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Guidelines on Closer-to-Nature Forest Management

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These guidelines have been prepared through active dialogue with Member State experts and key stakeholders, and they are based on a collaborative approach. The list of Member State authorities and organisations or stakeholders and civil society groups that participated in developing the document is included hereafter and the Commission wishes to thank them all.

Special thanks go to the representatives from Finland (Ministry of Agriculture and Forestry), Poland (Directorate-General for the State Forest), and Slovenia (Ministry of Agriculture, Forestry and Food), who co-led the process of drafting these guidelines.

The responsibility for the content, except when a source (for example, good practices) is directly referring to a Member State or other organisation, lies with the Commission. The text might not necessarily reflect the views of all the listed individual authorities and organisations since it includes compromise drafting for areas on which views in the group significantly diverged.

Contents

PREFACE

Under the European Green Deal, the EU biodiversity strategy for 2030[1] sets a path for the recovery of Europe's biodiversity, including its forest biodiversity. The biodiversity strategy for 2030 highlights the importance of sustainably managing forests as a nature-based solution in the fight against climate change, and it calls for biodiversity-friendly forestry practices to continue and to be further developed. To this end, it **asks the Commission to develop guidelines on closer-to-nature forest management**. The EU forest strategy for 2030[2] echoes this commitment and defines closer-to-nature forest management as a set of practices to ensure multifunctional forests by combining biodiversity goals, carbon stock preservation and timber-related revenues.

- ***<u>The aim of these guidelines is therefore</u>*** **to promote biodiversity-friendly and adaptive forest management** as part **of a common framework for closer-to-nature forest management.** They present relevant practices and showcase the benefits of these practices for forest multifunctionality and climate change resilience without neglecting socioeconomic benefits.
- ***<u>The guidelines will</u>*** **assist competent authorities and key stakeholders** in developing and promoting biodiversity-friendly and adaptive practices in forest management across different scales, discussing challenges and opportunities.

SCOPE

The guidelines will help public authorities, forest owners and forest managers across Europe by taking biodiversity and climate change into greater consideration in their operations.

These guidelines are for forests that have a commercial use for timber and non-timber forest products, and that are not explicitly designated as protected areas. Some aspects below might nevertheless also be suitable in protected areas or on other land with tree cover.

<u>PART I</u> presents the background for the guidelines, including existing actions by EU Member States. <u>PART II</u> specifies objectives and the key principles of closer-to-nature forest management to build a common understanding of this approach and its relation to other forest management concepts and practices. <u>PART III</u> provides a set of tools that can help forest management practices to move closer to nature. <u>PART IV</u> presents key drivers and critical enablers for implementing the principles of closer-to-nature forest management. <u>PART V</u> discusses challenges and opportunities in different EU biogeographical regions. <u>ANNEXES</u> present examples of good practice.

IMPORTANT NOTICE TO THE READER

This document has been prepared through active dialogue with Member State experts and key stakeholders to ensure that it is user-friendly, that is it fit for purpose and that it builds on a collaborative approach. The present document is not prescriptive in its intent, and all actions and measures it sets out are entirely voluntary. It aims to offer a useful source of information and advice to help authorities, site managers and civil society groups to better implement biodiversity-friendly and adaptive forest management in a way that complements national or subnational guidelines (where they exist). Since there is no 'one-size-fits-all' solution in forestry and forest management, this document gives readers the flexibility to choose the practices that are best suited to their situation depending on the local context. It can therefore be useful in supporting decisions at local level on forest management, while not constituting binding conditions in relation, for example, to support under state aid schemes or EU schemes to fund forest management.

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0380
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0572

PART I – INTRODUCTION

Why there is a need for closer-to-nature forest management

Forests provide invaluable benefits to people and the planet. They host the largest number of living species on land, and they are vital for climate regulation, water regulation, soil stabilisation, and the purification of air and water. They are an important ally in the fight against climate change thanks to their cooling effect, their sequestration of carbon during photosynthesis, and carbon storage capacity in soil and woody biomass, including in long-lived wood products. In addition, forests and the forest-based sector provide multiple socioeconomic functions and benefits, including jobs and development possibilities in rural areas. For the transition to a circular bioeconomy[3,4] and a healthy society, forests are indispensable due to: (i) the role of forests in providing bio-based and renewable raw materials, food and medicines; (ii) the function forests serve in protecting settlements and people from natural hazards; and (iii) the value of forests for recreation and learning from nature.

Forest biodiversity consists of species and populations that are found only in forests or that are particularly sensitive or threatened by forest management practices. The composition of forest species and the genetic diversity of populations of a given species are largely determined by the type of forest management practiced.

Attention should especially be given to:

(i) species that depend on the forest (both remarkable and ordinary biodiversity);

(ii) species on which the forest depends for its functioning (functional biodiversity) such as forest trees, keystone species that structure the forest environment and that are the direct object of forest management, soil functional groups (mycorrhizae, bacteria, different soil animal groups), and predators;

(iii) species sensitive to silvicultural interventions (logging, etc.) such as: (a) species with limited mobility; (b) species restricted to stages (such as old and pioneer stages) and habitats (such as deadwood, tree-related microhabitats, or large and old trees); (c) animal species sensitive to disturbance; (d) fauna and flora of the soil sensitive to compaction; (e) threatened taxa (as defined by the International Union for the Conservation of Nature (IUCN)); (f) rare species or populations; and (g) species or populations whose abundance is declining.

Forests in Europe are part of a widely and intensively used cultural landscape. For centuries, forest management was built on optimising or even maximising tree growth and yield measured by the production of wood. Formerly diverse forest landscapes were progressively replaced by less diverse plantations, with reforestation often reduced to a limited number of high-yield species harvested well before their longevity potential, leading to the simplification and homogenisation of European forests. This simplification and homogenisation contributed to making some European forests highly susceptible to disturbances[5], and undermined natural dynamics and resilience to environmental stress[6] leading to lower resilience to pest outbreaks like bark beetle or the increased fire risk in spruce-dominated forests[7,8].

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[3] https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/bioeconomy-strategy_en

[4] https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/adoption-bioeconomy-strategy-progress-report-2022-06-09_en

[5] Aszalós, R. et al. (2022). Natural disturbance regimes as a guide for sustainable forest management in Europe. *Ecological Applications, 32*(5), Article e2596. https://doi.org/10.1002/eap.2596

[6] Puettmann, K. J. et al. (2015). Silvicultural alternatives to conventional even-aged forest management - What limits global adoption? *Forest Ecosystems, 2*, Article 8. https://doi.org/10.1186/s40663-015-0031-x

[7] González, J. R. et al. (2006). A fire probability model for forest stands in Catalonia (north-east Spain). *Annals of Forest Science, 63*(2), 169-176. https://doi.org/10.1051/forest:2005109

[8] European Commission, Directorate-General for Environment. (2021). *Science for Environmental Policy: European Forests for biodiversity, climate change mitigation and adaptation*. Future Brief 25. https://data.europa.eu/doi/10.2779/764847

The simplification and homogenisation of European forests – in terms of both the number of tree species and the age of tree species – coupled with shortened silvicultural cycles have led to a significant under-representation of mature attributes in forests.

These mature attributes include features such as deadwood, tree-related microhabitats, or very large and old trees. There has therefore been a decline in species that depend on these attributes, posing a threat to forest biodiversity.

Forest management as a concept has significantly changed over the years, with the social and environmental aspects gaining in importance. However, because of historical practices, most EU forests currently have very limited tree species and age ranges, as shown in Figures 1 and 2.

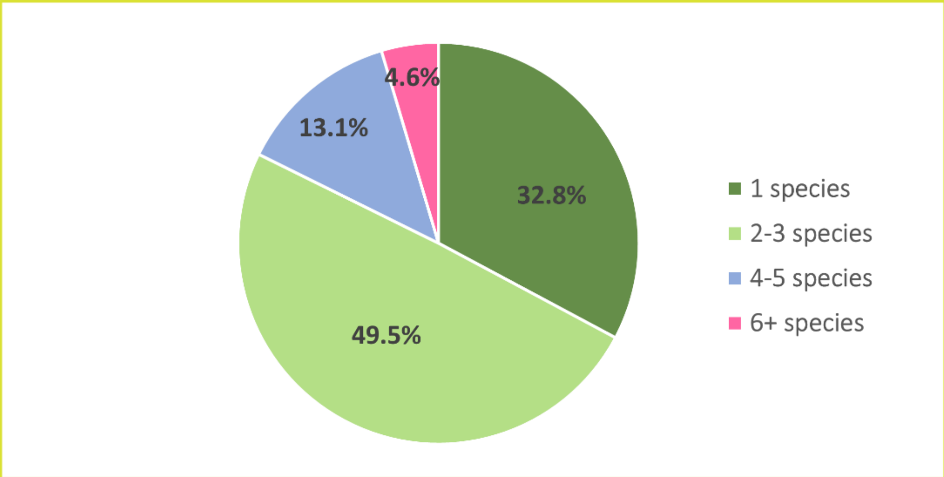

Figure 1: Forest area in Europe classified by number of tree species occurring in 2015[9]

