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Protecting old-growth forests in Europe

A review of scientific evidence to inform policy implementation

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I. Executive Summary

Introduction, objectives, and methods

Primary and old-growth forests in the EU are extremely rare and threatened, yet play an irreplaceable role in biodiversity conservation and the provision of other ecosystem services such as carbon storage. Recognising this, the EU Biodiversity Strategy for 2030 sets the target to strictly protect all remaining primary and old-growth forests. This target is part of a wider goal to protect 30% of EU land and to dedicate 10% of EU land for strict protection. Strict protection of the remaining EU primary and old-growth forests is a first and crucial step to ensure their long-term conservation. Despite the importance of this target, its implementation is currently prevented by several unanswered questions that require discussion among science and policy experts. This includes, for example, the question of how old-growth forest should be defined and where remaining primary and old-growth forests are located. In addition, there are ongoing discussions of how to best support strict protection of primary and old-growth forests and how to maintain and restore biodiversity, for example by preserving and allowing old-growth attributes to develop in forests that are managed for purposes other than conservation. This study specifically focuses on old-growth forests, given the increasing debate around this type of forest in Europe and their importance for forest biodiversity, but also includes information that is relevant for primary forests in a wider sense. The objective of this study is to inform discussions surrounding the implementation of the EU Biodiversity Strategy for 2030 target to strictly protect primary and old-growth forests. The methods of this study included a review of scientific literature on (i) Defining old-growth forests, (ii) Evidence of old and old-growth forests in Europe; (iii) Approaches to protect old-growth forests and to maintain and develop old-growth attributes, (iv) Associated benefits, consequences, and potential trade-offs of old-growth forest protection and management and development of old-growth forest attributes; and (v) Policy implications. The study further incorporates outcomes of a dedicated workshop held with twenty scientific experts; findings of this workshop can be found throughout the report.

Main findings

Chapter 2: Defining old-growth forests

One major obstacle in implementing the target to strictly protect all remaining old-growth forests lies in its definition. Across Europe and in the international literature, many terms describing high conservation value forests exist and are sometimes used interchangeably with the term old-growth forest. This then causes difficulties when informing policy and management. Collectively, the terms typically fall into one of two groups: (i) Terms describe forests of any age that have a history of minimal or absence of human disturbance, most often termed "*primary forest*" and (ii) Terms that describe old forests or forests in a late-successional stage with varying degrees of human disturbance, often termed "*old-growth forest*". There can be an overlap between old-growth forest and primary forest in the case that a primary forest is also of a late successional stage.

Given the popularity of the term "*primary forest*" to describe a wide variety of high conservation value forests, there have been initiatives at the international level to define it, with the result of varying definitions. Some international processes have provided a definition of primary forest specifically for use in Europe due to the rareness of forests without a legacy of human impact. For example, the definition given by the Convention on Biological Diversity (CBD) includes forests that have been modified directly for human use. Other experts, such as Buchwald (2005), have suggested that the concept of naturalness can be used as a framework for defining primary forests in a European context. Within the Buchwald (2005) framework, old-growth forests are integrated as a level of naturalness.

Difficulties adopting the term old-growth forest in Europe may be partly related to the origin of the old-growth definition. The first formal definition of 'old-growth forest' was created by the United States Department of Agriculture (USDA) Forest Service in 1986 in the Pacific Northwest region of the United States in response to the continued decline of old-growth forests and the loss of habitat of old-growth dependent species. The definition was also intended to guide uniform definitions of old-growth forest for all forest types of the United States. However, it was found to be inadequate due to the vast diversity of forest types. As a result, different types of definitions have been proposed across the US and beyond.

Definitions of old-growth forest are commonly based on either structural attributes or successional processes, or a combination of both. However, the different definitions have been criticised for several reasons. Structural definitions, for example, do not account for the vast diversity of forest types. Among structural definitions, especially those mainly based on tree age are considered to be problematic because maximum tree age depends on the species and the environment. Definitions based on successional processes have also been criticised because they do not account for diversity in and among forest types, but also because they are thought to be based on outdated ecological theory. New theories acknowledge the non-linearity of forest development and suggest that an old-growth forest should remain protected after a stand replacing large-scale disturbance, as it maintains its high conservation value.

Lack or absence of human disturbance is a common criterion included in old-growth definitions and has been criticised because evidence has shown that forests can recover from human disturbance to develop old-growth attributes or can be actively managed to develop these attributes. These arguments are also acknowledged in Europe, where the term "*secondary old-growth*" (i.e. forests that have recovered from human disturbance in the absence of management and have developed old-growth attributes over time) is highly relevant given the widespread intensive land-use that has resulted in very few primary forests. Suggestions have been made for developing "old-growthness" indices that help characterise the degree to which a forest meets the definition of old-growth and allow for measuring of progress towards developing secondary old-growth forests after the stop of management.

Overall, there is clear progress towards reaching a definition of old-growth forest in Europe, and indicies of old-growthness and levels of naturalness represent favourable options for developing such a defintion. Overall, the chosen definition should not be too strict in the context of the EU, and rather flexible to also include forests with some management legacy given the rarity of forests with a history of minimal human intervention and the high importance of secondary old-growth forests for biodiversity conservation. Using levels of naturalness and old-growth indicators may be a potential solution to encompass a wider range of forests.

Chapter 3: Evidence of old and old-growth forests in Europe

Efforts to identify and map old-growth and primary forests on a local and national scale in Europe have been numerous, although often incomplete and guided by many different definitions. Recently, huge progress has been made to gather and compile the results of these studies, as well as to standardise the definitions used. This effort, achieved by Sabatini et al., (2018) and Sabatini et al., (2020b, not certified by peer-review) has resulted in the most comprehensive maps of European primary forests to date, known as the European Primary Forest Database (EPFD) v1.0 and soon to be published v2.0. However, data gaps are still prevalent for some countries in the EPFD 2.0., which should be filled to effectively protect primary and old-growth forests. The results of these studies indicate that primary and old-growth forests are very rare in Europe and there is significant loss of both ongoing today. In ad dition, remaining European primary and old-growth forests are unevenly distributed and many European forest types have very little or no such forests left. The scarcity of primary and old-growth forests and their poor representation of European forest types underlines the need to develop secondary old-growth forests to create a more representative network of such high conservation value forests. In response to this situation, improved maps of European primary forests are crucially needed and should continue to be produced while discussions of definitions are ongoing. Information on locations and spatial extent will be useful regardless of the definition used, as previous studies show it is possible to effectively homogenise different definitions across Europe.

Apart from mapping, forest inventory-based reports detailing information on primary and old-growth forests (i.e. total area and data related to tree and stand age of forests) are also available, mainly in the Forest Europe *State of Europe's Forests* reports. However, these reports are characterised by incomplete country reporting and data reliability is negatively impacted by inconsistency in methods across countries and over time. Therefore, past trends of European old-growth forest area and related data on tree/stand age should only be analysed when presented in one report with consistent data coverage. Due to the data, limitations, these trends are insufficient to guide policy in relation to old-growth forests. While age is a common criteria of old-growth forest definitions, tree lifespan is very species and site dependent; thus, making it difficult to adopt a common age threshold to identify old forests. Identification of veteran trees may be a useful method to map old-growth forests without determining their exact age.

Chapter 4: Approaches to protect old-growth forests and to maintain and develop old-growth forest attributes

Forests serve a different portfolio of ecosystem services depending on location, ecological quality, and socio-economic demands. While many services can be simultaneously provided in multifunctional forest landscapes, there is a need to spatially separate certain services. Specifically, the remaining EU primary and old-growth forests can only be preserved through strict protection, without natural resource extraction. In addition to strict protection, maintaining and developing old-growth attributes in the forests that will remain managed for purposes other than conservation can complement the strictly protected forest area network. Therefore, the diversity of forest types, management traditions and socio-economic context in Europe is crucial to consider in the efforts to support the conservation of primary and old-growth forests. A considerable share of the forest area in Europe is part of the Natura 2000 network. At national level, additional schemes of protected areas exist. These may include other strict protection schemes but also areas that have clearly defined conservation management objectives that require active interventions for preserving/re-introducing specific forest types and attributes or providing favourable conditions for threatened species.

Currently, more than half of Europe's primary forests are without strict protection status. Upgrading the protection of these forests should be prioritised as the first step in ensuring their conservation. However, the remaining primary and old-growth forests represent only around 3% of the EU's land area and therefore strictly protecting them is not enough to meet the 10% strict protection of land area target of the EU Biodiversity Strategy. Implementing the target is an opportunity to significantly increase the share of (secondary) primary/old-growth forests in the long run, which would be very beneficial from a conservation perspective.

The remaining EU primary and old-growth forests are small and often also poorly connected. Strictly protecting areas in the immediate neighbourhood of remaining primary forests can considerably contribute to the effectiveness of conservation actions. This should be complemented with spatial elements that enhance connectivity between strictly protected areas. Designing these areas based on concepts of minimum dynamic area or wilderness area would ensure their long-term conservation by providing sufficient area for natural disturbance regimes and species populations. Planning the expansion of the strictly protected forest area network needs, however, to take into account also other factors such as land ownership. In some European countries, private ownership of forest land is high and identifying additional areas for strict protection of sufficient size to serve the protection purpose may turn out to be difficult. Systematic conservation planning could help in planning how strictly protected areas should be set aside to develop towards old-growth forests in the future.

As a complement to a network of strictly protected areas, biodiversity conservation measures incorporated into integrative forest management approaches (i.e. approaches that integrate biodiversity conservation and other ecosystem service objectives into managed forests) can support protecting and developing old-growth patches and old-growth attributes in multi-functional forests as well as improve habitat connectivity between primary and old-growth forests.

Chapter 5: Associated benefits, consequences, and potential trade-offs of old-growth forest protection and management and development of old-growth forest attributes

The benefits arising from the expansion of the strictly protected area network are numerous and include, but are not limited to: increased forest resilience, biodiversity conservation, habitats for rare and threatened species, and space for natural processes. It will, however, not be possible to simultaneously ensure all forest ecosystem services in the same location. Therefore, there is a need to manage conflicting demands, protection, and management objectives, which requires an in-depth analysis of potential trade-offs.

Setting-aside managed forest to establish secondary old-growth forests has several direct consequences inside or directly surrounding the newly designated forest under strict protection, including inter alia wood production losses and modified disturbance regimes. Further consequences and potential trade-offs may occur outside of the newly designated strict protection areas depending on the scale and local context. These may involve changes in management of the remaining forests in the EU, leakage effects in forests outside of Europe, or spill-over effects to other sectors (e.g. energy or construction). The overall impact of implementing the related target of the EU Biodiversity Strategy to strictly protect 10% of EU land area will thus be interlinked with decisions taken not only in the remaining forests outside of newly designated strict forest reserves, but also in other policy sectors.

Developing old-growth attributes through integrative forest management approaches also provides multiple ecological benefits and increased forest resilience when compared to forest management that strongly prioritises wood production over other ecosystem services. Integrative forest management approaches have shown the potential to contribute to forest biodiversity conservation especially if implemented on the large scale of managed forests, but they also have limitations, for example in the conservation of certain species e.g., with a particularly high deadwood demand. Such approaches are therefore to be seen as complementary to strictly protected forest areas. However, more systematic data and assessment of the benefits, limitations, and trade-offs associated with integrative forest management approaches are crucially needed. Such will provide not only a better understanding of the implications on the enterprise level, but also represent a sound basis for elaborating economic incentives, for example payments for ecosystem services schemes. These incentives could help to make implementing such approaches more attractive to forest managers and land owners in the long-term.

Chapter 6: Policy implications

In the course of the study's analysis, a number of potential policy implications became apparent. These are to be regarded as viewpoints from a scientific perspective without any intention to pre-empt any policy choices.

Depending on the choice of definitions, the extent of primary and old-growth forests in Europe could vary from almost non-existent to covering a notable share of existing forests. Concepts of secondary old-growth forest and indices to measure progress in the development of old-growth attributes are considered valuable to guide forest conservation efforts in Europe. It is suggested that in the implementation of the Biodiversity Strategy a general (broad) framework definition of old-growth forests could be combined with regional specifications related inter alia to forest types. Such regional and forest type related criteria could, for example, be used to consider common tree age differences among forest types when identifying old-growth forests.

The review of the evidence on old-growth forests and related tree attributes revealed a lack of consistent pan-European data on tree / forest age and their trends and better data is needed. However, tree age alone is not very useful for the identification of old-growth forests and a diverse set of old-growth forest attributes including e.g. disturbance history, tree species composition, tree layer complexity, DBH distribution, deadwood (quantities, diversity and spatial patterns), and the occurrence and types of tree-related microhabitats are of similar importance. Multiple attributes should be considered in indices of old-growthness, which would be well suited to measure progress towards developing secondary old-growth forest characteristics, and such indices could also be adopted to reflect differences between forest types.

There is strong evidence that the area of remaining primary and old-growth forests is continuing to decline. Given the scarcity of old-growth forests in Europe and the considerable amount of time it takes to restore old-growth features in previously managed forests, there is no alternative to preserving the still existing old-growth forests. As many of these remaining old-growth and primary forests are small and isolated, strictly protecting forests directly adjacent to them would help to improve their conservation. In the case where Natura 2000 areas are surrounding old-growth and primary forests, the management guidelines for these Natura 2000 areas could be adapted to specifically support development of secondary old-growth forests or old-growth attributes. In addition, in order to implement the targets of the EU Biodiversity Strategy it will be necessary in many countries to select new additional strictly protected areas that can develop into future secondary old-growth forests and corridors of green infrastructure.

Biodiversity policy implementation will benefit from forward-looking policy integration. This will help to balance benefits and potential trade-offs that may result from the expansion of the strictly protected area network from the local level for individual landowners to the global level, or in other sectors. Integrating different policies may further enhance existing synergies, for example in relation to climate change adaptation and climate change mitigation.

Different instruments for enhancing the protection of primary and old-growth forests and the development of old-growth attributes within and outside protected areas should be regarded as complementary. As the conservation of particular species or natural development processes will require sufficiently large areas, there is no alternative to strict protection. In the case land owners provide complementary measures to biodiversity conservation in managed forests, this should also be recognised. Well-designed compensation schemes may further encourage the spread of such beneficial practices.

Future policy implementation will need to address how land area protection targets set out in the EU Biodiversity Strategy could best be allocated across land-use types, and to what extent implementation targets could differ between Member States and regions, while taking into consideration the large diversity of forest types and land ownership situations.

Policy integration will also benefit from well-coordinated conservation and landscape planning. This will help design policy instruments that more holistically address the needs of all affected stakeholders. Using a forward-looking, inclusive approach jointly with stakeholders may help shift debates of confronting policy demands to a more science-based and societally inclusive strategic planning approach.

1. Objectives and methodological approach

The EU Biodiversity Strategy for 2030 stresses that within the target to protect 30% of EU land, specific focus should be given to strict protection of areas of very high biodiversity value or potential. The Strategy, in line with global ambitions, sets the target that one third of EU protected land should be strictly protected, requiring an increase from the current 3% to 10% (European Commission, 2020). According to the Strategy, "strict protection does not necessarily mean the area is not accessible to humans but leaves natural processes essentially undisturbed to respect the areas' ecological requirements". The Strategy further specifies that all remaining EU primary and old-growth forests shall be included in this 10% of land with strict protection status. While the Strategy details the importance of primary and old-growth forests as carbon-rich ecosystems that remove and store significant amounts of carbon from the atmosphere, these forests are additionally important because they have unique ecological features including diverse tree-related structures, standing and lying deadwood, naturally disturbed areas that provide a wide variety of wildlife habitats that are critically important for biodiversity, including highly specialised species (Bauhus et al., 2009; Commarmot et al., 2013; EUROPARC-Spain, 2017; Larrieu et al., 2018).

The EU Biodiversity Strategy refers to the protection of both primary and old-growth forests. While it is acknowledged that discussions are needed on the protection of primary forests of all ages and stages of natural succession, this study primarily focuses on old-growth forests due to their unique characteristics and the wide-spread debate specifically surrounding this type of forest in Europe. Nonetheless, information regarding old-growth forests can be difficult to separate from that of all other primary forests, and therefore this study includes information that is relevant for primary forests in a wider sense.

There are several issues that currently restrict effective implementation of the commitment to strictly protect all remaining EU primary and old-growth forests. For example, definitions are crucial for identification and mapping, but there are currently differing interpretations of how to define the terms, especially old-growth forest. Furthermore, discussion is ongoing on how to complement strict protection within an overall approach to protect forest biodiversity, for example by maintaining and developing features normally associated with primary and old-growth forest on the much larger area of European forests managed primarily for purposes other than conservation.

The ultimate goal of the study was to inform political processes regarding primary and old-growth forests in Europe, as detailed in the EU Biodiversity Strategy for 2030. This study investigates the following issues:

Chapter 2 – Defining old-growth forests: Where did the first old-growth definition originate from, how has it since developed, and how can old-growth forest be defined in the European context?

Chapter 3 – Evidence of old and old-growth forests in Europe: What information is available on known old and old-growth forest locations and their characteristics such as age?

Chapter 4 – Approaches to protect old-growth forests and to maintain and develop old-growth forest attributes: What roles can strict protection and integrative forest management approaches have in old-growth forest protection and in maintaining and developing old-growth forest attributes?

Chapter 5 – Associated benefits, consequences, and potential trade-offs of old-growth protection and management and development of old-growth forest attributes.

Chapter 6 – Policy implications

In terms of methods, this study applied a literature review of scientific evidence and used an expert workshop that was held with scientific experts in the subject. The experts' opinions derived from the workshop are included in blue boxes throughout the report either in the form of a 'Workshop statement' or as the results of a 'Workshop poll' (see visualisation below). The polls were created prior to the workshop and answered by the experts during the workshop. The opinions do not claim representativeness and are to be regarded as snapshots illustrating the workshop and the extensive discussions that took place.

Throughout the report, there are also yellow key statement boxes that were formulated together with the experts with the intention of summarising the report's findings (see visualisation below).

Workshop statement:

Workshop poll:

Key message:

2. Defining old-growth forests

2.1 Introduction

Motivated by a need to guide forest conservation and management, many initiatives and scholars around the world have sought to define 'old-growth forest'. These discussions have been particularly prominent in Europe for two main reasons. First, forests in Europe that qualify as old-growth are very rare, particularly in the Central and Western European countries (Wirth et al., 2009). Second, due to the high number of European languages, many different and often competing or not directly comparable terms exist to describe old-growth forests which causes complications when informing policy and management (Feced et al., 2015). In this chapter, we compare some of these alternative terms used to describe natural high conservation value forests with low levels of human influence, particularly focusing on the term *'primary forest'*, and provide a brief review of where the term *'old-growth forest'* originated from.

Finally, we review the most common characteristics of different old-growth forest definitions and summarise the scientific debate to date on the prospects of a future common definition.

2.2 Old-growth forest and related terms

2.2.1 Terms used to describe high conservation value forests

Wirth et al. (2009) reviewed the many different terms that are used interchangeably with old-growth based on a literature review. They found that these terms fall into two major groups:

(1) The 'Primary Group': terms that indicate that the stand had a history of minimal or no human impact for an extended period of time, regardless of stand age. This includes terms such as ancient, natural, primary, primeval, relict, pristine, and virgin **(*Fig. 1* horizontal box).**

(2) The 'Old-growth Group': terms that indicate that the stand is approaching or has reached a certain age or successional stage but can display varying degrees of human impact. This includes old-growth, climax, late-seral, late-successional, and overmature **(*Fig. 1* vertical box).**

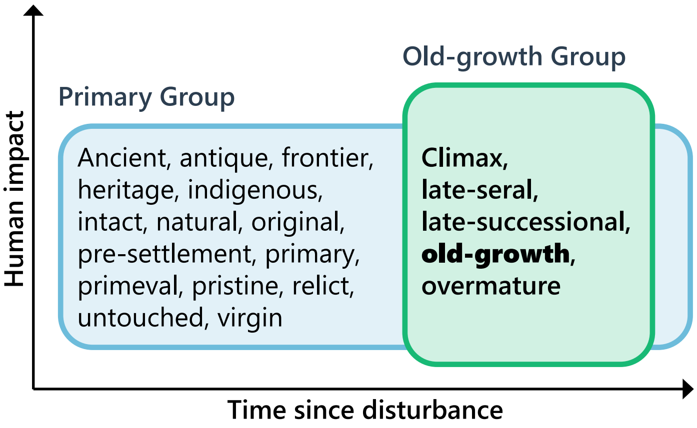


Figure 1. Categorisations of competing terms to describe high -conservation value forests (modified from Wirth et al., 2009): 'Primary Group' and 'Old-growth Group'. It should be noted that the grouping of terms in each box does not imply a hierarchy of either time since disturbance (horizontal box) or human impact (vertical box) but instead indicates that these types of forests can occur over a wide range of circumstances.

The categorisation of commonly used terms falling into the 'Primary Group' is mirrored in other literature stating that they collectively describe forests that have remained undisturbed by humans beyond historical times (Schuck et al., 1994; Burrascano, 2010). However, exact definitions vary by country and by user (Gilg, 2004). For example, in Norway and Sweden, the term '*virgin forest*' refers to forests with varying levels of naturalness ranging from a history of no human disturbance to low or moderate levels in the past (Rouvinen and Kouki, 2007). The term '*ancient forest*' differs, as it is often used to describe forests that have remained continuously wooded over time (an attribute known as 'ancientness'), but that could have experienced significant management (Cateau et al., 2017). In some cases, the term 'ancient forest' may also refer to forests with specific attributes including ancientness, but also the presence of deadwood, species diversity, complex forest structure, and diversity of tree age classes, including mature trees (Mansourian et al., 2013). Therefore, the term can be used to describe forests in either of the two groups of Wirth et al. (2009). Similarly, the term '*natural forest*' is used to describe forests that originated from the original forest cover and develop and regenerate naturally, but can have a history of past human disturbance (Parviainen, 2005). Another related concept, although not limited specifically to forests, are wilderness areas, which are defined by the European Commission (2013) as an "area governed by natural processes, [...] composed of native species, [...] large enough for the effective ecological functioning of processes, [...] unmodified or only slightly modified, [...] without intrusive or extractive human activity, settlements, infrastructure or visual disturbance". This corresponds with either International Union for Conservation of Nature (IUCN) category 1a (strict nature reserve) or 1b (wilderness). In the context of forests, wilderness areas are commonly used to describe primary forests on the landscape scale. The concept of forest naturalness and the term primary forest are described more in-depth in ***section 2.2.2*** and the old-growth term will be analysed in more detail in ***section 2.4.***

There are many situations where the terms in the two groups overlap. For example, a primary forest may also be old in terms of average tree age and could have developed the characteristics normally associated with old primary forest (FAO, 2002; Parviainen, 2005). Because of this overlap, some scholars suggest that the term primary forest should replace the term old-growth in order to avoid the use of problematic age thresholds and to acknowledge the roles of natural disturbance in forest ecosystems and the value of all the successional stages of primary forests (Frelich and Reich, 2003; Swanson et al., 2011). In some countries in Europe, where the old-growth forest term is not commonly applied, '*primeval forest*' is used to describe a forest that falls within the overlap between the two groups (Wirth et al., 2009). The term primary forest is useful to describe high conservation value forests with minimal human intervention. However, this term can be difficult to apply in the case that forests with minimal human disturbance are rare, such as in Europe. Therefore, in the following ***section 2.2.2***, we focus on previous attempts to adapt the definition of primary forest for use in Europe.

Key messages:

- Many terms describing high conservation value forests exist and are sometimes used interchangeably with the term old-growth forest, which causes difficulties when informing policy and management.
- Collectively, the terms typically fall into one of two groups: 1) terms describe forests of any age with a history of minimal or absence of human disturbance, most often termed 'primary forest' and 2) terms that describe old forests or forests in a late-successional stage with varying degrees of human disturbance, most often termed 'old-growth forest'.
- The term old-growth overlaps with the term primary forest in the case that a primary forest is also in a late successional stage.

