer species.

Reptiles: Within this group of species, which regulate their body temperature according to the amount of time they spend in the sun and shade, there are very few species specialized for forests. Preferring forest openings, rocky areas, and forest undergrowth with at least a few hours of sunlight, reptiles are more common in young stands and scrub that have not yet reached full closure. Thanks to their ability to occupy small areas, they are a common, if not abundant, species in every tree and shrub dominated ecosystem.

A Blotched Snake in a tree (*Elaphe sauromates*).

Amphibians: The critical habitat requirement of this group is aquatic (freshwater) ecosystems within forests, at least during the breeding season. Although many species of frogs and salamanders are found in terrestrial environments outside the breeding season – or even throughout their lives, as in the case of land salamanders – their moisture requirements are high. They may spend dry periods in summer hibernation, in which case it is essential to have safe places to hide (suitable microhabitats). Unlike reptiles, they prefer highly closed, shaded habitats to prevent excessive dehydration.

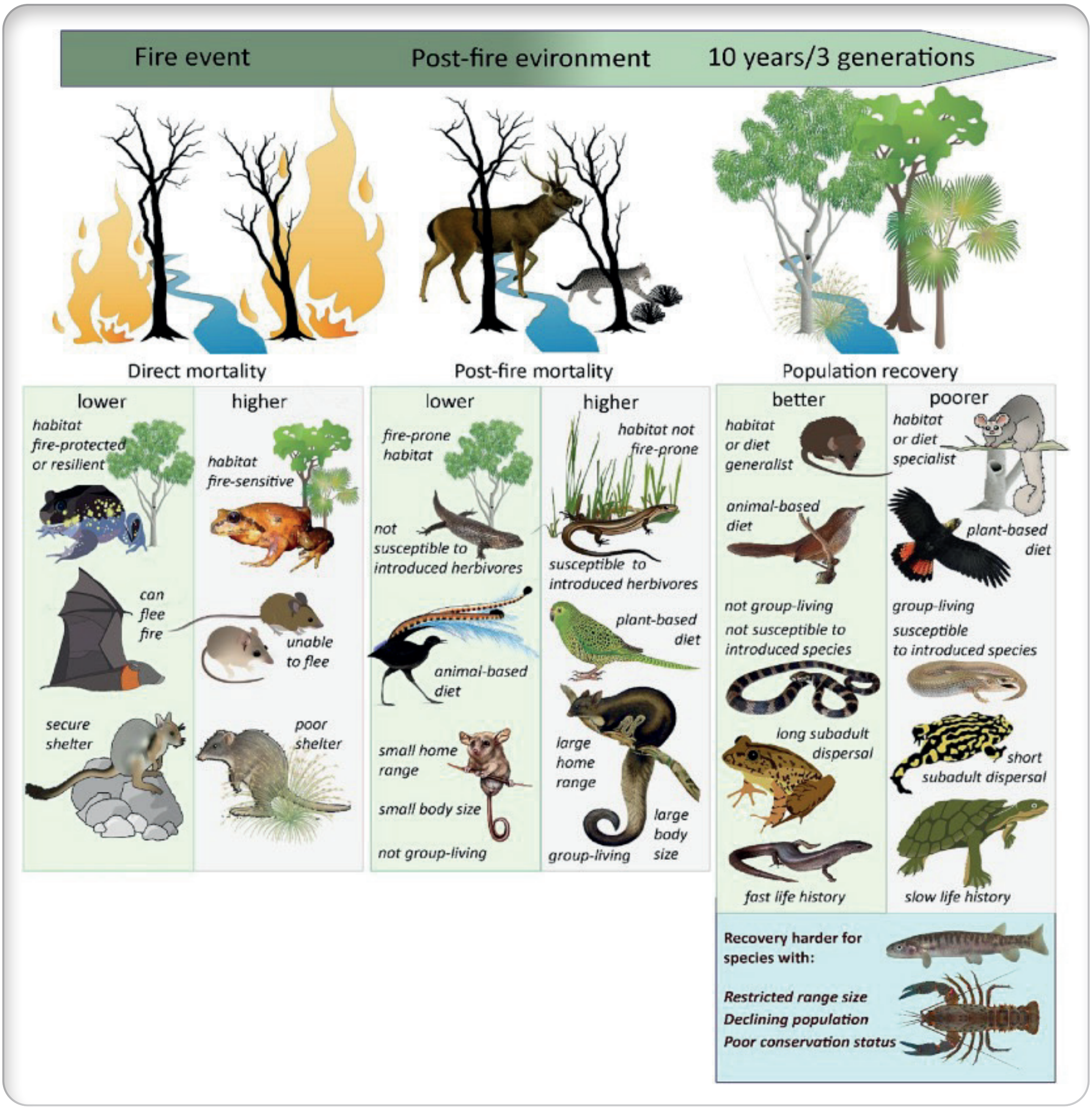
Fazila's salamander (*Lyciasalamandra fazilae*) spends the summer below ground in rock crevices.