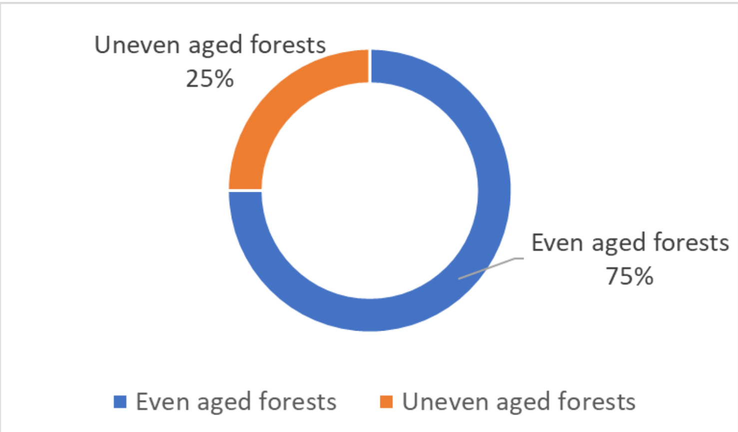

Figure 2: Forest age structure in the EU[9]

A variety of pressures are increasingly taking their toll on forest stability and productivity[10] and affecting the carbon storage potential of forests[11]. These pressures include: (i) climate change-driven pressures such as extreme droughts, heatwaves, bark beetle outbreaks or wildfires; and (ii) more direct human-induced pressures like forest and habitat fragmentation, forestland change, habitat loss, pollutants or the introduction of invasive alien species. Among these pressures, climate change and

[9] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[10] European Commission, Joint Research Centre, Maes, J. et al. (2020). *Mapping and assessment of ecosystems and their services: An EU ecosystem assessment*. Publications Office. https://data.europa.eu/doi/10.2760/757183

[11] Seidl, R. et al. (2014). Increasing forest disturbances in Europe and their impact on carbon storage. *Nature Climate Change, 4*, 806-810. https://doi.org/10.1038/nclimate2318

unsustainable human activities have the most severe impacts. Figure 3 gives an overview of the most relevant forest pressures by human intervention.

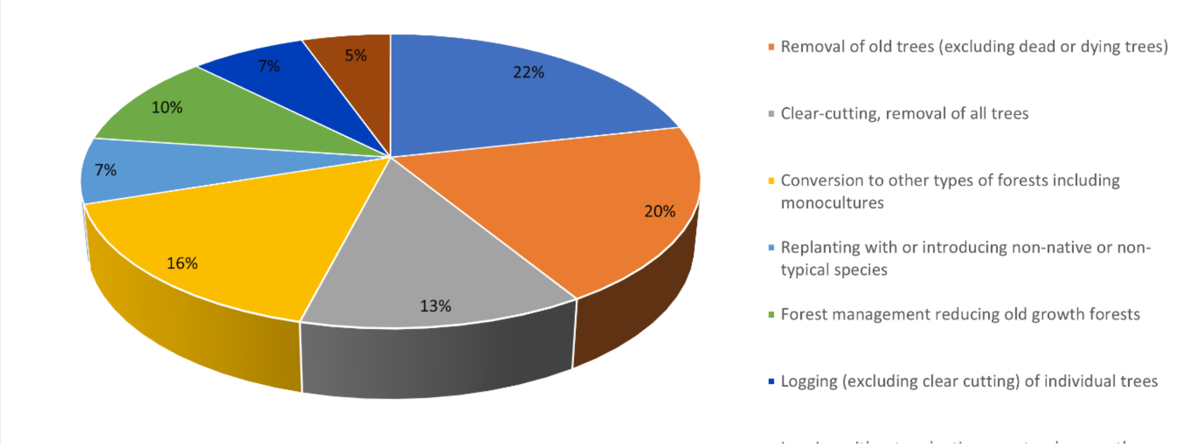

Figure 3: Share of the different forest pressures for Natura 2000 habitats and species (listed in Annexes I and II of the EU Habitat Directive)[12]

The restoration of natural forests or the planting of monocultures have increased forest cover in the EU in recent decades. However, these actions have very different consequences for biodiversity. The large-scale deployment of intensive plantations (including monocultures) replacing natural forests and subsistence farmlands will likely impact biodiversity negatively. It can also threaten food security, water security and local livelihoods[13]. Only 14% of the assessed forest habitats listed in Annex I of the EU Habitats Directive show good conservation status (30% have an unknown status), with notable differences among regions. Over 90% of assessments of Boreal forest habitats (i.e. forests in northern Europe) show an unfavourable conservation status and have worse trends than temperate and Mediterranean forests[12]. More generally, according to the IUCN, 27% of mammals, 10% of reptiles and 8% of amphibians linked to forest ecosystems are threatened with extinction in the EU region[14].

Natural dynamics and biodiversity are a determining factor for forest vulnerability, resilience and adaptive capacity. Forests composed of several tree species are often richer in biodiversity, more resilient and more functionally diverse than those with only one tree species[15,16]. Structural elements (like deadwood, microhabitats, old trees, etc.) can increase biodiversity in all forests. In turn, biodiversity positively affects ecosystem functions and services, including CO_2 absorption in terrestrial ecosystems[17].

> **Ecosystem functions** can be defined as ecological processes that control the flows of energy, nutrients and organic matter through an environment.
>
> **Ecosystem services** can be defined as the suite of benefits that ecosystems provide to humanity, either in regulatory, supporting, cultural or provisioning terms.

Approaches, objectives and instruments that are based on closer-to-nature forest management support biodiversity, resilience and climate adaptation in managed forest and forested landscapes. This makes it possible for forests to provide their full range of ecosystem services to our economy and

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[12] European Environment Agency. (2020). Conservation status of habitat types and species: datasets from Article 17, Habitats Directive 92/43/EEC reporting (2013-2018) - PUBLIC VERSION - Aug. 2020. Conservation status of habitat types and species: datasets from Article 17, Habitats Directive 92/43/EEC reporting (europa.eu)

[13] Díaz, S. et al. (Eds) (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat. https://zenodo.org/record/3553579/files/ipbes_global_assessment_report_summary_for_policymakers.pdf?download=1

[14] www.iucnredlist.org

[15] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[16] van der Plas, F. et al. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. *Nature Communications, 7*, Article 11109. https://doi.org/10.1038/ncomms11109

[17] Naeem, S. et al. (1994). Declining biodiversity can alter the performance of ecosystems. *Nature*, 368, 734-737. https://doi.org/10.1038/368734a0

society (including the stable production of timber and non-timber forest products) despite increasing uncertainty in the wake of climate change.

EU Member States' perceptions and actions

Forest management practices are constantly evolving. And new trends and approaches are already being tested in many Member States, as illustrated by a dedicated questionnaire to which several stakeholders and 23 Member States replied. The bullet points below set out nine insights that emerged from this questionnaire.

1. In the EU, there is a strong preference for an integrated approach to sustainable forest management. Priority objectives differ according to who owns the forest. Biodiversity and other non-marketed goods (such as recreation or cultural values) are generally valued in public forests, whereas wood production is a primary objective in most private forests, mainly due to the absence of markets for other ecosystem services.
2. EU Member States often use practices that mimic natural processes to help develop biodiversity. In addition, there is a general interest in using closer-to-nature approaches to prepare European forests for a changing climate and to increase their adaptive capacity. Those practices are also used to provide high-quality wood and deliver other ecosystem services.
3. In many EU Member States, various closer-to-nature management approaches are already being applied, mainly in public forests, unless legislation obliges all forest managers to follow this approach. Some Member States have introduced related principles or mandatory legislation on closer-to-nature forest management.
4. Several silvicultural activities and tools seem to be common to Member States' systems. These common tools and activities include: (i) single-tree or group harvesting; (ii) natural regeneration; (iii) species mixtures; (iv) 'stands' (i.e. groups of trees) comprising trees of different ages; (v) the use of native species; (vi) preserving key habitats and associated habitats[18]; (vii) maintaining old trees and tree-related habitats; (viii) setting up voluntary 'set-asides' (i.e. areas where forests are allowed to grow naturally without active planting or management by humans); (ix) leaving deadwood; (x) restoring wet habitats; and (xi) foregoing the use of pesticides. The relative importance of each of these tools and activities is likely to vary depending on the forest region at stake, and other tools could be added.
5. Closer-to-nature management concepts differ by country and region. Overall, in north-east Europe, the concept of mimicking natural disturbances and maintaining natural structures (key habitats, deadwood, etc.) is prominent. In central and eastern Europe, closer-to-nature forest management (the 'Pro Silva approach' and others) prevails, while in western Europe continuous-cover forestry (CCF) is mostly used.
6. Two different approaches to forest multifunctionality and the protection or restoration of biodiversity are used in forest management. The first is the segregation approach, creating specialised biodiversity protection areas such as set-asides with non-intervention or low-intervention management. The second is the integrated approach, which incorporates elements of biodiversity protection into productive forest management. Currently, the integrated approach is predominant in most EU Member States. The INTEGRATE network[19] is an example of promoting this approach in forest management.
7. There are several indicators (proxies) of relevance to assessing biodiversity in forests. These indicators vary between countries, mainly depending on biogeographical conditions, historical developments and the current management of the forest resource. The usefulness of these indicators depends on the temporal and special scopes in which they are considered. Hence, the needs and the challenges related to those indicators vary considerably.
8. The main barrier that questionnaire respondents said was preventing them from using practices favouring biodiversity appeared to be economic. This indicates that there is the perception that these practices would lead to a reduction in the economic return from forests – at least in the

[18] By associated habitats, we mean all the milieux present in forests such as open areas (grasslands and openings in the canopy), aquatic environments (forest ponds, peat bogs, wetlands, riparian zones), rocky areas, etc.
[19] https://integratenetwork.org/

short term. This reflects the general lack of markets for other ecosystem services – including the provision of habitats for biodiversity – and it suggests a lack of related incentives. Other reasons hampering the use of those practices are: (i) a lack of acceptance notably due to limited science-based knowledge; (ii) insufficient practical experience and skills; and (iii) other logistical, informational, cultural or historical constraints. Conversely, growing concern about the impacts of the climate and biodiversity crisis has increased interest in closer-to-nature practices.