2.2.2 Adapting the 'primary forest' definition for Europe

In Europe, forests have a strong management legacy; thus, forests without any previous human disturbance are extremely rare (Schulze et al., 2009; Sabatini et al., 2018). In response to this situation, attempts have been made to adapt the definition of primary forest for European use (***Box 1***). Some scholars suggest that a strict definition of primary forest should be replaced with the concept of "floating levels of naturalness" to account for the varying degrees of human impact (Frelich and Reich, 2003). A more complete review of the naturalness concept, together with another well-known term "hemeroby" (Jalas, 1955), can be found in a publication by McRoberts et al., (2012). A prominent example of an index of naturalness is the Buchwald (2005) *Hierarchical terminology for more or less natural forests in relation to sustainable management and biodiversity conservation*. It resulted from an Expert Meeting on 'Harmonizing Forest-related Definitions' in 2005 (FAO, 2005). Although it is not intended for use solely in Europe, the hierarchy has been suggested by some authors as well suited for the purposes of defining primary forests, including old-growth forests, in Europe (Sabatini et al., 2018; FAO, 2020; Sabatini et al., 2020a; Wild Europe, 2020a). Six levels of naturalness fall under the broader category of primary forest (as defined by the FAO, 2015): primeval forest (n10), virgin forest (n9), frontier forest (n8), near-virgin forest (n7), old-growth forest (n6), and long-untouched forest (n5) (listed from most natural to least) (***Fig. 2***). The definitions of these levels of naturalness are provided in ***Box 2***. The concept of levels of naturalness was also used for a test phase to implement the concept of 'High Nature Value Forests' in Europe by the European Environmental Agency (EEA) (EEA, 2014). In the EEA framework, naturalness was considered as a gradient, ranking from the extreme of absolutely natural to the opposite, absolutely artificial (***Fig. 3***).

Box 1. International definitions of primary forest and brief discussion

Convention on Biological Diversity (CBD) (2006) Primary forest (non-country specific): *"A forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age. It is referred to "direct human disturbance" as the intentional clearing of forest by any means (including fire) to manage or alter them for human use. Also included as primary, are forests that are used inconsequentially by indigenous and local communities living traditional lifestyles relevant for the conservation and sustainable use of biological diversity."*

In North America, this definition is very similar to the way that several other terms like natural, primeval, and pristine are used; to indicate forests with no or minimal human disturbance (Barton and Keeton, 2018). Due to the long history of human impact in forest landscapes, the CBD gives a separate definition for primary forests in Europe. The definition includes altered forests that have been modified directly for human use.

CBD (2006) Primary forest (Europe): *"An area of forest land which has probably been continuously wooded at least throughout historical times (e.g., the last thousand years). It has not been completely cleared or converted to another land use for any period of time. However traditional human disturbances such as patch felling for shifting cultivation, coppicing, burning and also, more recently, selective/partial logging may have occurred, as well as natural disturbances. The present cover is normally relatively close to the natural composition and has arisen (predominantly) through natural regeneration but planted stands can also be found."*

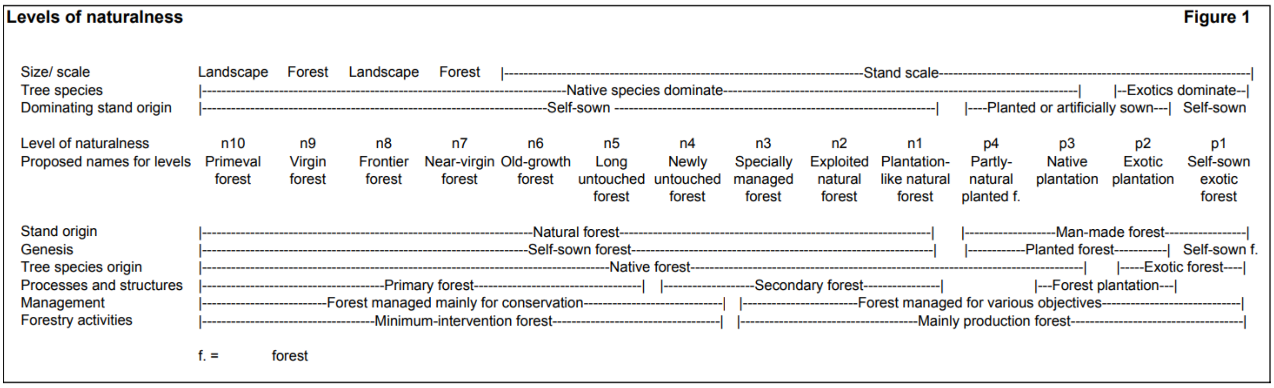
The EU Biodiversity Strategy for 2030 defines primary forest with the wording of the first sentence of the CBD non-country specific definition, instead of using the definition of primary forest specifically developed for Europe.

Food and Agriculture Organization of the United Nations (FAO) (2015) Primary forest: *"Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed."*

FAO (2015) Explanatory note on primary forest definition: *"Some key characteristics of primary forests are: natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes; large enough area to maintain its natural characteristics; no known significant human intervention or the last significant human intervention was long enough ago to have allowed the natural species composition and processes to have become re-established."*

Box 1. International definitions of primary forest and brief discussion

While the FAO does not provide an estimate of the length of time without human intervention required for a forest to be considered primary, some authors using the definition suggest this could be 60-80 years beyond the typical rotation cycle (Sabatini et al., 2018). Others argue for longer time periods. For example, studies have shown that a time period of 100 years after the last harvesting event are needed to re-establish levels of tree microhabitats normally associated with primary and old-growth forests (Larrieu et al., 2012; Larrieu et al., 2016).



Levels of naturalness **Figure 1**

Size/ scale	Landscape	Forest	Landscape	Forest	Stand scale									
Tree species	Native species dominate												Exotics dominate	
Dominating stand origin	Self-sown										Planted or artificially sown			Self-sown
Level of naturalness	n10	n9	n8	n7	n6	n5	n4	n3	n2	n1	p4	p3	p2	p1
Proposed names for levels	Primeval forest	Virgin forest	Frontier forest	Near-virgin forest	Old-growth forest	Long untouched forest	Newly untouched forest	Specially managed forest	Exploited natural forest	Plantation-like natural forest	Partly-natural planted f.	Native plantation	Exotic plantation	Self-sown exotic forest
Stand origin	Natural forest										Man-made forest			
Genesis	Self-sown forest										Planted forest			Self-sown f.
Tree species origin	Native forest												Exotic forest	
Processes and structures	Primary forest						Secondary forest					Forest plantation		
Management	Forest managed mainly for conservation							Forest managed for various objectives						
Forestry activities	Minimum-intervention forest							Mainly production forest						

f. = forest

Figure 2. Levels of naturalness from Buchwald (2005)

Box 2. Buchwald (2005) Definitions of primary forest and naturalness levels n5-n10

Primary forest (n5-n10) Relatively intact forest areas that have always or at least for the past 60 to 80 years been essentially unmodified by human activity. Human impacts in such forest areas have normally been limited to low levels of hunting, fishing and harvesting of forest products, and, in some cases, to historical or pre-historical low intensity agriculture.

Primeval Forest (n10) Ultimate degree of naturalness: Forest ecosystems (landscape-scale) never modified by modern civilisation even indirectly, where the degree of impact on the ecosystem by indigenous people has not been significantly higher than the impacts of natural wildfire and of large wild animals (e.g. beaver (Castor spp.) or megaherbivores). The fauna includes a multitude of large animal species and is not significantly affected by human-induced extinctions or changes to animal population densities. [...]

Box 2. Buchwald (2005) Definitions of primary forest and naturalness levels n5-n10

Virgin Forest (n9) Extremely high degree of naturalness: Forest ecosystems (forest-scale) virtually unmodified by man, and where the degree of former human impact on the forest - including soil and hydrology - has been only slightly more significant than the impacts of wildfire and animals (e.g. beaver (Castor spp.) or megaherbivores) and is no longer obvious. Wildlife inhabits the area with a fairly natural density and species composition including large herbivores and carnivores. [...]

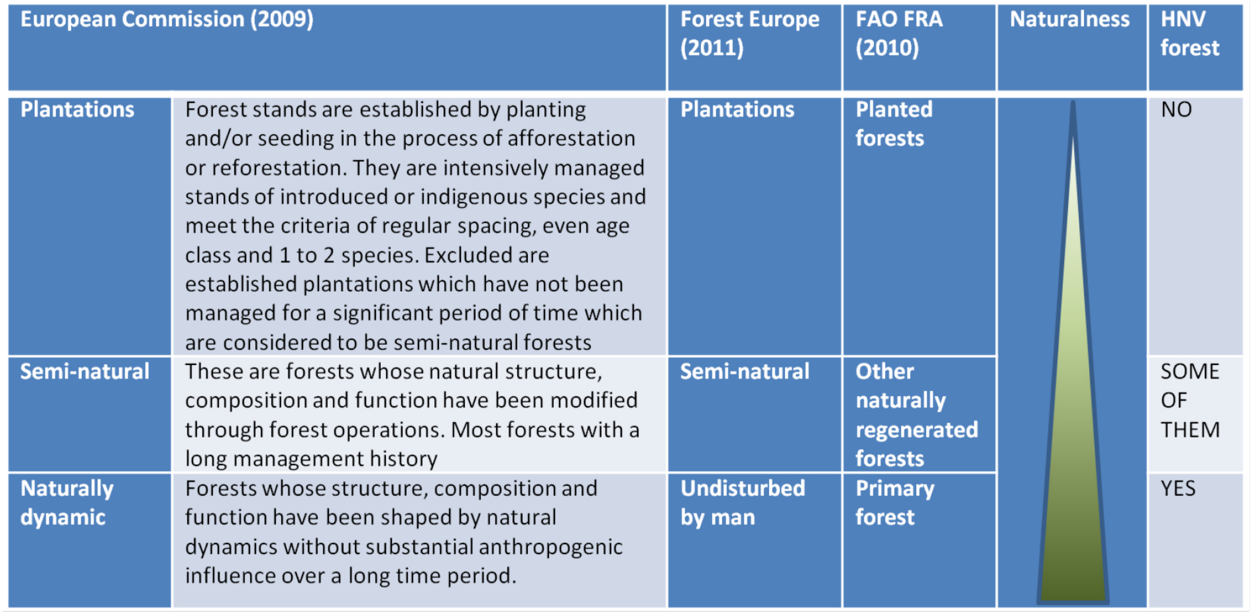
Frontier forest (n8) Very high degree of naturalness: An area (landscape-scale) meeting the following criteria: It is primarily forested and predominantly consists of indigenous tree species. It is big enough to support viable populations of all indigenous species associated with that forest type - measured by the forest's ability to support wide- ranging animal species. It is large enough to keep these species'. It is home to most, if not all, of the other plant and animal species that typically live in this type of forest. Its structure and composition are determined mainly by natural events, though limited human disturbance by traditional activities of the sort that have shaped forests for thousands of years -- such as low-density shifting cultivation -- is acceptable. As such, it remains relatively unmanaged by humans, and natural disturbances (such as fire) are permitted to shape much of the forest. In forests where patches of trees of different ages would naturally occur, the landscape exhibits this type of heterogeneity. (Rearranged/shortened from World Res. Inst.: http://www.wri.org/ffi/lff-eng/).

Near-virgin forest (n7) Very high degree of naturalness: Forest ecosystems (forest-scale) untouched long enough to have attained structures, dynamics and species composition similar to virgin forest, even though they may have been significantly modified, e.g. by clearcutting or agriculture at some time in the past. They are distinguished by a mixture in time and space between different seral stages, e.g. between old-growth stages and younger stages. Human impact on the forest structures is not obvious to see. The time necessary in untouched development before this level can be reached depends on how modified the situation was at the start. It is at least several hundred years if the starting point is a plantation-like forest.

Box 2. Buchwald (2005) Definitions of primary forest and naturalness levels n5-n10

Old-growth forest (n6) High degree of naturalness: Ecosystems (stand-scale) distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function. The age at which old-growth develops and the specific structural attributes that characterise old-growth will vary widely according to forest type, climate, site conditions, and disturbance regime. [...] However, old-growth is typically distinguished from younger growth by several of the following attributes: 1) large trees for species and site, 2) wide variation in tree sizes and spacing, 3) accumulations of large-size dead standing and fallen trees that are high relative to earlier stages, 4) decadence in the form of broken or deformed tops or bole and root decay, 5) multiple canopy layers, and 6) canopy gaps and understory patchiness. Old-growth is not necessarily “virgin” or “primeval.” Old-growth can develop following human disturbances. [...]

Long untouched forest (n5) Quite high degree of naturalness: Relatively intact forest (stand- level) that has been essentially unmodified by human activity for the past sixty to eighty years or for an unknown, but relatively long time. Signs of former human impacts may still be visible, but strongly blurred due to the decades without forestry operations. The time limit depends on how modified the forest was at the starting point. If the stand is known to be planted/sown or predominantly consists of exotics it is referred to level p4, partly-natural planted forest or p1/p2, Exotic forests.



European Commission (2009)		Forest Europe (2011)	FAO FRA (2010)	Naturalness	HNV forest
Plantations	Forest stands are established by planting and/or seeding in the process of afforestation or reforestation. They are intensively managed stands of introduced or indigenous species and meet the criteria of regular spacing, even age class and 1 to 2 species. Excluded are established plantations which have not been managed for a significant period of time which are considered to be semi-natural forests	**Plantations**	**Planted forests**		NO
Semi-natural	These are forests whose natural structure, composition and function have been modified through forest operations. Most forests with a long management history	**Semi-natural**	**Other naturally regenerated forests**		SOME OF THEM
Naturally dynamic	Forests whose structure, composition and function have been shaped by natural dynamics without substantial anthropogenic influence over a long time period.	**Undisturbed by man**	**Primary forest**		YES

Figure 3. Categories of forests (plantations, semi-natural, or naturally dynamic) as reported from different sources, and their relationship to naturalness and High Nature Value (HNV) forests (from EEA, 2014). Here, primary forest represents the highest level of forest naturalness.

Key messages:

- There have been initiatives at the international level to define primary forest which have resulted in different definitions.
- The CBD provided a definition of primary forest tailored for Europe, due to the rareness of forests without a legacy of human impact. The definition includes forests that have been modified directly through human use.
- The concept of naturalness (Fig. 2) is useful for defining primary forests in a European context and it integrates old-growth forests as one of the levels of naturalness.

2.3 Brief history of the old-growth definition

The old-growth forest term is most often used in the United States (Wirth et al., 2009). In Europe, it is also applied somewhat frequently in Sweden, Norway, and Finland but rarely in Central and Western countries due to the lack of forests that meet the criteria of old-growth (Rouvinen and Kouki, 2007; Wirth et al., 2009). The first formal definition of old-growth originated from the country's Pacific Northwest (PNW) region in 1986 (Old Growth Definition Task Group, 1986). In the PNW, old-growth forests are characterised by tree species that can grow very large such as Douglas-fir, Western Red Cedar, Western Hemlock, a stand age of over 200 years old, large amounts of deadwood, multi-layered canopies, and a history of minimal or absence of human disturbance (Bolsinger and Waddell, 1993). Logging had reduced the area of old-growth forests in the PNW from around 60,000 km^2 in the 1600s to 20,000 km^2 in 1986. In addition, at that time, 80% of the remaining forests did not have any legal protection status (Old Growth Definition Task Group, 1986).

In the 1970s, several key policies including the National Environmental Policy Act of 1970, the Endangered Species Act of 1973, and the National Forest Management Act of 1976 had been introduced with the intention to balance natural resources (forest) use and conservation, and protect endangered species (Barton and Keeton, 2018). Despite the adoption of the policies, logging of old-growth forests in the PNW continued and it was only a series of court cases based on violations of the laws that ultimately resulted in strongly reduced logging of old-growth forests in the late 1980s and early 1990s (Yaffee, 1994). The main focus of the litigation was the decline of the Northern Spotted Owl which is dependent on structures present in old-growth forests, particularly standing deadwood and tree height diversity (Carey, 1990; North et al., 1999). Due to its high dependence on old-growth habitat, the Northern Spotted Owl became a symbol of the movement to protect the remaining old-growth forests (Sher, 1993) and is cited as one of the key motivations for the conservation of old-growth forests in the PNW (Barton and Keeton, 2018). In response to the public's concern about old-growth forests, accelerated research projects were then implemented by the United States Department of Agriculture (USDA) Forest Service Pacific Northwest Research Station in 1982 and 1994, focussing on old-growth associated wildlife and forest ecosystem processes, respectively (Carey, 1998; Hilbert and Wiensczyk, 2007). The research projects aimed to define and identify old-growth forests, characterise species dependence on old-growth, and guide successful management (Carey, 1998).

Key message:

- The first formal definition of 'old-growth forest' originated from the Pacific Northwest region of the United States in the 1980s and was developed in a context of continued decline of old-growth forest, and a related loss of habitats for old-growth dependent species, particularly the Northern Spotted Owl.

In 1985, the USDA Forest Service created the Old Growth Definitions Task Group to define '*old-growth forest*' for inventory and management. In 1986, supported by the growing body of information on old-growth forests from the earlier launched research projects, the Task Group produced a draft of four interim definitions for mixed Douglas-fir and Sierra mixed conifer old-growth forests found in the Cascade Range in Washington and the Sierra Nevada range in California, respectively. Four definitions were created to account for the differences in the two forest types based on their geographical location. The definitions were composed of different structural criteria, including size and number of seral and climax dominant live trees, number of canopy layers, and structure and quantity of deadwood. A forest was considered to be old-growth if it met minimum values of these structural criteria (Old Growth Definition Task Group, 1986).

Recognising the need to expand initiatives to protect and define old-growth beyond the PNW, the National Old-Growth Task Group was created by the USDA Forest Service in 1988. The National Task Group influenced the recognition of old-growth as a distinct type of forest with unique associated ecological, social, and economic values by recommending that the USDA Forest Service declare it a formal forest resource, which was approved in the form of a national policy in 1989 (Greenberg, 1997). Most importantly, the National Old-Growth Task Group shaped how old-growth was defined across the US, and ultimately around the world, by developing the '*Generic Definition and Description of Old-Growth Forests'*. It was conceived as a reference for uniformly defining interim definitions of old-growth forests in all US forest types (Greenberg, 1997), later to be refined and used for regional inventories by the Forest Service in the early 1990s (USDA Forest Service, 1993). The Generic Definition, which described forests in "later stages of stand development", was based on the research of old-growth forests in the PNW (e.g., Franklin et al., 1981). Therefore, the ecological indicators for identification were based on those found in the PNW: old trees and related structural diversity, large tree size, large quantities of deadwood, high number of canopy layers, species composition, and ecosystem function (USDA Forest Service, 1993).

Although the Generic Definition was intended to guide uniform definitions of old-growth in all US forest types, it was found to be inadequate because of the vast diversity of forest types and their dissimilarity to PNW old-growth forests (Hilbert and Wiensczyk, 2007). In addition, it was criticised because it disregarded "patterns and dynamics of the forest landscape mosaics of an area" and by using threshold values, unintentionally introduced arbitrary lines of what is and what is not, old-growth (Rapp, 2003). Other PNW old-growth definitions formed before the General Definition experienced similar criticism. The four interim definitions previously created for Douglas-fir and Sierra mixed conifer forests were proven to be inadequate because they failed to account for the variations that arose from different geographical locations, and it was suggested that they be further refined based on site specificity (Franklin and Spies, 1991). Today, some researchers argue that the definitions are based on outdated knowledge and should be revised given the substantial scientific advances that have occurred since the first old-growth forest studies were carried out in the 1980s and 1990s (Merschel et al., 2019). As a result, different types of definitions have been proposed based on different theories and including different criteria, which are not exclusively related to the attributes that describe old-growth forests in the PNW. In the following ***section 2.4***, we elaborate on the common components of old-growth forest definitions and the scientific debate surrounding them.

Key message:

- The Generic Definition of old-growth forest created for the purpose of guiding uniform definitions of old-growth in all forest-types of the United States proved to be inadequate due to the vast diversity of forest types and their dissimilarity to old-growth in the US Pacific Northwest, where the term originated from. As a result, different types of definitions were proposed across the United States and beyond.

2.4 Characteristics of old-growth forest definitions

2.4.1 Common criteria of old-growth definitions

Ecological definitions of old-growth forest are most commonly based on either structural attributes or successional processes (Wirth et al., 2009). Structural and successional criteria are also often combined in old-growth definitions (e.g. Mosseler et al., 2003). Old-growth is also sometimes defined by the presence of species associated with old-growth, such as lichens (McMullin and Wiersma, 2019). However, this requires highly specialised experts for identification and can also lead to misidentifying old-growth forests unless used in combination with other indicators (Janssen et al., 2019). Therefore, we focus on structural and successional definitions. It is important also to note that old-growth forest is usually defined at the stand level (Buchwald, 2005; CBD, 2006), whereas other types of primary forest such as primeval and virgin forests are defined at the forest to landscape scale.

Structural attributes compose the majority of old-growth definitions and have been used to identify old-growth forests in Europe (Wirth et al., 2009; Burrascano et al., 2013; Knorn et al., 2013). These include:

- Tree age distributions (including trees in or approaching the maximum age of their species) (Helms, 2004; Wirth et al., 2009; Nagel et al., 2013)
- Tree size distributions (including very large trees) (Wirth et al., 2009)
- Heterogenous stand structure, including both vertical and horizontal heterogeneity (Wirth et al., 2009; Nagel et al., 2013)
- Diversity of tree species (Wells et al., 1998; Mosseler et al., 2003; McElhinny et al., 2006), and the quantity and spatial distribution of lying and standing deadwood (Wirth et al., 2009, Nagel et al., 2013)
- Tree related microhabitats (TreMs) (Paillet et al., 2017; Meyer et al., 2021)

Less common are definitions based on successional processes. Criteria of successional definitions include:

- Stands in the final, most stable stage of development (Mosseler et al., 2003)
- Tree establishment through gap-phase dynamics (Oliver and Larsson, 1996; Barton and Keeton, 2018)
- Forests initiated from natural disturbances (Nagel et al., 2013)
- The death of the original cohort of trees that established immediately after the last stand replacing disturbance (Oliver and Larsson, 1996; Barton and Keeton, 2018)
- The presence of late-successional tree species that have replaced early-successional pioneer species (Wirth et al., 2009; Barton and Keeton, 2018)
- The presence of small-scale disturbances that maintain old-growth attributes (e.g. large amounts of deadwood) (Mosseler et

al., 2003; Wirth et al., 2009; Frankovič et al., 2021)

- Time since the last stand-replacing natural disturbance exceeds the maximum longevity of the dominant tree species (Mosseler et al., 2003)
- Forests that developed in a lack/absence of human disturbance (Er and Innes, 2003; Helms, 2004; Nagel et al., 2013; Barton and Keeton, 2018).

Key messages:

- Definitions of old-growth are commonly based on structural attributes, successional processes, or a combination of both.
- Old-growth forests are typically defined on the stand-level.

2.4.2 Critiques of common elements and framing of definitions

The potential of definitions based on either structural attributes or successional processes have been debated by researchers. Definitions based on structural attributes have often been criticised because of their limited ability to apply to all forest types (***Tab. 1***). The various critiques are based on the overarching idea that there is no single structural attribute or set of attributes that can be found in all forests and their presence, time of development, qualities, quantities, and distribution can vary widely among forest types (Er and Innes, 2003; Spies, 2004; Hilbert and Wiensczyk, 2007; EUROPARC-Spain, 2017). For example, definitions based on the presence, quantity, and size of deadwood may fail to identify or rule out a forest as old-growth, because different successional stages can have similar quantities or qualities of deadwood; e.g. a disturbed, regenerating forest (Wirth et al., 2009; Larrieu et al., 2014). Use of deadwood indicators can be complicated because the rates of wood decomposition differ between forest types. For example, in Europe, deadwood in Mediterranean forests can decompose at five times the rate when compared to colder climates, such as those found in boreal forests or at higher altitudes (Lombardi et al., 2013; EUROPARC-Spain, 2017).