Butterflies: The best-studied among the insects, this group exhibits habitat preference traits that may be a model for other invertebrates. As with many insects, butterflies can differ significantly in morphology, physiology and behaviour between their young (larval) and adult stages. Since they feed on specific groups of plants called food plants during their early stages, adults lay their eggs only on these species. Therefore, the habitat of many species is very limited in this sense. However, adults often overcome this limitation by feeding in other habitats and on different food plants. Both for the few butterfly species dependent on certain tree species such as hawthorn, oak and hackberry, and for butterfly species that have broader preferences but are often found in forest ecosystems, small sunny areas are essential, as in the case of reptiles. These conditions also apply to most of the butterfly food plants.

How are different groups of animals affected by fire?

The effects of wildfires on species groups exposed to fire vary according to many factors, such as the type, size, frequency, and season of the fire. Crown fires undoubtedly cause more significant damage than surface fires. These types of fires can lead to a completely different vertical closure (or rather, the temporary disappearance of vertical closure) for at least five to 20 years, with the disappearance of the tree and shrub layer and the formation of a vegetation structure dominated by certain species with the formation of a unique floristic structure. Surface fires have a much more limited and temporary impact. The frequency of fires is also decisive in terms of delaying the re-establishment of habitats suitable for affected animal species, thus preventing them from returning to the fire site (Ensbey *et al.*, 2023).

Figure 9. Expected mortality during and after fires, and ease of population recovery



Source: Ensbey, M., 2023, Animal population decline and recovery after severe fire: Relating ecological and life history traits with expert estimates of population impacts from the Australian 2019-20 megafires. Biological conservation.

In the event of a fire, birds, bats, and large mammals flee the burning area. As fires are affecting larger and larger areas today, it is becoming more difficult for them to reach adjacent areas where they can relocate, and even more likely that they will be harmed because they cannot find safe corridors to escape. Most small mammals and reptiles can seek shelter from the fire intensity in soil and rock cracks and burrows below ground (Pausas and Parr, 2018). However, species such as tortoises and squirrels that are slow to move or do not use below ground as a shelter are unlikely to survive a fire. Frogs and other amphibians can find protection in aquatic environments or in subterranean shelters where they spend their summer hibernation. However, with the loss of the closure, the soil may become much hotter and drier than before, making it an unfavourable habitat for salamanders and frogs. Even if adult butterflies disappear, young individuals in the form of pupae under the soil may survive the fire relatively unharmed, like many other invertebrate species.