9. Most of the existing guidelines for forest management practices include: (i) natural regeneration; (ii) native species; (iii) local provenances; (iv) stands composed of trees of different ages; (v) mixed stands composed of different tree species; (vi) landscape variation; (vii) careful tending and harvesting operations; (viii) balancing the pressure of ungulate populations; (ix) preserving the quantity and diversity of deadwood; (x) preserving tree-related microhabitats; (xi) old groves; (xii) encouraging rare tree species; and (xiii) preserving special key biotopes.

PART II – CLOSER-TO-NATURE FOREST MANAGEMENT AS A CONCEPT

There is a need to strengthen the contribution made by our forests to the EU's ambitions for biodiversity and climate change. It is necessary to strengthen the capacity of forests to deliver a diverse mix of ecosystem services and supports to these services. These ecosystem services and supports include: (i) wood production; (ii) biodiversity conservation; (iii) the protection of wetlands; (iv) the protection of water quality; (v) recreation; (vi) carbon sequestration; and (vii) carbon storage. To achieve this, there is a need to strengthen both the environmental pillar of sustainable forest management and the resilience of forest ecosystems. Closer-to-nature forest management can help respond to those environmental and climate needs. In addition, the increased stability, resilience and adaptive capacity of forests managed according to closer-to-nature principles will also help to minimise the significant and fast-growing socioeconomic risks associated with forest damages and losses caused by climate change.

Basic considerations and objectives

Closer-to-nature forest management, based on ecosystem dynamics, encompasses existing approaches oriented to increasing biodiversity in managed forests under the umbrella concept of sustainable forest management. Refining the environmental pillar of sustainable forest management by focusing on safeguarding ecosystem functioning and resilience, closer-to-nature forest management also integrates technical, economical and social considerations. Closer-to-nature forest management considers forests as ecosystems composed of plants, animals, fungi, unicellular organisms and abiotic elements above and below the ground, all working together to constitute and maintain forest multifunctionality. Species have individual ecological requirements. Therefore, closer-to-nature forest management promotes reliance on natural and complex forest ecosystem dynamics instead of imposing artificial uniformity and manipulating natural site conditions. In closer-to-nature forest management, decisions on the forests' natural capital are based on: (i) the natural succession dynamics and interactions of species (which may include pioneer species for locally assisted migration for climate adaptation); (ii) environmental factors like water availability and soil quality; and (iii) climate conditions, including temperature, humidity and storm frequency. For biodiversity to thrive as a whole, diverse forest structure and composition are required. A given forest ecosystem should include various stages of development, including at species, stand and landscape levels, to offer different habitats and living conditions for the multitude of species it hosts.

General principles

While forest management needs a region- and context-specific approach, building on Larsen et al. (2022)[20], the general principles of closer-to-nature forest management are:

• learning from and permitting natural processes to develop;
• maintaining the heterogeneity and complexity of forest structures and patterns;
• integrating forest functions at different spatial scales;
• using a variety of silvicultural systems based on natural disturbance patterns of the region;
• low-impact timber harvesting with equal attention being paid to what is retained in the forest and what is removed, thus preserving habitats, forest soil and forest microclimates.

Main objectives

Closer-to-nature forest management serves as an accelerator for biodiversity restoration, biodiversity conservation and forest resilience to climate change based on two main objectives: (i) increasing structural complexity; and (ii) promoting natural forest dynamics. The paragraphs below discuss these two main objectives in more detail.

Increasing structural complexity

Closer-to-nature forest management strives to create more diverse and mixed forests in terms of height, diameter, age and species. It seeks to promote a mix of denser and sparser parts according to the natural mix of species and structures, depending on the type of forest[21] and its phase of development. Certain forests contain fewer species than others by nature or undergo phases in parts of their development cycle in which they are almost mono-species forests.

Tree species richness along with tree functional composition, forest structure, climate and soil are important key drivers of taxon-level biodiversity and overall forest-associated biodiversity[22]. Tree species diversity and structural diversity benefit the functions, services and ecosystem dynamics[23] of forests.

Closer-to-nature forest management also benefits long-term forest productivity[24] and resilience. Stands with a diversified species structure are more resistant and adaptable to climate change and disturbances[25,26]. Diversification also makes it possible to minimise financial risks: if one species is affected by a pest, there are other species that can still survive and ensure an economic return.

The variety of stand strata makes it possible to have many habitats for a wide variety of species. Horizontal patchiness (both at stand level and at forest landscape level) and vertical stratification are crucial components of the habitats of forest species. The diversity of structures on a fine scale promotes two things: (i) the accommodation of a great diversity of species with varied requirements due to the juxtaposition and superimposition of different strata; and (ii) the recolonisation by species with low dispersal capacity, due to the proximity of similar strata.

[20] Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12
[21] Brzeziecki, B. et al. (2021). A demographic equilibrium approach to stocking control in mixed, multiaged stands in the Białowieża Forest, northeast Poland. *Forest Ecology and Management, 481*, Article 118694. https://doi.org/10.1016/j.foreco.2020.118694
[22] Ampoorter, E. et al (2021). Tree diversity is key for promoting the diversity and abundance of forest-associated taxa in Europe. *Oikos, 129*(2), 133-146. https://doi.org/10.1111/oik.06290
[23] Gamfeldt, L. et al. (2013). Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications, 4*, Article 1340. https://doi.org/10.1038/ncomms2328
[24] Paquette, A., & Messier, C. (2010). The effect of biodiversity on tree productivity: From temperate to boreal forests. *Global Ecology and Biogeography, 20*(1), 170-180. https://doi.org/10.1111/j.1466-8238.2010.00592.x
[25] Cardinale, B. et al. (2012). Biodiversity loss and its impact on humanity. *Nature, 486*, 59-67. https://doi.org/10.1038/nature11148
[26] Mahecha, M. D. et al. (2022). Biodiversity loss and climate extremes — Study the feedbacks. *Nature, 612*, 30-32 (2022). https://doi.org/10.1038/d41586-022-04152-y

Maintaining or restoring natural heterogeneity in species and age classes is also an important way to preserve the forest's internal microclimate and to preserve the optimal functioning of the ecosystem more generally. Adapted stand structure and adapted tree species composition benefit species that thrive in shade or semi-shade, notably those that are sedentary or have poor dispersal ability. Emulating different natural disturbance patterns can further provide favourable conditions to other species, such as species that have a greater need for light.

Finally, restoring and conserving valuable associated biotopes existing in forests, such as springs, water bodies, peatlands, rocks and rare forest types, may help to generate a more complex structure with a greater variety of habitats.

Promoting natural forest dynamics

Closer-to-nature forest management relies as much as possible on natural dynamics and, by embracing and directing those dynamics, reduces the costs traditionally incurred in managed forests (for instance, for planting) in the long term. Natural disturbances including windthrow (individual trees/small groups of trees), bark beetle attacks, droughts, wildfires, flooding or beaver activity can be capitalised on to some extent to create deadwood and structural complexity which helps to strengthen biodiversity.

As much as possible, closer-to-nature forest management involves making light but regular interventions specific to the site to increase habitat complexity, community diversity and ecosystem service variety. Forest conditions are maintained or promoted in line with the natural range and distribution of existing and potential species in the considered site taking account of shifts in the natural ranges of species induced by climate change.

Biodiversity benefits of various forest practices

Individual forest management practices and wood harvesting regimes have different impacts on forest biodiversity and climate change resilience. The transition to closer-to-nature forest management will require different measures at different times. Table 1 provides an overview of different forestry practices, their biodiversity benefits and the challenges in these practices. The aim of the table is to help make it easier to identify starting points – and decide on a level of ambition – for closer-to-nature forest management.

Table 1: Forestry and forestry-related land management practices and their biodiversity benefits and challenges

Name	Main characteristics	Limitations
Close-to-nature silviculture	Close-to-nature silviculture aims to 'optimise maintenance, conservation, and utilisation of forest ecosystems in such a way that the ecological and socioeconomic functions are sustainable and profitable'[27]. Its main focus is single-tree selection harvesting based on a set of principles that can be translated to local conditions and challenges. Smaller group harvesting (< 0.2 ha) makes it possible to create 'mosaic' stands composed of a variety of tree species.	Risk of limited flexibility to ensure adaptive capacity of forest ecosystems in a changing climate subject to shifting ecological conditions and societal needs[28].
Integrated forest management 'Integrate Network'	Integrated forest management means combining the provision of several ecosystem services in one forest landscape. The Integrate Network focuses on aligning biodiversity conservation and sustainable wood production.	Maintaining or restoring the different components of forest biodiversity requires a comprehensive concept. This concept should combine segregative (protected areas/no-go areas) and integrative (off-reserve) conservation instruments in managed forests.

