Manual 14

EUROPARC-Spain Series of Manuals

Mediterranean Old-Growth Forests: Characteristics and Management Criteria in Protected Areas

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Mediterranean Old-Growth Forests:
Characteristics and Management Criteria in Protected Areas
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Pinus nigra forests with old and umbrella-shaped trees,
preserved thanks to the abrupt conditions of the place.
Barranco La Fou. Author: Bruno Durán / Parc Natural dels Ports

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EUROPARC ESPAÑA

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Pinus nigra forests occupy large areas of the Iberian Peninsula, often in a good conservation status. Barranco del Regatxol. Author: Bruno Durán / Parc Natural dels Ports

Contents

Many of the Mediterranean forests with attributes of maturity come from forests where human use has ceased.
Quercus suber and *Q. canariensis* stand of San Carlos del Tiradero, Los Alcornocales Natural Park. Author: José A. Atauri

Foreword

Forests comprise the most highly diverse land ecosystems. Their complex structure and the variety of vital ecological processes they support configures them as multifunctional systems par excellence. Over and above the intrinsic value of the natural and ethnographic heritage they hold within, forests provide a wealth of benefits to people's health and well-being.

Throughout practically all of Spain's Autonomous Regions, as well as all over Europe, forests and forest systems in the broadest sense represent the most widely distributed and diverse ecosystems. This fact is compounded of the existence of this unique treasure and the challenge of planning and managing it appropriately to safeguard its values and to enhance the services it renders.

This is no easy task in present times, when forests are largely exposed to two opposing forces depending on their characteristics and location: land use intensification and husbandry cessation, both with negative effects on habitat and biodiversity conservation in the absence of proper management. The challenge before us is colossal in every aspect, as it consists –broadly speaking– in transforming the currently predominant young, homogeneous and fragile woodlands into mature forests that are diverse and resilient to global change.

In this framework, preserving the few old-growth stands that remain in our country and continent takes on still greater significance. To the value of the habitats they offer and unique species they are host to, we must add their value as a reference for the structures and functionality toward which a large part of our forest planning and management should gravitate. The is no doubt that we need to preserve the oldest remnants of our forests, but this is not enough: we need to apply criteria for enhancing maturity throughout all forest ecosystems to ensure the conservation of the entire range of processes taking place in the full thicket-to-landscape spectrum.

Protected areas make up an extensive network in which to test pioneering and innovative responses to conservation challenges. In addition, many such spaces have been chosen for protection precisely because they are exemplary forest ecosystems and, very often, because they contain fragments of old-growth forests. Despite the protection and customised management committed to protected areas, a large percentage of such forests are found to be in unfavourable conservation conditions, as shown, for instance, in the periodic assessments conducted within the Natura 2000 Network.

Conservation of the oldest stands is a top priority within these protected areas, where many initiatives have been implemented in the various lines of action that need to be set in motion. Of these, we may mention three of the most important: firstly, the identification and detailed description of these stands in order to understand their structure and dynamics and define the parameters of reference for maturity. Secondly, the analysis and dissemination of the unique values and services inherent to these forests, which clearly reach far beyond timber harvesting and relate to their scientific value, the regulation of major ecological processes or the social uses and benefits they yield to society. Thirdly, protected areas have preferentially hosted innovative approaches in new forest management formulas, from non-intervention in the more mature stands to a silviculture inspired on nature and the conservation of ecological processes. All the above is achieved through the joint efforts of protected area managers, experts in the public or private forestry sector, forest landowners, scientists and representatives of the third environmental sector.

This previous experience has allowed a group of experts in Mediterranean silviculture and conservation to be formed, in the framework of EUROPARC-Spain, that since 2017 has intensified its activity thanks to the LIFE RedBosques Project. This manual compiles the main thoughts, experience and proposals of participants from different fields collaborating in the project, covering aspects ranging from the establishment of a common terminology and a methodology for identifying old-growth stands, to proposing management criteria for these stands and, in general, forest management with the aim of increasing forest maturity on different scales.

We stand at the threshold of the year 2020, a true milestone in national and international conservation policies, as we need to review –and to strengthen, in view of the poor results obtained to date– the principal strategic instruments. At the same time, many forestry policies are being rewritten, giving greater weight to conservation and its benefits to society. For instance, in the European context there is a demand to step up actions to protect and restore forests worldwide. Specifically regarding the conservation of old-growth forests, a large number of territories on the regional, Spanish and European scale are calling for the creation of networks of old-growth stands, viewed as an essential and indispensable action.

Internally within EUROPARC-Spain, 2020 marks the conclusion of our working programme "Society and Protected Areas". The degree to which its objectives have been met is currently being assessed as the point of departure for future work, in collaboration with our strategic allies, in the design of a new action plan. New forest conservation paradigms are a transversal issue running through practically every line of action within the programme, such as services rendered by ecosystems, the transfer of research to management, or new governance and funding models.

It seems obvious that the working group's results, presented below, will be of great value in defining our future priority actions.

The timing of this manual, therefore, is ideal as it makes key contributions to a scenario hindered by loopholes liable to delay or weaken decisions that need to be taken urgently to make headway in the conservation of our forests, especially the oldest among them, priceless jewels in our natural heritage and source of social health and well-being. I am convinced that this manual will prove an invaluable tool for everyone, from the managers of protected areas to those responsible for drafting strategic policies, in addressing major conservation challenges. Let us delay no further.

Carles Castell
Society and Protected Areas Programme 2020
EUROPARC-Spain

Some very scarce forest types such as *Tilio-Acerion* forests, take refuge in the most inaccessible places. Tilera del Barranco del Gisbert in Mosqueruela (Teruel). Author: Emili Martínez i Ibartz

Executive Summary

Primeval forests, that is, those that have evolved free from human intervention, are today extremely rare in Europe, and especially so in the Mediterranean region. However, stands of a certain maturity and a small human footprint can still be found locally.

Owing to their extreme scarcity, complexity and biodiversity, the identification and conservation of the last remaining fragments of old-growth forests is of enormous interest both in the scientific world and in conservation policies. The LIFE RedBosques Project has developed the necessary tools to identify old-growth stands, enabling many Spanish autonomous regions to begin processing the identification of stands to be included in a nationwide Network of Stands of Reference.

This document provides a comprehensive review of the scientific knowledge on forest maturity and its different meanings, an explanation of forest maturity with reference to the silvogenetic cycle, and a summary of the most significant and visible characteristics of old-growth forests (Chapter 2). Among these we may highlight the presence of trees whose age is close to their lifespan limit, gaps in the canopy enabling the regeneration of shade tolerant species, considerable amounts of dead wood –standing and fallen, in different stages of decomposition–, marked vertical diversification, and the absence of anthropic interventions or, at least, their cessation several decades ago.

The special structural characteristics of old-growth forests provide the habitat for large numbers of highly specialised species, who cannot survive in younger forests and are therefore restricted to older stands. The scarcity of such mature conditions is a severe threat to woodland biodiversity dependent on senescent forest conditions. A review is conducted in this document of the importance of old-growth stands to a range of different groups: birds, chiroptera, saproxylic coleoptera, vascular flora, lichens and fungi.

The remaining old-growth stands provide the most natural forest habitats available, and are therefore a valuable measure for comparison as a reference for each forest type. Chapter 3 develops this notion of old-growth stands as references, particularly from the perspective of their usefulness in evaluating the conservation status of Habitats of Community Interest as required in the Habitats Directive.

Chapter 4 conveys the above concepts to the field of forest management, proposing a management model that guarantees the preservation or recovery of maturity traits both in forests subject to conservation aims and in productive woodlands. Depending on each individual situation, these aims will be achieved through non-intervention in mature stands, management focused on increasing certain features of maturity in woodlands subject to conservation aims, or a productive management model compatible with certain features of maturity. Lastly, a number of woodland management and silvicultural techniques are proposed which, under proper guidance, may serve to promote features linked to forest maturity, and allow the generation of woodlands featuring greater diversity and resilience to climate change.

The recommendations given in the manual are illustrated in Chapter 5 through four case studies, each following a different management alternative: non-intervention in Parque Nacional de la Sierra de Guadarrama, dead wood management to increase diversity among saproxylic coleoptera in Parc Natural del Montseny, silviculture compatible with maturity on private estates in Parc Natural dels Ports, and enhancement of structural diversity in areas of Aleppo pine reforestation in Zaragoza.

The manual is rounded off with a glossary providing concise definitions of the terms most commonly used in the document, and a list of scientific and technical references cited in the text.

Although oak forests are very common in the Mediterranean, old-growth stands are very rare.
Carrascal del Plano, in the Sierra y Cañones de Guara Natural Park. Author: Emili Martínez i Ibartz

Due to their scarcity, old-growth stands of Mediterranean forests are singularities of great value.
Sierra de Espadán Natural Park. Author: S.E. Huesca

1 Introduction

Forests are one of the most important ecosystems in Europe, by extension (forest cover in the European Union amounts to 176 million ha, equivalent to 42% of the territory), by diversity (as many as 79 different types of forest habitat are recognised in the EU), for their great economic importance, and for the wide range of services they render to society (European Commission, 2015).

Spain, thanks to its biogeographical position, geomorphology and the succession of Paleoclimatic events occurring after the end of the Pleistocene, is home to a particularly diverse range of forests: woodlands formed in different climates, enduring and mingling over time. Spanish forests are mainly aligned with the peninsula's two dominant biogeographical regions, the Mediterranean and the Eurosiberian, to which we should add -besides the Macaronesian- relicts of past paleotropical or boreoalpine climates, among others (García Antón *et al.*, 2002).

The current surface area under forest cover in Spain totals 27.7 Mha, accounting for 54.8% of the national territory (European Commission, 2015), and harbours 27 different types of forest which are considered Habitat of Community Interest. Beechwoods, spruce forests and oak forests characteristic of temperate Europe, deciduous and marcescent forests of Pyrenean oak, Portuguese oak, Mediterranean pine, sclerophile forests of holm oak, cork oak, wild olive or carob, light woodland cover such as needle-leaf and scale-leaf juniper thickets, as well as riparian woodland, Macaronesian forests or other types specific to scree slopes or ravines, all combine forming a complex mosaic.

The forest types we encounter today were formed in the last ice age, but have been modified through climate changes during the Holocene, and most especially by human activity. European forests have been used since antiquity, of which evidence can be found in pollen registers dating to 8000 BP. Anthropic uses of the landscape that became generalised some 1000 ago have modelled our forests in several ways. The most outstanding modification to many forests involved the positive selection of canopy species, leading these to become dominant. This gave rise to more open woodlands, with a simpler structure and flora, which in the Iberian context mainly features the dehesa but also other formations such as juniper thickets. The current single-species make-up of Iberian pinewoods is also attributed to this effect. Indeed, in the absence of husbandry, mixed woodland would have been more common than at present (Sainz-Ollero *et al*., 2017; Sánchez de Dios *et al*., 2019). The second most important modification resulted from extracting firewood and charcoal from resprouting oak scrubland. The consequences were drastic structural simplification, the creation of strictly single-species woodlands, and a poor capacity for long-term endurance and recovery (García Antón *et al*., 2002).

To these alterations we must add the elimination of a wide variety of large herbivores (and their predators) that inhabited the European continent during interglacial periods and no doubt significantly conditioned the plant landscape, but were gradually wiped out during the Holocene and replaced with domestic livestock (Vermeulen, 2015; Palau, 2020).

Following this long history of intensive use that altered forests' natural structure, in the second half of the 20th century forest husbandry ceased suddenly owing to rural depopulation, the substitution of charcoal with other fuels, the drastic reduction in extensive livestock farming, and the loss of profitability in some of the main woodland harvests (MAGRAMA. 2014). Ever since, forests have gained considerably in surface area all over Europe, both through the colonisation of farmland and abandoned pastures and through proactive reforestation policies enacted from the late 19th century to the mid 20th century (especially in Spain).

As a result, the greater part of our forests is made up of young or rejuvenated woodlands, generally homogeneous as far as species and age structure is concerned, that are especially vulnerable to disturbances such as fire or plagues, and all the more so in the current context of climate change. Unaltered forests are exceptionally scarce, amounting to around 5% in the EU (European Commission, 2015), and a smaller percentage in the Mediterranean area.

A substantial part (almost one-third) of the Spanish forest cover is included within the Natura 2000 Network. This fact, besides highlighting the importance of forests to preserving biodiversity, implies a commitment to safeguarding their favourable conservation status. However, recent assessments published by the European Commission (2007-2012 report) indicate that most European forests currently present an unfavourable conservation status.

Forest conservation through every stage of development, from young woods to old-growth or senescent stands is imperative to ensure their preservation on a regional scale. Hence, it is essential to identify and preserve the last remaining stands in which key ecological processes operate freely, as these are the last examples available as references. Likewise, we should bear in mind that certain senescent stands are the last havens for taxons at risk of becoming extinct.

Furthermore, these remnant old-growth stands offer the opportunity to identify the structural characteristics most directly linked to maturity, prompting silviculture practices that mimic natural processes and allow structures or elements pertaining to scenarios of maturity to remain in place (Keeton, 2006; Tíscar, 2006), maintaining a favourable conservation status throughout the overall forest cover.

1.1. Content of this Manual

This manual is the outcome of reflections and contributions by a wide range of professionals, from scientific backgrounds and from the sphere of protected space management and forest management, focused on the need to gain deeper knowledge of old-growth forests in the Mediterranean area. It contains the results of work commenced by the EUROPARC-España working group on forests in 2013 and subsequently continued thanks to the LIFE RedBosques Project. The texts contained in this manual have been extensively discussed by the group and shared at a number of seminars, in which participants included managers of protected areas and woodlands across all of Spain.

These forums were instrumental in establishing a common terminology for old-growth forests in the Mediterranean area (Parc Natural dels Ports, November 2017), the Identification of good management practices (Parque Natural Sierra Norte de Guadalajara, November 2018) and discussing a preliminary proposal for forest maturity management criteria (Paisaje Protegido Pinares de Rodeno, May 2019).

As a result of the work conducted by this group a methodology has been developed for the identification of old-growth stands. Its implementation in the field has enabled a nation-wide Network of Stands of Reference to be configured.

Prior to the drafting of this manual, 27 examples of forest management targeting the promotion of maturity were identified and incorporated to the EUROPARC-España database of conservation actions (wikiconservacion.org).

The criteria proposed by the working group have been applied in practice, in a pilot project in Parc Natural dels Ports, specifically in the drafting of three woodland planning projects on three estates within the park, and the pilot implementation of management measures to promote forest maturity as proposed in said plans.

The seminar conclusions, the presentations given, the technical material generated for identifying stands and the RedBosques tool for accessing the Network of Stands of Reference are all available online (www.redbosques.eu).

From this perspective, this manual aims to:

- Clarify forest maturity concepts, propose a common terminology, and explain the values that justify the identification and conservation of old-growth stands.
- Propose general criteria for the conservation and management of old-growth stands.
- Demonstrate how forest management can enhance maturity throughout the forests included in the Natura 2000 Network.

This manual is intended for Natura 2000 Network planning and conservation professionals and the managers of the forest habitats encompassed therein. In Spain, these competences are shared among various professional groups including government officials responsible for the design and implementation of management plans and conservation projects within the Natura 2000 Network and protected areas, and those responsible for forest management on public woodlands and the supervision of privately-owned woodland management. In addition to these are company technicians (these are often public companies) working for the administration in developing the Natura 2000 Network.

Private ownership accounts for 70% of Spanish forests. We believe that this manual will be useful to landowners interested in re-orienting woodland management toward alternative uses such as social uses, preserving our natural heritage, or adapting to climate change.

The problems associated to forests –ancestral uses, recent abandonment, new conservation commitments, the dispersion of competencies, the importance of private ownership– are common to the EU as a whole. In the Mediterranean countries, the role played by fire and the effects of climate change are likewise a common denominator. Therefore, although developed within the Spanish context, the ideas put forward in this manual may invite reflection on a broader geographic scale.

Continued timber harvesting lead to a simplification of the forest structure.
Author: José A. Atauri

Attributes of forest maturity in a *Abies alba* stand in the Parc Natural del Montseny. Author: José A. Atauri

2 The Concept of Old-Growth Forest

2.1. Do Old-Growth Forests Exist?

Primeval forests, those that have developed free from disturbances, are extremely rare these days anywhere in the world. The best examples are found on the American continent, basically in the temperate and boreal forests of Canada and Alaska, and the Amazonian tropical forests. At the end of the last Ice Age these forests covered the greater part of Europe, but intense land use has led to the current situation in which hardly any untouched woodland remains, with the exception of boreal forests with very low levels of intervention in Russia, small areas in Scandinavia[1] and a few enclaves in the Ural and Carpathian Mountains (Bengtsson *et al*., 2000; Potapov *et al*., 2008; Sabatini *et al.*, 2018).

In the year 2000 untouched forest on the planet was estimated to cover 12,800,000 km², that is, 22% of global forest landscapes. Untouched forests are defined as those with an extension greater than 500 km², made up of a mosaic of woodlands and natural non-forest ecosystems, that evidence no signs of human activity or habitat fragmentation, and are large enough to sustain all native biological diversity, including viable populations of species dependent on great spaces. It is estimated that the surface area covered by such untouched woodland landscapes decreased by around 7.2% between 2000 and 2013 (Potapov *et al*., 2016).

Forest management and intensive land use have led to the predominance in Europe of young forests with a protracted history of intervention: secondary forests. These are forests subjected to human intervention, which may be intensive, through logging and replanting, for instance, or through the sustained harvesting of its resources, or to interventions promoting regeneration.

The absence of primary forests does not rule out the local existence of copses or stands with a low human footprint, at least as far as harvesting is concerned, that enables the forest to reach a certain maturity. Secondary forests in which human intervention has ceased may achieve features of maturity similar to those of primary forests (MCPFE, 2007).

1— http://www.intactforests.org/ data.ifl.html

An estimated 15 to 20 million hectares of forest with low levels of anthropic intervention survive in Europe, located fundamentally in the Russian taiga (Halkka & Lappalaien, 2001), which represent just 5% of the forest cover on the continent. This percentage is even smaller in the Mediterranean basin where it is estimated that only 2% of the original vegetation remains relatively unaltered, and concentrated in Turkey and Bulgaria (FAO, 2013). In our neighbouring countries the proportion shrinks further: in France only 0.2% of forest cover is unaltered woodland, and is found in highly inaccessible locations (Barthod & Trouvilliez, 2002).

In recent years, therefore, old-growth forests have attracted a great deal of interest, as well as intensive researching activity, although the degree of knowledge varies widely from one biogeographical region to another (Burrascano *et al*., 2013). Most research has been conducted on temperate and boreal ecosystems, and in the majority of cases, characterised by a pattern of frequent low-intensity disturbances. Studies on old-growth forests subject to major disturbances (such as fire) are scarce, and conducted on the American continent in ecosystems dominated by conifers (Binkley *et al*., 2007; Fiedler *et al*., 2007; Cortés *et al*., 2012).[2]

In the Mediterranean basin at present there is insufficient scientific knowledge of its old-growth forests, whether of conifers or fagaceae and other broad-leaved species (Mansourian *et al*., 2013). Studies conducted in Mediterranean areas, centred on France and Italy, generally refer to beech and spruce forests. In Spain, the few studies conducted in this field have also focused on Atlantic or Pyrenean forests (Antor & García, 1994; Bosch *et al*., 1992; Gil, 1989; Rozas, 2001, 2004, 2005), and Macaronesian woodlands (Fernández & Gómez, 2019).

2.2. Old-Growth Forests in the Context of Forest Dynamics: the Silvogenetic Cycle

The structural and ecological properties that characterise forest maturity should be analysed bearing in mind the complete life cycle of the forest, a continuous circle that is constantly re-started. In this process distinct phases or stages can be differentiated, characterised by changes in the whole structure of tree generation,

2— In the scientific literature a multitude of terms have been proposed, such as old-growth, virgin, natural or pristine forest. The expression 'old-growth forest' is the most widely used, especially in North America (Wirth *et al*., 2009), but in Great Britain 'ancient forest' and 'ancient woodland' are also used. The FAO (2012) recognises as many as 99 different terms under the heading 'old growth'. This has been translated into Italian as 'foresta vetusta', into French as 'forets anciennes' and into German as 'urwald'. In Spanish some confusion persists and both 'bosques maduros' and 'bosques viejos' are in use.

from the beginning of the process in the absence of significant disturbances to the natural death of all individuals initially generated. In addition, the different phases correspond to differences in the ecological processes occurring within the forest ecosystem at each point in time and among the functional traits of the tree species present (Bauhus *et al*., 2009) (Figure 1):

- **Clearing or "gap" phase:** the cycle starts –or restarts– when, following a low-intensity disturbance in which one or several large dominant old trees have fallen, a clearing –or "gap" - is formed freeing up several hundred square metres.
- **Regeneration or rejuvenation phase**: if the clearing is large enough, sunlight will enter giving rise to a new cohort of trees. The ensuing regeneration will be conditioned by the intensity of the disturbance, the surviving biological legacy, the characteristics of the location (soil type, slope, etc.) and the surrounding conditions. Intervening in this phase are species stemming from the soil seed bank, individuals surviving the disturbance, new stock growth in the case of resprouting species, and propagules from adjacent terrain.
- **Occupation phase:** after regeneration progressive occupation of the area begins, whose nature will depend on regeneration density and functional traits of the species present. Trees gain in height until a closed canopy is formed above the ground, competing without endangering each other. The time elapsed until the canopy is closed will depend basically on the density and growth rate of the regenerated vegetation.
- **Exclusion phase:** as soon as the canopy closes, competition for light becomes more intense, especially between the tree layer and the herbaceous and shrub layers, leading to the elimination of shade-intolerant species. With time, strong inter- and intra-species competition also arises, leading to the death of individuals failing to reach the canopy level. Dead wood thus arises, initially in small amounts and, in turn, a greater diversity of saprophytic and detritivore organisms (Franklin *et al*., 2002).
- **Maturity phase**: from this moment, a long phase begins in which differentiation takes place with regard to size and crown types, leading to horizontal and vertical diversification within the stand and, likewise, a considerable diversification of ecological niches (Bormann & Likens, 1994; Carey & Curtis, 1996; Oliver & Larson, 1996; Spies & Franklin, 1996). During this phase the trees forming the upper canopy achieve their maximum height and crown width. If no intense disturbances occur, some more shade tolerant species will reach the canopy under-layer (intermediate layer).

Tree mortality due to minor disturbances (windthrow, snowfall, lighting strikes, attacks by borer insects, etc.) and growth in height of surviving trees will likewise create favourable conditions for the establishment of new cohorts of species with varying degrees of tolerance to shade, depending on the size of the clearings formed. The generation of different strata through occupying smaller or larger gaps in the canopy leads to the structural diversification of the stand and, particularly, to the full occupation of the vertical profile.

In this phase, especially as a consequence of growth among the trees surviving from the initial generation, the greatest quantity of biomass is accumulated. Moreover, the loss of some of the initial generation of trees entails the appearance of significant volumes of coarse dead wood, standing or lying on the ground, and the emergence of saproxylic communities inherent to this type of woody material.

- **Senescent phase:** as surviving trees increase in age and size, so does the risk of non-lethal damage that generates a wide range of tree microhabitats (treetop breakages, fallen branches, hollows and damage to tree trunks, bark damage, dendrotelmata). Also more open crowns let in more sunlight to the benefit of vertical structure diversity. It is at this point that the greatest diversity of tree species specific to later stages of maturity appear, as well as very large trees, at the limit of their natural lifespan and in the senescent phase. These accelerates the generation of coarse dead wood, both standing and lying on the ground. These trees mingle with younger trees of all ages whose treetops populate the entire vertical profile. Mortality among small groups of adjacent trees gives rise to a mosaic of different-sized clearings that increase horizontal diversity and the possibility of establishing new generations of trees.

Each phase has a different duration within the full cycle: the regeneration and occupation phases represent 10% of the overall cycle duration, the exclusion and maturity phases another 35% respectively, and the senescent phase 20% (Bauhus *et al.*, 2009).

Photo 1. Regeneration following minor disturbance through treefall, in a stand of *Pinus nigra* (Monumento Natural Palancares y Tierra Muerta, Cuenca). Author: E. Arrechea.

2.2.1. Forest or Stand. The Importance of Scale

The different phases in the silvogenetic cycle do not occur evenly throughout the forest, but rather, as clearings are formed, different sectors or stands within the forest may be found in different phases forming an overall mosaic.

It is therefore impossible to comprehensively define the concept "old-growth forest" without taking into account landscape-scale considerations. From this point of view, old-growth forests are those from which anthropic disturbances are absent and where natural dynamics create a mosaic of stands undergoing every stage of development, including senescence.

This definition highlights the difference between *forest*, an ecosystem requiring a sufficient area for all the phases in the silvogenetic cycle to be represented, in which all its characteristic ecological processes and the ensuing forest biodiversity can be sustained over time, and *stands,* sectors within the forest simultaneously undergoing the same phase within the cycle, some of which may be in the final phases of maturity or senescence.

At the landscape scale, in order to speak of old-growth forests, we should also take into account the temporal scale: the pattern (frequency and intensity) of natural disturbances (highly stochastic) that induces drastic changes, more or less fully restarting the system and the lifespan of the trees it is composed of (Spies & Franklin, 1996; Kneeshaw & Gaulthier, 2003). For instance, disturbances that destroy vertical stratification induce regeneration dynamics that differ greatly from those that do not affect the lower layers within the stand (Sevilla, 2008).

This dynamic may in part be altered in ecosystems subject to major disturbances, such as Mediterranean ecosystems, that suffer episodes of intense drought and are characterised by forest fires as the principal agent of renovation. In ecosystems where fire is a recurrent disturbance, the cycle is frequently restarted, giving rise to a more complex mosaic on the landscape, while stands that achieve maturity contain less density of old trees and smaller quantities of dead wood, as well as presenting more open structures. When forest fires progress from being frequent low- or medium-intensity disturbances to becoming large-scale disturbances (as in the case of Mediterranean forests regenerated after having been neglected), the maturity phases may disappear altogether from the landscape (Kaufmann *et al*., 2007).

