LIFE RED BOSQUES

Redes de conocimiento y capacitación para la gestión eficaz de hábitats forestales mediterráneos en la Red Natura 2000

Old-growth forests: characteristics and conservation value

DRAFT 3 - DECEMBER 2017




RECOMMENDED CITATION:

EUROPARC-España. 2017. Old-growth forests: characteristics and conservation value. Ed. Fundación Fernando González Bernaldez, Madrid.

Co- authors:

Álvaro Hernández (Gobierno de Aragón); Oscar Schwendter (Bioma Forestal SL); Enrique Arrechea (Gobierno de Aragón); Josep María Forcadell (Generalitat de Catalunya) Daniel Guinart (Diputació de Barcelona); Ángel Vela (Junta de Comunidades de Castilla-La Mancha), Jordi Vayreda (CREAF), Lluís Comas (CREAF), Jordi Camprodón (Centre Tecnològic Forestal de Catalunya), Orcar García Cardo (GEACAM), Eduard Piera (consultor), José Antonio Atauri (Oficina Técnica de EUROPARC-España)

Chapter on biodiversity has been made thanks to Jordi Camprodón (Centre Tecnologic y Forestal de Catalunya); Eduard Piera (consultant), Óscar García Cardo (GEACAM), José María Fernández García (Fundación HAZI)

LIFE REDBOSQUES.

Funding: Funded by European Union through LIFE Programme – Governance and Environmental Information, 2015.

Reference: LIFE Redcapacita_2015 (LIFE15 GIE/ES/000809)

Total budget: 590.154 Euros

Duration: September 2016 – October 2019.

Coordinator: Fundación Fernando González Bernáldez.

Partners: Generalitat de Catalunya, CREAF, Fundació Catalunya-La Pedrera.

Contact: redbosques@fungobe.org

EXECUTIVE SUMMARY

"Primary forests", that is to say, those that have evolved throughout their entire history without human intervention, are now extremely scarce. However, old-growth stands with a certain degree of maturity and a low human impact can still be found locally. In the Mediterranean basin old-growth stands are estimated to represent only 2% of the original forests.

Due to their extreme scarcity, their complexity and the biodiversity they host, old-growth forests are a key issue in conservation policies. The EU is currently moving towards a common strategy for mature forests, and progress is being made in several countries concerning its identification and protection. In Spain, the Spanish Forestry Strategy foresees the creation of an Ecological Monitoring Network for Natural Forests, and many autonomous communities are in the process of identifying their last old-growth stands.

This document provides an exhaustive review of the scientific state of the art on forest maturity and its different meanings, and synthesizes the most significant and observable characteristics of old-growth stands. These include the existence of very old trees, gaps in the canopy that allows the regeneration of shade tolerant species, significant amounts of dead wood – both standing and in the soil - , a clear vertical diversification, and the absence of anthropic interventions.

The structural properties that characterize old-growth stands - and their associated ecological functions - gradually appear over time, and are the result of the ecosystem dynamics, in a cycle that is constantly re-starting. Moreover, it is necessary to take into account the scale factor; an old-growth forest will be composed simultaneously of stands in all phases of development, from young to old-growth, resulting in a heterogeneous landscape mosaic.

Due to its special structural characteristics, old-growth stands are the habitat of a large number of highly specialized species. The scarcity of old-growth stands implies that forest biodiversity related to senescent phases has become threatened. This document reviews the importance of old-growth stands for different groups: birds, chiroptera, saproxylic coleoptera, vascular flora, lichens and fungi.

The last old-growth stands are the most natural forest habitats available, and therefore, they are a valuable element of comparison, so they can be considered as "reference stands" for each type of forest. This reference character of old-growth stands takes on special relevance under the Habitats Directive and the Natura 2000 Network. Moreover, the study of old-growth stands can also provide criteria to guide forestry towards the achievement of conservation objectives of species or habitats, especially in protected areas.

In the last section of the document, a set of criteria for evaluating both structural parameters and anthropogenic influence is proposed, and a procedure for the practical evaluation of forest maturity is advanced.

CONTENTS

OLD-GROWTH FORESTS: CHARACTERISTICS AND CONSERVATION VALUE

1. INTRODUCTION

1.1. Do old-growth forests exist?

Primary forests that have developed free from anthropogenic interference and which, at the end of the last glaciation, covered 80% of Europe are today extremely rare. The best examples are to be found on the American continent, mainly in the temperate and boreal forests of Canada and Alaska, and tropical forests in Amazonia, but also in the almost untouched boreal forests of Russia and certain areas of Scandinavia. In Europe, intense land use by humans has led to the present situation in which there is practically no area of forest that has not been altered by the hand of man, with the exception of some areas in the Urals and the Carpathian mountains (Bengtsson et al., 2000).[1]

In 2000 it was calculated that the world's intact forest landscapes took up 12.8 million km^2, 22% of the world's forest landscapes. Intact forests are defined as being those with a surface area greater than 500 km^2 and formed of a seamless mosaic of forest and naturally treeless ecosystems which exhibit no signs of human activity or habitat fragmentation and are large enough to maintain all native biological diversity, including viable populations of wide-ranging species (Potapov et al., 2016). In the same study, it was calculated that the area of intact forest landscapes decreased by 7.2% between 2000 and 2013.

The absence of primary forests does not preclude the local presence of highly untouched forests or stands, consisting in mature wooded areas or stands with a very slight human footprint, at least with regard to logging or other extraction processes. An estimated 15-20 million ha of forest with minor anthropic intervention levels still survive, mainly on the Russian taiga (Halkka and Lappalaien, 2001), which represents just 5% of Europe's total forest cover. This proportion is even smaller in the Mediterranean basin, where it is estimated that a mere 2% of the original vegetation remains relatively untouched; unaltered forests account for 1.6 ha concentrated mainly in Turkey and Bulgaria (FAO, 2013). Furthermore, in more developed countries this ratio is smaller: in France only 0.2% of the forest cover is untouched forest, in very remote locations (Barthod & Trouvilliez, 2002).

[1] http://www.intactforests.org/ data.ifl.html

In Europe, forestry management and land uses have given rise to the predominance of young forests with a long history of intervention, known as secondary forests. Such forests have been subjected to human intervention, intensively -through felling and planting, for instance- or through continued harvesting of resources, and even through interventions seeking to establish natural regeneration. The likelihood that these forests might achieve the characteristics of a primary forest after an extended period of time free from intervention, or the possibility of conducting active management techniques to re-establish certain features of old-growth stands more quickly than through natural evolution, are currently under debate (D'Amato & Catanzaro, 2007; Paillet et al., 2015).

For these reasons, in recent years 'old' or 'mature' forests[2] have attracted considerable attention and generated intense researching activity, although the level of knowledge varies substantially from one biogeographical region to another (Burrascano et al., 2013). Most research has been focused on temperate and boreal ecosystems, and in the majority of cases these were subject to frequent, low-level disturbances, and in particular, free of damage by forest fires. Only rarely have studies been conducted on old-growth forests in which the disturbances include fire in a prominent role, and these are focused on conifer ecosystems on the American continent (Cortés et al., 2012). All these cases highlight the fact that fire is a key component in forest dynamics (Binkley et al., 2007; Fiedler et al., 2007).

In the Mediterranean basin, at present, there is insufficient scientific knowledge on old-growth forests in Mediterranean ecosystems, in which fire plays a major renovating role both in coniferous forests and in fagaceae and broad-leaved forests (Mansourian et al., 2013).

Studies on Mediterranean environments focused on France and Italy refer, in general, to mesic ecosystems such as beech or pine forests. In Spain, the few studies conducted in this field are also centred on Atlantic or Pyrenean areas (Antor & García, 1994; Bosch et al., 1992; Gil, 1989; Rozas, 2001, 2004, 2005; Rozas & Hernández, 2000).

Consequently, there is clear need for further research to establish common ground on which to define 'naturalness' in forest bodies (Lorber &

[2] The scientific literature has proposed many terms such as old-growth, virgin, natural, pristine, etc. forest. The expression 'old-growth forest' is the most widely used, especially in North America (Wirth et al., 2009), although in the United Kingdom the terms 'ancient forest' or 'ancient woodland' are also used. The FAO (2012) recognises as many as 99 different terms under 'old-growth'. In Italian, this term is translated as '*foresta vetusta*', in French as '*fôrets anciennes*' and in German as '*Urwald*'. Some confusion still remains in Spain, where both 'bosques maduros' and 'bosques viejos' are used. In this document, a clarification of Spanish terminology is proposed (see Glossary).

Vallauri, 2007) and 'maturity' in varying environmental conditions, as well as to consider the need for the characterisation of old-growth forests in Mediterranean climates (Chirici & Nocentini, 2010).

1.2. Old-growth forests in conservation policies

Interest in the conservation of old-growth forests sprang up in North America in the 1970s and 1980s, in reaction to the loss of primary forest bodies and to harvesting models that endangered biodiversity, most especially species highly dependent on old stands. These studies took place almost in parallel with the development of theories on the dynamics of woodland stands, and called for setting in motion an inter-agency committee (participated by the USDI Bureau of Land Management, Oregon State University, and National Forest and Research Branches of USDA Forest Service). This produced a working group for the establishment of the first definitions (Old-Growth Definition Task Group) that began in 1985, building on the work done in the previous decade, and by 1986 had established the draft definitions for some old-growth forests on the west coast of the USA (Old-Growth Definition Task Group, 1986). A review of the history of the origin of this concept is found in Franklin & Spies, 1991.

Since then, intense research has been conducted on this issue in North America, leading in June 2014 to the submission of a request to President Obama to enact a National Policy for the Conservation of Old-growth Forests signed by more than 75 scientists and forest managers in the USA and Canada. These scientists included renowned figures such as Edward O. Wilson or Gene E. Likens, and forest managers including heads of the USDA Forest Service.

This concept spread rapidly to Europe, and even in Spain studies on old-growth forests were launched (i.e. Bosch et al., 1992; Antor & García, 1994). Research on old-growth forests was initially led by France and central European and Scandinavian countries, which have now been actively joined by Italy. Generally speaking, old-growth forests are considered in Europe as secondary forests, in which intervention has ceased or low-impact management systems are maintained. These forests are valuable assets, not only for the biodiversity they support, but also as a reference both for conservation initiatives and for productive forest management.

A further aspect in which Europe has made progress is in building these concepts into its conservation policies. Thus, in 1995, the European Commission approved COST Action E4: Forest Reserves Research Network, with the aim of promoting coordination and enhancing research on natural and semi-natural forests in Europe. The objectives were to create a European network of forest reserves, to compile current research activity, to unite and standardise researching methods and to enable universal access to a central database on forest reserves (Parviainen et al., 1999).

In 2003 over 180 scientists from 18 countries signed the document "Scientists' call for the protection of forests in Europe", which included the demand for a specific policy to be issued by European governments and the EU assuring rigorous protection for extensive old-growth forests. This document requested the constitution of a coherent sub-network of strict forest reserves (Category I under the UICN) or central areas within National Parks (Category II), which was diagnosed as one of the weaknesses in many regions across Europe.

Though the inclusion of old-growth forests in conservation policies has been unequal, some countries have indeed taken old-growth forests into account in their biodiversity preservation policies, as in the case of Italy (Blasi et al., 2010). At present, the EU is working on concepts such as HNV (high conservation value) forests (EEA, 2014), which in the future are expected to shape EU policies.

In a recent document, the concept of old-growth forest is examined from the European viewpoint, and a systematic summary is given of the data available on old-growth forests in the 33 member countries of the European Environment Agency (García Feced et al., 2015), leading to the following conclusions:

- It is difficult to establish a common terminology owing to the many definitions given to a term and to the sundry criteria and indicators. Moreover, myriad related terms are used freely with little thought for their actual meaning. In Europe, this problem is multiplied by the number of languages spoken on the continent.
- A review of the data available reveals that the body of information is unevenly distributed throughout Europe. In some countries, the identification, inventory and protection of old-growth forests is at an advanced stage:
    - Scandinavian countries include the search for old-growth forests in their national forest inventories.
    - Specific mapping has been conducted in countries such as Bulgaria, Romania and Hungary.
    - Old-growth forests have been integrated in the biodiversity conservation policies of countries such as Austria, Germany and France where programmes have been launched to create integral reserve networks; or Italy, where a network of old-growth forests has been created within the Italian Network of National Parks.
- There is an overall shortage of appropriate specific information and insufficient access to critical forest data. Mapping is essential, and historical research is necessary; the same can be said of fieldwork to identify the characteristics of maturity.
- The availability of systematised information on ancient forests across Europe could provide fundamental knowledge for conservation programmes, as well as for establishing European indicators for the naturalness or intensity of forestry management.

Within the biodiversity conservation policies of certain Mediterranean countries such as France (Gilg, 2005) or Italy (Blasi et al., 2010), initiatives have been launched to locate and protect old-growth forests, or forests with the potential to reach this status; or, if these are not found, older woodland stands.

The Spanish Forestry Strategy[3] envisages the creation of a Network for the Ecological Monitoring of Natural Forests, which should include not only forest bodies that are 'representative of old-growth forest but also ancient forests. These two categories relate to the duration or continuity of existing old-growth forests, and to primary, natural, semi-natural and secondary forests, according to the categories assigned to their origin'. With this aim, the mentioned Strategy has commissioned a joint committee set up by the State and the Autonomous Regions to draft a national inventory of natural forests, to issue planning and management recommendations, for the incorporation of landowners to active management of forests and woodlands in the Network, and to engage in research on the Forest Reserves. These items in the Strategy have not been developed, although some Autonomous Regions pursue similar initiatives.

We may highlight the creation of Integral Reserves within old-growth forests (Muniellos, in Asturias; Aztaparreta and Lizardoia, in Navarra), or the inclusion on the UNESCO World Heritage List of the "Primeval beech forests of the Carpathians and other regions in Europe[4]", which comprise the beech forests of Tejera Negra (Castilla La Mancha) and Montejo (Madrid), Lizardoia and Aztaparreta (Navarra) and Cuesta Fría and Canal de Asotín in Picos de Europa (Castilla y León).

The greatest progress in studying, locating and protecting old-growth stands and forests has been made in Cataluña, where it is believed that primary forest is non-existent and relatively mature forests account for just 2% of the total surface area (Mallarach et al., 2013).

Despite having compiled an inventory of old-growth forests in the Garrotxa district (ANEGX,,2008), the Alt Pirineu Natural Park (Palau & Garriga, 2013), and the Montseny Natural Park (Sanitjas, 2013); having set in motion the SELVANS programme promoted by the Provincial Government of Gerona giving rise to 58 forest reserves (Hidalgo & Vila, 2013); or having drafted an inventory of singular forests throughout the autonomous region (CREAF, 2011), the survival of these small reservoirs of biodiversity are threatened by forest harvesting pressures (Montserrat, 2013). This

[3] Spanish Forestry Strategy (undated). Ministry of the Environment. Secretariat-General for the Environment. Directorate-General for Nature Conservation. http://www.mapama.gob.es/

[4] This is an international candidacy, in which Spain participates along with another nine countries: Albania, Austria, Belgium, Bulgaria, Croatia, Italy, Romania, Slovenia and Ukraine.

underscores one of the main conservation problems in these habitats. The Generalitat de Catalunya proposed the creation in 2015 of a "Network of Natural Evolution Forests", a pioneering initiative in Spain, along with the identification of stands of reference in Aragon by means of designing and implementing a method for the identification and characterisation of mature and old-growth forest stands that is applicable to habitats of Community interest.

Senescent fir forest in the Aragonese Pyrenees. Photo: Álvaro Hernández

2. THE CONCEPT OF OLD-GROWTH FOREST

The study of old-growth forests starts from the premise that forest ecosystems permanently undergo changes and that they persist over very long periods of time owing to the great longevity of the key species they contain, namely, trees. Over such periods of time, these ecosystems develop from their establishment to a state of maturity while simultaneously undergoing changes in their composition, structure and functions (Franklin & Spies, 1991).

In contrast with primary forests, old-growth forests may be secondary forests in which human intervention has ceased, allowing them to acquire mature properties that are similar to those of primary forests (MCPFE, 2007).

Several definitions have been given for old-growth forests, from a number of approaches: structural and with regard to their specific composition (Rotherham, 2011), historical -stressing the importance of the continuity of forest cover through an extended period- (Vallauri et al., 2012), based on the theory of ecological succession, and even on ecological processes. On many occasions a combination of these criteria is employed (f & Reich, 2003; Hilbert / Wiensczyk, 2007; Wirth et al., 2009).