[27] Pro Silva. (2012). *Pro Silva Principles*. https://www.prosilva.org/close-to-nature-forestry/pro-silva-principles/

[28] O'Hara K. L. (2016). What is close-to-nature silviculture in a changing world? *Forestry: An International Journal of Forest Research, 89*(1), 1-6. https://doi.org/10.1093/forestry/cpv043

		The goal of this combination is to support species within hotspots of their occurrence as well as across the forest matrix, at different spatial (stand, forest patch and landscape) and hierarchical (genes, species populations, communities and ecosystems) scales[29].
CCF	CCF or uneven-aged management maintains a heterogenous forest structure within a stand, by periodically selecting and harvesting individual trees or groups of trees[30]. Clear-felling is preferably limited to 0.25-ha areas to ensure continuity of woodland conditions. Modelling suggests that CCF management has benefits for carbon sequestration, biodiversity and other ecosystem services depending on the presence of deciduous trees and the extent of the mature forest structure[31,32].	Biodiversity benefits depend on the level of wood harvest intensity and how this intensity interacts with other measures like set-aside areas or deadwood retention[28].
Triad management	Triad management – also called combined objective forestry[33] – organises a forest in sectors with varying levels of management intensity and integration. Protected areas and intensive forest-use systems account for a part of the landscape, with the remainder occupied by integrated management systems, for example, continuous-cover and close-to-nature forest management. In this way 'triad management' (i.e. combining the three types of protected areas, intensive forest-use systems and integrated management systems) can make it possible to combine the conservation of a broad range of biodiversity with other forest management objectives[34].	This approach remains largely untested as to its biodiversity benefits in practice. There is a risk that separating a forest into areas with individual objectives might undermine multifunctionality and resilience. The implementation of triad management in mixed-ownership settings will require close cooperation and coordination among different owners[26].
Silvopastoral systems/Agroforestry	Agroforestry and agro-silvo-pastoral systems combine tree growing with agriculture on the same land. They are characterised by low tree density, low canopy closure, and low biomass and low-quality timber. Nevertheless, these systems are highly valuable woody landscapes for biodiversity, as they host many rare and endangered species. They are also multifunctional landscapes that provide multiple ecosystem services, including wood production. Traditional management techniques (such as mowing, coppicing and livestock grazing) keep a lower canopy, and maintain grasslands.	Agricultural landscapes have rapidly changed in recent decades, due to agricultural intensification, an exodus of people from rural areas, the abandonment of traditional practices and the natural regeneration of forests. These processes have all posed a threat to landscape and biodiversity conservation. Depending on the conservation vision, it is possible that there might be a need to restore and maintain natural processes or low-intensity management practices, even as complementary strategies[31].
Retention forestry	Retention forestry aims to strengthen biodiversity considerations in even-aged management and clear-cutting systems. It can also be applied in CCF. Biodiversity and ecological function at different spatial scales are promoted by strengthening continuity in forest structure, composition and	The benefits of tree retention as a conservation measure for biodiversity in clear-cut forests depend strongly on the position and volume of retention trees left in the stand. Post-harvest mortality can be significant

[29] Kraus D., & Krumm F. (Eds) (2013). Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute; Krumm, F. et al. (Eds) (2020). *How to balance forestry and biodiversity conservation – A view across Europe*. European Forest Institute and Swiss Federal Institute for Forest, Snow and Landscape Research.

[30] Gustafsson, L. et al. (2020). Retention as an integrated biodiversity conservation approach for continuous-cover forestry in Europe. *Ambio, 49*, 85-97. https://doi.org/10.1007/s13280-019-01190-1

[31] Peura, M. (2020). *Continuous cover forestry, biodiversity and ecosystem services* (Publication No 204) [Doctoral dissertation, Jyväskylän yliopisto]. JYU dissertations. http://urn.fi/URN:ISBN:978-951-39-8114-3

[32] Díaz-Yáñez, O. et al. (2020). Multifunctional comparison of different management strategies in boreal forests. *Forestry: An International Journal of Forest Research, 93*(1), 84-95. https://doi.org/10.1093/forestry/cpz053

[33] Duncker, P. S. et al. (2012). Classification of forest management approaches: A new conceptual framework and its applicability to European forestry. *Ecology and Society, 17*(4), Article 51. http://dx.doi.org/10.5751/ES-05262-170451

[34] Muys, B. et al. (2022). *Forest biodiversity in Europe. From Science to Policy 13*. European Forest Institute. https://doi.org/10.36333/fs13

	complexity[35]. Variable retention levels at landscape scale ensure structural diversity. The quality, diameter and age of tree species are important parameters.	depending on factors such as tree species and diameter[36]. Tree retention cannot maintain the structures and the microclimate that are important for species living in mature and old-growth forests. At present, it is unclear if red-listed species benefit from tree retention[37].

PART III – THE CLOSER-TO-NATURE FOREST MANAGEMENT TOOLBOX

Different types of interventions throughout the forest management cycle can help to: (i) strengthen structural complexity and natural dynamics; (ii) reduce anthropogenic pressures; (iii) protect habitats and species; and (iv) manage landscape connectivity. These interventions should be considered as mutually complementary, and the frequency and intensity of these interventions should depend on the local context. The box below sets out interventions and their objectives used in closer-to-nature forest management.

- Promoting natural tree regeneration
- Ensuring respectful harvest conditions
- Minimising other management interventions
- Preserving and restoring forest soils and water ecosystems
- Optimising deadwood retention
- Setting areas aside
- Protecting specific species on-site
- Managing ungulate species at natural carrying capacity
- Taking a scale-specific approach

Promoting natural tree regeneration

Natural regeneration should be the prevailing approach to regenerate forests. Natural regeneration promotes genetic diversity in the forest and thus promotes the adaptive resilience of forest stands. When the residual forest stand is characterised by features desired in the next generation (such desired features include: native and/or climate-adapted pioneer species, inter-species and intra-species genetic diversity, local provenance, quality, resistance and vitality), one should strive for the use of self-sown plants or vegetative propagating material (i.e. natural regeneration).

Artificial regeneration may be needed to complement natural regeneration in specific situations[38] such as those set out in the bullet points below.

- When there is reduced natural genetic diversity due to the historic use of uniform regeneration materials, and/or materials from inappropriate genetic sources.
- When there has been unsuccessful natural regeneration (e.g. due to the absence of suitable seed trees, ungulate grazing pressure or competitive ground vegetation). The introduction of highly biodiverse woodland islets composed of native species might be a tool for combining natural and artificial regeneration in areas without seed trees.

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[35] Kraus D., & Krumm F. (Eds) (2013). Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute; Krumm, F. et al. (Eds) (2020). *How to balance forestry and biodiversity conservation – A view across Europe*. European Forest Institute and Swiss Federal Institute for Forest, Snow and Landscape Research.

[36] Hämäläinen, A. et al. (2016). Retention tree characteristics have major influence on the post-harvest tree mortality and availability of coarse woody debris in clear-cut areas. *Forest Ecology and Management, 369*, 66-73. https://doi.org/10.1016/j.foreco.2016.03.037

[37] Gustafsson, L. et al. (2010). Tree retention as a conservation measure in clear-cut forests of northern Europe: A review of ecological consequences. *Scandinavian Journal of Forest Research, 25*(4), 295-308. https://doi.org/10.1080/02827581.2010.497495

[38] Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

- When there is a need for assisted migration to facilitate climate-adapted regeneration. This approach must always be cautious and gradual, following the precautionary principle.
- When there is a focus on restoring a suitable habitat for a species, such as when managers plant edible vegetation in order to create a food habitat for a precise species (e.g. the LIFE+ Corredores OSO introduced a food species to attract bears in the Pyrenees).

When natural regeneration is not working even if there are sufficient seed trees, it may be necessary to understand and tackle the processes that are hampering natural regeneration. Forest regeneration does not depend on the regeneration of the vegetation exclusively but requires a broader approach covering all forest ecosystems. For example, when soils are severely degraded (e.g. when they have high pH levels) or are under a very active degradation process (gully erosion), these problems may need to be addressed before artificial or natural regeneration can successfully take place.

Artificial regeneration should be based on reproductive materials obtained from natural stands or native trees of local provenance deployed in seed orchards mimicking natural pollination and reproduction. This may include materials from pioneer species for assisted migration to promote climate change adaptation. Nurseries may need to be adapted so that they offer a broader variety of native species. Selection should aim for vigorous and genetically diverse seed crops adapted to the site.

Closer-to-nature measures provide different possibilities to minimise the risk associated with climate change. Such measures include: supporting natural regeneration; creating mixed stands; and the gradual and cautious introduction through assisted migration of seedlings or small groups of pioneer species adapted to the site. Native species of local provenance adapted to the site should be favoured, including pioneer or low-productivity species. However, the use of non-native species adapted to future climatic conditions may be considered in very specific cases, for example, as pioneer or nurse trees that protect the regeneration of native species. In this context, important adaptability criteria include resistance to drought and heat, and compatibility with the existing ecological system notably the mycorrhizae as well as pest resilience and disease resilience.