In species groups that have difficulty moving away from the fire, mortality rates can be high enough to lead to the extinction of the local population. Some individuals do not survive for long due to wounds and burns sustained after, if not during, the fire. On the other hand, the fire event may cause some established species (for example, Turkish red pine) to regenerate their populations, while others may reach much higher population sizes than before the fire. Typically, herbaceous plants exhibit substantial growth in the first few years after a fire. This abundance often allows for a population explosion for herbivorous and seed predator small mammals, as well as for butterfly species whose food plants are from the Poaceae family. The high rodent population also provides new opportunities for the mammals that feed on them, such as caracals, foxes, and daytime raptors such as hawks and kestrels. As a result of the negative impacts of fires, an additional problem for species not directly damaged by the fire is that the habitat suitable for them disappears – at least for many years. In a place with a completely changed vegetation structure unsuitable for their feeding and shelter, their numbers will inevitably decrease and eventually disappear (or leave the area). On the other hand, such species will be replaced by new species adapted to living in clearings and thickets, but these new species will eventually be replaced by the "original" species present in the area before the fire. For example, the Coal Tit (Periparus ater) and Krüper's Nuthatch (Sitta krueperi) are typical of the bird fauna of pine stands over 30 years old. These two species, which feed entirely on trees, need tree cavities for nesting. After a crown fire, it is no longer possible for both species to take shelter in the area. The dense herbaceous vegetation and dwarf shrubs in the burnt area will now provide habitat for species adapted to clearings, such as the Cretzschmar's Bunting (*Emberiza caesia*). However, as the forest recovers over time and vertical closure develops, these clearing species will be replaced by forest species.

The return of species can take decades, or a few years. Highly mobile groups, such as birds, can reach the area as soon as the habitat elements they have adapted to begin to form. Small and slow-moving reptiles and amphibians may take much longer. There are several factors that can shorten this return process. First of all, the burnt area must be connected to neighbouring habitats. In this case, either their proximity in terms of distance, or being connected by a habitat corridor, speeds up the return. If small islands of preserved habitat remain within the burnt area, the presence of surviving species (especially small and slow-moving species) on these islands will accelerate the recolonization of the regenerated habitat. On the other hand, this process is slower for species dependent on elements that require a very long time for the old stand to form for nesting or feeding. In this respect, habitat management interventions to accelerate ecosystem restoration are essential.

Impacts of post-fire interventions on biodiversity

Post-fire treatments have significant effects on biodiversity (Table 3). While some practices can promote biodiversity, others can cause some damage to biodiversity. The ecosystem in which wildfires happen is the primary determinant of how post-fire practices will affect biodiversity. In a fire-adapted ecosystem where wildfires have occurred for millions of years, post-fire management activities that do not consider ecological and biological priorities are likely to negatively affect biodiversity and ecosystem recovery. Conversely, no intervention after wildfires in ecosystems where fire is not naturally occurring, and which are not adapted to fire, or after fires that appear outside the natural fire regime, can also negatively impact biodiversity.

The coexistence of areas burnt in different years is known to increase the diversity of plants (Tavşanoğlu, 2008; Cohn *et al.*, 2015), birds (Stillman *et al.*, 2023), and mammals (Soyumert, Ertürk and Tavşanoğlu, 2020). Thus, fire is essential in creating habitat heterogeneity at the landscape scale in many ecosystems. On the other hand, mega fires reduce wildlife refuges, and for wildlife – especially large mammals with large habitat requirements – there is less unburnt land to seek refuge in until burnt areas recover. This can increase the intensity of competition with individuals of their own species in the refuge area and increase the stress on individuals. Populations of bird species that use forest trees for feeding or nesting, such as woodpeckers, treecreepers, and great tits, are locally extirpated after large fires.

The first studies conducted in burnt areas are the production marketing studies carried out to cut the burnt trees and bring them to the timber industry. The tree cuttings carried out for this purpose are called production logging. Post-fire production logging is a widely practised method in Mediterranean forests for economic reasons, and for protection against insect infestations. With this method, pine trees that have died or will soon die due to fire are cut down and brought into the economy as timber and other products. Since salvage logging requires intervention in different forms in the forest area subjected to fire and has economic benefits, its positive or negative effects have been a topic of debate in all Mediterranean basin countries. Recent studies prove that full-area clear-cutting negatively impacts biodiversity (for example Leverkus *et al.,* 2012; Leverkus *et al.,* 2014). In particular, the positive effects of the microclimatic conditions provided by burnt trees left uncut after fire on the growth and development of young trees suggest that post-fire logging has adverse effects on the regeneration and the recovery of vegetation in Mediterranean low-elevation zone forests (Castro *et al.*, 2011). The intensive use of mechanization during post-fire production activities also damages the young trees and biodiversity in general (Castro *et al.*, 2011; Leverkus *et al.*, 2014). In post-fire production activities, issues such as not following the cutting-time plan, not leaving the site before natural regeneration begins, and failing to make cutting and skid trails per the technical standards, also harm biodiversity. It should be noted at this point that invertebrate species and some bird species that use the trees and other woody parts left uncut in the fire site benefit from the actual fires and standing burnt trees.
Following post-fire production, logging, regeneration, and restoration practices are carried out with different techniques. In many cases, passive restoration techniques have emerged as the most effective techniques for ecosystem regeneration. Natural regeneration reinforced by laying branches (conifer branches) and natural regeneration supported by reseeding are the most successful strategies for ecosystem regeneration. These approaches, which do not require intervention on forest soils, facilitate the natural regeneration of plant species from soil seed banks and bud banks after fire. At the same time, these two practices also address post-fire economic concerns as they promote the growth of Turkish red pine saplings. Therefore, these scenarios represent a win–win situation, securing both economic and ecological benefits.