Most of the definitions currently in use can be classed into three groups (Spies & Franklin, 1988; Hunter, 1989; Wells et al., 1998; Messier & Kneeshaw, 1999; Kimmins, 2003): the first lays emphasis on structural and compositional features; the second underscores the successional processes that lead to the mature stage and that are currently maintained; and the third group assumes criteria relating to biogeochemical processes (Wirth et al., 2009).

Below is a summary of the main features in each group:

Structural definitions

These are based on a description of distribution by age and size, and on spatial distribution patterns of living and dead trees (Wells et al., 1998). Among these indicators, data on age structure are the most valuable as these are directly related to the birth and death rates that shape the demographic structure.

This is the most commonly adopted approach, stemming from the idea that structural features are the result of functional aspects that are characteristic of old-growth forests (Spies & Franklin, 1988; Franklin & Spies, 1991; Marcot et al., 1991; Holt & Steeger, 1998; Kneeshaw & Burton, 1998; Wells et al., 1998; Braumandl & Holy, 2000), such as: big trees, old trees, many-layered canopy, abundance of large tree-stumps, diverse tree community, some very old trees, openings in the canopy, micro-topography of small elevations caused by fallen trees, complex structure, wide spaces between trees and more abundant undergrowth.

One of the main shortcomings to this approach is that the structural indicators have only been developed for the characterisation of old-growth forests' appearance in a limited set of forest types (Spies, 2004). The distribution of tree-girths is usually used to gather an approximate distribution of ages. However, data series for age and size are in many cases poorly correlated (Schulze et al., 2005).

Structural characterisation of dead wood in terms of size, abundance and state of decay is not a useful indicator to gauge conditions of maturity unless it is backed up with additional information on the structural permanence and history of the forest in question.

Additionally, it should be remembered that rates of decomposition will vary according to the biogeographical region. High rates will be found in humid, warm climates, which is why dead wood reserves in tropical forests are generally low (Wirth et al., 2009). In Mediterranean environments, wood decomposition rates may be up to five times faster that in boreal climates, owing to the higher mean temperature (Lombardi et al., 2010, 2013).

Moreover, different authors have found that structural characteristics cannot be taken as the sole criterion in identifying old-growth forests (Barnes, 1989) given that the degree of maturity and its appearance is affected by local productivity (Carleton & Gordon, 1992; Day & Carter, 1990) and the species involved. The most frequent criticism of definitions based on structure is that they fail to recognise the forest ecosystem's natural dynamic. The structure of old-growth forests is thought to vary as a result of many factors (Boyce, 1995) making this definition unsuitable for application to all forest types (c 2003).

Definitions based on succession

These are based on the theory of ecological succession, taking into account both the successional paths that have led to the old-growth forest and the processes that maintain it. According to Oliver and Larson (1996), *true old-growth 'describes stands composed entirely of trees which have developed in the absence of allogenic processes'*. By 'allogenic processes', large-scale disturbances are referred to, such as fire or major tree falls, which may potentially lead to secondary succession but exclude continuous external forces such as alterations in climate.

Other successional criteria interpret older stands as a phase that corresponds to the disappearance of the first cohort of individuals, replaced by species that are characteristic of more advanced stages of succession and that arrived later (Wirth et al., 2009), or as a stage composed of shade-tolerant species -a result of the successional process- that regenerate in small clearings (Climax old-growth: Frelich, 2002).

Further successional definitions highlight the processes sustaining old-growth forests, such as the dominant type of disturbance or an elevated tolerance to shade conditions among the dominant species (Mosseler et al., 2003).

Nevertheless, this type of definition disregards structural aspects, and a knowledge of the forest’s composition, establishment and history is essential before such definitions can be applied.

Biogeochemical definitions

These use criteria that indicate the maturity of the system for quantifying the ecological processes: full cycles of nutrients, reduced net primary protection of trees, net accumulation of zero biomass, and increased undergrowth diversity. However, although these quantifications are representative of maturity conditions, gathering most of these data involves exhaustive fieldwork and costly instrumentation, which greatly hinders their implementation beyond experimental spheres (Sala et al., 2000).

There is, however, no unique set of parameters with which to characterise old-growth forests, a situation that in view of the vast diversity of forest ecosystems is neither possible nor desirable (Mosseler, 2003; Spies, 2004; Wirth et al., 2009; Burrascano et al., 2013). Nevertheless, there is some consensus over an array of structural descriptors for maturity, which are in all likelihood the most significant and observable characteristics in all old-growth forests (Fiedler et al., 2007; Keeton et al. 2010). Among these we can highlight the following:

- A degree of ageing, with the existence of specimens of species pertaining to advanced successional stages with ages close to the limits of their longevity, and a mean age for the whole stand at the mid-point of said longevity. This old age can generally be distinguished by the existence of numerous trees of great dimensions.
- A composition and structure given by natural regeneration dynamics triggered by mild disturbances: irregular forest mass structure, openings in the canopy, regeneration of shade-tolerant species, variety of species. The specific composition of the undergrowth is dominated by nemoral species associated to the permanence of the forest canopy in a stand over time, and is mostly free from meadow, field and ruderal flora.
- An important presence of dead wood, standing and fallen, in several stages of decomposition.
- Vertical diversification: appearance of several clearly-differentiated strata, or a purely irregular structure leading to the presence of trees of all heights.
- Absence of anthropogenic interference, or cessation of such interference many decades ago. Old-growth forests should be subject only to autogenic disturbances.

In ecosystems where fire plays a leading role, these characteristics may be altered to some degree, as it is common for old trees to be found in old-growth forests, but not always trees of very large size: low density of trees, the latter distributed in groups; modest quantities of dead woody matter, standing or fallen; canopies with some openings; much diversity and biomass in the undergrowth and low levels of tree regeneration; and slow nutrient cycles (Egan, 2007; Fiedler et al., 2007).

Old-growth stand of *Pinus halepensis* in the province of Zaragoza. Photo: Enrique Arrechea

3. OLD-GROWTH FORESTS AND FOREST DYNAMICS

3.1. The silvogenetic cycle

The structural and ecological properties that are characteristic of old-growth forests appear gradually over time, as a consequence of the ecosystem's own dynamic in a continuous cycle of constant renewal.

The phases of development are the successive structural stages experienced by each generation of dominant vegetation in the absence of interference of any importance, from their origin after a full renovation of the forest floor to the demise of all the individuals comprised in the initial generation. Additionally, the development phases correspond to differences in the main ecological processes that take place in forest ecosystems.

The cycle begins when, following some disturbance and the ensuing clearing of space for vegetation, the **occupation** of this space occurs with a new generation of plants. The manner in which such occupation takes place is heavily influenced by the type of disturbance, the surviving biological legacy, the features of the terrain (soil type, slope, etc.) and the surrounding conditions.

During the occupation phase, every species present in the ecosystem will play a role, whether from seed banks, surviving individuals or propagules imported from undisturbed adjacent areas.

Following occupation, the newly-installed species will deploy their strategies to compete and survive. Trees, in particular, taking advantage of their taller stature and greater longevity in comparison with herbaceous plants and shrubs, will gain in height and biomass to form a closed canopy above the ground. This is known as the **height growth and tree canopy closure phase**. During this phase, biomass accumulation continues, becoming visibly dominant in the tree stratum.

As soon as the overhead tree canopy is complete, the **exclusion phase** commences: competition among species becomes stronger, especially in the tree stratum, but also in other strata that are deprived of light causing the elimination of plants that cannot tolerate shade. Meanwhile, fierce inter- and intra-species competition is established among trees, leading to the death of individuals through self-clearing (this phase is also known as "exclusion of failed trees".

At this point the extended **transition phase** (Bormann & Likens, 1979; Oliver & Larson, 1996) or **maturation phase** (Franklin et al., 2002; Spies & Franklin, 1996) begins, during which horizontal and vertical structural diversification of the forest stand takes place, giving rise to the diversification of available ecological niches (Carey & Curtis, 1996).

Full maturity among the trees forming the upper canopy, and the installation of intermediate levels, trigger a renewal dynamic that is determined by the longevity of the species present and the rate of disturbance. Where the level of interference is mild, the trees forming the canopy are gradually replaced, as individual trees die, by trees from the intermediate levels that are generally more resistant to shade conditions than those initially forming the canopy. The forest openings left by dead trees, due to competition or the growth in height of trees, provide the conditions for shade-tolerant plants to become established, giving rise to intermediate levels or potential regeneration drives. This phase in the cycle corresponds with 'old-growth stands' and may last for an extended period owing to the great longevity of forest species.

With the passage of time adult trees attain their full height, after which some begin to fail, either through having fulfilled their maximum life expectancy or due to disturbances. The openings thus created are occupied by trees from the lower levels or, in the event of major disturbances, the cycle will start all over again.

The development of intermediate layers, the growth of trees to replace adult trees in the openings left in the canopy, the growth of herbaceous plants and shrubs in the larger gaps, etc., ensure the structural diversity of the stand and, in particular, the occupation of the full vertical profile.

Moreover, the growth of the portion of trees surviving the initial generation allows them to reach a great size, accumulating the greatest percentage of biomass present in the entire ecosystem, while the death of another portion of the same generation accumulates a voluminous store of dead wood both fallen and standing.

Thanks to the great size and age reached by these trees, they suffer breakages, hollows, and alterations to the bark, etc. which, further to structural diversification, ensures a rich provision of ecological niches that are occupied by specialised taxons.

All the above leads, at this point, to the **senescence** or **'old-growth' phase**. Diverse vegetation, trees of great size (usually well spaced) intermingled with younger trees of all ages whose crowns occupy the entire vertical profile, and a large amount of dead biomass both standing -whole trees or severed trunks- and fallen (Oliver & Larson, 1996), as a consequence of the death of older trees.

This phase may extend over a long time by means of a renewal process in small openings, and the subsequent ageing of the replacement trees, or collapse altogether due to a major disturbance and re-start the cycle.

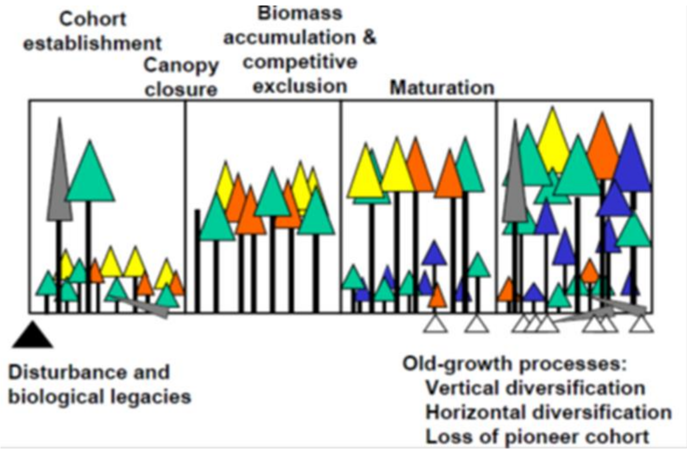

Figure 1. Principal structural properties in each of the phases in the silvogenetic cycle.

3.2. Forest or stand. The importance of scale

The concept of 'old-growth forest' cannot be fully defined without taking into account considerations on the scale of landscape. One of the latest definitions, and the closest to the reality of our ecological situation, has been coined in Italy, and defines old-growth forests thus: forests in which anthropic disturbances are absent and in which the natural dynamic creates a mosaic of stands in all stages of development, including senescence (Blasi et al., 2010).

This definition highlights the difference between *forests*, as ecosystems requiring a large surface area to ensure that all the characteristic ecological processes will occur and that they can support space-seeking elements of forest biodiversity, and the *stands* they are composed of, some of which may be in their final dynamic stages typically containing large, old trees, standing and fallen dead wood, and a composition of vascular plants according to the biogeographical context that includes highly specialised plants related to regeneration in forest clearings and micro-habitats resulting from a high level of structural heterogeneity.

To this landscape perspective must be added the role of disturbances, particularly the dominant type of disturbance (Spies et al., 1996): those that eliminate the intermediate layers induce regeneration dynamics that differ greatly from those that do not affect the stand's bottom layers. This leads to the question: what is the maximum degree of maturity that can be reached by Mediterranean ecosystems subjected to intense drought, the effects of grazing, and on many occasions characterised by forest fires as the principal renovating agent.

The silvogenetic cycle is likely to be longer in the event of major disturbances since, following the settlement of communities of pioneer species and the ensuing exclusion phase, tolerant species return and develop, leading to their regeneration and the demise of the pioneering species that initially filled the gap. The final step is the maturation of the communities of dominantly tolerant species.

To sum up, old-growth forests, as a result of disturbances, are simultaneously composed of stands or copses at every stage of development, all of which together make up a heterogeneous structure in the manner of a mosaic (Schwendtner & Cárcamo, 2010).

3.3. Forest management and the silvogenetic cycle

The commonest forest management practices, mainly directed at timber harvesting, are based on the exploitation of forests at the peak of their productivity, through constant renewal of the system and preventing the forest from reaching senescence. In this manner, forest management leads to a major transformation of the forest's structural characteristics. This basically consists of the continuous renewal of the forest mass by means of different logging practices, forestalling disturbances such as falling trees, fire or plagues that, in a natural state, would provoke a cycle of different-sized openings in the forest canopy enabling an endless rejuvenation process (Figure 2).

In forest terminology, the occupation phase is equivalent to the dissemination and thicket stage, and the 'height growth' and 'canopy closure' phases correspond to the 'thicket stage'. The exclusion phase comprises the 'pole stand' and 'young stemwood' stages, while the 'tall stemwood' stage signals the beginning of the maturation phase mentioned above. It is usually at this point that tree-felling for regeneration purposes is conducted, thus relaunching the cycle. This eliminates the maturity and senescence phases from husbanded forests and woodlands (and from forest terminology). This gap between cycles occurs as trees reach their maximum growth very early with respect to their longevity. This allows for logging campaigns at intervals that vary from 70 to 140 years for species whose natural longevity exceeding 500 years.

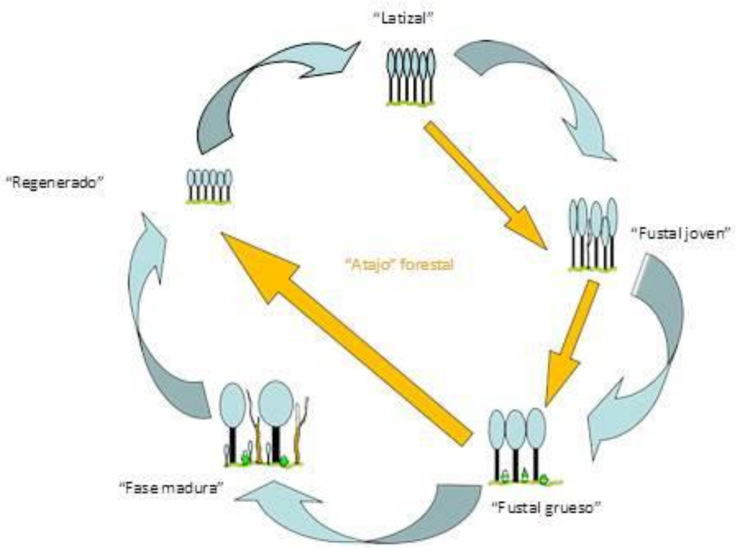

Figure 2. Diagram of the phases in the development over time of a stand, and the acceleration -or exclusion of certain phases- through forestry management. Systematic exclusion of the senescent phase, which is precisely the most transcendent for the conservation of threatened species. Schwendtner, 2014.

Regular forestry management, therefore, simplifies the structural and biological complexity of forests and woodland. Achieving a sustained yield rate does not, however, always mean that the forest ecosystem is sustainable (Muñoz & Schwendtner, 2005) and may be the cause of biodiversity loss (Gilg, 2005). In addition, this simplification is likely to impact forest structure and composition over an extended period of time.

A comparison of the specific wealth or alpha biodiversity in temperate and boreal European forests, harvested or non-harvested, yields the following results (Paillet et al., 2010):

- The overall wealth of species is slightly greater in non-harvested than in harvested forests, especially in the case of saproxylic coleoptera, fungi, lichens and bryophytes.

- The wealth of species dependent on the temporal continuity of the forest canopy and the presence of dead wood and big trees (bryophytes, lichens, fungi, saproxylic coleoptera and carabids) is negatively affected by forest exploitation.
- By contrast, vascular plant species benefit from harvesting practices, which explains their greater abundance in forests under exploitation.
- Whether there are differences regarding the wealth of birdlife is unclear, and is also dependent on factors such as habitat types in the vicinity and the landscape mosaic structure, as well as the structure of the stand itself.
- Overall differences in the wealth of species between harvested and non-harvested forests and woodlands increase with the length of time elapsed after they are abandoned, signalling a gradual recovery in biodiversity. This gain in species diversity is of particular significance in fungi and saproxylic insects, but may be considerably slower in the case of lichens and bryophytes.
- In exploited forests, a smaller abundance of species is seen in forests subjected to clear-cutting, especially when the subsequently regenerated forest mass, whether naturally or through replantation, is made up of different species to those that belong to the natural habitat in that location. However, forests subjected to felling for thinning purposes do not register significant losses in their wealth of species in comparison with non-harvested forests.