Extensive manipulation of soils (scarification) and hydrology (ditching and the construction of access roads) should be avoided or minimised to exceptional and well-justified cases under due consideration of its biodiversity impacts. The preparation of seeding sites should be limited to the planting hole. Loosening the spacing of crops, especially increasing the distance between rows of artificially introduced seedlings, can help to increase species diversity. This creates better opportunities for the self-sowing of many valuable, auxiliary tree and shrub species as well as herbaceous vegetation.

The Commission guidelines on biodiversity-friendly afforestation, reforestation and tree planting provide further guidance[39].

Ensuring respectful harvest conditions

When planning harvesting operations, it is necessary to take account of the need to preserve all the functions of the forest. This should be achieved by respecting all parts of the forest ecosystem (in particular, the soil, watercourses, and other natural environments within the forest and their buffer zones). But it should also be achieved by respecting all the individual trees and their ecological functioning in the stand, whether they are mature individuals, poles or seedlings. To preserve the forest's internal microclimate, wood production and regeneration should aim to safeguard and/or

[39] SWD(2023)61.

facilitate the rebuilding of the corresponding site-specific: (i) tree numbers; (ii) canopy; or (iii) share of canopy.

When harvesting wood, any intensive practice must be avoided as much as possible and subject to thorough qualitative analyses in relation to biodiversity benefits and increasing carbon stock capacity in the forest ecosystem and in the harvested wood products. The technique proposed by multifunctional approaches to promote diverse stands is partial harvesting (i.e. single-tree selection, group selection, or gap cuts (max. 0.2-0.5 ha)) mimicking natural disturbance patterns, as opposed to 'clear-cutting' larger areas. Clear-cuts reduce environmental complexity, alter natural ecosystem processes and thus diminish habitat variety. Clear-cuts also provide less support for high levels of species diversity[40]. Species composition and richness shift immediately after clear-cutting to species that are well adapted and thrive in disturbed or open habitats[41]. This risks increasing the negative effects of forest fragmentation on the distribution of sensitive forest bird species within forest fragments[42]. Below ground, fungal community composition decreases after clear-cutting, and there is especially a decrease in ectomycorrhizal fungi, which have important roles in carbon cycling and mediating disturbance-induced effects on soil[43]. When mechanisation is used during clear-felling, it often results in soil compaction and surface humus heterogeneity, enabling herb communities to gradually dominate the area, affecting the carbon and nitrogen cycle and hampering natural tree regeneration[44].

At the same time, small openings in selection gap cuts (max. 0.2-0.5 ha) can create suitable climatic conditions for species that prefer semi-shaded or semi-open conditions and enrich the forest structure. The formation of clear-cut felling margins in the form of bays creates favourable conditions for the establishment of self-sown plants and, above all, differentiates the light and heat conditions in the felling. Where natural disturbance regimes have been reduced or eliminated, small clear-cuts might be needed as part of restorative forest management to temporarily mimic natural disturbances. Decisions on the timing and location of small openings should reflect a mosaic approach to avoid small openings that are next to each other or within a short distance of each other and that could cumulate to have effects similar to a larger clear-cut scenario.

During harvest, buffer zones along streams should be set to reduce the impacts of harvesting on water courses in the forest[45]. The width of these buffer zones needs to reflect their purpose and the order of the riparian stream. For small streams in particular, buffers are often too small[46]. Different studies recommend buffer zones of 30 metres in width for small streams[47] and similar watercourses for the

[40] García-Tejero, S. et al. (2018). Natural succession and clearcutting as drivers of environmental heterogeneity and beta diversity in North American boreal forests. *PLoS ONE, 13*(11), Article e0206931. https://doi.org/10.1371/journal.pone.0206931

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[45] Kuglerová, L. et al. (2020). Cutting edge: A comparison of contemporary practices of riparian buffer retention around small streams in Canada, Finland, and Sweden. *Water Resources Research, 56*(9), Article e2019WR026381. https://doi.org/10.1029/2019WR026381

[46] Kuglerová, L. et al. (2020). Cutting edge: A comparison of contemporary practices of riparian buffer retention around small streams in Canada, Finland, and Sweden. *Water Resources Research, 56*(9), Article e2019WR026381. https://doi.org/10.1029/2019WR026381

[47] Sweeney, B. W., & Newbold, J. D. (2014). Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: A literature review. *Journal of the American Water Resources Association, 50*(3), 560-584. https://doi.org/10.1111/jawr.12203

protection of ecological integrity[48]. In these areas, it is recommended that natural ecotone zones are left in place or are created, especially by planting and nurturing shrubs where they do not exist.

One key element that must be maintained to ensure structural complexity is habitat trees. These trees have the physical characteristics of ancient trees even if they are not very old. For example, they are characterised by: (i) large girth; (ii) the progressive narrowing of successive annual increments in the stem; (iii) the ageing and associated decay of the central wood; (iv) the presence of hollows and cavities; and (v) changes in crown architecture and/or retrenchment. These singular structures provide unique microhabitats that are key elements for biodiversity conservation in forests. Specialist forest habitat species, which are more likely to be susceptible to extinction than generalist species, are often linked to these old-growth structures. Generalist species inhabit a wide niche range and can use diverse habitat resources. Conversely, specialist species inhabit narrow niche ranges and use limited habitat resources. Generalist species are therefore more likely to be tolerant of variable environment conditions than specialist species. Specialist species, meanwhile, are more likely to be susceptible to extinction. This means that the population trends for specialist forest species are declining in Europe.

Old trees or trees reaching a senescent stage are often host to tree-related microhabitats. A tree-related microhabitat is a distinct, well-delineated structure occurring on a living or standing dead tree that constitutes a particular and essential substrate or life site for species or species communities during at least a part of their life cycle to develop, feed, shelter or breed. Recent research has demonstrated the correlation between forest biodiversity and the abundance and diversity of tree-related microhabitats at the stand scale. These structures appear in all forests, even at a young age of the trees. To maintain these tree-related microhabitats, it is not only necessary to conserve existing tree-related microhabitats, it is also necessary to: (i) value and conserve forest stands with the potential to form tree-related microhabitats in the future; and (ii) avoid cutting down potential habitat trees during thinning operations[49]. In certain forest types, tree-related microhabitats dramatically improved on trees with diameter at breast height (DBH) ≥ 70 cm.

During ecologically sensitive periods such as nesting or breeding periods ideally, harvesting should not take place or minimise disturbance to birds in line with Article 5 of the EU Birds Directive[50]. Primary and old-growth forests remaining in the EU should be strictly protected considering their high value for both biodiversity and climate change mitigation[51]. The Commission guidelines for defining, mapping, monitoring and strictly protecting EU primary and old-growth forests provide further information and guidance on this subject[52].

Minimising other management interventions

Although closer-to-nature forest management aims to rely as much as possible on natural dynamics, some interventions may still be needed. Limited organic fertilisation can help to improve tree health by correcting nutrient imbalances in the soil (for example, boron deficiency), and carefully conducted liming can also help to prevent soil acidification. However, external inputs should be kept to a minimum and their composition carefully chosen to avoid sudden changes in the pH or nutrient content of the soil, since these risk damaging soil biodiversity or understory. Nitrogen fertilisers

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[50] Directive 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds.

[51] Barredo, J. I. et al. (2021). *Mapping and assessment of primary and old-growth forests in Europe*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/797591

[52] Guidelines for Defining, Mapping, Monitoring and Strictly Protecting EU Primary and Old-Growth Forests (europa.eu)

damage: (i) the richness and diversity of plant species; and (ii) the abundance of mosses, lichens, mycorrhizae, ground beetles, amphibians and ungulates[53]. In addition, fertilisers may hamper root development and therefore have a negative impact on trees' resistance to droughts[54].

Under certain exceptional conditions that would need rigorous assessment before use, the targeted use of biological pesticides might be acceptable to treat outbreaks of pests or pathogens in the absence of other possible measures. Here, it is important to note that closer-to-nature forest management will strengthen natural resilience to outbreaks of pests and diseases associated with a specific tree species (e.g. bark beetle and root rot in spruce) as the dispersal possibilities for such pests and diseases will be limited in mixed and varied stands compared to monoculture forests.

Preserving and restoring soil and water ecosystems in forests

Forest soil is an ecosystem of its own. It teems with life and stores large amounts of carbon. The condition of soil is crucial for the condition of a forest and for the forest's role in promoting biodiversity and climate change mitigation. The health of forest soil must be protected as much as possible to prevent serious and permanent deterioration. One relevant factor in the health of forest soil is fungi. Fungi act as symbionts, decomposers and pathogens, playing significant functions in forest ecosystems. The diversity of mushrooms is a prerequisite for forest health and vice versa. In a nutshell: Without fungi, no forest – without forest, no mushrooms.