Indicators of old-growth forest based on tree age are also often targets for criticism. Some researchers argue that determining a tree as ‘old’ has no sound scientific basis as the maximum longevity of a tree is dependent on the species and its environment (Helms, 2004; Wirth et al., 2009). Therefore, selection of age thresholds that determine whether a tree is ‘old’ or not are largely arbitrary (Hilbert and Wiensczyk, 2007; more detailed discussion covered in ***section 3.4***). Using tree age as the sole indicator to identify old-growth may result in forests not meeting the age criteria, while containing many other relevant structural indicators, not being identified as old-growth and vice-versa (de Assis Barros et al., 2021). Furthermore, determining chronological age can be inaccurate, labour intensive, and expensive, which can result in low efficiency and accuracy (Wirth et al., 2009; Racine et al., 2014). In addition, determining the age of a forest stand from tree age is problematic because the chronological age of a tree can differ significantly from the stand age. For example, if the oldest trees survived a past stand-replacing disturbance event, this makes them much older than the rest of the stand.

A collection of common critiques that focus on the diversity in and among forest types potentially preventing a single, general old-growth forest definition is provided in ***Tab. 1***.

Table 1. Common critiques of old-growth forest definitions focused on the diversity in and among forest types as a potential preventative of a single, general old-growth forest definition.

Common critiques of OGF definitions – Diversity in and among forest types	Reference
Variability in and among forest types, including components that overlap between development stages, makes a single, precise definition impossible	Wells et al. (1998); Wirth et al. (2009)
A single, precise definition is undesirable because its usefulness depends on intent of use	Wells et al. (1998)
Forests differ in many respects - tree sizes, longevity, wood decay rate, tolerance of shade and fire, disturbance frequency	Spies (2004)
Structural indicators do not change at the same rate in every forest and are not present in every forest type	Er and Innes (2003); Spies (2004); Wirth et al. (2009)
What is considered 'old' for a tree is problematic because maximum longevity is a product of the species and the environment	Helms (2004); Wirth et al. (2009)
Thresholds that determine if a tree is ‘old’ or ‘not old’ are arbitrary	Hilbert and Wiensczyk (2007)

Key messages:

- Structural definitions of old-growth forests have been criticised because they do not account for the vast diversity in and among forest types. Definitions based mainly on tree age are considered to be problematic because maximum tree age is a product of the species and the environment. The age of single trees also has limited ability to determine the age of the forest stand.

Failure to account for the diversity and variability in and among forest types is also a common criticism of definitions based on successional processes. For example, gap-phase dynamics (a late-phase of stand development) may largely be absent in forests that contain early successional pioneer species throughout the succession (Wirth et al., 2009). However, criticism and discussion around definitions based on successional processes often focus on the underlying ecological theory behind such definitions. Some authors claim that synonymising old-growth with forests approaching the end of a late-successional stage, (i.e. stable climax stage) is based on outdated scientific knowledge and ecological theory. Pesklevits et al. (2011) argue that identifying a succession stage to be the final one is illogical as a stand-replacing large-scale disturbance could occur at any point along the succession, making it the “final” stage. This argument is part of a larger movement to abandon the ecological theory which proposes that forests and other plant species all exhibit similar patterns and end stages of succession, known as mono-climax theory. A new theory emphasises the dynamic nature and non-linearity of old-growth forests due to the prominent role of different natural disturbances that occur at different magnitudes, and vary in timing (Donato et al., 2011; Barton and Keeton 2018). Relatedly, some researchers argue that once the final stage of succession ends with a stand replacing disturbance, the forest should not cease to qualify as old-growth, as such processes are important for biodiversity, one of the main motivations for conserving old-growth (Barton and Keeton, 2018). Furthermore, in unmanaged forests, some old-growth attributes are still present in the regeneration phase after natural disturbances and share similar profiles of old-growth attributes compared to later successional phases (Larrieu et al., 2014). For this reason, the term primary forest is seen as useful, as it encompasses forests in all stages of succession, including old-growth (Frelich and Reich, 2003). Therefore, it is important that even after an old-growth forest is replaced by large-scale disturbance, it should continue to receive protection status. A collection of common critiques that focus on the inability of successional processes to provide a clear single, general old-growth forest definition is provided in ***Tab. 2.***

Table 2. Common critiques that focus on the inability of the use of successional processes to provide a clear single, general old-growth forest definition.

Common Critiques of OGF Definitions – Successional Process Definitions	Reference
Gap-phase dynamics may be absent in forests that consist largely of pioneer species throughout succession	Wirth et al. (2009)
Declaring a stage as the "final-stage" of forest development is illogical because large-scale disturbances can occur at any point during succession and forest development can be considered as an (infinite) mosaic cycle	Pesklevits et al. (2011)
Mono-climax theory is widely thought to be outdated and has been replaced by new contemporary theories that emphasise the dynamic nature and non-linearity of old-growth forests	Hilbert and Wiensczyk (2007)
Large-scale disturbances should not mean the end of old-growth as such processes support biodiversity	Barton and Keeton (2018)

Key messages:

- Definitions based on successional processes have been criticised because they do not account for the diversity in and among forest types (similar to structural definitions), or also because they are thought to be based on outdated ecological theory.
- After an old-growth forest has been replaced by a large-scale disturbance, it should continue to receive protection as the forest maintains its high conservation value.

Whether a forest with a history of human disturbance can be defined as old-growth is also debated (***Tab. 3***). Minimal or no human disturbance is often an element used in the definition of old-growth in North America, despite that in 1989 the US Forest Service General Definition of old-growth specified that "old-growth is not necessarily 'virgin' or 'primeval'" and could develop after a history of human disturbance (USDA Forest Service, 1993)

Several scholars have suggested that primary but also secondary forests should be considered to meet the old-growth definition (Kneeshaw and Burton, 1998; Hilbert and Wiensczyk, 2007; Barton and Keeton, 2018) as old-growth features have been shown to recover with sufficient time (Er and Innes, 2003; Paillet et al., 2015; Barton and Keeton, 2018). Secondary old-growth has been defined and used in international definitions (***Box 3***).

Table 3. Common critiques of the criteria of absence of human disturbance in old-growth forest definitions

Common Critiques of OGF Definitions - Human disturbance	Reference
The difference between human disturbance from natural disturbance is irrelevant if the impact to the forest structure is the same	Spies (2004)
Such definitions assume forests cannot recover from human disturbances to develop old-growth features	Helms (2004); Er and Innes (2003); Barton and Keeton (2018)
Such definitions disregard forests with restoration management to introduce old-growth features	Helms (2004); Wirth et al., (2009)

Box 3. Secondary old-growth definitions

Frelich (2002) Secondary old-growth: A sub-category of old growth comprising stands that were previously logged, or had other major human disturbance that precludes them from being primary old growth. This forest may be managed for timber production. If managed for timber production, then it also falls under extended rotation forest.

CBD (2006) Old-growth forest: Old growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class.

Key message:

- Criteria of lack or absence of human disturbance for old-growth definitions have been criticised because evidence has shown that forests can recover from human disturbance to develop old-growth features. In addition, active restoration management may develop such features over time.

In Europe, the term 'secondary old-growth' is particularly useful given the legacy of intensive land-use that resulted in an abundance of secondary forests, but only a few remaining primary forests (EUROPARC-Spain, 2017). Given the rareness of primary old-growth in the continent, secondary forests that contain, or can develop, old-growth features are thought to be very important (Nagel et al., 2013). For example, in Sweden, Finland, and Norway, old-growth definitions include forests with a history of human disturbance (Rouvinen and Kouki, 2007). Similar to the concept of levels of naturalness proposed for primary forests, quantifying the degree "old-growthness" of forests using indices to account for the varying degrees of human impact and increased disturbance effects has been proposed in Europe (Ziaco et al., 2012; Schall and Ammer, 2013; Kahl and Bauhus, 2014; Sabatini et al., 2015; Meyer et al., 2021). The indices are typically based on structural indicators, including the diameter at breast height of the largest trees of a given tree species, and density of live large trees and dead standing and fallen trees (Ziaco et al., 2012). A recently published old-growth index included 10 thematic groups used to assess old-growthness including successional status, forest development stage, tree species diversity, native tree species, deadwood, and microhabitats (Meyer et al., 2021)

The concept of old-growth indices has also been proposed for Canada (Stewart et al., 2003; DeLong et al., 2004; de Assis Barros, 2021) and the United States (Acker et al., 1998). While not exclusively related to old-growth forests, an index for forest structural complexity was developed for Australia in order to identify forests of high conservation value and inform management (McElhinny et al., 2006). However, as the index must be adapted to the region of its intended use (McElhinny et al., 2006), it is important to consider limitations of structural or other indicators included in indices (Pesklevits et al., 2011). For example, index definitions have been criticised by some because they are at risk of being arbitrary. The threshold values needed for the multiple criteria included in such indicies would be difficult to determine as there is no single value or range of values that is truly representative of old-growth (Hunter and White, 1997; Er and Innes, 2003; Spies, 2004; Hilbert and Wiensczyk, 2007; Pesklevits et al., 2011).

Key message:

- Suggestions have been made for developing "old-growthness" indices that help to characterise the degree to which a forest meets the definition of old-growth in Europe and allow for the measuring of progress towards developing secondary old-growth forests through ecological restoration or non-intervention.

2.4.3 Prospects of a future single definition

In the continued quest for a single definition of old-growth, the issue has been revisited many times and the number of existing definitions, criteria, and classifications have been well documented but without success of consensus (Hilbert and Wiensczyk, 2007; Barton and Keeton, 2018). Despite the breadth of different types of definitions and the various elements that compose them, two common descriptions of old-growth forests may be the most agreeable indicators to form a conceptual definition: (1) relatively old and (2) relatively undisturbed by humans (Hunter, 1998; Barton and Keeton, 2018). However, citing the work of Hunter (1998), Barton and Keeton (2018) argue that while the description of old-growth forests as relatively old and undisturbed by humans may be satisfactory in certain aspects, there are no clear thresholds of age of a tree or time since human disturbance that make an old-growth forest distinct from other old, relatively undisturbed forests. Consequently, a definition incorporating the two common descriptions would be general and conceptual. Therefore, the larger debate is on how to manage the trade-offs of a single definition that is applicable to a large range of forests, and a specific definition that is applicable only to a specific forest type/set of growing conditions but detailed enough to be able to identify old-growth on the ground (Hilbert and Wiensczyk, 2007; Wirth et al., 2009; Pesklevits et al., 2011; Barton and Keeton, 2018).

Depending on the operationalisation, a broad, general definition may result in a larger than expected number of forests identified as old-growth. This provides an advantage because it is likely that all high conservation value forests would be identified and prioritisation for protection could be based on a combination of the forest's biodiversity value, vulnerability, or other relevant factors. In comparison, a specific definition may leave out forests that are widely considered to be old-growth, but do not match the exact definition (Hilbert and Wiensczyk, 2007). Spies (2004) claims that a single, specific definition would be highly subjective, as stand development is a continuous process, and therefore clear thresholds that could theoretically determine if a stand fits the criteria of old-growth, do not exist. As an alternative to a single definition, some authors advocate for a variety of specific definitions to account for the differences between forest types and geographic sites (Hunter 1989; Kimmins, 2003; Spies et al., 2004; Wirth et al., 2009). The debate over a general or specific definition is closely related to arguments that the inherent diversity of forest types makes the creation and agreement on an all-encompassing single definition very difficult or impossible (Wells et al., 1998; Barton and Keeton, 2018; Wirth et al., 2009). Moreover, some authors argue that a single definition is also not desirable because a definition should ultimately be shaped by the motivation of its use (Wells et al., 1998; Wirth et al., 2009). In any case, old-growth forests are under multiple pressures and threatened, which causes researchers to stress the urgency to reach a consensus on a definition(s) and subsequent identification processes (Er and Innes, 2003; Wirth et al., 2009).

Key messages:

- Strict (narrow) definitions of old-growth forests are not desirable because they can fail to include forests with valuable old-growth forest attributes.
- A broader, more conceptual definition is more favourable because it is more likely to encompass all high conservation value forests, and prioritisation for protection can still occur through assessing forest biodiversity value and vulnerability.

2.5 Summarising the main findings on defining old-growth forests

The first old-growth forest definition that originated from the Pacific Northwest (PNW) of United States in the 1980s has had considerable influence on the creation of old-growth definitions not only within the country, but across the world (Burgman, 1996). However, attempts to adopt the PNW old-growth forest definition globally have largely failed because of the specific, if not unique, nature of the PNW old-growth forests that had shaped this definition. Characterised by distinctive structural attributes and the increasingly rare quality of minimal or absence of human disturbances, the PNW old-growth forest definition could hardly be adapted to other parts of the world (Burgman, 1996; Dudley and Stolton, 2003; Humphrey, 2005; Hilbert and Wiensczyk, 2007). This has led to a large number of initiatives with the aim to provide alternative definitions of old-growth forest. The resulting definitions have overlaps, but literature that has attempted to describe and synthesise the different definitions have failed to produce an appropriate single definition (Wirth et al., 2009).

Difficulties reaching a consensus on an old-growth forest definition is also related to competition with many similar forest terms and complexity owing to different languages. In both Europe and North America, old-growth forests can be considered as part of the primary forest concept. While definitions of primary forest are often used to describe forests that have remained undisturbed by humans beyond historical times (Schuck et al., 1994; Burrascano, 2010), definitions provided by the CBD (2006) and FAO (2015) suggest that primary forests can include forests with varying levels and histories of human disturbance. This is especially relevant in Europe where forests without human disturbance are rare (Schulze et al., 2009; Sabatini et al., 2018). To account for differences in the degree of human impact, levels of naturalness for primary forests have been proposed as a potentially useful approach (Frelich and Reich, 2003; Buchwald, 2005) and applied to map primary forests in Europe (Sabatini et al., 2018). Similarly, indices of "old-growthness" have been proposed to characterise the degree to which a forest meets the definition of old-growth in Europe (Meyer et al., 2021). Experience shows that different operational regional (country- and project-level) definitions can be mapped onto the set of conceptual definitions applied in top-down assessments (Sabatini et al., 2018; Sabatini et al., 2020a).

The EU Biodiversity Strategy for 2030 currently defines primary forest as *"a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age".* The definition appears to be taken from the CBD (2006) non-country specific definition of primary forest, despite the CBD providing an alternative definition for primary forest in Europe (CBD, 2006). The EU Biodiversity Strategy defines an old-growth forest *as "a section of forest that has developed structures and species normally associated with old primary forest of that type"*, which partially mirrors the CBD (2006) definition. However, the Strategy also details the necessity to further define, map, monitor and strictly protect all the EU's remaining primary and old-growth forests. While the Strategy's definition of old-growth forest would include stands in both primary and secondary forests, the definition of primary forests is limited to forests which have a history of no or minimal human disturbance, an extremely rare occurrence in Europe. In addition, evidence of human disturbance in a forest can be difficult to prove and may not be important if the forest has high biodiversity value and maintains its ecological functions, regardless. Therefore, use of the Strategy's definition of primary forests could be problematic because it would exclude primary forests of varying levels of naturalness, which is the norm in Europe (Buchwald, 2005). A document produced by Wild Europe (2020a) seeking to provide input to the process to define primary and old-growth forests in the EU warns that "definitions" should not be "overly 'purist' or narrow in stipulating lack of human impact", or else protection of valuable forests will be scarce due to the few forests that fit the criteria.

In conclusion, one of the main challenges to implement the EU Biodiversity Strategy for 2030 will be to adopt an operational definition of primary and old-growth forests. On the one hand, a single specific definition applicable to all forest types is difficult due to the diversity in and among forest ecosystems (Wells et al., 1998; Spies, 2004; Wirth et al., 2009). Therefore, criteria applicable to identify old-growth forests in European regions and forest types may be required. On the other hand, a general (broad) definition is advantageous because it is likely to identify all high conservation value forests which could then be further prioritised for protection (Hilbert and Wiensczyk, 2007). Overall, there is progress towards reaching a consensus for an old-growth definition for use in Europe.

Key messages:

- Overall, there is progress towards reaching a consensus for an old-growth definition in Europe.
- The definition should not be too strict in the context of the EU Biodiversity Strategy 2030, and rather flexible to allow including forests with some management legacy given the rarity of forests with a history of minimal human intervention and the importance of secondary old-growth forests for biodiversity conservation. Using levels of naturalness and old-growth indicators may be potential solutions to encompass a wider range of forests.

3. Evidence of old and old-growth forests in Europe

3.1 Introduction

Efforts to identify and map old-growth and primary forests on a local and national scale in Europe have been numerous, although often incomplete and guided by many different definitions. In ***section 3.2***, we provide an overview of previous mapping efforts of primary and old-growth forests in Europe. Following this, we report on European primary forest distribution, their representativeness of European forest types, and evidence of their loss. Finally, we document ongoing initiatives to collect additional evidence of old-growth and primary forests in Europe. In ***section 3.3***, we compile data on primary forest area from inventory-based processes, such as Forest Europe. In ***section 3.4***, we present information on age structure and tree longevity in European forests, as these are commonly used criteria in old-growth definitions.

3.2 Evidence of primary and old-growth forests in Europe

3.2.1 Mapping primary and old-growth forests in Europe

A recent study by Sabatini et al. (2018) used a combination of existing spatial data sets, questionnaires, and a literature review to produce to date the most comprehensive data-base and map of known European primary forests[1], referred to as the European Primary Forest Database (EPFD) v1.0[2]. However, the database does not claim to be complete and still lacks information on primary forest locations in some countries (Sabatini et al., 2018). In addition to mapping known primary forests, the authors used predictive modelling to identify where locations of unknown and unmapped primary forests are most likely to occur. The study estimated a total of 1.4 Mha of known primary forests in Europe, the majority in Northern Europe, but spread across 32 countries in total (excluding Russia). The predictive modelling found that the majority of unknown and unmapped primary forests are also most likely located in Northern Europe, for example along the northern Finnish-Russian and Finnish-Swedish border. Further prospective locations were identified in various mountain ranges across Europe (Sabatini et al., 2018).

Efforts to map primary and old-growth forests on a local and regional scale in Europe have been numerous, although the data is not always available or published. A non-exhaustive compilation of datasets (32 in total), produced from local, regional, and national-scale inventories were included in the Supplementary Material of Sabatini et al., (2018). Local and regional studies have commonly focused on protected areas such as national parks (Blasi et al., 2010) and regions known to host a substantial portion of Europe's primary forests such as the Carpathians (Svoboda et al., 2014; Trotsiuk et al., 2014), the Northern Pyrenees (Savoie et al., 2015), Northern Europe (Svensson et al., 2020), or certain forest types such as beech (UNESCO, 2011; Kirchmeir et al., 2016). Only a small number of national-scale inventories have been completed and published (Sabatini et. al., 2018; Mikoláš et al., 2019b; Sabatini et al., 2020b, pre-print not certified by peer review). The Czech Republic is one example where a national-scale forest naturalness assessment found 490 old-growth forests, together totaling an area of 30,000 ha (Adam and Vrska, 2009; Kraus and Krumm, 2013). A recent study in the Slovak Republic also identified 261 primary forests (including old-growth) totaling 10,583 ha in a national scale inventory (Mikoláš et al., 2019). National-scale inventories of virgin forests were also completed for Bulgaria and Romania (Biris and Veen, 2005; Veen and Raev, 2006; Veen et al., 2010). For Bulgaria, 218,494 ha of primary forests larger than 50 ha were identified. In Romania, the estimates were much lower at 103,356 ha. However, these inventories relied mostly on remote sensing with no or limited validation in the field, and subsequently have lower data quality compared to the Slovak and Czech national inventories.

Newly available datasets from local, regional, and national mapping initiatives have been used to update the EPFD v1.0 of Sabatini et al. (2018) to produce a new, more comprehensive EPFD v2.0 (Sabatini et al., 2020b, pre-print not certified by peer review). While the compilation of data included in the EPFD v.2.0 is still not exhaustive, it contains the locations of approximately 1.6 Mha of primary forest in 32 countries (excluding Russia). Similar to the v1.0, the EPFD v2.0 identified the majority of known primary forests in Northern Europe, but it also identified a significant number in Western European countries such as Spain and Portugal that were not reported in the v1.0. Currently, the EPFD v1.0 and v2.0 do not include previously managed forests that were recently protected (i.e. forests unmanaged for less than 60-80 years after the normal rotation cycle) and may develop into old-growth overtime with the absence of management. Mapping these forests might be useful to estimate the future 'old-growth forest potential' in Europe. Prior to the creation of the EPFD v1.0 and v2.0, there were no maps that compiled all known primary forest locations on a European-scale. However, predictive maps of primary or other high conservation value forests in Europe have been produced in the past. The EEA (2014) produced a likelihood map of High Nature Value (HNV) beech forests using five indicators: (1) naturalness as the relationship between potential and real vegetation, (2) hemeroby as the potential degree of human influence on the ecosystem, (3) accessibility, (4) growing stock volume, and (5) connectivity (***Fig. 4***). Other predictive maps for Europe have commonly been part of global studies that used different definitions to describe forests of high conservation value (McCloskey and Spalding, 1989; Bryant et al., 1997; Sanderson et al., 2002; Potapov et al., 2008; Schulze et al., 2019).

Key messages:

- The European Primary Forest Database EPFD v1.0 and soon published v2.0 are the most comprehensive maps of European primary forests to date.
- Data gaps are still prevalent for some countries in the EPFD 2.0. Such data gaps must be filled to effectively protect primary and old-growth forests as outlined in the EU Biodiversity Strategy.

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[1] In Sabatini et al., (2018), primary forests were defined according to the 2015 FAO definition: "forests where the signs of former human impacts, if any, are strongly blurred due to decades (at least 60–80 years) without forestry operations". The authors deem that 60-80 years after the normal rotation cycle is necessary in order for the forest to be considered primary. The paper also acknowledges that primary forests in Europe may have differing levels of naturalness.

[2] The EPFD database has recently been updated in EPFD v2.0 (pre-print: Sabatini et al., 2020b). The updated results are included in the newly published report of Barredo et al. (2021), which was released after completing the review for this chapter.

