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Mapping and assessment of primary and old-growth forests in Europe

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Contents

Abstract

This report presents an assessment of the knowledge and documented spatial data on primary and old-growth forests in the EU, as well as in some neighbouring countries. The EU's biodiversity strategy to 2030 recognises the value of primary and old-growth forests, and calls for their strict protection.

This report provides a knowledge base contributing to the process of developing guidelines for the definition, mapping, monitoring and strictly protecting all the EU's remaining primary and old-growth forests. This process is coordinated by the Working Group on Forest and Nature (sub-group of the Coordination Group on Biodiversity and Nature), which brings together representatives of the forestry and nature conservation national authorities and relevant stakeholders.

The following main conclusions are drawn:

- Primary and old-growth forests in the EU are rare, small and fragmented.
- These forests represent below 3% of the total forest extent of the EU.
- Despite the small extent, primary and old-growth forests are of paramount importance for biodiversity and provide critical ecosystem services.
- The protection of these forests represents a win-win solution for biodiversity conservation and climate change mitigation.
- About 90% of the reported primary and old-growth forests in the EU is located in Sweden, Bulgaria, Finland and Romania.
- The mapped area of primary and old-growth forests in the EU is ~1.35 million hectares, however there is a pronounced mapping deficit estimated at ~4.4 million hectares, which is a total area bigger than the size of the Netherlands.
- About 93% of the mapped primary and old-growth forests are part of the Natura 2000 Network, and 87% are strictly protected. However, these figures should be considered with caution due to the mapping deficit calculated in this study, and to the unclear legal framework on strict protection.

The analysis of the information and data gathered in this study concluded that strict protection of primary and old-growth forests is an urgent priority requiring robust and up-to-date spatially-explicit data, and an efficient monitoring system for safeguarding their integrity. This will be possible through a strong partnership with all the parties involved, including land owners, nature conservation organisations, local and regional authorities, and the local communities.

Primary forest in the National Park Kalkalpen, Austria. Photo: © Matthias Schickhofer, 2018.

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Executive summary

Background and context

Primary and old-growth forests are ecosystems where signs of past human use are minimal or absent and ecological processes operate dynamically and with little impairment by anthropogenic influences. In the EU these forests are rare, small and fragmented, however they are critical for biodiversity and ecosystem conservation. This is one of the aspects addressed in the EU's biodiversity strategy to 2030, which calls to strictly protect all remaining EU primary and old-growth forests. Why? Beyond their priceless existence value, and despite their small extent, these forests provide a wide array of enhanced ecosystem services. They play a key role for biodiversity conservation, carbon sequestration and storage, fresh water provision, regulation of local climate regimes, the maintenance of human health and are home for imperilled species. Therefore, the protection of these forests is an effective win-win strategy for biodiversity conservation and carbon dioxide removal and storage.

This report presents the results of the integrated narrative on primary and old-growth forests specified in the MAES ecosystem assessment[1]. The aim of this report is to contribute to the process of developing guidelines on the definition, mapping, monitoring and strictly protecting all the EU's remaining primary and old-growth forests. This process is coordinated by the Working Group on Forest and Nature (sub-group of the CGBN), which brings together national authorities representing the forestry and nature conservation sectors and relevant stakeholders. Firstly, by summarising used definitions of primary and old-growth forests. Secondly, collecting all available spatially explicit data on primary and old-growth forests in Europe and identifying data gaps. Thirdly, assessing the level of protection of primary and old-growth forests in the EU, and addressing key questions for their effective conservation such as the minimum size of forest reserves, and the importance of buffer zones and connectivity.

Results

The reported extent of primary and old-growth forests in the EU is 3.7 Mha or 2.4% of the total forest area. If we consider also primary and old-growth forests in other wooded land, the total area increases to 4.9 Mha or 2.7% of the total area of forest and other wooded land. In the EU the distribution of these forests is uneven, being 90% located in Sweden, Bulgaria, Finland and Romania. Despite existing efforts for mapping, we found a pronounced mapping deficit of primary and old-growth forests of around 90% of the 4.9 Mha (excluding Sweden the deficit would drop to 23%). Renewed efforts for a comprehensive mapping are therefore needed to support the aims of the EU's biodiversity strategy to 2030.

Using collected mapping data we calculated that 93% of the documented primary and old-growth forests in the EU fall within Natura 2000 sites, and 87% within strictly protected areas, i.e. IUCN categories Ia, Ib and II. However, if we exclude Finland, which represents most of the mapped primary and old-growth forests in the EU, these shares drops to 87% and only 57%, respectively. Considering the wide data gaps in mapping, however, these figures should be considered with caution.

Conclusions

European primary and old-growth forests are natural treasures that have been providing benefits to humans for centuries, and hold important cultural and historical values for local communities. Their rarity, values and uniqueness make them a keystone element of nature conservation. Their strict protection is an urgent priority requiring robust spatially explicit data, holistic landscape planning, an efficient monitoring system, and an increased awareness of their value for people and the planet. This will be possible through a strong partnership with all the parties involved, including land owners, nature conservation organisations, researchers, local and regional authorities, and local communities.

[1] https://publications.jrc.ec.europa.eu/repository/handle/JRC120383

1 Introduction

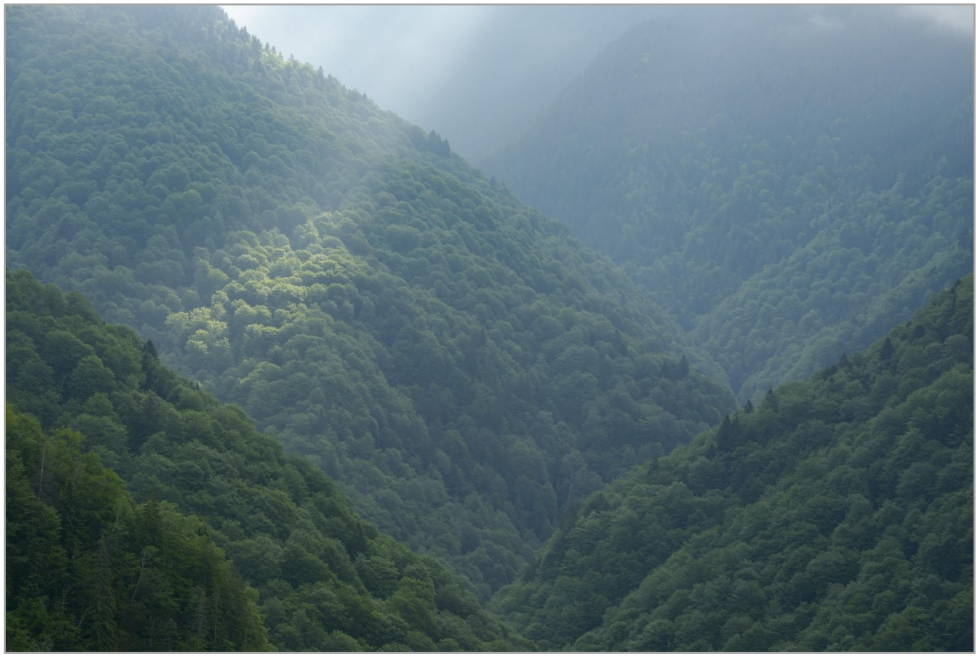
Primary and old-growth forests are ecosystems where signs of past human use are minimal or absent and ecological processes, such as natural disturbances, operate dynamically and with little impairment by anthropogenic influences. In Europe, forests have been modified since the mid-Holocene by clearing for cropland and pasture, or as a source of fuelwood and construction materials (Kaplan et al. 2009). 2009). At present, only a minor share of forests are primary or old-growth in Europe. Yet, even if rare, small and fragmented, these forests are critical for biodiversity, especially endangered and endemic species (Bas 2020; Eckelt et al. 2018). They also provide an exceptional array of ecosystem services, including high amounts of carbon stored in their living biomass, high amounts of deadwood and carbon-rich soils.

The new EU's biodiversity strategy to 2030 calls to strictly protect 10% of EU land and 10% of EU sea, including all remaining primary and old-growth forests. For reaching this aim it is key to define, map and monitor these forests. Retaining the integrity of European primary and old-growth forests is a priority for which reliable and updated information and data is essential.

This report presents the results of the integrated narrative on primary and old-growth forests specified in the MAES ecosystem assessment (Maes et al. 2020). The aim of the report is to contribute to an informed discussion in the frame of the Working Group on Forest and Nature (sub-group of the Co-ordination Group for Biodiversity and Nature – CGBN[2]) by providing an overview of key aspects related to these forests in the EU.

The objectives of this report are, i) to summarise commonly used definitions of primary and old-growth forests. This objective builds upon previous and on-going national and international initiatives. ii) To collect available spatially explicit data on primary and old-growth forests in Europe, with a focus in the EU territory. Several initiatives provide baseline georeferenced data for mapping primary and old-growth forests, however, remaining gaps need to be addressed for achieving a comprehensive mapping and monitoring system of these forests. iii) To assess the current level of protection of primary and old-growth forests in the EU, and provide baseline information on important topics for conservation such as the minimum size of forest reserves and the importance of buffer zones and connectivity. This assessment does not include forests in EU overseas territories.

Primary forest in the Boia Mica valley, Fagaras Mountains, Romania. Photo: © Matthias Schickhofer, 2018.



[2] https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=2210

2 What are primary and old-growth forests?

An operational definition of primary and old-growth forests is necessary for proper policy design, implementation and monitoring. With a view to implement the EU biodiversity strategy for 2030 the Working Group on Forest and Nature is working on defining, mapping, monitoring, and strictly protecting EU's primary and old-growth forests. In addition, FAO (2020b, 2021) is coordinating an expert consultation and a series of expert workshops to improve the operational methods for data collection and reporting on the extent of primary forests in the Global Forest Resources Assessment.

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, show no 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. These features include deadwood and old trees approaching their natural longevity, which is often much higher than the rotation cycle for a given tree species.

Primary forests are often composed of patches at different successional stages. Some can be late seral communities (mature, or old-growth) of high value, but young naturally regenerated patches can also be 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 in primary forest should be considered within the aims of protecting of these forests.