2.2.2. The Silvogenetic Cycle and Forest Management

The most common forestry husbandry practice, chiefly for timber extraction, is dependent on harvesting vigorous forest growth while constantly renewing the system to prevent senescence. Hence, harvesting causes major transformations in the structural characteristics of forests. Basically, these consist of permanently rejuvenating the forest, anticipating through different felling strategies the disturbances that would otherwise give rise to clearings of varying sizes in the canopy (for instance, treefall, forest fire or borer insects), allowing endless rejuvenation.

In forestry terminology, when the forest reaches the ‘tall stemwood’ stage, signalling the beginning of the maturation phase described earlier, felling is conducted for regeneration purposes and the cycle is thus restarted (Figure 1). In this manner the more advanced phases of maturity are never reached. Such shortening of the natural cycle is defended on the grounds that the forest is at its most productive (in terms of timber production) during the early phases in the trees’ lifespan. Trees are felled, therefore, at 70 to 140 years of age in the case of species whose natural lifespan reaches 300 to 500 years. Bauhus *et al*., (2009) estimates that forests managed for timber production cover 10% to 40% of the trees’ full silvogenetic cycle.

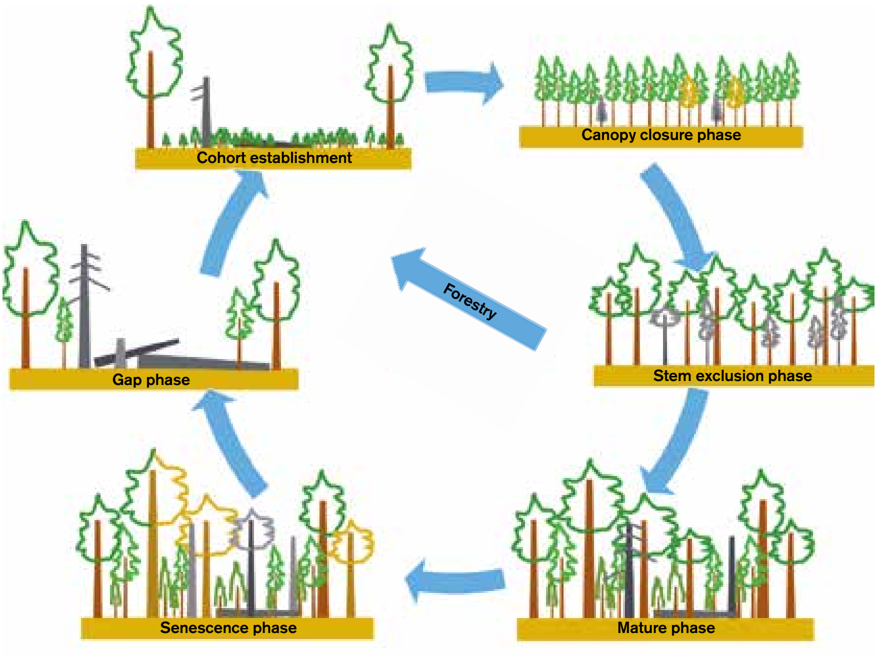


Figure 1. Timeline for the development of a forest stand. Forest management implies the systematic exclusion of the maturity and senescent phases, precisely those of greatest importance in the conservation of threatened species. Modified from the original in Schwendtner (2014).

By shortening the cutting cycle, regular forest management allows for sustained harvesting but produces a simplification in the associated forest structure and biodiversity (Franklin *et al,*. 2002; Paillet *et al.*, 2010; Seibold *et al.*, 2019; Thorn *et al.*, 2019). Besides, forest management will have long-term repercussions in the forest's structure and composition.

2.3. Characteristics of Forest Maturity

The study of forest maturity departs from the premise that forest ecosystems undergo constant change and persist over very long periods of time owing to the great longevity of their primary species: trees. Over such periods of time, the ecosystem develops from its establishment to maturity, while throughout this process its composition, structure and functions undergo major changes (Franklin & Spies, 1991).

In this perspective, forest maturity can be studied from three angles (Hunter, 1989; Wirth *et al.*, 2009; Rotherham, 2011):

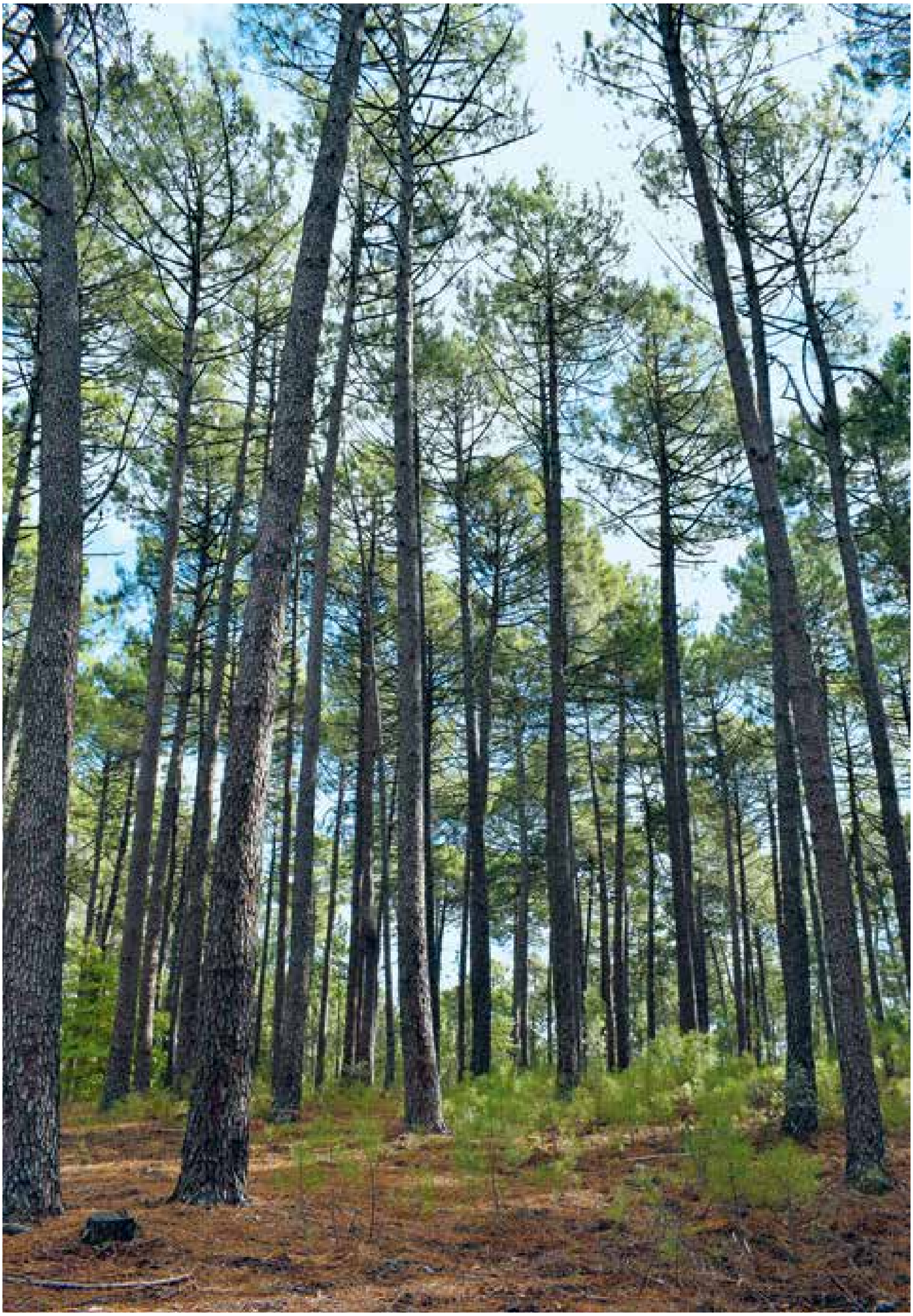


Photo 2. Tall stemwood of *Pinus pinaster* in which regeneration cuts have started. Arenas de San Pedro (Ávila). Author: E. Arrechea.

- the description of the structural characteristics and the composition of tree species,
- the study of the succesion processes leading up to and sustaining the maturity phase, or
- the study of its ecological and biogeochemical processes (for instance, edaphology, nutrient cycles, primary production, biomass accumulation).

Structural attributes of old-growth stands

The principal attributes related to the successional process of maturation and senescence measurable in the field are:

- **Composition of canopy species:** regeneration following minor disturbances gives rise to uneven- aged forest, regrowth of shade-tolerant species and the presence of several different species in the canopy.
- **Exceptional trees:** individual trees of species that correspond to advanced successional states, of an age close to the limit of their lifespan and with an average age throughout the stand of around half of said lifespan. A sign of this advanced age is the abundance of trees of great girths..
- **Horizontal complexity:** heterogeneous stands are to be expected, containing trees of diverse diameters and age types in the canopy. Estimating normal diameter and calculating the basal area allow measurements to be made and comparisons to be drawn with husbanded stands. Characteristically, trees with the largest girths will take up most of the basal area.
- **Vertical strata:** the successional process leads to the total occupation of vertical space, so that in old-growth and senescent stands photosynthetic structures (foliage) reach from the forest floor to the canopy roof. Different vertical strata can be distinguished, or alternatively a pure uneven-aged structure containing trees of all heights.
- **Dead wood:** old-growth stands produce great quantities of coarse dead wood, both standing and on the ground, at different stages of decomposition.
- **Gaps in the canopy:** old-growth forests are not homogeneous; very much to the contrary, gaps are frequently opened up with the collapse of old trees. A mature stand ought to be large and varied enough to contain gaps. In addition, the regeneration process among the canopy species should be verified to ensure not only the presence of new shoots but also that these should be at different stages of development.
- **Microhabitats:** thick and old trees are most liable to present irregularities and hollows caused by fungi, damage, etc. These irregularities provide a wide variety of microhabitats (hollows, debarking, cracks) for a broad spectrum of highly specialised biodiversity.

The simplest characterisation of maturity is the analysis of forest structure on the basis of dasometric variables (e.g. Franklin & Spies, 1991; Kneeshaw & Burton, 1998). These are based on a description of the distribution by age and size, and spatial distribution patterns, of both living and dead trees (Wells *et al*., 1998). The baseline tenet is that vegetation structure is related to ecological processes –which are harder to measure in the field– the former being a result of the latter. Hence, old-growth stands display structural characteristics that derive from their protracted existence over time and having withstood a succession of minor disturbances. The most significant structural descriptors of maturity observed in the mature or senescent phases are summed up below (Fiedler *et al*., 2007; Keeton *et al*., 2010).

These characteristics are to some extent modified in ecosystems subject to high levels of fire hazard. Such forests, on reaching maturity, may contain old trees, but these are not always large trees; low tree density, distributed in groups; modest quantities of standing or fallen dead wood; partially open canopies; high diversity and biomass at undergrowth level and low levels of tree regeneration; and slow nutrient cycles (Egan, 2007; Fiedler *et al*., 2007; Kaufmann *et al*., 2007).

From the fundamental attributes of old-growth stands we can derive indicators to determine their quantification on the ground (Table 1). These structural descriptors are usually complemented with indicators of the absence of anthropogenic interference (Gilg, 2005; Lorber & Valhalla, 2007; Mansourian *et al*., 2013; ERA, 2014; Laurie & Ongoing, 2010; Rossi & Valhalla, 2013), as these old-growth forests should only be affected by autogenic disturbances, free from anthropic intervention, at least for the last few decades. From considering ecological integrity, in this case represented by the maturity of the system, jointly with human influence emerges the concept of forest naturalness (ERA, 2014).

Table 1. Example of maturity assessment through qualitative criteria for the structure of the stand, developed for the LIFE RedBosques Project. Each indicator adds a point to the final assessment if the specified threshold is reached. A stand is deemed to have sufficient signs of maturity when the sum of all indicators reaches at least seven points.

Criterion	Indicator	Sampling variables	Threshold
Composition	Tree species	Number of species	≥ 2
Complexity	Structural diversity	Age distribution	Uneven
	Vertical strata	Number of strata	≥ 3
Senescence	Exceptional trees	Normal diameter (cm)	> N. ex*
	Standing dead wood	Number of trees with a normal diameter greater than 17 cm (trees/ha)	≥ 2 trees/ha
	Dead wood lying on the ground	Number of pieces with a normal diameter greater than 17 cm (trees/ha)	> 2 trees/ha
Microhabitats	Microhabitats in living trees	Number of different types	≥ 3
Dynamics	Gaps in the canopy (>100 m^2)	Number of gaps caused by treefall	≥ 1
	Advanced regenerated area (2,5<Dn<7,5 cm)	Occupation of regenerated area (%)	≥ 5%

(*) Dn. ex.: Exceptional diameter, in centimetres, measured as three times the dominant height, expressed in metres

Prospection and identification of old-growth stands in LIFE RedBosques

Among other aims, the LIFE RedBosques Project strives to provide tools for the characterisation of old-growth stands in the different forest types found throughout Spain. A procedure is proposed for the Identification of old-growth stands on the basis of field data in two successive phases:

- **Phase 1 — Prospection:** the initial phase consists of conducting a prospection over a wide area (autonomous region, province) in order to identify potential candidates. This comprises a simple description of the main features of maturity through a transect, compiling qualitative or semi-quantitative indicators. An expert can complete this in a short time. This phase allows an initial appraisal of the degree of maturity that, if deemed sufficient, leads to Phase 2.
- **Phase 2 — Identification:** having selected sufficiently mature candidate stands, a detailed description is made of these stands by means of quantitative forest structure variables (dasometry, species composition and dead wood) and past and recent human footprint. These variables are compiled through measurements in sample plots or transects. Variables are organised in a standardised layout enabling comparison with other stands, and for subsequent processing in the Network of Stands of Reference.

Manuals containing the procedures and standard forms can be downloaded from http://www.redbosques.eu

2.4. Biodiversity in Old-Growth Forests

The abundant biological diversity in old-growth forests is closely linked to their special structural characteristics and ecological processes. The presence in space and time of stands in every phase of the silvogenetic cycle creates the heterogeneous context for highly biodiverse landscapes. Old-growth and senescent stands present particularly high levels of a unique diversity. Furthermore, owing to the scarcity of such stands their associated biodiversity has become so rare that we can state that most threatened forest species are found in old-growth stands.

In the more advanced phases in the silvogenetic cycle, ecological processes associated with the growth, senescence and death of large trees provoke the emergence of a vast variety of ecological niches for host plants, microhabitats and microclimates, that are occupied by highly specialised biodiversity (Hilmers *et al.*, 2018). However, the gradual increase in specialised biodiversity in mature forests also depends on the regional reserve of species and their capacity for dispersion, highlighting the importance of connectivity and the ecological quality of the surrounding forest.

Among the various structural aspects that are characteristic of old-growth forests, coarse dead wood is the most directly related to specialised biodiversity. An enormous number of species of saproxylic fungi are responsible for wood decomposition, namely lichens and mosses (Hofmeister et al., 2015), as well as saproxylic insects (Gao *et al.*, 2015), that depend directly on the existence of dead wood.

Coarse dead wood can be at many different stages of decomposition, each of which provides the habitat for a vast number of taxons specialised in this resource. Decomposing dead wood frees up carbon and mineral elements stored in cellulose and lignite making them available again to plants. These elements are often redistributed around the dead trees thanks to saproxylic fungi and their mycellar networks (Simard *et al.*, 2015). Dead wood may also act as a seedling nursery for certain species (especially in soils with a thick organic layer), and it has also been found to protect the seeds of trees against pathogens (Lonsdale *et al.*, 2008).

This complex habitat changes over time owing to the decomposition process, allowing us to identify a succession associated to said process. During the decomposition process there is a shift from species specialised in the host tree to a stage in which this specific species loses relevance while the types of microhabitat available and the stage in the decomposition of the wood come to the fore (Méndez, 2009).

Rare species (and therefore often the most threatened) appear especially in the advanced stages of the decomposition process, which is why preserving dead wood in the forest is so important to the preservation of saproxylic biodiversity.

Dead wood, saproxylic insects and plagues

Higher risk of borer insect outbreaks is often attributed to larger amounts of dead wood. Consequently, the elimination of dead wood has been common practice in forests all over Europe. In boreal forests, this is estimated to have been reduced by 90-98% (Siitonen. 2001).

However, potentially harmful species to forest production (liable to behave as plagues or pathogens on healthy trees) are few and only appear in the early succession years while the wood is still alive. Of the vast diversity of insects that live on wood, only a small fraction –phloem-feeding insects and xylem-feeding insects– affect the wood of living trees, generally targeting weakened individuals (Kërvemo *et al*., 2017). In Spain, phylophages only affect conifers and belong to a single family (*Scolitidae*).

Regarding the diversity of saproxylic insects, the great majority never feeds on living wood: this includes decomposers (that feed, reproduce and shelter only in deade wood, and never use living trees), insects that live in hollows permanently filled with water, mycetophages (that live in or feed on wood-decomposing fungi), detritivores (dependent on sap exudates), and predators, parasites and necrophages dependent on all the above (Speight, 1989; Alexander, 2008).

Forests that are mature or in good conservation status are more resistant to attack by borer insects (Mulok & Christiansen, 1986, Romanik & Cadahia, 1992). Furthermore, the great biodiversity associated with old-growth forests generates higher numbers of predators on saproxylic insects and therefore a more effective control of their populations (Kirk & Cowling, 1984; Hunter *et al*., 1997; Schowalter, 2017; Paine, 2017).

Borers that affect living trees are key species in the ecosystem and contribute to opening up clearings in the canopy, thus increasing heterogeneity in the forest landscape (Müller *et al*., 2008), and forming part of the forests' natural dynamic. Therefore, preserving appreciable quantities of dead wood in the forest is a fundamental step toward forest restoration.

The existence of big trees alongside standing snags –on account of their role in generating essential microhabitats for woodland species– is also related to specialised biodiversity (Sandström 1992; Carlson *et al*., 1998, Camprodon y Plana, 2008; Gao *et al*., 2015). Old trees with rough bark and dead wood in their trunks and limbs allow diverse epiphyte flora to develop (lichens, mosses, bindweeds, etc.), that, in turn, provide the habitat for arthropods on which insectivorous birds feed. Similarly, with advanced age mould appears: rot fungi, and the substrates thus generated also provide the habitat for a multitude of arthropods.

In this manner, the presence of big trees featuring irregularities increases diversity among certain species that use hollows to reproduce or as shelter, such as birds and bats. Birds that drill trees to build their nests also need trees that are big enough for this purpose.

The formation of cavities (hollows, folds, etc.) in trees depends on a number of processes (fungal infections, insect attacks or drilling by woodpeckers, lightning strikes, fire and natural loss of branches) that increase and accumulate with tree age and size, and are therefore more frequent in old stands (Sandström, 1992; Carlson *et al.*, 1998). Cavities in the trunk appear after reaching a certain diameter (around 30 cm normal diameter) and the proportion of trees with cavities increases exponentially with diameter to the point in which only 5% of trees with a normal diameter of 40-50 cm have no cavities (Flaquer *et al.*, 2007).

For example in Scots pines, cavities are found in specimens of 150 or more years of age (Sandström, 1992); in the case of beech, the likelihood of cavities through malformation, rotting and damage increases after reaching the diameter classes of 50-55 cm (Camprodon & Plana, 2007). Given that the cutting cycle is every 80-120 years, these trees are very scarce or non-existent in forests subject to harvesting practices.

Another differentiating feature of old-growth forests is their greater structural heterogeneity: more vertical complexity (several strata) and horizontal complexity (gaps in the canopy), together with more varied age structure in the canopy, which translates as greater variety in tree diameter. This is linked to greater biodiversity, as a greater choice of possible environments or microhabitats become available (Vallauri *et al.*, 2010; Hofmeister *et al.*, 2015).

The permanence over time of a closed canopy explains why old-growth stands in general contain a higher proportion of shade-tolerant plant species (skiophiles), and greater diversity of biological types, as well as more rare or threatened species of saproxylic and epixyle organisms (fungi and epiphytes) (Burrascano *et al.*, 2008).

Likewise, however, gaps in the canopy in late senescent phases caused by dying trees lead to the regeneration of abundant vegetation and an increase in the number of vascular plant species, generally pioneering species which are no shade-tolerant. These gaps, in turn, induce greater diversity of phytophage arthropods (Seibold *et al.*, 2019) –as in the case of saproxylic coleoptera who need sources of nectar to feed on during adult activity (*Osmoderma*, *Gnorimus*, etc.)– and increased numbers of their predators, some of which are vertebrates.

Commercially exploited forests may present rich biocenosis, but in general the species present are limited to the less demanding taxons. It is the more specialised groups, such as certain fungi usually associated to heterotrophic succession, saproxylic insects, some birds (woodpeckers), and certain mammals (forest bats) that are more clearly linked to true mature forest environments (Mikusinski *et al*., 2001; Drever *et al*., 2008), and can therefore be taken as indicators of forest maturity.

Making use, therefore, of all the components of biodiversity as indicators of forest maturity is a valid tool, although generally speaking it is necessary to work with a community or a set of species associated with features of maturity (Speight, 1989). In France, for instance, a list of 300 species of saproxylic coleoptera has been used to evaluate the biological value and location of stands of reference (Brustel, 2007; Bouget *et al*., 2008). However, we may question the effectiveness of using biological indicators, bearing in mind that a forest inventory planned with this objective may be a simpler task yielding similar results (Grove, 2002; Gao *et al*., 2015).

The answer rests on which elements of maturity processes we seek to detect. For example, the role of saproxylic coleoptera may be more salient than acting as general indicators of maturity, with functions as indicators of specific processes related to the decomposition of woody necromass. This information involves considerable technical difficulty and expense in a conventional forest inventory. For instance, the presence of *Cetonia aurataeformis* or *Osmoderma eremia* is an indicator, besides being a type of microhabitat, of a series of decomposition processes thanks to the activity of larvae that enrich the quantities of nitrogen and carbon in the soil (Jönsson *et al*., 2004; Micó *et al*., 2011; Sánchez *et al*., 2016) and allow a different succession of decomposer species (Ranius, 2002).

Below is a review of the diversity characteristically associated with old-growth stands among the principal taxonomic groups and their potential as indicators of maturity.

Photo 3. Sporophyte of *Buxbaumia viridis* on a dead tree trunk in Parque Nacional de Ordesa y Monte Perdido. Author: E. Arrechea

2.4.1. Fungi

Old-growth stands contain a particularly high diversity of fungi: dead wood quantity and quality, size and type, as well as the species, age and size of trees, are structural forest attributes that influence the saproxylic fungi population and its rich variety in species (Nordén & Paltto, 2001; Lassauce *et al.*, 2011). In addition, fungi living on the wood modify the necromass both chemically and structurally, generating new habitats and nutritional resources (Boddy, 2001; Renvall, 1995).

Dead wood litter is difficult to decompose. The enzymatic digestion of resistant woody polymers such as lignin and cellulose is mainly taken care of by saproxylic fungi and bacteria, whose activity is complemented by additional mechanical disintegration caused by invertebrates (Keren and Diaci, 2018). Different types of saproxylic fungi make up a gradient of enzymatic capacities and can be classified according to the specific substrates they digest and the type of compounds produced. In general, "white" decomposition refers to lignin processing fungi, "brown" decomposition to those that digest hemicellulose, and "soft" decomposition refers to fungi able to decompose cellulose (Rajala *et al.*, 2015). The appearance of different species of fungi depends above all on environmental temperature, the rate at which wood dries out and the host species (Boddy, 2001).

Saproxylic wood fungi are able to colonise living trees and remain latent within the sapwood, until the hosts die or lose vitality (for instance, due to drought, root damage or light starvation). When sapwood water content drops, certain fungi start up decomposition processes forming their characteristic fruiting bodies. Subsequently, the wood is occupied by secondary colonising species that further the decomposition process. Dead wood acts as a permanently available source of nutrients that may be an important item in the forest nutrient cycle (Arnstadt *et al.*, 2016).

Countless interactions are established between fungi and invertebrates during this process. These may consist in behavioural alterations, by attraction, repulsion and detention; improvement of the nutritional environment, through enzymatic softening of the resources making feeding easier; or the destruction of inhibiting compounds in the resources and a reduction in the carbon/nutrient ratio. Similarly, invertebrates intervene in propagation, including transportation, inoculation and facilitating the colonisation of resources for fungi, and induce changes in the physiology and the metabolism of these organisms, even to the extent of altering the microbian community (Boddy & Jones, 2008). These interactions, occurring during the evolution of species, has transformed many organisms into opportunist –in some cases, mandatory– symbionts (Hatcher, 1995).

The wealth of fungi species is further increased with structural changes linked to forest maturity (Lelli *et al.*, 2019). As decomposers, saproxylic fungi start up ecological succession processes that sustain forest biodiversity, and are therefore extremely valuable forest organisms.

Many species of dead wood fungi have been described and more are being discovered all the time, but knowledge of their diversity or loss remains scarce (Hawksworth, 1991; Runnel & Lõhmus, 2017). The use of genetic material sequencing techniques allows detailed analysis of community composition, and may, therefore, uncover a hitherto unseen fungal diversity living in dead wood (Hoppe *et al.*, 2016).

2.4.2. Lichens and Bryophites

Lichens and bryophites are highly sensitive to slight environmental changes as their physiology is closely linked to moisture, solar radiation and temperature conditions, making them ideally suited for detecting changes in environmental conditions (Aragón *et al*., 2015). By and large, lichens and bryophites in nemoral habitats such as woodlands with an abundant canopy are more sensitive to environmental changes owing to their strong dependence on atmospheric humidity and photo-inhibition when exposed to more sunlight than they would receive in their normal environment. Their presence, therefore, may indicate long periods of continuity in the forest under a closed canopy.