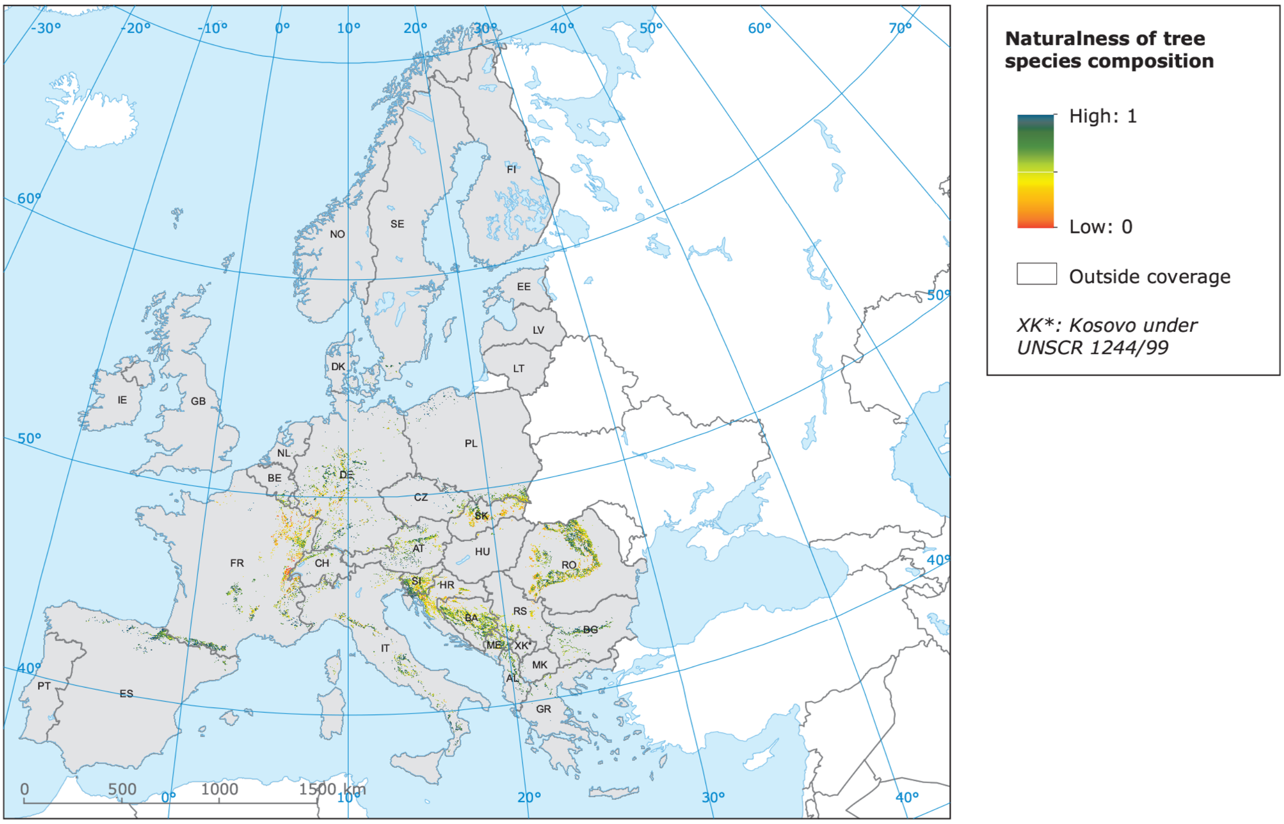

Figure 4. HNV likelihood map for beech forests from the aggregation of three input variables (from EEA, 2014).

European primary forest distribution, representation, and protection

Currently available data shows that primary forests are unevenly distributed across Europe. They are often confined to areas that are not easily accessible due to steep slopes, mountainous areas, high altitudes, or flood plains (Adam and Vska, 2009; Veen et al., 2010; Sabatini et al., 2018; Mikoláš et al., 2019; Forest Europe, 2020; Sabatini et al., 2020a). They are also most likely to occur in areas with specific climatic properties such as a colder climate or higher water availability, which are conditions less favourable to agriculture (Sabatini et al., 2018, Sabatini et al., 2020a). The location of primary forests is further related to certain socio-economic factors including low population density and long distances to major roads (Sabatini et al., 2018; Jonsson et al., 2019; Mikoláš et al., 2019). These factors determining primary forest location are similar to the factors that limit wood production and high harvest intensity in forests (Levers et al., 2014; Verkerk et al., 2015).

Sabatini et al. (2020a), using the results of the EPFD v1.0 from Sabatini et al. (2018), quantified the percentage of primary forest in 54 European forest types and found that shares were extremely low in most: around 25% of forest types had a proportion of primary forest between 1-5%, 60% had even less with 0.001-1%, while more than 10% did not have any known primary forest. The 10% of forest types without any known primary forest were mainly located in the Alpine and Atlantic biomes. Unequal distribution of primary forests in certain European forest types has been documented in other studies that focused on more localised mapping. Mikoláš et al., (2019) found that primary forests in Slovakia were limited largely to zones of mixed fir-beech and spruce-fir-beech forests, while other zones, such as those made up of broadleaf forests, were underrepresented or completely absent.

Sabatini et al. (2020a) also showed that forest types containing primary forests are not equally protected. Only 10 out of the 54 forest types had more than 50% of their area of primary forest strictly protected and three forest types (continental taiga, alpine acidophilous oak birch, and Mediterranean mesophilic deciduous) had no type of protection of primary forests (Sabatini et al., 2020a).

Primary forest loss in Europe

The rapid loss of Europe's remaining primary forests has been highlighted by several studies (Parviainen 2005; Knorn et al., 2013; Mikoláš et al., 2019). The former inaccessibility of remnant primary forest localities no longer ensures their preservation. Moreover, the rapid construction of new roads and new harvesting technologies have contributed to increased logging activity in primary forests (Mikoláš et al., 2017). Salvage logging of windthrow and bark-beetle outbreaks contributed strongly to primary forest loss in the Western Carpathians (Mikoláš et al., 2019) and in the Bialowieza forest in Poland, where it caused an intervention of the European Union to stop logging of Natura 2000 forests surrounding the Bialowieza National Park (Court of Justice of the European Union, 2018; Mikusiński et al., 2018; Blicharska et al., 2020).

Key messages:

- Recent data shows that remaining European primary and old-growth forests are not only unevenly distributed geographically, but also many forest types have very little or no primary forest.
- The scarcity of primary and old-growth forests in many forest types underlines the need to designate also secondary old-growth forests to create a more representative network of primary and old-growth forests.
- Significant loss of primary forests in Europe continues to take place today, pointing at the necessity of effective strict protection to achieve the targets of the EU Biodiversity Strategy.

Current initiatives to map and collect data of primary and old-growth forests in Europe

While the EPFD v1.0 and v2.0 have made substantial progress in compiling accessible data on European primary forest locations, data gaps and inconsistencies still exist primarily in Sweden and Norway but also in the Balkan region, Italy, Bulgaria, Estonia, and Denmark, as well as in countries such as Ukraine, Belarus, and Russia (Sabatini et al., 2020b, pre-print not certified by peer review). Recognising the need to fill gaps in existing data on primary and old-growth forests, there are several current ongoing initiatives that aim to contribute to further spatial mapping.

(1) The LIFE project RED BOSQUES is an ongoing study in Spain to spatially map and characterise the structural features of mature forest stands, defined as "fragments of forest that have remained untouched by human intervention, following their own natural evolution process" with characteristic features developed during ageing. In the ageing process, these stands acquire singular features (EUROPARC-Spain, 2017). The results of RED BOSQUES have been used for identification and mapping of old-growth forests in Spain, as well as for creating a series of old-growth reference stands to guide management of conservation areas in Mediterranean forests (EUROPARC-Spain, 2020).

(2) Mapping of both ancient and mature forest remnants is ongoing in several parts of France: the lowlands of the Occitanie region, Southwestern France (Gouix et al., 2019), the Alps (Danneville, 2020), some National and Regional Parks and the national network of natural reserves (e.g. Cizabuiroz, 2012; Cateau et al., 2017), and some emblematic forests of Southwestern France (Rossi et al. 2013; Ladet et Bauvet, 2017). However, these projects are led by different organisations using their own protocols.

(3) An EU-wide initiative led by the LIFE Preparatory Action Project PROGNOSES (Protection of Old-growth Forest in Europe, Natural Heritage, Outline, Synthesis and Ecosystem Services) addresses a call by the European Commission to strengthen primary and old-growth forest protection in Europe. The project aims to characterise primary and old-growth forests in Europe and ultimately produce a spatial map of these forests in the EU (European Commission, 2020, Life Preparatory Projects Guidelines for Applicants & Evaluation Guide).

Workshop statement:

- Improved maps of European primary forest are crucially needed, given the evidence that the few remaining forests are still threatened. It is therefore important that the mapping of primary forests continues despite/in parallel to discussions of how to define primary and old-growth forests. Information on locations and spatial extent will be useful regardless of the definition used, as previous studies show it is possible to map different operational, regional (country and project-level) definitions onto the set of conceptual definitions applied in top-down assessments.

3.3 Inventory based data on European primary and old-growth forests

Data routinely acquired in National Forest Inventories (NFIs) include several indicators that are potentially useful for assessing forest biodiversity and old-growthness: forest categories (for stratification), deadwood, forest age, forest structure, and forest naturalness (Winter et al., 2008; Chirici et al., 2011; Chirici et al., 2012; McRoberts et al., 2012). Although less common, some NFIs have recently been updated to include assessment of tree-related microhabitats (Brändli et al., 2016). Such data is often used for national forest biodivers ity reporting and forms the basis for European and international assessments.

Forest Europe produces a State of Europe’s Forests report every 4-5 years (ongoing from 2003-2020). The reports determine status and trends of several criteria (Forest Europe, 2015b) in European forests by assessment of quantitative or qualitative indicators. Criterion 4: “Maintenance, conservation, and appropriate enhancement of biological diversity in forest ecosystems” is assessed using ten indicators, including, for example, indicator 4.3 “naturalness” of forests and other wooded land. Based on available data from European countries, naturalness is classified into one of three categories: “Undisturbed by man”, “semi-natural”, or “plantations”. Forests and other wooded land undisturbed by man are defined as a forest in which “*the natural forest development cycle has remained or been restored, and show characteristics of natural tree species composition, natural age structure, deadwood component and natural regeneration and no visible sign of human activity*” (Forest Europe 2020). As the reports are based on sample-based inventories, it is only possible to derive an estimate of the total area of forests undisturbed by man, not their location. In the 2003, 2007, and 2011 reports, the total area of forests undisturbed by man in Europe (excluding Russia) ranged from 8-10 Mha, mainly located in North Europe but also a substantial proportion in Central-East and South-East Europe (Forest Europe, 2003; Forest Europe, 2007; Forest Europe et al., 2011). These estimates are substantially higher compared to estimates of 1.4 Mha remaining European primary forest by Sabatini et al., (2018). In the 2015 report, the area estimate of 7.3 Mha of forests undisturbed by man is lower than in the last three reports (Forest Europe, 2015a), while the most recent 2020 report estimates 4.6 Mha (Forest Europe, 2020), the lowest total area of all six reports.

It should be stressed, however, that the different Forest Europe reports are not directly comparable as the number of reporting countries varies. While certain countries may have reported data in some of the reports (but not all), other countries are missing data from all reports. Forest Europe advises to independently interpret reported trends in a given report instead of comparing results across reports. Due to these inconsistencies, it is hardly possible to compare the inventory based European results with mapping results by Sabatini et al. (2020b, pre-print not cerified by peer review). However, the decrease of forest area undisturbed by man in the 2020 and 2015 reports compared to earlier reporting years also occurred in regions where data has been consistently available. For example, in North Europe, 2.7 Mha of forest undisturbed by man was estimated in 2020, compared to 4.9 Mha in 2011 using the same definitions (Forest Europe et al., 2011, Forest Europe 2020). This suggests a substantial decline over the last decade.

Key Message:

- Inventory based reports at European level are subject to incomplete country reporting, and data reliability is negatively impacted by inconsistency in methods across countries and over time. Therefore, past trends of old-growth forests and old-growth forest attributes should only be analysed when presented in one report with consistent data coverage.

3.4 Knowledge on old-growth related tree attributes in European forests

The analysis in **chapter 2** underlined the importance of multiple criteria to describe and define old-growth forests. It became clear that using tree or stand age may be problematic if it is the only criteria used to assess forest old-growthness, because the maximum longevity of a tree depends on environmental conditions, site, forest and species type. Other criteria such as disturbance history, tree species composition, tree layer complexity, size distribution profiles of tree-related microhabitats, as well as the amount, diversity, and spatial patterns of deadwood may better contribute to determining if a forest is old-growth, whether used independently or together with age related criteria. However, we still consider it important to review scientific knowledge on tree and stand age of European forests, as it remains one of the most common criteria in old-growth forest definitions. In this chapter we therefore discuss evidence of variation of tree species' lifespan in ***section 3.4.1*** and how this lifespan varies based on the tree's site in ***section 3.4.2***. ***Section 3.4.3.*** then gives an overview of structures forests develop when old. Finally, ***section 3.4.4*** provides data on the age structure of European forests. Due to limited resources for this study, the following compiled information cannot be considered exhaustive. For example, more analysis is needed on how to determine the age of a forest stand. The age of the oldest trees in a stand might not be representative of the age of the stand even if it naturally regenerated after a stand-replacing disturbance. In addition, the other criteria listed above should be given equal attention in further investigations to assess their ability to accurately determine forest old-growthness.

3.4.1 Variation of tree species´ lifespan

Trees have different ecological characteristics. Key functional traits such as light demand, seed dispersal, leaf area index, and height vary considerably within species and successional groups. Some species, often labelled as pioneer species that can colonise open areas, are characterised by fast, early growth rates, and limited shade-tolerance and life expectancy. Late-successional species, on the other hand, often regenerate under the shade of pioneer species or in existing mature forest stands and are usually characterised by slow, early growth rates and longer lifespans. In between these extremes are mid-successional species, which may reach even higher maximum ages than late-successional species (see below). Species can be classified differently depending on the choice of ecological criteria used for the classification. For example, some species of pine have similar ecological strategies compared to pioneer species but as they have longer lifespans, they are classified in the mid-successional group in ***Tab. 4***.

Table 4. Life expectancy (maximum age under optimum conditions) of tree species in Europe from different sources.

	Area	Central Temperate European tree species[3]	UK[4]	Lithuania[5]	
	Species	Max age[6]	Life expectancy	Life expectancy[7]	Rotation age
Pioneer[8]	*Alnus glutinosa*	150		180-200	61
	Alnus incana	100	50-70	50-70	31
	Betula pendula	120	50-70	150	61
	Betula pubescens	120	50-70	100	-
	Populus tremula	100	50-70	80-100	41
	Prunus avium	150	70-100	100	-
	Prunus padus	80		150	-
	Salix alba L.	100	50-70	>100	31
	Salix fragilis	120	50-70	75	31
Mid successional	*Acer platanoides*	300	150-200	150-300	101
	Fraxinus excelsior	300	100-150	>300	101
	Pinus nigra	200	200-300		
	Pinus sylvestris	450	200-300	300-400	110
	Quercus petraea	500	200-300	500-600	-
	Quercus robur	500	200-300	500-600	121
	Ulmus glabra	400		300	101
	Ulmus laevis	250		250-300	101
	Ulmus minor	300		300	101
Late successional	*Carpinus betulus*	250		200-300	61
	Abies alba	450			
	Tilia cordata	400	200-300	500-600	61
	Fagus sylvatica	450	150-200	500	101
	Picea abies	300	100-150	200-300	71
	Castanea sativa	200	200-300		
	Taxus baccata	500	200-300		
	Tilia platyphylos	350	200-300	500-600	-

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[3] Leuschner & Meier (2018)
[4] https://www.britishhardwood.co.uk/tree-life-expectancy
[5] Petrokas et al. (2020)
[6] According to Brzeziecki and Kienast (1994); Ellenberg (1996)
[7] Navasaitis et al. (2003)
[8] The successional categories were taken from Leuschner and Ellenberg (2017); Petrokas et al. (2020); and Cojzer et al. (2014)

The exact age of a tree is rarely measured; therefore, the data included in the literature will always have a selection bias. As reported tree age is most commonly based on local studies without systematic sampling, it is very likely that the real maximum age of any species is not accurately described. Keeping the above in mind, the compilations of tree life expectancy in ***Tab. 4*** are only examples of typical ranges and do not claim that the absolute oldest observed individuals are included (some older, single tree observations are reported below). The data in ***Tab. 4*** refers to maximum ages of trees measured inside forests, whereas individual trees outside of forests without competition from neighbouring younger trees may get much older (for example Linden trees with an estimated age over 800 years). The presented information shows large differences in life expectancy between species in Europe, but also considerable difference between regions. Pioneer species are generally short lived and only in exceptional situations become older than 100 – 150 years; maximum ages for *Betula pubescens* were reported at 216 years in northern Sweden (Hofgaard, 1993) and 162 years in Russian Karelia (Kuuluvainen et al., 2002). Observed maximum age in these compilations for the mid and late-successional species of oak, pine, beech, and spruce were in the range of 400 to 620 years, but we will report some higher local observations in ***section 3.4.2*** below. One study reported in ***Tab. 4*** (Petrokas et al., 2020) also compared observed maximum ages with typical rotation ages of the same species in managed forests. We include this comparison to illustrate that in managed forests, trees are often harvested at an age that may not even be considered old for the species. Therefore, without human intervention, some of these trees could continue to thrive for many more decades or even centuries (unless affected by natural disturbances). A recent review of tree longevity also stressed that trees do not die because of genetically programmed senescence in their meristems, but instead are killed by an external agent or a disturbance event (Piovesan and Biondi, 2021). For the purpose of mapping primary and old-growth forests, it may not be necessary to determine the exact age of the oldest trees. Experience from primary forest inventories shows that veteran trees - the largest living and/or dead trees on the site which already show signs of slow dying - can be relatively easily identified (Mikoláš et al., 2019b).

3.4.2 Tree species´ lifespan depends on local site conditions

The lifespans of tree species are affected by multiple factors including the climate, functional traits (leaf area, roots, wood density), abiotic and biotic events, growth suppression, competition, and soil quality. Therefore, a range of biological, ecological, and historical drivers affect a tree’s growth and chances of survival until its maximum observed age. Below, we summarise literature describing drivers affecting the lifespan of four common European tree species. Given the diversity of drivers and constraints, it is not possible to consider tree longevity as a fixed parameter, and therefore determining a threshold for what age is considered to be old for a tree is also impossible.

European beech (Fagus sylvatica)

European beech lifespan can vary between 100 to 500 years and is closely linked to growing season temperature and geographic location of the tree. In the lowest elevation zone of Italy, beech survive only on deep and fertile soil and can reach a maximum of 200 years (Di Filippo et al., 2015). Comparatively, in the mountains of Pollino National Park at 1900 m elevation, two exceptional individuals dated at 622 and 620 years were found (Piovesan et al., 2019) (***Fig. 5***). Higher temperatures increase the growth rate of beech, but (according to regression models) simultaneously reduce beech lifespan by 23 to 30 years for each degree of warming (Di Filippo et al., 2012; Di Filippo et al., 2015). Another factor influencing the lifespan of beech is the water stress to which the trees are subjected to. Beech in the Apennines develop a more extensive and developed root structure due to the summer water stress, which makes them less prone to windthrow.

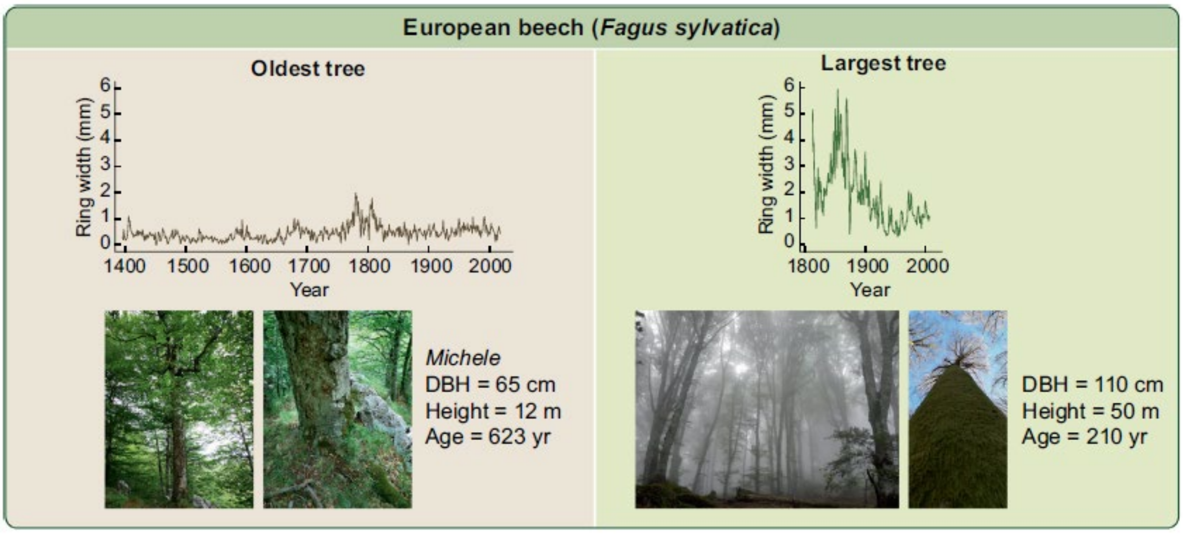


Figure 5. Comparison of the oldest and the largest beech trees found in the Italian Apennines (from Piovesan and Biondi, 2021). The oldest age is often reached on unproductive sites with limited growth rates (e.g. on steep rocky slopes at high altitude) and the ecological niche of maximal stem age is typically different from the optimum combination of site factors for growth.

Oak (Quercus spec.)

Among the oldest oak trees reported in Europe, one *Q. petrea* tree in Aspromonte National Park was found to be approximately 930 years old (Piovesan et al., 2020), while *Q. robur* individuals reached 518, 536, and 568 years in the Cantabrian mountains of Spain (Piovesan et al., 2019). *Q. robur* around 400-600 years were also reported in Sweden, where landscape, site, and tree properties affect oak longevity. Notably, alteration of the water regime due to land use changes appeared to affect old oak tree mortality (Drobyshev and Niklasson, 2010). Humid climate in the summer might create favourable growth conditions for oak, contributing to lower maximum age compared to areas with summer droughts and cold winters (Drobyshev et al., 2008). Oak has a much longer lifespan when growing with shade tolerant and semi-shade tolerant tree species which are regularly removed before they outcompete oak, or in a forest stand where beech is weakened by sub-optimal site conditions for the species (Leuschner and Ellenberg, 2017). The individual response to environmental factors of oak changes throughout its lifetime, and thus the diversity-productivity relationship might shift during secondary successions (Madrigal-González et al., 2017). The typical large size of old oaks may also cause increased sensitivity to wind damage (Drobyshev et al., 2008).

Norway spruce (Picea abies)

Individual Norway spruce trees exceeding 400 years are found in few regions of eastern Europe, the Alps, and in Fennoscandia. The oldest individuals are often found in harsh environments, such as at high altitudes in the Northern Swiss Alps (Bigler, 2016), or are individuals with unusual morphological characters (e.g. multiple stems, miniature trees, clonal individuals) (Castagneri et al., 2013). Wallenius et al. (2002) documented a 433-year-old *Picea abies* in east central Finland. Due to capacity for vegetative reproduction; however, spruce can become very old as a clonal organism, perpetuating themselves by layering. New shoots can develop from the lowermost snow pressed, rooted branches, whereupon new stems may eventually grow up. Radiocarbon dating suggests that two spruces in Sweden, Old Tjikko and Old Rasmus, are around 9,500 years old as an organism (ÖBerg and Kullman, 2011). Longevity of Norway spruce is further determined by the combined effects of growth rates, variable site conditions, and different tree morphology traits. Slow-growing individuals were found to accumulate more chemical defences and can have a higher wood density with increased resistance to pests or extreme events, and thus, can reach higher ages, such as 400 to 600 years in Norway (Castagneri et al., 2013). Increased average annual growth rate of 2mm instead of 1mm up to the age of 50 years was found to decrease the expected lifespan of Norway Spruce in the Swiss Alps by half (Bigler and Veblen, 2009). Longevity of Norway spruce was found to increase when lower storey trees had a larger crown diameter, but decreased with crown length, showing that longevity is also influenced by size dependent factors (Rötheli, et al., 2012).