The definitions used by a selection of international organisations are shown in Table 1. 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 ago as to have allowed the re-establishment of natural species composition, structures and processes. The FAO definition conceptually matches with the term "forest undisturbed by man", as used in FOREST EUROPE (2015). 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" and defines a set of criteria and indicators for their identification, mapping and strict protection. Its definition of virgin forests broadly overlaps with the concepts of primary forest, because 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 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 different meanings and nuances attributed to forest-related terms in international initiatives is a source of misunderstandings (Buchwald 2005). In some cases, different terms are used to define the same subject, while in other cases the same term underlies different meanings.

[3] http://www.carpathianconvention.org
[4] https://whc.unesco.org/en/list/1133
[5] https://www.cbd.int/forest/definitions.shtml

Table 1. Notions of primary forest and old-growth forest used in international initiatives.

Organisation (reference)	**Term and definition**
FAO - Forest Resource Assessment (FAO 2018)	**Primary forest**: "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. Some key characteristics of primary forests are 1) They show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes; 2) The area is large enough to maintain its natural ecological processes; and 3) 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 processes to have become re-established."
FOREST EUROPE (2015)	**Forest undisturbed by man**: "Forest (or other wooded land) which shows natural forest dynamics, such as natural tree composition, occurrence of deadwood, natural age structure and natural regeneration processes, the area of which is large enough to maintain its natural characteristics and where there has been no known significant human intervention or where the last significant human intervention was long enough ago to have allowed the natural species composition and processes to have become re-established."
Carpathian Convention (2014)	**Virgin forest**: "natural forests which have not been influenced directly by human activities in their development and natural forest means forests composed of tree species indigenous to the area with most of the principal characteristics and key elements of native ecosystems, such as complexity, structure and diversity."
UNESCO Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe (Kirchmeir and Kovarovics 2016)	Primeval forest (comprises virgin forests): - "**Primeval or virgin forests** means natural forests which have not been influenced directly by human activities in their development and 'natural forest' means forests composed of tree species indigenous to the area with most of the principal characteristics and key elements of native ecosystems, such as complexity, structure and diversity." - **"Ancient (beech) forest"**, considered synonymous with "**old-growth (beech) forest**", describe "forest stands which have been directly influenced by human activities in the past, but the last significant impact is dated back several decades (or even centuries). Throughout the period of missing impact (mainly absence of logging), natural processes have taken place and structures similar to untouched virgin forests have developed. 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/ha are already in place."
European Commission (2015)	**Primary forest**: Same as in FAO's Forest Resource Assessment (see above). **Old-growth forest**: "Old-growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type."
Convention on Biological Diversity (CBD)	**Primary forest**: "is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age. It is referred to 'direct human disturbance' as the intentional clearing of forest by any means (including fire) to manage or alter them for human use. (…). 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. However, the suggested definition above would include other forests, such as secondary forests."
	Old-growth forest: "Are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class."

Buchwald (2005) tried to disentangle the conflict surrounding different forest-related definitions. 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)'s framework contains 14 mutually exclusive levels of forest naturalness (Table 2). In this framework, the term primary forest represents an umbrella term, which includes the first six categories (n10 to n5). Primary forests therefore also include old-growth forests (level n6), although the framework does not explicitly specify 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 in Europe, 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.

The definition framework of Buchwald (2005) was used by Sabatini et al. (2018) for compiling the first pan-European map of primary forests from multiple sources. Sabatini and co-workers adopted the FAO (2018) definition of primary forest, which includes all forests having a high degree of naturalness. They then used the naturalness levels of Buchwald (2005) (forests in category n10 to n5) for harmonising data from multiple sources, establishing an explicit equivalence between the definition adopted in each source and the naturalness levels of Buchwald (2005).

In summary, Sabatini and co-workers (2020a; 2018) made operational the FAO (2018) definition of primary forest using the definition approach of Buchwald (2005) for the integration and harmonisation of pan-European data sets. This clearly shows the challenge of bottom-up approaches. Although all EU Member States report to the FAO's Forest Resource Assessment, thus embracing the FAO definition of primary forest at national level, the criteria or indicators used to identify primary and old-growth forests on the ground vary widely. A careful harmonization of country-level definitions, criteria and indicators should be at the basis of any EU-level synthesis efforts on primary and old-growth forests.

Table 2. Levels of forest naturalness, processes and structures, and spatial scale according to Buchwald (2005).

Level of forest naturalness	Processes and structures	Spatial scale
n10 – Primeval forest	Primary	Landscape
n9 – Virgin forest	Primary	Forest
n8 – Frontier forest	Primary	Landscape
n7 – Near-virgin forest	Primary	Forest
n6 – Old-growth forest*	Primary	Stand
n5 – Long-untouched forest	Primary	Stand
n4 – Newly-untouched forest	Secondary	Stand
n3 – Specially managed forest	Secondary	Stand
n2 – Exploited natural forest	Secondary	Stand
n1 – Plantation-like natural forest	Secondary	Stand
p4 – Partly-natural planted forest	Plantation	Stand
p3 – Native plantation	Plantation	Stand
p2 – Exotic plantation	Plantation	Stand
p1 – Self-sown exotic forest	Plantation	Stand

* May include both primary and secondary forests.

3 The value of primary and old-growth forests

Without the effect of human intervention, Europe's landscape would be largely covered by primary forests (Kaplan et al. 2009). In contrast with other forested regions of the world, e.g. Brazil, Canada or the Russian Federation, that together host 61% of the 1.11 billion hectares of the world primary forests (FAO 2020a), the EU counts a very limited extent of these forests. They represent only below 3% of the 158 million hectares of forest area in the EU (FAO 2020a; FOREST EUROPE 2020; Sabatini et al. 2020a).

Europe is the continent with the more pronounced human footprint of the Earth. This has profound implications for the condition of ecosystems and biodiversity (Santos-Martín et al. 2019; Venter et al. 2016). In addition, forests in Europe have been modified since the mid-Holocene by clearing for cropland and pasture, and have been used through history as a source of fuelwood and construction materials (Kaplan et al. 2009). As a consequence, intact forest ecosystems dominated by natural processes are rare in the EU (Potapov et al. 2017).

Despite their small extent in Europe, primary and old-growth forests play a key role for biodiversity conservation. They are often highly biodiverse when compared with other forests in the same ecological region (Paillet et al. 2010). The long temporal continuity, coupled with natural dynamics of regeneration and disturbance processes, contributes at creating a high structural complexity in these forests (Franklin and Pelt 2004). This complexity translates into a high variety and number of forest microhabitats (Kozák et al. 2018). These include deadwood, tree cavities, fruiting bodies of saproxylic fungi and other epiphytic and epixylic structures, and provide habitat or shelter to a range of beetles, birds, bats and other taxa. Primary and old-growth forests are species-rich and host specialised flora and fauna (Eckelt et al. 2018; Paillet et al. 2018).

Primary and old-growth forests also provide a wide array of other critical ecosystem services. A few examples are carbon sequestration and storage, fresh water provision, regulation of hydrological cycles and local climate regimes, and the maintenance of human health (Luyssaert et al. 2008; Watson et al. 2018) . In fact, the complex structures in primary forests represent important stores of energy, water and nutrients and offer protected environments that moderate responses to temporal fluctuations of environmental conditions (Franklin and Pelt 2004). The structural complexity of primary and old-growth forests, for instance, has been shown to effectively buffer forest-floor summer temperatures (Frey et al. 2016), therefore mitigating the effects of climate change on sensitive forest species (Betts et al. 2018). Finally, these forests are an irreplaceable part of our natural heritage, and their priceless existence value is widely recognised (IUCN World Conservation Congress 2020)[6].

Primary and old-growth forests often store more carbon per hectare than other forests in similar conditions (Burrascano et al. 2013; Glatthorn et al. 2018). This storage provides a crucial climate service, since carbon would flux into the atmosphere were these forests cleared or degraded. Tree removal and disturbances trigger the release of large amounts of carbon to the atmosphere, thus breaking the virtual cycle of carbon accumulation and storage in primary and old-growth forests and their soils (Keith et al. 2009; Luyssaert et al. 2008). Harvesting operations might also have additional climate consequences, which go beyond the removal of woody biomass. In temperate and boreal forests between one half and two thirds of carbon resides in soils (Pan et al. 2011). This is the result of carbon accumulation over centuries or millennia (Zhou et al. 2006). Harvesting operations have been shown to negatively affect soil carbon retention, causing an 8% release of soil carbon to the atmosphere, with wide variation across soil and forest types, and geographical regions (Nave et al. 2010).

Besides the important storage function of primary and old-growth forests, new evidence also suggests that these forests might continue to accrue carbon later into successional development than previously assumed. This points to the potential of these forests for carbon sequestration, i.e., the active removal of carbon from the atmosphere (Keeton 2018). This goes against previous views suggesting that most forests cease to accumulate carbon soon after reaching maturity. Even if some controversy remains, net ecosystem productivity has often been shown to be positive in old-growth forests (Gough et al. 2016; Gundersen et al. 2021; Luyssaert et al. 2008; Luyssaert et al. 2021; Schulze et al. 2009; Stephenson et al. 2014), with carbon accumulating in different pools, including coarse woody debris and soils (Zhou et al. 2006). From this evidence it results that forest carbon continues to increase for centuries in primary and old-growth forest ecosystems, which implies that these forests should not be seen as carbon neutral, but rather as active carbon sinks.

Figure 1 shows enhanced ecosystem services associated with primary and old-growth forests in Europe. The figure builds upon Watson et al. (2018) that summarised the evidence on the value of primary forests. Primary forests are also important for setting restoration targets of degraded forests of the same type. Well conserved sites are key for research activities providing information on natural structures and processes, which can be

[6] https://www.iucncongress2020.org/motion/125

used to guide restoration of degraded forest ecosystems (Veen et al. 2010). For example, selection of native tree species, tree density, forest age distribution, forest gaps, amounts of dead wood, dead wood diversity, organic matter in soils, are key target parameters for restoration that can be assessed in primary forests.