Passive restoration techniques encompass strategies that include both post-fire production cuts or leave-it-unmanaged strategies without any logging. These unmanaged areas are mainly scrublands that exhibit a high capacity for post-fire recovery. However, regeneration success by afforestation in previous fires has been lower. This suggests that depriving previously afforested but fire-exposed areas of post-fire management practices may not be optimal for ecosystem recovery. This may be attributed to the reduced resilience of the site due to previous forest management activities. In these exceptional cases where previous management activities have compromised post-fire resilience, active restoration techniques such as replanting may offer a viable solution for effective restoration (Tavşanoğlu and Pausas, 2022).

Afforestation practices based on post-fire land preparation and tillage are generally not well suited for biodiversity-based ecosystem restoration. Such practices can cause soil loss and erosion, especially when not carried out properly, and can significantly damage soil seed and bud banks, limiting vegetation regeneration and recovery (Tavşanoğlu and Pausas, 2022).

It has been shown many times that the practice of laying branches (conifers), which is used to support the natural regeneration of Turkish red pine within the scope of post-fire restoration works, is a practice that does not harm biodiversity (Ergan, 2017; Ürker, Tavsanoglu and Gürkan, 2018). Branches spread homogeneously on the burnt area reduce soil loss and support the natural regeneration of plants, especially Turkish red pine, by creating favourable microclimate conditions (Boydak, 2004; Boydak, Dirik and Çalıkoğlu, 2006; Tavşanoğlu, 2021b). On the other hand, practices that prioritize tillage can lead to dramatic changes in vegetation structure.

For example, in a study conducted in Marmaris, it was found that post-fire mechanized tillage transformed the Turkish red pine forest from a vegetation structure dominated by resprouting and woody species to a structure consisting of annual herbaceous plants and non-sprouting species (Ürker, Tavsanoglu and Gürkan, 2018).

In post-fire forest management in the Mediterranean basin, natural regeneration and reseeding assisted natural regeneration practices have been reported to be more successful in terms of both regeneration success and cost than mechanization and planting practices (Boydak, 2004; Leverkus *et al.*, 2012; Moreira *et al.*, 2012; Vallejo, Arianoutsou and Moreira, 2012). In addition, techniques that require less intervention in the burnt forest area have been found to increase plant diversity in Mediterranean forests (Leverkus *et al.*, 2014). Therefore, post-fire management of forests in the Mediterranean basin should have a multidimensional approach and should not only prioritize the presence of the dominant species of vegetation, but also support plant and animal biodiversity in a way that supports multiple ecosystem services (Moreira *et al.*, 2012; Doblas-Miranda *et al.*, 2015; Tavşanoğlu and Pausas, 2022).
In summary, passive restoration techniques generally seem to be the best solution to increase biodiversity in burnt Turkish red pine forests, hard-leaved forests, and scrub after a forest fire. Unless the post-fire resilience of the site was already significantly reduced before the fire (meaning, it was previously ploughed and afforested), active restoration, including artificial regeneration by planting seedlings, should be avoided as much as possible to support biodiversity in these forests.

