LIFE-PROGNOSES -Work Package 1.11

Old-growth criteria and indicators for beech forests (*Fageta*).

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Final version – March 2022

1. Introduction: indicators and a protocol for the assessment and mapping of primary and old-growth beech forests

In January 2021, the LIFE PROGNOSES project was launched. This EU LIFE Preparatory Project runs from 2021 to 2024 The project involves 15 partners from 8 countries, focusing on beech forests and building on the existing network of the UNESCO World Heritage Site 'Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe'.

The project aims to support the EU-DG-Environment in the development of definitions, methodologies, criteria and indicators for better mapping and assessment of primary and old-growth forests in Europe. The project will also develop field protocols to determine and quantify specific ecosystem services related to primary and old-growth forests (carbon sequestration, biodiversity conservation, recreational assets).

In a first phase, the report below will present a scientific literature overview of commonly applied definitions on primary and old-growth forests, and related criteria and indicators that are relevant to discern primary and old-growth forests and assess the level of 'old-growthness' for the wide variety of beech forests all over Europe.

Based on these indicators, a field protocol is being developed, that will allow to quantify the benchmark values and ranges for the proposed indicators (Kirchmeir et al. 2022).

This field protocol will then be applied in nine pilot areas in Europe, each covering both protected primary or old-growth forest (components of the UNESCO WH site), and regularly managed beech forests in their buffer zones. The results of this assessment will provide knowledge on the range of possible outcomes on different criteria and indicators in a wide range of beech forest contexts.

This will eventually result in a set of data that will allow for a better quantification and qualification of primary beech forests and different levels of secondary old-growth development.

2. Terminology and definitions on primary and old-growth forest, applied to beech forests

The EU Biodiversity Strategy for 2030 states that at least 30% of all land area should be protected, of which at least one third (10%) should be strictly protected. It further specifies that all remaining EU primary and old-growth forests should be included in this 10% of land with strict protection status.

Strictly protected areas are '*fully and legally protected areas designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes. Natural processes are therefore left essentially undisturbed from human pressures and threats to the area's overall ecological structure and functioning, independently of whether those pressures and threats are located inside or outside the strictly protected area"* (European Commission, 2022).

There are currently differing interpretations of how to define these terms, especially for 'old-growth' (Barredo et al. 2021, O'Brien et al. 2021). In an account of the different definitions of and qualities attributed to old-growth already Wirth et al. (2009) come to the conclusion that quite a wide scope of interpretation is given.

The term 'old-growth' was originally introduced for stands in the late successional phases of primary forests in the Pacific Northwest of the USA, that required protection from logging. This was mainly motivated from a conservation perspective in the framework of the conservation of species like Northern spotted owl (*Strix occidentalis caurina*) and Marbled murrelet (*Brachyramphus marmoratus*), two endangered species under the 'endangered species act'. All these old-growth stands were located within and part of primary forests.

However, the context is different in Europe, so old-growth stands can also occur in secondary forests, and may develop starting from previously managed forests (sometimes called 'secondary old-growth').

First, we will outline the difference between 'primary', 'secondary', 'ancient' and 'old-growth' forest, using the terms as they are applied in European forests, based on the definitions in the framework of FAO, CBD and working documents of EU DG-Environment, in cooperation with the EU Working Group on Nature and Forests, and other relevant literature.

2.1. Primary forest

The **FAO-definition on Primary forest** (FAO, 2020) is the only official definition on primary forests that is widely adopted and applied in the formal reporting on forests in the world (the FRA: Forest Resource Assessment). These are *"Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed."*

In other words, these are genuinely untouched forests, not disturbed in their natural development by human disturbances. In central-European literature, they have been often referred to as 'primeval' or 'virgin' forests (e.g. Westphal et al. 2005, Biriș & Veen, 2005; Hobi et al. 2015).

The explanatory notes to the FAO definition clarify that primary forests may also cover areas that are in a regeneration phase after natural stand-replacing disturbances (such as fire, storm, insect outbreaks…). It also clarifies that these forests *may be used by indigenous peoples for traditional 'forest stewardship activities' (such as reindeer herding) as long as they continue to meet the definition*. If, however, these activities (such as hunting, poaching…) have caused *significant native species loss or disturbance to ecological processes*, then the forest is no longer considered as 'primary'.

Some key characteristics of primary forests are (according to the explanatory notes to the FAO definition):

- *They show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, a natural age structure and natural regeneration processes;*
- *The area is large enough to maintain its natural ecological processes;*
- *There has been no known significant human intervention or the last significant human intervention was long enough ago to have allowed the natural species composition and structural processes to have become re-established.*

The 'opening' to interventions in a distant past appears contradictory to the baseline of 'no known significant human intervention'. Indeed, even after several centuries and even millennia, signs of (intensive) human interventions may still be noticeable in the structure and composition of the forest (e.g. Cannon et al., 2022), excluding them as primary forest. The paragraph (probably) refers to situations where there are no visible signs of former human interventions (such as stumps) and no indications in the current composition and age structure and dynamics of the forest, but there may be indirect indications (written sources, traces of charcoal kilns,…) that refer to human activities in a distant past.

Also, the note on minimal size is very vague : what is 'large enough' ? In general, primary forests are considered at a landscape scale, coving several hundreds or thousands of ha (in contrast to old-growth areas, that can be small, isolated stands of only a few ha: see further), but no clear threshold values are stated in the document.

The **Convention on Biological Diversity (CBD)** has also produced a working document with a definition for Primary forest (CBD,2006). It is referred to in several documents, including the EU Biodiversity strategy 2030:

A primary forest is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age.

These forests have not been subjected to significant direct human disturbance. Direct human disturbance is further defined 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'*.

Up to this paragraph, both FAO and CBD are approximately on the same line, and quite straightforward (with the nuance of 'no historic logging' to 'no more visible traces of former logging').

However, the CBD document adds an extra paragraph related to the 'specific European context of widespread historic use of forests, and suggests a much more inclusive and even confusing definition for Europe:

In much of Europe, primary forest has a different connotation and refers to 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.

Most of the forests in Europe have indeed been intensively used by humans in the past centuries. The CBD document wants to acknowledge this and cater for the specific historic context, but at the same time overstretches this by also including (partly) harvested and replanted forest stands in the definition of 'primary forest'..

The prerequisite of continuously wooded status is, moreover, mixing in the (different) concept of 'ancient woodland' into the description. Please see below how both concepts (primary/old-growth vs. ancient) are important for biodiversity, but clearly focus on different aspects.

The description of past management that the document now allows to be included in the 'European context' indeed no longer only involves true 'primary' forests, but also other forests, such as 'secondary (old-growth) forest' (see chapter 2.4), and could even involve -if interpreted in a 'liberal' way- all semi-natural mixed forests on ancient woodland sites. This unfortunately opens up the definition and makes it very vague and confusing. It is clearly in contradiction with the main prerequisite of primary forests, namely that it has not been significantly altered by human interventions. Yet, it remains debatable what exact intensity and type of human intervention or harvest can be considered as insignificant here.

The vast majority of **other relevant publications on primary forests** for European forests , e.g. by Biriș & Veen (2005), Fanta (2005), Wirth et al. (2009) and Commarmot et al. (2013) (in: Luick et al 2021) often use their own terminology (*Virgin, primeval, primary, natural, intact, undisturbed*) when describing primary forest, but generally follow a description that is close to the FAO-definition.

Buchwald (2005) however, introduced a new classification of 'naturalness levels' for forests in Europe, that is often referred to in EU documents. The classification covers 14 categories, including a 10-scale classification of 'natural forests' and a 4-scale subdivision of man-made forests. Natural forests range from 'Primeval forest'(= level n10) to 'plantation-like natural forests' (n1). The definition or description of primary forest then covels all natural forest classes from primeval (n10) up to 'long untouched forests' (n5). The description reads: *Relatively intact forest areas that have been essentially unmodified by human activity for the past 60-80 years or for an unknown, but relatively long time. Human impacts in such forest areas have normally been limited to low levels of hunting, fishing and harvesting of forest products (...).* This description is also applied as definition for 'primary forest' in the papers and dataset on primary forests by Sabatini et al (2018, 2020a, 2020b).

Due to its clear time frame (60-80 years unmanaged), the description has the advantage of being straightforward. However, it implicitly claims that forests may regain their natural characteristics and dynamics of the primary untouched forest already after at least 60-80 years of non-intervention. This is also a much wider interpretation of 'no significant human impact' than the FAO definition, and allows for formerly managed forests to be included in the 'primary' forest category. These are commonly considered as 'secondary old-growth' (see chapter 2.4).

Indeed, human induced perturbations may 'fade away' over time, after a transitional phase. A forest may resettle its 'shifting mosaic steady-state'(or 'dynamic steady state') condition, if it is left unmanaged for a longer period of time (see e.g. Borman & Likens, 1979). But this cannot be reached within 60-80 years, certainly not if there was some form of intense management in the past. In order to redevelop the species and age composition and structural processes of a genuine untouched primary forest, you need at least a cohort of trees to reach their natural longevity and die from natural processes. This will take several centuries or even millennia to redevelop (Cannon et al., 2022). It takes up to 300 years for beech trees to reach this natural longevity age (Korpél, 1995). Koop and Hilgen (1987) pointed out that the age structure of the Forest reserve of La Tillaie in the forest of Fontainebleau, after 150 years of non-intervention still reflected the effects of a larger scale harvest 600 years before. This means that formerly managed forests (or former wood pastures) may, after several decades of non-intervention, regain characteristics of the senescence phase of natural forests (thus acquiring the status of 'secondary old-growth, see further), but that does not make them primary forests.

<u>We conclude that the definition of Buchwald (2005) as also applied by Sabatini et al. (2018, 2020) clearly overstretch the definition of primary forests.</u> The criterium applied in these publications, namely 'forests that have been essentially unmodified by human activity for the past 60-80 years or for an unknown, but relatively long time', is straightforward and therefore appealing, but too inclusive. They may be helpful, however, to delineate secondary old-growth forests.

In the context of primary forests, also spatial scale is an important aspect: whereas 'old-growth' status is evaluated and defined at local scale (see below), primary forests are defined and delineated on a forest complex or landscape scale.

Primary forest will be composed of stands/patches/areas in different developmental stages, some of which are late-seral (old-growth phase), but some are also representing young, regenerating phases and aggradation phases after recent severe natural disturbance. This disturbance can be small-scaled, leading to patchy gap structures within the old-growth stand (e.g. Hobi et al., 2015), but depending on the forest type and local climate, can also be severe to stand replacing disturbances.

These natural regeneration phases however remain an essential part of the primary forest dynamics (Frelich and Reich, 2003) and continue to have high conservation value and maintain important old-growth features such as high deadwood volumes and structural diversity (Donato et al., 2012). A study by Larrieu et al (2014) showed that all developmental phases in a primary forest continued to contain large amounts of deadwood and a high density and diversity of tree related microhabitats.

It can be concluded that a primary forest is a *forest where species and structural composition, age distribution and natural dynamics have not been actively disturbed or altered by human activities. They generally cover large areas (landscape scale) and incorporate all developmental stages and age cohorts of a natural forest (including young stages).*

Most definitions don't strictly exclude areas with historic (low impact) human interaction, as long as the above characteristics were not significantly disturbed. In case of significant human interventions (e.g. logging, even selective logging), however, It will take several centuries or even millennia for the forest to fully regain these natural characteristics. Primary forests are therefore irreplaceable.

2.2. Secondary forest

In an international (mostly North-American and tropical) context, secondary forests are described as forests that have been intensively logged ('logged over'), but recovered afterwards (be it naturally or through human intervention). They are also called 'second growth'. This description relates to significant human disturbance in a forested context. This disturbance was recent enough to still be very recognizable in the forest: age structure and species composition (pioneers or secondary species instead of late successional climax composition).

In the European context however, the definition often relates to land-use history, deforestation and reforestation over time. A secondary forest is then a forest, that was actively or spontaneously re-afforested after a period of non-forest land use (arable land, grassland or heathland) in recent historic times (cfr. Rackham, 1980; Peterken, 1993).

CBD defines it as follows: *In Europe, secondary forest is forest land where there has been a period of complete clearance by humans with or without a period of conversion to another land use. Forest cover has regenerated naturally or artificially through planting*.

Here again, the interpretation of CBD differs from the common definition in scientific literature and intermixes both interpretations.

In the European interpretation and context, secondary forests developed on agricultural land are the antipode not of primary forests, but of 'Ancient' forests. They are sometimes also called 'recent forests'.