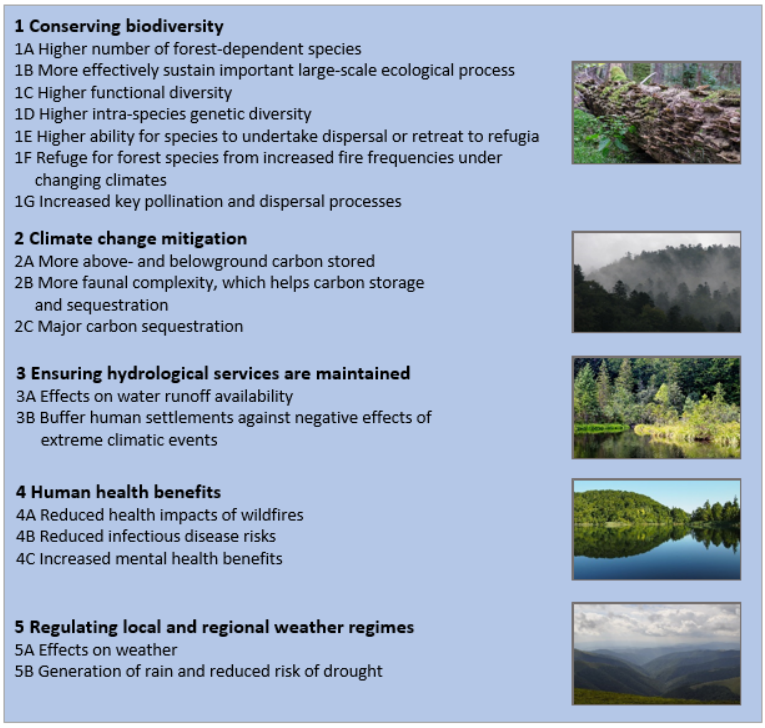


Figure 1. Key ecosystem services provided by primary and old-growth forests in relation to degraded forests in Europe. Own elaboration. Source of key ecosystem services: modified from Watson et al. (2018). Images from top to bottom by: Robert Pastryk (Bialowieza Forests, Poland), Eugen Visan (Carpathian forests), Dmitry Medved (Carpathian forests), Andreas H. (Plitvice Lakes National Park, Croatia) and Fishka1380 (Carpathian forests), all from Pixabay [https://pixabay.com].

In addition to the important role of primary and old-growth forests in the supply of ecosystem services, forests at the higher levels of naturalness are more resilient to external stressors than degraded ones (Thompson et al. 2009; Watson et al. 2018). Primary and old-growth forests are more resilient, stable, resistant and adaptive than modified forest or plantations (Alberto et al. 2013; Watson et al. 2013). However, resilience is influenced by the size of forests and by the condition of the surrounding areas. Therefore, a holistic approach towards protection of primary and old-growth forests and their buffer zones, supported by restoration in a well-connected surrounding landscape would represent a win-win pathway for biodiversity conservation and climate change mitigation, in addition to the full range of ecosystem services.

4 Primary and old-growth forests in Europe

The EU's biodiversity strategy to 2030 calls to define, map, monitor and strictly protect all the EU's remaining primary and old-growth forests. However, before addressing these aims it is necessary answering three key questions. First, what is the area covered by primary and old-growth forests? Second, where are these forests? Finally, what is the level of protection of these forests? In this section we review available information in an attempt to tackle these points.

4.1 Area of primary forest

We collected information on the area of primary forests from three sources:

1) Joint Forest Europe / UNECE / FAO Questionnaire on Pan-European Indicators for Sustainable Forest Management[7]. Results of the questionnaire are published in the State of Europe's Forests report (FOREST EUROPE 2020).

2) FAO's Global Forest Resources Assessment (FRA)[8] (FAO 2020a).

3) The European Primary Forest Database (EPFD v2.0) (Sabatini et al. 2020a).

According to these three sources, the inventoried area of primary forests in the EU represents around 2% to 3% of the total forest area. Which is equivalent to 3.2–4.9 Mha (Table 3). Country-level statistics from FAO and FOREST EUROPE (in forest and other wooded land) reveal that 90% of the primary forest in the EU is concentrated in only four countries, i.e. Sweden, Bulgaria, Finland and Romania. Note that the data reported by individual countries to FAO and FOREST EUROPE exclusively concern total extent of primary forest but not the geographical distribution of these forests.

Table 3 illustrates some discrepancies between the reported area of primary forests in the three sources. Discrepancies between FOREST EUROPE (2020) and the FRA (FAO 2020a) are minor because the reporting to these two organisations have been harmonised since 2013[9]. In fact, the information collected from these organisations in the reporting period 2020 is virtually the same. These two initiatives conduct a periodic survey for collecting data from the participating countries covering a number of forest parameters. Therefore, the data is provided directly by the countries. FAO (2020b) recognises that the reliability of data on primary forests is a cause of concern. This is because many countries base their estimates of the area of primary forests on proxies due to lack of observational or inventory data. Another aspect that should be considered concerns the different, or lack of, operational definitions of primary forests in place in the participating countries, which might influence the extent of primary forests that is reported. At the moment of drafting this report, FAO is implementing actions for improving the reporting on primary forests (see: FAO 2020b, 2021).

One major difference remains, however, the amount of primary forest in "other wooded land"[10] reported by FOREST EUROPE (2020), but not in FRA. It represents 1.2 Mha, which is around 31% of the total share of primary forests reported in "forest" by FOREST EUROPE (2020). Most of the primary forest in "other wooded land" was reported by Sweden (92%).

The third source is an independent assessment conducted by Sabatini and co-workers that produced a first map and GIS database (EPFD v2.0) of primary forests in Europe (Sabatini et al. 2020a). This study documented and mapped 3.17 Mha of primary forests in the EU (Table 3). For methodological reasons, however, this figure is not directly comparable to those reported in the FRA or in FOREST EUROPE (2020). This is because some of the largest polygons in the EPFD v2.0, mostly in Finland, Norway and Russia, represent large forest landscapes composed by a mosaic of land cover units including for instance lakes, wetlands and other non-treed land cover. Therefore, in these countries, the area of primary forest is most likely overestimated. This issue was addressed by Sabatini et al. (2018) concluding that the actual area of primary forest in Finland should be

[7] https://www.unece.org/forests/fpm/onlinedata.html
[8] http://www.fao.org/forest-resources-assessment/en/
[9] https://www.unece.org/forests/areas-of-work/forest-resources/methods-and-processes/pan-european-reporting-2015.html
[10] According to FOREST EUROPE (2015), 'forest' is "land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. 'Other wooded land' is "land not defined as forest, spanning more than 0.5 hectares; with trees higher than five meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use".

around 33%, or about 1 Mha, of the area represented in the polygons. Yet, this figure depends on the forest mask used in the calculation, and substantial uncertainties remain. Using this estimate, the total area of primary forest in the EU would be ~1.35 Mha, which would represent ~37% and ~28% of the primary forest area reported to FAO and Forest Europe (in forest and other wooded land), respectively, by EU countries.

A comparison of the information provided by countries to FOREST EUROPE and FAO, and the information documented in the EPFD v2.0 of Sabatini et al. (2020a) reveals considerable discrepancies. For example, the area of primary forests reported by Finland, 203,000 ha, is notably lower than the area documented in the EPFD v2.0, i.e. 2.8 Mha, even when considering the adjusted estimate of ~1 Mha mentioned above. In many other cases the discrepancy is in the contrary direction, i.e. more area reported by the countries to FOREST EUROPE and FAO than the area documented in the EPFD v2.0. These discrepancies vary strongly from country to country, but overall an important share of primary forests across the EU remains likely unmapped.

Sabatini et al. (2020a) identified some mapping limitations as incomplete (or lack of) inventories of primary forests, and inaccessible international scientific literature (e.g. language or digitalisation issues). The case of Sweden is illustrative, this country reported around 3.3 Mha of primary forests in "forest and other wooded land" in FOREST EUROPE (2020). However, in this country the EPFD v2.0 documented and mapped only 37,800 ha of primary forests due to several reasons discussed in Sabatini et al. (2020a) and Sabatini et al. (2018). Additionally, a formal definition of "primary forests" is not used in Sweden, as different terms are used.

Statistics of primary forests in a group of 14 non-EU countries are shown in Table 4. As in the case of the previous table, also in this case some discrepancies are present.

Table 3. Area of primary forests in EU countries. Forest area according to FOREST EUROPE (2020).

Country	Forest area 2020 [1,000 ha]	Forest undisturbed by man (Forest Europe, 2020)			Primary forests (FAO, 2020) [1,000 ha]	Primary forests (Sabatini et al. 2020a) [1,000 ha]
		In forest [1,000 ha]	In other wooded land [1,000 ha]	In forest and other wooded land [1,000 ha]		
Austria	3,881	63	55	118	63	15.2
Belgium	689	0	0	0	0	0.3
Bulgaria	3,833	704	0	704	704	56.9
Croatia	1,922	7	0	7	7	9.6
Cyprus	173	13[a]	ND	13	ND	0.0
Czech Republic	2,668	10	ND	10	10	12.8
Denmark	625	21	3	24	21	1.7
Estonia	2,421	52	2	55	52	0
Finland	22,409	203	11	214	203	2,814.6[c]
France	16,836	30[a]	0	30	ND	12.3
Germany	11,419	0	0	0	0	14.3
Greece	3,903	ND	ND	ND	ND	1.9
Hungary	2,061	0	ND	0	0	0.3
Ireland	755	ND	ND	ND	0	0.0
Italy	9,297	93	0	93	93	8.7
Latvia	3,391	17	0	17	17	4.8
Lithuania	2,187	27	0	27	27	32.0
Luxembourg	89	0	ND	ND	0	0.0
Malta	0	0	0	0	0	0.0
Netherlands	365	0	0	0	0	0.1
Poland	9,420	0	ND	0	0	22.4
Portugal	3,312	24[a]	ND	24	24[a]	16.4
Romania	6,901	165	0	165	165	70.0
Slovakia	1,922	11	0	11	11	13.1
Slovenia	1,248	34	17	50	34	9.5
Spain	18,551	ND	ND	ND	ND	10.3
Sweden	27,980	2,249	1,075	3,324	2,249	37.8[e]
Total EU	**158,258**	**3,723**	**1,163**	**4,886**	**3,679**	**3,165[d]**
% of forest	**100**	**2.35**	**-**	**2.71[b]**	**2.32**	**2.0**

([a]) 2015.
([b]) As percentage of the area of forest and other wooded land.
([c]) Note that this area is most likely overestimated. A more accurate extent would be ~1 Mha.
([d]) As consequence of the issue in note c, this area is most likely overestimated. A more accurate extent would be ~1.35 Mha (~0.9% of forest in the EU).
([e]) Note that Sabatini et al. (2020a) indicate the existence of 2.4 Mha of potential (unconfirmed) primary forests in Sweden. Therefore, the number in the table is likely underestimated.
ND: No data.