Forest structure is the principal factor determining the wealth of local species of lichens and mosses (Belinchón *et al*., 2011), especially epyphites (Boch *et al*., 2013). A high degree of heterogeneity, especially a variety of tree species, and the existence of trees of different ages and sizes –very big and very small trees– are aspects that contribute the most to increasing diversity among these groups (Hofmeister *et al*., 2015). Besides, on a micro-scale, tree characteristics also determine the heterogeneity and availability of suitable microhabitats and microclimates that govern the distribution and abundance of epiphyte lichens: the most important are tree age and size, and bark features such as pH and roughness (Merinero, 2015).

Lastly, permanence over time enables the development of more complex and complete communities, as the bark of very old trees (more than 300 years) has physical and chemical features that are absent on younger trunks, and encourage specific lichens that only appear in old stands. Epiphyte lichens and, in particular, species belonging to the alliance *Lobarion*, have been identified as characteristic of forests with a long record of permanence and scarce alteration through human activity or major disturbances (Potenza & Fascetti, 2010; Rose, 1985, 1988), and may serve as indicators of such long-standing ecological conditions (Rose, 1999; Coppins & Coppins, 2002; Brunialti *et al*., 2010).

A further important habitat for diversity among epiphyte lichens and mosses is dead wood, and in particuar, coarse dead wood (Hofmeister *et al*., 2015), a characteristic, in turn, of mature forests. For all the above, we usually find that diversity among epiphytes is lower in forests subject to harvesting than in woodlands under natural dynamics, and likewise that forests subjected in the past to intensive exploitation contain fewer of these species, owing to these woodlands' slow recovery (Ardelean *et al.,* 2015; Boch *et al*., 2013).

Photo 4. Young thallus of *Heterodermia speciosa*, a rare species, indicator of ecological continuity, at the base of an old beech tree. Author: Klaas Van Dort.

Epiphyte lichens in Dehesa de Peñalba

"Dehesa de Peñalba", in Parque Natural de la Sierra Norte de Guadalajara, is a mixed forest with a predominance of *Quercus pyrenaica* accompanied by *Quercus petraea*, aspen (*Populus tremula*), beech (*Fagus sylvatica*) and holly (*Ilex aquifolium*).

This is an ancient "dehesa" with abundant regeneration, containing many big trees and plenty of dead wood both standing and on the ground.

The inventory of four large specimens of *Quercus pyrenaica* has produced a list of 64 epiphyte species: 15 bryophites (12 mosses and 3 liverworts) and 49 lichens (including 2 non-lichenized ascomycetes), among which several groups of species can be distinguished, associated to different microhabitats (van Dort, 2020).

Besides pioneering communities on the branches and stems of young trees, in clumps of smooth-barked species where light intensity is high (L*ecanorion subfuscae; Arthonio-Lecidelletea elaeochromae*), past agricultural activity is reflected in the presence of species whose bark is enriched with nutrients provided by dust in suspension (*Anaptychia ciliaris, Physconia venusta, Ramalina fraxinea*) and indicator species of eutrophicated bark, such as *Candelaria concolor* and *Physcia adscendens.*

The most interesting species are those that grow on the trunks of old trees, as with increasing age their bark becomes rougher and gives rise to *Syntrichietum laevipilae* bryophites. A majority of pioneer lichens are able to persist, occupying more or less dry locations on the trunks of these old trees, giving rise to mixed communities rich in species.

Epiphyte lichens in Dehesa de Peñalba (continuation)

The most sensitive epiphyte species are found on the biggest and oldest trees. Areas with hygrophytic substrate are occupied by large foliose lichens with *Lobarion* cyanobacteria. Other specialists in rare microhabitats are found in these substrates, such as *Gyalecta ulmi* and *Piccolia ochrophora*. Finally, standing dead wood (tree trunks and dead branches) provide substrate for several pinhead lichens. The extensive mossy carpets covering broad trunks host several gelatinous lichens and species of *Peltigera*.

Dehesa de Peñalba, moreover, is of great importance for epiphyte lichens. Up to 19 threatened species of lichens have been found, of which 7 are considered as indicators of the forest's ecological continuity (Coppins & Coppins, 2002). Species that are characteristic to communities of *Lobarion* –internationally threatened– are well represented: *Fuscopannaria mediterranea, Heterodermia obscurata, Lobaria pulmonaria,* and *Ricasolia amplissima* (formerly *Lobaria amplissima*) (Table 2).

Table 2. Species of epiphyte lichens of special interest found on old trees in Dehesa de Peñalba

Species	Habitat of preference	Type
Calicium glaucellum	Snags	Pinhead Lichen
Calicium salicinum	Snags	Pinhead Lichen
Chaenothecopsis pusilla	Snags	Pinhead Lichen
Collema nigrescens *	Mature forest and old trees	Gelatinous lichen
Collema subflaccidum *	Mature forest and old trees	Gelatinous lichen
Collema subnigrescens *	Mature forest and old trees	Gelatinous lichen
Fuscopannaria mediterranea !	Mature forest and old trees	Squamulose cyanolichen
Gyalecta derivata	Mature forest and old trees	Crustacean lichen
Gyalecta ulmi !	Mature forest and old trees	Crustacean lichen
Heterodermia obscurata !	Mature forest and old trees	Foliose lichen
Leptogium saturninum !	Mature forest and old trees	Gelatinous lichen
Lobaria pulmonaria *	Mature forest and old trees	Foliose cyanolichen
Mycocalicium subtile	Snags	Pinhead Lichen
Peltigera collina !	Mature forest and old trees	Foliose cyanolichen
Peltigera horizontalis !	Mature forest and old trees	Foliose cyanolichen
Peltigera praetextata	Mature forest and old trees	Foliose cyanolichen
Piccolia ochrophora *	Mature forest and old trees	Crustacean lichen
Ricasolia amplissima *	Mature forest and old trees	Foliose cyanolichen
Scytinium lichenoides *	Mature forest and old trees	Gelatinous lichen

(*) Indicators of old-growth forests on the NIEC list (Coppins y Coppins, 2002)
(!) Species of regional conservation interest

2.4.3. Vascular Plants

Mature stands present certain common traits with regard to the composition of their flora. In general, they contain a greater proportion of shade-tolerant (skiophilous) species, due to the densely covered canopy that obstructs the full passage of light to the lower layers (Hermy *et al.*, 1999). Among these, species with nitrophilous tendencies are of less interest than non-nitrophilous species[3] and also contain greater diversity of biological types. Another characteristic feature of old-growth forests, especially the most humid, is the presence of epiphytes, geophytes, some hemiparasites and bindweeds. Besides, mature forests harbour species with low dispersion and colonisation capacities, which constitutes an indicator of the long-term permanence of the forest canopy (Wulf, 1997; Hermy *et al.*, 1999).

The permanence over time of old-growth forests, ensuring that their ecological conditions have remained stable for the last few centuries, also determines a greater frequency of relict species in the composition of their flora (species that have become isolated from their original populations owing to climate change during glaciations). In each different territory, these will be different species, as relict species in one area may not be so in another (Table 3).

The absence of mature and senescent phases in European forests determines that only small populations survive of many of the species closely linked to these environments, causing these to be classified as threatened to some degree. Thus, in mature stands the proportion of very scarce or endangered species is often high (Wulf, 1997).

Despite these differentiating features, the evaluation of a forest's maturity according to the composition of its flora is no easy task, as the presence or absence of certain plant species is not sufficient evidence (Rose, 1999). Even some species considered to be associated with old-growth forests at a given location may appear in husbanded stands or, in other environmental conditions, in open areas (Hermy *et al.*, 1999).

It is necessary, therefore, to draw up lists of species characteristically associated with phases of maturity, tailored to each type of forest habitat and biogeographical

3— Thus, for instance, for the forests in the Southern Iberian System the following are considered shade-tolerant species: *Aquilegia vulgaris, Arabis turrita, Astrantia major, Brachypodium sylvaticum, Campanula trachelium, Carex depauperata, Carex digitata, Convallaria majalis, Elymus caninus, Epipactis microphylla, Helleborus foetidus, Hepatica nobilis, Laserpitium latifolium, Laserpitium nestleri, Lathyrus pisiformis, Lathyrus vernus, Melica uniflora, Poa nemoralis, Polypodium cambricum, Sanicula europaea* and *Vicia sepium*, and as escio-nitrophylous species: *Alliaria petiolata, Geranium robertianum, Lapsana communis, Moehringia trinervia, Mycelis muralis* and *Polygonatum odoratum*.

region, as specific composition may vary with the local geology, topography, climate and history (Rose, 1999). To assess the maturity of a stand, references must be established to compare each forest type present in each biogeographical territory, jointly applying the criteria outlined herein: the composition of species, proportion of nano-phanerophytes and climbing plants, dominance of tree habitats, canopy cover and presence of relict and threatened species.

Table 3. Relict species in the Northern Iberian System, associated to forests (García Cardo, in prep.)

Species	Origin	Disjunction level
Actaea spicata	Euroasian	High
Adonis vernalis	Euroasian	Medium
Astrantia major	Eurosiberian	High
Atropa baetica	Ibero-North African	High
Betula pendula subsp. fontqueri	Ibero-North African	High
Campanula latifolia	Eurasian-North African	Very High
Carex digitata	Eurosiberian	High
Convallaria majalis	European	High
Dactylorhiza sambucina	Euroasian	High
Daphne mezereum	Euroasian	Very High
Dictamnus albus	Eurosiberian	Medium
Epipactis microphylla	Euroasian	Medium
Euonymus latifolius	European, Irano-Turanian and North African	Very High
Laserpitium latifolium	European	High
Lathyrus pisiformis	Euroasian	Very High
Lathyrus vernus	Euroasian	High
Lonicera splendida	Baetic System-Iberian system	High
Monotropa hypopitys	Circumboreal	Medium
Orthilia secunda	Circumboreal	Very High
Potentilla micrantha	Eurosiberian	High
Pyrola chlorantha	Circumboreal	High
Quercus petraea	Euroasian	High
Rhamnus catharticus	Eurosiberian	Medium
Rubus saxatilis	Euroasian	Very High
Tilia platyphyllos	Euroasian	High
Ulmus glabra	Euroasian	Medium
Viburnum tinus	Mediterranean	Low
Xiphion serotinum	Baetic System-Iberian system	High

2.4.4. Saproxylic Coleoptera

Saproxylic coleoptera, through myriad relationships with the different components of saproxylic biodiversity, together with fungi, play a key role in the processes of decomposition (Geib *et al.*, 2008; Quinto *et al.*, 2012; Ulyshen, 2015, 2016; Zuo *et al.*, 2016).

Both the number of species and their abundance are related to the maturity of the stand (Martikainen *et al.*, 2000; Lassauce *et al.*, 2013), specifically with the greater volume of dead wood, habitat heterogeneity (stages of decomposition, typologies, etc.) and presence of old trees. In hardwood stands, the greater wealth of coleoptera is also due to better quality microhabitats (Ranius, 2002), a factor that is hard to determine and in which coleoptera take on special importance as bio-indicators. For example, a relationship has been observed between the volume and quality of organic matter in clearings in Iberian dehesas and the composition of the saproxylic community of syrphid coleoptera and diptera (Quinto *et al.*, 2014).

There are over 2,500 Iberian and Macaronesian species of saproxylic coleoptera. Their presence in practically all forest habitats and most dead wood microhabitats, the greater knowledge of their ecology in comparison with other taxonomic groups, and a long experience in methods of study (Økland, 1996; Bouget *et al.*, 2008; Quinto *et al.*, 2014) has made them suitable indicators of processes associated to dead wood decomposition (Grove, 2002; Lachat *et al.*, 2012).

Moreover, it is worth noting that species associated to features of maturity (Russo *et al.*, 2011; Müller *et al.*, 2005; Chiari *et al.*, 2012; Hjältén *et al.*, 2012) are often species with small distribution areas, relict and often endangered species (Ranius, 2002; García *et al.*, 2018; Nieto & Alexander, 2010; Recalde, 2010), whose presence is closely tied to habitat quality, and may therefore be used to detect microhabitats of great value to conservation.

However, we should not forget that the presence of a given species is not necessarily an indicator of forest maturity. An example is *Limoniscus violaceus*, a highly threatened species that grows in basal cavities in trees of the genus *Quercus* or *Fagus*. Its existence is known in three locations on the Iberian Peninsula in old-growth stands (Sánchez & Recalde, 2012), whereas in France it can be found on old solitary trees in *bocage* landscapes (Gouix, 2013). The presence of a single species as indicator of a mature forest habitat may, therefore, lead to error, despite knowing that its presence may indicate a microhabitat that persists over a long period of time. A list of species associated with old-growth forests has not yet been compiled for Spanish forests.

Photo 5. *Rosalia alpina*, cerambycid considered Vulnerable by IUCN, associated to dead wood, preferably in beech forests. Author: CREAF

Community of saproxylic coleoptera in the pine forests of Villanueva de Huerva (Zaragoza)

The natural forests of Aleppo pine in Villanueva de Huerva, accompanied by holm oak and, more seldom, Portuguese oak, with scrublands dominated by Kermes oak and rosemary, contain areas undergoing phases of maturity, senescence and renovation, with an abundance of dead wood considering the standard in pine woods of this nature: up to 38 m3/ha, although this figure is highly variable.

For a full year, the community of saproxylic coleoptera present in the reserve zone within this pinewood, covering a surface area of 141.2 ha, was studied. Of the total specimens captured, 82.4% were of the saproxylic functional group, belonging to 35 families and 167 species.

Of this total number of species dependent on dead wood, 69.2% are considered strictly saproxylic, unable to colonise other types of microhabitat. Within the saproxylic functional subgroups, 40 xylophage species, 40 xylo-mycetophage species, 37 saprophage-saproxylophage species, 31 predator species, 10 ploephage-cambiumophage and 6 comensal species were found.

Moreover, 147 species of non-saproxylic coleoptera were identified, belonging in most cases to functional groups of predator and phytophage species, and to a lesser extent detritivorous, rhyzophagous and frugivorous species. The least represented species were those belonging to functional groups of coprophagous, comensalist, aquatic, mirmecophilous, parasite and decomposer species.

Among the saproxylic species, individuals were collected belonging to 14 different species and 6 families included on the Red List of Mediterranean saproxylic coleoptera, and 28 specimens belonging to 12 species considered to be indicators of forest maturity features (Table 4).

Table 4. Species collected included in the Red List of Mediterranean saproxylic coleoptera, number of individuals and level of threat.

(Source: Piera & Muñoz-Batet, 2019)

Family/species	No.	Threat level
Bostrichidae	**39**	
Scobicia pustulata	36	Lower concern (LC)
Xylopertha praeusta	3	Lower concern (LC)
Cerambycidae	**11**	
Cerambyx miles	2	Lower concern (LC)
Chlorophorus ruficornis	1	Lower concern (LC)
Ergates faber	1	Endangered (EN)
Hylotrupes bajulus	1	Endangered (EN)
Penichroa fasciata	5	Lower concern (LC)
Phymatodes testaceus	1	Endangered (EN)
Cleridae	**1**	
Thanasimus formicarius	1	Endangered (EN)
Elateridae	**10**	
Ampedus talamellii	1	Lower concern (LC)
Lacon punctatus	8	Lower concern (LC)
Melanotus villosus	1	Endangered (EN)
Erotylidae	**3**	
Triplax melanocephala	3	Nearly threatened (NT)
Tetratomidae	**1**	
Tetratoma baudueri	1	Nearly threatened (NT)

2.4.5. Birds

We cannot speak of birds that are exclusive to old-growth forests, at least in the Mediterranean area, or of any specific species as indicators of maturity; instead, we can refer to functional groups of species associated to different structures that are intrinsic to old-growth forests. From this viewpoint we can distinguish between species that drill trees to build their nests (picids), species that are secondary occupants of these cavities (treecreeper, blue nuthatch and nocturnal forest raptors), and species that occupy the crowns (mainly tits).

There is a positive relationship between the size of the trees and the presence of drilling birds (Carlson *et al.*, 1998). A clear tendency to occupy more mature stands is found among the woodpeckers, especially the black woodpecker (*Dryocopus martius*), the white-backed woodpecker *(Dendrocopos leucotos)* and the middle spotted woodpecker (*Leiopicus medius*) (Camprodon *et al.*, 2007). These species prefer to drill small-sized holes at great heights, to avoid predators, and with thick walls to provide insulation, conditions that can only be provided by big trees (over 30 cm normal diameter).

The proportion of big trees in a forest is also associated with greater density and variety of passerines, secondary occupants of cavities, especially the blue nuthatch (*Sitta europaea*), treecreepers (*Certhia brachydactyla* and *Certhia familiaris*) and the blue tit (*Cyanistes caeruleus*) (Camprodon *et al.*, 2008). Of these, the blue nuthatch can be considered the Iberian bird species that is the best indicator of forest maturity: its abundance increases with tree age and girth and the presence of standing dead wood (Camprodon *et al.*, 2007).

Tree age and girth are similarly related both to other species on the Iberian Peninsula, such as the European pied flycatcher (*Ficedula hypoleuca), the* collared flycatcher *(Ficedula albicollis)* and the common redstart *(Phoenicurus phoenicurus)* (Wesołowski, 2007). The boreal owl (*Aegolius funereus*), secondary nesters in cavities drilled by picidae, displays a similar tendency regarding stand selection for breeding (Mariné & Dalmau, 2000).

In short, trees that are big and old –at least 30 cm normal diameter– are a determining factor for forest birds, providing the cavities they need, whether through enlarging picidae nests or disturbances, breakages, etc. (Camprodon *et al.*, 2007).

There is also significant correlation between the amount of dead wood and the density of cavity-nesting birds, as large standing dead trees are suitable for drilling birds to nest in and, consequently, for secondary occupants of these hollows (Sandström, 1992, Redolfi *et al.*, 2016).

Photo 6. White-backed woodpecker *(Dendrocopos leucotos lilfordi)* carrying a xylophage coleoptera larva to the nest, dug out of a hollow in a large beech in the Navarran Pyrenees. Author: Alfonso Senosiain.

Forest maturity and the white-backed woodpecker in Montes de Quinto Real (Navarra)

The white-backed woodpecker (*Dendrocopos leucotos*) has a wide palearctic distribution. The subspecies *D. leucotos lilfordi* reaches its western limits in Spain, appearing only in the western Pyrenees, where some 100 pairs have been spotted and it is considered "in danger of extinction".

This species inhabits beech forests and mixed beech and fir forests, establishing breeding grounds in stands that offer certain features of maturity. Studies conducted in Montes de Quinto Real (Cárcamo *et al*., 2020) show that a sufficient number of thick trees is needed (a minimum of 30 per ha) suitable for making nest cavities, and a sufficient volume of standing dead wood (at least 7 m3/ha) as a source of food (saproxylic larvae) in the months during which fallen dead wood may be under the snow. These minimum thresholds must occur simultaneously: an abundance of thick trees with no dead wood, or an abundance of standing dead wood but no thick trees do not guarantee that birds will occupy the territory (Figure 2).

As these parameters are two of the principal descriptors for the structure of old-growth stands, this species may be viewed as a good indicator of mature conditions in forests consisting mainly of beech (*Fagus sylvatica*).

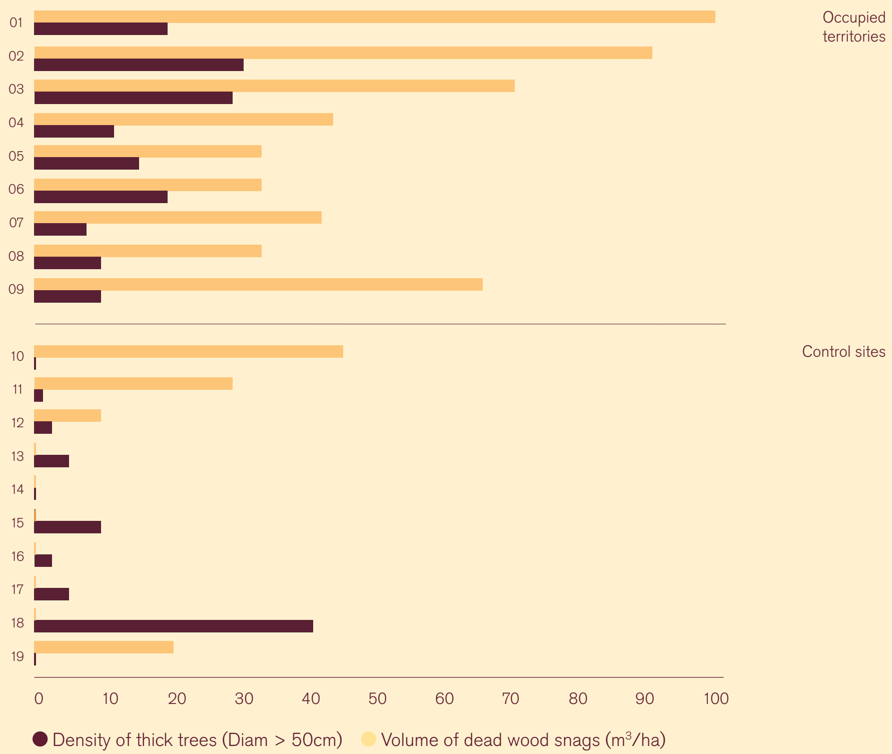


Figure 2. Density of thick trees (no. of trees/ha with a diameter of 50-60 cm) and volume of dead wood snags (m^3/ha) in stands that include territories occupied by the white-backed woodpecker, in comparison with stands without occupied territory (control sites). The thresholds for both critical variables are given (Source: Schwendtner et al, 2014).

2.4.6. Forest Chiroptera

Most species of bat use the forest at some point in their life cycle, whether for hunting, hibernating, temporary shelter, etc. Nevertheless, strictly arboreal species are more closely dependent on forest environments. Nine species of those known on the Iberian Peninsula are included In this category: the lesser noctule (*Nyctalus leisleri*), the greater noctule bat (*Nyctalus lasiopterus*), the common noctule (*Nyctalus noctula*), the barbastelle (*Barbastella barbastellus*), the brown long-eared bat (*Plecotus auritus*), the Alpine long-eared bat (*Plecotus macrobullaris*), the whiskered bat (*Myotis mystacinus*), the Alcathoe bat (*Myotis alcathoe*) and Bechstein's bat (*Myotis bechteinii*).

Photo 7. Specimen of the greater noctule bat *(Nyctalus lasiopterus)*, forest bat listed as Vulnerable in the National Catalogue of Threatened Species. Author: M.S. Redondo

These forest chiroptera depend directly on the trophic and structural quality of the habitat, where they find the food and shelter they need during their periods of inactivity. Strictly arboreal species hunt within the forest or on its fringes, and shelter mainly in tree hollows. However, certain species with crevice- or cave-dwelling habits, such as the common pipistrelle (*Pipistrellus pipistrellus),* the soprano pipistrelle *(Pipistrellus pygmaeus),* Daubenton's bat *(Myotis daubentonii)* and Natterer's bat *(Myotis nattereri)*, also occupy tree cavities and may use both types of shelter depending on their availability. They are likewise very sensitive to habitat alterations, and thus highly vulnerable (Vaughan *et al.*, 1997; Grindal & Brigham 1999; Kusch e Idelberger 2005; Flaquer *et al.*, 2007).

The wealth of forest chiroptera and their activity has been proved significantly greater in forests than in the adjacent areas, and increases with some of the parameters that characterise mature forests (Camprodon *et al.*, 2009). In particular, forests containing big trees (more than 45 cm normal diameter), heterogeneous structures and abundant dead wood are associated preferentially to forest chiroptera. This relationship is linked to the greater availability of shelter (cavities) both in very big trees and in dead wood snags, along with greater availability of trophic resources (Kunz, 1982; Russo *et al.*, 2004).

Rich variety of bats in Monte de Valsaín (Segovia)

In the Montes de Valsaín forest, 22 bat species have been registered (more than 70% of Iberian species), of which ten are catalogued as vulnerable (out of a total of 13 included in the Spanish Catalogue of Threatened Species (Royal Decree 139/2011) and seven are arboreal species.

In the Reserve Zone "Umbría de Siete Picos", an experiment based on bio-acoustic monitoring stations showed a far higher variety of bats than in control monitoring stations (Figure 3). This difference is explained by the structure of the stand: high density of exceptional trees (22/ha), many of these centuries-old, and an abundance of dead wood snags (26 m^3/ha) offering plenty of shelter for bats, complemented by numerous gaps in the canopy used as feeding grounds.

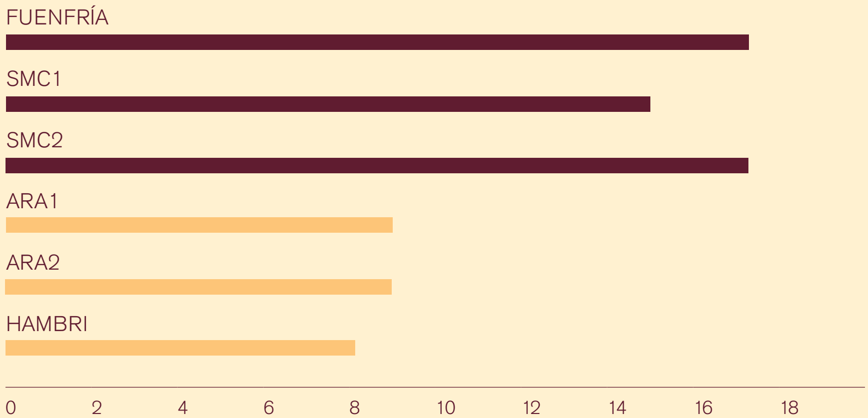


Figure 3. Overall number of chiroptera registered by sampling site, at three locations inside (green) and outside (yellow) the Reserve Zone in Parque Nacional de la Sierra de Guadarrama

2.5. Services Rendered by Old-Growth Forests

Old-growth stands are nearly always found in forests where logging, firewood gathering or livestock farming has disappeared, usually due to dwindling or negative economic returns; generally speaking, where these uses are no longer profitable.