2.3. 'Ancient' forest ('ancient woodland')

'Ancient' forest (also called 'ancient woodland') is a concept that was developed specifically for Europe and was first introduced in the UK (Rackham, 1980, Peterken, 1993...). It delineates areas of forest that have not been cleared to be replaced by other land-cover or land-use over a long period of time. The threshold period is most often related to the first detailed countrywide land-use mapping. In England, ancient woodland is defined as land that has been continuously wooded since at least 1600 (Goldberg et al., 2007). In Belgium, France, Germany, Austria and Hungary this is the end of the 18th century (De Keersmaeker et al., 2015; Wulf, 1997); in the Netherlands beginning of the 19th century. This continuity of forested status does not imply that no logging, clearcut or temporary open patches were occurring in the past, and can still be present today. The current forest stand can be an Ancient Semi-Natural Woodland (ASNW), but can also be fully artificial and consist of native or exotic Plantations on Ancient Woodland Sites (PAWS) (e.g. Pryor & Smith, 2002). The term 'Ancient' thus relates to land-use and has no link to the age or maturity[1] of the trees or the stand, as is clearly shown by Janssen et al. (2019) (fig.1).

Ancient woodlands/forests, however, do retain important features for nature conservation, such as dispersal limited plants, fungi or invertebrate communities, and unploughed, unimproved soils (Pryor et al., 2002). Specific lists of indicator plant species of ancient woodlands are commonly applied in literature and conservation practice (Hermy et al., 1999; Wulf, 2003; Hofmeister et al. 2019).

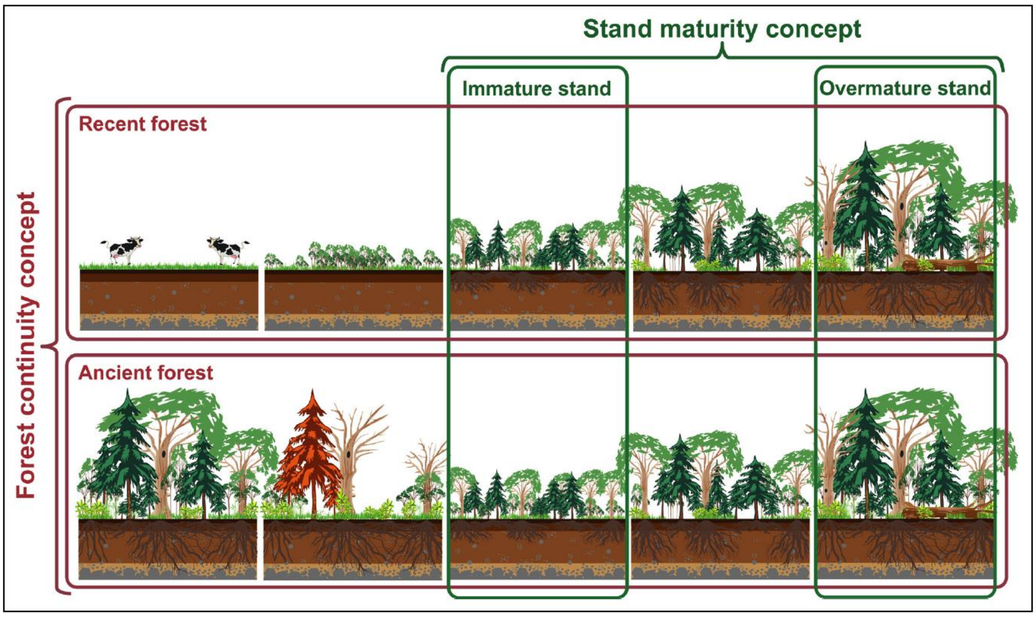

Fig.1. Depiction of the difference between forest continuity and stand maturity (related to the old-growth concept) from Janssen et al (2019). Please note that Ancient forests may also consist solely of young and immature stands, or even plantations on ancient woodland sites.

[1] In this figure, the term 'overmature' is also introduced to describe the level of maturity of the stand (or a tree). The term 'overmature' basically originates from even-aged forestry, and describes forest stands beyond the optimal harvest age of a stand (or a tree). In natural forest dynamics, 'overmature' may equal 'senescent' given that the majority of trees, or a dominant tree cohort consists of old trees in the senescent development phase.

In this context, ancient woodlands may contain 'old-growth' stands (see below), but most of the ancient forests are not old-growth, but young to mature, managed forest stands. Likewise, not even all old-growth should be ancient woodland: some old-growth stands may have originated from abandoned wood pastures (e.g. Hasbrucher Urwald, Sababurg, …), or may have developed over the last centuries from previous arable land (upper figure in fig.1). Both aspects – forest maturity (old-growthness) and forest continuity (ancientness) – appear to be important for completeness of species assemblages of various forest-dwelling taxa (Hofmeister et al., 2019).

2.4. Old-growth

2.4.1. Definition and description

The concept of 'old-growth forests' was quite recently developed originally in Northern America by Franklin and Spies (e.g. Franklin et al., 1981; Spies, 2004; Frelich & Reich, 2003; Wirth et al., 2009)and became established later on also in Europe (e.g. Bauhus et al., 2009; Burrascano et al., 2013; Di Filippo et al., 2017; Gilg, 2005; Lingua et al., 2011; Piovesan et al. 2005; Ziaco et al., 2012, Vandekerkhove, 2019).

Definitions of what constitutes an 'old-growth' forest are manifold and often ambiguous. Simple definitions based on a single criterion are rare in ecology, especially if the *definiendum* ('old-growth forest') is itself a complex dynamic system that is a result of gradual transitions involving several processes. But the common denominator is that they comprise forest ecosystems containing structural attributes that are associated with late-seral stages of stand development such as old trees, and large amounts of coarse woody debris (With et al., 2009). Old-growth is not necessarily "untouched' but can also develop following human disturbances.

The **US Forest Service** developed a generic **definition for old-growth** and specific sets of criteria and indicators for a wide range of forest types. The generic definition states: "*Old-growth forests are ecosystems 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"* (USDA, 1989; White & Lloyd, 1994).

In the working document by **CBD (2006),** old-growth is described as follows: '*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 and have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class*.'

The current draft version of the **Primary and Old-Growth Working Document of the EU-DG-Env. Working Group on Nature and Forests** describes old-growth as follows:

Old-growth forest are "forest areas or stands of native tree species that have developed, predominantly through natural processes, structures and dynamics normally associated with late-

successional[2] stages in primary or undisturbed forests of the same type. There may be visible signs or records of former human impact, but they are gradually phased out due to abolishment of human interventions, and ecological processes have redeveloped or are not significantly disturbed."

In the explanatory notes, it is clarified that the stands may include stands originating from natural regeneration, but also from planted or sown native tree species, as long as they meet the description. They may also contain stands with visible signs of abiotic damages (such as storm, snow, drought, fire) and biotic damages (such as pests and diseases), and traditional use by indigenous people (e.g. Saami reindeer grazing), as long as they meet the definition.

Some key characteristics of old-growth forest stands are structural features and dynamics such as natural regeneration, occurrence of large and diverse dead wood, presence of habitat-trees, structural complexity and presence of old and veteran trees. They have reached these structural features and dynamics through (sometimes several decades of) natural development.

We can conclude that these definitions and descriptions are very much in line and have following common denominators:

The evaluation of old-growth status is commonly made at the forest area/patch or stand level.

Contrary to the concept of 'primary' forest and 'ancient woodland', these areas are not defined by their land-use history or management history, but by their actual structural stand features (see below). Also contrary to 'primary forest', old-growth stands can originate from forest stands that were formerly managed. These may have developed through deliberate or unintentional non-intervention. They are the result of a more or less long process of maturation.

They refer to the typical characteristics of late- seral phases of forest development that are very rare or missing in regularly managed forests, due to the 'management shortcut' (Vandekerkhove, 2019) as illustrated by Emborg & Christensen (1990), see Fig. 2.

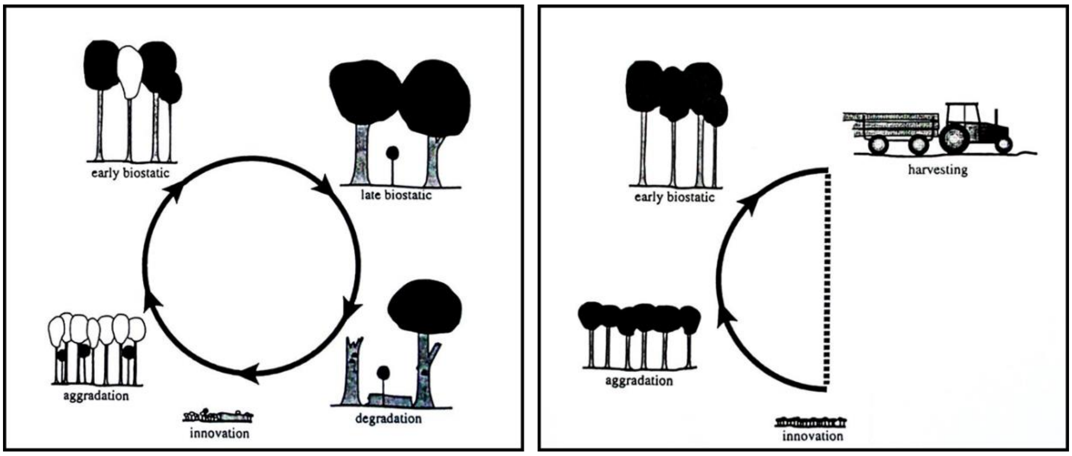

Fig 2. The 'management shortcut', eliminating the late-seral (late biostatic) and generation-transition phases (degradation phase) of the forest (Emborg & Christensen, 1990).

[2] The document now states 'late-successional': this could be interpreted as 'climax' stage in vegetation succession. What is meant is the 'late-seral' stage of stand development: this will most probably be corrected in the final version of the document.

These late developmental phases have different names in literature. They may be called 'senescence and breakdown phase, or 'late biostatic and degradation phase' (e.g. Emborg & Christensen (1990) or 'late seral'. Leibundgut and Zukrigl call these the 'ageing and breakdown phase'; Korpel (1995) speaks of 'Late optimal and collapsing phases'.

In managed forests, the full life cycle of trees and shifting mosaic cycle of stands is no longer present. First of all, the life cycle of the trees is aborted by the final harvest of trees. Trees are removed at their harvestable age, around the economic optimum of tree value, which is located at about one third or half of their natural life span (e.g. Christensen & Emborg, 1996; Scherzinger, 1996). Moreover, the stands are more even-aged than natural forests, ranging from moderately less uneven-aged, lacking the older age classes (as in 'Plenterwald'), up to fully even-aged.

2.4.2. Complexity of old-growth delineation.

Complexity of developmental phases

The dynamics of forests are often described and depicted in the form of a linear succession (see fig. 4), or a life cycle (as in Emborg et al., 2000, fig.2): trees regenerate, grow and compete among each other for light and space, mature, grow old and eventually decline, die and decompose (Fig. 2).

These life cycle phases can occur on different spatial scales, depending on the disturbance events that take place. They can occur at individual tree level scale, resulting in uneven aged forests (sometimes called 'plenter phase') or on larger scale (mosaic structure). If several trees simultaneously die or are blown over during windstorm events, patchy patterns may develop, that evolve over time and space, described as the 'dynamic steady state' or 'mosaic cycle' (e.g. Emborg et al., 2000; Bormann and Likens, 1979; Leibundgut, 1978; Korpel', 1995; Saniga and Schütz, 2001a).

In the event of a stand-replacing disturbance, for instance due to fire, bark beetle outbreak or large windthrow, the life cycle stages of trees may even occur on large scale, resulting in more or less even-aged large patches and stands, that follow a more unidirectional pathway towards maturity before re-entering the mosaic cycle (e.g. Bormann & Likens, 1979). Depending on the forest type, these large-scaled disturbance events are virtually absent (e.g. in temperate broadleaved forests) up to relatively frequent (boreal pine and spruce forests), shaping the age patterns in the forest (Angelstam, 1998) (Fig. 3).

This conceptual model of the shifting mosaic cycle, and its spatial and temporal sequence of phases, has been debated by recent research. It has been criticized as being too simplistic and has been questioned several times using quantitative spatial analyses, fruitlessly looking for non-random 'patchy' arrangements of growth and mortality processes (e.g. Szwagrzyk & Szewczyk, 2001). Král et al. (2014) did find a patch pattern of basic stand characteristics in natural beech-dominated forests through multi-scale spatial analyses: what appeared to be random at the fine scale of individual trees was revealed as a periodic patchy pattern at larger scales (patches usually 400–1100 m^2 in size).