Table 4. Area of primary forests in a group of 14 non-EU countries. Forest area according to FOREST EUROPE (2020).

		Forest undisturbed by man (Forest Europe, 2020)				
Country	**Forest area 2020 [1,000 ha]**	**In forest [1,000 ha]**	**In other wooded land [1,000 ha]**	**In forest and other wooded land [1,000 ha]**	**Primary forests (FAO, 2020) [1,000 ha]**	**Primary forests (Sabatini et al. 2020a) [1,000 ha]**
Albania	785	62[a]	0	62	85	14.0
Belarus	8,634	135	0	135	135	189.0
Bosnia Herzegovina	2,161	ND	ND	3	ND	3.4
Iceland	48	0	0	0	0	ND
Liechtenstein	7	2	ND	2	2	ND
Moldova	386	ND	ND	ND	ND	0.0
Montenegro	827	91	ND	91	2	3.6
North Macedonia	994	ND	ND	ND	ND	0.8
Norway	12,141	200	ND	200	200	277.5[c]
Serbia	2,720	ND	ND	ND	1	1.0
Switzerland	1,252	43	9	52	43	23.1
Turkey	21,630	ND	ND	ND	0	ND
Ukraine	9,657	59	0	59	59	107.9
United Kingdom	3,190	0	0	0	0	0.1
Total	**64,431**	**592**	**9**	**604**	**526**	**620 [c]**
Percentage of forest	**100**	**0.9**	**-**	**0.9[b]**	**0.8**	**1.0**

([a]) 2015.
([b]) As percentage of the area of forest and other wooded land.
([c]) Note that this area is most likely overestimated.
ND: No data.

4.2 Mapping primary forests

Several initiatives have been implemented in Europe for mapping primary and old-growth forests. Nevertheless, most georeferenced data sets (maps) only cover specific regions. Country-level systematic inventories are rare, and information remains overall fragmented. Furthermore, there is an overall lack of harmonisation on definitions across data sets. These have often different scales, baseline data, definitions, data types, temporal dimension, etc. This situation creates several challenges for producing a pan-European data set. Despite these constraints, two initiatives have produced harmonised pan-European data sets. First, the EPFD v2.0 of Sabatini et al. (2020a), second, the UNESCO Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe (Kirchmeir and Kovarovics 2016).

Sabatini et al. (2020a) collected and harmonised 51 different data sets of primary forests in the EPFD v2.0, including a literature review of scientific papers published in English between 2000 and 2018 on all primary, virgin and old-growth forests in Europe. As a result, they created a GIS database containing 16,897 polygon patches and 299 point features covering 41.2 Mha in 35 countries including Russia (Figure 2). Note that 37.4 Mha were mapped in European Russia alone. These figures should be seen as upper boundaries, though, since some of these polygons represent large forest landscapes, which also include non-forest land cover (see previous section). This database is the most complete collection of geo-referenced data on primary forests in Europe currently available. The database is disseminated almost entirely as Open Access. Only four out of the 51 data sets that compose the database are confidential and are therefore not disseminated within the EPFD v2.0. This is because the copyright holders of these data did not provide consent for Open Access dissemination.

Despite the key relevance of the EPFD v2.0 regarding mapping of primary forests in Europe, some data gaps are recognised by the authors. For instance, Table 3 and Table 4 show that the primary forest area mapped in the EPFD v2.0 is in some cases below the area reported by countries. Within the EU this issue is remarkable in Sweden, Italy, Bulgaria, Estonia and Denmark, but also for example in Romania. Nevertheless, the area reported by countries is subject to different interpretations and data sources. In addition, data quality varies widely across countries. Therefore, the comparison should be considered with caution.

The UNESCO's Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe[11] includes 12 countries of which 10 are part of the EU. The countries participating in this initiative are Albania, Austria, Belgium, Bulgaria, Croatia, Germany, Italy, Romania, Slovakia, Slovenia, Spain and Ukraine. These countries have proposed 79 forest zones as contribution to this initiative, totaling around 90,000 ha (excluding buffer zones). Most European beech (*Fagus sylvatica str.*) forest regions in Europe are represented with at least one component part, therefore the whole range of the European beech forests were unified in one World Heritage Site (Kirchmeir and Kovarovics 2016). Note that the data set derived from the UNESCO initiative is included in the EPFD v2.0 of Sabatini et al. (2020a).

In addition to the two pan-European initiatives described above, Table 5 shows a list of initiatives that have produced large data sets of primary forests in EU Member States. Note that these initiatives used different mapping approaches and scopes. Some, but not all, of the datasets listed in Table 5 are also integrated in the EPFD v2.0 and were used to derive the area estimates reported above. For example, the last three data sets in the table were not included in the EPFD v2.0 because represent potential primary forest, that is, not verified in the field. A comprehensive list of 51 data sets composing the EPFD v2.0 is available in Sabatini et al. (2020a).

The mapping initiatives mentioned in this section are a valuable contribution to the knowledge base on primary and old-growth forests in the EU. They are the result of efforts of scientists, NGOs, land owners and authorities. However, once a common definition is agreed at EU level in response to the EU's biodiversity strategy for 2030, a review of available mapping resources would be necessary. The mapping of primary and old-growth forests on the basis of a common definition will have to be coordinated at national level by the relevant authorities and in close collaboration with forest owners and NGOs. The data sets mentioned above can contribute to national level assessments, where deemed necessary.

[11] http://whc.unesco.org/en/list/1133/

Figure 2. Documented primary and old-growth forests in Europe according to the European Primary Forest Database (EPFD v2.0) of Sabatini et al. (2020a) and UNESCO's Primeval Beech Forests of the Carpathians and Other Regions of Europe (UNEP-WCMC 2021). Note that the boundary of the polygons was highlighted for better readability.

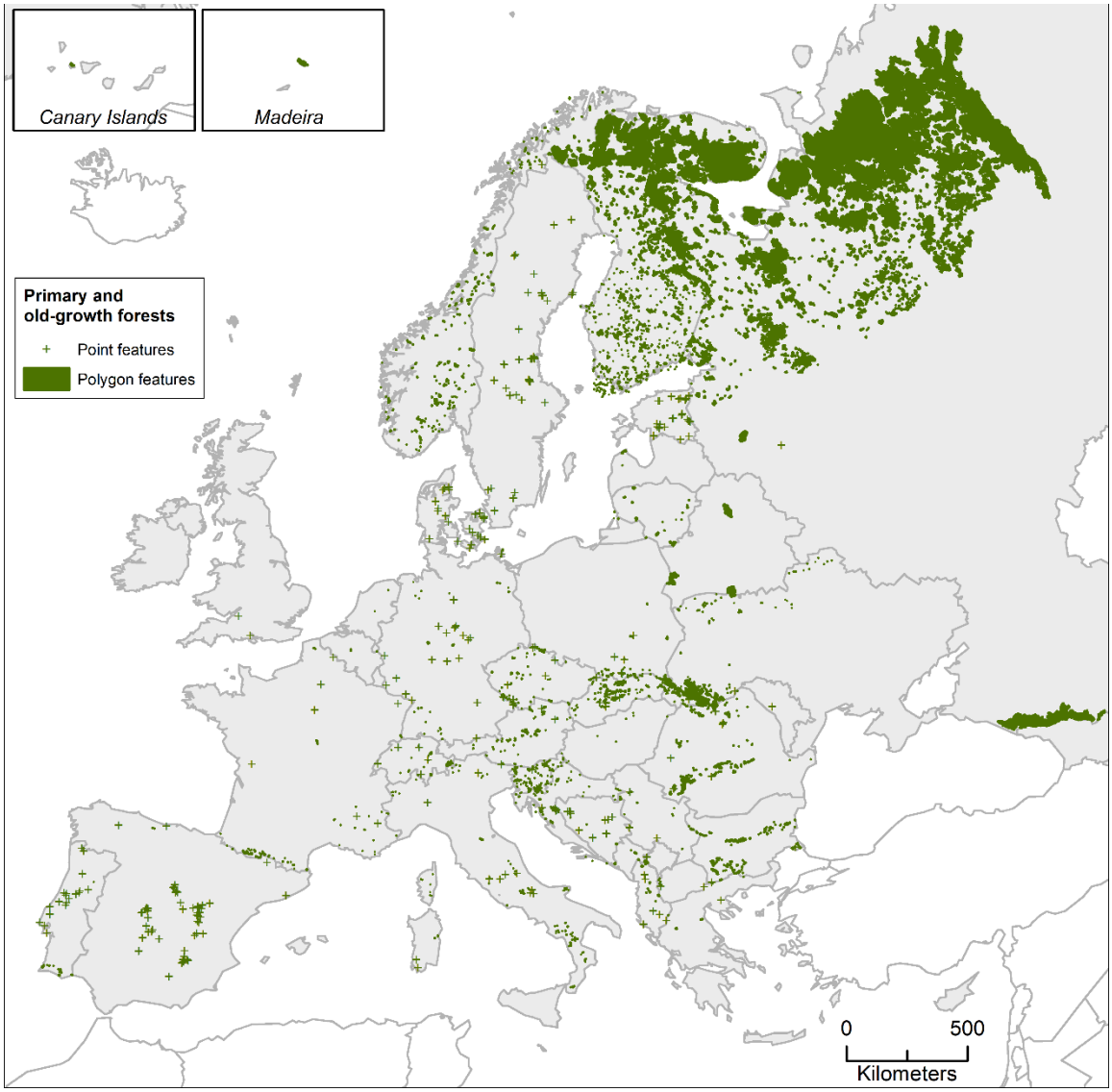


Table 5. National and regional initiatives producing large data sets of documented and potential primary and old-growth forests in the EU.