Pine (Pinus sylvestris and Pinus montana)

The lifespan of Scots pine (*Pinus sylvestris*) is also reported to be prolonged by poor growth (Backman, 1943) and slow metabolism (Molisch, 1938). In an unevenly aged Boreal forest in Russian Karelia, the interplay between disturbances, forest regeneration, and successional processes influenced the lifespan and size distribution of trees ranging from 250 to 525 years. The oldest trees survived several fires that had an important effect on the structure of this forest, preventing the invasion of *Picea* and deciduous trees. Moreover, the suppressed trees in the understorey regenerated in smaller numbers and grew slowly (Kuuluvainen et al., 2002). In Sweden, individuals of 435 years (Zackrisson et al., 1995) and 757 years (Andersson and Niklasson, 2004) have been found. In Scotland, the mean age of different stands of Scots Pines ranged from 132 to 355 years old (Fish et al., 2010). For *Pinus montana* lifespan was found to increase along a gradient from south- to north-facing sites and with increasing elevation and slope steepness, individual trees can reach a large diameter at the cost of reduced lifespan (Bigler, 2016).

Key Messages:

- Tree lifespan is very species and site dependent, and therefore it is difficult to adopt a common age threshold to identify old forests. For the purpose of identifying and mapping primary and old-growth forests, it may however be sufficient to identify veteran trees without determining their exact age.
- While the lifespans of pioneer trees are limited, mid- and late-successional species naturally grow much older than the common rotation period in managed forests.

3.4.3 Characteristics that trees develop when they grow old

When trees grow old, they can develop certain characteristics that allow them to survive and develop unique biodiversity structures. Slow growing trees, such as beech at higher altitude in Italy, accumulate expanding layers of biomass throughout their life and maintain a stunted height. Shorter trees have narrow conduits that appear to confer embolism resistance, which can make them more resilient to frost and droughts (Piovesan et al., 2019). With increasing tree age and size, their diameter and bark thickness increases, creating space for abundant and diverse tree-related microhabitats (TreMs) (Michel et al., 2011; Courbaud et al., 2017; Paillet et al., 2017; Larrieu et al., 2014). Oaks, when becoming overmature, develop cavities and hollows that facilitate increased population density of saproxylic beetle species, woodpecker species, saproxylic fungi, cavity roosting bats, cavity dwelling birds, and small organism groups (e.g. oribatid mites) (Mölder et al., 2019). When a tree's lower branches die in the shade, they give entry to heart-rot fungi which are not able to penetrate the tree unless there are injuries. The age at which trees develop cavities varies by species and depends on their physiology and processes such as environmental conditions, natural disturbances, and management practices. TreMs dynamics are closely related to tree biology, such as growth-defence trade-offs, formation of wood, relationship with fungi and insects, and development of wood decay. Tree cavities develop more rapidly in fast-growing trees but persist in slow-growing trees. Microhabitat development can also be enhanced in even-aged production forests among young trees affected by ungulate browsing, fires, or insect attacks. However, in such conditions, the long-term functioning of microhabitats may be missing (Korkjas et al., 2021).

3.4.4 Information on age structure of European forests

The age structure of European forests has significantly changed since 1950 (Vilén et al., 2012). The share of old stands (>100 years) in 25 European countries (excluding Russia) decreased from 26% in 1950 to 17% in 2010, and the mean age over the study area decreased from 67 to 60 years. However, trends varied between countries. One contributing factor for the decreasing average age was afforestation and natural forest expansion on abandoned agricultural lands, as this increased the share of young forests (Vilén and Lindner, 2014; Fuchs et al., 2015). The share of mature stands (> 80 years) increased in many countries after 1980, but the forest area of old forests was still lower in 2010 than in 1950 in absolute terms (Vilén et al., 2012). A more detailed analysis of national inventory data in Finland and the Czech Republic further showed that old forest stands had a significantly lower growing stock in the 1950s when compared to 2010 (Vilén et al., 2016). Stands were classified as old based on the oldest tree present in the cohort, even though selective harvesting had removed considerable biomass from these stands. When interpreting data on the ages of stands and the age structures of forests, it is important to note that forest ecosystems assessments and forest inventories are lacking a consensus on how the age of a forest stand should be determined. Moreover, mean stand age is not relevant in uneven-aged stands with irregular vertical structure and diameter distribution. Several methods and indicators exist that vary according to different forest types and national reporting practices (Chirici et al., 2011).

The State of Europe's Forests reports produced by Forest Europe include indicator 1.3 "Age structure and/or diameter distribution of forest". In the first three reports (2003, 2007, and 2011), age structure of even-aged forests is described according to different age ranges, compared to the last two (2015, 2020), where even-aged stands are instead divided into four groups: "even-aged regeneration", "even-aged intermediate", "even-aged mature", and "even-aged unspecified". It should also be noted that the 2020 report exclusively documents age structure of forests available for wood supply and not all even-aged European forests.

In the State of Europe's Forests 2007 report, in which age structure of even-aged forests was reported according to different age ranges, data was mainly available for East Europe, North Europe, and Central Europe. In Central Europe, two-thirds of even-aged forest area consisted of forests younger than 60 years. By contrast, East Europe had high shares in the older age ranges of 81-100, 101-120, and 121-140, with over 15%, 10%, and 5%, respectively. The Nordic/Baltic regions contained even younger forests than Central Europe but out of the three regions, had the highest share of forests in the oldest age range of 121-140 years, with slightly higher than 5% (Forest Europe, 2007).

In the 2011 report, even-aged forests were reported in different age classes than in the 2007 report. They were divided into three classes, <20, 21-80, and >80 years. For the oldest age class, Central-West and North Europe held the highest share, with over 20%. Central-East and South-East followed ranging between 10-20%, and the South-West had the lowest share with less than 5%. Overall, 18% of even-aged forest were >80 years (Forest Europe et al., 2011).

The latest 2020 report only reported data for a small number of countries and did not present regional averages. At the European level, it indicated that around 18% of forest available for wood supply fall into the class of even-aged mature (i.e., even-aged forests older than 90% of the recommended rotation age).

Key Message:

- The State of Europe's Forests reports produced by Forest Europe represent the main European compilation on forest age structure, but due to varying methodologies and incomplete reporting the information is insufficient to guide policy in relation to protection of old forests.

4. Approaches to protect old-growth forests and to maintain and develop old-growth forest attributes

4.1 Introduction

The EU Biodiversity Strategy for 2030 sets the targets that 30% of EU land should be protected with specific focus on areas of very high biodiversity value or potential and that one third of protected areas should have strict protection status, including all remaining EU primary and old-growth forests. This chapter reviews the approaches that are available to protect old-growth forests and to maintain and develop old-growth attributes. We first provide some context on forest management and forest protection in Europe, followed by a discussion of possible approaches to improve the conservation of remaining primary and old-growth forests through strict protection, before concluding with a section documenting complementary approaches to maintain and develop old-growth forest attributes in managed forests.

4.2 Context: European forests differ in their provision of ecosystem services and protection status

Europe's forests vary widely in site conditions, history, management regimes, and socio-economic value (Bollman and Braunisch, 2013). Forests provide multiple ecosystem services including not only wood and non-wood forest products, but also carbon sequestration and climate regulation, water retention, biodiversity, recreation, and cultural identity (Duncker et al., 2012; Jansson et al., 2015; Blicharska et al., 2017). Ensuring the provision of these multiple ecosystem services in forest management and balancing between diverging societal demands is a key objective of sustainable forest management (Holvoet and Muys, 2004). While several ecosystem services can be combined through multifunctional stand management (cf. ecosystem service bundles, Mouchet et al., 2017), other services are clearly conflicting. Habitat provision through old-growth forest preservation entails a trade-off with wood production (Winkel et al., 2015) that can only be solved by spatially separating the service provisioning (Duncker et al., 2012). In Europe, although wood production is possible in most forests and is less dependent on a specific location (although site productivity and infrastructure for wood extraction and processing differ significantly), other ecosystem services can hardly be moved or replaced. For example, the recreational demand of forests is more prominent in urban areas and forests in mountainous areas protect settlements, roads, and railway lines against natural hazards like avalanches or rockfalls. Similarly, non-replaceability is also a main argument for protecting the remaining primary and old-growth forests in Europe. Service demands of forests are continuously changing, and in recent decades more forests with strong forest management legacy in or close to urban areas have been protected for biodiversity conservation purposes (for example parts of the Sonian forest next to Brussels, Belgium, or the Sihlwald in Zürich, Switzerland). It will, however, take considerable time to restore such forests to old-growth status (Lilja et al., 2006; Vandekerkhove et al., 2009; Bouget et al., 2014; Paillet et al., 2015).

Primary and old-growth forests in Europe are scarce, partially threatened, and are critically important for biodiversity conservation (McGee, 2018), ecosystem services such as carbon storage (Ford and Keeton, 2017; European Commission, 2020), as well as irreplaceable references for studying natural disturbance processes and rare and threatened species (Nagel et al., 2013). To some experts, these factors explain the motivation behind the strict protection outlined in the EU Biodiversity Strategy (***Box 4***). It is clear that strict protection should be granted to all the EU's remaining primary and old-growth forests that are not protected or lack strong enough protection status to ensure their long-term conservation (Sabatini et al., 2018; Sabatini et al., 2020a; Forest Europe et al., 2011; European Commission, 2020). In addition, the strictly protected area network would need to be expanded in order to support the conservation of these forests (Barredo et al., 2021). This topic is further discussed in ***section 4.3.***

Key Message:

- Forests provide different portfolios of ecosystem services depending on location, ecological quality, and socio-economic demands. While many services can be simultaneously provided in multifunctional forest landscapes, there are also conflicting ecosystem services which need to be spatially separated. Specifically, the few remaining EU primary and old-growth forests can only be preserved through strict protection, without natural resource extraction.

In addition to location, forest governance and ownership strongly influence the conservation and management of European forests. The majority of strictly protected forests currently occur on public land, whereas several EU Member States have predominantly private forest ownership (UNECE and FAO, 2021). Ownership and management objectives vary considerably in Europe, which may affect the designation of additional future protected areas. However, forests sustainably managed for wood production increasingly take biodiversity conservation objectives into consideration through e.g., national legislation standards and certification schemes. If approaches embed the restoration of old-growth forest attributes in managed forests, they may be regarded as complementary measures to strict protection and may help to strengthen aspects of biodiversity conservation in European forests overall. We discuss this further in ***section 4.4***.

More than a quarter (27%) of the EU forest area is designated for species or habitat protection under the Natura 2000 framework (EEA, 2020). The network covers 93% of the primary and old-growth forests in the EU (Barredo et al., 2021). However, management guidelines for these areas are variable, can be different for each separate dedicated area, and are still lacking for some. The majority of forests within Natura 2000 areas continue to be managed for different objectives, including wood production, and conservation objectives set for them do not only focus on the development of old-growth attributes (Winkel et al, 2015; Sotirov, 2017). Natura 2000 areas are nevertheless relevant for the analysis in this report especially in the case that: (i) their protection aims are directed towards increasing the areas of primary and old-growth forest (***section 3.3***), or (ii) their management supports the development of old-growth attributes (***section 3.4***).

Landscape protection is another approach for protection that is common in some countries, for example to conserve traditional landscape features or to preserve traditional management systems such as coppice, coppice with standards, woodland pastures, or large intact forest landscapes such as in the Scandinavian mountains (***Box 5***). Such traditional management regimes can provide important habitats especially for endangered thermophilic and photophilic species (Lassauce et al., 2012), but conserving them requires continuation of a sometimes quite intensive management like in coppice forests, which is not compatible with developing old-growth forest characteristics. In ***section 4.3***, we will further discuss how to expand strictly protected forest areas to support conservation of old-growth forests.

Key Messages:

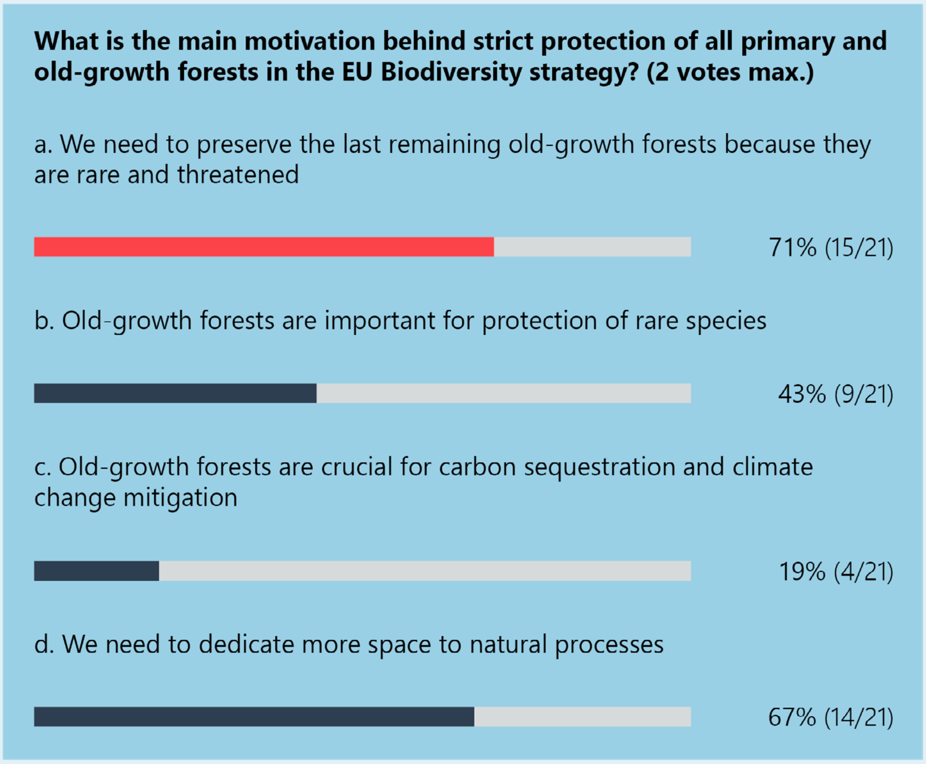
- The diversity of forest types, management traditions and socio-economic context in Europe is crucial to consider in the efforts to improve conservation of primary and old-growth forests.
- A considerable share of the forest area in Europe is part of the Natura 2000 network. At national level, additional schemes of protected areas exist. These schemes may include strict protection of primary and old-growth forests and maintaining and developing old-growth attributes, but they may also have other conservation management objectives that require active interventions to preserve specific forest types or favour specific threatened species.

4.3 Expanding the strictly protected forest area network

Strictly protected forest areas in Europe cover only 1.8% (EU28 2.1%) of the forest area (Forest Europe, 2020). This area has increased by 100% from 2000 to 2020; however, in the last five years, increases have been minor (Forest Europe, 2020). However, different interpretations of strict protection (Frank et al., 2007) and inconsistent reporting by countries limit the quality of information on strictly protected forest areas. Although the status of National Park is the strongest possible protection scheme in some countries, forests included in the core zones of National Parks may still be managed and partly harvested, for example in France. Of the mapped 1.4 Mha of primary forests in Europe, 46% were categorised as strictly protected (Sabatini et al., 2018), although this includes protected forest areas classified as IUCN level II (National Park). Strictly protecting the remaining 54% will require setting-aside 0.3% of Europe's land area (or roughly 1% of Europe's forest area), in addition to increasing the protection status of around 5,000 km^2 of remaining primary and old-growth forests (Sabatini et al., 2020a). The small area of remaining European primary forest with very low shares in several forest types is by far not enough to meet the share of the 10% strict protection of land area target as specified in the EU Biodiversity Strategy. Sabatini et al. (2020a) found that meeting a target of 10% of European forest area in primary status (similar to the EU Biodiversity Strategy target) would require allowing an additional area of 107,000 km^2 to revert to primary and old-growth status inside and outside protected areas.

Allowing for forests to revert to old-growth or primary status through strict protection will often take many decades or centuries (e.g. northern boreal forests, Lilja et al., 2006; or lowland beech-oak forests, Larrieu et al., 2017; Larrieu et al., 2019). In developing an index to quantify forest old-growthness, Meyer et al. (2021) found that European beech forests left to natural development (with time since abandonment from 4 to 43 years following low intensity management) only displayed old-growth values of 0.13 - 0.42 compared to reference old-growth beech in Slovakia which ranged from 0.71 - 0.74 (the index ranged from 0 to 1, with 1 indicating the highest possible old-growth value). Not only the time since abandonment, but also the previous management type and intensity influence the old-growthness of the forests (Meyer et al., 2021).

Box 4 - Workshop poll on the motivation for strict protection of primary and old-growth forests:



What is the main motivation behind strict protection of all primary and old-growth forests in the EU Biodiversity strategy? (2 votes max.)

a. We need to preserve the last remaining old-growth forests because they are rare and threatened

71% (15/21)

b. Old-growth forests are important for protection of rare species

43% (9/21)

c. Old-growth forests are crucial for carbon sequestration and climate change mitigation

19% (4/21)

d. We need to dedicate more space to natural processes

67% (14/21)

Key Messages:

- More than half of Europe's primary forests are without strict protection status. Upgrading the protection of these forests should be prioritised as the first step in ensuring their conservation.
- The EU Biodiversity Strategy sets the target to strictly protect ("leaving natural processes essentially undisturbed") 10% of EU land area. The remaining EU primary and old-growth forests make up less than 3% of Europe's forest area. Therefore, strictly protecting these remaining forests will not be enough to meet the 10% strict protection target. Implementing the target is an opportunity to significantly increase the share of (secondary) primary/old growth forests in the long run, which would be very beneficial from a conservation perspective.

Expanding the network of strictly protected primary and old-growth forests is crucial also because many of the remaining patches are extremely limited in size. For example, Sabatini et al., (2018) found that the median size of all remaining primary forests was only 24 ha. In general, 65% of European protected areas are smaller than 100 ha (EEA, 2012). Small patch sizes, however, reduce forest and species resilience to climate change (Maes, 2020) and prevent natural dynamics (Wild Europe 2020a). Moreover, smaller patch sizes are correlated with larger areas with edge effects arising from the surrounding environment. For example, Svensson et al., (2019) found that when considering edge effects up to 100m in northern Sweden inland forest landscapes, the estimated intact patch core area was only 6-7% of the total forest area. Consequently, some European protected areas carry an extinction debt (i.e. a high future species extinction risk due to events of the past) (Berglund and Jonsson, 2005; Báldi and Vörös, 2006), including European old-growth patches (Penttilä et al., 2006).

Box 5. An example of expanding the strictly protected forest area network to support primary forest conservation in Sweden

In northern Europe, the "Scandinavian Mountains Green Belt" (Svensson et al., 2020) has been presented as a broadly intact forest landscape with a substantial share of primary and old-growth forests, which extends south to north across close to 1000 km in the foothills region in Sweden. Owing to strict logging regulations and to the fact that a large share of the forests occurs in small, isolated, and technically challenging sites with lower tree growth capacity, the landscape developed high biodiversity value, which resulted in the strict protection of 58% of the forestland (Jonsson et al., 2019; Angelstam et al., 2020). Recently, a parliamentary revision of the national forest policy has put a strategy in place for additional protection of the remaining core areas up to around 80% of the forest land, equal to around 2 million ha forestlands in a landscape that is largely intact (Svensson et al., in prep.). Despite historical forestry and other land use, such as indigenous Sami people reindeer husbandry, forest connectivity and continuity has been maintained more or less continuously along the whole mountain stretch (Mikusiński et al., 2021). Given the extensive transformation of forests and forest landscapes in the inland and coastal regions of the boreal region in Sweden, the Scandinavian Mountains Green Belt plays an important role in the protection of old-growth and intact forest attributes in Northern Europe.

Strictly protecting areas adjacent to old-growth forest patches could be one pathway to expansion (Wild Europe, 2020a). This approach could be informed by the concept of ecosystem minimum dynamic area (MDA). MDA is defined by Pickett and Thompson (1978) as "the smallest area with a natural disturbance regime, which maintains internal recolonization sources and hence minimizes extinction". The MDA is the area large enough to cover patches of all successional stages and ensure ecosystem regeneration through natural disturbances (White et al., 2018). Few studies have estimated the size of possible MDA (Leroux et al., 2007). However, larger areas are required where disturbances, particularly large-scale natural disturbances (Schultze et al., 2014), are more common (Peters et al., 1997). It was suggested that the MDA should be greater (e.g. double) in area than the largest disturbance patches (Johnson and Van Wagner, 1985; Leroux et al., 2007) or 50 times the size of an average disturbance patch (Shugart, 1984). More precise estimates can be derived from models that determine the likelihood of a stand-replacing disturbance based on the area of the forest (Haney et al., 2000). By designating MDA larger than the maximum disturbance size: (i) biodiversity loss is less likely to occur due to extinction debt in small protected area, (ii) there is a lower probability that natural disturbances within the forest will also affect surrounding productive forest area within the landscape matrix, and (iii) there is a higher chance that the intensity and extent of negative effects (i.e. edge effects, reduced connectivity) caused by the management of the land surrounding the protected forest area will be mitigated (Baker et al., 1992; Poiani et al., 2000).

Whereas the MDA concept is not readily used in forest protection targets in Europe, the concept of wilderness areas is more widely recognised since the 2009 adoption of the European Parliament Resolution on Wilderness in Europe (2008/2210(INI)), which recommended Member States to create new wilderness areas. The minimum size of a wilderness area may vary depending on the type of ecosystem, its location, and environmental conditions (European Commission, 2013). Large strictly protected areas are important for conserving biodiversity and allowing for natural dynamics, but such areas are not available everywhere. Continuous forest areas across ownership types larger than 100,000 ha, without considerable separation by other land uses, form 64% of European forests and mainly occur in Northern European countries (Forest Europe, 2020). In other regions such as Central-West Europe, such account to only 33% of the forest area (Forest Europe, 2020). However, smaller protected areas in Europe have been found to have higher than expected species richness compared to what is expected from their size (Hoffmann et al., 2018). Therefore, they are thought to play an important role for biodiversity conservation in the highly fragmented landscapes in Europe (Götmark and Thorell, 2003).

A study by Ward et al. (2020) found that less than 10% of the global protected network area is structurally connected, and therefore habitat retention and restoration to improve connectivity of primary forests is crucial (EEA, 2020; Maes, 2020; Selva et al., 2020). Wild Europe (2020b) proposed guidelines for sustainable protection and restoration of primary and old-growth forests, suggesting that protecting a total of 11-12% of European forest area in the direct vicinity of the remaining primary and old-growth patches could improve connectivity, and as a result, reduce vulnerability to climate change and improve the conservation status of threatened species that depend on this type of forest. In addition, smaller, strictly protected forest areas can play an important role as so-called 'stepping stones' in a protected area network to facilitate species migration in the face of climate change (Saura et al., 2014). The use of managed forests with high ecological integrity as "green corridors" could in addition help achieving connectivity objectives (Maes, 2020) as further discussed in ***section 4.4***. Improving connectivity could be supported by the development of comprehensive, high-precision pan-national land cover maps that allow for spatial assessment of forest type distribution, including their degree of management impact (Svensson et al., 2020; Mikusiński et al, 2021).

Key Message:

- Strictly protecting areas surrounding remaining primary forests could contribute to the effectiveness of conservation actions. Designing these areas based on concepts of minimum dynamic area or wilderness area would ensure their long-term conservation by providing sufficient area for natural disturbance regimes and species populations.

Reaching the 10% strict protection target in the EU Biodiversity Strategy for 2030 based on setting-aside wilderness areas or MDA will be difficult to implement in the most developed (urbanised) regions. A study by Brackhane et al. (2019) found that the percentage of land available to develop sites for wilderness areas in Germany varied greatly regionally and depends on the target minimum area. With a minimum non-fragmented land area (considering compactness through buffer zones) of 1,000 ha, around 10% of Germany's land-area could potentially be used, as opposed to 4.1% with 3,000 ha area or 0.6% with 10,000 ha. The study also found that forest ownership will be a main challenge to implementing the 2% wilderness target of the National Strategy on Biological Diversity for Germany, considering that most wilderness areas will need to be designated in State or federally owned forest areas to mitigate trade-offs with management objectives of private and communal forest owners. As the majority of the forest area in Germany is privately owned or is communal forest, this significantly reduces the candidate areas for strict protection. Availability of land for large scale strict protection varies strongly across European regions. More than half of the strictly protected forest area is located in Northern Finland, Sweden, Ukraine, Italy, Estonia, Greece and Belarus (Forest Europe, 2020). These protected areas occur mostly on public land and predominantly in remote, low productive areas.