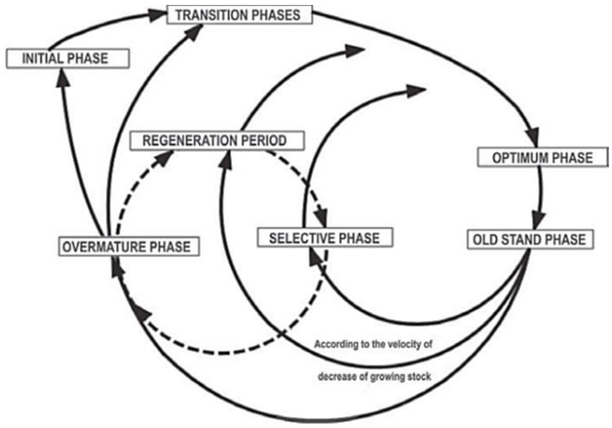

Fig 3 Schematic visualisation of the shifting mosaic cycle for natural beech-fir-spruce forests in Central Europe (source: Rüther and Walentowski, 2008, based on Zukrigl et al., 1963) showing the different disturbance scales: stand-replacing disturbance pathway is shown in the upper-left cycle and individual tree-dieback scale in the smallest cycle; patchy disturbances in the middle cycle.

These rather small-scaled patch structure is described by several studies specifically for beech forests (Alessandrini et al., 2011; Hobi et al., 2015; Peck et al., 2015; Tabaku and Meyer, 1999; Zeibig et al., 2005; Peck & Zenner, 2019). Still, Král et al. (2017) found that the consecutive sequence of developmental stages (from regeneration and growth, through maturity and senescence, to breakdown and back to regeneration) is oversimplifying the development. When analysing shifts over time, less than 40% of all observed transitions could be classified as cyclic (following the model cycle), and thus more than 60% of the transitions were acyclic (moving across or backward in the model cycle). The overall pattern of all observed transitions resembled a complex web rather than a simple repeating cycle.

We can conclude that the life-cycle of forests, like many processes in nature, is much more complex than can be depicted in conceptual models.

'Old-growth' is a gradual, not a dichotomous feature

Different forest developmental phases, including the old-growth-phase in natural forests are not discrete, but gradually develop from one to the other, as illustrated in the figures below. Any threshold-line on this gradient is therefore arbitrary and disregards the complexity of old-growth-feature development.

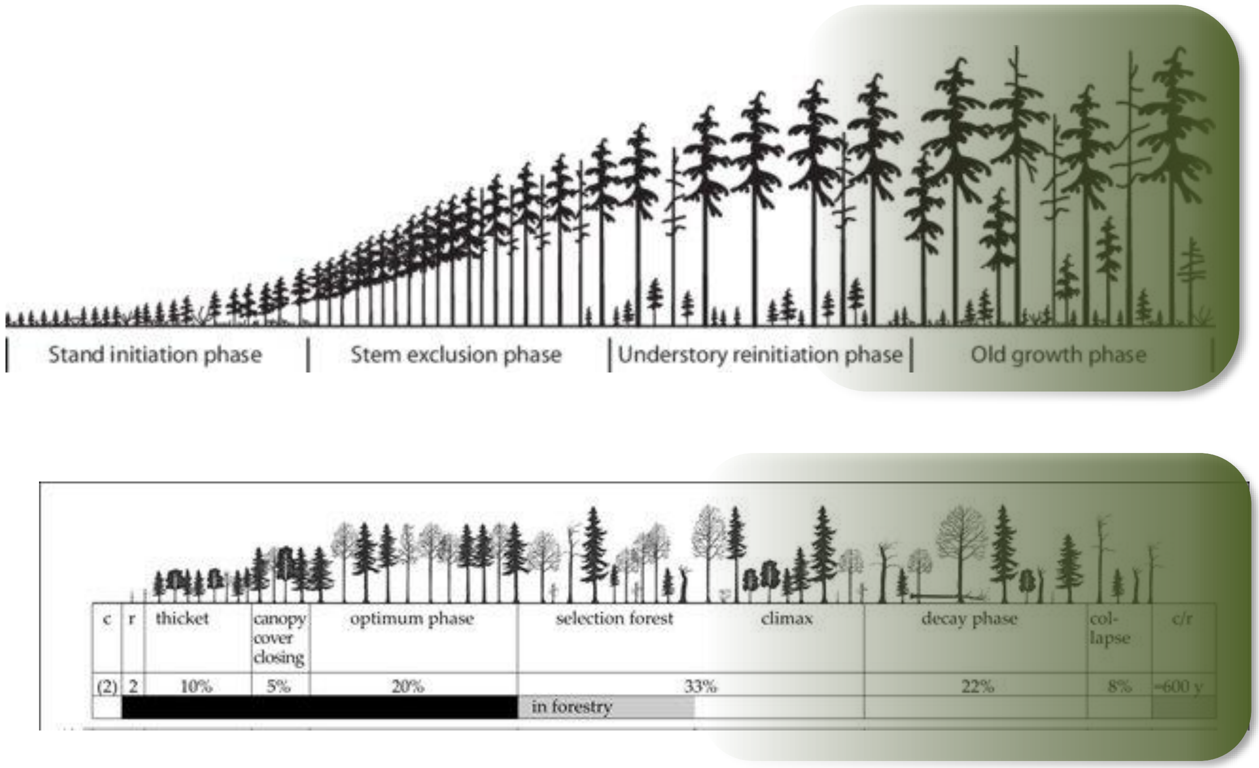

Fig.4 Gradual development of old-growth-characteristics in a (simplified) linear life-cycle development (based on Kimmins, 2003 and Scherzinger, 1997). Both authors provide arbitrary 'border lines' to delineate the different phases, while the development towards 'old-growthness' is a gradual and complex process.

As described above, it is already very hard to delineate the different developmental phases in a forest, as they often intertwine and overlap, especially when several natural life cycles succeed one another, as illustrated below in Fig. 5 and fig. 6.

Indeed, old-growth features are not exclusively located in the typical late development phases of a forest, but overlap. That is why also the regeneration phase after a larger-scale or stand-replacing disturbance should still be considered as old-growth. The fig. 6 by Bouget et al. (2021) clearly showing the difference between the regeneration phase in a managed forest compared to the regeneration phase in a second or later developmental cycle after an old-growth phase, where a strong 'legacy' of the elements of the late-seral phase remain.

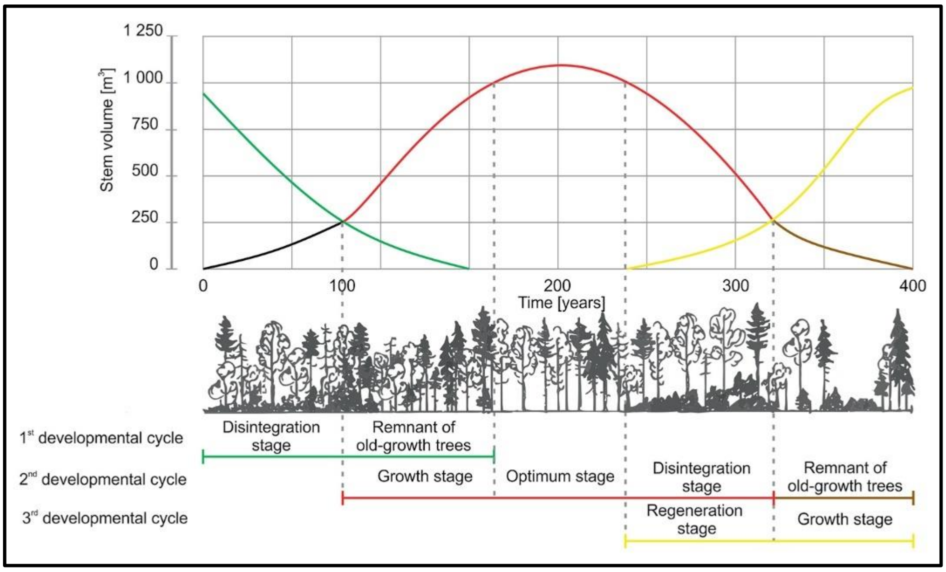

Fig.5 Illustrates that the different developmental phases not only develop gradually, but also overlap over different generations of tree cohorts. During the ageing and disintegration phase of the first developmental cycle, the regeneration and growth phase of the second cycle already takes off. During this phase, important remnants of old-growth features may still be present. Figure from Machar et al (2017) based on Korpel (1995)

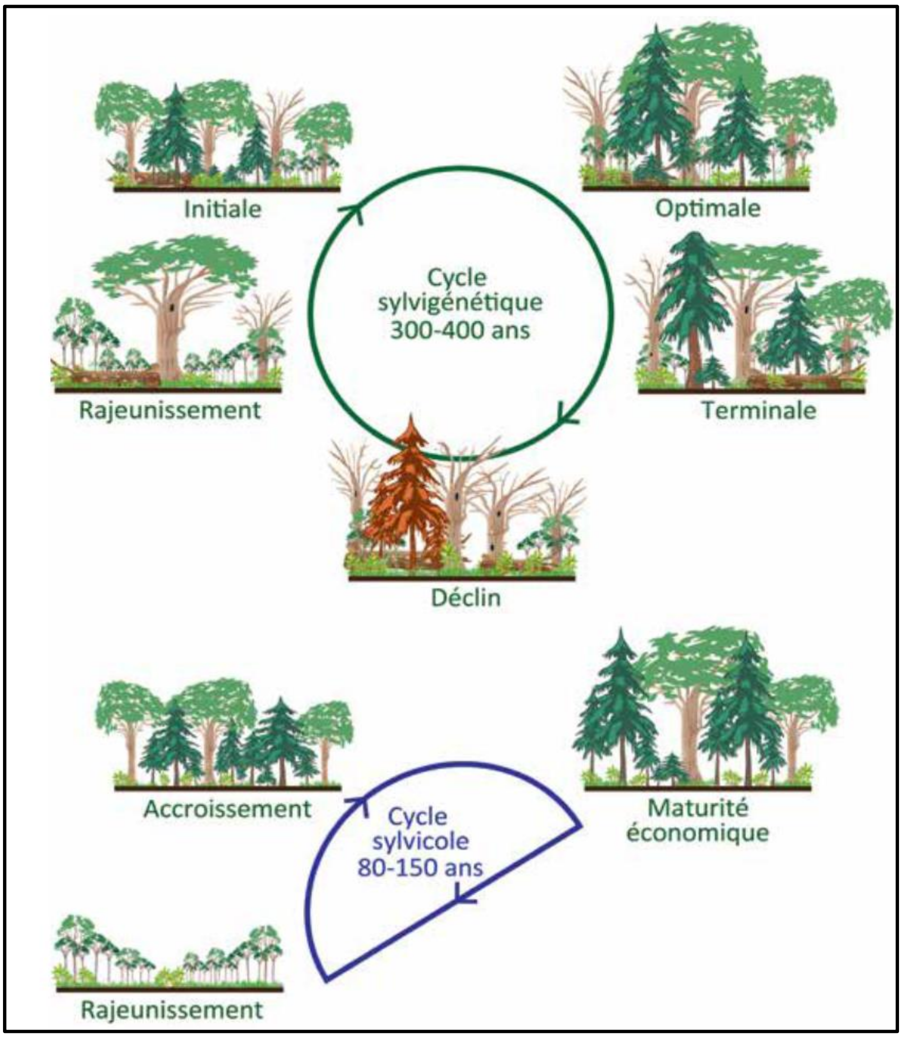

Fig.6 illustrates how the rejuvenation phase (Rajeunissement) after an old-growth late-seral (Terminale) and decay phase (Déclin), e.g. due to stand-replacing disturbance clearly differs from the rejuvenation phase after harvest in a managed forest. (from Bouget et al. 2021) .

Once a forest stand or area has reached the late seral phase, it may remain in this status for a long time, but may also further develop to the regeneration phase (although this still is clearly different from a managed regeneration phase, as illustrated above), especially when subject to severe, stand replacing disturbances such as bark beetle outbreaks, fire, storms or flooding. These forests still contain high conservation values, although their level of 'old-growthness' may have temporarily dropped.

There is debate among scientists whether these stands can still be called old-growth in this particular situation. Bauhus et al (2009), for instance, clearly limit the term 'old-growth' to the stands and patches of forest that are in the late-seral phase, without stand-replacing disturbances. Larrieu et al. (2014) state that the overall aggregate of old-growth indicators (see below) such as tree-related microhabitat and dead wood amount and diversity will not significantly change over time, not even in the case of large disturbances, once the natural cycle is closed.