It must nevertheless be pointed out that these observations by Paillet and collaborators refer to wealth as the specific number of species without taking into account their ecological value. Absolute value in biodiversity has more to do with the scarcity and specificity of species rather than their numbers.

3.4. Management of old-growth stands

Forest management in protected areas may incorporate specific management measures focusing on forest maturity. A first measure is to set in motion actions to identify this type of stands, which are at present but little known. As appropriate, other conservation measures are also taken to guarantee the stands’ long-term survival (e.g., their declaration as candidates for inclusion in protection schemes).

From the forest manager’s or landowner’s perspective, or the managers of protected spaces, it is advisable to define the conditions under which different management options should be applied as, in principle, this will depend on the degree of maturity of the forest stands. Table 1 summarizes the preferred type of management for each type of stand.

In older stands, non-intervention is the preferred management option. These are stands that have not been managed for a long time, and should be left to the action of nature’s ecological processes. Having identified such stands, it may be necessary to assess whether any specific measures are needed to assure their long-term conservation. These sites may require some restrictions to public uses. Likewise, they are scenarios of preference for research and monitoring schemes. At all events, it should be borne in mind that non-intervention, properly planned and in accordance with fixed targets, is also a management measure (EUROPARC-España, 2011).

In old-growth stands, or those in the process of maturing, in addition to prospection, identification and conservation measures, it may be advisable to implement certain proactive intervention measures aiming to reach or enhance certain features of maturity that may be missing in the stand (for instance, increasing the amount of decaying woody matter, the proportion of clearings or vertical heterogeneity) by means of forestry techniques. It is important that such techniques should target explicit and grounded results (for instance, increasing the populations of a threatened saproxylic species).

In singular stands, measures such those mentioned above may sometimes be desirable to promote certain aspects of ageing. In these stands, however, other criteria involving their cultural value (pollarded trees, for example) should also be taken into consideration.

In all other young or rejuvenated forest and woodland bodies, and in productive forests, the chosen management type should be oriented toward building their resilience against disturbances and toward strengthening their adaptability to climate change, by increasing their heterogeneity and diversity.

The identification of the characteristics and processes pertaining to the mature stages of a forest (i.e., big trees, dead wood, complex undergrowth layers), and their relation to values that are of interest to managers (biodiversity, resilience against disturbances, carbon storage, etc.) is of enormous interest for its silvicultural applications.

Old-growth forests provide references for silvicultural practices that imitate natural processes, and that add value to forest management by bringing new and profitable uses much appreciated by society.

Table 1. Possible management measures depending on the degree of maturity of the stand

Type of stand	**CHARACTERISTICS**	**MANAGEMENT MEASURES**
III - PRIMARY	Stands that have developed free from anthropogenic interference, and which covered 80% of Europe at the end of the last Ice Age, are today extremely rare and absent from the Mediterranean region.	– Monitoring and research – Characterisation of determinant ecological processes – Preservation – In the Mediterranean region, search for historical references

IIb – OLD-GROWTH	Stands that are fully mature and have reached their senescent stage. Large, very old trees, at the limit of their longevity, together with dead trees, in addition to the previous maturity features.	– Priority search and characterisation – Creation of a Network of Stands of Reference – Conservation and declaration under specific protection measures – Recommended management: preservation, research and monitoring. No intervention
IIa – MATURE	Highly untouched stands, consisting in relatively mature wooded areas or stands with a very slight human footprint, at least with regard to logging or other extraction processes.	– Priority search and characterisation – Creation of a Network of Stands of Reference – Conservation – Recommended management: preservation, research and monitoring + spot measures regarding certain maturity attributes
I – SINGULAR	Stands with some attributes of maturity that are the result of erstwhile interventions, especially those that take longest to achieve. Examples of this case are abandoned *dehesas*, 'Cathedral forests', biogeographical relicts, stands that provide refuge to a wide range of biodiversity	– To implement knowledge and experience gained from the monitoring and characterisation network on level II (and III) of the Network of Stands of Reference – Priority search and characterisation – Recommended management: actions aiming to fulfil the envisaged maturity paying special attention to ecological processes that are lacking or over-represented for artificial reasons: exclusion of land for grazing, ringing, coppicing, etc. – These actions, in the middle term, could lead to level II
0 – NATURAL, ARTIFICIAL, NATURALISED	Other natural tree masses, young or rejuvenated through management or disturbances, and naturalised artificial tree masses (with autochthonous species).	– To implement knowledge and experience gained from actions on levels I and II. Silviculture close to nature/enhancement of maturity features – To establish as one of the conservation targets in protected areas, through regulations and forest/conservation planning instruments, the creation at each site of a reserve stand (example 35 in Navarra) with the clear aim of preserving biodiversity and left to evolve freely – In the long term, these reserve areas could reach level I or even II

4. BIODIVERSITY ASSOCIATED WITH OLD-GROWTH FORESTS

The special structural characteristics of old-growth forests provide habitats to a large number of highly specialised species, which do not settle in the younger phases of forest growth and are therefore restricted to more mature stands. The scarcity of such mature locations has caused forest biodiversity associated with senescent stages of forest development to become so rare that we can state that a majority of threatened forest-dwelling species are restricted to old-growth forests (Schwendtner et al., 2005).

Among the structural aspects that are characteristic to old-growth forests, large bodies of dead wood are most directly related to specialised biodiversity (Gao et al., 2015). Large pieces of dead wood offer several different stages of decomposition, each of which provides a habitat for a diversity of taxons (several thousand insect and fungus species in total), specialised in the direct use of this resource both as shelter and for food. Rotting wood liberates carbon and other minerals stored in cellulose and lignin, making these available to new plants. These elements are often redistributed around the dead trees by saproxylic fungi and their myceliar networks (Simard et al., 2015). Dead wood may also act as a nursery for certain species' seedlings (especially in forests with a thick organic layer), and has also been found to provide positive protection to tree seeds against pathogens (Lonsdale et al., 2008).

This complex habitat changes over time with the process of decay, allowing us to speak of a succession associated to this process. Potentially harmful species (liable to behave as plagues or pathogens on healthy trees) only appear during the early years in the succession process, while rare (and often threatened) species emerge in later stages of this succession. Throughout this succession, species specialised in the host give way to a scenario in which the precise species of tree becomes of lesser importance, whereas the habitat types available and the stage of decomposition take on greater prominence (Méndez, 2009).

Big trees, along with dead trees that are still standing, are also related to their own biodiversity due to the latter's role in generating micro-habitats that are vital to forest species (Sandström 1998; Carlson et al., 1998; Camprodon 2003; Gao et al., 2015). The formation of cavities (hollows, folds, etc.) in trees depends on a variety of processes (fungus infection, insect attack, perforation by termites and woodpeckers, lightning strikes, fire and naturally falling branches) that increase as trees age, and are therefore more frequent in old-growth stands. Tree hollows only appear in trees that have reached a certain diameter (approximately 30 cm) and the proportion of trees with cavities increases exponentially with their girth: only 5% of trees with a diameter of 40-50 cm have hollows whereas 50% of trees with a girth of 70-80 cm have them (Flaquer et al., 2007). In addition, old trees with dead wood on their trunks and branches allow a diversity of epiphyte flora to thrive (lichens, mosses, creepers, etc.) and provide the habitat for arthropods that, in turn, are food to insectivorous birds (Ferris-Kaan et al., 1993).

For instance, hollows in wild pines are found in individuals of 150 years or more (diametric class 30; Sandström, 1992); in the case of beech, the probability of hollows occurring through malformation, rotting or wounds increases in diametric classes 50-55 (Camprodon 2003). Considering that the age for cutting down trees is around 80-120 years, trees featuring hollows become extremely scarce or cease to exist in forests where wood is harvested.

Another differentiating feature in old-growth forests is their greater **structural heterogeneity**: greater vertical (several strata) and horizontal complexity (openings in the canopy), together with greater variety in the canopy's age structure, gives a diversity of tree girths. This is linked to greater biodiversity, as it provides a broader range of possible environments or micro-habitats (Vallauri et al., 2010).

Lastly, **permanence over time** leads to the development of a community that is more complex and more complete, both in the greater development of the ground and in that of the trees themselves. To give an example, the bark or rhytidome of old-growth trees, often over 300 years old, has physical and chemical features absent from younger trees' trunks that hosts lichen flora that is specific to old-growth stands.

4.1. Species that are indicators of forest maturity

Forests that are husbanded in a regular and intensive manner may present a rich biocenosis, but in general the species present tend to be the less demanding taxons. It is the more specialised groups such as certain fungi generally associated with heterotrophic succession, saproxylic insects, certain birds (woodpeckers) and some mammals (forest bats), that are more clearly linked to old-growth forest environments (Schwendtner et al., 2005; Mikusinski et al., 2001; Drever et al., 2008, Roberge et al., 2008).

4.1.1. Birds associated with old-growth forests

Most woodland bird species associated with old-growth forests have their geographic origins in the deciduous forests of Central Europe. As their distribution advances southward, their variety and abundance diminishes (Blondel 1985, Tellería 1992), as a result of which Mediterranean countries are relatively poor in forest birdlife species in comparison with the northernmost regions on the European continent: few endemisms and wide dispersion of baricentres toward the SW of the Palearctic in species whose breeding grounds are in the Mediterranean region (Covas & Blondel 1998). However, mountainous areas maintain populations of central or boreal European origin: the Pyrenees, the Cantabrian and the northern Sistema Ibérico mountain ranges harbour some cold forest environment species: the Western capercaillie (*Tetrao urogallus*), the boreal owl (*Aegolius funereus*), the white-backed woodpecker (*Dendrocopos leucotos*), the black woodpecker (*Dryocopus martius*), the middle spotted woodpecker (*Leiopicus medius*), the marsh tit (*Poecile palustris*), the goldcrest (*Regulus regulus*) or the Eurasian treecreeper (*Certhia familiaris*), to mention a few. These species reached southern Europe with the Würm glaciation and remained isolated in the highest mountains after the glaciers retreated. Therefore, a major part of the Iberian forest species belong to this central European irradiation and, for many of them, the Iberian Peninsula is the southernmost limit to their distribution (Hagemeijer & Blair 1997).

We cannot speak of birds that are exclusive to old-growth forests, at least on the Iberian Peninsula, or of species that unequivocally signal a forest's maturity. Rather, we need to look at functional groups of species that are associated to the various structures present in old-growth forests.

Birdlife associated to old-growth forests consists mainly of specialists in exploiting forest resources, and can be distinguished among species that make holes in trees for nesting (*Picidae*), those that take up secondary occupation of such hollows (the treecreeper, blue nuthatch and forest-dwelling nocturnal birds of prey) and tree-top dwellers (mostly *Paridae*).

There is a positive relation between tree size and the presence of drilling birds (Beebe, 1974; Carlson et al., 1998). On the one hand, these species prefer small-sized holes at great height where they are free from predators, and thick walls for insulation. These conditions are only found in large trees (over 30 cm diameter). On the other hand, many bird species prefer to feed in these larger trees (Robles et al., 2007). The tendency to occupy stands of greater maturity has been documented among woodpeckers, especially the black woodpecker (*Dryocopus martius*), the white-backed woodpecker (*Dendrocopos leucotos*) and the middle spotted woodpecker (*Leiopicus medius*) (Camprodon et al., 2007).

Tree hollow numbers are influenced by the combination of tree-top species, the intensity of forest treatment, the amount of dead or dying wood, the normal diameter, height and age of the trees and the malformations present (Sandström 1998, Carlson et al., Camprodon 2001).

The proportion of big trees in a given forest is also associated with greater density and variety of passerines, secondary tree hollow occupants who use them for breeding and for shelter, in particular the blue nuthatch (*Sitta europea*), the treecreepers (*Certhia brachydactyla* and *Certhia familiaris*) and the blue tit (*Cyanistes caeruleus*) (Camprodon 2003, 2014; Camprodon et al., 2008). Among these, the blue nuthatch can be considered as the Iberian bird species that acts as the best indicator of forest maturity: its abundance increases with tree age and girth and the presence of standing dead wood (Camprodon et al., 2003).

A similar ratio is found between tree age and girth and central European passerines, secondary occupants of tree cavities, both in the more common species (coal tit, blue tit, blue nuthatch, treecreeper, European starling (Robles et al., 2011), and in species rare to the Iberian peninsula such as the European pied flycatcher (*Ficedula hypoleuca*), the collared flycatcher (*Ficedula albicolis*) and the common redstart (*Phoenicurus phoenicurus*) Wesołowski 2007). The boreal owl (*Aegolius funereus*), secondary occupant of Picidae tree hollows, displays a similar trend as far as selecting a tree stand in which to nest (Mariné & Dalmau 2000).

In sum, old-growth, and hence large trees of at least 30 cm in diameter, are a determinant factor to forest birds, since these are the trees that offer the hollows that these birds need, whether these are Picidaes' nests or disturbances or breakages (Camprodon et al., 2007).

There is also a significant correlation between the amount of dead wood and the density of cave-dwelling birds, as large dead trees are an excellent nesting medium for drilling birds, and likewise for secondary occupants of these hollows (Sandström 1992, Camprodon 2003, Redolfi et al., 2016).

4.1.2. Forest Chiroptera

Most bat species use forest habitats at some stage in their life cycle, whether this is to hunt, hibernate, or seek temporary shelter. However, some species are more closely linked to forest environments and known as 'strictly forest species'. Included within this category are nine species of those identified on the Iberian peninsula: 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 bechsteinii*).

These forest bats are closely dependent on trophic and structural habitat qualities, from which they obtain trophic resources and shelter in which to spend their periods of inactivity. Strictly forest species hunt in the forest or its fringes and take shelter mainly in tree hollows (although some species roost in caves or fissures, such as the common pipistrelle (*Pipistrellus pipistrellus*), the soprano pipistrelle (*Pipistrellus pygmaeus*), Daubento's bat (*Myotis daubentonii*) and Natterer's bat (*Myotis nattereri*), and may combine both types of shelter depending on its availability). These bats are also highly sensitive to alterations in the habitat, which makes them extremely vulnerable (Vaughan et al., 1997, Grindal & Brigham 1999, Swystun et al., 2001, Kusch et al., 2004, Kusch & Idelberger 2005, Menzel et al., 2005, Flaquer et al., 2007a).

The rich abundance of forest chiroptera and their activity has been shown to be significantly greater in forests than in their fringes, and greater still under conditions characteristic of old-growth forests (Camprodon et al., 2009; Camprodon & Guixé 2007). In concrete terms, forests containing big trees (greater than 45 cm normal diameter), heterogeneous structures and an abundance of dead wood are preferentially associated with forest chiroptera. This relationship involves the greater availability of shelter (tree hollows) both in large trees and in standing dead wood, together with greater availability of trophic resources (Kunz 1982; Russo et al., 2004). Thus, the presence of forest chiroptera may be interpreted as a symptom of forest maturity.

All the above factors are conditioned by forest management. Old-growth, dead or deformed trees are generally seen negatively for wood harvesting purposes, and are eliminated, thus reducing opportunities for the establishment of chiroptera (Flaquer et al., 2008).

Table 2. Strictly forest-dwelling Iberian chiroptera on the Iberian Peninsula

Species	**Threaten Category***
Myotis bechsteinii	*Vulnerable*
Myotis alcathoe	-
Myotis mystacinus	*Vulnerable*
Barbastella barbastellus	-
Plecotus auritus	-
Plecotus macrobullaris	-
Nyctalus lasiopterus	*Vulnerable*
Nyctalus noctula	*Vulnerable*
Nyctalus leisleri	-

* Source: Catalogo Español de Especies Amenazadas, MAPAMA

4.1.3. Saproxylic coleoptera

Biodiversity associated to the decomposition of dead wood -known as saproxylic- contains one of the most rich and complex communities present on Earth's ecosystems (Harmon et al., 1986, Speight 1989). One quarter of temperate forest species are saproxylic (Stokland, 2003) (fungi, lichens, arthropod invertebrates, etc.) and this ratio may increase depending on the type of forest (Grove, 2002). The most highly diverse macroscopic saproxylic organisms are insects and saprophytic wood-rotting fungi (Speight, 1989). As for insects, the greatest diversity is found in the orders coleoptera, hymenoptera and diptera.