As multiple aspects influence the success of forest protection to achieve the conservation goals, systematic conservation planning (Margules and Pressey, 2000) could provide the guidance necessary to select areas that will develop into secondary old-growth forests in the future, ultimately developing a representative network of strictly protected forests across the European landscape that are effective in reaching conservation goals (Sabatini et al., 2020a). In systematic conservation planning, several criteria are used to select protected areas. A study by Schultze et al. (2014) found that in the selection of strictly protected forest areas for Europe the criteria of representativeness, completeness (size and shape of area), and threat are most important. Systematic conservation planning has, however, not been commonly employed in Europe in the past, although selection of protected areas from the Natura 2000 network did utilise some aspects of the framework (Gaston et al., 2008). Therefore, actively incorporating all steps of systematic conservation planning efforts could accomplish further progress in selecting future protected areas. The low utilisation of systematic conservation planning in Europe may be due to several factors including the lack of biodiversity data (although old-growth indices could provide a potential solution), and that responsible regional authorities prefer different planning methods (Gaston et al., 2018). In addition, there is a lack of data at the EU level on the cost of setting-aside additional protected areas, which is an important consideration in systematic conservation planning (Müller et al., 2020). Therefore, progress in filling these gaps will be important to improve the effectiveness of conservation planning in Europe.

Key Message:

- Strictly protected large areas surrounding the remaining primary and old growth forests will need to take into account the situation of land ownership. In several European countries, private ownership of forest land is dominating and identifying additional areas for strict protection of sufficient size to serve the protection purpose may turn out to be difficult.
- Systematic conservation planning could help to plan how strictly protected areas should be set aside to develop towards old-growth forests in the future. Increased availability of biodiversity data and cost calculations of setting aside additional forest areas could help to facilitate systematic conservation planning.

4.4 Integrative management approaches to maintain and develop old-growth forest attributes

European forests are characterised by a long history of human use; thus, they have been considerably altered over the centuries (Welzholz and Johann, 2007). More than 80% of the forests are managed, most of them with a strong focus on wood production. When comparing managed forests to unmanaged forests in Europe, they typically have lower species richness, and may lack site adapted tree species and diversity in the stand structure (Paillet et al., 2010; Spiecker et al., 2004). Specifically, late development phases as well as natural processes associated with tree senescence are often completely lacking in those forests as trees are harvested before they reach such development stages (Kraus and Krumm, 2013). Such phases, however, often support rare habitats and associated species including relict species of primeval forests (Hermy and Verheyen 2007; Bollmann and Müller 2012; Eckelt et al., 2018). Old-growth attributes normally associated with forest ecosystems driven by natural succession and dynamics are consequently reduced in managed forests (Bauhus et al., 2009; Dieler et al., 2017), although this can differ depending on the management intensity and region (Angelstam and Dönz-Breuss, 2004). The retention and active restoration of old-growth attributes in managed forests has recieved increased attention as a management objective. Such may complement an expansion of a network of strictly protected forest areas including old-growth forests, and also improve their connectivity (Bengtsson et al., 2003; Keeton, 2006; Nagel et al., 2013; Chazdon et al., 2017; Mansourian, 2017; Maes et al., 2020). One potential management measure is to diversify the forest structure while retaining the damaged and downed trees and forest gaps that are created by natural dynamics following a natural disturbance event (Thorn et al., 2018).

Part of the protection instruments applied in managed forests (see ***Tab. 5***) include spatially separated elements at the forest patch level (e.g. old-growth forest islands, special biotopes, corridors and linear structures). The retention and active promotion of structural features typical for late forest development phases can be supported through protection of old/methuselah and habitat trees and gaps and by increasing the amounts of standing and lying dead wood. Active restoration to increase quantities and diversity of deadwood can be achieved through a variety of measures, including tree girdling, creation of high stumps, uprooting trees, and topping of tree canopies (Lewis 1998; Cavalli et al., 2003; Jonsell et al., 2004; Lindhe et al., 2004; Vítková et al., 2018). Other active restoration measures such as refilling of drainage to restore wet forest biotopes can also support forest biodiversity conservation (Mazziotta et al., 2016). In the Nordic countries, practices include active creation of deadwood, as well as the retention of forest composition and specific stand structures such as forest edges, shelter trees, and patches that will become part of the next generation stand (Gustafsson et al., 2020).

So-called 'ecological process areas', which are temporarily restricted areas embedded within the managed forest, can be established to allow for natural dynamics to take place for several decades after the occurrence of a natural disturbance (Bollmann and Braunisch, 2013). These areas support the development of early successional stages that result after a large-scale natural disturbance and can be later re-integrated into the regular management planning at the forest enterprise level.

Table 5. Selected conservation instruments at different spatial scales (adapted from Bollmann and Braunisch, 2013). Landscape scale protection instruments are not listed. Type (S: segregation; I: Integration).

Instrument	Description	Type
Forest patch		
Strictly protected forest areas	Protected area in which biodiversity is preserved by allowing natural dynamics with either no or minimal intervention (see MCPFE Classes 1.1 and 1.2).	S
Special forest reserves	Protected area aiming at enhancing forest biodiversity through active habitat restoration or management (see MCPFE-class 1.3).	S
Wildlife corridors	Areas allowing wildlife species to move between populations which have been separated by human activities or structures.	I
Ecological process areas	Temporally restricted, spatially flexible conservation instrument within managed forests which integrates natural dynamics after a disturbance event; after some decades the area can be again managed while a new area where a disturbance has occurred takes its place.	I
Stand		
Old-growth / old forest islands	Small old growth stands including mature, decaying and dead trees. Such stands can serve as stepping stones within managed forests.	I
Linear structures	Forest edges, tree groupings along water courses.	I
Rare forest biotopes	Rare, near natural forest communities e.g. riparian forests, bogs, wetlands or specific natural formations (rock formations, dunes etc).	S/I
Structural retention		
Habitat tree	A standing living (or dead) tree having developed ecological niches, so called microhabitats. Different species may depend on particular tree related microhabitat structures for their full or part of their life cycle.	I
Methuselah tree	Usually referred to as very old trees. The term may also be applied to trees that surpass a defined diameter at breast height threshold above which they are left to further develop naturally until breakdown.	I
Deadwood	Snags or lying deadwood	I
Gaps	Small scale openings in forest stands caused by disturbance events.	I

Measures that are applied in managed forests to increase the availability of old-growth structures are often temporary in nature. For example, habitat trees that are designated throughout managed forest areas (often based on a given target number of habitat trees per ha, e.g. between 2 and 10) will at some point in the future senesce or be downed as a result of a disturbance event. In their place, new habitat trees (or habitat candidate trees) are then designated where available (Mergner and Kraus, 2020, Krumm et al., 2013). A similarly transient nature applies to so called old-growth patches/islands or old tree groups of varying sizes found within managed forests. Once such designated patches collapse, they will be subject to natural regeneration, to once again be integrated within regular forest management. Other such old-growth patches that persist within a managed forest will then be left for natural development until patch loss likewise occurs in their place.

How to best combine segregative and integrative instruments will depend on forest biodiversity conservation objectives and related legislation, the given conditions, as well as silvicultural legacies in a particular country. Ideally, different segregative and integrative approaches can complement one another in the approach to maintain and enhance biodiversity conservation while ensuring the provision of a multitude of forest ecosystem services and respecting the broad range of forest ownership situations (Bollmannn and Braunisch, 2013; ***Fig. 6***).

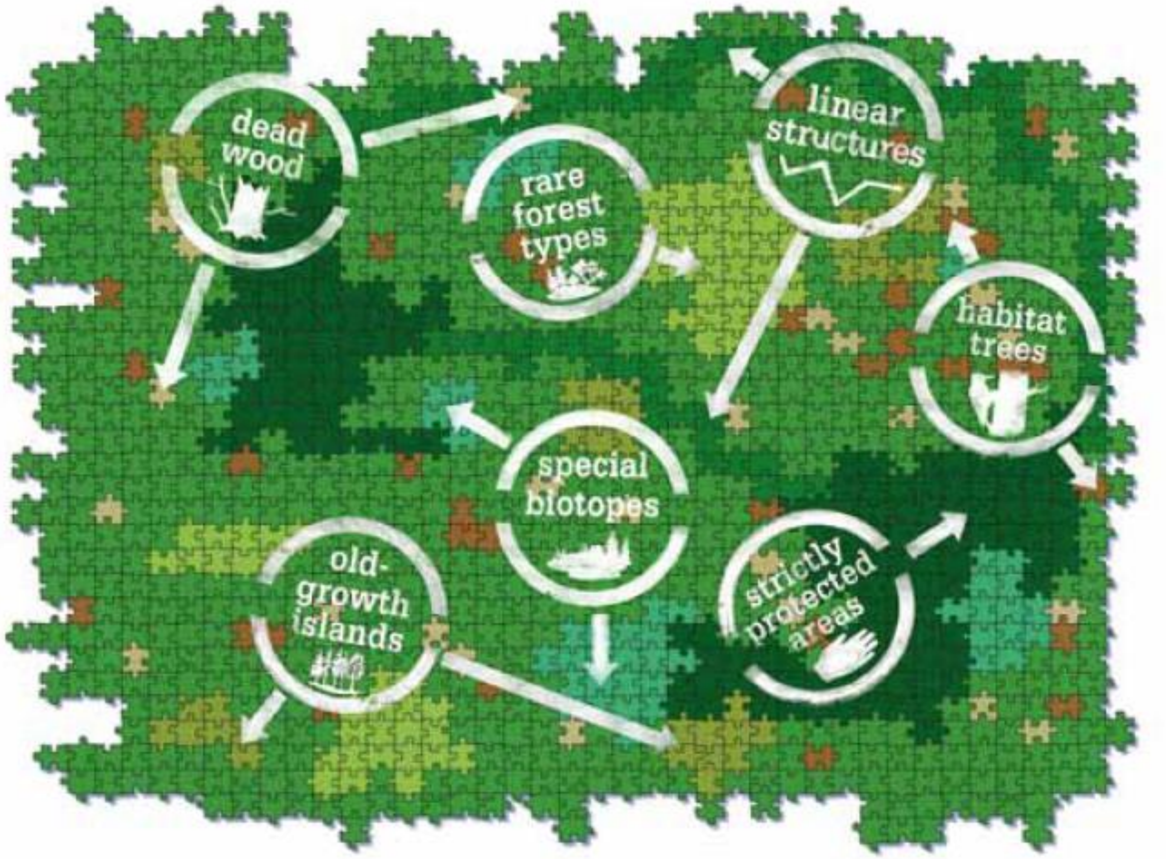


Figure 6. An idealised forest landscape with elements building on a management strategy that embraces segregative elements such as special biotopes, strict reserves, old-growth/old forest islands, linear structures, and also habitat trees and deadwood that are spatially embedded within forests applying close-to-nature management principles (taken from Krumm et al., 2013).

Maintaining and enhancing European forests' biological diversity as well as ensuring their resilience and adaptability in a rapidly changing environment is key for the sustainability of forests and the well-being of European societies. Integrated forest management that applies multifunctional, close-to-nature management principles (Aggestam et al., 2020) will need to be addressed at an enterprise or even at a landscape level. This is necessary to ensure habitat connectivity within forests and consideration of interfaces to other ecosystems and land uses such as open land and agriculture but also water bodies or settlements (Chazdon, 2018; Krumm et al, 2020a). Krumm et al. (2020b) present a set of case examples of such integrative forest management approaches tailored to the local context (see ***Fig. 7***).

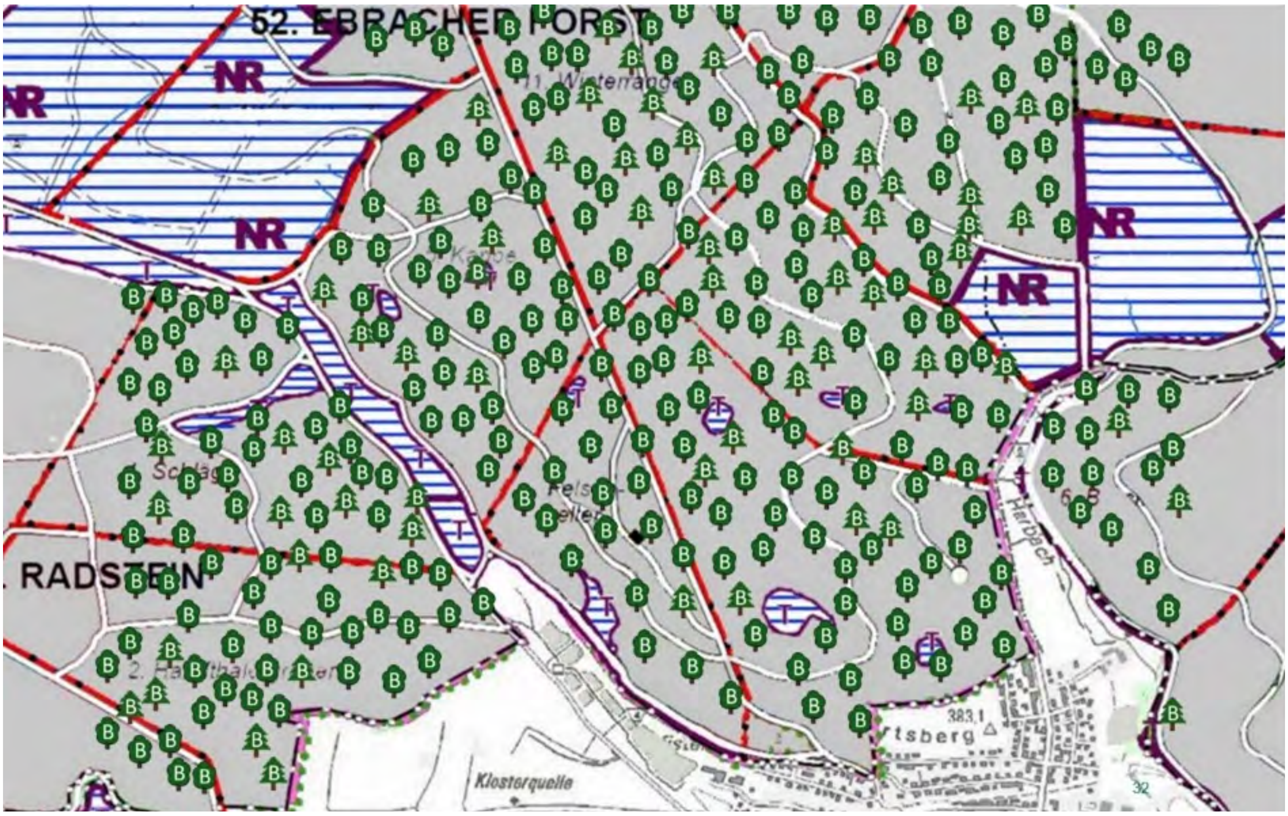


Figure 7. Example of an integrative forest management approach in a forest enterprise. Strict forest reserves (NR), Stepping stones (T) (old/large dimension tree patches; corridors with special features e.g. water ecosystems), habitat trees across the whole managed forest area (B), and a dead wood management concept (not shown in figure) with set targets, may be applied in an enterprise. Figure 7 was provided by Ulrich Mergner, Bavarian State Forest Enterprise, Ebrach, Germany. More details on the Ebrach Forest Enterprise case study can be found in Mergner and Kraus (2020).

Key Messages:

- Integrating biodiversity conservation measures into forest management can support protecting and developing old-growth patches and old-growth attributes in multi-functional forests.
- Integrative biodiversity conservation measures in managed forests in combination with strictly protected forest areas can improve habitat connectivity between primary and old-growth forests.

Biodiversity protection measures in managed forests can be partly legally required (for example in response to EU species protection directives; Borrass et al., 2015), but are often voluntary (Miljand et al., 2021) with sustainable forest management certification as one widely adopted instrument. Depending on the certification scheme, several standards are set related to protection, including many of those discussed above. For example, a scheme could set standards for the number of habitat trees or the designation of special habitats or buffer zones along water bodies. Increased uptake of retention forest management practices in the Nordic countries (cf. Gustafsson et al., 2012) can probably be partly attributed to the adoption of sustainable forest management certification, although in Finland, levels of retention are too low to provide the habitat quality and continuity needed for declining and red-listed forest species (Kuuluvainen et al., 2019). The Forest Stewardship Council (FSC) and the Program for Endorsement of Forest Certification (PEFC) are the most common international certification standards in Europe. Both FSC and PEFC certification schemes have general standards and more detailed national standard requirements. Standards in the North of Europe tend to contain more detailed requirements (e.g. number of dead and dying trees related to forest growth-phase), while standards for the South of Europe are more descriptive (e.g. protected areas and habitat tree identification) and may lack minimum thresholds for deadwood and habitat tree retention. Several national standards require at least 5 – 15% of the total managed forest area to be set-aside and left unmanaged (Abruscato et al., 2020). Implementing such targets on larger parts of managed forests could support enhancing the protection of old-growth attributes. Currently, small private forests owners use certification less often than public forests (Maesano et al., 2018). At the same time, studies have shown that small-scale private forests can contain significantly higher portions of tree microhabitats than public forests due to variable management practices and/or lack of management (Johann and Schaich, 2016). This points at the necessity to carefully investigate the interrelationship of socio-economic factors as well as the impacts of various conservation policy instruments, which goes beyond the scope of this report.

5. Associated benefits, consequences, and potential trade-offs of old-growth forest protection and development of old-growth forest attributes

5.1 Introduction

In the analysis of **chapter 4**, three main conclusions were drawn: (1) all remaining EU primary and old-growth forests should be strictly protected (Sabatini et al., 2018); (2) in order to create future secondary old-growth and improve the long-term conservation of EU primary and old-growth forests (i.e. creating minimum dynamic areas, improving area connectivity) the strictly protected area network would need to be expanded, thereby contributing to the EU Biodiversity Strategy target to strictly protect 10% of EU land area; and (3) integrative forest management approaches can contribute to maintaining and developing old-growth attributes in the EU forests outside of the strict protection network.

In the expansion of the strictly protected forest area network and implementation of integrative forest management approaches into managed forests, associated consequences arise. These consequences may then bring benefits but also could cause potential trade-offs with policy implications. As discussed in ***section 4.2***, trade-offs can arise because it is not possible to simultaneously provide all forest ecosystem services in the same location. There is a need to manage conflicting service demands and management objectives, which can be illustrated for example by the basic trade-off between forest conservation and wood production and the decision of whether to remove biomass or leave it in the stand (Winkel et al., 2015; Bauhus et al., 2017).

This chapter therefore explores benefits, consequences, and potential trade-offs that could lead to policy implications of: (1) Setting aside managed forest in order to expand the strictly protected forest area to support the conservation of existing primary and old-growth forests (***section 5.2***) and (2) implementation of integrative forest management approaches (***section 5.3***). The benefits of both approaches should be properly weighed against potential trade-offs in further studies.

5.2 Benefits, consequences, and potential trade-offs of expanding the strict protection network to support old-growth forest conservation

The EU Biodiversity Strategy for 2030 definition of strict forest protection "leaving natural processes essentially undisturbed" implies a complete ban of forest management interventions. As discussed in ***section 4.3***, once all remaining EU primary and old-growth forests (Sabatini et al., 2018) have been strictly protected, the strictly protected forest area network should be expanded to create future secondary old-growth and support the conservation of the remaining primary and old-growth forests given their small size and poor connectivity. In some EU countries, it will be possible to set aside currently unmanaged forest and/or public forest to contribute to meeting the EU Biodiversity Strategy target to strictly protect 10% of EU land area without or with only minor associated trade-offs and policy implications. However, in some other countries, it may be necessary to set-aside currently managed forests in order to meet the target. This would also be necessary if the extended strictly protected area network is made to equally represent all EU forest types.

In this section, we first provide a non-exhaustive list of the benefits provided by expanding the strictly protected area network. We then list some consequences of expanding the strictly protected area network that occur inside and in the direct surroundings of the managed forest area designated for strict protection. Finally, we look at potential impacts and trade-offs that could affect other forests in Europe and around the world, as well as other sectors (e.g. energy, agriculture).

The benefits of expanding the strictly protected forest area network include:

- Functioning of natural development processes on a large-scale (if sufficiently larger areas are set aside) (European Commission, 2013). These processes keep the area ecologically intact, including disturbance-dependent species and habitats (Nicklasson et al., 2010; Navarro et al., 2015, Rosenthal et al., 2021).
- Long-term biodiversity conservation, including that of certain rare and threatened species (Rosenthal et al., 2020; Lõhmus et al., 2004).
- Meeting societal demand especially from urban populations to allocate space for rewilding in intensively used landscapes (Pereira and Navarro, 2015; van Meerbeck et al., 2019).
- Provisioning of ecosystem services such as water regulation (Dudley and Stolton, 2003) and carbon sequestration and storage (Keith et al., 2021; European Commission, 2020) and recreation and cultural activities (European Commission, 2012).
- Supporting adaptation to climate change by facilitating migration of species and populations through improved protected area connectivity, providing climate refuges, and reducing the vulnerability to floods, droughts, and other climatic extremes (Mansourian et al., 2009).
- Providing a reference of the functioning of natural dynamics and in the case of protected secondary forests, serving as a control to evaluate the impact of forest management on the ecosystem. Together, these functions make protected areas excellent areas for education (Nagel et al., 2013).

Setting-aside managed forest for strict protection has a number of direct consequences inside or in the area surrounding the managed forest that is permanently set aside for strict protection:

- Provisioning of wood products will no longer be possible and related incomes may subside in the case that the forest owner cannot shift wood harvests to forest stands outside of the strictly protected area (Leppänen et al., 2005).
- Return of natural disturbance dynamics is an intended consequence of expanding protected areas surrounding the remaining old-growth forests that has multiple ecological benefits. If natural disturbances are no longer controlled by management interventions, forest dynamics will be driven by natural disturbance regimes (e.g. wind, fire, insects and pathogens), which may affect neighbouring managed forests, unless prevented through targeted management of buffer zones (Hlásny et al., 2019).
- Forest adaptation to climate change will rely on the natural adaptive capacity of the present forest species populations and natural migration. Species that cannot adapt under the changing conditions will disappear, potentially leading to a decline of species diversity unless disappearing species are replaced by other better adapted species that are able to naturally migrate to the area (acknowledging that speed of natural migration, especially in fragmented landscapes, may not be sufficient under climate change; Meier et al., 2012).
- If the collection of non-timber forest products by the public is restricted, associated cultural, recreation, and subsistence needs of the public (Lovrić et al., 2021) may be compromised.
- If non-native species are not removed at the time strict protection designation is given, or if new non-native species later become an issue due to climate change or other factors, this could cause biodiversity loss

or have other environmental impacts, unless exceptional invasive species management is allowed.

- If hunting is restricted, game damage on natural tree regeneration may occur, especially in small protected areas with a limited or lacking population of large predators. This can then potentially result in a shift in the tree species composition (selective browsing), an overall lack of regeneration, and reduced protection function.