Anyhow, it is important that even after an old-growth forest is replaced by large-scale disturbance, it should continue to receive strict protection status, and be left unmanaged (Sabatini et al., 2018, O'Brien et al., 2021).

Finally, and as stated in the definition, many old-growth forests in Europe have a history of human intervention, harvest and management. They have redeveloped the typical old-growth features such as overmature trees, habitat trees and large amounts and diversity of deadwood through deliberate or unintentional non-intervention over shorter or longer time. The time it takes to develop these features will depend on local growth conditions, and the composition and age structure of the original managed stand, but may take from a few decades to several centuries to reach a high level of old-growthness. In this case, the term 'secondary old-growth' is more and more applied. These situations are often easier to discern than in complex primary forest contexts. Still, the delineation remains arbitrary, as also the redevelopment of old-growth features is a gradual process.

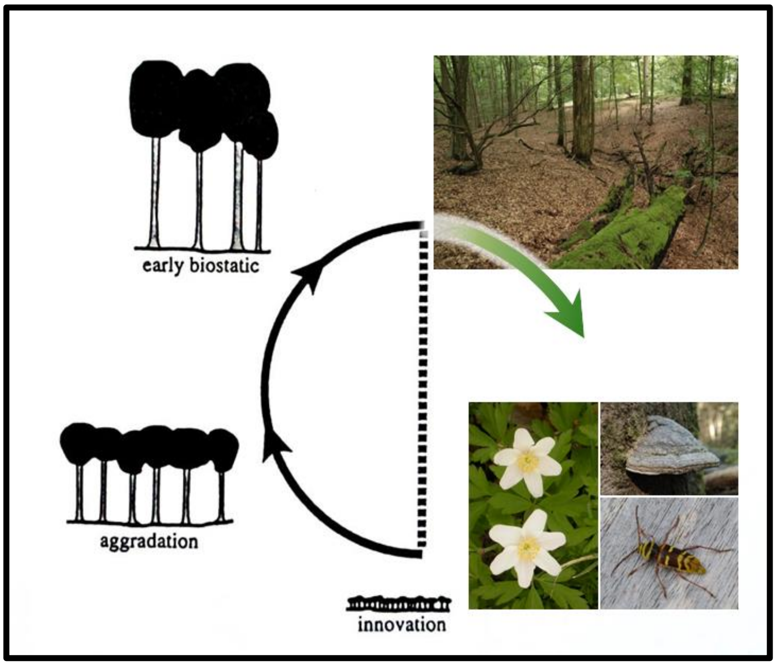

Fig. 7: Old-growth features may re-develop if previously managed forests are deliberately or unintentionally left for free development. In this case the term 'secondary old-growth' is often applied (figure from Vandekerkhove, 2019, based on Emborg & Christensen, 1990)

Conclusion

Old-growth forest can be defined as a forest area containing structural attributes that are associated with late-seral stages of stand development in natural forests. They are the result of self-regulated developments. They can be part of the life-cycle phases of a primary forest, but can also re-develop from managed forests that are left for natural development (so-called secondary old-growth).

The old-growth phase is not always easy to discern and may intertwine with other developmental phases. Old-growth is also not a binary feature (yes/no) of a forest stand, but a gradual feature, that can be qualified or assessed by a set of different indicators. Instead of applying strict dichotomous decisions on determining old-growth, there is a strong tendency to apply a gradual scale (index of old-growthness or OGI) to indicate the extent to which a forest or stand meets specific criteria thresholds or approximates certain reference values typical of primary old-growth stages (Kimmins, 2003; Di Filippo et al. 2017, Meyer et al. 2021).

The time to develop old-growth features will depend strongly on the species and age composition of the original area, related to the type and intensity of human disturbance (eg. clearcut vs. irregular selectively harvested stands) and site conditions.

In order to evaluate the old-growth status or level of a forest area, a set of criteria and indicators was developed in the framework of this project, based on scientific literature. These indicators are described in Chapter 3 of this report.

Lost in translation.

The terminology on primary, ancient and old-growth is not straightforward, and some of the terms are often interchanged and misinterpreted, which leads to a lot of confusion. This is even enhanced when translated to other languages. This was also the case in the translations of the term 'old-growth' in the official translations of the EU Biodiversity Strategy 2030.

In the German translation: old-growth is translated to 'Urwälder' : *alle verbleibenden Primär- und Urwälder der EU zu bestimmen, zu erfassen, zu überwachen und streng zu schützen* . This term is normally used as a synonym for primary forests (Primärwald). The correct term for old-growth is rather 'Altholz' (in the context of 'Altholzinsel') or Alte Waldbestände. Thus the German translations uses two synonyms to describe two different things. This has already lead to misinterpretations on the possible consequences of the implementation of the strategy (e.g. Dieter & Iost, 2021).

The Dutch translation does not even provide two terms and translates 'primary and old-growth' to 'oerbossen': '*alle resterende oerbossen in de EU te identificeren, in kaart te brengen, te monitoren en strikt te beschermen*.

The French translation uses the term 'forêts anciennes' for old-growth: *protéger strictement toutes les forêts primaires et anciennes encore présentes dans l'UE*. This term is the literal translation of 'ancient woodland', and is in fact (at least in France and Belgium) used to describe these forests that were never deforested (but may be consisting of young or artificial stands) (cfr. Cateau et al., 2015; Inventaire Forestier). Old-growth should be translated as 'forêt subnaturelle' or 'forêt mature'.

In Spanish, old-growth is translated as 'bosques maduros' : *proteger rigurosamente todos los bosques primarios y maduros que quedan en la UE.* Literal translation of 'maduro' is mature *('*que ha superado la juventud pero aún no entra en la vejez') and is also translated as 'ready to harvest' or 'fully developed' or 'advanced in years'. Still, the EUROPARC-Espana reference work on old-growth forest protection also uses the term 'bosque maduro'or 'bosque viejo' for old-growth.

In the framework of the UNESCO- world heritage site 'Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe', the terms 'ancient' and 'primeval' are described differently: 'Ancient' is explicitly used in the meaning of 'old-growth 'forest, as explicited in the glossary of the nomination dossier for the second extension (Kirchmeier & Kovarovics, 2016) :

In the context of this nomination dossier, the term 'ancient (beech) forest' is synonymously used with 'old-growth (beech) forest'. (…). For beech forests, this includes trees that are significantly older than the usual period of logging rotation (100–120 years) and deadwood amounts of over 20 m^3 are already in place

The confusion of terms is extended to 'primeval' forests in this publication. Primeval is normally related to 'Primary' or 'virgin forests but 'w*ithin this World Heritage Nomination Dossier, the term 'primeval forest' is used in a slightly broader way than in other contexts. In this document, the term 'primeval' comprises 'virgin' and 'ancient' forests. Virgin forests are forests that have never been directly affected by humans. Ancient forests are forests that have been exposed to human influence (e.g. logging) a long time ago, but the current structure and species combination is close to 'virgin forests'.*

Reading the description, the correct name of the UNESCO-site thus should be 'Primary and Old-Growth beech forests of the Carpathians and other regions of Europe.'

3. Criteria and indicators for primary and old-growth forests: an overview

3.1. Criteria for primary forests

Primary forests are defined as 'naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed'. They are therefore identified by a single, absolute criterium: the absence of harvest or other significant human intervention. They have maintained the natural forest cycle, including all developmental phases and age cohorts.

In forest types with predominant small-scale disturbances (like most beech forests) this will -at a larger scale- result in a dynamic steady-state, dominated by mature and late-seral developmental phases, and late-successional species. Other forests types (e.g. boreal, alpine) may be characterised by severe stand-replacing and mid-intensity disturbances leading to areas in reiteration or rejuvenation state, with large amounts of dead biomass, but low standing volume, and temporary absence of old trees in disturbed patches. These disturbances may be more frequent than traditionally assumed, even in beech forests (Pettit et al., 2021).

Specific criteria and indicators of primary forest will therefore focus on the absence of (visible) signs of human interventions. These can be direct signs such as stumps, but also indirect signs, such as tree species composition).

For primary forests, following criteria are commonly proposed in the scientific literature. They are more descriptive when compared to criteria and indicators for 'old-growthness' (below):

- Absence of traces of (recent) human disturbance (Er and Innes, 2003; Helms, 2004; Nagel et al., 2013; Barton and Keeton, 2018).

- Forests initiated from natural disturbances and regeneration (Nagel et al., 2013)

- Different developmental phases are present, including late-seral phases that maintain (at larger scale) a continuity of old-growth attributes (e.g. large amounts of deadwood) (Mosseler et al., 2003) Wirth et al., 2009; Frankovič et al.,2021)

- Tree establishment through gap-phase dynamics (Oliver and Larsson, 1996; Barton and Keeton, 2018) or cohort of trees that established immediately after the last stand replacing disturbance (Barton and Keeton, 2018)

- Area should be large enough to contain the different developmental phases, including severe disturbance patterns

3.2. Criteria for old-growth forests

Old-growth is typically distinguished from other forests by the presence of large or old trees and habitat trees, accumulation of large-size dead wood, high structural diversity and high aboveground biomass (USDA 1989, Wells et al 1998).

The definition and delineation of old-growth forest, however, is not straightforward. These forests are not defined or identified by a single attribute, but a combination of several factors may serve as important indicators. There is a wide variability and combination of features exhibited in old-growth forests, and the features do not simply 'add-up' as the sum of a series of rigid criteria (Greenberg et al., 1997).

Instead of applying strict dichotomous decisions on determining old-growth, there is also a strong tendency to apply a gradual scale (index of old-growthness or OGI) to indicate the extent to which a forest or stand meets specific criteria thresholds or approximates certain reference values (Kimmins, 2003; Di Filippo et al. 2017; Meyer et al. 2021). These reference and natural ranges values may be derived from primary forests of that type.

Old-growth forests or stands are therefore mainly described or delineated based on a set of multiple criteria that may or may not be simultaneously present.

The list of criteria may slightly vary amongst publications, and often relates to the forest type and growth conditions in which they are applied (see Tyrell et al. 1998, below).

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).

For status of old-growthness, a list is given below of the main criteria (underlined) and derived numeric indicators that are applied in international literature to characterise old-growth areas and considered relevant for beech old-growth forests (based on Meyer et al., 2021; Frelich & Reich, 2003; Burrascano et al., 2013; Knorn et al., 2013; Wirth et al., 2009, Ziaco et al 2012; Di Filippo et al 2017;...).

Criterium 1 : presence of large and old trees :
- presence of old (overmature) and/or Very Large Trees (N/ha)
- dominance of large and very large trees : share of biomass/basal area covered by LT and VLT (m^2/ha; m^3/ha; % of BA/growing stock)
- presence of old trees : tree age surpasses ½ of its maximum lifetime for local conditions (N/ha) Age of the 3 oldest trees per ha; Average age of dominant trees
- presence of trees with specific lifetime growth trajectories
- Tree with the highest DBH

(Helms, 2004; Wirth et al., 2009; Nagel et al., 2013; Hofmeister et al. 2015; Piovesan et al. 2019; Piovesan and Biondi, 2021, Meyer et al., 2021)

Criterium 2 : quantity and quality of lying and standing deadwood
- total quantity of deadwood (m^3/ha)
- DBH-range of deadwood (SD, Min/Max, interquartile range)

- presence of coarse woody debris (DBH threshold 30-50cm or 1 m³): volume/ha;
- share of deadwood on total aboveground biomass (%)
- diversity and share of different types of coarse woody debris : decay stages, standing and lying (% per category)

(e.g. Wirth et al., 2009, Nagel et al., 2013, Hofmeister et al., 2015; Meyer et al., 2021)

<u>Criterium 3 : Structural diversity of living stand:</u>
- high aboveground biomass (BA or volume/ha)
- diameter/size distribution + spatial pattern of tree sizes (SD on diameter, InterQuartile Range, ...)
- presence of different age cohorts
- horizontal diversity : random or clumped spacing of trees (vs. regular spacing : Ripley's function)
- horizontal diversity : diversity in canopy density (scale or %); spatial patterns of canopy dimensions and canopy gaps (gap pattern and size distribution,...)
- vertical diversity : layering and vertical continuity of the canopy (Height-distribution)

(e.g. Wirth et al., 2009; Alessandrini et al. 2011; Ziaco et al. 2012; Nagel et al., 2013, Meyer et al., 2021)

<u>Criterium 4 : Tree species composition:</u>
- tree species diversity (N/plot; N/ha or Shannon-index)
- share of non-native species (presence/absence or admixture: % of BA or volume)
- share of late-successional species (% of BA or vol.)
- composition of regeneration (native vs. non-native; planted vs. natural regeneration)

(e.g. Wells et al., 1998; Mosseler et al., 2003; McElhinny et al., 2006; Larrieu & Cabanettes, 2012, Meyer et al., 2021)

<u>Criterium 5 : soil microstructures (micro-relief)</u>

- density and size of pit-and-mound structures (N/ha)

(e. g.. Barker Plotkin et al. 2017; Meyer et al., 2021)

<u>Criterium 6 : tree microstructures</u>
- Density of habitat trees = trees bearing Tree related Microhabitats (TreMs) (N/ha)
- share of trees with TREMs
- diversity and density of TREMs per plot or per ha

(Paillet et al., 2017; Larrieu et al.2018; Meyer et al., 2021)

<u>Criterium 7 : presence of indicator species</u>
- presence of indicator species (fungi, lichen, insects, birds) of late-seral stages or indicative for long continuity of late-seral stages with overmature trees and large dead wood.