WWF - Old-growth forests in Bulgaria - WWF created a data set of old-growth forests in the Balkan range and Rhodopes Mountain, Bulgaria. This was implemented in the framework of the project "Mapping of old-growth forests in Bulgaria", that mapped around 52,000 ha of old-growth forests. - https://www.wwf.mg/en/governance/?uNewsID=363462 - https://wwf.panda.org/?215230/An-online-platform-maps-the-old-growth- - https://gis.wwf.bg/mobilz/en/#
Ministry of Water and Forests, Romania - Romanian National Catalogue of Virgin and Quasi-Virgin Forests - By November 2020, the National Catalogue accounted for 43,823 ha of virgin and quasi-virgin forests. - http://www.mmediu.ro/articol/editia-august-2020-a-catalogului-padurilor-virgine-si-cvasivirgine-din-romania/3774
WWF – Primary forests in Romania - Since 2013 WWF has been working in the identification of primary forest in Romania. Over 9,000 ha of the identified forests have been included in the Romanian National Catalogue of Virgin and Quasi-Virgin Forests. WWF created the data set using orthophotos and field measurements. In addition, they used

previous information collected by the Pin Matra project (Biriş and Veen 2005) which was updated and verified. The data set covers around 47,000 ha of primary forests in Romania.
- https://lemncontrolat.ro/interactive-maps/map-of-protected-natural-areas-in-romania/
- https://wwf.panda.org/?323870/More-virgin-forests-protected-in-Romania
- https://www.wwf.mg/oceans_footer/?uNewsID=335430
- https://old.wwf.ro/ce_facem/paduri/pduri_virgine/

WWF – Unprotected state forest areas with considerable natural values in Finland
- Data set mapping unprotected state forest areas with high considerable natural value, including natural and semi-natural forests in Finland. The data set covers around 71,000 ha of primary forests.
- https://wwf.fi/alueet/suomen-metsat/kansallisomaisuus-turvaan/
- https://wwf.fi/app/uploads/x/j/l/goiuw7bawnammlg3xqmvsse/metso-suojeluesitys2012_valmis_lowres.pdf

SYKE - Finnish Old-Growth Forests
- Data set delineating old-growth forests based on nature conservation areas, wilderness areas and old-growth forests sites not included in the legal protection area network of Finland. The data set covers around 2.7 Mha of old-growth forests.

Institute of Forest Management and Wood Science, Aleksandras Stulginskis University – Data set of long untouched forests in Lithuania
- Data set describing the location and key attributes of some 32,000 ha of natural forests in Lithuania (Sabatini et al. 2020a).

PRALES database, Slovakia
- Database resulting from a comprehensive inventory of primary forests in Slovakia. The database includes 10,583 ha of primary forests (Mikoláš et al. 2019).

http://en.pralesy.sk

Czech natural forests databank
- This data set contains up-to-date available information on primary forest in Czech Republic. About 30,000 ha of primary and old-growth forests were identified (Adam and Vrška 2009).
- http://naturalforests.cz/czech-natural-forests-databank

Old-growth forests in 23 Italian National Parks
- The data set is owned by the Ministry for the Environment, Land and Sea Protection and by the Interuniversity Research Center "Biodiversity, Plant Sociology and Landscape Ecology", Sapienza University of Rome (Blasi et al. 2010).

Greenpeace - Potential Primary Forests Map of Romania
- The map (data set) is an estimation of the location and extent of potential (i.e. unconfirmed) primary forests in Romania. It was created using remote sensing and GIS techniques. The map represents 296,000 ha of potential primary forests in Romania.
- https://maps.greenpeace.org/project/potential-primary-forests-map-of-romania/
- https://www.greenpeace.org/romania/raport/1235/harta-padurilor-virgine-potentiale-si-studiul-situatia-padurilor-virgine-din-romania/
- https://storage.googleapis.com/planet4-romania-stateless/2019/07/f16ecbe6-f16ecbe6-potential_primary_forests_map_of_romania_low_res.pdf

PRIMOFARO - Inventory of Potential Primary and Old-Growth Forest Areas in Romania
- This data set was compiled by visual analyses of satellite and aerial images, in addition, existing inventories of primary forest were assessed for mapping intact remains. The final dataset identifies about 525,000 ha of potential primary and old-growth forests in Romania.
- https://www.saveparadiseforests.eu/en/a-snapshot-of-forests-with-great-potential/
- https://www.saveparadiseforests.eu/wp-content/uploads/2019/10/PRIMOFARO_24092019_layouted.pdf

Sabatini et al. (2020a) – Map of potential primary forests in Sweden
- Sabatini et al. (2020a) created a map of potential (unconfirmed) primary forests using maps describing several forests traits. They produced 14,300 polygons covering about of 2.4 Mha of potential primary forests. This dataset is available within the EPFD v2.0. Being unconfirmed, however, it was not used to derive the area estimates reported above.
- https://www.biorxiv.org/content/10.1101/2020.10.30.362434v1

4.3 Protection status of primary forests

We calculated the area of primary and old-growth forests documented in the EPFD v2.0 (Sabatini et al. 2020a) falling within Natura 2000 sites (version Natura 2000 End 2019) (EEA 2020) and within the protected areas in the IUCN data base (UNEP-WCMC 2019)[12,13]. Before considering the figures presented in this section, the reader should keep in mind the limitations of the EPFD v2.0 highlighted in the previous two sections, and the fact that not all polygons in the IUCN database of protected areas contain complete information on the level of protection. The EPFD v2.0 includes both polygon and point features representing primary and old-growth forests. Polygons are the more substantial part of the database, representing 16,897 non overlapping patches, while point features are 299. Some point features contain information on forest extent, other, for which the area is more uncertain, are classified in ranges (i.e. 0-10 ha, 10-100 ha, 100-1000 ha and > 1000 ha). We used the upper range of the points for computing the area of primary forest, i.e. 10 ha, 100 ha, 1000 ha and 2000 ha. All point features were represented as circles of proportional size for the analysis. Points with no extent information were excluded.

A large proportion of the documented primary and old-growth forests in the EU fall in Natura 2000 sites (Table 6). In most EU countries the share is above 75%. At EU level the share is 93% of the documented 3.2 Mha of primary forest. Therefore, in the EU the primary forest area not included in Natura 2000 sites is estimated at 206,000 ha. It must be noted, however, that not all management plans of Natura 2000 sites might recognise the explicit value of primary and old-growth forests, and that protected forest conservation measures might not completely exclude some forest harvesting (European Commission 2015), which might be incompatible with the long-term conservation of primary and old-growth forests (Thorn et al. 2018; Thorn et al. 2020).

The country with the lowest share of primary forests in Natura 2000 sites is Sweden (37%), but this figure is most likely affected by major mapping data gaps in the EPFD v2.0. Furthermore, most documented primary forest in Sweden are represented by point features, rather than polygons, in the EPFD v2.0. This increases the uncertainty when estimating the fraction of primary forests currently under protection in this country.

Within the scope of this report, we considered strictly protected areas the categories Ia, Ib and II of the IUCN typology of protected areas[14]. This choice is in line with the pan-European analysis reported in Sabatini et al. (2020b) but it does not necessarily reflect an official position of the European Commission. However, a certain degree of timber harvesting, as well as salvage logging, is allowed in most national parks in Europe, at least outside core areas. While we note that this might conflict with the long-term conservation goals for primary and old-growth forests (Thorn et al. 2018; Thorn et al. 2020), we acknowledge that at the moment of drafting this report discussions are on-going regarding strict protection of primary and old-growth forests in the EU.

Our assessment indicates that the share of documented primary and old-growth forests in strictly protected areas is 87% in the EU (categories Ia, Ib and II in Table 6). However, if we exclude Finland, which represents most of the documented primary forest in the EU, the share drops to only 57%. Nevertheless, note that this figure could change if better mapping data becomes available for Sweden. This is because there is a large amount of primary forest in this country, i.e., potentially 2.4 Mha according to Sabatini et al. (2020a), 2.2 Mha according to FAO (2020a) and approximately 3.3 Mha (in forest in forest and other wooded land together) according to FOREST EUROPE (2020) (Table 3).

The estimates in Table 6, however, might also suffer from limitations in the IUCN database of protected areas. This is, for instance, the case of Croatia, for which Table 6 reports zero share of primary forest in strictly protected areas. As a matter of fact, almost the totality of the polygons of protected areas in Croatia are not attributed to any protection category in the IUCN database of protected areas, but rather remain either not assigned or not reported.

Statistics on primary and old-growth forests in protected areas for a group of 14 non-EU countries is shown in Table 7. In this case the share of strictly protected primary forests is 35%, out of a total of 620,000 ha.

A discussion on the role and effect of strict protection on primary and old-growth forests is beyond the scope of this report. However, results of Heino et al. (2015) indicate that only in the period 2000-2012 about 100,000 ha of forest were disturbed in strict protected areas in the EU. To what extent these disturbance events relate to direct human impact (e.g. legal or illegal logging, silvicultural activities) or natural causes (e.g. wildfires, diseases, pests and wind storms) remains unclear. Natural disturbances are not a threat to the primary status of a forest, being part of its natural dynamics. Nevertheless, an increasing high fraction of forest has undergone

[12] https://www.iucn.org/theme/protected-areas/about/protected-area-categories
[13] Accessed on: 12-11-2020
[14] https://www.iucn.org/theme/protected-areas/about/protected-area-categories

wood removal in recent years in Europe (Ceccherini et al. 2020; Senf et al. 2018), even inside protected areas (Mikoláš et al. 2019). This suggests that the role of strictly protected areas should be monitored and enforced to be fully effective.