Table 3. Effects of post-fire techniques on species groups

	Herbaceous plants	Woody plants	Reptiles	Amphibians	Birds	Invertebrates	Small mammals	Large mammals	Bats	Impact score
Mechanical tillage	-	-	-	-	-	-	-	0	0	-7
Forest road and firebreak	0/-	0/-	+	-	+/-	+/-	0	+	+	+1
Fire-resistant plant strip	0/-	0/-	0	0	+	+	0	0	0	+1
Leaving standing burnt trees	+/0	+/0	0	0	+	+	0	+	+	+5
Branch laying	+	+	+	+	+/-	+	+	0	0	+6
Terracing and planting pine seedlings	0/-	0/-	-	-	-	0	+/-	+/-	0	-4
Seed replenishment and reseeding	0	0	0	0	0	0	0	0	0	0

Note: (+), 0 and (-) indicate positive, neutral, and adverse effects, respectively.

Source: Author's own elaboration

Implementation recommendations for post-fire biodiversity

In the early 2000s, the OGM started to take some essential steps to carry out forestry based on sustainable forest management criteria and indicators. Among these steps are the transition to ecosystem-based functional planning and the integration of biodiversity into forest management (Ülgen, Zeydanlı and Lise, 2020). The integration of biodiversity into forest management plans started in 2002 within the scope of the Biodiversity and Natural Resource Management project, known as the GEF II project, and then many exemplary projects were developed in cooperation with the OGM and DKM. Within the scope of these studies, two essential works that will serve as a roadmap have been produced:

1. Integrating Biodiversity into Forestry: A Planner's Guide (Zeydanlı and Özüt, 2019).
2. Integrating Biodiversity into Forestry: A Practitioner's Guide (Özüt, Tufanoğlu and Zeydanlı, 2019).

In the process of these studies, the OGM has acquired substantial experience in biodiversity inventory, evaluation, development of implementation recommendations, and their implementation in the field.

The Biodiversity-focused post-fire forestry practices guideline is based on this experience and the approach developed.

Within the framework of this approach, general principles that positively affect biodiversity in forest and scrub ecosystems are given below. Then, post-fire practices that do not harm different species groups in Turkish red pine forests – and that have the potential to increase biodiversity and techniques that should be avoided as they negatively affect a species group – are listed.

Implementation recommendations for post-fire biodiversity: general recommendations

Although the characteristics and habitat requirements of different species groups may vary, there are some general principles that maintain ecosystem structure and support biodiversity in forests and scrub.

Heterogeneous structure: Biodiversity is known to be higher in stands with a non-uniform, vertical or horizontal structure, and more than one dominant tree species. The vertical structure is created by different layers of vegetation from the forest floor upwards. As the number of layers increases, other species living or feeding in each layer will be present in the ecosystem. Vertical structure is essential for birds. Fallen trees on the forest floor are also valuable in this context.

Horizontal structure is determined by elements such as small openings, ravines and cliffs, which increase spatial heterogeneity. In addition, the juxtaposition of stands of different ages or with different canopy covers positively affects biodiversity. Heterogeneity in the horizontal structure can occur naturally due to processes such as wind cycles, landslides, fires, and so on, or by human intervention through clearing or clear-cutting. Generally, stands with medium and low closure are richer than fully closed stands.

The presence of more than one dominant species (especially if they differ physiognomically from each other) is generally recognized to increase the biodiversity of an area. Coniferous and phrygana species provide shelter for many animals, especially in winter. Deciduous species are more preferred as a food source.

Soil and litter: As an ecosystem element that contains root systems, seed, bud and shoot banks, is rich in microbial and invertebrate life, and is essential for nutrient cycling and carbon sequestration, the soil and overlying litter should be disturbed as little as possible. Dead plant material (decomposition) on the soil surface is a good seedbed. Soil preparation through mechanized tillage, while enabling rapid and effective afforestation, often leads to degradation of soil structure, loss of organic matter and carbon, and destroys many small mammals, reptiles, amphibians, and invertebrates, as well as spontaneous seedlings and saplings. In standing sales, which are widely practised for production purposes after mega fires, ensuring that companies obtain permission from the relevant local forest administration before opening hauling roads can prevent excessive opening of hauling roads for salvage logging, and also therefore prevent soil loss.

