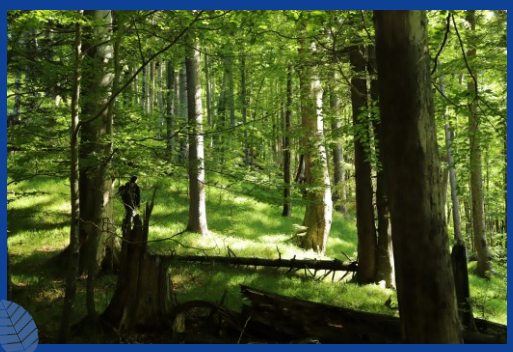
Life Prognoses

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POLICY BRIEF

Identification, Mapping and Protection of European Old-Growth Forests

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Key findings

- Old-growth forests deliver ecosystem services regarding carbon storage, cooling effects, biodiversity and recreation of higher quality than the average managed forests.
- 'Old-growth' is a gradual and not a black-or-white characteristic: forests have a certain level of *old-growthness*.
- The characteristics of old-growth forests vary regionally.
- With remote sensing (RS), forests can be distinguished as 'potentially old-growth'.
- To conclusively identify a forest as old-growth, the RS assessment must be complemented with a field assessment.
- The rapid assessment allows for determining old-growthness in the field based on as few as five key features.

Policy implications

- The ecosystem services delivered by old-growth forests cannot be fully substituted by their counterparts under management.
- Old-growth forest protection is crucial to achieve the objectives of the EU Green Deal and acquire sustainable landscapes for future generations.
- Given their regional variations and gradual development, we should assess old-growthness based on multiple criteria.
- RS can be used to make a preselection of potentially old-growth forests and focus the efforts of field assessment and mapping.
- As 'old-growth' is not a categorical but a gradual characteristic, and highly dependent on forest type and site productivity, the setting of national or local discriminants and methodologies for identification and mapping is urgently needed. These thresholds should be scientifically substantiated and endorsed through consultation with scientists and stakeholders.
- The tandem of the RS approach for preselection and the rapid assessment in the field allows for a timely mapping of all old-growth forests across Europe.

As long as this mapping exercise is not complete, it is necessary to 'freeze' management activities in forests identified or debated as potentially old-growth until a field assessment provides a conclusive identification.

Executive summary

Primary and old-growth forests occupy a very limited area in Europe due to long-term historical exploitation. These forests are crucial for biological diversity, carbon storage, hydrology, ecosystem adaptation to disturbances, and public health. Despite their scarcity and importance, not all of them are protected against logging and other human interventions, but the EU is taking steps to address this issue. To support the envisaged protected status, the partners of the Life Prognoses project quantified the added value of the characteristic ecosystem services of primary and old-growth forests, as compared to managed forests and contributed to the development of identification criteria and mapping methods for European old-growth forests, focusing specifically on beech forest ecosystems.

The exceptional value of European old-growth forests

The Life Prognoses partners conducted measurements and analyses to further quantify the characteristics and added value of the unmanaged character of primary and old-growth beech forests. The research results demonstrate

1. the superior regulatory processes resulting in a stronger microclimatic effect, i.e. old-growth patches provide more cooling during hot summer days and form overall better temperature buffers.
2. The overall carbon stocks in primary and old-growth forests are significantly higher than in managed forests. Carbon stored in very large trees and large amounts of deadwood, but also in the soil, accounts for this difference. Moreover, the variety of carbon stocks provided by old-growth forests (above- and belowground, and in living and dead biomass, i.e. deadwood in its many forms) is clearly much higher in old-growth forests.
3. The importance of old-growth forests for specialised biodiversity, mainly via various forms of deadwood and tree-related microhabitats.
4. Human appreciation for the pristine aesthetics of old-growth forests and their significance for human wellbeing.

The proven added value of unmanaged forests is a strong argument for strict protection.

Situating old-growth forests in Europe

Primary and old-growth forests are crucial for biological diversity, carbon storage, hydrology, ecosystem adaptation to disturbances, and public health. Unfortunately, they are vulnerable and threatened: due to historical exploitation, primary and old-growth forests are highly fragmented and occupy a very limited area, especially in central and western Europe. Despite their fragile state and ongoing decline, they are not always fully protected against logging and other human interventions. Many old-growth forests remain unmapped, making them vulnerable to (even legal) logging.

The EU Biodiversity strategy (2020), for the first time, brings up this problem at the highest policy level, stating the explicit goal to map and strictly protect all remaining primary and old-growth forests. However, no clear definition, criteria and indicators of what would qualify as a primary or old-growth forest in Europe were explicated, and so, it was impossible to identify and map these forests. The partners of the Life Prognoses project participated in the first steps towards strict old-growth forest protection by contributing to the development of the scientific framework for identifying and mapping European old-growth beech forests.

Defining European old-growth forests

The Europe-wide defining characteristics of old-growth forests relate to their current structural features. The structural attributes that define old-growth forest are those that are associated with late-seral stages of stand development, such as the presence of substantial amounts of deadwood and old trees. Old-growth characteristics may develop in both primary and secondary forests, provided natural processes dominate over extended periods. This flexibility allows for a broad application in Europe, where forests often have diverse management histories and growth conditions.

There is no sharp delineation between old-growth and non-old-growth forests. The defining structural features develop over time at rates varying with the local context. This means that the features characterising old-growth forests do not appear all at once, but gradually. This is the reason we decided to talk about 'old-growthness', allowing us to characterise a forest as having a certain level of old-growthness instead of being either fully old-growth or not at all (Vandekerkhove et al, 2022).