Table 6. Area of primary and old-growth forests in EU countries according to the European Primary Forest Database (EPFD v2.0) of Sabatini et al. (2020a) and percentage falling in Natura 2000 sites (EEA 2020) and in IUCN protected areas (UNEP-WCMC 2019).

Country	Primary forests (Sabatini et al., 2020) (1,000 ha)	Natura 2000 (%)	IUCN category (%)						
			Ia	Ib	II	III	IV	V	VI
Austria	15.2	78	0	13	38	0	27	14	0
Belgium	0.3	100	0	0	0	0	69	0	8
Bulgaria	56.9	99	75	0	3	1	1	4	2
Croatia	9.6	99	0	0	0	0	0	0	0
Cyprus	0	-	-	-	-	-	-	-	-
Czech Republic	12.8	82	10	6	10	3	24	46	0
Denmark	1.7	75	6	0	26	0	30	1	0
Estonia	0	-	-	-	-	-	-	-	-
Finland	2,814.6	94	6	69	16	0	2	0	0
France	12.3	85	16	0	4	0	45	8	0
Germany	14.3	82	0	0	43	0	24	10	0
Greece	1.9	99	39	0	44	12	5	0	0
Hungary	0.3	100	0	0	49	0	18	22	0
Ireland	0	-	-	-	-	-	-	-	-
Italy	8.7	93	22	0	71	0	2	1	0
Latvia	4.8	100	0	2	98	0	0	0	0
Lithuania	32.0	99	77	0	12	0	0	11	0
Luxembourg	0	-	-	-	-	-	-	-	-
Malta	0	-	-	-	-	-	-	-	-
Netherlands	0.1	97	0	0	0	0	100	0	0
Poland	22.4	100	1	0	85	0	11	2	0
Portugal	16.4	77	13	13	1	1	0	7	53
Romania	70.0	92	2	0	48	0	7	5	0
Slovakia	13.1	97	45	8	3	0	1	36	0
Slovenia	9.5	96	0	29	8	2	0	7	0
Spain	10.3	90	35	2	48	1	1	1	0
Sweden	37.8	37	2	31	3	0	2	0	0
Total	**3,165**	**93[a]**	**8**	**62**	**17**	**0**	**2**	**1**	**0**

([a]) 87% excluding Finland.

Table 7. Area of primary and old-growth forests in a group of 14 non-EU countries according to the European Primary Forest Database (EPFD v2.0) of Sabatini et al. (2020a) and percentage falling in IUCN protected areas (UNEP-WCMC 2019).

		IUCN category (%)						
Country	**Primary forests (Sabatini et al., 2020) (1,000 ha)**	**Ia**	**Ib**	**II**	**III**	**IV**	**V**	**VI**
Albania	14.0	37	0	23	0	0	4	0
Belarus	189.0	31	0	18	0	0	0	0
Bosnia Herzegovina	3.4	3	0	45	3	0	0	0
Iceland	ND	-	-	-	-	-	-	-
Liechtenstein	ND	-	-	-	-	-	-	-
Moldova	0	0	0	0	0	0	0	0
Montenegro	3.6	0	0	74	0	0	0	0
North Macedonia	0.8	0	0	99	0	0	0	0
Norway	277.5	16	0	6	0	1	0	0
Serbia	1.0	3	4	11	0	31	22	0
Switzerland	23.1	74	0	0	0	3	0	0
Turkey	ND	-	-	-	-	-	-	-
Ukraine	107.9	22	0	7	0	8	1	0
United Kingdom	0.1	0	0	0	0	66	0	0
Total	**620**	**24**	**0**	**11**	**0**	**2**	**0**	**0**

5 Landscape management, buffer zones and minimum size of primary and old-growth forests

Ideally, conservation of primary and old-growth forests should rely on a functionally connected network of strict forest reserves, aimed at integrating all small and isolated primary and old-growth forest patches, with adequately managed buffer zones and corridors. For instance, large (e.g. 10,000 ha or larger) non-intervention landscapes (e.g. valley systems), might be adequate to ensure that natural disturbance and recovery dynamics operate unimpaired by human influence. Delineating buffer zones of an adequate size is therefore essential for the conservation of isolated and small stands of primary and old-growth forests (Veen et al. 2010). Functions of the buffer zones are:

- Protection of the integrity of primary forest stands and protected areas.
- Maximise connectivity between stands of primary forest which are part of a cluster and between forest stands located at a reasonable distance from each other.
- Integrate primary forest stands with landscape scale conservation measures.

An example application in the designation of buffer zones around primary beech forests derives from the UNESCO initiative on Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe (Kirchmeir and Kovarovics 2016; Kirchmeir et al. 2020). The UNESCO initiative has identified 79 sites (component parts) of primary beech forests disseminated across 12 European countries. The (core) sites account for a total area of around 90,000 ha. The size of the sites varies notably from a minimum of 58 ha in Monte Cimino, Italy, to more than 10,000 ha. All sites are associated to a buffer zone of variable size. The delineation and setting up of buffer zones around beech primary forest sites is an important landscape measure for their protection, as long as the provisions regulating forest management in the core (property) and buffer zones are oriented to nature protection and conservation.

While in some cases the buffer zone is close to the size of the core site, in most cases the buffer zone is larger, sometimes even by a factor of 10. In general, the smaller is the core area of a primary forest, in a UNESCO site, the larger is the proportion of buffer zone with respect to the core area. In addition, many small core sites have been grouped in clusters inside one single buffer zone. This reinforces conservation of the smaller sites and facilitates connectivity between them. The total area of the buffer zones alone of the 79 UNESCO sites is 254,000 ha, which gives a ratio of 1 to 2.8 between core sites and buffer zones. Figure 3 shows the distribution of the size of core sites in relation to the size of the buffer zones. In 63% of the cases the area of the buffer zone is larger than that of the core site. Note that core sites falling inside the same buffer zone (clusters) are counted once in this calculation and in Figure 3.

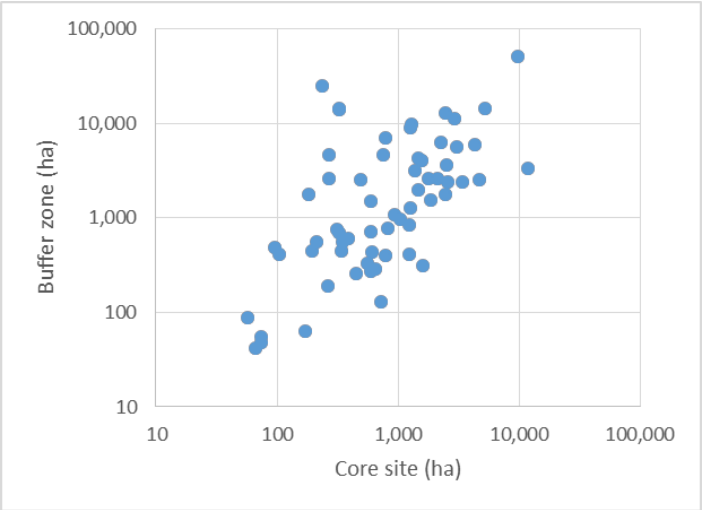


Figure 3. Size of core sites and buffer zones of the 79 sites of the UNESCO initiative on Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe. Note logarithmic scale in both axis for better readability. Source of data: https://whc.unesco.org/en/list/1133/multiple=1&unique_number=2152.

According to Kirchmeir and Kovarovics (2016) the minimum width of buffer zones in UNESCO beech primary forest sites is 50 m. However, this should be considered as a lower bound because in most cases buffer zones are wider; in addition, the minimum width was extended to 100 m in the on-going extension process of this World Heritage Site. The average width of buffer zones in the UNESCO primary beech forests sites is about 1,500 m around the core sites.

Some changes have been implemented recently in the buffer zone management of the UNESCO serial property. The buffer zone has been split in two sub-zones with different functionality and management regimes. The first sub-zone, directly surrounding the core site (property), is designed to protect the core site from negative external micro-climatic effects. This sub-zone has almost the same strict protection regime as the core site. The second sub-zone ensures the preservation of forests for providing a positive cooling effect on the mesoclimate, and to preserve the forest-landscape matrix around the core site.

With some exceptions, most primary and old-growth forests mapped in the EU countries are relatively small. For example, inventories in Romania (Biriş and Veen 2005) and Bulgaria (Veen and Raev 2006) adopted a minimum area criterion of 50 ha. Romania adopted national legislation on virgin and quasi-virgin forests in 2012, and the minimum area for designating virgin forest is 20 ha, 30 ha for quasi-virgin forests, and in some exceptional cases (unique ecosystem type for Romania) it can be as small as 10 ha. At European level the median size of primary forest stands is below 50 ha. In fact, information provided by the first version of the EPFD of Sabatini et al. (2018) indicates that the median size was only 24 ha and only 4.3% of the stands were larger than 1,000 ha. It is remarkable that the minimum mapping unit of the EPFD v2.0 is 0.5 ha (Sabatini et al. 2020a).

A question that emerges is what should be the minimum reserve size to ensure that primary and old-growth forests stands are protected effectively. This should include considerations on minimum dynamic areas and extinction debt. Minimum dynamic areas are defined as “the smallest area with a natural disturbance regime which maintains internal recolonisation sources and hence minimises extinctions” (Pickett and Thompson 1978). Reserves larger than the minimum dynamic areas would ensure the occurrence of all developmental phases of forest habitats, and the shifting mosaic of dynamics between them, while effectively protecting the biota of the sites. They would also minimize extinction debt, i.e. time delayed biodiversity loss after habitat loss or fragmentation (Berglund and Jonsson 2005).

The size of an individual stand in beech forests is often between 20 and 25 ha. There is a large variability, though, as it can be as small as 5-10 ha (Mikoláš et al. 2019; Peck et al. 2015) or may reach an extent of 50 ha (Vandekerkhove 2017). While these small sizes might be sufficient to allow the occurrence of small-scale gap dynamics and disturbances in beech forests, recent evidence suggests that fine-scale disturbance is not the only agent in these forests. Larger, higher-severity disturbance events might also occur, although infrequently (Frankovič et al. 2021). This bears similarities to boreal forests, which are characterised by a combination of small-scale and stand-replacing disturbance (Kuuluvainen and Aakala 2011).