However, old stands and mature stands are a precious heritage for the wealth of unique biodiversity they contain, and are of great scientific interest both on account of their scarcity and the opportunity they raise for gaining knowledge of the ecological processes linked to forest dynamics.

Old-growth stands' singularity endows them with specific value; these forest enclaves possess a genuinely different nature rendering them potential sources of complementary resources in forests currently lacking any economic yield. Their conservation may be of interest to some landowners, especially those with social aims such as town councils or nature conservation bodies. Today, the social function of forests is becoming increasingly important, and their contribution to well-being is one of their most cherished values. Old-growth stands may serve as scenarios for recreation and awareness-raising, and even health-related uses (Maller *et al.*, 2008; Castell, 2019).

Social uses in La Mola de Catí

Mola de Catí, a forest owned by the municipality of Tortosa (Tarragona) comprising 411 ha of Pinus nigra ssp salzmannii and P. sylvestris with clear features of maturity, in Parc Natural dels Ports.

This forest has been harvested for wood throughout history. Since the 1980s, however, this use has declined and today the forest is dedicated eminently to social uses, greatly appreciated by the local population for recreation and as a point of contact with nature.

The town council's priorities and demands at present are not to obtain economic returns from timber, but to keep the forest in good condition and disseminate its value to society at large and, most especially, to the local population.

For these reasons the town council is promoting a new forest management approach geared toward preserving the ecological processes inherent to the various existing forest habitats, underscoring the importance of eco-tourism uses and the dissemination of environmental knowledge, paying special attention to the forest's therapeutic functions.

For private landowners, the preservation of old-growth stands may represent an alternative source of revenue, through uses other than logging that do not interfere with forest maturity (mushrooms, truffles, game), through properly planned recreational uses, or through access to certain lines of financing specific to silvicultural programmes for conservation aims.

Forests in general, and old-growth forests in particular, provide a multitude of services over and above their economic yield, as they are essential to what are known as "regulation services" that include such aspects as the protection of the soil, control of the hydrological cycle, or climate regulation, all of which are vital in the Mediterranean area (Palahi *et al.*, 2008).

In the current context of climate change these services are all the more relevant and their maintenance should be a priority. The future will be warmer, dryer and more variable, and old-growth forests represent an opportunity for developing 'natural solutions' in the struggle against climate change.

To begin with, old-growth forests play a role in the mitigation of climate change by contributing to the removal of carbon from the atmosphere. They are long-term carbon stores, accumulating more biomass than young forests. In old-growth stands carbon remains locked in the trees for hundreds of years (Gunn *et al.*, 2014M; McGarvey *et al.*, 2015; Lutz *et al.*, 2018; Luyssaert *et al.*, 2008).

Recently reported evidence shows that old-growth forests (over 200 years old) maintain their capacity as carbon sinks (e.g., Harmon *et al.*, 1990, Keeton *et al.*, 2007; Luyssaert *et al.*, 2008). This capacity for carbon sequestration at advanced old age is attributed to two factors: firstly, to old forests' complex vertical structure, and to the combination of species whose functional traits are complementary, giving rise to more effective light interception, nutrient capture and water absorption through the roots (Stephenson *et al.*, 2014). Secondly, the capacity of the forest floor to maintain a rate of carbon sequestration over extended periods of time (Zhou, 2006; Harmon, 2009).

From the viewpoint of adaptation to climate change, the structural complexity and diversity of arboreal species are the features of old-growth forests that strengthen their resilience. The greater diversity among species offers a broader array of responses to new climate scenarios, higher resistance against disturbances (Dănescu *et al.*, 2018; Pretzsch *et al.*, 2018; Gustafsson *et al.*, 2019) and smaller risk of the forest collapsing through potential disturbances due to plagues and pathogens (Gross *et al.*, 2014).

In this light, a determining factor is that this diversity should be made up of species with different functional traits, presenting greater adaptability to different stress factors. These functional traits include properties such as timber height, density and structure, seed size, specific foliage area, resprouting capacity, bark thickness, or root depth (Aubin *et al.*, 2016). In addition, adaptability is enhanced when several species share the same functional traits, in order to keep up a similar diversity of traits in the event of the loss of any of these species (Messier *et al.*, 2019).

In sum, old-growth forests' heterogeneity and diversity give them greater resilience against disturbances and, therefore, improve their capacity to adapt to climate change. This makes old-growth forests models or references for the overall transformed forest matrix, currently highly vulnerable owing to its great homogeneity: old-growth forests may serve as a reference to silviculture, favouring in woodland the elements of maturity that ensure the highest adaptability..

Economic returns from old-growth stands in Parque Natural dels Ports

The declining local forestry sector and low timber prices have brought forest intervention to a practical standstill on the estates within Parque Natural dels Ports (Tarragona) over the last 20 years. Most of these forests (public and private) have witnessed how logging has ceased to be their principal resource. This effect is producing changes in forest landowners' productive scenarios, as non-timber resources are coming to the fore in routine forest management activities. This situation outlines a new paradigm for estate management, in which game, grazing and truffles are replacing logging products as the main productive target. Furthermore, the conservation guidelines in the Habitats Directive and in national and regional laws are leading landowners to plan and apply criteria and management targets geared toward the enhancement and preservation of habitats.

Thanks to LIFE RedBosques, a number of silvicultural activities have been conducted for demonstration purposes on three private estates within the Natural Park, based on promoting maturity and encouraging forest multi-functionality, bearing in mind productive, protective and biodiversity conservation aspects.

The overall economic balance has shown that the execution of some of these demonstration actions is self-funded with the income generated by the sale of timber (extracted as a result of implementing some of the silvicultural techniques described in Chapter 5) and from hunting. The economic balance from conservation-oriented silviculture would be positive in every case studied if to all the foregoing we add the potential implementation of financial instruments subject to conservation aims and adaptation to climate change (FEADER) to compensate for income loss.

Forests without human intervention are valuable as benchmarks to compare with.
Beech forest in the Ordesa y Monte Perdido National Park. Author: E. Vinuales

3 Old-Growth Stands as a Reference

3.1. Old-Growth Forests in Conservation Policies

The interest in preserving old-growth forests first emerged in North America in the 1970s and 1980s in response to the loss of primeval forest cover and logging methods that endangered biodiversity, most especially species highly dependent on old stands. For a brief history of the origins of this concept, see Franklin and Spies (1991).

In Europe the concept was rapidly adopted, and studies were launched in Spain on mature forests (i.e. Bosch *et al.*, 1992, Antor & García, 1994). Research on old-growth forests was led initially by France and central European and Scandinavian countries, to be followed closely by Italy.

A further aspect in which Europe has made progress is integrating this concept in conservation policies. Thus, in 1995, the European Commission approved COST Action E4: Forest Reserves Research Network with the aim of promoting coordination and raising the standard of research on European natural and semi-natural forests. The objectives were to create a European network of forest reserves, compile ongoing research work, unify and standardise research methodology and provide open access to a central data bank on forest reserves (Parviainen *et al.*, 1999). The EU is currently developing concepts such as high natural value (HNV) forest areas or high conservation value forests (EEA, 2014) that may shape EU policies in the future.

Although the inclusion of mature forests in conservation policies in EU member States is inconsistent (García Feced *et al.*, 2015), in some cases, such as Italy or France (Gilg, 2005; Blasi *et al.*, 2010), initiatives have been set up within biodiversity preservation programmes for the location and protection of old-growth forests, or forests with the potential to reach maturity.

In Spain, the Spanish Forestry Strategy[4] contemplates creating a Network for the Ecological Monitoring of Natural Forests, that should include not only woodlands "that represent *old-growth forest*, but also *ancient forest*, two categories related to the duration or continuity *in situ* of the forest, and to primary, natural, semi-natural

4—The Spanish Forestry Strategy of 1999 is currently under revision.

and secondary forest, depending on the categories related to the origins of their development". To this end, the Strategy has set up a committee, made up of the central and regional governments, to promote the drafting of a national inventory of natural forests, planning and management recommendations, the incorporation of landowners to active forest management within the Network and research in the forest reserves. These items in the Strategy have not been developed, although similar initiatives are being undertaken in some autonomous regions.

In this sense, we may highlight the creation of strict old-growth forest reserves (Muniellos in Asturias; Aztaparreta and Lizardoia, in Navarre) or the UNESCO's inclusion in the World Heritage List of "Primeval beechwoods in the Carpathians and other regions across Europe[5]", comprising the beech forests of Tejera Negra (Castilla-La Mancha) and Montejo (Madrid), Lizardoia and Aztaparreta (Navarre) and Cuesta Fría y Canal de Asotín in Picos de Europa (Castilla y León).

The inventory of old-growth forests in Spain originated in Catalonia, where studies on the location and protection of mature stands and forests are at an advanced stage. The inventory of old-growth forests in the district of La Garrotxa (ANEGX, 2008), in Parque Natural del Alt Pirineu (Palau and Garriga, 2013), or in Parque Natural del Montseny (Monserrat, 2013), the establishment of 58 forest reserves by the Diputació de Girona (Hidalgo and Vila, 2013) or the Inventory of Singular Forests of Catalonia (CREAF, 2011) are further notable examples. All these initiatives have been complemented with prospections for stands in several autonomous regions in a process driven by the LIFE RedBosques Project aiming to identify a nation-wide Network of Stands of Reference.

3.2. Old-Growth Stands and the Natura 2000 Network. The Favourable Conservation Status

Nearly every natural woodland formation in the Spanish State (with the significant exception of forests of *Pinus sylvestris* and *Abies alba*) fits one of the habitats catalogued by Directive 92/43/EEC (Habitats Directive) as 'Habitats of Community Interest' (HCI). In Spain there are 27 forest HCI representing 29% of the State's total forest cover (Table 5). Forest HCI occupy almost 80,000 km^2, equivalent to 58% of the overall surface area protected by the Natura 2000 Network throughout the State.

5— This is an international figure in which Spain participates together with another nine countries: Albania, Austria, Belgium, Bulgaria, Croatia, Italy, Romania, Slovenia and Ukraine.

Toward a Network of Stands of Reference

The LIFE RedBosques Project aims, among other objectives, to provide tools for evaluating the conservation status of forest habitats. Promoted and coordinated by EUROPARC-España, the plan is to establish a Network of Stands of Reference across the entire State.

To this end, a procedure has been developed for evaluating potential candidates for inclusion in the network. Three indicators are arrived at through aggregation and weighting of a series of variables measured in the field: maturity, human footprint and spatial integrity. Stands gaining the highest points are incorporated to the nation-wide Network of Stands of Reference which, once complete, will comprise representatives for each of forest habitat type (Figure 4).

To facilitate uploading, processing and consulting these data, and drawing comparisons between each of the stands identified and the corresponding stands of reference, a database and geo-portal have been made accessible online*.

(*) http://redbosques.creaf.cat/redbosques/

The Habitats Directive, and its transposition into national legislation, establishes the commitment to maintain or re-establish habitat types within their natural area of distribution in a 'favourable conservation status', especially those comprised in the network of protected areas set up for this purpose: the Natura 2000 Network.

In general, most forest habitat types do not currently present a good conservation status. Forests within the European Union are subject to pressures among which the principal factors are identified as reforestation with non-native species, excessive removal of dead wood, the construction of infrastructures and loss of connectivity, or alien invasive species, which in the Mediterranean area are compounded by the abandonment of traditional uses, excessive recurrence of forest fires, or strong pressure from domestic or wild herbivory. Lastly, climate change poses a global

Table 5. Forest types of Community interest present in Spain, by biogeographical region.

91	**Temperate European Forests**				
9120	Atlantic acidophilous beech forests with *Ilex* and, sometimes, *Taxus* (*Quercion-rubori-petraeae* or *Ilici-Fagenion*)	MED	ATL	ALP	
9130	*Asperulo-Fagetum* beech forests			ALP	
9150	Mid-European limestone beech forests *Cephalanthero-Fagion*	MED	ATL	ALP	
9160	Sub-Atlantic and mid-European oak/oak-hornbeam forests *Carpinion betuli*		ATL	ALP	
9180	*Tilio-Acerion* forests of slopes, creeks and ravines(*)	MED		ALP	
91B0	Thermophilous *Fraxinus angustifolia* woods	MED			
91E0	Alluvial forests with *Alnus glutinosa* and *F. excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) (*)	MED	ATL	ALP	
92	**Mediterranean Deciduous Forests**				
9230	Galician-Portuguese oakwoods of *Quercus robur* and *Quercus pyrenaica*	MED	ATL		
9240	*Quercus faginea* and *Quercus canariensis* Iberian woods	MED	ATL	ALP	
9260	*Castanea* sativa woods	MED	ATL		
92A0	*Salix alba* and *Populus alba* galleries	MED	ATL	ALP	
92B0	Riparian formations on intermittent Med. courses with *Rhododendron ponticum, Salix* and others	MED			
92D0	Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*)	MED			MAC
93	**Mediterranean Sclerophyll Forests**				
9320	*Olea* and *Ceratonia* forests	MED			MAC
9330	*Quercus suber* forests	MED	ATL		
9340	*Quercus ilex* and *Quercus rotundifolia* forests	MED	ATL	ALP	
9360	Macaronesian laurel forests (*Laurus, Octoea*) (*)				MAC
9370	Palm groves of *Phoenix* (*)				MAC
9380	Forests of *Ilex aquifolium*	MED	ATL		
94	**Temperate Mountain Conifer Forests**				
9430	Subalpine and montane *Pinus uncinata* forests (* on chalky or limestone substrates)	MED		ALP	
95	**Mediterranean and Macaronesian Mountain Conifer Forests**				
9520	*Abies pinsapo* forests	MED			
9530	(Sub-) Mediterranean pine forest with endemic black pine (*)	MED		ALP	
9540	Mediterranean pine forests with endemic Mesogean pines (*)	MED			
9550	Canarian endemic pines forests	MED			MAC
9560	Endemic forests with *Juniperus* spp. (*)	MED	ATL		MAC
9570	*Tetraclinis articulata* forests (*)	MED			
9580	Mediterranean *Taxus baccata* woods	MED	ATL		

MED: Mediterranean / ATL: Atlantic / ALP: Alpine / MAC: Macaronesian.

threat to all forest habitats, especially mesophilic forests, or those with restricted distribution or at the limits of their distribution, those that are of insufficient size or highly fragmented, or riparian forests (European Commission, 2015).

Article 1 of the Habitats Directive defines the conservation status of a habitat as 'the set of influences acting on it and its typical species, and that may have long-term effects on these habitats' natural distribution, their structure and functions, and the survival of their typical species'. In the same article, the conservation status of a natural habitat shall be deemed favourable when:

- its range of natural distribution and the size of the range remain stable or expand, and
- the structure and natural functions necessary for its long-term continuity exist and may be expected to remain for the foreseeable future, and
- the conservation status of its typical species is favourable.

To assist in the the assessment of conservation status the concept of 'favourable reference values' has been put forward; that is, values in terms of range occupied, structure, functioning and composition of typical species that may be considered determinants of 'favourable conservation status' (DG Environment, 2017).

In many cases, the actual implementation of these definitions is far from immediate. The values of reference relating to the extension occupied by a habitat can be estimated from historic data sources (cartography, photography, bibliographical sources). For an assessment of structure and function, however, in many cases there is a lack of clear guidelines for the structure and functions deemed 'favourable'. In this sense, we must highlight the efforts made to compile extant knowledge (VVAA, 2009) and propose standardised methods for assessing conservation status (Espinoza *et al.*, 2017; Simón *et al.*, 2019).

The conservation status assessment of a given habitat type is based on comparison with a 'favourable conservation status'. Generally speaking, a 'favourable conservation status' (FCS) for forest habitats should comply with the following (Paños, 2018):

- Surface parameters: area of distribution and optimal occupied range.
- Presence of stages of maturity including old-growth or highly evolved structures, as these host the habitat's greatest diversity in species and ecological processes, integrated in a mosaic that also contains stands in different degrees of maturity, ensuring the resilience generated by landscape heterogeneity.
- Representation of typical species, characteristic to the habitat. The species lists should be specific to each variant within habitat types.

Given that assessment is conducted on a regional scale and for a selected habitat type, the conservation status that is most functional and resilient against possible disturbances would be a heterogeneous landscape mosaic, in which all stages of the silvogenetic cycle and their associated biodiversity were positively represented (DG Environment, 2017). Therefore, a forest habitat cannot be understood to be in a favourable conservation status in the absence of mature stages alongside young and intermediate stages of development.

Conservation status assessment of the forests of community interest in Castilla-La Mancha

To comply with the monitoring obligations set forth in the Habitats Directive, the Council of Communities of Castilla-La Mancha has developed a system for the regional assessment and monitoring of conservation status within Habitats of Community Interest.

In conducting a global forest conservation status assessment, parameters are gathered in each habitat referring to the aspects established in the Habitats Directive; range and area covered, structure and function, and future perspectives.

Each of these aspects is quantitatively evaluated by means of a series of indicators. Weighting the scores thus obtained in all the measured aspects enables a global index to be generated, in turn allowing assignment to each of the conservation statuses envisaged in the Habitats Directive: 'favourable', 'unfavourable-inadequate' or 'unfavourable-poor'.

To assess the conservation status of forest habitat structure and functions, field sampling is applied to gather indicator values relating to maturity as per the procedure proposed by RedBosques, from which a structural index is obtained (SI; between 0 and 1) (Table 6). The sampling effort depends on the habitat's geographical distribution, its uniqueness, singularity and value to the region. For more widely distributed habitats, samples are taken from permanent sites, while for more restricted or highly singular habitats more intensive sampling is required, in some cases reaching every patch in the habitat mosaic.

Table 6. Parameters and criteria used to assess the structure of forest Habitats of Community Interest in Castilla-La Mancha region.

Parameter	Criteria	Value
Canopy cover	High ≥ 80% Intermediate ≥ 50% - 80% Low < 50%	1 0,5 0
Basal area	≥30 m^2/ha 10 - 30 m^2/ha <10 m^2/ha	1 0,5 0
Dominant Heigth	≥ 2/3 maximum species' heigth 1/3 - 2/3 maximum species' heigth < 1/3 maximum species' heigth	1 0,5 0
Number of vertical strata	2-3 strata + lianas 2-3 strata 1 strata	1 0,5 0
Tree age distribution	Uneven-aged Two-aged Even-aged	1 0,5 0
Existence of gaps	≥ 10% of canopy cover 5 -10% of canopy cover ≤ 5% of canopy cover	1 0,5 0
Recent and advanced regeneration	Both recent and advanced regeneration Recent or advanced regeneration No regeneration	1 0,5 0
Distribution of diametric classes	Positive assimetry Normal (Gauss) distribution Negative assimetry	1 0,5 0
Deadwood	Woody debris and snags Woody debis or snags lacking No deadwood	1 0,5 0
Microhabitats	Frequent in branches >25 cm Occasionally, in branches >25 cm Lacking in branches >25 cm	1 0,5 0
TOTAL		0-10
IE: STRUCTURAL INDEX		TOTAL/10

Favorable (FV)	Inadequate (U1)	Unfavorable (U2)
IE ≥0,6	0,6 > IE ≥ 0,4	IE < 0,4

3.3. Stands of Reference

At present, most of the forests of community interest in Spain are undergoing stages prior to maturity, while transition stages to maturity and senescence are very scarce or, in some habitats types, non-existent. With regard to the Mediterranean biogeographical region, where it is generally considered that pristine forests do not exist, the last stands kept free from harvesting or whose natural dynamic has been recovered through abandonment, are of the greatest interest as references for comparison.

Old-growth stands are the most natural relicts available, and hence precious elements for comparison, and can be considered as 'stands of reference' for each forest types, showing the structure and functions of the different forest types under non-intervention conditions.

We should bear in mind, however, that for a mature stand to be considered 'of reference' it must represent an average situation for the habitat type in question. In the light of old-growth stands' extreme scarcity, in many cases they are associated to exceptional situations that have favoured their conservation (screes, very steep slopes).

The identification of the characteristics and processes inherent to the mature forest phases provide references for the preservation of biodiversity throughout the scope of the Natura 2000 Network. For instance, we can learn from old-growth stands the duration of the silvogenetic cycle phases in the different Mediterranean habitat types and climates, the role of forests as carbon sinks and how this varies with age, the ratio of very large trees needed to maintain stable populations of certain species of fauna and flora of interest, the amount and size of dead wood snags and litter necessary to sustain a stable community of saproxylic fauna, the conditions and quantity of dead trees and decomposing dead wood needed to increase biodiversity among certain threatened species, etc.

In addition, old-growth stands can serve as inspiration for forests management, providing references for a silviculture that mimics natural processes enabling husbanded forests to enhance their value by adding other assets, highly appreciated by society, to the timber yield.

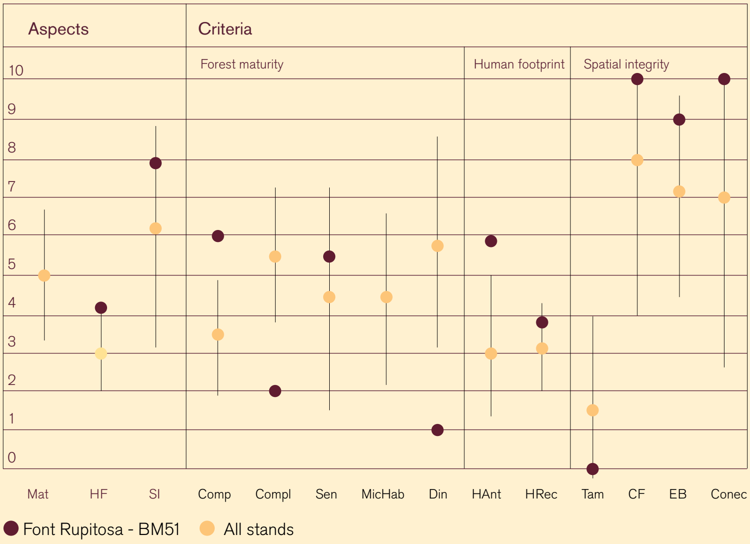
Evaluation of the Stands of Reference in the LIFE RedBosques Project

RedBosques is an application for evaluating the naturalness of forest stands, for their incorporation to the Network of Stands of Reference promoted by EUROPARC-España in the context of the LIFE RedBosques Project. It is a tool for managers and scientists, supporting their forest management decision-making processes and the search for references of high conservation value.

Evaluating the naturalness of forest stands is a process based on calculations involving a broad array of indicators grouped around three distinct aspects:

- **Forest maturity:** the weighted result of aggregating structural and dasometric indicators measured in the field;
- **Human footprint:** as a result of the weighted aggregate of indicators for users and harvesting, past or recent; and
- **Spatial integrity:** taken from cartographic landscape indicators (continuity, connectivity) that describe the forest context in which the stand is immersed.

Weighting the variables against criteria allows us to assign a value between 0 and 10 to each of these three aspects, and to establish comparisons with other stands of the same habitat type in the network, and also with the mean value for this habitat type obtained from the National Forest Inventory. The result will enable to identify representatives of each habitat type with the highest naturalness score, that may be considered 'stands of reference' nationwide, both for conservation objectives in the context of the Natura 2000 Network and for silviculture throughout the country's forests.



Mat: maturity | HF: human footprint | SI: spatial integrity | Comp: species composition | Compl: maturity | Sen: senescence | MicHab: microhabitats | Din: dynamics | HAnt: ancient footprint | HRec: recent footprint | Size: size | CF: forest continuity | EB: edge effect | Conec: connectivity

Figure 4. Comparing a stand vs. mean values of a set of stands.

Access to RedBosques: http://redbosques.creaf.cat/redbosques/

Canopy opening (felling beech trees) around an outstanding specimen of *Quercus petraea* (Roblón de Tremellosa) in Parque Nacional de Picos de Europa. Author: Luis García Esteban/OAPN

4 Managing for Forest Maturity

4.1. Why do we Need Forest Management that Promotes Maturity?

The declaration of protected areas with explicit commitments to the conservation of certain species or habitats has led to the incorporation of conservation criteria in the development of forest management including, for instance, non-intervention areas surrounding nests, halting works during the breeding season, etc., to reduce interference with protected species such as bats, picidae, Western capercaillie, etc. (e. g. Jiménez, *et al.*, 2006; Camprodon & Plana, 2007).

A more comprehensive approach to preserving the ecological processes responsible for forest dynamics has sprung from recent confirmation of the extreme scarcity of stands undergoing the final phases in the silvogenetic cycle, and the value of the biodiversity associated thereto (Mallarach *et al.*, 2013; Schwendtner, 2013; Sabatini *et al.*, 2018). All this, along with evidence of the high degree of forest artificialization through harvesting (Schwendtner, 2012), has led us to propose forest management practices that are more respectful of these traits deriving from forest maturity, both through protection and non-intervention in the few remaining old-growth stands, and the enhancement of maturity in the most advanced phases, and maintaining or promoting certain elements of maturity in forests subject to commercial harvesting (e. g. Beltrán *et al.*, 2018).

This approach, first implemented in the 1990s in temperate forests of North America (Franklin, 1989; Gillis, 1990; Hansen *et al.*, 1991) and referred to at the time as "New Forestry", is more recently being applied in the Mediterranean area (Glig, 2004; Burrascano *et al.*, 2008; Torras & Saura, 2008; Brunet *et al.*, 2010; Brunialti *et al.*, 2010; Mansourian *et al.*, 2013).

In principle, this type of forest management should be mandatory in forests within protected areas in which there is a legal commitment to certain conservation targets such as maintaining the favourable conservation status of forests of community interest present on the sites included in the Natura 2000 Network.

In forests with explicit conservation targets, silviculture may be a fundamental management tool. The techniques initially devised for obtaining sustained economic returns from timber may be re-orientated to boosting instead the values intrinsic to old-growth forests. By and large, this type of management makes it possible to maintain or simulate the ecological processes responsible for developing the structural characteristics of mature phases (Bauhus *et al.*, 2009), thus improving the conservation status of habitats and species.