Ploughing and tillage operations affect both: (i) the health of fungi and soil; and (ii) forest resilience. This is because these operations reduce the abundance of species that help to reduce harmful forest pests[55]. Recent studies also show that the shaping of terraces (introduced in mountainous regions to prevent erosion in plantations) has significant negative impacts on soil functions, and that it promotes erosion, biodiversity loss and the loss of soil organic content[56]. In addition, the impact of heavy machinery and the building of access roads can lead to superficial and deep impacts, such as: soil erosion; soil removal; soil displacement; soil compaction; rutting; puddling and consequent hydromorphology; soil asphyxiation; the stimulation of germination of competing social herbaceous or semi-ligneous species. All these impacts hamper the natural regeneration of forest soil. Those negative impacts must be avoided as much as possible by promoting minimal intervention techniques. When it is not possible to avoid machinery, light or low-bearing machines (or, in general, machines with a large and light footprint, such as tracks) must be preferred.

Protecting natural landforms and geomorphic processes is the basis of healthy soils, but it is also the basis of healthy aquatic ecosystems. Forests include aquatic ecosystems such as wetlands, rivers and lakes, making them an important component of water management. Preserving the quantity and quality of water ecosystems makes it possible to reduce the impact of droughts on surrounding ecosystems and human activity.

Riparian forests are an important part of river dynamics and have an important role in providing different ecosystem services[57] such as: (i) flood protection downstream; (ii) the control of sediment;

[53] Muys, B. et al. (2022). *Forest biodiversity in Europe. From Science to Policy 13*. European Forest Institute. https://doi.org/10.36333/fs13

[54] Jacobs, D. F. et al. (2004). Fertilization at planting impairs root system development and drought avoidance of Douglas-fir (*Pseudotsuga menziesii*) seedlings. *Annals of Forest Science, 61*(7), 643-651. https://doi.org/10.1051/forest:2004065

[55] Kosewska, A. et al. (2018). Assemblages of carabid beetles (Col. Carabidae) and ground-dwelling spiders (Araneae) in natural and artificial regeneration of pine forests. *Community Ecology, 19*(2), 156-167. https://doi.org/10.1556/168.2018.19.2.8

[56] Dos Santos Martins, M. A. (2022). *Integrated impact assessment of terrace construction on forest soil functions* [Doctoral dissertation, Universidade de Aveiro].

[57] Barth, N.-C., & Döll, P. (2016). Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach. *Ecosystem Services, 21*(Part A), 39-52. https://doi.org/10.1016/j.ecoser.2016.07.012

(iii) the stabilisation of riverbanks; (iv) the prevention of surface water pollution; and (v) the provision of shade, shelter and food for different aquatic organisms. Riparian forests also provide wildlife habitats and corridors for terrestrial organisms. Periodic removal of riparian vegetation, traditionally called 'clean-ups', should be avoided, as it does not have any proven function in reducing the impact of floods, but it can have strong negative ecological, hydrological and hydrogeological impacts on the river or stream concerned.

Optimising deadwood retention

There is no waste in the forest. Deadwood plays an important role in the forest ecosystem by serving as a natural habitat, a nutrient pool, water storage and a precursor of soil organic matter for several thousand species. In addition, deadwood accumulation is positively correlated with higher stand age and greater growing-stock volume, and it has also been found to be linked to higher quality in forest soils[58].

In Europe, it has been estimated that 20-40% of organisms in forested ecosystems, so-called saproxylic species, are dependent on dead or dying wood at some point in their life cycle[59]. The volume of deadwood required by species is much greater than the amounts required in the management plans (MP) of some selected Natura 2000 sites, as shown in Figure 4[60].

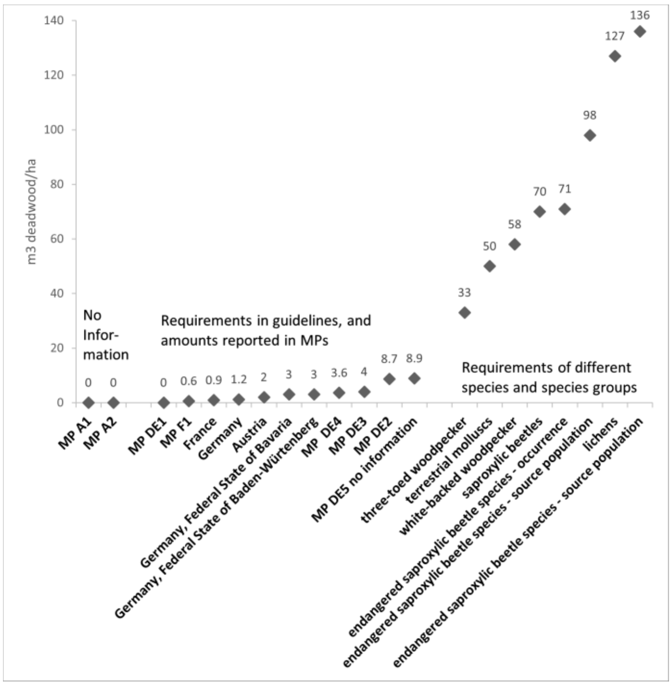

Figure 4: Deadwood requirements

Certain species of fungus, lichen, moss and insect will not occur in a forest without deadwood. After deadwood volume, the type of deadwood and its stage of decay are the next most important features of deadwood for species promotion. Bird species such as woodpeckers, titmice and cuckoos find the most favourable conditions on standing dead trees with a breast height DBH of over 25 cm, even on broken trees without crowns.

Leaving enough deadwood in the forest in all stages of decomposition (including standing dead and dying trees with actual or potential cavities for nesting and roosting) is therefore an important measure for biodiversity restoration and conservation. It can be particularly valuable to leave den (hollow) trees in the forest, especially near roads, near dividing lines, and on the edges of the forest bordering agricultural land and water bodies. This is because deadwood in these three areas is especially helpful in providing living space for many animal species. The issue of how much deadwood is enough – meaning enough to satisfy biodiversity needs – has been the topic of many articles and

[58] Bujoczek, L. et al. (2021). How much, why and where? Deadwood in forest ecosystems: The case of Poland. *Ecological Indicators, 121*, Article 107027. https://doi.org/10.1016/j.ecolind.2020.107027

[59] Bauhus, J. et al. (2018). *Dead wood in forest ecosystems*. Oxford Bibliographies Online Datasets. https://doi.org/10.1093/obo/9780199830060-0196

[60] Winter, S. et al. (2014). The impact of Natura 2000 on forest management: A socio-ecological analysis in the continental region of the European Union. *Biodiversity and Conservation, 23*, 3451-3482. https://doi.org/10.1007/s10531-014-0822-3

discussions[61,62]. Depending on the type of forest and the sort of management applied, the amount of deadwood present in a forest can vary enormously. For central European forest types, establishing forest stands with deadwood amounts of more than 20 m^3 ha^{-1} in a network of forest landscapes rather than a lower mean in all stands has been recommended for biodiversity conservation[63].

Actual volumes, density and locations should be decided with consideration given to fire management, safety aspects (recreation), and the control of pest outbreaks guided by biological knowledge, management objectives, and the situation in a particular stand (forest type, basal area of living trees, stand age, natural disturbances and species composition). Removing all deadwood (for example, as part of sanitary logging to address extreme events) should be seen as a last solution. This is because it will counteract efforts to improve biodiversity, for example, by: (i) disrupting natural processes and regeneration; (ii) simplifying landscape heterogeneity; and (iii) increasing susceptibility to further natural disturbances. Where disturbance by bark beetles, storms or floods are natural parts of the forest ecosystem, and unnatural gaps without biomass would be created, sanitary logging should not be considered.

Setting areas aside

Voluntary set-aside areas can be a measure to support closer-to-nature forest management. These areas are an important tool for integrating biodiversity conservation into forest management. They facilitate the preservation of key habitats and topological features, like streams, woodland ponds and peat bogs. They also facilitate the establishment of transition zones between different landscape features. Many forest owners leave set-asides in places that are important for them or that are difficult to harvest. However, the actual benefit of set-asides for biodiversity will depend on: (i) how well the needs for biodiversity conservation and biodiversity restoration in a given area are covered; and (ii) a set of parameters including the permanence, size, representativeness and connectivity of these set-aside areas. Assessments of nature conservation value that consider these parameters can help to estimate actual biodiversity benefits. Free-developing stands that cover areas greater than 2 ha have a high probability of providing sufficient deadwood quantity and diversity to support saproxylic species[64]. Set-aside areas larger than 10 ha have been shown to provide a diverse resource of tree related microhabitats[65]. For the conservation of lesser-spotted woodpeckers (*Dendrocopos minor*), management should focus on a minimum of 40 ha of forest dominated by deciduous trees, which may be fragmented over a maximum of 200 ha[66].

Summing up, the selection and establishment of set-aside areas should aim to:

- preserve tree-related microhabitats and veteran trees to contribute to multi-taxon species richness in forest ecosystems;
- allow parts of trees to go through their full life cycle and preserve forest biota in forest landscapes that are representative of the different development stages of a forest to strengthen naturalness;

[61] Bütler Sauvain, R. (2003). *Dead wood in managed forests: how much and how much is enough?* (Publication No. 2761) [Doctoral dissertation, École polytechnique fédérale de Lausanne]. EPFL scientific publications. https://infoscience.epfl.ch/record/33236?ln=en

[62] Müller, J. (2007). How much deadwood does the forest need? A science-based concept against species loss on coenoses of dead wood. *Naturschutz und Landschaftsplanung, 39*(6), 165-170.