(cfr. Nitare et al. 2000; Christensen et al. 2005b; Eckelt et al., 2018; Hofmeister et al., 2019).

This last criterium is commonly applied in the delineation of High Nature Value forests, often old-growth forests in Scandinavia. In other countries, the delineation or assessment of old-growth is mainly based on the above structural features.

From this list, a specific set of criteria and indicators relevant for beech forests will be derived, which are applicable in field assessment. The selection procedure and the results are explained in detail in chapter 4.

All the above criteria and indicators allow for direct assessment of the status of old-growthness of a forest area or stand. In some studies, also indirect indicators are assessed, often to evaluate the level of (present and past) human interference, and to derive the potential presence of old-growth forest, especially in remote areas. These include indicators related to intensity of past management or presence of /distance to human infrastructure :

- Presence or density of old skidding trails
- Presence and density of cut stumps
- Distance to infrastructure (walking trails, roads, buildings,…)

These are not further elaborated, but they can be incorporated in the field protocol (see chapter 4).

3.3. How to assess and combine criteria and indicators

The development of scientifically robust criteria and indicators and a methodology to objectively assess the level and quality of "old-growthness" of a forest stand/area is one of the main goals of the LIFE Project PROGNOSES.

These criteria and assessment method should allow for better delineation and mapping of old-growthness, focusing specifically on beech forest ecosystems all over Europe.

Specific indicators can be quantified or assessed using qualitative indicators, as shown above. However, it is not evident how to evaluate these values and combine them to create a final score.

Several approaches have been developed in literature to quantify and combine indicator values to one 'outcome', taking into account the variability of attributes, and variability in forest types and site conditions. It should allow for differentiated as well as aggregated evaluations of the many features which characterise old-growth stands in contrast to managed forests, combining many attributes into a coherent indicator without losing the ability for differentiated evaluations.

One forest stand or area will not perform high to all possible indicators: dependent of forest type (natural characteristics of stand age, tree size,...) and site conditions (eg the size that a given species of tree can reach are conditioned by soil and climate), or disturbance regime and history, different aspects typically are or become temporarily predominant. They also don't simply add up. Therefore, Tyrell et al. 1998 suggest that forests should be evaluated using radardiagrams, as illustrated below.

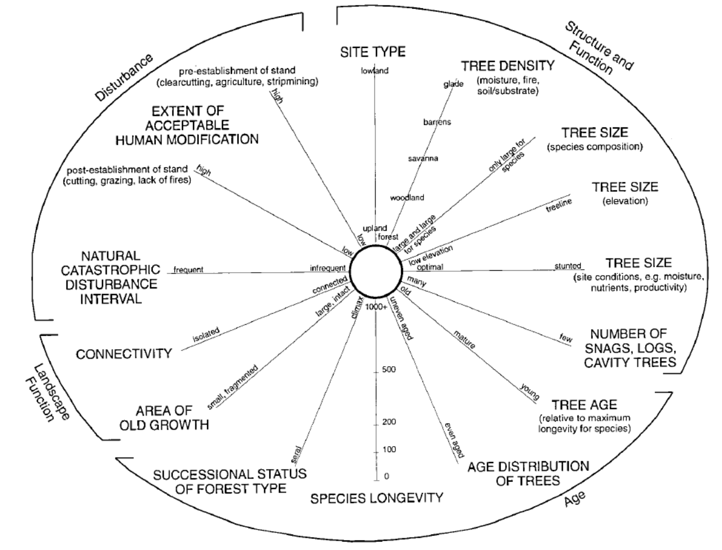

Figure 1.—*Model for the concept of old growth. Attributes representing the core concept of old growth are located at the hub of the wheel.*

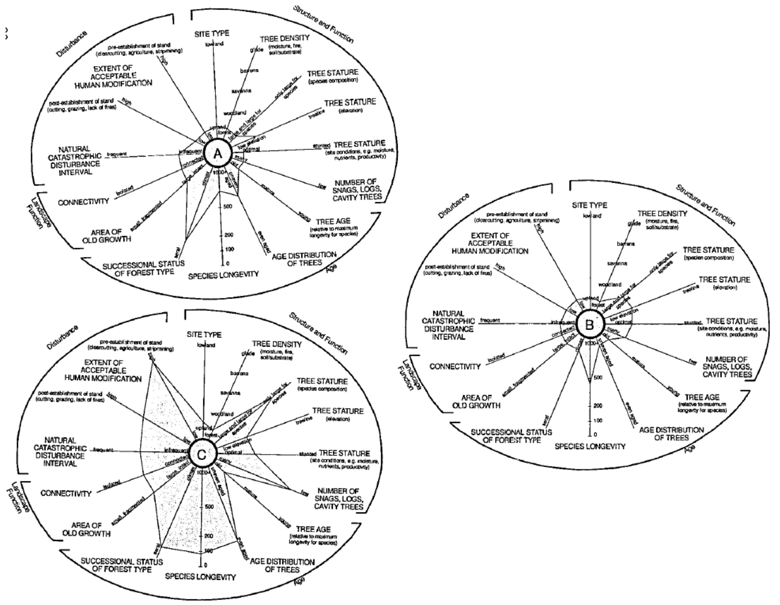

Figure 2.—*Examples of the old-growth model for: (A) Douglas-fir, (B) northern hardwoods, (C) aspen.*

Fig. 8 Above: overview of the criteria in the radar diagram; below: illustration of the importance of the different aspects, depending on the forest type that is under investigation (from: Tyrell et al. 1998).

This approach allows to visually compare the result for a specific stand/area to a reference area of the same forest type, taking into account the specificity of this forest type. It also avoids the simplification and loss of information of combining different indicators to one aggregated value. A methodology to rate the the similarity of the forest area to the reference stand is however missing and there is no weighting between the different indicators on their power to describe old-growthness.

In Austria, a methodology was developed to assess the 'Hemeroby' of forests (Grabherr et al., 1998). Here also, a set of 11 indicators was developed to assess the level of human influence on forest ecosystems (with 'hemeroby' being the inverse of 'naturalness'). Although the assessment of 'naturalness' not necessarily always coincides with 'level of old-growthness', the applied method to score and combine criteria and indicators is relevant here, as it is based on the same basic principle to compare forest stands to a 'forest reference' of the same forest type (according to the phytosociological forest association) along a multi-criteria approach.

The rating approach is following a fuzzy-logic approach. For each indicator a transformation table from the measured data in the field into a scale of 1-9 describing the 'level of naturalness' was generated, taking into account the natural ranges found in reference forests of that type. The 11 indicator values are then aggregated stepwise to one index value of hemeroby/naturalness using weighted means or logical combinations. The weighting done by a Delphi-inquiry to rate the importance of indicators based on expert opinion.

This multi-criteria approach results in one index value that classifies the naturalness in an ordinal scale. Drawbacks of this approach is that it requires reference data for all different forest types, and uses expert appreciation for the weighting and aggregation of the criteria. Finally this method results in one aggregated value that no longer allows for differentiated evaluations of separate indicators.

The Old-Growth Indicator (OGI), developed by Meyer et al (2021) presents an interesting and promising new approach to produce aggregated and relative scores to specific quantitative indicators of old-growth. It quantifies in a direct way the similarity of the value and range of scores for a specific forest structure to a primary forest old-growth state, as illustrated in fig.10. This value will range between 0 and 1.
In total, 27 variables are scored in this way. The results of the variables are weighted to balance the different aspects of old-growth, and added up to produce one final OGI-result, again ranging from 0 to 1.

This OGI is a multivariate indicator that takes into account the variability of attributes. The method allows for differentiated as well as aggregated evaluations of the many features which characterise old-growth stands in contrast to managed forests and solves the problem of combining many attributes into a coherent indicator without losing the ability for differentiated evaluations.

In a later phase of the PROGNOSES-project, we will analyse how far this method can also be applied to our assessment data that are to be produced for the WH-test sites and their managed buffer zones.

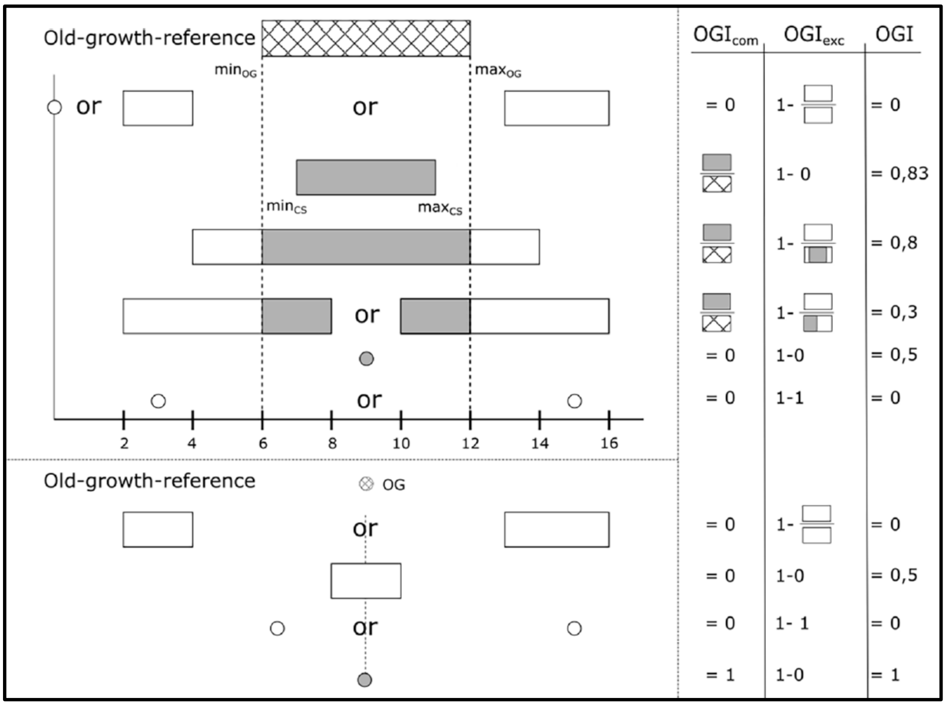

Fig. 9 From Meyer et al. (2021). Calculation of the old-growth indicator (OGI) resulting from the overlap (OGIcom, grey bars) and excess (OGIexc, white bars) variability between the comparison stands and reference range (crosshatched bar and dot, respectively). The scale on the x-axis is exemplary for a value of one attribute, to make the calculation examples on the right side comprehensible. Where more than one case is depicted in one line the calculation examples are valid for both sides

4. Indicators of old-growthness for beech forests to be applied in the field protocol

One of the main tasks of the PROGNOSES-project, is the assessment in the field of the 'level of old-growthness' of forest patches and stands, both inside the areas of old-growth forest and managed buffer zones of a selection of UNESCO-WH-component parts, covering all major beech forest types of Europe.

In order to do so, a field protocol was developed for the delineation of forest stands/patches with different levels of old-growthness, ranging from young, managed beech stands up to old-growth and primary forest, and for the assessment in the field of old-growth criteria, translated into measurable indicators.

This protocol is published separately (Kirchmeir et al. 2022) and will be applied in the field in the summer of 2022.

In preparation of this field protocol, a set of possible criteria and indicators specific for beech old-growth forests was derived from the list of commonly applied indicators in chapter 3, and is presented below, with some basic indication of possible reference values, and proposed method for assessment in the field.