Moreover, many forests, including those within protected areas, lack a priority conservation target. Where such conservation rules are missing, it may be wise to consider maintaining some of the characteristics inherent to forest maturity in a manner that is compatible with harvesting in productive forests, or with permanence in those focused towards soil protection.

Traditional silviculture has viewed maintaining forest maturity structures as being linked to poorer timber output, and therefore smaller returns for landowners. Actions such as maintaining exceptional trees, standing dead wood or maintaining dead wood litter on the forest floor, lengthening felling cycles, or maintaining certain quarters free from intervention are associated to an increase in costs for landowners (D'Amato & Catanzaro, 2005) (Figure 5).

However, this may amount to over-simplification. Currently available evidence shows that some of the features characteristic to old-growth forests, such as their greater specific and structural diversity, encourage higher productivity in terms of biomass (Vilà *et al.*, 2013; Liang *et al.*, 2016; Jactel *et al.*, 2018). Consequently, by means of appropriate planning and flexible forestry models it is possible to maintain the

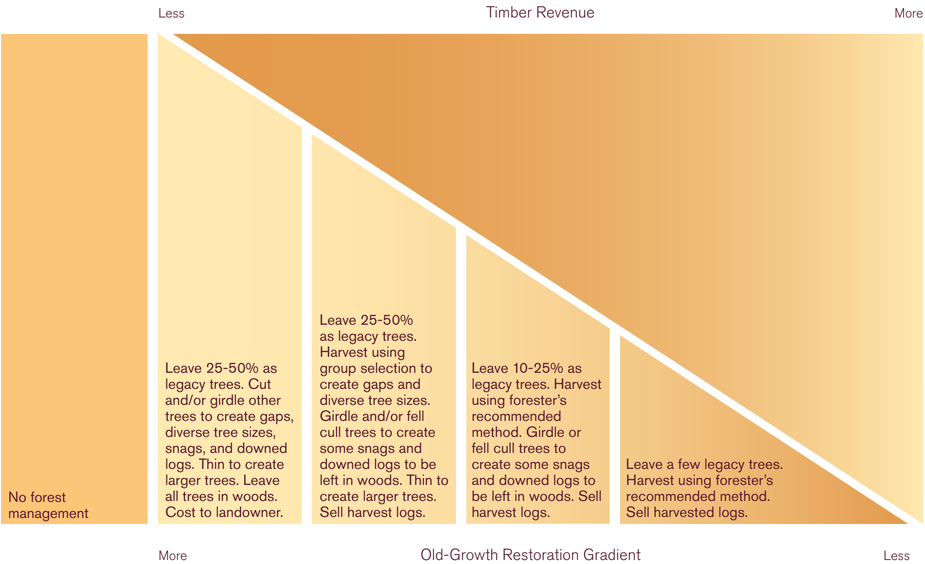


Figure 5. Theoretical relationship between the maturity gradient and timber yield (D'Amato & Catanzaro, 2005)

compatibility of ecological values linked to greater naturalness and maturity with profitable harvesting.

In some places, economic yield based solely on timber may not be a realistic option in the current context of low prices. In such locations, the presence of stands showing traits of maturity is explained by the loss of profitability from logging activities over many years and the existence of old-growth stands allows other forest assets to come to the fore. In some forests, income may be generated from alternative harvesting (mushrooms, truffles, game), or through public uses (provided this poses no threat to the maturity of the forest).

Silviculture aiming to promote forest maturity may also bring opportunities for local development and provide landowners with financial and management tools that might otherwise have been unavailable. These actions can be financed through funds aimed to the promotion of sustainable forest management, for example, through FEADER, provided this type of measures are incorporated in the corresponding rural development programmes.

In other cases, further formulas may be applied to compensate for production loss through voluntary agreements with landowners, for instance, Land Stewardship.

Land Stewardship for the conservation of old-growth forests in Catalonia

Fundació Catalunya-La Pedrera is a private not-for-profit organisation whose objectives include nature conservation. It is the largest private forest landowner in Catalonia: it owns 7,658 ha on estates dedicated to conservation (99% is in the Natura 2000 Network) and to environmental awareness-raising (they receive some 450,000 visitors per year).

Furthermore, the Fundació aims to improve conservation status across the territory by means of engaging private landowners. Land Stewardship agreements are reached in which management plans are designed jointly with landowners with a focus on the conservation and restoration of biodiversity. As for the conservation of old-growth stands, the medium-term survival of a number of singular stands has been safeguarded through agreements for the purchase of felling rights on 30 properties encompassing 166 ha, over periods of between 25 to 40 years (Table 7).

Table 7. Total area and number of estates affected by stewardship agreements with Fundació Catalunya-La Pedrera, and average amount per hectare and per year received for each forest type.

Forest type	No. of estates	Surface area (ha)	€/ha per year
Spruce forest	3	21,70	33,4
Subalpine forest	22	120,10	66,4
Beech forest	1	4,50	88,9
Black pine forest	7	59,09	80,0

Photo 8. Felling of exotic species (Douglas fir, *Pseudotsuga menziesii*) in the Supervised Management Zone to recover the autochthonous riparian forest. (Author: D. Guinart)

Land Stewardship in riparian forests on the Montseny

In the framework on the LIFE Tritó Montseny project, the Provincial Council of Barcelona has promoted Land Stewardship agreements with the owners of estates on which the endemic Montseny brook newt (Calotriton arnoldi) is found. This newt, totally dependent on the natural habitat of little brooks, is the most endangered amphibian in Western Europe. These 20-year agreements aim primarily to preserve riparian forests, to achieve which a Supervised Management Zone has been set up following the brooks in these estates. The management objective is to maintain the riparian forests' natural dynamics, or to promote forest activities aiming to eliminate threats and to boost species inherent to mature riparian forests.

Lastly, it is necessary to take into account that, in the current context of climate change, with foreseeably greater incidence of disturbances such as fire or drought, managing these risks and preserving the favourable conservation status of these estates may encourage active management practices by many landowners who see beyond short-term economic benefits. Management actions promoting maturity – maintaining both structures inherent to maturity and the reserve of sectors under natural dynamics– make up a more heterogeneous, more diverse and hence more resilient forest mosaic.

Below is an analysis of the situations in which it makes sense to apply forest management oriented toward promoting maturity, a few general criteria are put forward and a number of forest planning and management tools that may be of use in reaching these objectives are proposed[6].

4.1.1. Forest Management According to the Degree of Maturity

Specific management measures aiming to maintain or increase forest maturity cover a wide spectrum. A first measure is to set in motion actions for the identification of these stands, currently very little known. This phase consists in determining the geographical limits of these stands and describing their maturity status. A second phase should comprise taking suitable protective measures to guarantee the permanence of the stands (such as a declaration under legal terms), and ultimately the implementation of silvicultural actions wherever these are deemed appropriate.

From the perspective of forest managers, forest landowners or protected area managers, it is convenient to clearly state the conditions in which different management options are the most appropriate, though these are likely to depend on the degree of maturity within each stand (Table 8):

- **Old-growth stands.** These are stands that have remained free from husbandry for centuries, that have reached the final phases in the silvogenetic cycle with trees at the limits of their lifespan and in which the array of structures associated with maturity are visible.
  These are very scarce in the Euro-Siberian area and extremely rare in the Mediterranean area.
  Natural ecological processes must be allowed to unfold freely in these enclaves. Once identified, specific measures may be considered to guarantee their long-term conservation, and non-intervention is the management strategy of preference. These stands are scenarios for research and monitoring and may necessarily require strict regulations regarding public use. Active management measures will, in all cases, be applied to the surrounding woodlands in order to improve connectivity among old-growth stands and reduce risks.

6— For forestry terminology refer to: USDA Forest Service (2013). Silvicultural Activities: Description and Terminology. White Paper F14-SO-WP-SILV-34

- **Near-mature stands.** Stands in advanced phases in the silvogenetic cycle, subject to no logging activities and with a small human footprint.
  Very scarce in the Mediterranean area, they may be absent from some forest types. Distribution is normally isolated and restricted. Currently in the process of prospection and characterisation.
  Owing to the effects of earlier uses, some of the structures inherent to this phase of maturity may be missing. As well as prospection, identification and conservation measures, it may be advisable to restore processes responsible for traits of maturity that may be missing in the stand, by means of silvicultural actions such as increasing the dead wood litter or stand heterogeneity. It is important that any such actions taken respond to explicit and grounded objectives.

- **Singular stands.** Stands subject to some degree of human intervention causing deep structural modifications, with an abundance of old trees and a wealth of biodiversity. These stands often have cultural value (for instance, pollarded stands).
  Relatively abundant: these may be the closest formation to maturity in many forest habitat types, especially oaks.
  These present some elements of maturity (especially very old big trees), but a strong human footprint. It may be advisable to take measures aiming to promote some of the lacking traits of maturity, for instance in the case of dehesas where livestock uses have ceased. Maintaining cultural values may also be a valid objective.

- **Young stands.** Young or rejuvenated forests, prevented from maturing by husbandry or forest fire, whether these are productive or protective forests.
  These forests constitute the greater part of Spanish forests, from managed woodlands to reforestations or coppice forests, occupying considerable continuous extensions.
  In this type of forests, especially within protected areas, management geared toward the restoration of certain processes and elements of maturity is also possible, thus increasing resilience against disturbances and enhancing adaptability to climate change, increasing heterogeneity and diversity, and improving their conservation status.

Table 8. Possible management measures depending on stand maturity.

Type of stand	Characteristics	Management aims	Possible Conservation and Management Measures
III **Old-Growth**	Stands undergoing the final stages of maturity, reaching the senescent phase. Very old big trees at the limits of their lifespan, with dead wood snags and all other traits of maturity	Safeguarding natural dynamics	▪ Geographical delimitation and characterisation ▪ Incorporation to the Network of Stands of Reference ▪ Declaration under specific protection legal figures ▪ Non-intervention, research and monitoring ▪ Management of the forest matrix (connectivity, risks)
II **Near Mature**	Stands with a high degree of naturalness, showing traits of maturity and a small human footprint. Free from extractive harvesting (logging or others).	Restore lost ecological processes, favour traits of maturity, complete the silvogenetic cycle	▪ Geographical delimitation and characterisation ▪ Incorporation to the Network of Stands of Reference ▪ Declaration under legal protection figures or in planning instruments (planning mandates, management plans) ▪ Research and monitoring. ▪ Support measures for the improvement of certain traits of maturity (dead wood, clearings...). ▪ Management of the forest matrix as a measure of protection (connectivity, risks)
I **Singular**	Stands that present certain traits of maturity as a result of intervention in the past, especially those acquired over the longest periods of time. Examples of these cases are abandoned dehesas or pollarded stands.	Preserve cultural values, preserve or promote values linked to maturity (biodiversity)	▪ Geographical delimitation and characterisation ▪ Preservation of singular traits of cultural value ▪ Restoration of processes and traits of maturity that are absent for artificial causes.
0 **Young Forests**	Natural stands of young forest, or rejuvenated through husbandry or disturbances	Structural improvement associated with maturity (heterogeneity, biodiversity)	▪ Establishment of reserve zones ▪ Identification and protection of singular elements (e.g. old trees) ▪ Silviculture compatible with boosting traits of maturity, increasing heterogeneity and diversity
	Artificial stands naturalised with autochthonous species (plantations)	Improvement of the conservation status (diversity, resilience)	▪ Identification and protection of singular elements (e.g. old trees) ▪ Naturalisation, increasing heterogeneity and diversity

4.2. Forest Maturity in the Planning Stage

The first step in which intervention is possible to improve the traits of maturity in a forest patch is to define the long-term objectives aimed for and the means through which they will be achieved.

Conservation objectives (which in the Natura 2000 Network are the maintenance or recovery of a favourable conservation status for the different habitat types) must be set initially on the biogeographical region scale, or at least on the landscape scale. This means that the array of habitat types present must be considered, their representativeness and conservation status on the regional scale, so that priorities may be set for each site within the network. In some cases conflicts will arise between conservation commitments regarding habitats representing the final phases in the succession (forests) and others that are intermediate phases sustained by human activity (scrub, pastures) that will need to be prioritised.

In a given territory, to consider a forest to be in a good conservation status, it should display a representation of every phase in the silvogenetic cycle. This ensures not only the existence of old-growth stands, but guarantees their successive replacement over time. A forest in good condition will therefore contain gaps, young stands, stands in the process of ageing, and some proportion of old-growth or senescent stands. This does not imply that every forest (or property) should contain a mature stand, but rather that this target applies to the landscape scale.

In addition, at this planning stage it is also essential to consider the forest matrix surrounding old-growth stands to achieve their healthy conservation status. Thus, planning should guide management to focus on old-growth stands reducing the vulnerability of the forest matrix to disturbances such as plagues or fire or assuring its resilience against climate change.

It is also important to maintain or restore connectivity among old-growth stands, currently few and far between, to assure the conservation of species linked to the senescent phases. In this sense many elements of the green infrastructure (lines of trees, isolated stands, even old trees) may act as corridors or stepping stones for species associated to old-growth stands.

Such planning strategies aiming to promote forest maturity should be applied on different scales, from territorial planning instruments to detailed planning at the stand level.

4.2.1. Landscape scale

From a territorial perspective the coordination of the various planning tools affecting a single territory is key, through planning at a higher level. In the case of protected areas this is achieved by incorporating general criteria to guide forest management in planning instruments, such as management plans within protected areas and Natura 200 sites. This allows the harmonisation, for instance, of the choice of reserve stands so that these are grouped in adjacent terrain resulting in larger stands or improved connectivity.

Forest management plans at a county level operate on this same scale. In these instruments, the areas of forest in which it is possible to create reserve areas or areas of silvicultural intervention focused on promoting maturity should be located and selected. To do so, an analysis should be conducted of the intrinsic value of the forests included in the territory affected by the scheme, the different situations regarding public or private property and potential loss of profit on ceasing or modifying forest exploitation, and the legal capacity of the plan to modify the management conditions currently in force.

The decision to opt for non-intervention in a given stand should be accompanied by a legal instrument ensuring its permanence in the long term. Among the options available we may mention the following:

- **A formal declaration:** on some occasions, if reinforced protection is required or the stand is not included in a protected area, it may be found convenient to draft a specific protection formula or to issue a formal declaration (e.g., natural monument).
- **Inclusion in zoning:** in protected areas, management plans allow conservation objectives within the territory to be differentiated through zoning. Thus, a simple solution is to incorporate old-growth stands or those in the process of ageing in the reserve zones foreseen in the management plan. Within these reserve zones non-intervention criteria may be established applying more restrictive regulations than for the rest of the territory, depending on the degree of maturity within the stand.

Decree 27/2015, of 24 February, issued by the Government of Aragon, regulating the Catalogue of Trees and Singular Groves in Aragon

Singular groves are selected by applying an index that takes into account features of maturity such as the presence of large trees, dead trees, heterogeneous structure, gaps and regeneration of skiophilous species. Protection regimes are established in these groves that include a ban on felling and regulating any activities liable to affect their conservation status. The groves thus declared to date are the following:

- **"Pinar de pino moro".** (*Pinus uncinata*). These are southernmost populations of this species. Besides this location it is only found in the Alps, the Pyrenees and Sierra Cebollera.
- **"Pinar del pino salgareño en Valdiguara".** (*Pinus nigra*). (*Pinus nigra*). A stand of *Pinus nigra* subsp. *salzmannii*, the endemic western variant of *Pinus nigra*, frequently found mixed with reforestation areas of *Pinus nigra* subsp. *nigra* (European black pine).
- **"Ribera de Chopo Cabecero".** (*Populus nigra*). Riparian formations of pollarded black poplar, of high cultural and ecological value owing to the unique biodiversity they host.
- **"Hayedo en El Moncayo".** (*Fagus sylvatica*). A pure stand of beech located in the Iberian System. This is one of the southernmost populations of this species.
- **"Pinsapar de Orcajo".** (*Abies pinsapo*). This forest enclave is the result of a reforestation initiative in the early 20th century, and unique due to the great distance from the species' natural distribution range and the abundant regeneration displayed.
- **"Sabinar de Olalla".** (*Juniperus thurifera*). A former dehesa used for agriculture and grazing containing many trees that are centuries old (Declared by Order DRS/354/2019).

4.2.2. The local scale (forest management plan)

The conservation objectives fixed in the management plans at the landscape or protected area scale, may be detailed on a more detailed scale within each of each of the estates or propierties within the territory. The planning tool at the estate level is the forest management plan. It must be borne in mind that there are forests (mainly publicly owned) covering very great extensions, in the region of thousands of hectares, for which planning is nearly always on a district scale.

To begin with, and still at the planning scheme stage, it will be necessary to select the appropriate silvicultural approach, in which emphasis should be placed on the processes to be simulated and that are associated with maturity situations, such as minor recurrent disturbances, canopy openings, natural regeneration, senescence, etc.

The preferred silvicultural systems will be those that generate heterogeneity stand-by-stand or tree-by-tree, such as individual tree silviculture, silviculture close to nature (Tíscar *et al.*, 2015) or silviculture for the preservation of processes (Schwendtner, 2007). In the absence of these, it will always be preferable to avoid homogeneously treating extensive areas (Serrada, 2016).

Silviculture for the preservation of processes

Silviculture for the preservation of ecological processes is an alternative approach to traditional forestry based on the knowledge and imitation of forest ecosystem dynamics. This approach was developed in the late 1980s in Germany, drawing on the newly acquired knowledge of forest dynamics in Europe (Schwendtner, 2007).

This silvicultural model aims to achieve high levels of naturalness both in the natural dynamics of each stand and in the species community naturally occurring within the forest, without ceasing to harvest timber products.

Among others, silviculture for the preservation of processes is based on the following management criteria:

- In each forest, areas free from intervention are identified to serve as references in observing the natural processes that will guide the management of commercially exploited stands.
- In commercially exploited forests, dead wood should reach a minimum of 10% of standing trees. Trees containing nests of endangered bird species and any rare or singular specimens must be preserved.
- Authoctonous tree species are encouraged througn silvicultural practices. Natural regeneration is encouraged, with only exceptional recourse to sowing and artificial plantation.
- Interventions are conducted only on individuals of species not included among the "natural association", or on poor quality individuals that hinder the development of healthy specimens of the naturally associated species.
- In each intervention, individual trees or small groups of trees are felled creating clearings of a maximum of 0.25 ha. The maximum percentage of living timber extracted is 30%, respecting trees of advanced age or with an outstanding ecological, economic or aesthetic value. Standing trees should be equivalent to at least 80% of those found in natural forests free from intervention.
- Monitoring checks on forest dynamics are conducted every 10 years.
- All the following should be avoided: clear-cutting, single-species plantations or those of non-authoctonous species, the use of pesticides, fertilisation, drainage of wetlands, interventions during ecologically sensitive periods and feeding of game species.

Some aspects to be borne in mind during this phase that will increase the values linked to forest maturity are the following (Martín Herrero, 2003):

- **Choice of silvicultural system:** One of the main characteristics of mature forests is their vast vertical and horizontal heterogeneity, resulting from a dynamic of minor recurrent disturbances. Therefore, the preferred silvicultural system should allow the integration of several targets (for instance, through spatial segregation), and promote spatial heterogeneity. Among these methods, we may mention planning on the basis of stands, on account of their adaptation to forest variability and specific, customised targets (González *et al.*, 2006; EUROPARC-España, 2013). Less flexible methods or those affecting large homogeneous extensions should be dismissed.

- **The regeneration method:** coppice forests are highly anthropized structures, generally resulting from successive coppicing in stands of resprouting species for the purpose of obtaining firewood. As a consequence of very short felling cycles, coppice forests display little maturity value, high homogeneity, and a poor capacity for regeneration from seeds (Reque, 2008). As a general rule, therefore, woodland structures should be maintained or recovered in order to return to the stand's natural dynamic.
- **Stand structure:** Old-growth stands are distinguished for containing trees of all age types in the canopy. To reach or sustain this structure, even-aged stands should be avoided, while uneven-aged are preferable (Serrada, 2017).
- **Definition of cutting cycle:** This concept is related primarily to the definition of the logging yield peak, and is therefore not applicable in woodlands whose sole target is the preservation of biodiversity or other environmental services.

  In forests subject to productive objectives (as principal objective or subordinate to conservation aims) one way to allow greater maturity to develop, while simultaneously achieving higher-value timber production, is to dedicate stands to producing timber of great dimensions by means of applying a longer cutting cycle (two or three times the normal cycle according to criteria for maximum returns) (Tíscar, 2015; Martín Herrero, 2003). Such stands are referred to as 'ageing stands'.

  Another option is to keep a small proportion of trees prevented to be harvested, thus maintaining very old and very big trees in the forest. In this manner, these stands, provided they present high site quality and are made up of long-lived species (e.g., *Pinus nigra, P. sylvestris, P. uncinata, Abies alba, Quercus petraea, Q. robur, Q. pyrenaica*) will produce very large trees with traits of senescence (Bauhus 2009), as well as a higher proportion of biomass per hectare than in the remainder of the forest, while sequestering greater amounts of carbon for a longer time.

Forest management plan for Parc Natural dels Ports (Tarragona)

In the LIFE RedBosques Project, forest management plans have been drafted for three private estates within the Park. These estates are focused on production and conservation, and consist mostly of mixed stands of Pinus nigra and P. sylvestris, that were subjected to intensive logging until some 40 years ago when this activity lost profitability.

The proposed planning schemes are based on the tenets of 'silviculture for the conservation of processes', applying low-expenditure interventions that mimic natural ecological processes, and that aim to generate quality timber in the future along with enhanced habitat conservation status, promoting certain traits of forest maturity such as the presence of standing and fallen dead wood, the opening of clearings and fewer competitors to secondary canopy species.

- **The definition of reserve areas or stands:** Regardless of the planning method applied, if the target is to maximise features of maturity within the forest or the quarter, natural dynamics may be allowed to operate freely in some stands in which the silvogenetic cycle is thus completed, having excluded therein all production aims and granting them forest reserve status. Non-intervention is the management option for the final maturity phases. This option, however, may also be appropriate in ageing stands in which natural processes are allowed to take over, in which case a sufficiently long time frame should be assured.

  In forests that are large enough, such stands may be grouped in a reserve area comprising stands at different phases in the silvogenetic cycle to ensure that the various ecological processes active in the silvogenetic cycle unfold at their own pace.

  In some cases, the economic feasibility of harvesting activities has caused the more inaccessible areas to be avoided, giving rise to many stands, and even whole tracts of forest, operating as reserve areas. However, it is important that reserve areas should also include stands in favourable environmental conditions. These reserve areas should encompass different situations within the forest, representing the different phases in the silvogenetic cycle (albeit lacking old stands), and should likewise occupy a significant extension within the forest.

Planning Project for the MUP 100 "El Pinar" de Codos (Zaragoza)

The forest "El Pinar" (317 ha), has been designated as Site of Community Interest (SCI), harbouring the Habitats of Community Interest 9340 (forest of *Quercus ilex*) and 9540 (Mediterranean pinewoods of endemic Mesogean pine – in this case, *Pinus pinaster*).

A reserve area of 73 ha has been marked out (23% of the forest). The remainder has been classified as a productive-protective area and divided into stands, a part of which are even-aged in which 10 trees/hectare are reserved after a cutting cycle of 120 years (instead of 80-90 years as per traditional production tables) while the remainder of stands are uneven-aged (Figure 6).

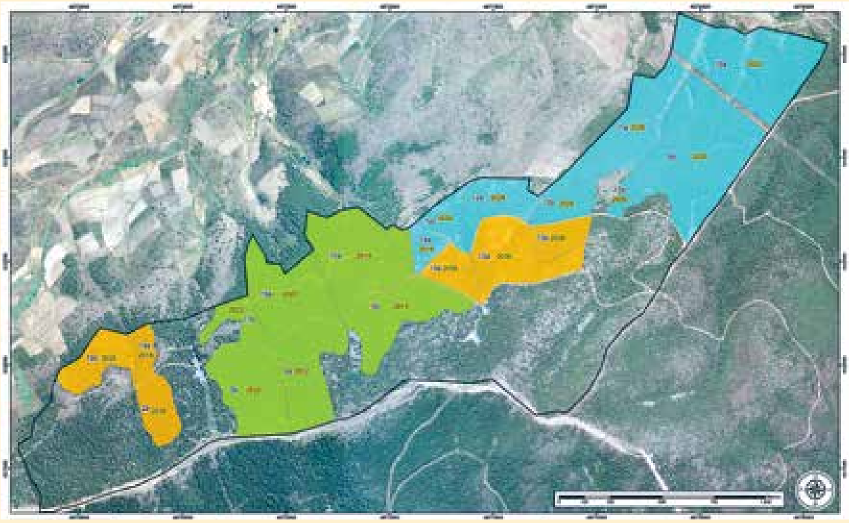


Figure 6. Forest management plan for Monte El Pinar de Codos (Zaragoza). The uncoloured area represents the reserve area within the forest.

Reserve areas in forest management plans for Navarre

According to the forests regulation developed in Regional Law 13/1990, on the protection and development of forest heritage in Navarre, 'in the forests listed in the catalogue, whether for public use or for protective purposes, at least 5% of their area shall be preserved free from human activity, subject to its natural dynamic'. This indication has been expressly included in the terms and conditions for drafting forest management plans, specifying that a reserve area must be created, with a minimum extension of 5% of the total forest, dedicated for public use or protective purposes.

4.3. Forest Management in Non-Intervention Areas

Forest management in the stands allowing the silvogenetic cycle to be driven by natural processes should be based on non-intervention, focusing in all cases on avoiding anthropic disturbances from affecting the structure of the stand (silvicultural treatments of any type) or altering the regeneration processes (livestock farming, human pressure).