[63] Müller, J., & Bütler, R. (2010). A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. *European Journal of Forest Research, 129*, 981-992. https://doi.org/10.1007/s10342-010-0400-5

[64] Jakoby, O. et al. (2010). Modelling dead wood islands in European beech forests: How much and how reliably would they provide dead wood? *European Journal of Forest Research, 129*, 659-668. https://doi.org/10.1007/s10342-010-0366-3

[65] Larrieu, L. et al. (2014). Tree microhabitats at the stand scale in montane beech–fir forests: Practical information for taxa conservation in forestry. *European Journal of Forest Research, 133*, 355-367. https://doi.org/10.1007/s10342-013-0767-1

[66] Wiktander, U. et al. (2001). Seasonal variation in home-range size, and habitat area requirement of the lesser spotted woodpecker (*Dendrocopos minor*) in southern Sweden. *Biological Conservation, 100*(3), 387-395. https://doi.org/10.1016/S0006-3207(01)00045-3

- help protect threatened species (e.g. on the IUCN Red List and on national lists of threatened species);
- facilitate biodiversity networks and corridors across scales in coordination with adjacent forest owners/managers (in this context, it is particularly important to outline the need to avoid fencing[67] around forest areas, except in particular cases[68]);
- promote integrative tools to preserve the richness of rare and threatened species to support species diversity and representativeness within conservation hotspots;
- ensure the diversity of associated habitats and species linked to the forest (e.g. water ecosystems such as ponds, riparian forests, peat bogs, rocky areas and grassland);
- maintain or improve trees that stand out (remarkable or heritage trees) because of their beauty, size or age, and also maintain or improve landscape elements (viewpoints, remains, etc.) to conserve natural heritage.

Taking a scale-specific approach

Scale matters in closer-to-nature forest management. The management needs to take account of three levels: (i) the level of individual trees and groups of trees; (ii) the level of the stand; and (iii) the level of the landscape. The paragraphs below look at each of these levels in more detail.

The level of individual trees and groups of trees

Management measures specified for individual trees or groups of trees should take account of their role in the forest ecosystem throughout their life cycle. During forestry management operations, each tree or group of trees should therefore be evaluated in terms of its usefulness. Criteria for harvesting should consider the trees' role in the ecosystem and should balance climate, environmental, social and economic criteria in line with the overall objectives of: (i) restoring and conserving biodiversity; and (ii) promoting resilience against climate change.

The level of the stand

The stand, a spatially explicit part of the forest defined by selected commonalities, is a crucial level for planning forest management for both ecological and economic purposes. The size of a stand can vary from a few to several hectares. Commonalities for delineating a stand should be chosen in line with the stand's closer-to-nature objectives (e.g. to increase within-stand variability). These objectives could include vertical complexity, soil fertility, tree age or dominant tree species. In any case, the definition of a stand's boundaries should be flexible and make it possible to adapt to changes in the light of natural dynamics, forest-ecosystem dynamics or landscape planning.

The level of the landscape

Promoting structural complexity and the heterogeneity of a forest ecosystem is also relevant at landscape level. However, this is not always in the hands of the forest owners. It requires a certain degree of planning that goes beyond the forest holding and might have to involve some intervention or 'nudging' from the competent authorities to promote diversity at landscape level. The benefits of such a 'mosaic' approach include the increase in the abundance of species or groups of species across a landscape. If those mosaics of diverse forests are coupled with ecological corridors, the benefits are multiplied and positively affect: (i) the richness, abundance and services provided by pollinators; as well as (ii) the genetic diversity of many other species. Where landscapes cover large areas of a river catchment, increasing forest share can also have a positive effect on river-fish biomass. Moreover,

[67] Sun, J. et al. (2021). Fences undermine biodiversity targets. *Science, 374*(6565), 269-269. https://doi.org/10.1126/science.abm3642

[68] Jaeger, J. A. G., & Fahrig, L. (2003). *Under what conditions do fences reduce the effects of transportation infrastructure on population persistence?* Habitat fragmentation due to transport infrastructure & COST-341 action - IENE 2003. https://www.glel.carleton.ca/RESEARCH/pdf/landPub/04/04JaegerFahrigIENE03.pdf

landscape-scale management enables economies of scale on certain services and investments, creating synergies across ownership and balancing the different interests of different players.

For wood harvesting, a mosaic approach to landscape-level management of forests also makes it possible to balance exploitation intensity with biodiversity restoration, conservation and climate change resilience. Harvesting operations or gap-cutting of limited size (e.g. to promote the restoration of light-demanding species) needs consideration in a wider context. Otherwise, there is a risk of cumulative impacts with, for example, many small-gap cuts within a given area or over a short period becoming one big clear-cut.

Managing ungulate species at natural carrying capacity

While not the focus of these guidelines, it is important to address the management of ungulate species, considering its implication for natural and artificial forest regeneration processes.

Grazing pressure is quite high in many European forests, hampering natural and artificial forest regeneration and the permanent and quick renewal of mixed stands. Reasons for this high grazing pressure can include the limited availability of alternative forage. Promoting or maintaining ground vegetation can help to reduce grazing pressure on seedlings and saplings. It is necessary to protect existing or expected seedlings so as not to jeopardise the future of the forest in areas where damage by ungulate species is such as to compromise the renewal and natural diversity of the forest.

To protect seedlings from grazing there are two options that have proven effective. The paragraphs below address each of these options in turn.

1. Create adapted and site-specific barriers or protective measures such as stem fencing or temporary and small-scale plot fencing in a way that does not disturb the connectivity of forest habitats.

These barriers and measures might entail high costs to install and maintain. For oak trees, evidence shows[69] that fencing has a strong positive effect on height growth during the first 5 years after installation of the fencing. In the long run, however, the protective effect from fences can be complicated by competition from other woody vegetation. Compared to oak seedlings, other woody and faster-growing species that are also protected from grazing inside the fences may then out-compete the young oaks. Thus, growth and survival can also be reduced inside fences. Therefore, management interventions may be needed in addition to fencing.

2. Regulate ungulate populations.

This option must be adapted to the state of the ungulate population, the state of biotopes and the extent of the damage. A balanced hunting policy, in combination with protective silvicultural measures, will allow young trees to develop, and at the same time make it possible to maintain healthy populations of ungulate species. The search for the right balance requires the cooperation of all relevant stakeholders (e.g. regulatory authorities, forest owners and hunters) reflecting on the distribution of ungulate populations concerned. It is often necessary to consider and analyse the wider landscape context to understand the sources of – and reasons behind – grazing damage in a forest stand.

[69] Löf, M. et al. (2021). The influence of fencing on seedling establishment during reforestation of oak stands: A comparison of artificial and natural regeneration techniques including costs. *European Journal of Forest Research, 140*, 807-817. https://doi.org/10.1007/s10342-021-01369-w

PART IV – ENABLING THE TRANSITION

A successful transition to implementing closer-to-nature forest management practices depends on a variety of critical enablers. This chapter provides an overview of the most common enablers and how to make best use of them.

Training and skills

There is growing interest in – and experience with – closer-to-nature forest management practices. However, the level of experience and interest is not evenly spread across countries or eco-regions. To promote the uptake of closer-to-nature forest management, there is a need to: (i) further improve awareness among forest owners and other stakeholders; and (ii) ensure knowledge transfer and relevant skills among forestry practitioners[70]. One of the ways that this can be supported is by setting up a platform for dialogue and exchange on closer-to-nature forestry opportunities and challenges. Two relevant networks to involve in such a platform are: (i) Pro Silva[71], an organisation dedicated to close-to-nature forest management; and (ii) Integrate Network[72], an organisation dedicated to integrating nature conservation into sustainable forest management.

The European Commission supports organisations that seek to strengthen training and skills. Through the Pact for Skills, a shared engagement model for skills development in Europe, the European Commission encourages stakeholders in a variety of sectors to join forces for upskilling and reskilling in Europe. Signatories of the pact can receive help to set up a network and they can also receive information and guidance on relevant policies, projects, instruments, best practices and relevant EU funding opportunities.

The European Social Fund Plus (ESF+) gives financial support to Member States: (i) for educational programmes on how to adopt more sustainable management practices; (ii) to promote forest biodiversity; (iii) to foster innovation in science; and (iv) to promote knowledge exchange.

Under the common agricultural policy (CAP), Member States can support various forms of cooperation, including European Innovation Partnerships, which could be very useful for trying new methods to improve the provision of ecosystem services in various ways.

Economic viability as a driver for closer-to-nature forest management

A recurrent demand by forestry practitioners in developing these guidelines was the need to address the economic viability of closer-to-nature forest management with – but also without – public subsidies. Economic viability in forest management is influenced by different factors, including site productivity, timber quality, market prices, market demand, timescales and operational costs. This section discusses aspects that should be considered for a context-specific cost-benefit analysis and business plan for closer-to-nature forest management and the transition to it.