First, a short summary of the delineation and plot selection procedure is given followed by the description of the potential indicators that can be applied and can be assessed based on field data .

4.1. Delineation of units and plot selection

A unit (stand/patch) has a size of 5-50 ha; (exceptional: 0.5-5 ha or > 100 ha). Its' delineation strongly relates to the management history and forest characteristics. A unit is delineated if

1. It is considered 'homogeneous' considering management history
2. Relatively 'uniform' in its current overall stand characteristics (age or development phase, species composition...)
3. Relatively homogenous in respect of site conditions (exposition, bedrock, relief, …)

These are the criteria commonly applied to 'stands' or forest management units in traditional forest management plans.
If a forest area is, by nature, uneven aged intermixing different developmental phases and age cohorts, as is the case in natural forests, these phases/cohorts should not be separately delineated and scored, but are considered as part of one unit. The plot design, however, (see below) should cover the full forest life cycle.
The units can be derived from management plans, RS-data, delineation in the field ...

Within each unit, one or more sample points are selected. Preferably at least 10 plots per set of units with similar management type/developmental phase are selected (cfr Meyer et al. 2021) They are to be selected in a desktop procedure (not in the field) using a systematic grid or random point selection . The plots have a fixed size (0.05-0.1 ha) where standard dendrometric measurements are performed.

However, some elements such as very large trees, coarse woody debris or pit-and-mound structures can be rare, so have a high probability to be 'missed' by the sampling plot design. For these specific (rare) elements additional plotless sampling (from the plot center) can be applied (e.g. order method)

4.2. Listing of possible of indicators

Criterium 1: Large and old trees :

Indicator: Presence of old/overmature trees or very large trees

Old (senescent, overmature) trees are trees of which the age of the tree is beyond ½ of its average natural lifespan in a specific environment /forest type (Larrieu et al., 2008; Branquart et al., 2005; Mosseler et al., 2003; Piovesan and Biondi, 2021). For beech trees in closed-canopy forests, the natural lifespan is generally considered to be > 300 yr (Wirth et al., 2009). So for beech trees/stands the age threshold for 'old' trees of 150-180 years. This age is also an important threshold age for the development of specific species and structures (Moning & Müller, 2009; Brunet et al. 2010, Larrieu et al, 2008).
To determine the age of trees would require coring of trees (especially in beech, due to suppressed vs. released growth patterns). This is not realistic for this study. Only a few dozen cores per site are foreseen in the PROGNOSES-project, in the framework of carbon assessment (determination of wood density).

As an alternative, the presence/density of very large trees is often applied as an indicator for the presence of overmature trees. In line with previous, one could state that a Very large Tree (VLT) could be related to the average DBH reached at age of 150-180 years.

Threshold value VLT related to local growth conditions
The maximum size of the tree and its DBH in relation to its age, will be dependent on suppressed vs. released growth conditions, but also on local site conditions (climate, soil, exposure, …). This would mean that the threshold value should be dependent of these conditions. One could propose to relate these thresholds to specific forest or habitat types, biogeographic regions, etc… but this would result in a multitude of recombinations that all would require specific thresholds. Moreover, local growth conditions within one forest type may even be very diverse.

We therefore propose a straightforward approach that links the threshold DBH of VLT to the local growth potential. As traditionally applied in forestry yield classes, the upper canopy height of dominant adult trees, is a good proxy to derive local growth potential.

We propose a subdivision in 3 classes: high- medium- and low-productive sites. They are determined by upper canopy heights of >30m, 20-30m and <20m respectively.

In normal to good growing conditions (high productive sites), the threshold of DBH > 80 cm is often applied (e.g. Burrascano et al., 2013; Vandekerkhove et al., 2018;...). We now propose specific lower thresholds for sites with medium to poor growth conditions.

To do so, we could make use of a dataset of DBH and height of beech trees from 247 unmanaged semi-natural to natural beech plots in Austria (provided by Hanns Kirchmeir) and over 400 plots from the REMOTE database (mostly primary forests) provided by Daniel Kozák (REMOTE research team, Univ. of Life Sciences, Prague).
The relation between stand hight and maximum DBH for the 247 Austrian plots indicates that indeed few plots with stand hights between 20 and 30m reach a max. DBH of over 80cm. The max. DBH in this hight class ranges between 45 and 75 cm. For the stands with height <20m, the maximum DBH is only rarely over 60 cm. Only 5% of the plots, however, reach the threshold DBH. This is mainly due to the small size of the plots: larger trees are often outside of the plots.

The REMOTE dataset, using larger plots, allows for a more detailed comparison for sites with upper canopy height >30m (N=106), between 20 and 30m (N=269) and <20m (N= 57). The density of trees with threshold DBH of respectively 80, 70 and 60 cm was analysed and showed very comparable densities in the three subgroups. In all subgroups all plots had a density of >5 trees meeting the threshold DBH, about 90% with >10 trees per ha, and 70-75% of the plots with densities of 15 and more trees.
This makes us conclude that a threshold DBH for Very Large Trees (VLT) set at respectively 80 cm, 70 cm and 60 cm DBH for the different growth conditions could be a reasonable figure.

Upper canopy height (mature)	**> 30 m**	**20-30 m**	**< 20 m**
Threshold DBH for VLT	80 cm	70 cm	60 cm

Measure: Count and measure DBH of all trees > threshold DBH in the sample plot. If none are present in the sample plot: measure the distance to the nearest VLT up to 50m from the plot centre or up to the stand border (= order method), and register its characteristics (species, DBH).

Indicator: density per ha (N/ha); derived indicators: % of BA or % of aboveground biomass, min/max range,...

Reference value: In primary beech forests: 5-15 VLT/ha (Vandekerkhove et al., 2018)

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: Dominance of Large trees and Very Large Trees

Threshold value:
This indicator takes into account both large (mature) and VLT (overmature) trees. For size thresholds, following figures are proposed (cfr. Meyer et al., 2021):

Upper canopy height (mature)	> 30 m	20-30 m	< 20 m
Threshold DBH for VLT	80 cm	70 cm	60 cm
Threshold DBH for Large trees	50 cm	40 cm	30 cm

Measure: dendrometric plot data

Indicator: % of Basal Area or % of Living volume (growing stock)

Reference value: In primary beech forests: 20-50% = VLT; VLT+LT > 70% (Vandekerkhove et al., 2018)

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Criterium 2 : Dead wood

Indicator: overall deadwood amount

Threshold value: starting from a threshold DBH of preferably 10 cm (20 cm at the least). For lying deadwood, fragment length of at least 1m; for standing deadwood, height of at least 1m; no stumps are measured (only registered if there are cut stumps in the plot).

Measure: All dead wood is sampled in the dendrometric plots (both standing and lying deadwood). For lying deadwood, both Line Intersect data or Full Area Sampling of the plot can be used. Beware that LIS will only provide reliable and precise figures on higher assembly level, not at plot level (no local estimator).

Indicator: volume per ha (m^3/ha) both standing and lying deadwood
Derived indicators: % of Total Aboveground Biomass consisting of deadwood, …
– if available: the difference between 'natural' vs. 'man-made' deadwood (harvest residuals) can be registered and calculated
Reference value: for primary beech forests, average volumes of dead wood of 100-150 m^3/ha are reported (e.g. Christensen et al. 2005a; Vandekerkhove et al. 2013, Commarmot et al. 2013, Hobi et al. 2015, Stillhard et al. 2022), fluctuating between 50 m^3/ha in the aggradation phase up to 300 m^3/ha and more in the degradation phase and at high severity disturbances (Saniga & Schütz, 2001)

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: presence of coarse woody debris

Threshold value: Coarse Woody Debris is defined using a wide range of thresholds, sometimes as low as 20 cm DBH (Meyer et al., 2021). We propose a threshold that refers to mature trees that may have reached the upper canopy, or very large branches (primary limbs of VLT)

Again, we propose a threshold dependent of the growth potential of the site. We suggest a size that is half of that of a VLT.

Upper canopy height (matu	> 30 m	20-30 m	< 20 m
Threshold Diameter at the largest end	40 cm	35 cm	30 cm

Measure: Snags, logs and fragments meeting the size threshold are registered in the circular plot (LIS or FAS).

If none are present within the plot, distance to and diameter at the base (largest end) of the nearest object is measured, as well as its full length. For standing dead trees and snags, also DBH and length (height) is registered – For all objects, also species, diameter and decay stage are registered (see below)

For lying CWD, both Line Intersect data or Full Area Sampling of the plot can be used. Beware that LIS will only provide reliable and precise figures on higher assembly level, not at plot level (no local estimator).

Indicator: volume per ha (m^3/ha) both standing and lying deadwood - man-made stumps not included
Derived indicators: % of Total Aboveground Biomass consisting of Coarse Woody Debris, % of the total deadwood volume consisting of CWD…

Reference value : In primary forests, at least 50% of volume consists of CWD

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicators on diversity of deadwood

Threshold value: see total deadwood volume (diameter 10 cm)

Measure: All dead wood is sampled in the dendrometric plots (both standing and lying deadwood). For lying deadwood, both Line Intersect data or Full Area Sampling of the plot can be used. Beware that LIS will only provide reliable and precise figures on higher assembly level, not at plot level (no local estimator).

Indicators: focus on size ranges, decay stages, status (lying vs. standing) and species :

- Share of standing vs. lying volume (%)
- Size range and size distribution: Inter-Quartile range (IQR), Range (Max-min) or Variance (5-95% values)
- Decay range and decay range distribution: % of volume in different decay classes (usually 5 classes: see Christensen and Vesterdal, 2003)
- Species composition of deadwood (in so far as it is identifiable): at least conifer vs. broadleaved

Reference value: for primary beech forests, the share of lying dead wood is about 75% on average (Vandekerkhove et al. 2009);
the size range is in line with the size range in the living stand (in aggradation and dynamic steady state) or higher (in the reiteration phase)
all decay stages are present, with majority of volume in classes 3-4 (mid- and advancing decay) (Müller-Using & Bartsch, 2009; Commarmot et al. 2013; Larrieu et al. 2012).

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Criterium 3: Structural complexity and diversity of living stand

Threshold value aboveground biomass: Living trees: often 5-10 cm DBH is used as threshold DBH – minimum required =10 cm DBH; Deadwood: idem or higher (minimum required = 20 cm DBH)

Measure: All living and dead trees (both standing and lying) are sampled in the dendrometric plots. For lying deadwood, both Line Intersect data or Full Area Sampling of the plot can be used. Beware that LIS will only provide reliable and precise figures on higher assembly level, not at plot level (no local estimator). Cut stumps and natural stumps < 1 m high are not registered.

Indicator: high aboveground biomass

Indicators: TAB (Total Aboveground Biomass) = living + dead volume (m^3/ha, also: Mg/ha)

Reference value: for primary beech forests, the TAB reaches values on average of 500-800 m^3/ha (Hobi et al; Meyer et al., 2021), or sometimes even higher for very productive sites (>800-1000 m^3/ha) (Vandekerkhove et al. 2018). On low productive sites (due to marginal soil or climate condition), this will be 300-500 m^3/ha (Ziaco et al. 2012)
After severe disturbance events, this volume may consist mainly of dead wood, and in the subsequent aggradation phase, the TAB may temporarily drop below the reference value (as the new stand is still developing and the dead trees are decaying rapidly).

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: size distribution of living trees

Indicators:
- diameter distribution: overall DBH-distribution for every stand or management type: shape of the distribution (reverse J, bimodal, normal distribution…)
- InterQuartile Range (IQR); size range (min-max); variance: assessed at plot assembly level (data on single plot level too limited)

Reference value: for primary beech forests, the size range in beech forests normally goes up to 100 cm DBH, with exceptions up to 130 and even 150 cm DBH (Vandekerkhove et al., 2018). On low-productive sites, size may be limited to 60-80 cm DBH (di Filippo et al; Piovesan et al).
Size distribution of trees generally follows a reverse J-shape, or rotated sigmoid shape (Westphall et al. 2008; Alessandrini et al., 2011) in cases of more severe disturbance events, also bimodal distributions do occur.
Values for IQR vary from 30 cm on poor sites to up to 50 cm on rich sites.
Also the size of the largest tree can be an important indicator: Hofmeister et al. (2015) found that the tree with the highest DBH can predict local species diversity, especially of cryptogams.

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: spatial pattern of trees – presence of gaps

Threshold: a canopy opening is considered a ‘gap’ if canopy opening > 100 m² (= average canopy size of at least one full-grown canopy tree) and regenerating trees present in the gap are <2m high.