Therefore, stands dedicated to natural evolution are considered incompatible with any action that implies the modification of natural processes or that involves the elimination or reduction of features linked to maturity. Within these areas, the removal of dead wood should be avoided, whether fallen, standing or in the process of decay. The systematic removal of dead wood is one of the reasons why stands in which felling has been absent for decades nevertheless lack the characteristic features of maturity.

Selling dead or decaying trees for firewood for local communities in reserve stands should be avoided. Similarly, sanitation cutting or the systematic elimination of parasites such as mistletoe are viewed as inappropriate without a detailed study of the environmental and economic advantages and disadvantages.

In the event of natural disturbances (wind, landslides, fire) the criteria should be to leave fallen trees in place. This dead wood should not be viewed as a hazard to the health of the forest, especially if the surrounding forest patches are in good condition (Thorn *et al*., 2019). In any case, suitable monitoring systems should be set up in order to quantify the effect of disturbances on the forest.

Wild herbivory is a natural process that should be present in forests allowed to evolve freely, although high densities may hinder tree regeneration. In non-intervention zones, livestock should be excluded by means of fencing or other methods.

Visits to reserve zones should be severely restricted, allowed exclusively for the purposes of research and monitoring, to avoid anthropic disturbance (for instance trampling, disturbing fauna, etc.). In exceptional cases where public recreational uses are allowed, these must be carefully planned and managed to ensure minimum impact on the ecosystem.

Restrictions on uses within reserve stands can be established in the rules for drafting protected areas management plans or forest management plans. Given that many forests are privately owned, the most effective option is to reach agreements with the owners of the stands to be protected. A range of options is available, including for instance land stewarship, or compensation in the event of income loss. In these cases, the longest term possible should be agreed, preferentially in perpetuity.

Agreements with landowners for the preservation of old-growth stands in Parc Natural del Montseny

In Parc Natural del Montseny, 85% of the forest is privately owned; hence the need to reach forest management agreements with landowners. Having identified, between 2008 and 2014, the stands of greatest interest from the point of view of their maturity, a number of strategies have been established to safeguard their preservation.

On public land, conservation is the overriding objective, respecting natural dynamics and applying spot interventions to promote forest heterogeneity. On private estates, the main target is to avoid harvesting in stands that display maturity features, by means of administrative mechanisms guaranteeing their long-term exclusion from timber extractions activities. Owing to the fact that these forests are not subject to specific protection measures, and that current legislation allows their exploitation, the Natural Park's managing body is pursuing three lines of action according to the opportunities and peculiarities of the property:

1. **The creation of forest reserves,** through 20 year covenants between the administration and the ownership, with the aim of maintaining the forest's natural dynamic. In return, landowners receive an indemnity for the sale of felling rights for the duration of the covenant. At present there are four forest reserves within the park (5 ha and 38 ha of beechwoods, 8 ha of holm oak and oak groves and 6 ha of oak forest).
2. **Permutation of land between private landowners and the administration.** This is proposed as an alternative to land purchase when there is insufficient budget or the landowner is unwilling to sell. Permutations involve stands in public forests of little value in biodiversity but of interest from the forestry point of view, in exchange for mature stands of high conservation value. This is the case of a stand of centuries-old holm oaks (*Quecus ilex*) and a mixed stand primarily of beech (*Fagus sylvatica*), undergoing administrative processes to establishe their permutation for stands of holm oak subject to traditional exploitation.
3. **Land stewardship contract,** signed in the framework of the LIFE Tritó Montseny project for the conservation of riparian forests, is a good alternative on certain estates containing mature stands and where, despite the owner's unwillingness to exploit them, it is convenient to reach agreements for their protection and management shared or tutored by the administration.

4.4. Silviculture for Maturity

Silviculture is applicable to all forest types with the aim of maintaining or boosting certain attributes that are unique to old-growth stands. In general terms, the underlying premise for respecting or promoting forest maturity through silvicultural actions is twofold:

- In forests subject to conservation aims, generally located within protected areas or the Natura 2000 Network, achieving and maintaining the highest possible degree of maturity may be an objective in itself given that, as we have seen, such situations are of the highest value from the point of view of conservation.
- In forests subject to production or soil protection purposes, silvicultural actions may be conducted provided they respect features of maturity that are compatible with logging activities, and that they enhance biodiversity and resilience.

Existing old-growth stands for each forest type may be used as references for silviculture, and techniques may be applied to promote maturity traits. The identification of appropriate silvicultural measures must be carefully reasoned and chosen according to the age of the stand and the human footprint present therein.

This task may be facilitated by assigning the stand to a specific maturity phase and identifying which features of maturity are lacking in the stand, and thus assessing the feasibility of taking action for its improvement (Table 8). Having established an order of priority for the features of maturity to strive for, the most appropriate techniques may be selected. Always take into account that a single action may, in some cases, affect several attributes.

The attributes linked to maturity on which intervention is possible, and examples of measures applicable in each case, are summarised in Table 9. In general, these aim to:

- Maintain traits that are characteristic of forest maturity (big, old trees) preventing their removal or promoting them.
- Maintain or increase the amount of dead wood snags and litter on account of its direct relationship with the diversity of saproxylic species. Restore ecological processes associated with their presence (Sandstrom *et al*., 2019).
- Increase forest heterogeneity and diversity, imitating a regime of frequent minor disturbances (Franklin *et al*., 2002).

Table 9. Features of maturity and husbandry techniques for achieving them (adapted from Keeton, 2005)

Attribute	Silvicultural Techniques
Very big trees	▪ Inventory and preservation (legacy trees, reserve trees of interest to biodiversity, of cultural value...) ▪ Lengthening the cutting cycle ▪ Crown thinning to reduce competitors and boost growth. ▪ Convert coppice forests to high forests by culling
Large dead wood snags	▪ Selectibe girdling (bark ringing) of big trees ▪ Decrowning
Coarse dead wood litter	▪ Felling of big trees without removal ▪ Maintenance *in situ* of fallen trees
Dendro-microhabitats	▪ *"Veteranization"* of trees ▪ Pollarding
Diversity of species in the canopy	▪ Crown thinning to encourage accompanying species
Vertical canopy stratification	▪ Selective thinning ▪ Heavy crown thinning, group selection cutting ▪ Selective felling
Diversity in the diameter and age of trees in the forest canopy	▪ Selective cutting of codominant trees ▪ Maintenance of dominated trees ▪ Selective crown thinning ▪ Selection cutting to create heterogeneity (uneven-aged dsitribution)
Canopy gaps due to fallen old trees	▪ Group selection cutting (without extraction) ▪ Felling of big trees without removal
Advanced regeneration	▪ Exclusion of herbivores to facilitate regeneration ▪ Crown thinning or preparatory cuts. Group selection cutting

We should take into account that these attributes appear in old-growth stands as a result of the ecological processes inherent to the silvogenetic cycle. Replicating these traits in isolation, therefore, cannot make a stand become mature, but may nevertheless allow some desirable characteristics to be gained when promoting the population of certain associated species of interest or when seeking more heterogeneous forests with a greater variety of ecological processes.

When targeting forest maturity, certain silvicultural techniques should be avoided. These include those promoting simplification (regularisation, shorter cutting cycles), those with a uniform impact over large extensions, those involving the selective elimination of singular elements (such as sanitation cuttting, felling overmature individuals, felling dead trees, or selective felling of large-diameter trees), those that bring genetic contamination (artificial plantations) or tend to eliminate vertical stratification and undergrowth diversity (Reque, 2008).

Described below are some silvicultural techniques that are suitable for boosting some features of forest maturity.

In executing these actions in protected areas, it is necessary to pay special attention to the works conducted to avoid adverse effects on conservation targets. Care must be taken in selecting machinery, felling and skidding techniques, and seasons for each type of intervention (EUROPARC-España, 2011).

When conducting interventions regarding singular trees, bark-ringing and thinning, tree marking is particularly important as a successful outcome will depend on the correct selection of trees. It is therefore of vital importance that the staff responsible for marking the trees to be felled or culled be suitably qualified, since the technical justification for these actions may not be evident to staff unskilled in tasks involving the preservation of biodiversity.

4.4.1. Preservation of Exceptional Trees

Exceptional trees are those with a normal diameter considerably larger than average[7], and all old-growth or senescent trees. In many young forests (both natural or created by reforestation) the only trees of exceptional diameter are the survivors of erstwhile forest grazing uses (pollarding, remnant trees from former forests). On other occasions, these are exemplars referred to in older planning projects as 'overmature' trees that have remained in the forest for different reasons and that usually display traits of senescence (dead branches, injuries, hollows...) of great interest as microhabitats.

These specimens possess a singular value from a diversity point of view, which makes their preservation a priority (Reque, 2008). If they are found within a forest stand dominated by younger trees (of the same or a different species), they will be at risk of premature death from competition with other more vigorous trees. Thus it may be necessary to take action in the area surrounding these trees to protect their growth vitality. As these individuals are many years old (and less adaptable to sudden change), the gradual moderate clearing of adjacent trees is recommended, and bark-ringing as an alternative to felling may be considered. Pruning operations on very old trees may accelerate their decadence, and should therefore be limited to situations in which it is necessary to avoid personal risk (visitors).

7— As a simple guide an exceptional diameter may be measured as three times the dominant height (in metres) expressed in centimetres. For a stand with a dominant height of 20 m, an exceptional diameter would be from 60 cm.

4.4.2. Preserving Dead Wood Snags

Dead trees that are still standing, especially those of large proportions, are of special interest for the conservation of biodiversity, for which reason it should be a priority to leave them in place.

In the case of standing dead trees in a forest in which intervention of any kind is planned, a significant number of trees should be maintained safe from cutting, except if they represent a threat (for instance, pines displaying decay in areas affected by *Bursaphelenchus xylophilus)*.

4.4.3. Bark-ringing/Girdling

This consists in the removal of a band of bark and cambium to prevent the flow of sap around the entire perimeter of a living tree trunk. This produces the weakening and gradual death of the tree over a period of several years depending on the species and the depth of the damage. Deep cuts that do not entirely eliminate the bark may also work, as a simpler and more economical method.

This technique is applied principally to create dead wood snags, but may also be used to progressively free tolerant species or veteran trees from competitors, thus avoiding the possible damage caused by felling or sudden canopy opening.

In any case, it is preferable to maintain existing standing dead trees rather than intentionally creating them. It is essential to maintain the proportion of living trees and snags that will not compromise the continuity of the forest. This proportion will vary in stands managed for timber production as opposed stands allowed to follow their natural dynamic.

Bark-ringing should be practised at a certain height (more than 1 m) because, should the tree break off at the girdling level, the remaining stump will of higher value to the conservation of saproxylic fauna.

Nevertheless, bark-ringing may be applied on softwoods and hardwoods alike and, in general, on trees with larger diameters, as coarser dead wood is usually more scarce and is the most suitable for saproxylic organisms.

Bark-ringing should not be applied on veteran trees, with crown dead wood, hollows, or offering dendro microhabitats as these, in themselves, are important to the preservation of forest biodiversity.

Bark-ringing should be programmed on a timescale to provide wood in different stages of decomposition rather than generating this resource simultaneously.

Photo 9. Dead wood snag (*Pinus sylvestris*) in Parque Nacional de la Sierra de Guadarrama. Author: J.A. Atauri..

Photo 10. Bark-ringing in a trunk of *Fagus sylvatica* to create standing dead wood, in Parque Natural de Urbasa y Andía (Navarra). Author: J. A. Atauri

Likewise, when girdling conifers, the risk of increasing the number of bark beetles should be taken into account. Available scientific evidence –which is scarce and referred to boreal forests in northern Europe– is not conclusive in proving that maintaining standing dead wood necessarily implies increased damage from borers in living trees, rather than attacks on a few weaker trees whose death forms part of the normal regime of forest disturbances (Hedgren, 2002 and 2003; Eriksson *et l*., 2006, 2007; Kärvemo *et al*., 2007; Göthlin *et al*., 2010). Moreover, by avoiding these species' periods of maximum activity (late spring and summer) problems are unlikely to arise.

It is advisable to conduct bark-ringing in a disperse manner, although in some cases (e.g., encouraging chiroptera) girdling groups of trees may be appropriate as certain animals prefer sheltering in such dead wood groves.

Photo 11. A group of *Pinus sylvestris* decrowned as part of thinning works in a 1964 reforestation (Litago, Zaragoza). Author: E. Arrechea

4.4.4. Decrowning

This technique consists in removing the crown of some trees leaving a large portion or the whole of the trunk. The aim is to create standing dead wood in the form of poles.

This method is extremely simple if forest harvesting machinery with a processing head and grapple arm capable of cutting at heights of 3 to 5 m may be used.

The main difference between decrowning and bark-ringing, in the case of conifers, is that the latter causes the tree's gradual demise, whereas decrowning has an immediate effect and leaves only the trunk standing simulating the natural breakage of the crown. This difference should be borne in mind in assessing the risk of bark beetle outbreaks or the advantages of preserving dead crowns standing or as dead wood litter.

The crowns may be processed and harvested or left on the forest floor, simulating natural windthrow or snow damage. Harvesting the crowns may offset loss of income from timber left in the forest. This technique may be applied to timber harvesting in stands of any age, and may be suitable, in softwood reforestation stands, for

Photo 12. Beech tree felled to generate dead wood litter in Parque Natural de Urbasa y Andía (Navarra). Author: E. Arrechea.

generating dead wood in the forest from the first thinning operations, selecting the thickest trees for this purpose.

In thinning operations, stumps of greater height than usual may be left (up to 25-30 m) in young forests will provide the only shelter and food for certain coleoptera that depend on large dead wood to complete their life cycle.

We should likewise remember that hardwoods' resprouting capacity is sufficient to replace the removed crowns (giving rise to pollarded stems) or to grow from the stock or root of girdled trees.

4.4.5. Felling without Tree Removal

This mimics the natural death and collapse of trees by felling individuals selected for their size or physical characteristics, leaving them unprocessed or cut into shorter pieces on the forest floor.

This method aims to generate dead wood litter to encourage saproxylic species. It also contributes to regeneration by opening a gap in the canopy.

Felling without tree removal can be conducted with forest processing machinery or chainsaw harvesting. An alternative felling method is to crack or splinter tree trunks by traction, producing damage similar to that caused by natural perturbation.

When a relatively high stump is left (up to 1.5 m) the result may be similar to decrowning, described above. It is sometimes advantageous to de-branch and possibly cut up trees felled for this purpose. These variations modify contact between the soil and the log, thus conditioning the appearance of different species of saproxylic organisms.

4.4.6. Thinning

Thinning reduces the number of trees in the forest to reduce competition and enhance growth in the remaining trees, as well as extracting marketable products. Thinning is usually applied to even-aged forest stands as defined for each species and season in silvicultural models (production tables, silvicultural norms, etc.). These models are developed to optimise the production of timber or other goods through each full cutting cycle, in balance with other sustainability or structural stability targets.

In ecological terms, thinning operations constitute a disturbance freeing up resources for the remaining trees - such as water or nutrients - and allowing more light to reach the forest floor. The subsequent development of the remaining trees gradually reduces and extinguishes these two effects, at which point it is time to repeat thinning operations.

Thinning increases trees' vitality and therefore their growth, increasing their girth. In addition, it allows for greater variety of plant species and greater activity and development of fungi and, consequently, the diversification of food chains and, very often, a habitat structure that is better suited to the needs of scarce fauna in excessively dense woodland.

Thinning also enhances adaptability to drought, forecast to become more recurrent with climate change, given that a smaller number of trees has better chances of surviving prolonged periods of water shortage provided that thinning does not result in excessive exposure to sunlight.

The heavier the thinning operation, the more evident will these effects become. However, thinning should never be so intense as to unduly rejuvenate the forest, causing a scrubland effect, potential massive treefall, or generalised rootstock resprouting, all of which would exacerbate the woodlands' previous problems.

Photo 13. Liberation thinning in a beech forest to favour specimens of *Taxus baccata* (Parc Natural del Montseny). Author: D. Guinart

Thinning intensity should therefore be measured according to the forest's main target, evaluating the processes that will commence after felling (revitalization, scrubland encroachment, advanced regeneration...) and how the forest's subsequent evolution will impact this target. It will always be preferable to observe how these processes develop in forest types similar to those to be treated and to avoid simplistic expectations or a 'one size fits all' approach.

In conducting crown thinning operations, the trees chosen to remain within the forest should be carefully identified, and their strongest competitors eliminated, to ensure that no healthy trees are removed without gaining positive benefits therefrom. This technique offers the economic benefit of allowing larger and more valuable products to be extracted, and at the same time ensures greater future revenue from the improved forest stand.

Heavy thinning (both low or crown thinning) may be recommended in single-species artificial stands within protected areas with little or no previous management. Despite the stand's potential loss of productivity during the cutting cycle (while the presence and vigour of other species is enhanced), in forest subject to production targets

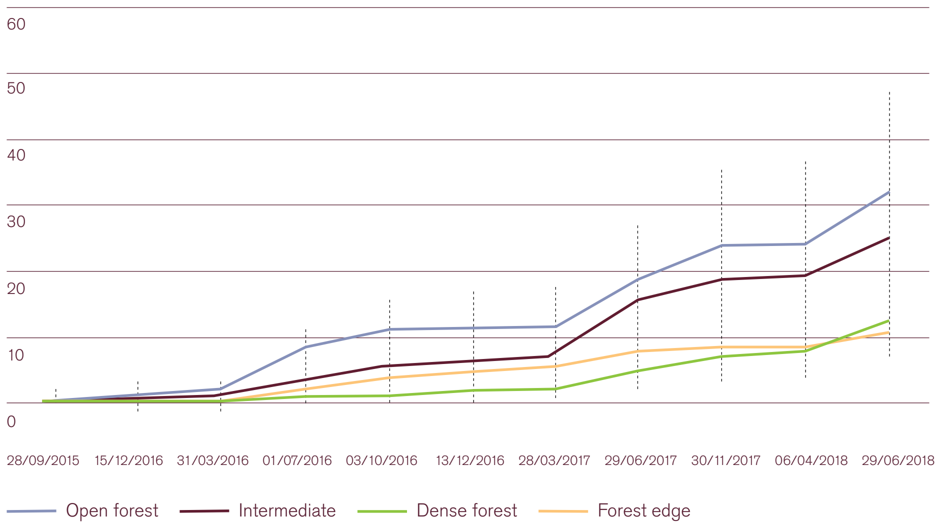


Figure 7. Accumulated growth of yews (*Taxus baccata*) registered by dendro-flexometer in the various types of liberation thinnings conducted in 2012-2013 in Parc Natural del Montseny, in which stronger growth is appreciated in the stands subjected to heavier thinnings.

heavy thinning may be conducted on a percentage of the surface area earmarked for intervention (1-10%), performing the rest of the treatment with the intensity recommended by the corresponding silvicultural production models.

4.4.6.1. Liberation thinning

Crown thinning may favour tree canopy species diversification, and be used to remove competitors from trees of special interest for economic or biodiversity reasons. Thinning out their competitors can enhance secondary species' growth. These may be new saplings or established trees weakened by competition or lack of sunlight, or even old trees that are being crowded out by new forest growth (Figure 7).

In all these cases, special attention must be paid to the target species' tolerance to light, as this will condition the intensity of the liberating effect. We should not forget that enhanced vitality in these individuals not only leads to more growth but also to improved fruit-bearing, which in turn will favour the presence of new propagules of the species in the forest.

4.4.7. Culling

With time, abandoned coppice forests show symptoms of decay owing to the high density of the population, which implies fierce competition for food resources and water. Silvicultural treatments may be applied to such stands to reduce the level of competition. These are known generically as culling.

Culling consists in selectively felling trees in the coppice forest allowing a certain number of shoots to grow, greater or smaller according to the targets aimed for in the treated woodland (Vericat *et al.*, 2012; Arrechea, 2015). By reducing competitors, more resources become available to the remaining trees, boosting their growth and, more importantly, causing them to produce seeds, which had previously almost ceased. This type of felling diversifies the structure of the stand and favours the development of big trees.

Coppice forests resulting from clear-cuts in the past may be culled to encourage their conversion to true forests, or at least to achieve a stratum of taller trees. This structure offers advantages from the preservation of biodiversity viewpoint, and greater resilience than those resulting from coppicing, leading over time to features of proper maturity (Arrechea, 2015).

When the target is conversion to true forest, culling should consist in selecting vigorous trees, generally by means of removing feeble or overpowered saplings and leaving a density of healthy shoots of 800 to 1200 trees per ha in the first intervention. Accompanying species should be respected, and resprouting should be eliminated by periodic pruning or by allowing grazing to prevent a profusion of epicormic and rootstock shoots.

Alternatively, the treatment applied may consist in aiming for a scenario with an upper layer of trees saved from felling and a lower layer of new shoots. The density of trees in the upper layer should be around 350 to 500 per ha, depending on the quality of the site and on the development of the saved individuals' crowns. In subsequent cutting cycles (on a regular rotation) the intervention should involve both layers, respecting specimens in both, in a silvicultural approach permanently redefined on the basis of successive detailed inventories. In such cases, accompanying species should likewise be respected. This method is applicable to forests in which there is is still a demand for firewood and it is possible to limit access by livestock, as grazing is incompatible with the undergrowth layer.

One of the most important aspects of these felling activities is to control the end-state density of resprouted shoots, which must be matched to site quality. Similarly, each species' capacity to resprout from the rootstock and to issue epicormic shoots must

Photo 14. Forest stand of *Quercus pyrenaica* ten years after culling. The upper and lower layers can be distinguished. (MUP 240, Añón, Zaragoza). Author: E. Arrechea

be taken into account (the fewer the shoots left, the stronger and more abundant the resprouting, and vice-versa). The technical and economic capacity to monitor resprouting is a further variable to take into account in determining the intensity of each intervention.

As a general rule, it is recommended to intervene gently and moderately, allowing stocks to adapt gradually to the new conditions, avoiding cutting all the shoots growing from a single rootstock (Serrada, 2011).

4.4.8. Regeneration Cutting

In timber productive forests, the cutting cycle promotes forest regeneration (establishment of new individuals) by eliminating part of or all the top canopy layer. These felling operations yield the greater part of the timber produced per productive cycle.

In principle, these may be viewed as hindering stand maturity (as adult specimens are replaced with younger ones), but the cutting cycle may also imitate the natural dynamic of disturbances that gives rise to regeneration in clearings, and can be conducted in productive forests in a manner more respectful toward certain features of forest maturity.

In regeneration cutting operations in forests subject to conservation targets, the overriding recommendation for promoting greater structural and species diversity consists in adopting natural regeneration, over the longest possible regeneration period, imitating natural disturbances (Reque, 2008).

Thus, when conducting regeneration cutting in stands subject to productive targets, it is convenient to exclude from felling a number of very big trees for their importance in preserving the microhabitats that are essential to certain species of fauna and fungi, while the forest structure returns to a condition similar to its previous state.

The trees left standing should belong to the larger diametric categories and may be selected from among those left as parent trees during final regeneration felling, or alternatively among the most distorted (not from genetic causes) or damaged trees, as these usually provide more microhabitats and have poorer commercial value. No recommendations are given regarding the number of trees set aside from felling or their spatial distribution (isolated or in groups) but the general rule of thumb is 3 to 10 trees per hectare.

Natural regeneration occurring after cutting cycles is composed of a diversity of tree and shrub species. In traditional forestry thinning was used to select one particular species to the detriment of all others. Forest management subject to conservation aims needs to pay attention to the screening of individuals for regeneration cutting, as the species content of the next forest stage can be custom-designed. The same applies to subsequent stages if tolerant species are encouraged and protected.

Photo 15. Opening of a clearing in Parque Nacional de los Picos de Europa. Author: J. Ezquerra

4.4.8.1. Group selection cutting

This cutting method enables the simulation of minor natural disturbances (treefall or stem breakage) that hasten regeneration by starting a new silvogenetic cycle.

It is executed preferentially in stands in which abundant regeneration is foreseen or in which this has already begun. Tree group size will depend on species' temperament and the weight and shape of the target species' seeds and mode of dispersion, which will likewise influence the decision on whether or not to leave reserve trees within the copse. Once regeneration is under way, it may be necessary to increase the size of the copse to allow for growth of new trees. Copse size is usually defined according to the dominant height within the stand, while copse diameter may range depending on species' temperament between 1 to 4 times said dominant height.

4.4.8.2. Single tree selection cuttting

This consists in felling some of the larger trees in the stand to make room for regenerated growth. In the same operation, some medium and smaller diameter

Photo 16. Uneven-aged stand of *Pinus pinea* and *P. pinaster* treated by tree selection cutting, showing regeneration of stone pine and holm oak, in MUP 110, Valladolid. Author: J. Ezquerra.

trees are removed in order to encourage growth in the remaining trees, maintaining a pre-established proportion of trees within each diameter category.

Single tree selection cuttting is applied to achieve an uneven-aged structure (several age groups within the stand), one of the features of old-growth stands. Though considered better suited to tolerant species, this technique may also be applied to non-tolerant species such as stone pine or Aleppo pine.

Execution is complex as it involves detailed prior tree marking of the diametric categories present in the forest and may cause difficulties for the extraction of marketable timber products. Nonetheless, it makes it easier to maintain heterogeneous structures, diversity of species and age classes, and the presence of trees of different sizes and physiological conditions (including senescent specimens). Similarly, single tree selection cuttting may boost high-yield products while remaining compatible with biodiversity conservation targets.

4.4.9. Livestock Control

Herbivory is a process that is natural to forests and conditions their structure by increasing spatial heterogeneity and specific diversity. For some authors, the total eradication of herbivory leads to closed forest structures that are unlike the natural structure of old-growth forests, making it advisable in some cases to maintain or re-introduce domestic or wild herbivores (Vermeulen, 2015).