Connections: Biodiversity is enhanced when connections between forest and scrub patches are separated from each other by wide openings or human-made barriers that enable the movement of species and the interaction of ecological processes. Small streams and aquatic corridors often provide these connections through riparian vegetation. Small woodlands interspersed between large fragments of forest also act as stepping stones for many species.

In summary, the forest or scrub patches with the highest biodiversity value are multilayered stands dominated by more than one species, with open canopy and unbroken interconnections. Therefore, it is recommended that any regeneration or restoration effort should be targeted at forest stands with these characteristics.

Implementation recommendations for post-fire biodiversity: recommendations by species groups

Herbaceous and woody plants

- Post-fire production logging should be carried out carefully so as not to damage the soil seed and bud banks in the area.
- During production logging in areas larger than 12 ha, some burnt trees (three to ten trees per hectare) should be left intact in clusters or groups if possible, or individually if not.
- Mechanical tillage should be avoided as much as possible, and if necessary, it should be done in strips rather than in the whole area.
- Branch laying should be done in such a way that the branches are laid homogeneously on the field.
- If terracing is to be done, terraces should be built according to the technical standards, ensure soil stabilization, and be formed with narrow openings and with the least possible intervention so as not to damage the soil seed and bud bank.
- Preserve forest openings and spaces that existed before the fire and create openings if they do not exist, if they are not smaller than 3 ha, depending on the size of the fire.

Amphibians

- Avoid mechanical tillage of the soil, and where tillage is necessary, take into account the habitat requirements of amphibians.
- Branch laying should be done in such a way that the branches are laid homogeneously in the area.
- Avoid terracing, and where terracing is necessary, take into account the habitat requirements of amphibians.
- Protect water resources.

Reptiles

- Avoid mechanical tillage of the soil and take into account the habitat requirements of reptiles in cases where tillage is necessary.
- Branch laying should be done in such a way that the branches are laid homogeneously in the area.
- Avoid terracing, and where terracing is necessary, the habitat requirements of reptiles should be taken into consideration.
- Preserve forest openings and spaces that existed before the fire and create openings if they do not exist, provided that they are not smaller than 3 ha, depending on the size of the fire.

Birds

- Leave some burnt trees (at least 10–50 trees per hectare) in clusters and groups if possible, and if not, leave them in the area without cutting them individually during post-fire production logging.
- Avoid mechanical tillage of the soil and take into account the habitat requirements of birds in cases where tillage is necessary.
- Branch laying should be done in such a way that the branches are laid homogeneously in the area.
- Avoid terracing, and where terracing is necessary, consider the habitat requirements of birds.
- Create a fire-resistant plant strip.
- Preserve forest openings and spaces that existed before the fire and create openings if they do not exist, if they are not smaller than 3 ha, depending on the size of the fire.
- Ensure multilayered, different-aged or mixed stands, if possible.
- Place nesting boxes in appropriate locations.

Invertebrates

- Leave some burnt trees (three to ten trees per hectare) uncut in clusters and groups if possible, or individually if not, during post-fire production logging.
- Avoid mechanical tillage of the soil, and where tillage is necessary, take into account the habitat requirements of invertebrates.
- Branch laying should be done in such a way that the branches are laid homogeneously in the area.
- Create a fire-resistant plant strip.
- Ensure the formation of stands of different ages or mixed stands, if possible.

Small mammals

- Avoid mechanical tillage, and where tillage is necessary, take into account the habitat requirements of small mammals.
- Branch laying should be done in such a way that the branches are laid homogeneously over the area.
- Maintain forest openings of less than 3 ha within the stand or establish them if they do not exist.
- Ensure the formation of multilayered, different-aged or mixed stands, if possible.

Large mammals

- Leave some burnt trees (three to ten trees per hectare) in clusters during salvage logging.
- Establish forest roads and firebreaks.
- Maintain forest openings of less than 3 ha in the stand or establish them if they do not exist.
- If possible, ensure the formation of multilayered, different-aged or mixed stands.
- Leave scrub and phrygana species, which can be food plants, in their natural state in and around rocky areas.