Measure:
- Register if (part of) the plot is coinciding with a canopy gap
- also register the density of the upper canopy (dense to sparce or patchy: see description in Kirchmeir et al. 2022)

- optional: individual tree positioning (distance + azimuth or X/Y)

Indicators:
- % of plots with gaps
- variability in canopy density (inter plot variability)
- spacing of individual trees: Ripley’s K-function (clustered - random - regular): requires large plots of at least 1 ha with full tree positioning, so often not possible for plot data.
- total cover of gaps (gap share) and canopy gap size distribution requires specific full area surveys, preferably using RS and LiDAR measures (e.g. Hobi et al. 2015; Solano et al., 2021)

Reference value: for primary beech forests, the spacing of trees is random to clustered (Vandekerkhove et al. 2018). In most primary beech forests, low intensity disturbances and single-tree mortality events are characteristic, leading to low shares of gaps (less than 5-15% -Hobi et al., 2015, Standovar & Kelemen, Solano et al., 2021..), and high prevalence of medium and small gaps of <1000 m²; in areas with frequent or intermediate-severe disturbances, also larger gaps may be present and more frequent (Pettit et al. 2021).

Scoring : numeric / ordinal categoric /

Indicator: vertical diversity: layering - vertical continuity of the canopy (Height-distribution)

Threshold value: taken into account are living trees in and around the plot (visual observation from plot centre) : often 5-10 cm DBH is used as threshold DBH

Measure: in standard surveys, not all tree heights are measured, but only a selection of trees over different DBH classes, in order to produce DBH-Height curves for volume calculations. For evaluation of vertical diversity, a descriptive categorical parameter is often used describing the height distribution in and around the plot centre (single layered, double, multiple layered; continuous vertical canopy) (Kirchmeir et al. 2022).

Canopy irregularity can also be derived from RS-Lidar data.

Indicators: Local canopy layering per plot and variability in canopy layering at stand level.

Reference value: In primary beech forests, there can be a continuum in tree heights, but sometimes with higher concentrations in the upper canopy layers ('cathedral'-like stands in the aggradation phase) - canopy layers can be distinct (upper - lower canopy - regeneration) or be continuous

Scoring: categorical or quantitative indicator of canopy irregularity (cfr. Hobi et al)

Criterium 4: tree species composition

Indicator: species richness of tree layer

Threshold value: recorded living trees in the dendrometric sample plot: often 5-10 cm DBH is used as threshold DBH

Indicators: Number of species per plot or per stand (average of all plots N/ha) - diversity indices (such as Shannon index)

Reference value: In primary beech forests, species richness of the tree layer can be very low, and strongly dominated by beech (lowland conditions and high mountain beech forest in Mediterranean basin) (cfr. e.g. Meyer et al., 2021; Leuschner, 2015; Piovesan et al., 2005) or mixtures of beech, spruce and fir (submountainous), with limited admixture of species like sycamore, elm and ash, birch, Sorbus, Taxus

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: dominance of late-successional tree species

Old-growth forests are often dominated by late-successional species; this is particularly true for old-growth beech forests.

Threshold value: recorded living trees in the dendrometric plots : often 5-10 cm DBH is used as threshold DBH

Indicator: index of dominance by late-successional species; can be based on absolute numbers (see Meyer et al., 2021), or % of Basal area or volume.

Reference value: The tree layer in primary beech forest is usually strongly dominated by late-successional species *Fagus sylvatica, Picea abies* and *Abies alba* (Korpel, 1995) sometimes with *Taxus baccata, Ilex aquifolium, Carpinus betulus, Quercus ilex* in the subcanopy (Saulnier et al., 2020). There is limited admixture of mid-successional species (*Acer, Quercus, Fraxinus, Ulmus, Sorbus*); pioneer species (*Betula, Populus, Salix, Pinus...)* are uncommon, limited to rare severe disturbance events.

Scoring: numeric / ordinal categoric / similarity index (Meyer et al. 2021)

Indicator: Presence of Non-native species in the tree layer

Threshold value: recorded living trees in the dendrometric plots : often 5-10 cm DBH is used as threshold DBH

Indicator: share of non-native tree species in the tree layer (% of stem number, the basal area or volume). In this context, non-native should be interpreted not only as 'non-native to the country' but also 'not typical for the natural vegetation type' (e.g. Norway spruce outside its natural altitudinal range).

Reference: Non-native species are obviously missing in primary beech forests

Scoring: numeric / presence-absence

Indicator: Species composition and pattern of regeneration

Threshold value: established tree regeneration within the sampling plot or subplot : often 50 cm height and DBH< 5cm is applied to define established regeneration

Indicator: this is a rough categoric and descriptive indicator, that allows to evaluate if the regeneration is native and/or of planted origin. First, it is evaluated whether regeneration is established (see Kirchmeir et al. 2022), and then qualified:

- Non-native species absent/subordinate/dominant in the regeneration
- Planted trees are absent/subordinate/dominant in the regeneration

In this context, non-native should be interpreted not only as 'non-native to the country' but also 'not typical for the natural vegetation type' (e.g. Norway spruce outside its natural altitudinal range).

Reference: Non-native species are obviously missing in primary beech forests

Scoring: categoric

Criterium 5: Soil microstructures

Several elements, often referred to as 'microstructures' are characteristic for old-growth forests, and harbour a specific fauna and flora.

Old-growth forests often contain specific soil microrelief, that is related to windthrow and decay of large trees. Even when a large dead tree is fully decomposed, traces of it will be traceable in the forest soil, with specific accumulations of minerals and organic carbon. Windthrow will create the typical microstructure of rootplates and associated pit-and-mound structures, that may remain clearly visible in the forest microtopography, even when the tree is already completely decomposed.

Indicator: density of rootplates / pit and mound structures:

Threshold value: rootplates of uprooted trees and pit/mound microrelief: relief-differences between sole of the pit and summit of the mound should be at least 50 cm.

Measure: Count the rootplates and pit&mound structures in the plot – if none are present in the sample plot: measure the distance to the nearest (up to 50m from the plot centre or up to the stand border).

Indicators: Number of pit-mound structures per ha

Reference value: In primary beech forests, density of rootplates and pit/mounds are between 1.6-7.8 /ha (Meyer et al., 2021). About 10 root-plates/ha and 42 pits&mounds (i.e. decomposed former rootplates)/ha were registered at Uholka forest (Commarmot et al. 2013) – however, no threshold was indicated here.

Criterium 6: tree-related microstructures

Also very characteristic and determining for the unique biodiversity of old-growth forest stands, is the presence of so-called habitat trees. These are trees bearing Tree Related Microhabitats (TReM's) (Larrieu et al. 2014; 2018). These TReM's include cavities, cracks and wounds, broken canopy parts and tops, dendrothelms, conks and epiphytes... In managed forests, such trees are often removed during thinnings as they often have limited economic value. They also occur much more frequently in overmature trees, that are often absent or very rare in regular managed forests.

Good indicators would be diversity and density of TReM's (Larrieu et al.2018). However, the set of TReM's is very diverse, and some are difficult to observe. As this protocol is intensive and time-consuming and has some issues on repeatability and comparability (observer effects), a more 'basic' protocol was developed which is presented below.

For the development of a set of indicators related to tree microhabitats, we selected a number of elements that can be relatively frequent and their recording can be standardized easily. This selection is in line with the recommendations in Larrieu et al. (2021).

Threshold value: TReMs are sampled on every living or dead standing tree or stem (in case of multi-stemmed trees) with a DBH > 20 cm within the sampling plot.

Measure: survey the trunk only, up to the first primary branch (except parameter 'crown damage') for elements mentioned below.

Group	Subgroup	description
Cavities on trunk	Woodpecker Trunk cavity	entrance width > 4 cm for smallest diameter – observed area: trunk from 50 cm above the ground up to first primary branch
	Rot-hole trunk cavity	entrance width > 10 cm for smallest diameter - above 50 cm up to first primary branch
	Trunk crack	not superficial but >5cm deep; surface > 100 cm² LxW (eg. 2cm wide but over 50 cm long; trunk up to first primary branch
superficial bark damage on trunk	Bark Pocket	Bark is loose, but still attached to the trunk - At least 10 x10 cm in size; trunk up to first primary branch
	Bark loss; exposed wood	Bark is missing, wood exposed on the trunk – at least 10x10 cm in size; trunk up to first primary branch
Trunk base elements	Trunk base cavity	Rot-hole below 50 cm, often in contact with the soil;
	Root buttress concavity	Concavity, consisting of living tissue (no rot-hole) at base of trunk; entrance width > 10 cm; high > 10 cm - at least 10 cm deep (test with boot tip)
	Dendrotelm	(At least temporary) Water-holding deformation at the trunk base, or at tree fork, up to 50 cm above ground
Exsudates	Sap/ resin run/necrosis	local death and bursting of the bark, with sap or resin discharge, also necrotic changes and puffing in beech
Crown damage	Crown partly dead	Over 25% of the crown consists of dead branches
	Crown partly broken	Over 25% of the crown has broken off
fungi	Perennial polypore	*Fomes* etc... fruitbodies min. 10 cm wide/high on the trunk
Epiphytes	Epiphytes (mosses, lichens, ivy)	Cover > 1/3 of the lower 3 m of trunk surface.

Required: record presence/absence per tree for every of the 13 elements. Always relate the recording to the individual tree (of which you also recorded at least its DBH, species, living/dead status).

OPTIONAL:

ADDITIONAL: for 'countable elements' : count the number of occurrences on every tree.

ADDITIONAL sampling:
- use the 47 types of Larrieu et al., 2018;
- sample also tree crowns;
- sample also lying dead trees

If additional elements are sampled, always make sure that you separate the results from the required protocol!

Based on these recordings, **several indicators can be derived:**

Indicator: share of habitat trees

(%) = trees bearing at least one of the above TreMs

Indicator: density of trees (N/ha) bearing a specific microhabitat

(e.g. number of woodpecker-cavity-bearing trees per ha)

Indicator: diversity of microhabitats per plot or per ha

(= number of different microhabitats per plot or per stand)

> For 'countable' elements: in case also the number of cases occurring per tree are counted, also indicators on density of the microhabitats themselves can be derived (e.g. density of fruitbodies of perennial fungi per ha)

Reference value: In primary beech forests, density of conk-bearing trees is between 5-10.8/ha, density of cavity-bearing trees is 18-30 trees per ha (Meyer et al., 2021).

Criterium 7: Indicator species of old-growth

This type of indicator was applied in the pacific NW to delineate old-growth patches to be conserved for conservation of species under the Endangered Species Act (e.g. Northern spotted owl).

In Scandinavian countries indicator species are also used to pinpoint forest areas to be protected (e.g. Nitare et al, 2000).

Specific lists of indicator species of birds (e.g. Angelstam et al., 2003), fungi (Christensen et al. 2005b) and beetles (Lachat et al. 2012; Müller et al., 2005; Eckelt et al., 2018) were developed that are specifically indicative for old-growth qualities, also specifically for beech forests (e.g. Lachat et al., 2012; Christensen et al. 2005b). They are species strictly related to specific minimum amounts or qualities of dead wood and other typical late-seral features and microhabitats (rot-holes, dendrotelms...).

It could appear overcomplicated to do these labour-intensive and specialised inventories of species, if the structures can simply be assessed directly (see indicators above).

However, the indicator species often not only give an indication of the current quality of old-growthness, but also indicate for continuity in time and spacial aspects of connectivity and minimum size for viable populations.

White-backed woodpecker (*Dendrocopos leucotos*), for instance, not only requires deadwood amounts of at least 50m³/ha (Müller & Bütler, 2010), these should also occur over an area of at least 50 ha. For a viable population of this species, several hundreds of ha of well developed old-growth forest should thus be available. Certain saproxylic beetles and fungi that are strongly linked to old-growth forests are dispersal limited: their presence indicates that old-growth conditions have been present at the site for at least several decades; some of the most demanding and dispersal limited species can even be indicative for areas with very long continuity of old-growth features and are therefore called 'primeval forest relic species' (Eckelt et a. 2018).

This type of inventories requires very specific knowledge and can be dependent of local conditions, so not readily applicable for a Europe-wide incorporation in Indicator sets.

They will therefore not be applied in the set of indicators to be assessed in the pilot study areas of the PROGNOSES project.