In any case, excessive herbivory (domestic or wild) is liable to compromise natural regeneration (Bernes *et al*., 2018). Many stands in the process of ageing in Spain correspond to abandoned silvopastoral uses (dehesas) in which ancient trees provide a reserve of maturity. In the absence of grazing, regeneration prospers unhindered, as these open stretches of terrain are particularly sensitive to herbivores. Even in conditions of full cover, excessive pressure from herbivory is liable to eradicate tolerant undergrowth and slow down regeneration, posing a survival hazard to trees or a change of species in favour of others that are less palatable. Herbivory control, in such situations, is vital to allow the various forest strata to develop (Reque, 2008) and scrubland may take on exceptional importance as a facilitator of regeneration, making it harder for livestock to reach the young seedlings.

Suppression of grazing in Dehesa de Peñalba (Parque Natural Sierra Norte de Guadalajara)

This oakwood covers almost 300 ha, in a dehesa-like structure resulting from centuries of use as grazing and firewood extraction by pruning, containing many specimens of *Quercus pyrenaica*, *Quercus petraea* and *Fagus sylvatica* with girths exceeding a normal diameter of one metre.

Decades of firewood abandonment has propitiated the appearance of certain features of maturity, especially with regard to senescent trees and dead wood. However, the presence of cows and rising numbers of wild ungulates (roe deer and wild boar) have effectively impeded regeneration and severely affected undergrowth species.

A grazing barrier was installed in 2016, by agreement with the landowners, in a stand occupying 11 ha for a 15-year term (open to renewal for a further similar period), consisting of a wire fence 1.5 m high and therefore ineffective against roe deer.

Follow-up showed abundant regeneration from seed of *Ilex aquifolium*, *Quercus petraea* and *Fagus sylvatica* and profuse resprouting of *Populus tremula*, browsed by roe deer. Relict species were found to have flourished in this area, including *Carex sylvatica*, *Lilium martagon* and fungi such as *Boletus regius* which had previously been unable to complete their life-cycle being trampled on and eaten by livestock.

Photo 17. Stand of pollarded beech trees in Parque Natural de Urkiola (Bizkaia). Author: J. A. Atauri

4.4.10. Tree Veteranization

Tree veteranisation aims to simulate natural processes in which, as a result of exposure to colonisation by fungi and to the air, columns of rotting wood are created along with their associated habitats (Lonsdale, 2013). This should only be practised where there is a dire need for this type of habitats and enough trees to be left 'unveteranized' (for instance, in sites containing very few veteran trees and lacking trees in advanced stages of maturity as potential short- and long-term successors). This technique is more closely associated to arboriculture than to silviculture, being more focused on the characteristics of certain trees rather than on those of the forest as a whole, which renders it unsuitable as a forest-scale approach.

Given that, in general, these techniques foreshorten trees' lifespan, the treatments chosen should be sufficiently gentle to allow trees to survive for many years. In situations with an abundance of relatively young trees, some of these may be treated intensively in order to develop the habitat types that would naturally evolve after damage caused by major meteorological disturbances (wind and snow).

Photo 18. *Quercus faginea* surviving from the forest prior to reforestation, currently overpowered by pines (Undués, Zaragoza). Author: A. Hernández

The methods of treatment used to 'veteranize' trees may include the following:

- De-branching to simulate damage caused by limbs breaking off at their base.
- V-shaped cuts in tree trunks to generate dysfunctional strips and rot in the trees' bark.
- Inflicting bruises at the base of the stem (with a mallet, for instance) to encourage basal rotting.
- Girdling high up on the trunk, to cause tree decay, death and decomposition above that point.
- Inflicting irregular fracture of branches.

In many cases, veteran trees have descended from ancient pollarded stocks, as a result of traditional harvesting practices that have been abandoned. Occasionally, singular measures are taken to preserve this type of pollarded trees on account of their value in cultural terms and to the preservation of biodiversity.

Actions to promote diversity and encourage maturity in reforestation stands in Undués de Lerda, Cinco Villas (Zaragoza)

This is a reforestation of *Pinus nigra* ssp *nigra* and *P. nigra* ssp *salzmannii* covering 350 ha, conducted in 1966 and 1968, for which forest harvesting has been designed for an extension of 184 ha. This sector was replanted in strips not exceeding 2 m, in mechanically-dug trenches for single rows of trees.

There are scattered large specimens (reaching 80 cm normal diameter) of Portuguese oak (*Quercus faginea*) on the lower altitudes, formerly dedicated to agro-pastoral uses, and an understory of oak groves on higher levels with trees of up to 40 cm normal diameter, among which are found epiphyte lichens of high ecological value (*Lobaria* sp.). Likewise, scattered specimens of field maple are found in shaded areas (*Acer campestre*) and Montpellier maple in sunnier locations (*Acer monspessulanum*).

The treatment designed in this case aims to apply measures that will retain and restore the woodland structure, as the means to enhance its features:

- **Reducing thinning intensity** so that the canopy opening does not harm the old oaks, which for 30 years have been fully dominated by the pinewood, or the lichens, vulnerable to photo-inhibition. Thinning operations have been reduced from 50% to 33% of trees.
- Criteria for tree selection in the higher zone is **freeing oaks from competitors,** especially those having reached a height similar to that of the pinewood canopy. The oaks on the lower zone of silvopastoral ancient use, subject to more competition, are to be selected for gradual canopy opening.
- **No impact on trees with a high ecological value:** felling oaks or maples with a normal diameter greater than 10 cm is banned, and the same applies to pines with a normal diameter exceeding 35 cm, still rare in the forest (an estimated 1.1% of the overall number of pines). Felling trees of this description shall be assessed as per legal conditions (50 €/tree) and charged as damages.
- **No impact on the scant dead wood currently present** in the forest. Felling dead trees, regardless of species, with a normal diameter above 20 cm will be assessed as per legal conditions (50 €/tree) and charged as damages.
- **Generation of new dead wood.** In those areas destined for felling by means of forestry processing machinery, 2.5 trees/ha will be decrowned, cutting the trunks at a height of 2 to 4 m and leaving the fallen crowns untouched. Decrowned trees should be of medium to large diameters, and form groups of at least 5 trees, with at east one such group for every 2 ha, thus favouring species that depend on poles and hollows of varying sizes and shapes within a short distance of each other.
- **Harvesting by means of aerial cables** in the steepest areas, opening roads of no more than 2 m wide separated by 40 m. In these highly inaccessible areas, hardwoods may be felled on the mentioned roads but the timber must left in the forest to increase the dead wood litter. By contrast, in less steep areas in which logging operations are conducted with a forwarder or forestry tractor, hardwoods with a normal diameter exceeding 20 cm will make it necessary to alter the logging roadway plan.

Mixed forest of *Pinus nigra* and *P. sylvestris*, showing attributes of maturity.
La Mola de Catí. Author: Bruno Durán / Parc Natural dels Ports

5 Pilot Cases

Pilot Case 1

Non-Intervention in a Reserve Stand in Parque Nacional de la Sierra de Guadarrama

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(3) Aranzada Gestión Forestal, S.L.P

Coarse dead wood standing and on the ground in the Umbria de Siete Picos. Author: J.M. Forcadell

5.1.1. Description of the Area

The area known as Umbría de Siete Picos, below the peaks of Siete Picos and Cerro Ventoso on the northern slopes of Sierra de Guadarrama, hosts a magnificent sample of old-growth Scots pine forest (*Pinus sylvestris*). Tree vegetation consists almost exclusively of Scots pine, alongside scrubs of juniper, broom, heather, bilberry, etc. The herbaceous layer comprises matgrass and psychro-xerophile grasslands, the latter notable for their Iberian endemism *Armeria caespitosa*.

Umbría de Siete Picos forms part of the Protection Quarter in the "Pinar de Valsaín" forest (no. 2, Catalogue of Forests for Public Uses [CUP] in the province of Segovia). Jointly with the "Matas de Valsaín" forest (no. 1, CUP in the province of Segovia), these forest cover 11,000 ha property of the National Parks agency, which is responsible for their management.

The first document referring to the management of these forests dates back to 1874; a Royal Charter issued in the eighteenth century and some earlier ordinances are also recorded. At present, the forest management and silvopastoral documents referring to these two forests managed by CMAV are in the process of revision.

The forests of Valsaín are guarded under several figures of protection, the most recent and most important applying to Umbría de Siete Picos being its inclusion in the Sierra de Guadarrama National Park.

5.1.2. Actions Performed

The approval in May 2019 of the management plan for the portion of this National Park belonging to the region of Castilla-Leon has enabled the creation of two RZ – Reserve Zones – on the northern extreme of the park: the RZ Umbría de Siete Picos, with 117.5 ha, and the RZ Umbría de Cerro Ventoso with 50.9 ha, separated by a a narrow strip that provides access to Collado Ventoso.

In these reserve zones there is a ban against all types of logging, firewood collection, extensive grazing (although there are no physical barriers against livestock) and access in general, unless for scientific or management purposes.

These reserve zones contain a representative stand of mature Scots pine forest comprising very big trees, openings in the canopy, copses of regenerated growth, dead wood snags and litter, microhabitats in the tree trunks and practically no signs of human intervention. There is evidence of pines several hundred years old, and 13 trees dating from the sixteenth century, one of which is known to date from the year 1554. These individuals are close to the limits of their lifespan.

The forests of Valsaín have a long tradition of forest uses, with timber extraction practices of varying intensity over several centuries. The higher, steeper and more inaccessible areas were always harvested more lightly. Umbría de Siete Picos was designated as a protection quarter in 1978, upon which logging activities ceased. The stumps of trees from which large branches were cut are till discernible in the eastern and western reaches of the area, more accessible from the passes of Fuenfría, Collado Ventoso and Navacerrada, caused by the need for firewood during the post-war years. Since then, only minor cutting has been recorded in the Umbría de Siete Picos, and the removal of trees near the Fuenfría pass as a consequence of a heavy treefall episode precisely in 1978.

Another more recent storm gave rise to large quantities of dead wood in the area, replenishing previously low levels of this material. In 1996, heavy snowfall left a depth of 150 mm on 21 January and a total of 559 mm throughout that month (the highest level registered at the Puerto de Navacerrada meteorological station since its installation in 1946). This exceptionally heavy precipitation followed by strong winds (with gusts exceeding hundred 20 km/h) caused trees to fall amounting to over 47,000 m^3 of timber in the higher reaches of the pine forest (106,000 trees greater than 20 cm normal diameter and 160,000 trees with a normal diameter between 10 and 20 cm), giving rise to a huge amount of dead wood litter within the protection quarter where it was left on the forest floor, in contrast to the rest of the forest where over subsequent years this litter was removed.

For a complete description of the stand, 21 plots of 50 x 50 m were stablished to provide a range of dasometric information. Thus, the largest diameter recorded measures 127.3 cm although the forest contains some trees larger than this. Trees with very thick girths in this area are those with normal a diameter exceeding 60 cm. The forest contains an average of 22.85 such trees per hectare. The maximum height is 27.1 m, which is tall for an area close to the species altitude limit. The mean volume per hectare of big trees is 282.24 m^3; the basal area is 43.45 m^2 per hectare of which 15.09 m^2/ ha corresponds to thick trees ($Dn \geq 60$), 23.61 m^2/ha to medium-girth trees ($60 > Dn \geq 10$cm) and 6.64 m^2/ha to small-diameter trees ($Dn < 10$ cm).

Dead wood snags account for 21.84 m^3/ha and the volume of dead wood litter 8.34 m3/ha, which represents 10.69% of the volume of living timber. Lastly, the presence of regenerated small trees is 196/ha.

5.1.3. Results Obtained

The structural characteristics of old-growth stands enable the presence of species that require habitats specifically linked to this phase of forest development. These include fungi, mosses, lichens, birds, mammals and insects, all of which may be considered indicators of forest maturity.

As for species of fauna that may be considered indicators of mature forest features, the most outstanding are strictly arboreal bats. Within the stand at Umbría de Siete Picos all strictly arboreal bat species whose distribution includes this area are present (*Nyctalus lasiopterus, Nyctalus leisleri, Nyctalus noctula, Plecotus auritus, Barbastella barbastella, Myotis beschteini* and *Myotis mystacinus*), in addition to which bats have been found to be more active in this stand than in other neighbouring stands.

Common among the birdlife is the blue nuthatch (*Sitta europaea*), a species that becomes more abundant as trees increase in age and girth. No information is available on other birds present that may be indicators of forest maturity, such as woodpeckers and other cave-dwelling species, preventing possible comparisons with other less mature stands in the forest.

Decomposing wood and the abundance of microhabitats, typical of forest maturity, goes hand-in-hand with presence of saproxylic insects (coleoptera, diptera, myriapods, springtails, etc.). Over recent years projects have been launched with the aim of gaining further knowledge of the saproxylic insects present in Umbría de Siete Picos and to draw a comparison with other nearby stands. So far, initial results from these studies have confirmed the existence of coleoptera and other insects typical of these processes.

With regard to species acting as indicators of forest maturity, much work remains to be done, beginning with drafting catalogues of the species of lichens, fungi and bryophytes found to be present, and completing the insect catalogues. As a result of the work conducted in revising the forest management plans, data is also available allowing the evolution of certain indicators of the status within the area to be monitored. The 8th revision of the forest management plan for Pinar de Valsaín provides a 3D model with the maximum detail of one of the designated 50 x 50 m plots, which will enable the evolution over time of the structure and layout of tree and shrub vegetation –standing or fallen, stems and bark, crowns, etc.– to be monitored.

All this information will serve to monitor and gain deeper knowledge of these two reserve zones established in the Management Plan, comprising one of the best examples of old-growth Scots pine forest on the Iberian Peninsula, and whose aim is to preserve a forest stand in an advanced phase of maturity left to evolve without human intervention.

Pilot Case 2

Generating Dead Wood in a Beech Forest in Parc Natural y Reserva de la Biosfera del Montseny

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(1) Independent consultant

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(3) Diputació de Barcelona

(4) Diputació de Girona

Generating coarse woody debris, in the Parc Natural del Montseny. Author: D. Guinart

5.2.1. Description of the Area

Fageda del Campament de Santa Fe is an acidophile beech forest in Parque Natural y Reserva de la Biosfera del Montseny, property of the Provincial Council of Barcelona. The dominant species is *Fagus sylvatica,* with the presence of *Ilex aquifolium*, *Abies alba*, *Corylus avellana* and *Populus tremula* as accompanying species. Undergrowth is almost non-existent (except for the presence of *Cytisus scoparius*, *Calluna vulgaris*, *Hedera helix* and *Rubus sp*. in the few open spaces) and the scant herbaceous stratum is populated by *Anemone nemorosa*, *Lamium galeobdolon* and *Viola sp*. The beech forest structure is even-aged, with a dominant height of around 25 m.

Most of the trees are no older than 100 years and, although there is no evidence of logging activity, no thinning operations for the purpose of improving the forest have been planned. Despite the absence of silvicultural intervention for the last 50 years, boosting the forest's potential to reach maturity, certain structural attributes are missing (dead wood litter is sparse and natural regeneration is poor due to the absence of clearings) along with their associated elements of biodiversity. Therefore, since 2012, the managing bodies of the Parque Natural y Reserva del Montseny (the Provincial Councils of Barcelona and Girona) have been conducting interventions to generate dead wood, diversify the structure of the forest and open up clearings in several beechwoods in the park, among which Fageda del Campament is included.

5.2.2. Actions Performed

Silvicultural actions for the generation of dead wood conducted from 2014 to 2018:

- Felling of 50 beech trees of various normal diameters (between 20 and 60 cm), at 50 cm to 100 cm from ground level, to evaluate the different colonisation by saproxylic organisms depending on the size of the stump. Trunks are left whole on the forest floor. In some cases, branches have been cut up to ensure greater contact between the trunk and the ground.
- Bark-ringing of 12 beech trees of various normal diameters (40 to 60 cm), at a height of 50 cm from the ground.

In total, 62 trees were obtained (standing or lying whole on the forest floor), subsequently monitored to study the ensuing biodiversity of saproxylic insects during 2018. In the case of Fageda de Campament, a specific methodological approach was designed to assess the effects of dead wood generation on saproxylic insects, especially on the order coleoptera (Piera and Muñoz-Batet, 2019).

The four monitoring plots set up in 2018 (each covering 1000 m^2) were located to accommodate four different situations regarding the dead wood generated:

- **Plot A:** Dead wood generated in 2014
- **Plot B:** Dead wood generated in 2018 and 2014
- **Plot C:** Dead wood generated in 2018
- **Plot D (control):** No artificially generated dead wood

Six CROSSTRAP flight interception traps were installed in each plot, at a height of 2 m above the ground, on a hexagonal plan with sides measuring 20 m. These traps remained in use from 25 May to 4 September 2018, checked fortnightly. Moreover, data were taken in each plot of the forest maturity indicators most relevant to saproxylic organisms: shrub and herbaceous cover, arboreal cover and dominant and sub-dominant tree height of the main species, data of all living and dead trees with a normal diameter greater than 7.5 cm, and a description of the coarse dead wood litter.

5.2.3. Results Obtained

Overall, 88 species of saproxylic coleoptera were identified (close to 67% of all the species collected), of which 19 were included on the IUCN Red List of saproxylic coleoptera, all classified as "least concern" (LC). Six species were added to the catalogue in Parc Natural y Reserva de la Biosfera del Montseny. Outstanding among the diversity of species identified for their conservation value were *Acalles misellus*, *Ischnomera sanguinicollis*, *Sinodendron cylindricum* and *Pediacus dermestoides*. *Rosalia alpina*, despite not having been captured in the traps, was detected and photographed on the trunk of a tree felled during one of the interventions conducted.

The saproxylic community's response to the interventions performed has been unequal, with plot B showing by far the greatest diversity and wealth of species and families of saproxylic insects in particular, and coleoptera in general, both catalogued and not catalogued by IUCN. Additionally, this plot provided the best indicators of maturity, though not significantly different to the remaining plots.

Regarding the structural parameters for the forest stand, the volume of dead wood (depending on the stage of decomposition) and the presence of clearings are the variables that best describe the characteristics of the saproxylic community. It should be highlighted that despite still being far from maturity, silvicultural operations have contributed to considerably improving the diversity of saproxylic life in the beech forest, yielding higher values than in other high-quality beech forests (Müller & Bussler, 2008), for which reason it is recommended to extend these operations to a large part of the beech forest, respecting the natural dynamic in the remainder of the forest. The mean volume of coarse dead wood in Fageda del Campament de Santa Fe, in comparison with other beech forests on the Iberian Peninsula and in Europe, shows the way forward in enhancing this attribute of forest maturity (Table 10).

Table 10. Mean volume of coarse dead wood (m^3/ha; Dn > 7.5 cm) in Fageda del Campament de Santa Fe and other beech forests in the Montseny, the Iberian Peninsula and Europe. Source: Piera & Muñoz-Batet (2019) and Sanitjas *et al.* (2017)

	Mean volume of dead wood (m^3/ha)
Fageda del Campament de Santa Fe	2,1
Hayedos de Matagalls – Parc Natural del Montseny (Sanitjas *et al.*, 2017)	4,2
European forest reserves of beech (Christensen *et al.*, 2005)	130
European beech forests under exploitation (Christensen *et al.*, 2005)	< 10
Beech forests in Sierra de Aralar (Navarre)*	34
European beech forests (Müller y Bütler, 2010)**	Beech forests in Sierra de Aralar (Navarre)

(*) Beech forests at the same phase of development as Fageda del Campament de Santa Fe.
(**) Values deemed minimal and optimal for the saproxylic communities of European beech forests.

No strict saproxylic coleoptera dependent on microhabitats associated with old trees have been captured, as in the Montseny beech trees older than 200 years are rare. In this sense, the recommendation is to deliberately encourage old trees and even to implement measures for tree veteranisation, such as the artificial generation of microhabitats. A further recommendation is to make the most of disturbances caused by gales, snowstorms or heavy rain, or periods of drought, which are increasingly common scenarios in the current context of climate change and contribute to the generation of dead wood, the opening of clearings and greater structural diversity.

Pilot Case 3

Silviculture for Maturity in Parc Natural dels Ports

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(2) Parc Natural dels Ports

Generating dead wood and snags in an experimental plot in the Parc Natural dels Ports.
Author: J. Sabaté

5.3.1. Description of the Area

La Campana is a property in the municipality of Alfara de Carles, encompassed within Parc Natural dels Ports, and in the Natura 2000 Network as Special Conservation Area (SCA) and Special Protection Area (SPA).

In the protection area known as Els Clots, a mixed forest of Scots pine (*Pinus sylvestris*) and Black pine (*Pinus nigra* subsp. *salzmannii*) grows with an uneven aged structure. Under these pines appear secondary species such as holm oak (*Quercus ilex*), holly (*Ilex aquifolium*), maple (*Acer opalus* subsp. *granatense*) and yew (*Taxus baccata*). This stand features an abundant and complex shrub layer, comprising box (*Buxus sempervirens*) as the dominant species, along with serviceberry (*Amelanchier ovalis*), juniper (*Juniperus* sp.), and a number of herbaceous plants listed in the Catalogue of Threatened Flora of Catalonia, such as *Pyrola chlorantha* and *Centaurea podospermifolia*. For the last 40 years or so, this stand has remained untouched by felling for productive purposes. This circumstance has given rise to greater diversity of forest species that prefer undisturbed environmental conditions and processes inherent to natural forest dynamics.

The La Campana estate was purchased by its present owners in 1973. During the first few years no planning was followed, despite which intensive felling operations were carried out in 1975 and 1995. The first forest management plan was approved in 1995 with the principal aim of producing timber. Twelve years elapsed without felling operations, due to low profitability of timber; the last trees were cut in the specific area in hand in the late 1980s.

In 2007, a new forest management plan was drafted to include the diversification of objectives and assigning greater weight to non-timber uses such as game and the production of truffles, as well as initiatives aiming for the conservation of the habitats of greatest interest. Thus, in 2012, a number of clearings were opened up taking advantage of former paddocks that had been invaded by trees. The overriding aim was to recover open spaces, improve pastures for game and to reduce vulnerability to forest fires.

5.3.2. Actions Performed

During 2018, in the framework of the LIFE RedBosques Project, a demonstrative management plan was drafted for the La Campana forest, proposing the application of a silvicultural model in which conservation and productive targets are compatible.

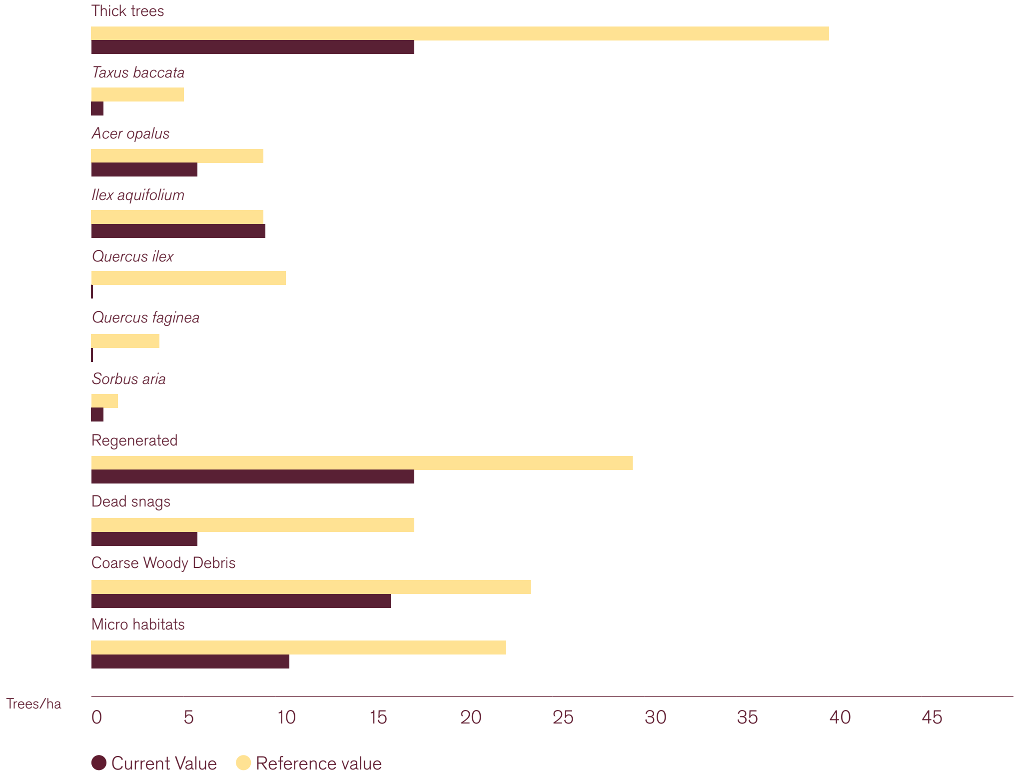

Figura 8. Indicators of forest naturalness and maturity in the stand in question (black) in comparison with the thresholds obtained in the stands of reference (orange) (percentile 90 of the values in all 14 stands) .

To assess habitat structure, a field inventory was drawn up of structural elements acting as indicators of forest maturity (thick trees, dead wood, minority species, regeneration clusters and dendro-microhabitats). The results obtained were compared to a reference structure established on the basis of analysing a total of 14 mixed forest stands of *Pinus nigra* subsp. *salzmannii* and *Pinus sylvestris* in the area of Ports that represent the highest maturity indices found in the Park (see Figure 8).