The dominant diversity among coleoptera in this functional group, comprising around 2,500 Iberian and Macaronesian species, is the main reason for their selection as indicators for the saproxylic community and processes associated with the decomposition of dead wood (Grove, 2002; Lachat et al., 2012). Further reasons are the multiplex relationships with the different aspects of saproxylic biodiversity (Quinto et al.; Zuo et al., 2016), which, along with fungi, play a key role in rotting processes (Geib et al., 2008; Ulyshen, 2015, 2016); their presence in practically all forest habitats and in the majority of dead wood micro-habitats; the greater knowledge of their ecology with respect to other taxonomic groups; and lastly, the broad experience of study methods (Økland, 1996; Bouget et al., 2009a, b; Quinto et al., 2013). In addition, there is a large group of stenotopic saproxylic beetles that only occupy micro-habitats -extremely scarce nowadays- associated with mature wood (Ranius, 2002; Gouix, 2013).

Priority use of coleoptera in the research and studies on the conservation of saproxylic organisms conducted over recent decades, chiefly in Northern Europe but also in North America and in Oceania, has allowed us to discern a series of relationships with old-growth forests and elements of maturity. Both the wealth of species and their abundance are related to the maturity of the stand (Martikainen et al., 2000; Lassauce et al., 2013), principally owing to the fact that these are habitats with more dead wood, greater heterogeneity (stages of decomposition, typologies, etc.) and abundance of dead trees.

In stands of flowering plants, higher numbers of coleoptera also respond to the better quality of micro-habitats (Ranius, 2000), a factor that is difficult to characterise and in which coleoptera acquire special importance as bioindicators. An example of this are the tree hollows in Iberian *dehesas*, in which a relationship has been found between the volume and quality of organic matter in the hollow and the make-up of the saproxylic community (Quinto et al., 2014) after the characterisation of these micro-habitats and samplings of coleoptera and diptera (Diptera: Syrphidae).

Moreover, we may highlight the species associated with elements of maturity (Russo et al., 2010; Müller et al., 2005; Chiari et al., 2012; Hjältén et al., 2012), as stenoic, relict or listed species on the UICN Red List (Nieto & Alexander, 2010; Recalde, 2010), that maintain a relationship with the quality of the habitat and are useful in the detection of micro-habitats that are highly valuable for conservation purposes.

Nevertheless, it is important to bear in mind that the presence of one species does not in itself necessarily indicate the presence of an old-growth stand. We find an example in *Limoniscus violaceus* (Müller, 1821) (Coleoptera: Elateridae), a severely threatened species that grows in the basal cavities of Quercus or Fagus. It is known to exist at three sites on the Iberian Peninsula in old-growth stands (Sánchez & Recalde, 2012), but in France it is found on old, solitary trees in *bocage* landscapes (Gouix, 2013). Therefore, taking the presence of a single species as an indication of a mature forest habitat may lead to error, despite knowing that its presence may tell us of a micro-habitat that is likely to persist over time.

The use of saproxylic coleoptera as indicators of old-growth stands or stands of reference is, therefore, a valid tool provided that an entire community or set of species associated with elements of maturity is taken into account (Speight, 1989).

In France, for instance, a list of 300 species has been used to evaluate the biological value and location of stands of reference (Brustel. 2004 and 2007; Bouget et al., 2008).

However, we may wonder at this use of the community of saproxylic coleoptera, in the knowledge that a forest inventory planned with this aim in view can be more efficient (Grove, 2002; Gao et al., 2015). The response stems from the required degree of knowledge with respect to describing an old-growth forest or which elements or processes relating to maturity are to be detected.

It is here that saproxylic coleoptera may play a more significant role, beyond acting as indicators of maturity structures, in which they act as indicators of processes related to the decomposition of woody necromass. This information involves considerable technical difficulty and a large budget for a conventional forest inventory. For instance, the presence of Cetonia aurataeformis (Curti, 1913) or Osmoderma eremita (Scopoli, 1763) (Coleoptera: Cetoniidae) are indicators, besides a type of micro-habitat, of a series of decomposition processes thanks to the action of larvae that enrich the humus levels of N and C (Jönsson et al., 2004; Micó et al., 2011; Sánchez et al., 2016) and that enable a different succession of decay-inducing species (Ranius, 2002).

A list of species associated with old-growth forests has not yet been drafted for Spanish forests. As an example, a list is provided of saproxylic species associated with long-lasting micro-habitats, or that are only found in forests in advanced states of maturity.

Regeneration after minor disturbance. Photo: Enrique Arrechea

Table 3. Saproxylic coleoptera associated with old-growth forest habitats

Familia	Species	Bioregion	Associated tree	Habitat
Aderidae	*Euglenes oculatus* (Paykull, 1798)	Eurosiberiana	Quercus	Hollows in old trees
Anthribidae	*Platystomos albinus* (Linnaeus 1758)	Eurosiberiana	Frondosas	Saproxilic fungus
Biphyllidae	*Diplocoelus fagi* (Chevrolat 1837)	Eurosiberiana	Frondosas	Saproxilic fungus
Bostrychidae	*Stephanopachys brunneus* (Wollaston, 1862)	Macaronésica	*Pinus canariensis*	Coarse dead wood
Bothrideridae	*Bothrideres interstitialis* (Heyden, 1870)	Mediterránea	Quercus/Fagus	Hollows in old trees
Buprestidae	*Buprestis splendens* (Fabricius, 1775)	Mediterránea	Pinus	Big trunks
Cerambycidae	*Tragosoma depsarium* (Linnaeus, 1767)	Boreoalpina	*Pinus uncinata*	Big trunks
Cerophytidae	*Cerophytum elateroides* (Latreille, 1804)	Eurosiberiana/Mediterránea	Quercus	Old trees
Cetoniidae	*Osmoderma eremita* (Scopoli, 1763)	Eurosiberiana/Mediterránea	Quercus/Fagus	Basal hollows in old trees
Cleridae	*Tillus elongatus* (Linnaeus 1758)	Eurosiberiana	Frondosas	Big trunks
Cucujidae	*Cucujus cinnaberinus (Scopoli, 1774)*	Eurosiberiana	Frondosas / Coníferas	Big trunks
Curculionidae	*Camptorhinus statua* (Rossi 1790)	Eurosiberiana	Quercus	Big dead branches
Elateridae	*Limoniscus violaceus* (Müller, 1821)	Eurosiberiana/Mediterránea	Quercus/Fagus	Basal hollows in old trees
Endomychidae	*Mycetina cruciata* (Schaller 1783)	Eurosiberiana	Frondosas/ Coníferas	Saproxilic fungus
Erotylidae	*Triplax lacordairii (Crotch, 1870)*	Mediterránea	Frondosas/ Coníferas	Saproxilic fungus
Eucnemidae	*Farsus dubius* (Piller & Mitterbacher,	Mediterránea	Frondosas	Coarse dead wood

Familia	Species	Bioregion	Associated tree	Habitat
	1783)			
Histeridae	*Merohister ariasi* (Marseul 1864)	Mediterráne a	Frondosas	Predator
Laemophlaeidae	*Notolaemus unifasciatus* (Latreille 1804)	Eurosiberia na	Mediterránea	Predator. Big trunks
Leiodidae	*Anisotoma humeralis* (Fabricius 1792)	Holàrtica	Eurosiberian a	Sub cortical fungus
Lucanidae	*Aesalus scarabaeoides* (Panzer, 1794)	Eurosiberia na	Frondosas	Coarse deadwood
Lycidae	*Pyropterus nig roruber* (DeGeer, 1774)	Eurosiberia na	Frondosas	Predator
Lymexylidae	*Lymexylon navale (Linnaeus, 1758)*	Eurosiberia na/Mediterr ánea	Quercus/Fagus	Old tres and coarse deadwood
Melandryiidae	*Melandrya caraboides* (Linnaeus 1761)	Eurosiberia na	Frondosas	Pudrición blanca
Mordellidae	*Mordellochroa milleri* (Emery, 1876)	Eurosiberia na	Frondosas	Recent deadfwood
Mycetophagidae	*Mycetophagus quadriguttatus (Müller, 1821)*	Eurosiberia na	Quercus	Saproxilic fungus
Oedemeridae	*Nacerdes carniolica* (Gistel 1834)	Europea	Coníferas	Big trunks
Ptinidae	*Ptinomorphus angustatus* (Brisout,1862)	Mediterráne a	Quercus	Xilófaga
Pyrochroidae	*Pyrochroa coccinea* (Linnaeus 1760)	Europea	Frondosas	Big trunks
Pythidae	*Pytho depressus* (Linnaeus 1767)	Eurosiberia na	Coníferas	Coarse Deadwood
Rhysodidae	*Rhysodes sulcatus* (Fabricius, 1787)	Boreoalpina	Coníferas	Saproxilic fungus
Salpingidae	*Vincenzellus ruficollis* (Panzer 1794)	Eurosiberia na	Frondosas	Predator
Scirtidae	*Prionocyphon serricornis* (P.W.J. Muller, 1821)	Eurosiberia na	Frondosas	Holes with water (dendrotelmas)
Scraptiidae	*Cyrtanaspis phalerata* (Germar 1847)	Europea	Frondosas con coníferas	Decomposed seadwood
Silvanidae	*Dendrophagus crenatus* (Paykull 1799)	Boreoalpina	Coníferas	Coarse deadwood (trunks)

Familia	Species	Bioregion	Associated tree	Habitat
Sphindidae	*Aspidiphorus lareyniei* (Jacquelin du Val, 1859)	Mediterránea	Coníferas/ Frondosas	Saproxilic fungus
Staphylinidae	*Scaphidium quadrimaculatum* (Olivier, 1790)	Eurosiberiana	Coníferas/ Frondosas	Coarse deadwood (trunks)
Tenebrionidae	*Prionychus ater* (Fabricius, 1775)	Mediterránea	Frondosas	Holes in old trees
Teredidae	*Teredus cylindricus* (Olivier 1790)	Eurosiberiana/Mediterránea	Acer/Alnus	Coarse deadwood (trunks)
Tetratomidae	*Tetratoma baudieri* (Perris, 1864)	Mediterránea	Quercus/Fraxinus	Saproxilic fungus
Throscidae	*Aulonothroscus laticollis* (Ribinsky, 1897)	Eurosiberiana	Quercus	Old tres
Trogidae	*Trox scaber (Linnaeus, 1767)*	Eurosiberiana	Quercus	Holes in old trees
Trogossitidae	*Calitys scabra* (Thunberg, 1784)	Boreoalpina	Pinus	Coarse deadwood (trunks)
Zopheridae	*Pycnomerus terebrans* (A.G. Olivier, 1790)	Eurosiberiana	Quercus	Coarse deadwood (trunks)

4.1.4. Vascular plants

Old-growth stands show some features in common with regard to their floristic make-up. By and large, old-growth stands contain a greater proportion of shade-tolerant (skiophilous) species due to the close tree canopy that prevents full sunlight from reaching the lower layers (Hermy et al., 1999). Among these, species with nitrophilous tendencies are of less interest than non-nitrophilous plants[5].

[5] Thus, for instance, in the forests of the southern Sistema Ibérico, the following species can be considered skiophilous 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 the following as skiophilous-nitrophilous species: *Alliaria*

Old-growth stands also contain greater diversity of biological types, among which macrophanerophytes and vines stand out while terophytes are of lesser importance.

Table 4. Species, by biological type, present in the relict lime tree forests of the southern Sistema Ibérico (García Cardo, in preparation)

Macrofanerophytes	**Meso & nanofanerophytes**	**Scandents**	**Terophyites, Hemicriptophytes, Geophytes, etc.**
Acer monspessulanum, Betula pendula subsp. *fontqueri, Corylus avellana, Fraxinus excelsior, Ilex aquifolium, Populus tremula, Salix caprea, Sorbus aria, Sorbus torminalis, Sorbus latifolia, Taxus baccata, Tilia platyphyllos, Ulmus glabra*	*Buxus sempervirens, Cornus sanguinea, Euonymus europaeus, Ligustrum vulgare, Prunus mahaleb, Rhamnus alpina, Rhamnus catharticus, Ribes alpinum, Ribes uva-crispa, Viburnum lantana*	*Clematis vitalba, Hedera helix, Lonicera xylosteum*	*Alliaria petiolata, Arabis turrita, Brachypodium sylvaticum, Campanula trachelium, Convallaria majalis, Epipactis microphylla, Geranium robertianum, Hepatica nobilis, Laserpitium latifolium, Laserpitium nestleri, Lathyrus pisiformis, Melica uniflora, Monotropa hypopitys, Neottia nidus-avis, Poa nemoralis, Sanicula europaea,* etc.

Also more frequently found are species with a limited capacity for dispersion and colonisation, which is an indicator of the forest canopy's long-term permanence (Wulf, 1997; Hermy et al., 1999). This continuity in old-growth forests, safeguarding the stability of their ecological conditions over the last few centuries, has also ensured that they contain a greater abundance of relict species among their flora (species that have become isolated from their original populations as climate varied during glaciation periods. In each territory these species differ, as some species are of a relictual nature in a given geographical area but not in others.

Table 5. Relictual species in the southern Sistema Ibérico associated with forests (García Cardo, in preparation)

petiolata, Geranium robertianum, Lapsana communis, Moehringia trinervia, Mycelis muralis and *Polygonatum odoratum*.

Species	Origin	Disyunction level
Actaea spicata	Euroasiatic	High
Adonis vernalis	Euroasiatic	Medium
Astrantia major	Eurosiberian	High
Atropa baetica	Ibero-northafrican	High
Betula pendula subsp. *fontqueri*	Ibero-northafrican	High
Campanula latifolia	Euroasiatic-Northafrican	Very High
Carex digitata	Eurosiberian	High
Convallaria majalis	European	High
Dactylorhiza sambucina	Euroasiatic	High
Daphne mezereum	Euroasiatic	Very High
Dictamnus albus	Eurosiberian	Medium
Epipactis microphylla	Euroasiatic	Medium
Euonymus latifolius	European, Iranoturanian & Northafrican	Very High
Laserpitium latifolium	European	High
Lathyrus pisiformis	Euroasiatic	Very High
Lathyrus vernus	Euroasiatic	High
Lonicera splendida	Bétic-Sistema Ibérico	High
Monotropa hypopitys	Circumboreal	Medio
Orthilia secunda	Circumboreal	Very High
Potentilla micrantha	Eurosiberian	High
Pyrola chlorantha	Circumboreal	High
Quercus petraea	Euroasiatic	High
Rhamnus catharticus	Eurosiberian	Medium
Rubus saxatilis	Euroasiatic	Very High
Tilia platyphyllos	Euroasiatic	High
Ulmus glabra	Euroasiatic	Medium
Viburnum tinus	Mediterránea	Medium
Xiphion serotinum	Bético-Sistema Ibérico	Alto

The lack of mature and senescent phases in European forests causes many of the species most closely linked to these environments to endure in very small populations and, therefore, to be listed as threatened to some degree. This means that in old-growth stands, the proportion of scarce or threatened species is often very high (Wulf, 1997).

Despite these differentiating features, the assessment of a forest's maturity based on its floristic composition is no easy task, since the presence or absence of certain plant species is not enough to go by (Rose, 1999). Even species considered to be associated to old-growth forests in a given location may appear in husbanded stands or on open ground under different environmental conditions (Hermy et al., 1999).

It is therefore deemed necessary to draw up lists of species that act as indicators of maturity, adapted to each type of forest habitat and each biogeographical region, as each specific composition varies with geology, topology, climate and local history (Rose, 1999).

In assessing the degree of maturity of a given stand, it is necessary to establish references against which to compare each forest type within the selected biogeographical territory, jointly evaluating the criteria described herein: composition of species, nanophanerophytes/climbing plants ratio, predominance of tree habitats, canopy cover and presence of relictual and threatened species.

4.1.5. Lichens and bryophytes

Lichens and bryophytes are highly sensitive to minor alterations to the environment as their physiology is closely linked to humidity, solar radiation and temperature, which makes them extremely useful in detecting changes in atmospheric conditions (Aragón et al., 2015). Overall, the lichens and bryophytes found in nemoral habitats such as forests with close canopies are more sensitive to environmental changes, owing to their strong dependence on atmospheric humidity and their tendency to suffer photo-inhibition when exposed to more sunlight than would reach them in their normal surroundings. Their presence, therefore, may indicate extended periods of continuity in forests with closed canopies. Conversely, old-growth forests enable the presence of species that cannot grow in forests with frequent openings in the forest canopy.

As for the variety and abundance of species, although some open areas may offer greater diversity, the forest structure acts as the main factor determining habitat quality for these organisms at a local scale (Belinchón et al., 2011). This causes old-growth stands to accumulate a wealth of lichen and moss types, in particular epiphytic species (Boch et al., 2013). In this line, a number of studies conducted in different climates have highlighted the importance of old-growth forests for quality of epiphyte habitats deriving from their heterogeneity, and especially from the diversity of arboreal species, and the existence of trees of different ages and sizes, comprising very large trees (Hofmeister et al., 2015) and very small trees (Hofmeister et al., 2015; Merinero, 2015).