Still, they are very valuable and complementary to structural indicators. For sites where detailed and specific inventories are available, specific indicators can be applied:

Indicator: species richness of indicator species of wood-decaying fungi
Threshold value: presence/absence in the site of indicator species (total list is 23 species) from Christensen et al. (2005b)
Indicators: Number of species per site
Reference value: In primary beech forests, 10-15 of these indicator species may occur (Christensen et al., 2005b)

Indicator: presence of primeval forest relic beetles
Threshold value: presence/absence in the site of indicator species category 1 (= relic species sensu stricto; n=60) and category 2 (sensu lato; n=108) from Eckelt et al. (2018)
Indicators: Number of species per site/stand/management type
Reference value: In primary beech forests, 5-10 of the species of List 1 may occur and several more of list 2 (Eckelt et al., 2018; Müller et al. 2005)

Specific indicators for primary forest

The criterium of absence of human disturbance is the basic criterium to identify primary forests.

This criterium is, however, not essential for old-growth forests: as described in the definition of old-growth forest, this concept is focusing on forest areas and forest stands containing elements of late-seral stages. They can perfectly be present in formerly managed forests that still exhibit elements of human interference and management. mature.

They may even contain signs of relatively recent human interventions like selective felling, removal of invasive species, or recreational paths.

The criterium of absence of human disturbance, however, is primordial in the delineation of primary forest, as described for forests in central Europe by Mikolas et al. (2019): main criteria for inclusion in the category of primary forests was <u>the absence of detectable historical human activities</u>, as assessed based on the combination of forest stand maps, historical maps, and field observations.

If this criterium is assessed (for potential primary forests), following indicators can be assessed in the field:

<u>Indicator</u>: distance to the nearest traces of human intervention

- wood harvest tracks, skidding tracks, cut stumps...

- planted trees (if still traceable for native species)

- other remains of human activity: constructions, charcoal kiln remains

5. Literature

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Annex 1 : terminology and definitions related to primary and old-growth, published in Barredo et al. (2021).

The notions of primary and old-growth forests adopted by international initiatives share many commonalities (Buchwald 2005; FAO 2018; FOREST EUROPE 2015; Sabatini et al. 2020a; Sabatini et al. 2018). On the one hand, primary forests are considered relatively intact forests following natural dynamics, are naturally regenerated, composed by native species, and especially, there are no visible indication of human activities. Old-growth forests, on the other hand, are commonly indicated as late-successional forests, which contain structures and species which distinguishes them from forests of younger age classes, such as deadwood and old trees approaching their natural longevity, which is often much higher than the rotation cycle for a given tree species.

Primary forest are often composed of patches at different successional stages. Some can be late seral communities (mature) of high value, likewise young naturally regenerated patches are important components of primary forest landscapes (Swanson et al. 2011). Natural disturbance cycles, which are characteristic of primary forest, contribute to the expected distribution of stand ages and succession of seral stages in a primary forest mosaic. Therefore, the importance and value of early-successional stands of primary forest should be considered within the aims of protection of these forests.

The definitions used by a selection of international organisations are shown in **Fout! Verwijzingsbron niet gevonden.**. FAO (2018) uses the term "primary forest" in the reporting of the Forest Resource Assessment (FRA). According to FAO, in primary forests there is no known significant human intervention or the last significant human intervention was long enough as to have allowed the natural species composition, structures and processes re-established. The FAO definition agrees with FOREST EUROPE (2015). Nevertheless, Forest Europe uses the term "forest undisturbed by man". Also in this case it is assumed no known significant human intervention or the last significant human intervention was long enough as to allow natural species composition and processes.

The Carpathian convention (2014)[3] represented by seven European countries of which five are part of the EU, uses the term "virgin forests" with the purpose of defining criteria and indicators for its identification, mapping and strict protection. Their definition of virgin forests considers forests that have not been influenced directly by human activities in their development.

The UNESCO initiative on Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe[4] includes 12 European countries of which 10 are part of the EU. UNESCO uses the terms "primeval forest" and "ancient (beech) forests". In this case, primeval forests is considered synonymous with "virgin forests". In addition, they consider ancient (beech) forests synonymous with "old-growth (beech) forest". Since 2020, the UNESCO definition of primeval forests (Kirchmeir and Kovarovics 2016) matches that of virgin forests used in the Carpathian Convention.

The notion of old-growth forest may include both primary and secondary forests as long as the stands have developed for a long period without important anthropogenic disturbance. Old-growth forests

[3] http://www.carpathianconvention.org
[4] https://whc.unesco.org/en/list/1133

are characterised by functional, structural and compositional characteristics normally associated with old primary forests of the same type. This notion is adopted by the European Commission (2015) and the Convention on Biological Diversity (CBD)[5].

The consequence of the different terms and meanings used in international initiatives is the risk of misunderstandings (Buchwald 2005). In some cases, different terms are used to define the same subject, while in other cases the same term adopts different meanings.

Coping with this issue, that was documented some years ago, was the focus of the study of Buchwald (2005). He proposed a hierarchical terminology of primary forests for biodiversity conservation based on a gradient of forest naturalness levels. The terminology builds upon definitions used in international initiatives, i.e. UNCED, FAO, EU and the World Bank. Buchwald's terminology uses the following fundamental forest features for classifying forests into a naturalness gradient:

- Origin: natural forest // man-made forest
- Genesis: self-sown forest // planted forest
- Tree species origin: native forest // exotic forest
- Processes and structures: primary forest // secondary forest // forest plantation
- Continuity: untouched forest // land use changes (ancient woodland // recent woodland)
- Management: conservation management // forest managed for various objectives
- Forestry activities: minimum-intervention forest // mainly production forest

In practice, each of the features is a continuum though breaks can be present. Representing these features in a multidimensional space eases creating a hierarchical gradient of forest naturalness. Buchwald (2005) used this approach resulting in 14 mutually exclusive levels of forest naturalness (**Fout! Verwijzingsbron niet gevonden.**). In this approach, primary forests (including old-growth forests) are represented by the first six categories (n10 to n6). This framework however, includes old-growth forests under the umbrella term 'primary forests', without clearly specifying that old-growth forests might also originate from secondary forests. Note that the first three categories (n10 to n8) are not expected to be found inEurope, except possibly in Northern Fennoscandia and European Russia (Sabatini et al. 2020a; Sabatini et al. 2018). Annex 1 shows the definition of each naturalness level.

Sabatini et al. (2018) compiled the first pan-European map of primary forests using the approach of Buchwald (2005). They used data from multiple sources that was harmonised for the creation of a GIS database. The original database (v1) was improved and extended in the v2 in Sabatini et al. (2020a). Sabatini and co-workers adopted the FAO (2018) definition of primary forests, which includes all forests having a high degree of naturalness. Then, for harmonising the collected data they used the naturalness levels of Buchwald (2005) (forests in category n10 to n5). Thus, an equivalence was established between the definition adopted for the creation of each data set collected by Sabatini et al. and the naturalness levels of Buchwald (2005). This strategy facilitated the harmonisation of the collected data sets of primary forests that were include in the database

Organisation (referenc	**Term and definition**
FAO - Forest Resource Assessment (FAO 2018)	**Primary forest**: "Naturally regenerated forest of native tree species, where the no clearly visible indications of human activities and the ecological processes a significantly disturbed. Some key characteristics of primary forests are 1) They natural forest dynamics, such as natural tree species composition, occurrence of wood, natural age structure and natural regeneration processes; 2) The area is

[5] https://www.cbd.int/forest/definitions.shtml

	enough to maintain its natural ecological processes; and 3) There has been no k significant human intervention or the last significant human intervention was enough ago to have allowed the natural species composition and processes to become re-established.”
FOREST EUROPE (2015)	**<u>Forest undisturbed by man</u>**: “Forest (or other wooded land) which shows na forest dynamics, such as natural tree composition, occurrence of deadwood, na age structure and natural regeneration processes, the area of which is large er to maintain its natural characteristics and where there has been no known signi human intervention or where the last significant human intervention was enough ago to have allowed the natural species composition and processes to become re-established.”
Carpathian conve (2014)	**<u>Virgin forest</u>**: “natural forests which have not been influenced directly by h activities in their development and natural forest means forests composed o species indigenous to the area with most of the principal characteristics an elements of native ecosystems, such as complexity, structure and diversity.”
UNESCO Ancient and Primeval Beech Forests the Carpathians and Ot Regions of Europe (Kirchmeir and Kovarov 2016)	**<u>Primeval forest</u>** (comprises **virgin forests)**: - “**<u>Primeval or virgin forests</u>** means natural forests which have not been influe directly by human activities in their development and ‘natural forest’ means fo composed of tree species indigenous to the area with most of the prin characteristics and key elements of native ecosystems, such as compl structure and diversity.” - **“Ancient (beech) forest”**, considered synonymous with “**old-growth (b forest**”, describe “forest stands which have been directly influenced by h activities in the past, but the last significant impact is dated back several de (or even centuries). Throughout the period of missing impact (mainly abser logging), natural processes have taken place and structures similar to untou virgin forests have developed. For beech forests, this includes trees tha significantly older than the usual period of logging rotation (100–120 years deadwood amounts of over 20 m^3/ha are already in place.”
European Commission (2015)	**<u>Primary forest</u>**: Same as in FAO’s Forest Resource Assessment (see above). **<u>Old growth forest</u>**: “Old growth forest stands are stands in primary or seco forests that have developed the structures and species normally associated wi primary forest of that type.”
Convention on Biologic Diversity (CBD)	**<u>Primary forest</u>**: is a forest that has never been logged and has developed follo natural disturbances and under natural processes, regardless of its age. It is ref to "direct human disturbance" as the intentional clearing of forest by any m (including fire) to manage or alter them for human use. (…). In much of Eu primary forest has a different connotation and refers to an area of forest land w has probably been continuously wooded at least throughout historical times (e.g last thousand years). It has not been completely cleared or converted to anothe use for any period of time. However traditional human disturbances such as felling for shifting cultivation, coppicing, burning and also, more rec selective/partial logging may have occurred, as well as natural disturbances present cover is normally relatively close to the natural composition and has a (predominantly) through natural regeneration, but planted stands can also be fo However, the suggested definition above would include other forests, su secondary forests. **<u>Old growth forest</u>**: Are stands in primary or secondary forests that have deve the structures and species normally associated with old primary forest of that have sufficiently accumulated to act as a forest ecosystem distinct from any yo age class.

Annex 2 : Guidance on strict protection in primary and old-growth forests in the Commission Staff Working Document SWD(2022)23 on Criteria and guidance for protected areas designations

Strictly protected areas are fully and legally protected areas designated to conserve and/or restore the integrity of biodiversity-rich natural areas with their underlying ecological structure and supporting natural environmental processes. Natural processes are therefore left essentially undisturbed from human pressures and threats to the area's overall ecological structure and functioning, independently of whether those pressures and threats are located inside or outside the strictly protected area.

Strict protection is not an end in itself, but should be applied in areas hosting natural features which can thrive through natural processes, such as primary and old-growth forests, raised bogs or seagrass beds.

The condition that natural processes should be left essentially undisturbed by human pressures and threats means that <u>many strictly protected areas will be non-intervention areas</u>, where only limited and well-controlled activities that either do not interfere with natural processes or enhance them will be allowed. <u>Such activities may, in many cases, include scientific research, natural disaster prevention (e.g. wildfires), invasive alien species control, non-intrusive activities and installations, non-intrusive and strictly controlled recreational activities, when such activities are compatible with the conservation objectives of the areas on the basis of a case-by-case assessment.</u>

(…)

4.1.2. Primary and old-growth forests

In addition to the Biodiversity Strategy, the EU Forest Strategy includes measures to step up EU efforts to protect forest biodiversity, including the <u>mapping and the strict protection of all remaining primary and old growth forests.</u> The Commission is working in cooperation with Member States and stakeholders to agree, by the end of 2021, on a common definition for primary and old-growth forests and the strict protection regime. Member States should urgently engage in completing the mapping and monitoring of these forests, and ensuring no deterioration until they start to apply the protection regime.

According to the strategy, it will be crucial to define, map, monitor and strictly protect all the EU's remaining primary and old-growth forests, to ensure their conservation. Work towards a common definition of primary and old-growth forests is currently ongoing in the Working Group on Forests and Nature.

When that group has achieved its goal, all areas identified as primary and old-growth forests according to the agreed definition should be granted strict protection.

The estimated cover of primary and old-growth forests is only around 3% of EU forested land and patches are generally small and fragmented. Primary and old-growth forests are not only among the richest EU forest ecosystems, but they store significant carbon stocks and also remove carbon from the atmosphere, while being of paramount importance for biodiversity and the provision of critical ecosystem services.