Protecting individual stands, therefore, might not capture the whole variability of forest stands occurring in the landscape, nor will it ensure that the disturbance dynamics can operate freely. Rather, only large core zones might ensure that this variability is represented and protected. Large reserves are also crucial to maintain viable populations of old-growth specialist species in the landscape against extinction debt (Berglund and Jonsson 2005). A landscape approach is therefore recommended to ensure that small primary and old-growth forests are surrounded by large non-intervention, and\or buffer zones, and are sufficiently connected to each other. Such a landscape perspective is important both in intensively used, fragmented landscapes, and in intact forest landscapes.

A practical application of the minimum dynamic area concept is reported in Mikoláš et al. (2019), where they compare two alternative approaches to primary forest conservation in Slovakia (Figure 4). In the first case, a large reserve was established in the Ticha and Koprova valleys, where fragmented primary forests (363 ha) were connected into a 9,188 ha forest complex which was left for natural development. In the second case, only fragmented patches (tens of ha) were protected in Low Tatra mountains without embedding these fragments within a larger non-intervention zone. After a severe natural disturbance (windstorm and bark beetle outbreak) large-scale harvesting motivated by salvage logging was conducted in the buffer zones surrounding the old-growth forest fragments in Low Tatra mountains, which remained isolated. The fragments within the large Ticha and Koprova forest complex remained, instead, connected even if equally hit.

Windstorms and insect outbreaks might increase the naturalness of a formerly managed forest. The positive effects of natural disturbance, however, might be nullified if extensive post-disturbance salvage logging takes place (Thorn et al. 2018; Thorn et al. 2020). The case of the Bohemian Forest is emblematic (Thorn et al. 2017).

In 2007 the windstorm Kyrill felled a large area of spruce forest in the Bavarian Forest National Park. Four large windthrown areas were experimentally excluded from the salvage-logging operations. This led to the recovery in the populations of some formerly-extinct specialized lichen, mosses and wood-inhabiting fungi species (Thorn et al. 2017).

The points mentioned above call for urgent protection of primary and old-growth forests, particularly remnants in rare forest types. The protection of the small and fragmented patches of these forests should be conceived from a holistic perspective. The goal should be increasing the connectivity between primary forest patches and ensure that these are adequately enclosed in larger reserves with an adequate buffer. Restoration of semi-natural forest areas that may reach, with time, old-growth forest characteristics can create cushion zones and connectivity bridges. Restoration could either happen passively (e.g. setting aside forest and discontinuing salvage logging or disturbance suppression) or actively (e.g. promoting the development of deadwood or other key features), depending on the socio-ecological context. In both cases, restoration can be instrumental to increase the share of forest with old-growth characteristics in regions and for forest types where primary and old-growth forests are currently scarce. This is crucial, because remaining primary and old-growth forests are not representative of the diversity of forest types in Europe (Sabatini et al. 2020b). Most primary and old-growth forests are located in relatively unproductive and inaccessible regions in northern Fennoscandia, or in mountain ranges. Mesic lowland and Mediterranean forest types, instead, compose only a tiny fraction of the primary forests currently documented. This implies that creating functional networks of protected primary forests reserves at the EU-level requires extensive restoration of near-natural forests in many European landscapes (Sabatini et al. 2020b).

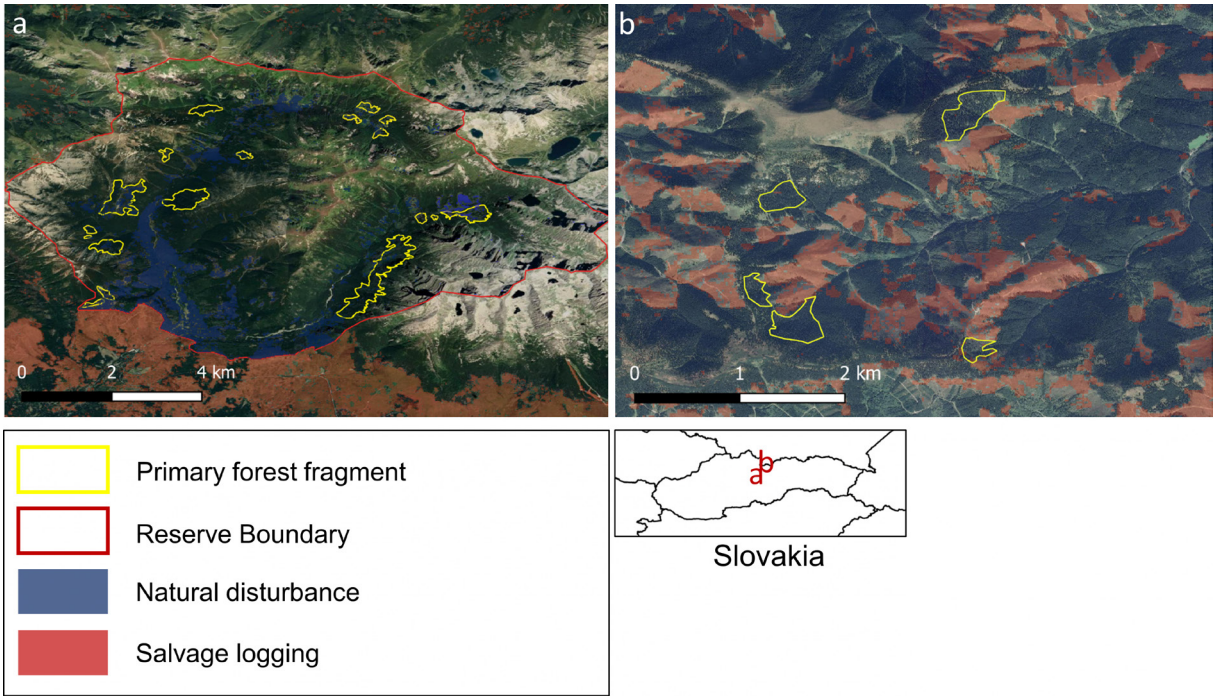


Figure 4. Two alternative forest reserve designs in Slovakia. a) The reserve in Ticha and Koprova valley connects 363 ha (yellow polygons) of primary forest into one strictly protected valley complex (total area 9,188 ha, red polygon). b) Only primary forest fragments are protected in the Low Tatra Mts. After extensive natural disturbance, most of the forest in the Ticha and Koprova valley was left to natural development (blue shading), retaining the connectivity of the primary forest patches. Extensive salvage-logging (red shading) was conducted in the buffer zone surrounding the primary forest patches in the Low Tatras, instead, further increasing the isolation of these fragments. Source: Modified from Mikoláš et al. (2019).

6 Knowledge and data gaps

Results of this report are in line with previous studies indicating gaps in GIS data of primary and old-growth forests across the EU (e.g. Mikoláš et al. 2019; Sabatini et al. 2020b). The data collected in Table 3 shows discrepancies between the area of primary forest reported by Members States and the area in the maps collected by Sabatini et al. (2020a) in the EPFD v2.0.

The area reported by Member States to the FAO (FAO 2020a) indicates a likely mapping deficit of at least 3.2 Mha of primary forest in the EU. That is, the sum of the differences between the area reported by countries to FAO and the area mapped in the EPFD v2.0. This calculation takes into consideration only those countries where the reported area is larger than the mapped area. Regarding the data reported to FOREST EUROPE (2020) the mapping deficit is more pronounced, climbing to 4.4 Mha, because it includes also primary forest in other wooded land. Nevertheless, most of the mapping deficit occurs in Sweden, i.e. 2.2 Mha and 3.3 Mha, with respect to the area reported to FAO and FOREST EUROPE, respectively. When excluding Sweden, the overall mapping deficit would be 1 Mha and 1.1 Mha, respectively. Other countries exhibiting large absolute mapping deficits are Bulgaria and Romania, with 647,000 ha and 95,000 ha, respectively. Nevertheless, efforts for further mapping primary and old-growth forests are on-going, e.g. in Finland, Romania and Bulgaria[15], which is an encouraging step forward.

These figures should be considered a lower bound because the available information does not permit to verify whether there is spatial correspondence between the area mapped in the EPFD v2.0 and that reported to FAO and FOREST EUROPE. In case of little or no correspondence, the mapping deficit might even be higher. Clearly, this mapping deficit has profound implications for implementing the strict protection of primary and old-growth forests required by the EU's biodiversity strategy to 2030.

Concerning the definition of primary and old-growth forest, while it cannot be considered a knowledge gap, more work is necessary for its operationalisation. Specifically, defining regionally-targeted criteria supporting the delineation and mapping of primary and old-growth forests in the EU will be crucial. Further discussions are required to agree on a set of criteria to ensure an adequate consistency level in the delineation of primary and old-growth forests across Member States. Any criteria for delineating primary and old-growth forests should be biome-specific (FAO 2021), and account for the wide variability in forest characteristics across Europe's biomes, biogeographical regions and forest types. At the moment of drafting this report the Working Group on Forests and Nature is dealing with this matter.

[15] https://ec.europa.eu/environment/nature/natura2000/awards/application-2020/winners/citizens-award/index_en.htm

7 Outlook

Despite the high conservation value of primary and old-growth forests, it is only recently that provisions for their strict protection have been issued in the EU. The EU's biodiversity strategy to 2030 calls to strictly protect these forests. However, their protection requires accurate and robust information and data that seems to be lacking in some regions.

This report identified a significant mapping deficit in several European regions that should be tackled for several reasons. Firstly, having a complete picture of the amount and location (delineation) of primary and old-growth forests. Secondly, ensuring strict protection, adequately managed buffer zones, sufficient connectivity, and appropriate conservation management measures in these areas (Sabatini et al. 2020b). Thirdly, implementing an agile monitoring framework capable of providing near-real time information regarding pressures and disturbances affecting primary and old-growth forests in the EU.