Furthermore, on a microscale, tree characteristics also determine the heterogeneity and availability of suitable micro-habitats and microclimates that condition the distribution and abundance of epiphyte lichens: the foremost being tree age and size, and certain features of the park such as pH and roughness (Merinero, 2015).

Another important habitat for lichen and epiphyte moss diversity is dead wood, especially large woody debris (Hofmeister et al., 2015), which is another characteristic of old growth forests.

This makes it quite usual to find less diversity of epiphytes in forests that are harvested then in forests allowed to evolve naturally, and that in forests subjected to intensive exploitation in the past, despite having been left to return to a natural state of evolution, fewer species are present (Ardelean et al., 2015; Boch et al., 2013) and these recover but slowly (Infante & Heras, 2008).

Epiphyte lichens, therefore, and in particular the species belonging to the Lobarion community, have been identified as characteristic of forests that have remained over a long period of time with very little interference from human activity or heavy disturbances (Potenza & Fascetti, 2010; Rose, 1985, 1988). These can be used as indicators of such situations involving long-term ecological continuity (Rose, 1999; Coppins & Coppins, 2002; Brunialti et al., 2010).

Table 6. List of bryophytes (mosses and hepatica), epiphytes and epixyles (growing on bark or dead wood) found in the Turieto fir forest (Parque Nacional de Ordesa y Monte Perdido).

Mosses		**Hepatics**	
Anomodon viticulosus		*Anastrophyllum hellerianum*	*DW* CR
Antitrichia curtipendula	*sens*	*Anastrophyllum minutum*	*DW*
Brachythecium rutabulum		*Blepharostoma trichophyllum*	*DW*
Bryum flaccidum		*Cephalozia catenulata*	*DW* DD
Buxbaumia viridis	*DW* VU	*Cephalozia leucantha*	*DW*
Ctenidium molluscum		*Chiloscyphus polyanthos*	
Dicranum scoparium	NT	*Frullania dilatata*	
Dicranum tauricum		*Frullania fragilifolia*	*sens*
Eurhynchium striatum		*Frullania tamarisci*	*sens*
Herzogiella seligeri	*DW*	*Lejeunea lamacerina*	*sens*
Homalothecium sericeum		*Lejeunea ulicina*	*sens*
Hylocomium splendens		*Lepidozia reptans*	*DW*
Hypnum cupressiforme		*Lophocolea heterophylla*	
Isothecium alopecuroides		*Metzgeria furcata*	
Leptodon smithii		*Nowellia curvifolia*	*DW*
Leucodon sciuroides		*Plagiochila porelloides*	NT
Mnium hornum		*Porella arboris-vitae*	*sens*
Mnium spinosum	*Sens* NT	*Porella platyphylla*	*sens*
Neckera besseri	*sens*	*Radula complanata*	
Neckera complanata		*Riccardia latifrons*	*DW*
Neckera crispa		*Tritomaria exsectiformis*	*DW*
Neckera pumila	*sens*		
Orthotrichum affine			
Orthotrichum lyelii			
Orthotrichum pulchellum	VU		
Orthotrichum pumilum	*Sens* NT		
Orthotrichum speciosum			

Orthotrichum stramineum			
Orthotrichum striatum			
Paraleucobryum longifolium			
Plagiomnium spp.			
Plagiomnium undulatum			
Pseudoleskeella nervosa			
Pterigynandrum filiforme	NT		
Pterogonium gracile			
Rhizomnium punctatum			
Rhytidiadelphus triquetrus			
Schistidium cf. crassipilum			
Scorpiurium circinatum			
Tetraphis pellucida	*DW*		
Tortella tortuosa			
Ulota crispa			
Zygodon baumgartneri			

Table 7. List of epiphyte and epixyle lichens (growing on bark or dead wood) found in the Turieto fir forest (Parque Nacional de Ordesa y Monte Perdido, Huesca, Spain).

Agonimia tristicula		*Micarea micrococca*	
Arthonia radiata		*Micarea prasina*	*DW*
Bacidia rosella	*sens*	*Mycobilimbia sabuletorum*	
Bacidia rubella	*sens*	*Mycocalicium subtile*	*DW*
Bacidia laurocerasi	*sens*	*Nephroma laevigatum*	*LOB*
Bryoria capillaris	*sens*	*Nephroma parile*	*LOB*
Bryoria fuscescens	*sens*	*Nephroma resupinatum*	*LOB*
Buellia disciformis	*sens*	*Normandina pulchella*	*LOB*
Calicium salicinum	*DW*	*Ochrolechia species*	*sens*
Caloplaca herbidella	*sens*	*Opegrapha rufescens*	
Candelariella vitellina		*Opegrapha varia*	
Candelariella xanthostigma		*Pachyphiale carneola*	*LOB*
Catillaria atropurpurea	*sens*	*Pannaria conoplea*	*LOB*
Chaenotheca brunneola	*DW*	*Parmelia saxatilis*	
Chaenotheca xyloxena	*DW*	*Parmelia submontana*	*sens*
Cladonia caespiticia	*sens*	*Parmelia sulcata*	
Cladonia coniocraea		*Parmeliella testacea*	*LOB*
Cladonia digitata	*DW*	*Parmeliella triptophylla*	*LOB*

Cladonia fimbriata		*Parmeliopsis ambigua*	*sens*
Cladonia pyxidata		*Parmeliopsis hyperopta*	*sens*
Cladonia species		*Peltigera horizontalis*	*LOB*
Collema furfuraceum	*sens*	*Peltigera lactucifolia*	*sens*
Collema species	*sens*	*Peltigera praetextata*	*LOB*
Dimerella pineti		*Pertusaria albescens*	*sens*
Graphis scripta		*Pertusaria amara*	*sens*
Graphis species	*sens*	*Pertusaria coccodes*	*sens*
Gyalideopsis anastomosans		*Pertusaria flavida*	*sens*
Hypogymnia physodes		*Pertusaria hymenea*	*sens*
Hypogymnia tubulosa		*Pertusaria pertusa*	*sens*
Lecanora allophana	*sens*	*Phaeophyscia species*	
Lecanora argentata	*sens*	*Phlyctis agelaea*	*sens*
Lecanora chlarotera		*Phlyctis argena*	
Lecanora glabrata	*sens*	*Physconia species*	
Lecidella elaeochroma		*Platismatia glauca*	*sens*
Lepraria incana		*Porina aenea*	
Lepraria lobificans		*Pyrenula nitida*	*sens*
Leptogium furfuraceum	*LOB*	*Ramalina farinacea*	
Leptogium gelatinosum	*LOB*	*Rinodina species*	
Leptogium lichenoides	*LOB*	*Sclerophora pallida*	*sens*
Leptogium saturninum	*LOB*	*Trapeliopsis granulosa*	
Lobaria amplissima	*LOB*	*Trapeliopsis pseudogranulosa*	
Lobaria pulmonaria	*LOB*	*Usnea filipendula*	*sens*
Melanelia glabratula		*Usnea hirta*	*sens*
Melanelia subaurifera		*Usnea species*	*sens*

(*sens*) species sensitive to habitat alterations.
(*DW*) species specialised in dead wood.
(LOB) species belonging to the *Lobarion* community.

5. THE VALUE OF OLD-GROWTH FORESTS

The values associated to old-growth forests are manifold. We have already discussed the value of the heritage they convey in terms of biodiversity, and their scientific value as rare ecosystems hosting singular ecological processes. But in addition to these, the value of old-growth stands also responds to more practical reasons.

Besides, we should bear in mind the climatic scenarios we can already foresee: the future is expected to be warmer, drier and more variable, and silviculture may contribute to enhancing the adaptive qualities of forests to the new conditions, preserving the services that forests offer to society. Old-growth stands, on account of their greater heterogeneity, are more resilient in the face of climate change and from their structure and functions we can draw useful guidance for the forest management in the future (EUROPARC-España, 2017). We should also examine their role in mitigating climate change, as the forest nutrient cycle is very slow and retains vast quantities of carbon, both in the above-ground biomass and on the forest floor (Zhou et al., 2006; Luyssaert et al.; Keeton et al., 2010).

Lastly, it is important to consider the social value of forests and their contribution to our wellbeing (EUROPARC-España, 2013b). The new services demanded by society from forests are increasingly important. Among these, we may highlight public uses, leisure spaces, and environmental awareness raising. These are aspects that should be covered in forest management strategies, and old-growth stands are the scenarios of preference.

The contribution of forests to social wellbeing is becoming recognised even in the field of preventive medicine. Although the psychological effects of contact with nature have been known to environmental psychologists for decades (Kaplan & Kaplan, 1989), studies on the therapeutic benefits of contact with nature have only recently begun (Maller et al., 2009), particularly those focusing on older forests. Some evidence of the psychological and physiological effects of contact with old forests has led to developing therapies based on contact with forests, especially in Japan (Park et al., 2010; Song et al., 2016). These are gradually being implemented in Spain (known as 'forest walkabouts'; Fernandez Muerza, 2017).

5.1. Stands of reference in the assessment of conservation status

European forests are currently undergoing rapid changes for which no referents are available, whether from the socioeconomic angle (abandonment of forest harvesting, loss of profitability) or from an ecological point of view (changes induced by discontinuing land uses and climate change). The last old-growth stands represent the most natural forest habitats available and, therefore, are valuable items for comparison. Hence their status as **'stands of reference'** for each forest type: they allow us to identify the foreseeable structure and functions for different forest types in a non-intervention context.

Featuring old-growth stands as 'stands of reference' takes on special importance under the Habitats Directive and the Natura 2000 Network. This directive sets forth EU Member States' obligation to conduct six-yearly assessments of the conservation status of all habitats of Community interest present on their territories (Table 8).

Stands of reference are an essential tool in the assessment of forest habitat conservation status. Indeed, the "Preliminary ecological bases for the conservation of habitat types of Community interest in Spain" (Several authors, 2009), referring to forest and woodland habitats, propose the assessment of their conservation status by means of comparison with the structure and biological indicators inherent to old-growth forests (the presence of big trees, dead wood, irregular distribution, species such as Picidae, xylophage insects, etc.). Although the above publication acknowledges large gaps in the body of knowledge on how Spanish forests function, it views forest maturity as a point of comparison in the assessment of conservation status. The study and characterisation of old-growth stands and woodland is therefore considered as the most useful tool for establishing models of reference to allow the assessment of conservation status in the various forest habitats of Community interest.

Studying old-growth stands may also provide criteria to guide silviculture toward reaching species or habitat conservation goals, particularly in protected areas (EUROPARC-España, 2013a). At the same time, it is obvious that a large forest area needs proper management, whether geared toward production targets, adaptation to climate change, or risk control (forest fires). In this context, old-growth stands help us to identify the structural characteristics most directly linked to biodiversity assets, allowing silvicultural practices to be conducted that imitate natural processes by maintaining forest structures or features that are in keeping with highly mature situations (Keeton, 2006; Tíscar, 2006, 2011) and maintaining a favourable conservation status throughout all forest and woodland spaces.

Table 8. Forest habitats of Community interest present in the Spanish Mediterranean biogeographical region

CÓDIGO	NOMBRE
9120	Atlantic acidophilous beech forests with Ilex and sometimes also Taxus in the shrublayer (Quercion robori-petraeae or Ilici-Fagenion)
9150	Medio-European limestone beech forests of the Cephalanthero-Fagion
9180	Tilio-Acerion forests of slopes, screes and ravines (*)
91B0	Thermophilous Fraxinus angustifolia woods
91E0	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae) (*)
9230	Galicio-Portuguese oak woods with Quercus robur and Quercus pyrenaica
9240	Quercus faginea and Quercus canariensis Iberian woods
9260	Castanea sativa woods
92A0	Salix alba and Populus alba galleries

92B0	Riparian formations on intermittent Mediterranean water courses with Rhododendron ponticum, Salix and others
92D0	Southern riparian galleries and thickets (Nerio-Tamaricetea and Securinegion tinctoriae)
9320	Olea and Ceratonia forests
9330	*Quercus suber* forests
9340	*Quercus ilex* and *Quercus rotundifolia forests*
9380	*Ilex aquifolium forests*
9430	Subalpine and montane Pinus uncinata forests (* if on gypsum or limestone)
9520	*Abies pinsapo* forests
9530	(Sub-) Mediterranean pine forests with endemic black pines
9540	Mediterranean pine forests with endemic Mesogean pines
9560	Endemic forests with Juniperus spp (*)
9570	*Tetraclinis articulata* forests
9580	Mediterranean *Taxus baccata* woods

On a national scale and under the promotion and coordination of EUROPARC-España, the LIFE RedBosques project aims to identify a network of 'stands of reference' nationwide. With this purpose, a two-phase plan with a gradual increase in complexity is proposed: an initial phase to identify potential mature stands in situ, and a second phase for their characterisation by means of a set of indicators.

Stands thus identified will form part of the nationwide Network of Stands of Reference made up of the most mature stands found in each forest habitat.

The process for identifying these stands will be implemented by the competent administrations within their territories, and the results will be published online as part of a database by the EUROPARC-España Technical Department. Further details and technical manuals for the identification of forest stands may be consulted at www.redbosques.eu

Some old-growth stands identified on the Iberian Peninsula (www.redbosques.eu)

6. CONCLUSIONS

Mature forests are assets of enormous interest and their identification and characterisation have aroused considerable attention (e.g., Goldberg et al., 2007). The virtual absence of this type of forests and the extreme scarcity of senescent stands in Spain, together with the fact that many of these lie within protected spaces, Natura 2000 Network sites or forests open to public use, calls for identification methods and management criteria to be devised for their proper conservation.

The working group on forests within the EUROPARC-España Conservation Group began, in 2013, a line of work on this subject, among whose findings are the following (EUROPARC-España, 2013c, 2014):

- The conservation of forest ecosystems demands the presence of all successional stages, from the pioneering stages to mature and senescent conditions, in the form of a mosaic on a landscape scale.
- Mature forests are an essential stage in forest ecosystem dynamics, and a very valuable asset due to their extreme scarcity, their fragility, for hosting highly specialised flora that would be unable to find shelter in other habitats, and their impossible recovery in the event of being lost or altered.
- There is insufficient knowledge of the structure and dynamics of mature forests, especially in the Mediterranean region, to determine their favourable conservation status. In particular, the use of temperate or boreal ecosystem indicators for Mediterranean forests may lead to major errors. It is therefore essential to identify old-growth stands of reference in every type of forest, not only in unfavourable environmental conditions but also on good quality sites.
- To keep forests in favourable conservation conditions, not only is it vital to preserve old-growth stands, but younger stands should be planned and managed with the aim of achieving greater extensions of this type of ecosystem in the future. Although some features of maturity can be achieved more quickly by means of management actions (concentrated growth of certain tree types, dead wood, spatial heterogeneity, presence of emblematic species), special attention must be given to maintaining or restoring the ecological processes that lead to maturity.
- It is essential to improve communication to society of the value of forests in general and old-growth forests in particular, highlighting the value of the various components of maturity (thick tree-trunks with hollows, dead trees, rotting woody matter, complex undergrowth) and of the management skills needed to maintain or recover forests and woodland.

The implementation of the proposed set of indicators in a sample of pilot stands will enable progress toward assessing the degree of maturity and natural evolution of forests. Several lines of work are envisaged, namely:

- To create a 'Forest of Reference Network', made up of the most natural stands, to become a reference in the assessment of the conservation status of different types of forest habitat.
- To establish permanently monitored plots that will enhance our knowledge of the structure and function of old-growth stands.
- To develop forest management techniques aiming to maintain forests' natural features and to maximise the naturalness of interventions, as well as to identify the most appropriate management measures to accelerate forest dynamics leading to maturity.

7. GLOSSARY

Below is a concise description and explanation of terms used in this text.

- **Forest**: ecosystem whose physiognomy and main structure is determined by a more or less unbroken woodland formation composed of a mosaic of stands in different successional stages, some consisting of shrubs or herbaceous plants as a result of natural disturbances.

  Altogether, the forest-scale dynamic is a shifting mosaic: the forest is made up of mosaic tiles, each at a different degree of maturity (or 'phase'), including recently regenerated stands, young stands, stands in full-scale development and senescent stands. The latter may be replaced by young stands, or remain more or less perpetually over varying lengths of time.

- **Stand**: a forest sector whose structural, specific and ecological characteristics are relatively homogeneous and is clearly distinguished from other surrounding sectors.