Identifying European old-growth forests

Old-growth forests are identified based on their structural and ecological complexity. Unlike primary forests, old-growth characteristics can also develop in areas with historical human disturbance, provided the forest was (actively or passively) set aside and natural processes and structures took over again over time. Key criteria for old-growthness include, among other

aspects, the presence of large and old trees, high volume and diversity of deadwood, structural stand complexity (uneven-aged stands with multiple canopy layers and natural gaps), dominance of late-successional species and a lack of invasive or non-native tree species (Vandekerkhove et al, 2022).

Given the gradual development of the old-growth characteristics and thus of the old-growth character of a forest, and given the regional differences in how explicitly characteristics develop, it is recommended to assess the old-growth character of a forest based on multiple criteria and tailor them to the local forest type and growth conditions. We developed a scoring system, called the adapted 'Old-growth indicator' OGI (based on the OGI concept of Meyer et al., 2021), that can be applied in all biogeographic regions of Europe and allows for comparison across regions in Europe.

Mapping European old-growth forests

Field assessment

We developed the Mapping Guideline and Field Survey Protocol, providing instructions for every step in the process of a detailed assessment of old-growth characteristics, specifically for European beech-dominated stands, but sufficiently generalizable (Kirchmeir et al, 2023). The steps discussed are:

1. The selection of the mapping area.
2. The delineation of homogenous forest patches/stands (pre-classification).
3. The set-up of the sampling design (i.e. shape and area of a sampling plot, indicators to measure, etc.).
4. The collection of field data on sampling plots (including structural parameters and, in a selection of sites, also tree-cores, microhabitat inventory and soil samples).
5. The final evaluation of old-growthness for each polygon or forest stand, based on the assessment of old-growth indicators.

Remote sensing approach

RS offers a wide range of data and methods to map forests and their properties, applicable from the local to continental scale. Indirect approaches integrate various existing data sets to predict OGF existence. These approaches have also been used for large area mapping, with a main drawback of missing physical evidence of the identified areas to really hold OGFs as compared to the likelihood of OGF existence (Hirschmugl et al. 2023).

We developed an algorithm to identify stand age characteristics based on Sentinel-2 satellite and Airborne LiDAR data. Training data quality and local stand variability have a strong impact

on the classification output and the related accuracy values. We reached high accuracies (>80%) in the Sonian Forest and in Bulgaria, while the results for the mountainous Kalkalpen National Park and Abruzzo National Park were significantly lower.

We could further prove that the inclusion of ALS data improved the overall accuracy of the map by approximately 6%, but also varied according to site. The error matrices show that the method is very powerful to discriminate between young to mid-aged stands on the one hand, and old and overmature stands on the other. Uncertainty is higher when trying to discriminate between old (mature) and overmature (old-growth). In general, we conclude that our algorithm is apt to identify patches of forest with a high likelihood of being old or old-growth. However, field assessments remain essential to identify a forest patch conclusively as old-growth. The remote sensing approach can speed up the mapping of old-growth forests in Europe: a remote sensing assessment can make a preselection of potentially old-growth patches, significantly limiting the surface area that ought to be visited for a field assessment.

OGI assessment and 'rapid field assessment'

We developed a method to calculate the level of old-growthness from data for the EU indicators for beech-dominated forests. This method, named the 'adjusted Old-Growth Indicator' or 'OGI_{ad}', builds on the old-growth indicator (OGI) proposed by Meyer et al (2021). For its development, we used a large dataset collected according to the field mapping approach in ten forests across Europe, included in the world heritage site 'Ancient and Primeval Beech Forests of the Carpathians and Other Regions in Europe'. With this dataset, the coverage of the natural range of variability of beech old-growth forests could be improved significantly. Also, the OGI_{ad} requires less data to assess old-growthness, and thus is more broadly applicable. The full-fledged field mapping approach, however, is rather labour-intensive. This is a serious drawback to realising a timely mapping of all old-growth forests Europe-wide. To accommodate the time limitation, we proposed key points for a 'rapid' field assessment to collect just as much data as to estimate the OGI_{ad} with sufficient accuracy. The elaborate field data collection could be reduced to the collection of data for five indicators: as much as 95% of the variability of the OGI_{ad} scores in productive beech forests is explained by the density of very large and cavity trees, the share of native tree species, and the total volume of the living stand and of deadwood. Therefore, we suggest emphasising these indicators for rapid field assessments. For the design of the rapid assessment, we recommend a two-step approach combining remote sensing to delineate areas for field mapping with a transect inventory in the field. To conclude, as an outcome of the Life Prognoses project, a ready-to-use rapid assessment can promptly be worked out. This would allow us to identify and map old-growth forests across all member states by 2030.

Next steps towards strict protection

The ongoing decline of primary and old-growth forests requires quick action. Old-growth forests are disappearing while we are completing the European old-growth mapping. The conservation of hitherto unidentified old-growth forests must be guaranteed. Still, time is needed to develop national thresholds and perform a countrywide mapping. In the meantime, important old-growth forests may degrade or even disappear before they are duly identified and protected (Mikolāš et al, 2023). Therefore, we adhere to the principle, stated in the EU Guidelines (2023), that all management activities, especially logging, should be 'frozen' from the moment a patch of forest is debated or identified as potentially old-growth by remote sensing methods. This way, there remains more time for the field assessment, based on which it can be decided whether the forest will be strictly protected or not.

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Project identity	The Life Prognoses project was a preparatory project subsidised by the Life Programme of the European Commission. It was carried out between 2021 and 2025 by fifteen partners of eight European countries and embedded in the World Heritage Site *Ancient and Primeval Beech Forests of the Carpathians and Other Places in Europe*. The project combined empiric and conceptual scientific research with outreach and awareness raising at the local, national and European levels.
Read more about the project and our research here	https://lifeprognoses.eu Outputs of the project – LIFE Prognoses
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