Given that there is not yet any information available on how the 10% strict protection of EU land area target will translate into required set-aside of productive forest area, it is not possible to determine the impact of the target's implementation on wood production within the EU. In the case that the implementation of the target leads to decreased wood supply, the following consequences and potential trade-offs may occur outside of the newly designated strict protection areas:

- Intensifed forest management: the remaining forest area outside of the protected areas may be managed more intensively (cf. land sparing; Edwards et al., 2014; Paul and Knoke 2015). In the long run, biodiversity benefits within set-aside areas could coincide with negative impacts on biodiversity and ecosystem services in areas under management intensification.
- Increased competition for wood resources: existing wood resources may not be sufficient to satisfy all demands. To mitigate supply shortage, wood resources may need to be used more efficiently (with increased wood product output per unit of raw material input), reducing the amount of residues available for low value wood products (e.g. particle boards) or energetic use (Saal et al., 2019).
- Wood trade: more wood products may be imported with potential side effects such as increased deforestation and forest degradation outside of Europe (O'Brien and Bringezu, 2018; Dieter et al., 2020) and a may pose a risk of accidental introduction of alien pests and pathogens (Roy et al., 2014).
- Plantation forests: part of the future wood demand could be met through establishing fast growing forest plantations on marginal agricultural land (Freer-Smith et al., 2019), which may provide new income to agricultural landowners, but simultaneously decrease crop or livestock production potentials.
- Substitution of wood products: decreasing amounts of available wood products could be substituted with non-wood product equivalents (the opposite of substitution effects caused by expanding wood product utilisation; Leskinen et al., 2018).
- Shift in renewable energy sources: replacement of wood by other renewable resources (e.g. solar and wind power).

Some of the listed consequences may be desirable for other policy objectives (e.g. substituting wood bioenergy with solar and wind energy) and certain trade-offs like substituting wood products with non-renewable materials could be less likely than other consequences. However, even in those cases, it is important to recognise these direct and indirect impacts. For example, a reduction of available wood resources for bioenergy implies that a significant pilar of current EU renewable energy production (Camia et al., 2021) decreases in importance (bioenergy based on woody biomass contributed 7% of total EU energy consumption in 2016) (European Commission's Knowledge Centre for Bioeconomy, 2018). To guide policy implementation, the benefits, consequences, and trade-offs should be investigated in-depth, which was beyond the scope of this study. From the analysis already presented in this chapter, it is evident that the consequences of setting-aside managed forests for strict protection to create secondary old-growth and support the conservation of primary and old-growth forests depend on the specific local context and will depend considerably on policy and management decisions taken in forests outside strict reserves and in other policy sectors (e.g. energy, trade). **Chapter 6** will explore some further policy implications arising from these issues.

Key Messages:

- Expanding the strictly forest protected forest area network has many benefits, including long-term biodiversity conservation, especially related to rare forest dependent species, the provisioning of ecosystem services such as carbon storage and water regulation, and enhancing forest resilience.
- Setting-aside managed forest to establish secondary old-growth forests has a number of direct consequences inside or directly surrounding the newly designated forest under strict protection, including inter alia wood production losses and modified disturbance regimes.
- Further consequences and potential trade-offs may occur outside of the newly designated strict protection areas depending on the scale and local context. These may involve changes in management of the remaining forests in the EU, leakage effects in forests outside of Europe, or spill-over effects to other sectors (e.g. energy or construction).

5.3 Benefits, potential limitations and trade-offs of integrative management approaches

Section 4.4 presented examples of the potential of integrative forest management approaches to develop old-growth forest attributes in managed forest landscapes outside of the strictly protected forest area network. Integrative forest management approaches have the potential to provide multiple ecological benefits and increased forest resilience compared to forest management that strongly prioritises wood production over other ecosystem services (Aggestam et al., 2020).

Decisions in managed forests to retain habitat trees and increased quantities and types of deadwood can also have economic benefits in addition to ecological benefits. By focussing on processing the most valuable timber, integrative forest management approaches may generate a higher profit per m^3 of timber sold, and may have lower costs of harvesting operations (including crown parting) compared to traditional management practices (Mergner and Kraus, 2020). However, it should be noted, that there are opportunity costs of such set-aside measures for the landowner (***Box 6***).

Box 6. Exemplary calculation of opportunity costs of voluntary biodiversity conservation measures in the Bavarian State Forest Enterprise Ebrach, Germany

Mergner and Kraus (2020) calculated associated costs of integrative forest management from reduced revenue and additional expenditures for the Bavarian State Forest Enterprise Ebrach, Germany (16,500 ha). Approximately 11% of the enterprise's forests are not managed for wood production. This includes 1,200 ha that are set-aside for the purposes of biodiversity conservation (e.g. old-growth islands or special habitats) and the designation of habitat trees (10/ha) which add another 750 ha not available for timber harvest. The results of the study found that if costs of the set-aside areas are calculated using the average growth conditions in the forestry district and average timber prices, a yearly sum of nearly €600,000 in revenue was lost. In addition, the retention of deadwood (25,000 m^3) in the areas of the enterprise that are still managed for timber production constituted an additional €500,000. Considering all these elements, the cost from reduced revenue was approximated to about €1.1 million per year (€67/ha). To put this in context, average costs associated with implementing Natura 2000 in forests of 10 EU countries were approximated with €37/ha per year (Ecochard et al., 2017) and similar amounts were also found in a review of income losses due to implementation of the EU Habitats Directive in Germany (Rosenkranz et al., 2014).

Development of old-growth forest attributes takes time. If designating strictly protected areas to create future secondary old-growth, selecting forests that already display a high degree of old-growthness may be favourable to limit the time needed to reach secondary old-growth status. However, in some cases, such forests with high old-growthness may be the result of traditional management practices (e.g. coppice with standards) or approaches that give increased attention to integrating nature conservation measures into managed forests. A potential trade-off for the forest managers/owners could then be that such forests may be considered for strict protection. However, it should be noted that a high level of old-growthness in managed forests is not always directly correlated with past forest management decisions, and may instead be a product of limited accessibility, a neglect of management (knowingly or unwittingly) or other factors.

As discussed in ***section 4.4***, integrative forest management approaches can support the conservation of species dependent on old-growth forests by developing and maintaining old-growth attributes in managed forests. However, these approaches also have limitations as they are not able to facilitate dynamic natural processes on large scales to support certain species (Nagel et al., 2017). In particular, the quantities of deadwood required to sustain some species are many times higher than what can be realistically achieved in a forest that is also managed for timber production (Bässler and Müller, 2010; Thorn et al., 2020). Therefore, conservation of these species can only be met by strictly protected forest areas (Lõhmus et al., 2004; Sabatini et al., 2020a). In addition, although integrative forest management approaches can contribute to forest adaptation to climate change (Krumm et al., 2020a), they lack the forest complexity that characterises old-growth forests and provides related high diversity and enhanced forest resilience at a level that is difficult to replicate in managed forests (Puettmann et al., 2008). However, as discussed in ***section 5.2***, strictly protected forests with no-intervention may also limit the natural adaptive capacity due to the rate of climate change that exceeds unassisted species migration rates. Therefore, integrative forest management can be seen as an important complementary approach to a network of strictly protected areas but cannot replace such a network.

While integrative forest management approaches have huge potential for biodiversity conservation when implemented on a large scale (i.e. the majority of managed forests in Europe), their implementation is also challenging as it requires the continuous balancing of trade-offs between conservation objectives and production objectives from forest managers (Winkel et al., 2015; Aggestam et al., 2020; and Krumm et al., 2020). In addition, as integrative forest management approaches are often voluntary, it cannot be guaranteed that they will be maintained in the long-term or permanently. As they lack a legal protection status, targeted instruments may be needed to ensure that forest managers' efforts to apply such management can be sustained. State forest enterprises could set examples of how to advance biodiversity conservation objectives in managed forests on a large scale. In the case of privately owned forest, economic incentives may be needed to support the implementation of such approaches (cf. opportunity costs discussed in ***Box 6***), for example through payments for ecosystem services.

Key Messages:

- Biodiversity conservation in integrative forest management systems can bring multiple ecological benefits, as well as benefits to the forest manager/owner and society, but can also carry opportunity costs for the landowner.

- Integrative forest management approaches have a huge potential for forest biodiversity conservation, especially if implemented on the large scale of managed forests. However, they also have limitations for example in the conservation of certain species and in the level of forest complexity induced forest resilience. Therefore, such approaches are complementary to a strictly protected forest area network.

- More systematic data and assessment of the benefits, limitations, and trade-offs associated with integrative forest management approaches are needed. Providing support with economic incentives, for example payments for ecosystem services schemes, could help to make implementing such approaches more attractive to forest managers/owners in the long-term.

6. Policy implications

6.1 Introduction

The analysis in **chapters 2** and **3** reviewed different perspectives on defining old-growth forests and related terms and the evidence of what we currently know about primary and old-growth forests and related attributes. **Chapter 4** looked at options for improving old-growth forest protection in European forests. Throughout these chapters, it became clear that terms and definitions related to high conservation value forests are often interpreted in different ways. While some progress on finding a common understanding has been made, for example on how to identify old-growth forests, we still lack an overall agreement on definitions. In addition, data on primary and old-growth forests is incomplete and questions remain on how to effectively implement ambitious protection targets. The choice of a definition has implications, and any policy and management instrument will have an impact on forest conservation and the provisioning of forest ecosystem services. Some trade-offs associated with setting aside managed forest to improve the conservation of the remaining primary and old-growth forests and management of old-growth forest attributes were described in **chapter 5**. In this chapter, we discuss potential policy implications that became apparent in the study's analysis. Our aim is to present viewpoints from a scientific perspective without the intention to pre-empt any policy choices. Throughout this chapter, opinions of scientific experts are presented as poll results that were obtained in the workshop held with scientific experts (cf. **chapter 1**).

6.2 Definition of old-growth forests

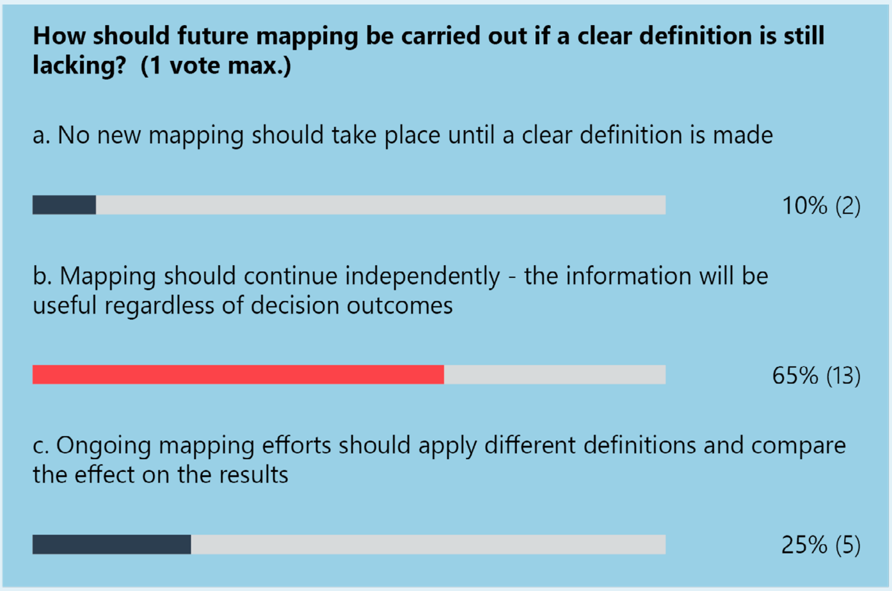
Chapter 2 presented different interpretations of old-growth forest and related terms to describe high conservation value forests. Applying the definition of old-growth forest that was developed in the specific context of the Pacific Northwest (PNW) region of the United States to forests with different environmental and socio-ecological conditions leads to challenges. We discussed the critiques in-depth that were made in regard to past definitions of old-growth forest (cf. ***section 2.4.2***). The strong management legacy of European forests is especially relevant when seeking to adopt a definition of old-growth forest for the EU. The lack of visible management impacts was a key criterion for identifying old-growth forests in North America, but as such forests are extremely rare in Europe, applying such a definition would result in identifying very few forests as old-growth, and would leave out other high conservation value forests with old-growth attributes, despite having a management legacy. Considerations of Europe's forest management legacy have been adopted in some international definitions of terms describing high conservation value forests. For example, the CBD (2006) international definition of primary forests was modified to better reflect the situation in Europe, and even considers certain actively managed forests to fit the primary forest definition (***Box 1***).

The discussion around defining primary and old-growth forests in Europe has evolved over the years. The concept of naturalness as described in Buchwald (2005) has been identified by some as an effective option to integrate different commonly used terms to describe high conservation value forests in a common framework in a European context. An important aspect of Buchwald's framework is the explicit consideration of scale. Old-growth forest is defined at the stand level, whereas other types of primary forest such as primeval and virgin forests are defined at the forest (multiple forest stands) to landscape scale. This implies that a virgin forest might be composed of stands, some of which are old-growth forests. An old-growth forest is regarded as late-successional and can be part of a primary forest that may also include areas that were recently affected by natural disturbances, and therefore contain pioneer and mid-successional species. The question of scale attached to these different terms is also important for conservation policy: to ensure the long-term conservation of primary forests, larger areas are necessary which then may allow natural disturbance dynamics and succession to take place (cf. Minimum Dynamic Area concept introduced in ***section 4.3***). Old-growth forests are also worthy of protection at the patch (clusters of trees; cf. old-growth islands, ***section 4.4***) to stand level because of their importance for local biodiversity. However, they may be more difficult to maintain in a desirable state if the surrounding matrix does not have favourable conditions.

Depending on the choice of definitions, the extent of primary and old-growth forests in Europe could therefore vary from almost non-existent to covering a notable share of existing forests. Choice of the old-growth forest definition could also have other consequences, for example, basing the definition on a specific age threshold could potentially result in also declaring forests that are managed with a long rotation period as old-growth forest. Concepts of secondary old-growth forest and indices to quantify a forest's 'old-growthness' or to measure progress in the development of old-growth attributes are considered important to address management legacy and valuable to guide forest conservation efforts in Europe.

Until the EU Biodiversity Strategy reaches its target to define primary and old-growth forest, it is likely that there will be uncertainty regarding ongoing and planned national primary forest mapping activities, including the question of whether or not a consensus should first be made before continuing the identification of primary and old-growth forests. This question was also posed in a poll at the workshop carried out as part of this study (***Box 7***). A common opinion among experts suggested that regional initiatives to map primary and old-growth forests should continue, as results may then be put in context to any commonly agreed definition once available. In line with this expert vote, it could be argued that in the implementation of the Biodiversity Strategy a general (broad) framework definition of old-growth forests could be combined with regional specifications through regional and/or forest type related criteria: Regional and forest type related criteria could thus be used to refine the general definition at regional and/or forest type scales, for example adjusting for common tree age differences among forest types.

Box 7 - Workshop poll on future primary and old-growth forest mapping:



How should future mapping be carried out if a clear definition is still lacking? (1 vote max.)

a. No new mapping should take place until a clear definition is made

10% (2)

b. Mapping should continue independently - the information will be useful regardless of decision outcomes

65% (13)

c. Ongoing mapping efforts should apply different definitions and compare the effect on the results

25% (5)

6.3 Evidence of old-growth forests and old-growth attributes

The review in ***section 3.2*** showed that the knowledge-base on primary forests has improved considerably as a result of repeated multi-national reviews and mapping exercises (Sabatini et al., 2018 and follow up work). However, it is noteworthy that the data on primary forest locations is still incomplete, particularly for certain countries, and more effort is needed to achieve a robust and harmonised evidence-base to inform future conservation policy implementation. The State of Europe's Forests reports compiled by Forest Europe suffer from changing definitions and classifications throughout their history of publication. Varying methods and definitions amongst European countries hamper the comparability of results (cf. Barredo et al., 2021). This stresses the importance for coordinated inventory and mapping that includes spatial information on protected areas, forest naturalness and management intensity as well as improved interpretation of tree age and biodiversity related information provided by plot based national forest inventories.

While age of the oldest trees is only one of several important indicators to measure old-growthness and the conservation value of forests, it is also crucial to observe trends in the share of old stands for other reasons. For example, the forest age class distribution affects carbon sequestration rates and reflects harvest intensity or disturbance history, while also influencing vulnerability to future natural disturbances. The lack of consistent pan-European data suggests that concerted efforts are necessary to generate better data on the age of trees and forests in Europe and their trends. As most countries nowadays use plot-based forest inventories (with regular inventory cycles to gather data for international reporting commitments such as under the United Nations Framework Convention on Climate Change), information on tree age (or at least diameter as a proxy) is generally measured in all inventories. Developing new methods to aggregate this information and observe trends could be beneficial in closing this information gap.

The review of information on tree and forest age in this report stressed the context sensitivity of both variables. Tree age alone is not very useful for the identification of old-growth forests and can lead to misleading results. For example, presence of particularly old trees can also be evidence of past management interventions such as in the case of oak forests in Central Europe, which on many sites need regular management to set back the natural succession and conversion to other forest types e.g. forests dominated by beech. For such old forests, a continuation of the current management scheme (and not strict protection) can be the appropriate strategy to conserve their high biodiversity value characteristics. This highlights the importance of considering the specific circumstances of the respective forests and forest types. It also shows the importance of considering a diverse set of old-growth forest attributes including e.g. disturbance history, tree species composition, tree layer complexity, DBH distribution, dead wood (quantities, diversity and spatial patterns), and the occurrence and types of tree-related microhabitats. Multiple attributes can be considered in indices of old-growthness which are better suited to measure progress towards developing secondary old-growth forests characteristics, and such indices can also be adopted to reflect differences between forest types.

6.4 Approaches to protect old-growth forests and to maintain and develop old-growth forest attributes

6.4.1 Expanding the strictly protected forest area network

Protecting the remaining old-growth and primary forests

There is strong evidence that the area of remaining primary and old-growth forests is continuing to decline. Given the scarcity of old-growth forests in Europe and the considerable amount of time it takes to restore old-growth features in previously managed forests, there is no alternative to preserving the still existing old-growth forests now. Therefore, effective conservation strategies are needed to stop the rapid loss and fragmentation of Europe’s last primary and old-growth forests. A large share of the mapped remaining primary forests are currently located in protected areas. However, only around 50% of those have strict protection status while the remaining half are located in protected areas, often Natura 2000 areas, which allow varying types of forest management practices (Sabatini et al., 2018). In addition, also in strictly protected areas it may be legally permitted in some countries to carry out sanitary or salvage logging (hereafter we only refer to salvage logging) in the case that the forests are affected by disturbance agents such as the spruce bark beetle or windthrow. Such interventions are often conflicting with forest conservation objectives in protected areas (Thorn et al., 2018), and have been reported to include the complete removal of stands and their biomass in the case of bark beetle outbreaks (Court of Justice of the European Union, 2018). An old-growth spruce forest that is killed by a spruce bark beetle will, depending on the definition applied, no longer be considered an old-growth stand after the stand-replacing insect outbreak. However, without salvage logging it will remain a primary forest and continue to have high conservation value and maintain some important old-growth features such as high deadwood volumes and structural diversity (Donato et al., 2012). Salvage logging in relation to the effective conservation of primary and old-growth forests hence needs to be addressed for an effective conservation strategy (Sabatini et al., 2018), and such stands should keep their protection status regardless of stand replacing disturbances.

Strictly protecting forests directly adjacent to the remaining primary and old-growth forests would help to improve the conservation of remaining primary and old-growth forests, as they are typically small and isolated. This would also allow for natural development to take place without management intervention and provide sufficient space to cover the complete range of successional stages that would naturally be present in primary forests (including pioneer stages after natural disturbances). Where primary forests are located along national borders, it is beneficial if protection efforts are combined across country borders (including also the EU borders to neighbouring countries, which may host valuable primary forests such as in the Ukraine). In order to implement the targets of the EU Biodiversity Strategy, it will be necessary in many countries to select new additional protected areas that can develop into future secondary old-growth forests and corridors of green infrastructure that increase protected area connectivity. Depending on the management legacy, active ecological restoration could be used to support secondary old-growth forest development. Green infrastructure will continue to gain importance under climate change as stepping-stones of secondary old-growth forest islands in the landscape may facilitate migration of species to suitable habitats. Systematic conservation planning and old-growthness indices are promising tools to support this process.

In the case that Natura 2000 areas are surrounding old-growth and primary forests, the management guidelines for these areas could be adapted to specifically support development of secondary old-growth forests or old-growth attributes to address the problem of fragmentation. However, lessons from the Natura 2000 implementation process show that trade-offs between conservation and forest use objectives, but also a lack of communication between land owners/forest managers and conservation departments as well as a lack of financial support mechanisms can prevent effective implementation (Winkel et al., 2015; Sotirov, 2017). This stresses the importance of open transparent communication about the policy objectives and benefits combined with multi-stakeholder engagement to identify realistic implementation pathways for Natura 2000, but also for other conservation policy instruments (Blicharska et al., 2020).

Developing secondary old-growth forests to expand the strictly protected forest areas network

As stated previously, the 10% target for strict land protection of the EU Biodiversity strategy provides an opportunity to restore old-growth forests through passive ecological restoration as a result of no intervention, and supported by active restoration (e.g. removal of invasive species) in preparation for strict protection, where necessary. In this section, we will review this target in more detail from a conservation (policy) perspective. We note, however, that fully addressing this target and its implementation is a complex task that goes beyond the mandate of this report, so our assessment remains exploratory.

First, the targets set in the EU Biodiversity Strategy may look very clear, but a closer inspection reveals that several statements require further clarification for policy implementation. For example, the definition for strict protection stated in the Strategy "to leave natural processes essentially undisturbed" gives room for interpretation, and some Member States do not have their own definition of strict protection (Parviainen et al., 2000; WG Forest and Nature, 2020). Second, it is not clear how this objective will be applied to different land use categories, with forests however likely being prominent here for their conservation value. Other open questions include how general land area protection targets should be applied to forests at the regional level (see ***Box 8***). It should be possible for some countries with abundant forest resources in remote biogeographical regions to achieve a 10% strict protection target more easily, whereas for some others it would not be feasible without dealing with major trade-offs. Focussing on forests, this strongly depends on the regional context: for example, in mountainous or Mediterranean forests, many owners are not prioritising wood production and quite large areas are currently without active management and/or designated as protection forests without economic use (but without legal protection for conservation purposes). In this context it could be expected that trade-offs related to expanding strictly protected forest areas can be more easily resolved. In the case of Slovakia, the share of strictly protected forests is currently already 4.5%, and according to the National Environmental Strategy 2030, ca. 7-9% of forests should be strictly protected. Given the expansion of core zones of national parks based on existing national strategies, the target of 10% strict protection seems achievable for Slovakia (Mikoláš et al., 2019a). In other countries with intense forest use and/or fragmented forests and/or predominantly private ownership, it will be very challenging to identify and strictly protect 10% of the forest area.

Box 8. Open questions how to implement EU Biodiversity Strategy 2030 targets

There are number of questions how general land area protection targets should be applied to forests at the European level, and more specifically at the regional level. Many of them are of an essentially political nature, and some of them are listed in this box:

1. How exactly will "strict protection" and "leaving natural processes essentially undisturbed" be defined and implemented in a forest context?

2. Does the 10% strict protection of EU land area mean that the target for strictly protected forest area is also 10% at the European level?

3. If this is the case, is the idea that all countries meet the 10% target, or should the target be amended according to regional circumstances?