  In husbanded forests, each stand is usually given a preferential use and specific treatment throughout its extension. In forests that are not husbanded, stands are formed by disturbances that impact a medium to large area. The forest dynamic forms a mosaic or tesselated pattern, in which clearings are made by fallen trees, forest fires or other causes.

  Depending on the size of such patches, thickets, copses or stands are formed. To adopt a convention for reference, we may speak of a minimum area of 1 ha, although it is more common for such patches to cover a surface area ranging from 5 to 50 ha.

- **Primary forest**: a forest untouched by human intervention. By definition, any primary forest should be mature.
- **Secondary forest**: a forest that, at some time, has been modified by human actions. It is still a matter for debate whether a secondary forest can acquire the characteristics of a primary forest after the cessation of human intervention.

- **Mature forest:** a forest whose dynamic is free from human intervention, that is made up of stands in all stages of development or maturity and whose singular feature is the presence of senescent stands.

  A true mature forest should cover a sufficient extension to allow ecological cycles to be maintained, and to ensure that each stage of development fulfils its cycle, so that any of its older stands can be replaced in the future with another that has the degree of maturity to cover all functions: in other words, to ensure that the mature forest's characteristics are perpetuated.

- **Old-growth forest:** This refers to a dynamic phase within a stand, rather than to an entire forest. In fact, given that finding an entire old-growth forest is most improbable, we should use the expression 'Mature forest'. See "mature forest" and "old-growth stand".

- **Mature stand:** a forest stand displaying 'features of maturity': very large trees, openings in the canopy cover, regenerating thickets, significant amounts of dead biomass both standing and fallen on the forest floor, abundance of micro-habitats on the trunks of large trees and full, complex ecological cycles.

- **Old-growth stand:** a forest sector in an advanced stage of maturity, that has reached senescence. This results in a population of very old trees, at the limits of their longevity, and the presence of dead trees.

- **Stand of reference:** for a Habitat of Community Interest, a stand displaying the most advanced maturity available within the territory. This is the best example of the dynamics of untouched forests, and can be taken as a reference for assessing the conservation status of other forests masses in the same habitat.

- **[Cultural old-growth stand]:** a stand made up mostly of old trees, resulting from previous forest management. Generally speaking, older stands of this type, with anthropic origins, lack some or many of the necessary characteristics of maturity for consideration as an old-growth stand, especially regarding its natural population dynamic.

  For example, a grove of pollarded beech or oak, or a dehesa of holm or cork oak.

8. REFERENCES

ANEGX, 2008. *Revalorització i protecció dels boscos madurs de la Garrotxa*. ANEGX, Delegació de la Garrotxa de la ICHN, 182 pp.

ANTOR, R. J., GARCÍA, M. B., 1994. Primeros datos sobre la estructura y dinámica del hayedo del Parque Nacional de Ordesa y Monte Perdido. Lucas Mallada 6: 9-15.

ANTOR, R. J., GARCÍA, M. B., 1994. Primeros datos sobre la estructura y dinámica del hayedo del Parque Nacional de Ordesa y Monte Perdido. Lucas Mallada 6: 9-15.

ARAGÓN, G., ABUJA, L., BELINCHÓN, R., MARTÍNEZ, A., 2015. Edge type determines the intensity of forest edge effect on epiphytic communities. Eur J Forest Res (2015), 134, pp. 443–451.

ARDELEAN, I. V., KELLER, C., SCHEIDEGGER, C., 2015. Effects of management on lichen species richness, ecological traits and community structure in the Rodnei Mountains National Park (Romania). PLoS One. 2015; 10(12): e0145808. doi: 10.1371/journal.pone.0145808

BARNES, B. V., 1989. Old-growth forests of the Northern Lake States: a landscape ecosystem perspective. Natural Areas Journal 9: 45-47.

BARTHOD, C., TROUVILLIEZ, J., 2002. La protection des forêts dans la politique forestière française. Cas particulier des réserves intégrales. Revue Forestière Française, LIV, 1-2002, pp. 7-16.

BAUHUS, J., KLAUS, P., MESSIER, C., 2009. *Silviculture for old-growth attributes*. Forest Ecology and Management, 258 (2009), pp.525-537. http://dx.doi.org/10.1016/j.foreco.2009.01.053.

BEEBE, S.B. 1974. Relationships between insectivorous hole-nesting birds and forest management. Yale Univ. Sch. of For. Environ. Studies. New Haven.

BELINCHÓN, R., MARTÍNEZ, I., ARAGÓN, G., ESCUDERO, A., DE LA CRUZ, M., 2011. Fine spatial pattern of an epiphytic lichen species is affected by habitat conditions in two forest types in the Iberian Mediterranean region. Fungal Biology, v. 115 (n. 12); pp. 1270-1278

BENGTSSON, J., NILSSON, S. G., FRANC, A., AND MENOZZI, P., 2000. Biodiversity, disturbances, ecosystem function and management of European forests. Forest Ecology and Management 132: 39-50.

BINKLEY, D., SISK, T., CHAMBERSS, C., SPRINGER, J., BLOCK, W., 2007. *The role of old-growth forests in frequent-fire landscapes*. Ecology and Society 12(2): 18. http://www.ecologyandsociety.org/vol12/iss2/art18/

BLASI, C., BURRASCANO, S., MATURANI, A., SABATINI, F. M. (eds.), 2010. *Old-growth forest in Italy. A thematic contribution to the National Biodiversity Strategy*. Ministero dell'Ambiente e de la Tutella del Territorio y del Mare.

BLASI, C., BURRASCANO, S., MATURANI, A., SABATINI, F. M. (eds.), 2010. Old-growth forest in Italy. A thematic contribution to the National Biodiversity Strategy. Ministero dell'Ambiente e de la Tutella del Territorio y del Mare.

BLONDEL, J. 1985. Historical and ecological evidence on the development of Mediterrenean avifaunas. Acta XVIII Int. Congr. Ornith., vol 2, 373-386.

BOCH, S., PRATI, D., HESSENMÖLLER, D., SCHULZE, E., FISCHER, M., 2013. Richness of lichen species, especially of threatened ones, is promoted by management methods furthering stand continuity. PLoS One. 2013; 8(1): e55461. doi: 10.1371/journal.pone.0055461

BORMANN, F. H., LIKENS, G. E., 1994. *Pattern and process in a forested ecosystem.* Springer-Verlag, New York.

BOSCH, O., GINÉ, L., RAMADORI, E. D., BERNAT, A., GUTIÉRREZ, E., 1992. *Disturbance, age, and size structure in stands of* Pinus uncinata Ram. Pirineos, 140: 5-14.

BOSCH, O., GINÉ, L., RAMADORI, E. D., BERNAT, A., GUTIÉRREZ, E., 1992. Disturbance, age, and size structure in stands of Pinus uncinata Ram. Pirineos, 140: 5-14.

BOUGET C, BRUSTEL H, BRIN A, VALLADARES L. 2009. Evaluation of window flight traps for effectiveness at monitoring dead wood-associated beetles: the effect of ethanol lure under contrasting environmental conditions. Agric For Entomol.;11(2):143-152. doi:10.1111/j.1461-9563.2008.00400.x.

BOUGET C, BRUSTEL H, ZAGATTI P. 2008. The French Information system on Saproxylic BEetle Ecology (FRISBEE): An ecological and taxonomical database to help with the assessment of forest conservation status. Rev d'Ecologie (La Terre la Vie).;63(SUPPL. 10):33-36.

BOUGET C, NAGELEISEN L-M. 2009. Saproxylic Coleoptera. In: Forest Insect Studies: Methods and Techniques. Key Consideration for Standardisation. Vol 19. ;:100-105.

BOYCE, S., 1995. *Landscape forestry*. John Wiley and Sons, New York, N.Y.

BRAUMANDL, T. F., HOLY, R. F., 2000. *Refining definitions of old growth to aid in locating old-growth forest reserves*. Southern Interior Forest Extension and Research Partnership, Kamloops, B.C., pp. 41–4.

BRUNIALTI G., L. FRATI, M. ALEFFI, M. MARIGNANI, L. ROSATI, S. BURRASCANO & S. RAVERA. 2010. Lichens and bryophytes as indicators of old-growth features in Mediterranean forests. Plant Biosyst - An Int J Deal with all Asp Plant Biol.;144(1):221-233. doi:10.1080/11263500903560959.

BRUSTEL H. 2004. Coléoptères Saproxyliques et Valeur Biologique Des Forêts Françaises : Perspectives Pour La Conservation Du Patrimoine Naturel.

BRUSTEL H. 2007. Avaluació del valor biològic dels boscos francesos per mitjà dels coleòpters saproxílics. In: Els Arbres Vells I La Conservació de La Biodiversitat. Perpinyà: Office National des Forets. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya:246.

BURRASCANO S, LOMBARDI F, MARCHETTI M. 2008. Old-growth forest structure and deadwood: Are they indicators of plant species composition? A case study from central Italy. Plant Biosyst - An Int J Deal with all Asp Plant Biol.;142(2):313-323. doi:10.1080/11263500802150613.

BURRASCANO S, ROSATI L, BLASI C. 2009. Plant species diversity in Mediterranean old-growth forests: A case study from central Italy. Plant Biosyst - An Int J Deal with all Asp Plant Biol.;143(1):190-200. doi:10.1080/11263500802709699.

BURRASCANO, S., KEETON, W. S., SABATINI, M., BLASI, C., 2013. *Commonality and variability in the structural attributes of moist temperate old-growth forests: A global review*. Forest Ecology and Management 291 (2013) 458-479. http://dx.doi.org/10.1016/j.foreco.2012.11.020.

CAMPRODON J. 2008. Elementos biológicos a tener en cuenta en la planificación forestal a escala de rodal y de paisaje. Cuad Soc Esp Cienc.;27:79-86.

CAMPRODON, J. 2003. Estructura dels boscos i gestió forestal al nord-est ibèric: efecte sobre la composició, abundància i conservació dels ocells. Tesi doctoral. Universitat de Barcelona.

CAMPRODON, J. 2007. Tratamientos forestales y gestión de la fauna vertebrada. In CAMPRODON, J. I PLANA, E. (eds.). Conservación de la biodiversidad, fauna vertebrada y gestión forestal. 2ª edició. Edicions Universitat de Barcelona i Centre Tecnològic Forestal de Catalunya. Barcelona.

CAMPRODON, J. Y GUIXÉ, D. 2009. La comunitat de ratpenats a les fagedes del Montseny en comparació amb les fagedes del nord-est de Catalunya i en relació amb la gestió forestal. Trobada d'Estudiosos del Montseny.

CAMPRODON, J., CAMPIÓN, D., MARTÍNEZ-VIDAL, R., ONRUBIA, A., ROBLES, H., ROMERO, J. L., SENOSIAIN, A. 2007. Estatus, selección del hábitat i conservación de los pícidos ibéricos. In Camprodon, J. i Plana, E. (eds.). Conservación de la biodiversidad, fauna vertebrada y gestión forestal. 2ª edició. Edicions Universitat de Barcelona i Centre Tecnològic Forestal de Catalunya. Barcelona.

CAMPRODON, J., GUIXÉ, D., FLAQUER, C. 2009. Efecto de la gestión forestal sobre los quirópteros en hayedos de Cataluña. Galemys, 21 (nº especial): 195-215.

CAMPRODON, J., SALVANYÀ, J., SOLER-ZURITA, J. 2008. The abundance and suitability of tree cavities and their impact on hole-nesting bird populations in beech forests of the NE Iberian Peninsula. Acta Ornithologica, 43 (1): 17-31

CAREY, A. B., CURTIS, R. O., 1996. *Conservation of biodiversity: a useful paradigm for forest ecosystem management*. Wildlife Society Bulletin 1996, 24(4):610-620

CARLETON, T. J., GORDON, A. M., 1992. *Understanding old-growth red and White pine dominated forests in Ontario*. Ontario Ministry of Natural Resources.

CARLETON, T., 2003. *Old growth in the Great Lakes forest*. Environmental Review 11:115–13.

CARLSON A., SANDSTRÖM U., OLSSON K. 1998. Availability and use of natural tree holes by cavity nesting birds in a Swedish deciduous forest. Ardea 86: 109–119.

CHIARI S, MARINI L, AUDISIO P, RANIUS T. 2012. Habitat of an Endangered Saproxylic Beetle, Osmoderma eremita, in Mediterranean Woodlands. Ecoscience.;19(4):299-307. doi:10.2980/19-4-3505.

CHIRICI, G., NOCENTINI, S., 2010. *Old-growth forests in Italy: recent research developments and future perspectives*. L'Italia Forestale e Montana, 65 (5): 475-480. http://dx.doi.org/10.4129/ifm.2010.5.01.

COPPINS, A. M., COPPINS, B. J., 2002. Indices of Ecological Continuity for Woodland Epiphytic Lichen Habitats in the British Isles. British Lichen Society.

CORTÉS, C., FULÉ, P. Z., FALK, D. A., VILLANUEVA-DÍAZ, J., YOCOM, L. L., 2012. *Linking old-growth forest composition, structure, fire history, climate and land-use in the mountains of northern México*. Ecosphere 3(11):106. http://dx.doi.org/10.1890/ES12-00161.1.

COVAS R., BLONDEL, J. 1998. Biogeography and history of the Mediterranean bird fauna. Ibis, 140: 395-407.

CREAF, 2011. *Inventari dels boscos singulars de Catalunya*. http://www.creaf.uab.es/BoscosSingulars/index.htm

D'AMATO, A., CATANZARO, P., 2007. Restoring Old-Growth Characteristics. University of Massachusetts–Amherst.

DAY, R. J., CARTER, J. V., 1990. Stand structure and sucesional development of the white pine and red pine communities in the Temagami forest. Ontario Ministry of Natural Resources. 203 p.

DREVER M. C., K. H. AITKEN, A. R. NORRIS, K. MARTIN. 2008. Woodpeckers as reliable indicators of bird richness, forest health and harvest. Biological Conservation, 141: 624– 634

EEA, 2014. *Developing a forest naturalness indicator for Europe*. European Environment Agency, Copenhagen.

EEA, 2014. Developing a forest naturalness indicator for Europe. EEA Technical report Nº 13/2014. European Environment Agency.

EGAN, D., 2007. *Conserving and restoring old growth in frequent-fire forests: cycles of disruption and recovery*. Ecology and Society 12(2): 23. http://www.ecologyandsociety.org/vol12/iss2/art23/

EUROPARC - España. 2013b. Salud y áreas protegidas en España. Identificación de los beneficios de las áreas protegidas sobre la salud y el bienestar social. Aplicación de casos prácticos en la sociedad. www.redeuroparc.org

EUROPARC-España. 2011. Guía de aplicación del estándar de calidad en la gestión para la conservación en espacios protegidos. Fundación Fernando González Bernáldez. Madrid.

EUROPARC-España. 2013a. Proyectos de ordenación de montes: herramientas para la conservación en los espacios protegidos. Fundación Fernando González Bernáldez, Madrid.

EUROPARC-España. 2013c. Conclusiones del seminario "Gestión para la conservación de los hábitats forestales en la red natura 2000" Parc Natural de l'Alt Pirineu, 6-8 de noviembre de 2013.

EUROPARC-España. 2014. Conclusiones del seminario "Evaluación del estado de conservación de los hábitats forestales en la red natura 2000: hacia una red de bosques de referencia". Alcalá de la Selva (Teruel), 29-31 de octubre de 2014

EUROPARC-España. 2017. Integración de la adaptación al cambio climático en la planificación y gestión de las áreas protegidas. Serie Manuales nº13. Fundación Fernando González Bernáldez, Madrid.

FAO, 2012. Expert Meeting on Harmonizing forest-related definitions for use by various stakeholders. Proceedings. Food and Agriculture Organization of the United Nations. Rome, 22-25 January 2002

FAO, 2013. *State of Mediterranean forest 2013*. . Food and Agriculture Organization of the United Nations.

FERRIS-KANN, R., LONDSDALE, D., WINTER, T. 1993. The conservation management of deadwood in forest. The Forestry Authority. Forest Commission. Wrecclesham.

FERNÁNDEZ MUERZA, A. 2017. Los baños de bosque, una propuesta de salud. DKV Salud y seguros médicos, Barcelona.

FIEDLER, C., FRIEDERICI, E. P., PETRUNCIO, M., DENTON, C., HACKER, W. D., 2007. *Managing for old growth in frequent-fire landscapes*. Ecology and Society 12(2): 20.http://www.ecologyandsociety.org/vol12/iss2/art20/

FLAQUER, C., TORRE, I., ARRIZABALAGA, A. 2007. Selección de refugios, gestión forestal y conservación de los quirópteros forestales. Pàg. 469-488, In: Camprodon, J., Plana, E. (Eds.). Conservación de la biodiversidad, fauna vertebrada y gestión forestal.. Edicions de la Universitat de Barcelona -Centre Tecnològic Forestal de Catalunya.