Silvicultural system was geared toward merging the preservation of biodiversity and habitats with productive forest interests. Such system proposes silvicultural measures that imitate natural dynamics leading gradually to forest structures featuring the levels of naturalness and maturity inherent to these habitats in their natural state. The objectives include the following:

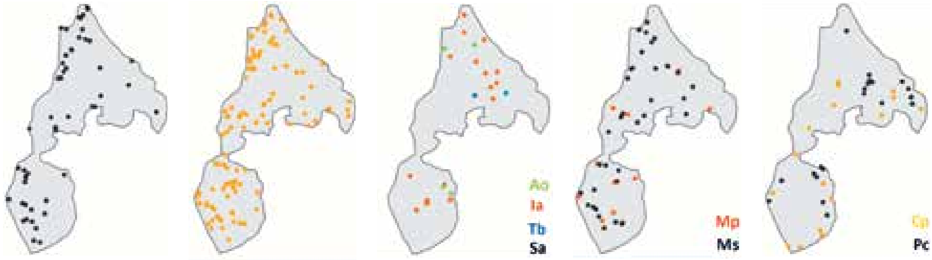

Figura 9. Identification of single trees, differentiating them according to the target.
Ia: *Illex aquifolium* / Ao: *Acer opalus* / Tb: *Taxus baccata* / Mp: Madera muerta en pie / Ms: Madera muerta en suelo / Cp: *Centaurea podospermifolia* / Pc: *Pyrola chlorantha*

Productive objectives:

- To promote maximum growth of future trees.
- To achieve large stems with a cutting cycle of around 250 years.
- To use felled trees to improve growth in future trees.

Environmental objectives:

- To guarantee that a number of very big trees reach physiological maturity.
- To promote maximum growth of such trees, as habitats for target species.
- To improve the presence and development of other arboreal species.
- To encourage the existence of coarse dead wood, both standing and on the forest floor.
- To apply preventive measures to safeguard the shrub layer, paying special attention to regeneration clusters and threatened flora.

To manage the tree layer on a tree-by-tree basis, selecting trees for the future (legacy trees). Each tree was geo-referenced individually, and a productive or biodiversity preservation target being assigned (Figure 9).

The silvicultural techniques applied sought to imitate natural processes associated to minor disturbances, achieving these by means of intermittent interventions of medium to high intensity, centred on improving the growth of future trees. In the inventory phase (and subsequent revision during the marking phase before taking action), the trees believed to benefit from silvicultural treatment on adjacent specimens were identified and listed. For each tree thus identified, any of the following treatment methods were applied:

- **Liberation thinning:** this consists in felling trees in the dominant and/or intermediate stratum that are in forceful competition with future trees.
- **Bark-ringing for reducing competence:** this entails the bark-ringing of trees that compete strongly with selected trees of interest.
- **Bark-ringing for the generation of dead wood:** some trees identified as being of interest for conservation purposes are banded.
- **No treatment:** trees that are currently free from competitors do not require treatment of any kind. These trees should be re-assessed in the event of future interventions.

5.3.3. Results Obtained

In the area under intervention, 200 trees have been identified included in the silvicultural model, of which 4 have been the object of treatment (21% of the total number of future trees). Of these, 7 were assisted for their timber value and 35 in the interest of biodiversity. The greatest effort has been focused on liberating specimens of holly from competitors. Overall, 41 trees have been felled and 42 gridled, with an intervention regime of 31 trees/ha, with normal diameters of 20 to 35 cm (Figure 10).

To monitor the actions taken, data collected in the field (15 monitoring plots and a stand in the control zone) was combined with cartography drafted post-process from aerial photographs taken by a drone.

Funding for drafting the silvicultural model and conducting the silvicultural fieldwork was provided by the LIFE RedBosques Project and the Department of Territory and Sustainability of the Generalitat de Cataluña.

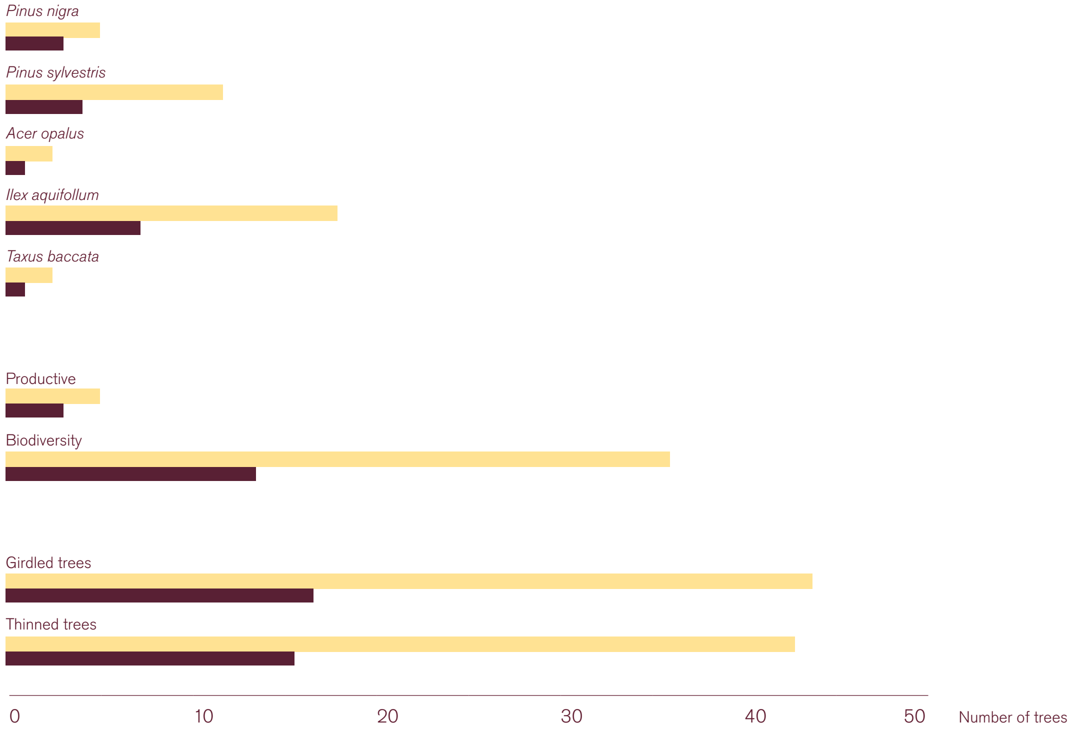

Figura 10. Quantitative results of treatments applied according to species' interest (productive or biodiversity) and the type of technique applied (thinning or bark-ringing). Data are presented in absolute terms (coloured bars) and trees per hectare (non-coloured bars).

Pilot Case 4

Promoting Structural and Specific Diversity in Planted Forests of Aleppo Pine in the Province of Zaragoza

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Stand without thinning: stagnation and death of trees due to competition, and total absence of vertical strata. Author: A. Hernández

5.4.1. Description of the Area

This is a reforestation stand of Aleppo pine (*Pinus halepensis*) in “El Cierzo” forest, owned by the municipality of Tarazona (Zaragoza). Reforestation was conducted in 1955 by manual plantation means. In January 1999, the 44-year-old pinewood was subjected to its first silvicultural treatment, consisting in thinning operations.

Prior to the actions described below, this stand was highly homogeneous, with a density of 2000 trees/ha, a basal area of around 33 m^2/ha and a volume of 125 m^3/ha. Juniper (*Juniperus thurifera*) and Kermes oak (*Quercus coccifera*) showed some slight regeneration, as well as very scant shrubby specimens of spindle (*Rhamnus alternates*) and buckthorn (*Rhamnus lycioides*). No regeneration of Aleppo pine was observed, and trees had begun to die of excessive density (recorded as 75 trees/ha), mainly affecting overpowered or submerged trees.

5.4.2. Actions Performed

To assess the impact of thinning operations on stand structure, a treatment testing area was set up at Plana de Las Gavancillas, with a total surface area of 6400 m^2 (80 x 80 m) in which four different assay plots were marked out (20 m x 20 m). Two thinning operations were conducted, one in 1999 and another in 2017, with different intensity:

- **MF treatment:** Very heavy extraction of the best specimens (almost 60% of the trees) while more than half of the overpowered or intermediate trees were left standing. Selective crown and low thinning (1/2 N) extracting 49% of trees and 57% of the basal area.
- **F treatment:** Heavy extraction, but less intensive than MF. Removal of around 50% of the best trees, leaving nearly all dominated and intermediate trees. Selective crown and low thinning (2/3 N) removing 59% of trees and 57% of the basal area.
- **N treatment:** Treatment normally applied for production purposes:
  First thinning operation: Extraction of the great majority of dominated and intermediate trees and one-third of dominant and codominant trees. Light selective thinning (1/2 N), extracting 44% of trees and 37% of the basal area.
  Second thinning operation: selective low thinning, extracting only trees of smaller diameter, removing 34% of trees and 19% of the basal area.
- **T treatment:** the control plot remained untouched.

A perimeter of 10 m was allowed around each plot, which was treated in the same manner as the plot to reduce the boundary effect. Measurements were taken in 1999, 2010 and 2016, and dendro-chronological data were taken in 2018. In Table 11 is a summary of some of the main characteristics of the forest before and after these interventions.

Table 11. Tree density and basal area in each of the four experimental plots, before and after thinning.

	Density (trees/ha)				Basal area (m²/ha)			
	MF	F	N	T	MF	F	N	T
1999 Before thinning	1.925	1.875	1.875	2.000	34,3	34,3	33,7	31,0
1999 After thinning	975	775	1.050	2.000	15,5	14,8	21,3	31,0
2016 Before thinning	625	500	1.025	1.700	18,5	20,9	37,3	39,4
2017 After thinning			675				30,1	

5.4.3. Results Obtained

The main results obtained show major differences in the forest structure resulting from thinning operations of varying intensity.

The structural diversity of the living trees is greater after treatments MF and F: in these cases, the trees have developed unevenly giving rise to trees belonging to 5 or 6 diametrical classes respectively, whereas after N treatment trees are grouped in 3 classes, as opposed to 4 classes in T (control) treatment. While the range of diameters after MF treatment exceeds 23 cm, after N treatment this range was just over 10 cm (Figure 11).

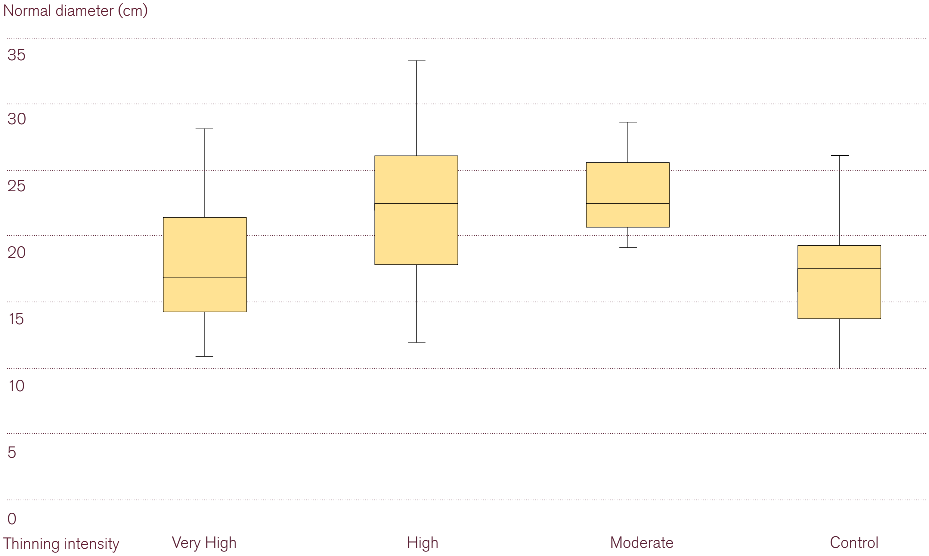

Figure 11. Normal diameter values (cm) in each of the experimental plots. The boxes show the median and percentiles 25 and 75. The extreme values are the minimum and maximum values.

The generation of dead wood (Table 12) was radically different depending on thinning intensity. Treatments MF and F caused some destabilisation of the canopy, which in the first few years suffered treefall through wind leading, in turn, to some trees becoming colonised by bark beetles, as opposed to treatment N, which caused practically no tree mortality, and treatment T, in which tree mortality occurred only from competition affecting small overpowered or submerged trees.

Table 12. Presence and diameter of standing and fallen dead wood after treatment, in each of the experimental plots.

Dead wood (m^3/ha)	**MF**	**F**	**N**	**T**
Standing	2,40	8,53	0,64	2,72
Broken trees	15,90	9,91	0,00	0,00
Fallen trees	14,68	15,50	0,00	4,56
Total	32,99	33,95	0,64	7,27
Normal diameter of the dead wood (cm)	**MF**	**F**	**N**	**T**
Medium	16,7	19,4	9,7	8,3
Maximum	24,3	29,5	9,7	15,0

While inaction in treatment T led to stagnation in the system, and treatment N concentrated the site's productive capacity in the tree canopy, treatments MF and F led to trees' under-utilisation of resources causing the appearance of intermediate layers, in this case the regeneration of tree species, providing a diversification of ages within the pine wood and the specific diversification of the canopy (Table 13).

From the logging perspective, treatments MF and F imply very heavy one-time timber extraction but restrict productive capacity, precisely by diverting the accumulation of biomass toward layers other than the main canopy, causing accumulated three growth in the stand to be much less than under treatment N which, conversely, maximises growth in the canopy.

Table 13. Indicators of reforestation and replacement of tolerant species after treatment, in each of the experimental plots.

Regeneration of Aleppo pine (trees/ha)	**MF**	**F**	**N**	**T**
Trees h < 0.5 m	Very abundant	Very abundant	Abundant	Non-existent
Trees h 0.5-1.3 m	1.375	500	-	-
Trees h > 1.3 and Dn < 2.5 cm	350	-	-	-
Trees h > 1.3 and Dn < 2.5 - 5 cm	25	-	-	-
TOTAL	1.750	500	-	-
Replacement of tolerant species (trees/ha)				
Kermes oak (*Quercus coccifera*)	275	400	Very scarce	Very scarce
Spanish juniper (*Juniperus thurifera*)	100	25	Very scarce	-
Mediterranean buckthorn (*Rhamnus alaternus*)	-	Scarce	Very scarce	Very scarce
Buckthorn (*Rhamnus lyciodes*)	-	-	Very scarce	Very scarce
TOTAL	375	425	-	-

Nevertheless, for a more comprehensive view of the ecosystems' production capacity, the volume of living trees and necromass as well as that of extracted trees must be quantified. Total volume proved to be similar under treatments F and N (the latter before the second thinning), whose only differentiating feature was the proportion of living and dead volume. Treatment MF accumulated less biomass, which explains its higher regeneration rate. Treatment T, for its part, significantly evidenced stagnation and slower growth deriving from high levels of competition (Table 14).

Heavy crown thinning cause the forest canopy to become uneven-aged, inducing mortality and regeneration, and produce a visible drop in standing timber production. Heavy thinning in which more than 50% of the basal area is extracted makes windthrow and breakages caused by snow more likely, which may be followed up by minor attacks by borer insects. All the above create spatrial heterogeneity, leaving gaps in the forest that are immediately occupied by regenerated Aleppo pine, and also propitiate the appearance and development of other species that cannot grow in deep shade.

Diversification of the initial state of the reforestation is rapidly reached, gaining in specific and structural diversity and promoting heterogeneity in tree diameter and age. The dominant trees remaining after thinning experience a surge in growth leading to the appearance of trees of considerable girth in a short period of time. After crown thinning stands have less density and stability and are more vulnerable to treefall, wich increases the volume of dead wood. From the point of view of productivity, heavy cown thinning cause decreased production in comparison to more moderate thinning regimes.

Table 14. Accumulated volume of timber and biomass (in tonnes of dry matter) after treatment operations, in each of the experimental plots.

Accumulated volume of timber with its bark (m^3/ha)	**MF**	**F**	**C**	**D**
Initial volume (1999)	130,01	130,68	127,85	115,72
Extracted in the 1st thinning operation	71,93	74,34	46,43	
Extracted in the 2nd thinning operation			27,41	
Final volume of standing timber (2016, C: 2017)	73,36	85,67	122,67	152,68
Total volume extracted	71,93	74,34	73,84	
Accumulated volume (standing + extracted)	145,29	160,01	196,51	152,68

In contrast, moderate low thinning of dominated trees, extracting around 50% of trees and 33% of the basal area, by contrast, allows the stand to remain in excellent conditions of health, with practically no mortality, and also maximises production. Such thinning promotes the homogenisation of the forest by removing the lower fraction of its metric distribution and encouraging the uniform development of the remaining trees. As no regeneration or dead wood is produced, and no significant individual increases in diameter are produced, no increase occurs in the structural and specific diversity which, to the contrary, may diminish in comparison with areas free from intervention.

Regarding the enhancement of biodiversity, more intensive crown thinning may be recommended in reforested land included in the Natura 2000 Network sites, taking action uniformly or, better still, alternating stands subjected to heavy thinning with others treated as recommended in classic productive silvicultural models.

The Blue Nuthatch (*Sitta europaea*) is characteristically associated with old-growth stands. Author: E. Martínez i Ibartz

6 Conclusions and Perspectives

European forests –and in particular those in the Mediterranean area– are at a crossroads. After centuries of highly intensive uses followed by sudden abandonment, the greater part of these forests today is made up of young or rejuvenated stands. They are highly simplified from the biodiversity point of view, and are particularly vulnerable to disturbances such as major forest fires and insect outbreaks. This vulnerability is aggravated in the climate change scenario that induces forecasts of higher temperatures and more severe droughts.

Both the failure to act and bussines-as-usual policies will lead us to a dead-end. It is therefore a priority to act to ensure that our forests, vital to the well-being of society, are in a healthy conservation status to assure their long-term survival. To this end, protected areas and the Natura 2000 Network are preferential scenarios in which to develop new forestry policies.

The participatory process set in motion thanks to the LIFE RedBosques Project, enabling over 100 conservation and forest management professionals to act together, has allowed us to identify some of the challenges and principal lines of work for the immediate future with regard to managing our woodlands:

- In the context of generalised rural abandonment and loss of profitability in harvesting forest timber products, it is necessary to give preference to the array of services that forests offer to society. Forest management should incorporate a greater variety of targets, such as the preservation of biodiversity, the recovery or ecological processes or adaptation to climate change.
  It is essential to adopt a strategic approach with long-term targets, on a broad territorial scale –greater than the estate or forest scale– as an opportunity to progress toward new management models. This involves the need to regard the forest on a landscape scale, as a heterogeneous mosaic containing all of the different phases in the silvogenetic cycle and its associated ecological processes.
- A key factor is to gain deeper knowledge of Mediterranean forest ecosystem dynamics regarding forest maturity and its relationship with the regime of disturbances (most particularly, forest fires). Current models based on boreal and Atlantic forests need to be adapted to landscapes that are regularly affected by major disturbances.

- Silviculture is a powerful tool for improving the conservation status of forests, and may be implemented in many locations with this aim. It is, therefore, necessary to promote a new mindset at all levels, from decision makers to planners and field workers, in order to bring new targets to traditional management practices. To achieve this, it is essential to improve the skills of all players, political and technical alike.

- Key to restoring our forests' ecological functions is the need to identify and characterise the last remaining old-growth stands, for their singularity and importance as reservoirs of biodiversity, and as references for silvicultural trends that promote greater heterogeneity and diversity and hence, greater resilience.

- Once identified, some locations will need to be given effective protection by means of the appropriate legal instruments. A wide range of possibilities is available for this purpose, from legal protection in certain sites to forestry planning instruments or voluntary agreements with landowners. The last remaining old-growth stands should form part of a nation-wide network, in turn integrated in international networks.

- Forest management geared toward improving conservation status should become an opportunity for obtaining financial resources. Communication with European fund managers should be enhanced in order to incorporate appropriate actions and criteria for the preservation of biodiversity to the implementation of the measured established in Rural Development Programmes.

- Forest management aiming to reach such a variety of objectives requires the participation of all stakeholders in forest management, especially public and private landowners, engaging them in the drive to improve woodlands' conservation status over and beyond their direct economic yield. In the current context of climate change and higher frequency of disturbances such fire and drought, risk management and keeping estates in a favourable conservation status, should be an incentive to forest management.

- It is vital to disseminate to the best advantage the value of forests in general and of old-growth stands in particular, and the importance of the various management options needed for their conservation (ranging from non-intervention to active management), as a means to obtaining support for their preservation. Such outreach should be addressed to society at large as well as to decision-makers and forest landowners.

The Natura 2000 Network is the cornerstone of EU biodiversity preservation policy. Forests represent 50% of the surface area under the protection of Natura 2000; therefore, raising their conservation status is a priority for the EU as a whole and for each of its member States. In this sense, the new Biodiversity Strategy for 2030 and the European Green Deal developed by the Commission are outstanding opportunities for placing forest conservation on the international agenda.

The declaration as a reserve in 1972 has allowed the natural evolution of the *Abies pinsapo* forests in the Sierra de Grazalema Natural Park. Author: J.A. Atauri

7 Glossary

Below is a concise description of the meaning given in this document of the most important terms:

Ancient forest
Forest that has existed for centuries without interruption, although not necessarily mature if it has been regularly husbanded.

Coppicing
A traditional harvesting technique in which trees are cut to 2 or 3 metres from the ground at intervals of around 20 years. This allows for the coexistence of wood and firewood harvesting with extensive grazing.

Culling
Selective felling of trees within a forest.

Cultural old stand
A stand formed mostly of old trees, resulting from husbandry practices in the past. Generally speaking, this type of old stands of anthropic origin are lacking in some or many features of maturity necessary to classify as old stand, especially a natural population dynamic. For instance, a coppice of beech oak, or a dehesa of holm oak or cork oak.

Dehesa
Open forest – mainly of *Quercus* species- managed mostly for grazing and coalwood, frequently owned and administered by local communities.

Dendro-microhabitats
A type of microhabitats characteristically associated to trees.

Diametric class
Intervals established for grouping data referring to normal diameter and its statistical study. In Spain this generally presents an amplitude of 5 cm.

Even-aged stand
Forest stand made up of trees in the same age class. Age difference among the trees is small, in the order of 10 to 20 years at the most.

Felling
Cutting down a tree to ground level.

Forest habitat
Habitat of community interest in accordance with the forest category.

Forest
Ecosystem whose physiognomy and principal structure is determined by a more or less continuous formation of trees. Composed of a mosaic of patches or 'stands' in different successional stages, some of which may be shrubby or herbaceous vegetation owing to natural disturbances. Overall, the forest scale dynamic is a 'shifting mosaic: the forest is formed of a mosaic of patches in varying degrees of maturation (or 'phases') from newly regenerated stands to young stands, fully developed stands, of senescent stands. The latter may eventually be replaced by young stands or perpetuate themselves over more or less extensive periods of time.

Mature stand
Those displaying 'features of maturity' as a consequence of having lived for an extended period and undergone minor disturbances: very large trees, gaps in the canopy, patches of tree regeneration, abundance of standing and fallen dead wood, frequent microhabitats in the trunks of large trees.

Mixed forest
As opposed to single-species or 'pure' woodlands, those in which space in the canopy is shared by several species. It has recently been proposed (Sainz Ollero *et al.* 2017) that we should consider as mixed forest those made up of several tree species in which no single species dominates more than 70% of the tile it inhabits.

Natural dynamic
A stand or wood is understood to be managed respecting its natural dynamic when the silvogenetic cycle and ecological succession occur without human intervention. This is generally found within preserved areas.

Normal diameter
Trunk diameter of a living tree measured at 1.30 m above the ground (sometimes referred to as chest-height diameter).

Old-growth forest
Woodland whose dynamic is free from human intervention, composed of stands in every phase of development or maturity, singularly with the presence of stands in their 'senescent phase'. An old-growth forest ought to be large enough to sustain all phases in the silvogenetic cycle, such that a given old-growth stand may be replaced in the future by another reaching sufficient maturity.

Overmature tree
In classic silviculture, a tree exceeding the maximum diameter maintained in the forest that must be felled to homogenize the resulting forest stand.

Planning method
Management planning system for woodland resources and functions, aiming to establish a theoretical organisational model for a given forest. The methods applied usually are oriented toward making wood harvesting compatible with the persistence of the forest.

Primeval forest
Forest unaltered by human action at any time in its history.

Regeneration method
Procedure followed and operations conducted in forests to achieve regeneration.

Secondary forest
Forest that has been altered by human action at some point in time.

Silvicultural treatment
Intervention or set of interventions on the forest, generally consisting of felling, designed and conducted for a given purpose.

Skiophilous plant
A plant that lives in the shade.

Stand of reference

In a Habitat of Community Interest, a stand with the most advanced features of maturity available in the territory. This is the best representation of forest dynamic free from human intervention, and can therefore be held as a reference for assessing the conservation status of other forest patches within the same habitat.

Stand

Sector of forest with relatively homogeneous structural, specific and ecological characteristics, clearly differentiated from the surrounding sectors. In husbanded forests, each stand may be dedicated to a preferential use and given specific treatment throughout its extension. In unmanaged forests, stands originate from disturbances affecting a medium to large extension of the forest. By convention and as a reference, stands are held to take up a minimum of one hectare, although they commonly comprise an area between 5 and 50 ha.

Temperament (of a species)

Tolerance of a plant species toward direct sunlight in the early stages of its life-cycle. According to their temperament species vary between light-tolerant (or shade-intolerant) and shade-tolerant (or simplly tolerant).

Tolerant species

Species that, for the first few years, tolerate and demand more or less heavily shaded locations.

Types of Habitat of Community Interest

Habitats that, across the European member States' territory, are under threat of disappearance in the natural areas of distribution; or whose natural areas of distribution have been reduced due to regression or to their intrinsically small extension; or that represent examples of the typical characteristics of one or several biogeographical regions. The habitat types are listed in Annex 1 to the Habitats Directive.

Uneven-aged stand

Forest stand whose canopy is made up of trees of different age types.

Veteranization

Actions taken on certain old trees to simulate or force the appearance of features pertaining to old trees, in the case of individuals of insufficient age to have developed such traits (debarking, wounds, hollows...).

Old-growth stands harbor a characteristic biodiversity of mosses, lichens and fungi.
Lobaria amplissima on *Quercus ilex* in the Sierra y Cañones de Guara Natural Park. Author: D. Martínez i Ibartz

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Photo 19. Participants in the third seminar on old-growth forests held in 2019 the Protected Landscape Pinares de Rodeno (Teruel), in the context of the LIFE RedBosques project. Author: E. Martínez i Ibartz

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