The definition of clear operational criteria for mapping primary and old-growth forests in the EU is of utmost importance for completing the mapping of these areas in a coherent manner. This process is currently on-going under the Working Group on Forests and Nature.

While the identification of undocumented primary and old-growth forests in the field remains crucial, inventorying and monitoring applications might benefit from using state-of-art remote sensing technology (e.g. Copernicus) and automated workflows in open-access platforms.

The study of Mikoláš et al. (2019), mapping primary forest in the Slovak Republic, is a good example of the integrated use of remote sensing and ground level data. It clearly shows that remote sensing methods, while important for an initial screening of the forests to inventory, need to be complemented with ground level data for model fitting and validation of the mapping results. In addition, setting variables and criteria derived from ground inventories for facilitating the delineation of these forests is a fundamental step.

The recently started LIFE Preparatory Action project PROGNOSES (PRotection of Old Growth Forests in Europe: Natural heritage, Outline, Synthesis and Ecosystem Services) will bring a contribution to the further assessment of the ecosystem services delivered by primary and old-growth beech forests. However, more research will be needed to cover other types of primary and old-growth forests, with a view to better define conservation objectives and raise more awareness of the value of these forests.

Modelling tools might also help achieve better estimates of the distribution and protection status of primary and old-growth forests in Europe. The recently published pan-European analysis by Sabatini et al. (2020b) provides an example (Figure 5). They disaggregated country level estimates of primary forests in Europe (excluding Russia) using grid cell-level probabilities of primary forest occurrence. Probabilities derived from a machine learning statistical model relating primary forest occurrence and a set of biophysical, socio-economic and historical land use predictors. Besides creating predictions of where unmapped primary forest is most likely to occur, the methodology allowed estimating the amount of primary forests in different forest types, the share of these forests in need of protection, as well as areas where restoration of primary forests is needed and feasible (Sabatini et al. 2020b). While waiting for improved on-the-ground information to become available, similar modelling exercises might help set conservation and restoration priorities and guide future mapping efforts.

The discussion on the minimum size of primary and old-growth forest stands should consider the fragmented and marginal character of primary and old-growth forests in the EU. Findings of this report indicate that most mapped primary and old-growth forest stands have a relatively small size in the order of 10-50 ha, or less. Even when small in size, patches of primary and old-growth forests are important, as they provide unique services such as refugia and habitat for imperilled species (see: Eckelt et al. 2018; Paillet et al. 2018), especially in intensively-used landscapes (FAO 2021; Vandekerkhove et al. 2011). Securing these patches of primary and old-growth forest, and the biodiversity they contain, requires a holistic landscape perspective, so to ensure that these forests are embedded in large forest complexes, are surrounded by adequately managed buffer zones, and are engrained into functionally connected landscape networks. Strict protection and buffer zones are measures at local scale. Nevertheless, the inclusion of the patches in a larger Green Infrastructure network would result in a more integrated approach for protection and conservation (Angelstam et al. 2020).

Primary and old-growth forests are too precious to be lost or degraded. As indicated in the section on the value of primary forests, the protection and conservation of primary and old-growth forests is an effective nature based solution providing a win-win strategy for biodiversity conservation and climate change mitigation. Policy action in these areas should take into consideration the overall benefits of protecting these forests from degradation and human-driven disturbances.

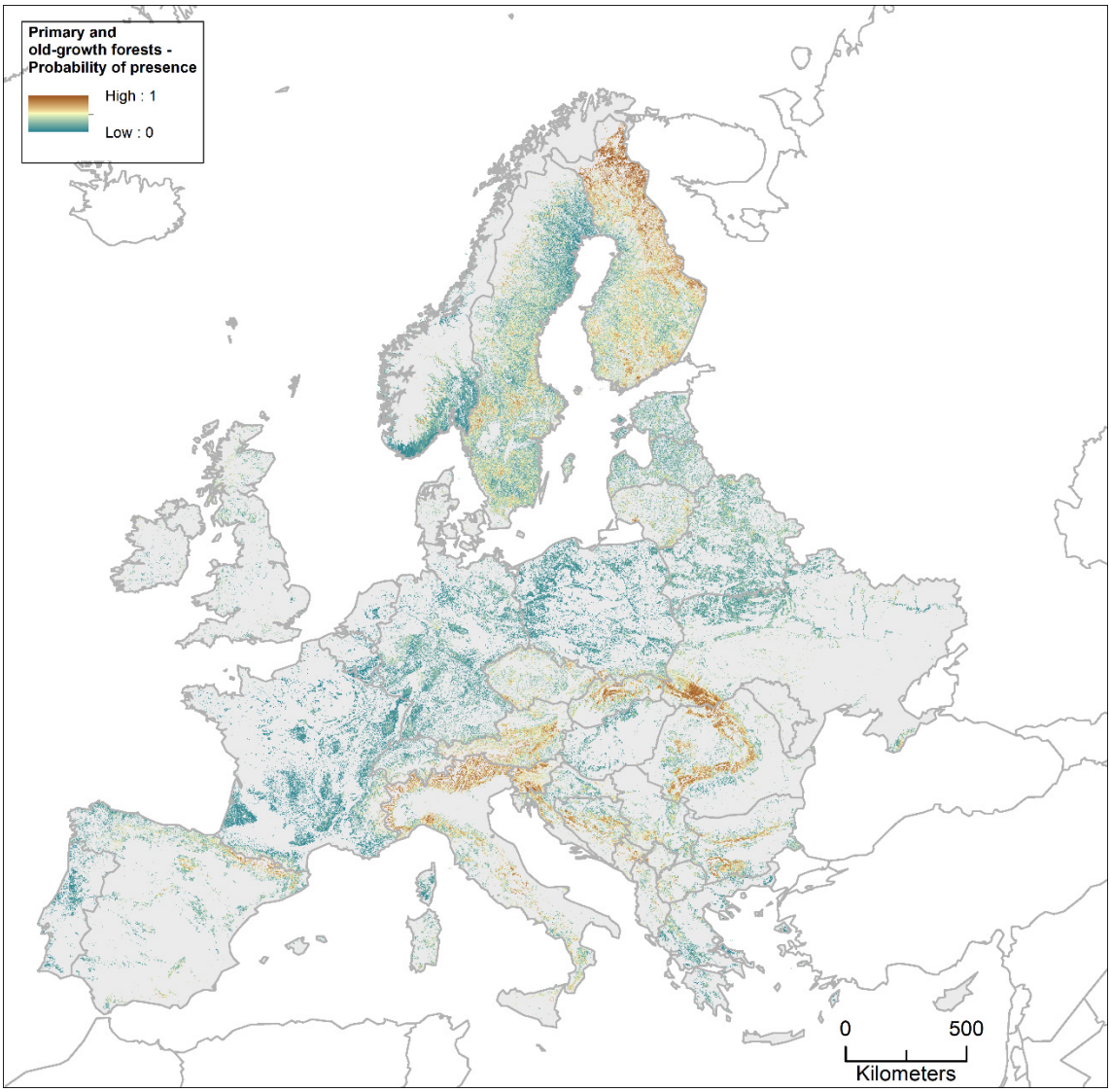


Figure 5. Likelihood of presence of primary and old-growth forests. Map at 250 m grid size implemented by Sabatini et al. (2020b) using a spatially explicit boosted regression trees model relating the presence of primary and old-growth forests and 15 biophysical, socio-economic and historical land use predictors. EU areas outside the domain of the map not included in the model.

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List of abbreviations and definitions

CGBN	Coordination Group on Biodiversity and Nature
EPFD	European primary forest database
OWL	Other wooded land

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Annexes

Annex 1. Definitions of forest naturalness levels n10 to n5 according to Buchwald (2005)

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

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

n8 Frontier forest (very high degree of naturalness): "A frontier forest is an area meeting the following criteria: It is primarily forested and predominantly consists of indigenous tree species. It is big enough to support viable populations of all indigenous species associated with that forest type -- measured by the forest's ability to support wide-ranging animal species (such as elephants, harpy eagles or brown bears). It is large enough to keep these species' populations viable even in the face of the natural disasters -- such as hurricanes, fires, and pest or disease outbreaks –that might occur there in a century. It is home to most, if not all, of the other plant and animal species that typically live in this type of forest. Its structure and composition are determined mainly by natural events, though limited human disturbance by traditional activities of the sort that have shaped forests for thousands of years -- such as low-density shifting cultivation -- is acceptable. As such, it remains relatively unmanaged by humans, and natural disturbances (such as fire) are permitted to shape much of the forest. In forests where patches of trees of different ages would naturally occur, the landscape exhibits this type of heterogeneity."

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

n6 Old-growth forest (high degree of naturalness): "Ecosystems (stand scale) distinguished by old trees and related structural attributes. Old-growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function. The age at which old-growth develops and the specific structural attributes that characterise old-growth will vary widely according to forest type, climate, site conditions, and disturbance regime. For example, old-growth in fire-dependent forest types may not differ from younger forests in the number of canopy layers or accumulation of down woody material. However, old-growth is typically distinguished from younger growth by several of the following attributes: 1) large trees for species and site, 2) wide variation in tree sizes and spacing, 3) accumulations of large-size dead standing and fallen trees that are high relative to earlier stages, 4) decadence in the form of broken or deformed tops or bole and root decay, 5) multiple canopy layers, and 6) canopy gaps and understory patchiness. Old-growth is not necessarily "virgin" or "primeval." Old-growth can develop following human disturbances. If the stand is known to be planted/sown or predominantly consists of exotics it is referred to level p4, Partly-natural planted forest or p1/p2, Exotic forests."

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

n4 Newly untouched forests: "Forest stands where forestry operations have been discontinued or never occurred since stand establishment, and which are known to have been left untouched for less than sixty to eighty years. Signs of former human management are usually easily visible, becoming more blurred with time.

In principle any stand would belong here between forestry operations. If discontinuation of operations is only because of long management intervals, the stand is referred to lower levels. If the stand is known to be planted/sown or predominantly consists of exotics it is referred to level p4, Partly-natural planted forest or p1/p2, Exotic forests."

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

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