FLAQUER, C., TORRE, I., RÀFOLS, R. G. , ARRIZABALAGA, A. 2005b. Inventari de la fauna quiropterològica del Parc Natural del Montseny com a eina de gestió del territori. VI Trobada d'Estudiosos del Montseny. Diputació de Barcelona.

FRANKLIN, J. F., SPIES, T. A., 1991. *Ecological Definitions of Old-Growth Douglas-Fir Forests*. In: Wildlife and Vegetation of Unmanaged Douglas-Fir Forests. Gen. Tech. Rep. PNW-GTR-285. Portland, OR: USDA, Forest Service, Pacific Northwest Forest and Range Experiment Station, pp. 61-69.

FRANKLIN, J. F., SPIES, T. A., 1991. Ecological Definitions of Old-Growth Douglas-Fir Forests. En: Wildlife and Vegetation of Unmanaged Douglas-fir Forests, tech. coords. L F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, pp. 61-69. Gen. Tech. Rep. PNW-GTR-285, USDA Forest Service, Portland, Oregon.

FRANKLIN, J. F., SPIES, T. A., VAN PELT, R., CAREY, A. B., THORNBURG, D. A., LINDENMAYER, D. B., HARMON, M. E., KEETON, W. S., SHAW, D. C., BIBLE, K., CHEN, J., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management, Vol. 155 (2002), pp. 399-423.

FRELICH, L. E., REICH, P. B., 2003. Perspectives on development of definitions and values related to old-growth forests. Environmental Review, 11: 9-22. http://dx.doi.org/10.1139/a03-011.

FRELICH, L.E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge.

GAO T, NIELSEN AB, HEDBLOM M. 2015. Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. Ecol Indic.;57(October):420-434. doi:10.1016/j.ecolind.2015.05.028.

GARCÍA CARDO, O. En preparación. Atlas de la flora singular y amezanada de la provincia de Cuenca. Tesis doctoral, Universidad de Alcala, Alcalá de Henares.

GARCÍA FECED, C., BERGLUND, H. AND STRNAD, M., 2015. Scoping document: information related to European old growth forests. ETC/BD report to the EEA.

GARILLETI, R., ALBERTOS, B. (Coord.) 2012. Atlas y Libro Rojo de los Briófitos Amenazados de España. Ed. Organismo Autónomo Parques Nacionales. Madrid, 288 pp.

GEIB SM, FILLEY TR, HATCHER PG. 2008. Lignin degradation in wood-feeding insects. Proc Natl Acad Sci U S A.;105(35):12932-12937. doi:10.1073/pnas.0805257105.

GIL, E., VILLAR, L., LÓPEZ, F., 1989. Sobre la estructura de un hayedo-abetal virgen en el pirineo occidental: la selva de Aztaparreta (Alto Roncal-Navarra). Acta biol. mont., 1989 (IX) : 225-236.

GILG, O., 2005. Forêts à caractère naturel: caracteristiques, conservation et suivi. Cahiers techniques de l'ATEN, 74. Montpellier. (Se ha utilizado su traducción al ingles: Old-Growth forests: characteristics, conservation and monitoring).

GOLDBERG, E., KIRBY, K., HALL, J., LATHAM, J. 2007. *The ancient woodland concept as a practical conservation tool in Great Britain*. Journal for Nature Conservation 15 (2007) 109—119

GOUIX N. 2013. Gestion forestière et biodiversité, les enjeux de conservation d'une espèce parapluie: Limoniscus violaceus (Coleoptera).

GRINDAL, S. D. BRIGHAM, R. M.. 1999. Impacts of forest harvesting on habitat use by foraging insectivo- rous bats at different spatial scales. Ecoscience, 6: 25-34.

GROVE SJ. 2002. Saproxylic Insect Ecology and the Sustainable Management of Forests. Annu Rev Ecol Syst.;33(1):1-23. doi:10.1146/annurev.ecolsys.33.010802.150507.

GROVE SJ. 2002. Tree basal area and dead wood as surrogate indicators of saproxylic insect faunal integrity: a case study from the Australian lowland tropics. Ecol Indic.;1:171-188. doi:10.1016/S1470-160X(01)00016-4.

HAGEMEIJER, W. J. W., BLAIR, M. J. (eds.). 1997. The EBCC Atlas of European Breeding Birds: their distribution and abundance. T. & A. D. Poyser. London.

HALKKA, A., LAPPALAINEN, L., 2001. *Insights into Europe´s forests protection*. WWF-World Wide Fund For Nature, Gland, Switzerland.

HARMON M. E, FRANKLIN JF, SWANSON FJ,1986. Ecology of coarse woody debris in temperate ecosystems. Adv Ecol Reserch.;15:133-302.

HERMY M, HONNAY O, FIRBANK L, GRASHOF-BOKDAM C, LAWESSON JE. 1999. An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. Biol Conserv. 91(1):9-22. doi:10.1016/S0006-3207(99)00045-2.

HIDALGO, J., VILA, J. 2013. *Les reserves forestals del programa Sèlvans. Resultats i perspectives*. En: MALLARACH, J. M., MONTSERRAT, J., VILA, J., (coord.), 2013. Reptes per preserver els boscos madurs a Catalunya. II Jornades sobre boscos madurs. Santa Coloma de Farners, 2013. Institució Catalana d'Històrica Natural.

HILBERT, J., WIENSCZYK, A., 2007. *Old-growth definitions and management: A literature review*. British Columbia Journal of Ecosystems and Management 8(1):15-31.

HJÄLTÉN J, STENBACKA F, PETTERSSON RB. 2012. Micro and macro-habitat associations in saproxylic beetles: Implications for biodiversity management. PLoS One;7(7). doi:10.1371/journal.pone.0041100.

HOFMEISTER, J., HOSEK, J., BRABEC, M., DVORÁK, D., BERAN, M., DECKEROVÁ, H., BUREL, J., KOIŽ, M., BOROVIOKA, J., JAN BOTÁK, J., VAŠUTOVÁ, M., MALÍOEK, J., PALICE, Z., SYROVÁTKOVÁ, L., STEINOVÁ, J., CERNAJOVÁ, I., HOLÁ, E., NOVOZÁMSKÁ, E., CÍŽEK, L., IAREMA, V., BALTAZIUK, K., SVOBODA, T., 2015. Value of old forest attributes related to cryptogam species richness in temperate forests: A quantitative assessment. Ecological Indicators, 57 (2015), pp. 497–504. http://dx.doi.org/10.1016/j.ecolind.2015.05.015.

HOLT, R. F., STEEGER, C., 1998. An ecological methodology for old seral identification, assessment and ranking at a landscape scale, in the Nelson Forest Region: Phase II. Kootenay Boundary Land Use Implementation Task Force, Nelson Forest Region, Nelson, B.C. Final report.

HUNTER, M. L., 1989. What constitutes an old-growth stand? J For 87:33–35.

INFANTE, M., HERAS, P., 2008. Briófitos del hayedo de Oieleku. Seguimiento de comunidades epifíticas y lignícolas. Actualizaciones. Memoria diciembre 2008. Dirección de Montes y Medio Natural, Departamento para el Desarrollo del Medio Rural, Diputación Foral de Gipuzkoa.

JÖNSSON N, MÉNDEZ M, RANIUS T. 2004. Nutrient richness of wood mould in tree hollows with the Scarabaeid beetle Osmoderma eremita. Anim Biodivers Conserv.;27(2):79-82.

KAPLAN R., KAPLAN S. 1989. The experience of nature: a psychological perspective. Cambidge University Press. Cambidge, New York.

KEETON W. S., M. CHERNYAVSKYY, G. GRATZER, M. MAIN‐KNORN, M. SHPYLCHAK, AND Y. BIHUN. 2010. Structural characteristics and aboveground biomass of old‐growth spruce-fir stands in the eastern Carpathian mountains, Ukraine. Plant Biosystems, 144 (1) http://dx.doi.org/10.1080/11263500903560512

KEETON, W.S. 2006. Managing for late-successional/old-growth characteristics in northern hardwood-conifer forests. Forest Ecology and Management 235 (2006) 129–142

KIMMINS, J. P., 2003. Old-growth forest: an ancient and stable sylvan equilibrium, or a relatively transitory ecosystem condition that offers people a visual and emotional feast? Answer – it depends. For Chron 79:429–440.

KNEESHAW, D. D. Y BURTON, P. J., 1998. Assessment of functional old-growth status: a case study in the Sub-boreal Spruce Zone of British Columbia, Canada. Natural Areas Journal 18:293–308.

KUNZ T. H. 1982. Roosting ecology. A T. H. Kunz (ed.). Ecology of bats. Plenum press. New York. Pp 1-55.

KUSCH, J. IDELBERGER, S. 2005. Spatial and temporal variability of bat foraging in a western JIMÉNEZ, F.J., GORDO, F.J. GONZÁLEZ, A. 2006. Manual sobre criterios de gestión forestal compatibles con la conservación de las especies de aves y quirópteros asociados a hábitats forestales. Junta de Castilla y León.

LACHAT T, WERMELINGER B, GOSSNER MM, BUSSLER H, ISACSSON G, MÜLLER J. 2012. Saproxylic beetles as indicator species for dead-wood amount and temperature in European beech forests. Ecol Indic.;23:323-331. doi:10.1016/j.ecolind.2012.04.013.

LARRIEU, L., GONIN, P. 2010 L'indice de biodiversité potentielle ou IBP : un outil pratique au service de la biodiversité ordinaire des forêts. Forêt-entreprise n°190-Janvier 2010 http://www.foretpriveefrancaise.com/ibp/

LASSAUCE A, LARRIEU L, PAILLET Y, LIEUTIER F, BOUGET C. 2013. The effects of forest age on saproxylic beetle biodiversity: Implications of shortened and extended rotation lengths in a French oak high forest. Insect Conserv Divers.;6:396-410. doi:10.1111/j.1752-4598.2012.00214.x.

LOMBARDI, F., CHERUBINI, P., TOGNETTI, R., COCOZZA, C., LASERRE, B., MARCHETTI, M., 2013. *Investigating biochemical processes to assess deadwood decay of beech and silver fir in Mediterranean mountain forests*. Annals of Forest Science (2013) 70:101–111. http://dx.doi.org/ 10.1007/s13595-012-0230-3.

LOMBARDI, F., CHIRICI, G., MARCHETTI, M., TOGNETTI, R., LASERRE, B., CORONA, P., BARBATI, A., FERRARI, B., DI PAOLO, S., GIULIARELLI, D., MASON, F., IOVINO, F., NICOLACI, A., BIANCHI, L., MALTONI, A., TRAVAGLINI, D., 2010. *Deadwood in forest stands close to old-growthness under Mediterranean conditions in the Italian Peninsula*. L'Italia Forestale e Montana, 65 (5): 481-504. http://dx.doi.org/10.4129/ifm.2010.5.02.

LONSDALE D, PAUTASSO M, HOLDENRIEDER O. Wood-decaying fungi in the forest: Conservation needs and management options. Eur J For Res. 2008;127(1):1-22. doi:10.1007/s10342-007-0182-6.

LORBER D., VALLAURI, D., 2007. Contribution à l'analyse des forêts anciennes de Méditerranée. 1. Critères et indicateurs du gradient de naturalité. Rapport WWF, Marseille, 95 pages.

LUYSSAERT S, E D SCHULZE, A BÖRNER, A KNOHL, D HESSENMÖLLER, B E. LAW, PH CIAIS, J GRACE. 2008. Old-growth forests as global carbon sinks. Nature 455, 213-215 (11 September 2008) | doi:10.1038/nature07276

MALLARACH, J. M., MONTSERRAT, J., VILA, J., (coord.), 2013. *Reptes per preserver els boscos madurs a Catalunya*. II Jornades sobre boscos madurs. Santa Coloma de Farners, 2013. Institució Catalana d'Històrica Natural.

MALLER C, TOWNSEND M, ST LEGER L, HENDERSON-WILSON C, PRYOR A, PROSSER L, MOORE M. 2009. Healthy Parks, Healthy People: The Health Benefits of Contact with Nature in a Park Context. The Goerge Wright Forum; 26(2): 51-83

MANSOURIAN, S., ROSSI, M., VALLAURI, D., 2013. Ancient Forests in the Northern Mediterranean: Neglected High Conservation Value Areas. Marseille: WWF France, 80 p.

MARCOT, B. G., HOLTHAUSEN, R. S., TEPLY, J., CARRIER, W. D., 1991. Old-growth inventories: status, definitions, and visions for the future. In: Wildlife and vegetation of unmanaged Douglas-fir forests. Ruggiero L. F., Aubry K. B., Carey A.

B., Huff M. H. (technical coordinators). U.S. Department of Agriculture, Forest Service, Portland, Oreg. General Technical Report PNW-285.

MARINÉ, R., DALMAU, J. 2000. Uso del hábitat por el mochuelo boreal (Aegolius funereus) en Andorra (Pirineo Oriental) durante el período reproductor. Ardeola, 47: 29-36.

MARTIKAINEN P, SIITONEN J, PUNTTILA P, KAILA L, RAUH J. 2000. Species richness of Coleoptera in mature managed and old-growth boreal forests in southern Finland. Biol Conserv.;94:199-209. doi:10.1016/S0006-3207(99)00175-5.

MCPFE, *2007. State of Europe's forests 2007. The MCPFE report on sustainable forest management in Europe*. Ministerial Conference on the Protection of Forests in Europe MCPFE Liaison Unit Warsaw, Poland.

MÉNDEZ, M. *Los insectos saproxílicos: qué sabemos y qué nos gustaría saber*. Boletín Sociedad Entomológica Aragonesa, nº 44 (2009): 505–512.

MENZEL, J. M., MENZEL, M. A., KILGO, J. C., FORD, W. M., EDWARDS, J. W. MCCRACKEN, G. F. 2005. Effect of habitat and foraging height on bat activity in the coastal plain of south Carolina. Journal of Wildlife Management, 69(1):235-245.

MERINERO, S., 2015. Ecología y conservación del liquen Lobarina scrobiculata (Scop.) Nyl. Ex Cromb. en la Península Ibérica. Tesis Doctoral. Universidad Rey Juan Carlos.

MESSIER, C., KNEESHAW, D. D., 1999. Thinking and acting differently for sustainable management of the boreal forest. Forestry Chronicle 75(6):929–938.

MICÓ E, JUÁREZ M, SÁNCHEZ A, GALANTE E. 2011. Action of the saproxylic scarab larva Cetonia aurataeformis (Coleoptera: Scarabaeoidea: Cetoniidae) on woody substrates. J Nat Hist.;45(41-42):2527-2542. doi:10.1080/00222933.2011.596953.

MIKUSINSKI G., M. GROMADZKI AND P. CHILARECKI. 2001. Woodpeckers as indicators of forest bird diversity. Conservation Biology, 15 (1):208-217

MONSERRAT, J., 2013. Estat de conservació dels boscos madurs de Catalunya. L'Atzavara, 22: 73-78.

MOSSELER, A., LYNDS, J. A., MAJOR, J. E., 2003. *Old-growth forests of the Acadian Forest Region*. Environ Rev 11:S47-S77.

MÜLLER J, BUßLER H, BENSE U, ET AL. 2005. Urwald relict species – Saproxylic beetles indicating structural qualities and habitat tradition. Waldökologie online;2:106-113.

MUÑOZ, P., SCHWENDTNER, O., 2005. *La selvicultura hacia bosques maduros, herramienta para la conservación de la biodiversidad en los hayedos de Navarra*. Primeras Jornadas Técnicas sobre árboles viejos, bosques maduros y su biodiversidad. http://www.arbolesviejos.org/documentos.

NIETO A, ALEXANDER KNA. 2010. European Red List of Saproxylic Beetles. Luxembourg: International Union for Conservation of Nature. Office of the European Unio.

NOCENTINI, S. 2010. *Old-growth forests in Italy: inputs for forest management and planning in areas with long-standing human impact*. L'Italia Forestale e Montana, 65 (5): 545-555. http://dx.doi.org/10.4129/ifm.2010.5.06.

ØKLAND B. 1996. A comparison of three methods of trapping saproxylic beetles. Eur J Entomol.;93(2):195-209.

OLD-GROWTH DEFINITION TASK GROUP, 1986. Interim Definitions for OldGrowth Douglas-Fir and Mixed-Conifer Forests in the Pacific Northwest and California. USDA Forest Service. Pacific Northwest Research Station. Research Note PNW-447, July 1986.

OLIVER, C. D., LARSON, B. C., 1996. *Forest stand dynamics. Update edition*. John Wiley and Sons, Inc.