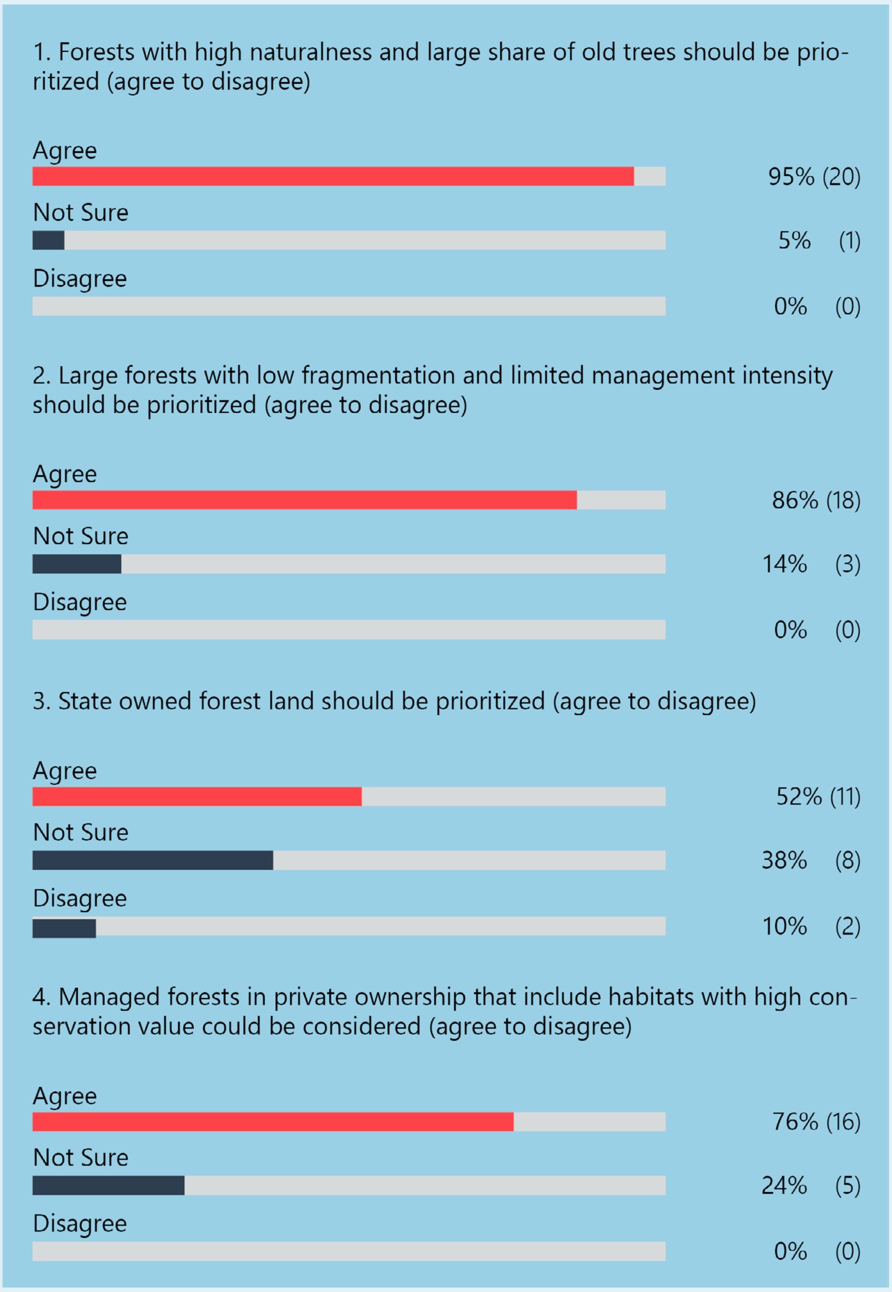
4. Should protection targets ensure that all European forest types are covered, and if so, should they be covered equally?

5. How will trade-offs in relation to strict protection be addressed? For example, will there be a focus on publicly owned forests and how will conservation objectives be weighed against other objectives? Will less productive forests be prioritised or are specifications intended in relation to priority forest types?

Another open question is how large individual protected areas should be. Protecting a larger number of smaller areas could be a more feasible approach to increase the total protected area in a fragmented forest landscape. Yet, the ecological integrity of small areas can be limited, critically depending on the forest type and how the surrounding forest area is managed and how well connected the areas are. From a conservation perspective, applying the minimum dynamic area concept (cf. ***section 4.3***) could offer guidance, but older reported estimates of 20-60 ha in temperate European forests compiled in Schultze et al. (2014) may need to be revised due to climate change altered disturbance dynamics. Understanding of natural disturbance regimes is critical and this is currently rapidly evolving in relation to European forests (Senf and Seidl, 2021), especially because disturbance regimes are strongly interacting with effects of climate change and associated extreme events. Considering the size of recent windstorm and insect disturbance events, the minimum dynamic area would be considerably larger, most likely in the range of 1,000 to 10,000 ha. Thus, protecting primary and old-growth forests should not focus only on preserving a particular development phase but also allow for the occurrence of natural development processes within such areas, in order to develop adaptive ecosystems with open-ended trajectories. This implies a stronger focus on functions and processes and providing space to maintain or restore the features that rely on natural disturbances. The study of Brackhane et al. (2019) demonstrated that with an increase of the minimum area size required for designating new strictly protected wilderness areas (including forests) the potentially available land area will decrease sharply. For example, if the target was a minimum of 10,000 ha continuous land area outside of settlements (some countries apply this as minimum for national park designation), less than 1% of the land area in Germany would meet this critera. The study also pointed out regional differences within the country, as population density and infrastructure networks vary enormously.

The question of where to select forests to expand the strictly protected forest area network was also addressed in the workshop polls (see ***Box 9***).

Box 9 - Workshop poll on where to select forest area to be strictly protected:



1. Forests with high naturalness and large share of old trees should be prioritized (agree to disagree)

2. Large forests with low fragmentation and limited management intensity should be prioritized (agree to disagree)

3. State owned forest land should be prioritized (agree to disagree)

4. Managed forests in private ownership that include habitats with high conservation value could be considered (agree to disagree)

The existing forests under strict protection are predominantly located on public land, but the large area of privately owned forest in some countries may make it challenging to identify and designate suitable strict protection target areas to develop secondary old-growth forests. As the distribution of forest types on public and private land can differ, the candidate areas under public ownership may not be able to cover a representative set of forest types (for example in Scandinavia the majority of protected areas are located on public land in less productive forest types, cf. ***Box 6***).

In regions where large, functioning, connected ecosystems are lacking and where forest ownership constrains the designation of large new strictly protected areas, the question arises of whether voluntary set-aside measures in certified forests (see ***section 6.4.2***) as well as abandoned, or for other reasons not-used forests could count towards protection targets, which could have significant potential to ease tensions between forestry and conservation targets (Winkel, 2007). Voluntarily setting aside e.g. 10% of the forest area (with emphasis on old-growth forest patches, rare forest biotopes, linear structures etc.) within a managed forest district (or 15% according to certain national forest certification standards; Gentree, 2020) may be easier to implement than protecting extensive areas, especially considering that in many European countries private forest ownership is common, and the average size of forest holdings is rather small. However, such accounting would require a thorough consideration of the permanency and conservation values of such voluntary commitments, and such an approach may also be counterproductive if land owners fear future restrictions to their property rights.

In addition, expanding protected areas on private forest land will require appropriate incentives. Approaches for nature protection may vary between countries and may include compensatory payments, tax compensations, payments for ecosystem services, etc. Within the European Horizon 2020 project SINCERE, "reverse auctions" have been successfully applied where private land owners provide offers of their land for (strict) biodiversity protection which are then bid on and are funded by the State (for example in Denmark). This tool has shown substantial promise to align land owner motivations and objectives with conservation policy objectives. Payments for Ecosystem Services (PES) schemes to incentivise the voluntary set-aside of forest areas from management could also be adopted as contractual nature conservation instrument. The German parliament recently decided on introducing such a PES scheme. The METSO scheme has been operating in Finland for several years (Primmer et al., 2013) and is designed to temporarily protect old-growth forest on private forest land for 20 years. However, further investigation is needed on effective measures to ensure continuous protection of these areas after the expiry of subsidies. It was outside of the scope of this study to review such instruments in more detail, but this topic will need to be taken into consideration when operationalising the EU Biodiversity Strategy, as in many countries the share of privately owned forest is quite substantial. Similarly, also on public lands, multiple forest related objectives need to be aligned if the protected area network is going to be extended, for instance, economic expectations towards timber targets and revenues from public lands need to be adapted.

It can be concluded from this analysis that many clarifications and decisions will need to be addressed when it comes to policy implementation. If strict criteria are used for the identification of old-growth or primary forests in the EU and if minimum size requirements are set for new strictly protected areas for the purpose of creating future secondary old-growth forests, it is more likely that the area chosen for strict protection may fall short of the EU Biodiversity Strategy target to strictly protect 10% of the EU land area. Adopting more flexible approaches that also allow for the designation of smaller areas as part of the strictly protected forest area network may help in achieving the 10% target for forests, with the drawback that the ecological integrity of these areas could be limited (cf. ***section 4.3***). In the case of voluntary set-aside measures, the long-term continuation of protection is not guaranteed. Further, due to the strong management legacy of European forests and the importance of many other forest ecosystem services, it is evident that conservation of primary and old-growth forests in many countries will need to be accompanied by a strong focus on forest restoration both passively and actively, allowing for the development of secondary old-growth forests as well as maintaining and developing old-growth forest attributes in managed forests. This will take considerable time to achieve and involves questions related to the discussion of land sparing vs. land and the associated trade-offs. This will be picked up later in ***section 6.5.***, after discussing the situation in managed forests in the next section.

6.4.2 Facilitating integrative forest management approaches to enhance biodiversity conservation

The analysis in **chapter 4** presented the context of forest types and management regimes in European forests and clarified that integrative forest management approaches cannot replace strict protection in the case of the remaining primary and old-growth forests. From a conservation perpective, the question is then how integrative forest management can best complement the protected area network to achieve biodiversity conservation targets for forests, including connectivity, at the landscape level and beyond (see ***Box 10*** on how important the contribution of managed forests to meet biodiversity conservation goals is regarded by experts).

An important question is how zones around remaining old-growth forests should be managed. Restoring natural species composition and developing old-growth features in such areas provides a safety net to buffer the ecological integrity of the remaining old-growth stands. Less strict protection schemes including Natura 2000 can play a crucial role, and appropriate management guidelines for these areas that take into account socio-economic considerations (Blicharska et al., 2016) are needed. While all Natura 2000 areas should have management plans by law, the implementation of this measure and of the plans may lack behind the legal requirements (Sotirov, 2017).

Complementing the legal protection of old-growth and primary forests, forest conservation measures in managed forests can consist of regulatory and often also voluntary instruments. Approaches such as designating habitat trees, setting aside existing old-growth patches, or allowing natural dynamics after a disturbance event to take place over larger areas may represent temporary measures. For example, this could occur after a contract expires, or when the function of a voluntary conservation measure is no longer met, wood production may again become the main goal. This does not need to be a negative trade-off, as dynamically assigning such set-aside areas or habitat trees allows for the maintenance of a certain level of protection of old-growth attributes at the district level even though individual stands pass through different developmental stages. Depending on the context, different policy instruments are needed to support implementation of forest conservation measures and concepts in managed forests. To enable longer term voluntary conservation commitments, it would be desirable to develop longer term contracts with incentives such as PES. It should be noted that voluntary commitments without any instrument do also exist. Finally, the development of old-growth attributes may also be an unintended result simply due to a lack of economic interest in active forest management, e.g. in forests located on difficult terrain or poor sites. Without dedicated protection status, there is a risk that changing economic circumstances and accumulating growing stock may make these areas with old-growth attributes attractive for harvesting.

More analysis is needed to better understand the political, social, and economic dimensions of protecting and developing old-growth attributes in managed forests. For example, it is necessary to explore what policy instruments could facilitate further implementation of integrative approaches to forest management, including legal instruments, economic instruments, certification, and advisory services. The role of land ownership, education, and practical knowledge related to forest management effects on biodiversity conservation are further topics that influence uptake of good practices, for example how to preserve and develop tree microhabitats that support biodiversity (Cosyns et al., 2020). Stakeholder dialogue, trust building, and raising awareness are further aspects which can greatly support biodiversity conservation (cf. Blicharska et al., 2020).

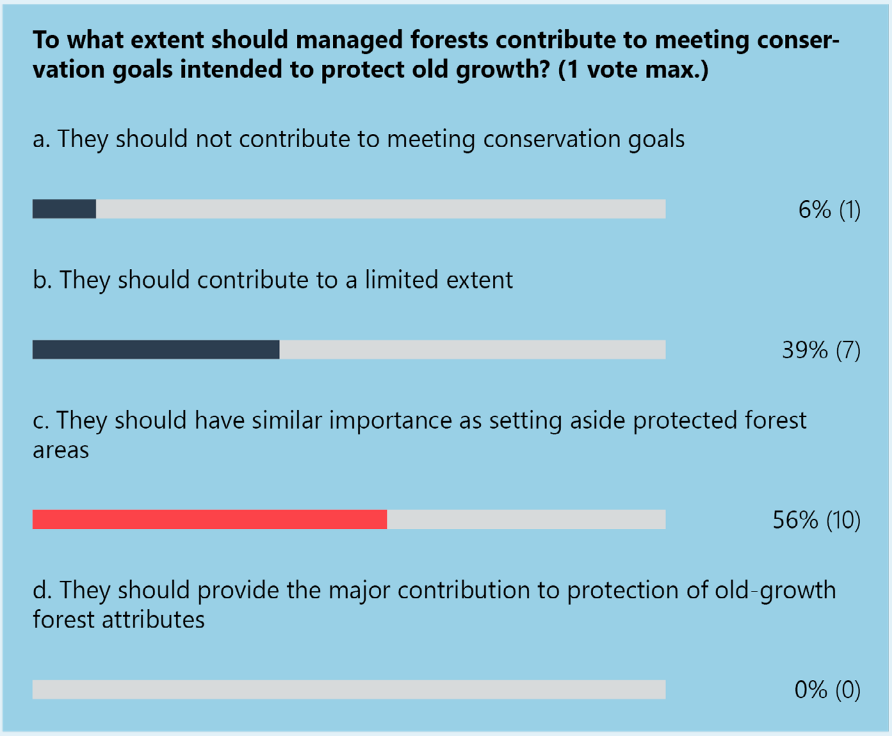
A sensitive topic is the possibility that due to practices of forest managers that give considerable emphasis to integrating biodiversity conservation measures, the resulting high conservation value forests with old-growth attributes could be proposed for strict protection (i.e. to limit the amount of time needed to develop secondary old-growth in the area). While this may reflect a societal commitment in state owned forests to meet set conservation targets, private forest land owners would need to be offered adequate compensation mechanisms and contractual solutions in order to avoid disincentives for managing towards high conservation value forests now and in future. This may be especially tricky as such stands can have also a high economic wood value (e.g. in many oak forests in Central Europe), creating high opportunity costs for conservation. However, on private lands, adequate compensation schemes might provide a solution to manage this specific trade-off. In some cases, if similar ecological objectives could be achieved by an alternative strategy to setting aside recently disturbed forests instead of salvage cutting the damaged wood that has limited economic value, this could have fewer trade-offs for the landowners. The recently disturbed forests would still require considerable time to develop into secondary old-growth forests, however leaving the dead trees on the site to create deadwood and structural diversity would create old-growth attributes more quickly than in stands only recently set aside after being regularly managed.

It was pointed out in ***section 6.3*** that information about the share of old forests in Europe is not well documented. With improved processing of existing tree age data (or share of large dimension trees), it should be possible to define reference levels and desired trends for the share of old stands in managed forests. If a given management intensity allows for maintaining (or increasing) the share of such forests, the harvesting regime could be considered sustainable also in respect to old-growth attributes.

The question for integrative forest management of how to plan, incentivise and achieve the balance between productive functions and biodiversity protection requires an adaptive approach and continuous monitoring (Mergner and Kraus, 2020). For instance, the biodiversity-friendly integrative forest management applied in the Bavarian State Forest Enterprise Ebrach, Germany, is constantly surveyed through research programmes (Doerfler et al., 2017; Schauer et al., 2018; Zytynska et al., 2018). Species groups commonly linked to natural disturbances and old-growth attributes including deadwood serve as meaningful indicators to monitor the conservation success of the enterprise’s integrative management approach (Mergner and Kraus, 2020).

Multifunctionality of forests is practiced in very different ways across Europe. Whereas some regions have a strong tradition of close-to-nature forest management and forest ecosystem services such as recreation and protective functions may hold at least a similar importance compared to wood production, there are other regions where wood production is by far the most important function. Therefore, it will be necessary to consider that decisions on the provision of ecosystem services in managed forests will have significant influence on potential trade-offs, which is discussed in ***section 6.5***.

Box 10 - Workshop poll on the contribution of managed forests to meet conservation goals:



To what extent should managed forests contribute to meeting conservation goals intended to protect old growth? (1 vote max.)

a. They should not contribute to meeting conservation goals

6% (1)

b. They should contribute to a limited extent

39% (7)

c. They should have similar importance as setting aside protected forest areas

56% (10)

d. They should provide the major contribution to protection of old-growth forest attributes

0% (0)

6.5 Benefits and potential trade-offs of expanding the protected area network to improve old-growth forest protection and developing old-growth attributes in managed forests

Chapter 5 listed several benefits, consequences and potential trade-offs of expanding the protected area network to improve old-growth forest protection. While the direct consequences of strictly banning management interventions cannot be changed, policy and management have multiple options to prevent or at least mitigate indirect trade-offs. Adapting management in other forests may allow for sustaining a comparable level of wood production at the landscape or regional level and several other means were listed in ***section 5.2*** that may counteract undesired consequences. However, it is important to study potential external effects such as leakage, as intensified wood harvesting in other regions of the world may be linked with unsustainable forest management, including deforestation or forest degradation that could have detrimental effects on biodiversity that outweigh local improvements.

Discontinuing pest control and fire suppression in protected forests enables the development of natural disturbance regimes that facilitate natural ecosystem processes and favour specific species which are often rare in managed forest landscapes. These are intended benefits of the strict protection, which, however, may also create risks for managed forests surrounding the protected areas. Therefore, it is important to plan sufficient buffer zones surrounding old-growth forests in which disturbance risks can be managed to mitigate risks to the managed forests adjacent to the protected areas. This can be achieved by placing protected areas with active conservation management around the strictly protected old-growth and primary forests. Providing space for natural disturbance dynamics is an important argument to establish large protected areas, as the required buffer zone areas are then much smaller in relative terms compared to establishing many small isolated fragments within managed landscapes.

Climate change poses great risks to biodiversity and may also challenge conservation policy. While strictly protected forests should not be actively managed, it should be considered if surrounding protected areas may require active interventions to facilitate adaptation to the changing conditions. For example, some protected species may need support to migrate to suitable habitats. Careful design of protected area networks with stepping-stones and green infrastructure connections along rivers or mountain ranges may facilitate natural migration. But in many parts of urbanised landscapes there are insufficient connectivity to allow certain species to migrate to suitable habitats. In addition, the pace of climate change may overwhelm the capacity of species to adapt through natural migration.

Especially in regions with limited public forest ownership, successful biodiversity protection will require increased efforts to motivate private forest owners to adopt voluntary conservation measures or to compensate them for strictly protecting their forests. The willingness of owners to participate in such measures can be influenced by the design of the instruments and accompanying awareness and information campaigns (Miljand et al., 2021). Especially for small forest owners there could be significant interest in such instruments, particularly following disturbance impacts that destroyed the wood production potential for many decades. Integrative forest management approaches favour mixed forests, and these are generally also more resilient regarding disturbances compared to traditional forest management, particularly of pure coniferous stands. It is critical for conservation policy on private lands to strive for synergies with private landowner interests, and recent research demonstrates that a substantial part of private landowners in Europe are interested in biodiversity conservation on their land (Torralba et al., 2020). Awareness and information campaigns accompanying conservation incentives should thus highlight the synergies that biodiversity conservation can provide for enhancing resilience to climate change and disturbances through integrative forest management.

6.6 Overall policy integration

Biodiversity protection policy in forests needs to be integrated with other policy objectives such as advancing a renewable circular bioeconomy. Impacts of enhanced forest protection on climate change mitigation need to consider the holistic effects, including mid- to long-term effects, of changes in forest and wood utilisation on global greenhouse gas emissions and other climate drivers.

Biodiversity policy implementation will benefit from forward looking policy integration. The previous section already presented benefits and potential trade-offs that may result from the expansion of the strictly protected area network and that could occur from the local level for individual landowners to the global level, or in other sectors. Integrating different policies may also enhance existing synergies, for example in relation to climate change adaptation and climate change mitigation. External impacts of significantly increasing the share of strictly protected forests, for instance in the frame of the 10% goal of the EU Biodiversity Strategy, are likely to be outweighed by management decisions in the other 90% of European forests. In several countries with relatively low felling ratio (harvest removals relative to volume increment), there may be space to balance the loss of wood production from strictly protecting managed forests at the regional level. If management outside of protected forests is locally intensified following the land sparing principle, this could however have significant environmental trade-offs in those forests. This is particularly true in countries or regions that already have a very high utilisation rate of forest resources (Biber et al., 2020). However, there are also examples of combining land sparing (protected and intensive sustainable forest management) with land sharing in integrative forest management at different spatial scales. Such schemes include the TRIAD zoning approach, which includes strictly protected areas, some intensively managed plantations for provisioning service products, and a large matrix of multifunctional integrative forest management (Tittler et al., 2016; Nagel et al., 2017; Betts et al., 2021). The latter fraction of the matrix would include Natura 2000 areas that are not strictly protected (as part of the 30% protected land area target of the EU Biodiversity Strategy), but also integrative forest management outside of protected areas.

The complementarity of different instruments for enhancing the protection of primary and old-growth forests and the development of old-growth attributes has been mentioned throughout this report. This seems to be crucial on different levels. Expanding the area of strictly protected primary and old-growth forests cannot be substituted by other measures as the conservation of certain species requires sufficiently large areas without any management. However, forest owners deserve recognition for the important complementary contributions of managed forests to biodiversity conservation and dedicated compensation schemes could help to encourage spreading such good practices.

An important step in future policy implementation will be for policy makers to agree on how the overall EU Biodiversity Strategy for 2030 targets on protection and strict protection of EU land area should be allocated, for example, to land-use types, Member States and regions within individual countries, and forest ownership (see ***Box 8***). In the case the same targets are applied to inaccessible remote areas and to regions with high demand for diverse services from forests, this would likely lead to trade-offs with other policies and stakeholder interests. While support for protection may be larger in urbanised regions than in rural areas where the population relies more strongly on the income from forestry, it is more difficult to set aside large, connected forest areas in densely populated regions, especially outside of state-owned forests. Guidance is needed on how to best utilise synergies with the large forest area that is managed for a wide range of ecosystem services and how to ensure that the network of protected forest areas will represent most or all forest types in the European Union. The current locations of most remaining primary and old-growth forests in Europe are confined to very remote areas or located on less productive land. If there is a target to set aside large areas (e.g. as wilderness areas) to allow for undistur bed development of primary and secondary old-growth forests under the 10% target, some EU countries will not be able to contribute sufficient area to reach the target. In such cases, implementing protected area targets embedded into managed landscapes could be easier to achieve.

Policy integration will strongly benefit from coordinated conservation planning that goes hand in hand with landscape planning and design of policy instruments targeted to stakeholder needs (Sotirov and Storch, 2018; Miljand et al., 2021). Using a forward-looking, inclusive approach together with stakeholders, such policy implementation could also shift the land sparing vs land sharing debate from confronting policy demands to a science based and societally inclusive strategic planning approach. Areas with remaining old-growth legacies need land sparing approaches while areas with a long history of human disturbance history may have developed conservation features that need a continued land sharing approach (Van Meerbeek et al., 2019). Overall, the combination of strict protection, protected areas with conservation management and management for multiple ecosystem services in European forests needs to be tailored to the social-ecological and socio-economic context including the diversity of forest types, ownership and forest governance, and societal demands in the different regions. Adapting forest conservation and management practices on the ground to set political targets in addition to providing a meaningful supportive policy framework to mitigate trade-offs and better exploit synergies will remain a major challenge but at the same time needs to be the ambition for Europe's forest and biodiversity conservation policy.

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