Bats

- Leave some burnt trees (three to ten trees per hectare) in clusters and groups if possible, and if not, leave them on the site without cutting them individually during post-fire production logging.
- Establish forest roads and firebreaks.
- Preserve forest openings and spaces that existed before the fire and create openings if they do not exist, if they are not smaller than 3 ha, depending on the size of the fire.
- If possible, ensure the formation of multilayered, different-aged or mixed stands.

It would be beneficial to initiate these practices primarily where rare and threatened flora and fauna elements are found. These practices define the basic principles not only for rare and threatened species, but also for a holistic ecosystem restoration approach in establishing the post-fire forest ecosystem. In this context, it is essential to prepare and implement a post-fire restoration plan that includes production and marketing processes immediately after the fire (Sabuncu *et al.*, 2023). It is vital that such a plan is prepared by a team of experts (on the subjects of ecology, biology, socioeconomics, hydrology, remote sensing, and so on) and that all implementation processes are carried out under the supervision of this team. This plan should be based on ecological and biological foundations.

All post-fire production and planning activities should support the natural regeneration processes after the fire, work-time planning should be done appropriately, and cutting, hauling, and removing the product from the site should be completed before natural regeneration. The creation of hauling and forest roads during these works should be built in accordance with the correct technique, and ecological and biological damage should be avoided. Attention should be paid to the sensitivity of the habitats of some particular species groups, such as in and near streams, and the use of these areas for hauling and forest roads should be avoided. The adverse effects of mechanical tillage on biodiversity should be recognized, and it should not be applied unless necessary. Work should be done in strips instead of full field tillage, and growing environments like those near streams should be spared as much as possible.

Box 1. Pilot application – bird nest boxes

In line with the recommendations presented in these guidelines, a pilot application was carried out for bird species within the scope of the Restoration of Post-Fire Forest and Maquis Ecosystems in Muğla Province (TCP/TUR/3902/C2) project. In order to increase the breeding potential and populations of the target bird species in the area, namely the Tawny owl, Coal Tit and Krüper's Nuthatch, nest boxes were placed on tree clusters within the fire areas. Tree clusters in the burnt area were detected by remote sensing via satellite images, and potential areas where the boxes could be hung were determined for both pilot areas by aligning them with the points where the target species were recorded during field studies.

Source: Google Earth Pro 7.3.6., 2024, Google LLC.

Adhering to the standard received from the GDF, Department of Forest Pest Control, nest boxes were produced by changing only the entrance hole size for the small ones.

Item	**Entrance Hole**	**Height between the top and the entrance hole**	**Width of the box**	**Height of the box**	**Total number of nest boxes**
Coal Tit & Krüper's Nuthatch nest boxes	35 mm	25 mm	140 mm	200 mm	100
Item	**Height of the entrance hole**	**Width of the entrance hole**	**Width of the base**	**Height of the box**	**Total number of nest boxes**
Tawny owl nest boxes	200 mm	255 mm	255 mm	600 mm	20

It is recommended that the nests be controlled twice in April, before the fire season. The following points should be taken into consideration when checking the nests:

- There should be a ladder of at least 2 m to climb to the nests.
- Approach the nest boxes from the side of the entrance hole, and lightly tap on the box to allow time for the individual inside to leave the nest. If a warning sound is heard from inside and the mother has not left the nest, do not disturb, and simply take note that there is breeding activity present.
- If the mother individual has left the nest, the interior of the nest box should be recorded using the endoscope camera as quickly and gently as possible through the entrance hole, and then the vicinity of the nest should be vacated as soon as possible.
- It is appropriate to use endoscope cameras that are compatible with phones and tablets, capable of high-resolution photo and video recording.
- Due to the relatively large entrance openings of owl nests, monitoring of these nests should be conducted either by attaching cameras to a telescopic pole for checking through the nest opening or by climbing to a tree opposite the nest with the help of a ladder and observing with binoculars.
- It is crucial to record the activity status of each nest (breeding, nest material, no activity, and so on) and save it to the corresponding coordinates.

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