PAILLET, Y, C. PERNOT, V. BOULANGER, N. DEBAIVE, M. FUHR, O. GILG, F. GOSSELIN. 2015. *Quantifying the recovery of old*-growth attributes in forest reserves: A first reference for France. Forest Ecology and Management 346 (2015) 51–64.

PAILLET, Y., BERGÈS, L, HJÄLTÉN, J., ÓDOR, P., AVON,C., BERNHARDT-RÖMERMANN, M., RIENK-JAN BIJLSMA, R., DE BRUYN, L., FUHR, M., GRANDIN, U., KANKA, R., LUNDIN, L., LUQUE, S., MAGURA, T., MATESANZ, S., MÉSZÁROS, I., SEBASTIÀ, M. T., SCHMIDT, W., STANDOVÁR, T., TÓTHMÉRÉSZ, B., UOTILA, A., VALLADARES, F., VELLAK, K., VIRTANEN, R., 2010. *Biodiversity Differences between Managed and Unmanaged*

Forests: Meta-Analysis of Species Richness in Europe. Conservation Biology, Volume 24, No. 1, 101-112. http://dx.doi.org/10.1111/j.1523-1739.2009.01399.x

PALAU, J, GARRIGA, M., 2013. *Inventari i conservació de boscos madurs al Parc Natural del'Alt Pirineu.* En: MALLARACH, J. M., MONTSERRAT, J., VILA, J., (coord.), 2013. *Reptes per preserver els boscos madurs a Catalunya.* II Jornades sobre boscos madurs. Santa Coloma de Farners, 2013. Institució Catalana d'Històrica Natural.

PARK, BJ; TSUNETSUGU Y; KASETANI T; KAGAWA T; MIYAZAKI Y .2010. «The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): evidence from field experiments in 24 forests across Japan». Environmental Health and Preventive Medicine 15 (1): 18-26. doi:10.1007/s12199-009-0086-9.

PARVIAINEN, J., LITTLE, D., DOYLE, M., O'SULLIVAN, A., KETTUNEN, M., KORHONEN, M., (eds.), 1999. Research in Forest Reserves and Natural Forests in European Countries. EFI Proceedings N° 16, 1999. European Forest Institute.

POTAPOV P., YAROSHENKO A., TURUBANOVA S., DUBININ M., LAESTADIUS L., THIES C., AKSENOV D., EGOROV A., YESIPOVA Y., GLUSHKOV I., KARPACHEVSKIY M., KOSTIKOVA A., MANISHA A., TSYBIKOVA E., ZHURAVLEVA I. 2008. Mapping the World's Intact Forest Landscapes by Remote Sensing. Ecology and Society, 13 (2)

POTAPOV, P., HANSEN, M. C., LAESTADIUS L., TURUBANOVA S., YAROSHENKO A., THIES C., SMITH W., ZHURAVLEVA I., KOMAROVA A., MINNEMEYER S., ESIPOVA E. 2016. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. Science Advances, 2017; 3:e1600821.

POTENZA, G., FASCETTI, S., 2010. Lobarion as indicator of ancient forest in the Appennino Lucano (Basilicata-southern Italy). L'Italia Forestale e Montana / Italian Journal of Forest and Mountain Environments 65 (6): 765-774, 2010

QUINTO J, MARCOS-GARCÍA MÁ, DÍAZ-CASTELAZO C, et al. Breaking down Complex Saproxylic Communities: Understanding Sub-Networks Structure and Implications to Network Robustness. PLoS One. 2012;7(9). doi:10.1371/journal.pone.0045062.

QUINTO J, MARCOS-GARCÍA MDLÁ, BRUSTEL H, GALANTE E, MICÓ E. 2013. Effectiveness of three sampling methods to survey saproxylic beetle assemblages in Mediterranean woodland. J Insect Conserv.;17(4):765-776. doi:10.1007/s10841-013-9559-7.

QUINTO J, MICÓ E, MARTÍNEZ-FALCÓN AP, GALANTE E, MARCOS-GARCÍA MDLÁ. 2014. Influence of tree hollow characteristics on the diversity of saproxylic insect guilds in Iberian Mediterranean woodlands. J Insect Conserv.;18(5):981-992. doi:10.1007/s10841-014-9705-x.

RANIUS T, JANSSON N. 2000. The influence of forest regrowth , original canopy cover and tree size on saproxylic beetles associated with old oaks. Biol Conserv.;95:85-94.

RANIUS T. 2002. Influence of stand size and quality of tree hollows on saproxylic beetles in Sweden. Biol Conserv.;103:85-91. doi:10.1016/S0006-3207(01)00124-0.

RANIUS T. 2002. Osmoderma eremita as an indicator of species richness. Biodivers Conserv.;11:931-941.

RECALDE JI. 2010. «Lista Roja europea de escarabajos saproxílicos» (Coleoptera) presentes en la Península Ibérica: actualización y perspectivas. Heteropterus Rev Enomología.;10(2):157-166.

REDOLFI L., S. ROSSI DE GASPERIS, L. FIORE, C. BATTISTI AND G. M. CARPANETO. 2016. The importance of dead wood for hole-nesting birds: a two years study in three beech forests of central Italy. Israel Journal of Ecology & Evolution. DOI: 10.1080/15659801.2016.1191168

ROBERGE J. M., G. MIKUSINSKI AND S. SVENSSON. 2008. The white-backed woodpecker: umbrella species for forest conservation planning? Biodiversity Conservation 17:2479–2494. DOI 10.1007/s10531-008-9394-4

ROBLES H., C. CIUDAD AND E. MATTHYSEN. 2011. Tree-cavity occurrence,cavity occupation and reproductive performance of secondary cavity-nesting birds in oak forests:The role of traditional management practices. Forest Ecology and Management 261 (2011) 1428–1435

ROBLES H., C. CIUDAD, R. VERA, P. P. OLEA, F. J. PURROY AND E. MATTHYSEN. 2007. Sylvopastoral management and conservation of the middle spotted woodpecker at the south-western edge of its distribution range. Forest Ecology and Management, 242: 343–352

ROSE, 1988. Phytogeographical and ecological aspects of Lobarion communities in Europe. Botanical Journal of the Linnean Society (1988), 96: 69-79

ROSE, F., 1985. The old forests of Western Europe and their epiphytic lichens. British Lichen Society Bulletin, 56: 1–8

ROSE, F., 1999. Indicators of ancient woodland - the use of vascular plants in evaluating ancient woods for nature conservation. British Wildlife 10: 241–251.

ROSSI, M., VALLAURI, D. 2013. *Evaluer la naturalité. Guide pratique, version 1.2.* WWF, Marseille, 154 pag. http://www.foretsanciennes.fr/wp-content/uploads/Rossi-Vallauri-2013.pdf

ROTHERHAM, I. D., 2011. A landscape history approach to the assessment of ancient woodlands. En: WALLACE, E. B. (ed.), 2011.Woodlands: Ecology, Management and Conservation. Nova Science Publishers.

ROZAS, V., 2001. Dinámica forestal y tendencias sucesionales en un bosque maduro de roble y haya de la zona central de la Cornisa Cantábrica. Ecología, N° 15, 2001, pp. 179-211.

ROZAS, V., 2004. A dendroecological reconstruction of age structure and past management in an old-growth pollarded parkland in northern Spain. Forest Ecology and Management 195 (2004) 205-219.

ROZAS, V., 2005. Heterogeneidad estructural y patrones espaciales en un bosque caducifolio maduro: implicaciones para la restauración y la gestión sostenible. En: S.E.C.F.-Gobierno de Aragón (eds.), Actas 4° Congreso Forestal Español. CD-Rom. Imprenta Repes, S.C. Zaragoza. Tomo 1, pág. 145.

ROZAS, V., FERNÁNDEZ, J. A., 2000. Competition, mortality, and development of spatial patterns in two Cantabrian populations of Fagus sylvatica L. Anales del Jardín Botánico de Madrid, 58 (1) 2000, pp. 117-131.

RUSSO D, CISTRONE L, GARONNA AP. 2010. Habitat selection by the highly endangered long-horned beetle Rosalia alpina in Southern Europe: a multiple spatial scale assessment. J Insect Conserv.;15(5):685-693. doi:10.1007/s10841-010-9366-3.

RUSSO D., L. CISTRONE G. JONES MAZZOLENI S. 2004. Roost selection by barbastelle bats (Barbastella Barbastellus, Chiroptera: Vespertilionidae) in beech woodlis of central Italy: consequences for conservation. Biological Conservation, 117: 73-81.

SALA, O. E., JACKSON, R. B., MOONEY, H. A., HOWARTH, R. W., 2000. Methods in ecosystem science. Springer, New York. SANITJAS, A., 2013. Inventari de rodals amb un cert grau de maduresa i reserves forestals al Parc Natural del Montseny. En: MALLARACH, J. M., MONTSERRAT, J., VILA, J., (coord.), 2013. Reptes per preserver els boscos madurs a Catalunya. II Jornades sobre boscos madurs. Santa Coloma de Farners, 2013. Institució Catalana d'Històrica Natural.

SÁNCHEZ A, MICÓ E, GALANTE E, JUÁREZ M. 2017. Chemical transformation of Quercus wood by Cetonia larvae (Coleoptera: Cetoniidae): An improvement of carbon and nitrogen available in saproxylic environments. Eur J Soil Biol.;78:57-65. doi:10.1016/j.ejsobi.2016.12.003.

SÁNCHEZ A, RECALDE JI. 2012. Limoniscus violaceus. In: Bases Ecológicas Preliminares Para La Conservación de Las Especies de Interés Comunitario En España: Invertebrados. Madrid: Ministerio de Agricultura, Alimentación y Medio Ambiente.:229-231.

SANDSTRÖM U. 1992. Cavities in trees: Their occurrence, formation and importance for hole-nesting birds in relation to silvicultural practice. Swedish University of Agricultural Sciences, Uppsala.

SCHULZE, E. D, WIRTH, C., MOLLICONE, D., ZIEGLER, W., 2005. Succession after stand replacing disturbances by fire, windthrow and insects in the dark Taiga of Central Siberia. Oecologia 146:77–88

SCHWENDTNER, O., 2014. Los hayedos maduros como referencia para la gestión selvícola. Navarra Forestal, 33: 10-13..

SCHWENDTNER, O., CÁRCAMO, S., 2010. *Bosques viejos y árboles viejos: importancia para la fauna*. En: JORDÁN, F. M., MARTÍNEZ, C. (coords.), 2010. *Gestión y conservación de la fauna salvaje*. IV Encuentro del día forestal mundial. Ayuntamiento de Ponferrada.

SCHWENDTNER, O., RECALDE, I., ALCALDE, J. T., GÓMEZ, J., CÁRCAMO, S., 2005. *Importancia de los árboles senescentes y la madera muerta en la gestión de los bosques naturales*. En: S.E.C.F.-Gobierno de Aragón (eds.), Actas 4° Congreso Forestal Español. CD-Rom. Imprenta Repes, S.C. Zaragoza. Tomo 1, pág. 146.

SEDGELEY, J.A. O'DONNELL, C.F.J. 1999b. Roost selection by the long-tailed bat Chalinolobus tuberculatus in temperate New Zeland rainforest and its implication for conservation of bats in managed forests. Biological Conservation, 88:261-276.

SIMARD, S. W., ASAY, A. K., BEILER, K. J., BINGHAM, M. A., DESLIPPE, J. R., XINHUA, H., PHILIP, L. J., SONG, Y., TESTE, F. P. (2015). Resource transfer between plants through ectomycorrhizal fungal networks. In: Horton TR, ed. Mycorrhizal networks. Springer berlin Heidelberg.

SIERRO, A. 1999. Habitat selection by barbastelle bats (Barbastella barbastellus) in the Swiss Alps (Valais). Journal of Zoology, 248:4:429-432.

SONG C, IKEI H, MIYAZAKI Y. 2016. Physiological effects of nature therapy: a review of the research in Japan. International Journal of Environmental Research and Public Health;13 (8). doi: 10.3390/ijerph13080781.

SPEIGHT MCD. 1989. Saproxylic invertebrates and their conservation. Nat Environ Ser.;42:78.

SPIES, T. A., FRANKLIN, J. F., 1988. Old-growth and forest dynamics in the Douglas-fir region of western Oregon and Washington. Natural Areas Journal 8:190–201.

SPIES, T. A., 2004. Ecological concepts and diversity of old-growth forests. Journal of Forestry, 102: 14-20.

SPIES, T. A., FRANKLIN, J. F., 1996. *The diversity and maintenance of old-growth forests*. En: SZARO, R. C., JOHNSTON, D. W. (eds.), 1996. *Biodiversity in Managed Landscapes: Theory and Practice*. Oxford University Press. New York. 778 p.

STOKLAND J. 2004. Development of dead wood indicators for biodiversity monitoring: experiences from Scandinavia. In: MARCHETTI M, (ed). Monitoring and Indicators of Forest Biodiversity in Europe – From Ideas to Operationality. EFI Workshop, 12–15 November 2003. Findland: European Forest Institute;:207–226.

SWYSTUN, M. B., PSYLLAKIS, J. M. BRIGHAM, R. M. 2001. The influence of residual tree patch isolation on habitat ude by bats in central British Columbia. Acta Chiropterologica, 3(2):197-201.

TELLERÍA, J.L. 1992. Gestión forestal y conservación de las aves en España peninsular. Ardeola, 39: 99-114.

THIBAULT, J. C. PRODON, R., VILLARD, P., SEGUIN, J. F. 2006. Habitat requirements and foraging behaviour of the Corsican nuthatch Sitta whiteheadi. Jojurnal of Avian Biology, 37 (5): 477–486.

TÍSCAR P.A. 2006. La gestión próxima a la naturaleza en el nuevo paradigma de la ciencia forestal. En: TÍSCAR P.A. (coord.): La Gestión Forestal Próxima a la Naturaleza. Prosilva, pp. 15-39.

TISCAR, P. A., LINARES, J. C., 2011. Pinus nigra subsp. salzmannii forests from southeast Spain: using structure and process information to guide management. En: FRISIRAS, C. T. (ed.), 2011. Pine Forest: Type, threats and management. Nova Science Publishers.

ULYSHEN MD. 2015. Insect-mediated nitrogen dynamics in decomposing wood. Ecol Entomol.;40(S1):97-112. doi:10.1111/een.12176.

ULYSHEN MD. 2016. Wood decomposition as influenced by invertebrates. Biol Rev.;91(1):70-85. doi:10.1111/brv.12158.

VALLAURI D, ANFRÉ J, GÉNOT J-C, DE PALMA, J-P, EYNARD-MARCHET, R (Coords). 2010. Biodiversité, naturalité, humanité. Pour inspires la gestion des forets. WWF/Tec&Doc, 474 pp. París.

VALLAURI, D., GREL, A., GRANIER, E., DUPOUEY, J. L., 2012. *Les forets de Cassini. Analyse quantitative et comparaison avec les forets actuelles*. Rapport WWF/INRA, Marseille, 64 pages + CD.

VAUGHAN, N., J. GARETH, HARRIS, S. 1997. Habitat use by bats (Chiroptera) asssessed by means of a broad-bi acoustic method. Journal of Applied Ecology, 34:716-730.

VV.AA., 2009. Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en España. Madrid: Ministerio de Medio Ambiente, y Medio Rural y Marino.

WELLS, R. W., LERTZMAN, K. P., SAUNDERS, S. C., 1998. *Old-growth definitions for the forests of British Columbia, Canada*. Nat Areas J 18:279–292

WESOŁOWSKI, T. 2007. Lessons from long-term hole-nester studies in a primeval temperate forest. Journal of Ornithology, 148 (2): 395–405.

WIRTH C, MESSIER C, BERGERON Y, FRANK D, FANKHÄNEL A. 2009. *Old-Growth Forest Definitions: a Pragmatic View*. In: Wirth Christian et al, ed. *Old-Growth Forests*. Berlin Heidelberg: Springer Verlag; 2009:11-33. doi:10.1007/978.

WULF M. 1997. Plant species as indicators of ancient woodland in northwestern Germany. J Veg Sci.;8:635-642. doi:10.2307/3237367.

ZHOU G, LIU S, LI Z, ZHANG D, TANG X, ZHOU C, YAN J, MO, J. 2006. Old-Growth Forests Can Accumulate Carbon in Soils. Science (80-). 2006;314(5804):1417 LP - 1417.

ZUO J, CORNELISSEN JHC, HEFTING MM. 2016. The (w)hole story: Facilitation of dead wood fauna by bark beetles? Soil Biol Biochem.;95(April):70-77. doi:10.1016/j.soilbio.2015.12.015.

EUROPARC-Spain Working Group on forests, in an annual meeting. Parc Natural del Alt Pirineu (November 2013).