Studies[73,74] and management experiences[75,76] suggest that closer-to-nature forest management can be financially more profitable than when forests are managed in an intensive manner. These studies and management experiences also show that this greater profitability can be achieved while simultaneously reducing risks of damages through storms or droughts for example. Operational costs

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[70] Mason, W. L. et al. (2021). Continuous cover forestry in Europe: Usage and the knowledge gaps and challenges to wider adoption. Forestry: *An International Journal of Forest Research, 95*(1), 1-12. https://doi.org/10.1093/forestry/cpab038

[71] https://www.prosilva.org

[72] https://integratenetwork.org/

[73] Knoke, T. (2009). On the financial attractiveness of continuous cover forest management and transformation: A review. *Schweizerische Zeitschrift fur Forstwesen, 160*(6), 152-161 (in German). https://doi.org/10.3188/szf.2009.0152

[74] https://www.uef.fi/en/article/continuous-cover-forestry-is-financially-profitable-in-spruce-dominated-peatland-forests.

[75] Learning from nature: Integrative forest management in Ebrach, Germany. https://www.researchgate.net/publication/346718854

[76] AFI. https://prosilva.fr/files/Brochure_AFI-180x240correc-04.pdf

for wood production are likely lower in closer-to-nature forest management compared with intensive forestry if the forest manager relies as much as possible on natural processes and limits interventions. These natural processes include: (i) scarification; (ii) complementary planting; (iii) cleaning, and thinning or post-clear-cut treatment of sites; and a (iv) deadwood-enrichment strategy. When forests are richer in biodiversity, they are more resilient against damage and against the loss of income due to storms, droughts, diseases or pest outbreaks. Furthermore, closer-to-nature forestry management can reduce the risk of pests due to the presence of more tree species of different ages. Therefore, forest management according to closer-to-nature principles will likely provide greater stability in timber production in the long term.

Partial and selective harvesting gives the possibility of harvesting trees when their individual financial maturity is attained. Longer retention cycles (i.e. cutting down trees when they are older) generate greater volumes of timber per tree and often higher-quality timber for longer-term uses like construction. Timber from such trees can typically fetch higher prices depending on market dynamics. These approaches have been shown to not radically change the overall economic viability of a forest, since ecological benefits are often linked to economic benefits[77]. A case study on a forest deadwood-enrichment strategy, achieved by only harvesting sawn wood (and to a minor degree industrial timber) and leaving the complete tree crowns on-site, has proven the strategy to be economically efficient.

However, the starting point in closer-to-nature forest management is often an even-aged managed stand, and the financial maturity of trees in such a stand is an important additional factor in the calculations of forest managers. The optimal age to convert from even-aged management to uneven-aged selection felling has been estimated at about 55 years for most types of forests, when sufficient natural seeding can be expected. If the stand is almost at the economic optimal rotation age, clear-felling can be the more profitable regime compared with closer-to-nature harvesting practices[78]. However, time and investment costs for transition to a structural, complex and diverse stand after clear-cutting will likely be higher and should be considered.

Forests have much more to offer than wood. Closer-to-nature forest management provides an opportunity to diversify economic profits for long-term benefits that mitigate market volatilities in wood prices and wood demand. This can help to compensate interim revenue losses from timber. Non-wood forest products, such as honey, mushrooms and wild meat, are marketable sources of income. In addition, the value of ecosystem services is also increasingly recognised in monetary terms. Payment-for-ecosystem-services schemes have been proven as a tool for rewarding forest owners and foresters for non-marketable forest services such as water purification, carbon sequestration or recreational possibilities. Payment-for-ecosystem-services schemes can be privately or publicly funded and provide an alternative or additional source of revenues. The European Commission's guidance on the development of public and private payment schemes for forest ecosystem services (currently being drawn up) will provide further information on EU support possibilities and examples of good practice. Moreover, the proposed EU-wide certification framework for carbon removals[79] will recognise both: (i) the quality and value of carbon sequestration activities; and (ii) possible sustainability co-benefits from the protection and restoration of biodiversity and ecosystems.

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[77] Mergner, U., & Kraus, D. (2020). Ebrach – Learning from nature: Integrative forest management. In F. Krumm et al. (Eds), *How to balance forestry and biodiversity conservation – A view across Europe* (pp. 205-217). European Forest Institute and Swiss Federal Institute for Forest, Snow and Landscape Research.

[78] Tarp, P. et al. (2000). Modelling near-natural silvicultural regimes for beech – An economic sensitivity analysis. *Forest Ecology and Management, 130*(1–3), 187-198. https://doi.org/10.1016/S0378-1127(99)00190-5

[79] Carbon Removal Certification (europa.eu)

Finances

A variety of EU funding instruments exist that can support closer-to-nature forest management. For example, these schemes can be used to: (i) compensate income foregone during a transition period; (ii) strengthen cooperation and innovation; or (iii) promote different measures in a specific context. A guide[80] on all funding options for the environment in the 2021-2027 funding programmes was published by DG Environment in 2022. It provides practical information on possible EU funding options and technical assistance for interested project promoters. The following paragraphs give a short overview of the most relevant funding opportunities for closer-to-nature forest management.

The **CAP**, and in particular its rural development programme[81] and 2023-2027 strategic plans[82], supports a variety of specific management commitments and investments. These commitments and investments support multifunctional forests and contribute to the maintenance and/or improvement of ecosystem services. Possible support under the rural development programme and national strategic plans includes, for example, investments in: (i) multifunctional sustainable forest management that contributes to the better provision of ecosystem services (biodiversity, water and soil protection, climate change adaptation, or increasing the social and cultural value of forests); (ii) specific and voluntary management commitments going beyond legal obligations and targeting biodiversity, habitat protection, water purification, recreation and public health; and (iii) the prevention and restoration of damage to forests from forest fires, natural disasters, and catastrophic events, including pest and disease outbreaks, and climate-related threats.

Under the new guidelines for **state aid in the agricultural and forestry sectors** and in rural areas[83], Member States can support services related to biodiversity, climate, water or soil. In addition to granting 100% compensation for additional costs and income foregone by providing these services, it will be possible for forest managers to receive an additional incentive of 20% of the eligible costs for the ecosystem services provided. Aid may also be granted to support voluntary management commitments that go beyond existing legal obligations and that contribute to: (i) climate change mitigation and adaptation; (ii) sustainable development and efficient management of natural resources such as water, soil and air; and (iii) halting and reversing biodiversity loss, improving ecosystem services, and preserving habitats and landscapes.

The **EU's LIFE Programme**[84] contributes to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value. The EU co-financing rate is between 60% and 75%, and projects are required to find the remaining 40-35% elsewhere. The current 2021-2027 programme for the environment and climate action has a budget of EUR 5.43 billion. The programme includes, for example, support to: (i) restore natural or semi-natural forest habitats and species in their structure, composition and functioning; (ii) improve forest resilience to fires, droughts, diseases and climate change, and prevent/reduce the impact of natural disasters; (iii) protect the EU's primary and old-growth forests; (iv) create ecological corridors and other green infrastructure; and (v) test/demonstrate new management approaches, including closer-to-nature forestry practices.

The **European Regional Development Fund (ERDF), ESF+ and Cohesion Fund** provide investments to measures such as: (i) protecting and preserving nature and biodiversity; (ii) managing and restoring Natura 2000 sites and other biodiversity hotspots; (iii) creating interconnections between green

[80] Find your EU funding programme for the environment (europa.eu)
[81] Rural development (europa.eu)
[82] CAP Strategic Plans (europa.eu)
[83] OJ C 485, 21.12.2022, pp. 1-90.
[84] https://cinea.ec.europa.eu/programmes/life_en

spaces (e.g. green corridors); (iv) ecosystem restoration projects; (v) nature-based solutions for climate change adaptation and disaster risk reduction; and (vi) green infrastructure with multiple benefits (climate, water, air and risk management).

The **Technical Support Instrument**[85] provides technical support upon request to help Member States design and implement reforms at Member State level. The support is provided upon request by a Member State and across a wide range of policy areas, including the implementation of the EU's forest and biodiversity strategies at Member State level.

Beyond public financing, also private certification schemes under the future EU carbon removal certification framework will enable land managers to market their forest ecosystem services, thus supporting the development at scale of closer-to-nature forest practices.

Mapping and monitoring biodiversity and forest trends

Forests are complex systems, and many forests have been subject to regulatory interventions for centuries. This makes it difficult to assess biodiversity trends and predict how the forest ecosystem and its biodiversity will react to measures applied. It will be important to establish baselines to evaluate progress and set measurable objectives for biodiversity improvements. Remaining patches of primary and old-growth forests can be useful for baseline setting, since their ecosystem dynamics and biodiversity patterns can be a reference for a natural forest system in a specific context[86]. It will also be important to assess the status quo and closely monitor both biodiversity development and reactions to forest management measures. The lessons learned from this should be included in further management activities. To that end, it will be key to develop an EU-wide robust monitoring framework enabling the collection of accurate, timely, comparable and accessible forest data, as also announced by the EU forest strategy[87]. Measurable biodiversity indicators, thresholds and targets are important to assess status and trends in biodiversity. Their selection should be representative of the forest ecosystem, its microhabitats and its biodiversity as a whole. As a given tree stand or plot might represent only part of a forest ecosystem, it will be important to ensure that assessment and monitoring take place at a meaningful scale by seeking coordination with neighbouring forest owners and managers[88]. Table 2 provides some examples of indicators relevant for biodiversity in forest ecosystems.

Table 2: Examples of indicators relevant for biodiversity[89]

Good forestry practice	Example indicators
FOREST-STAND AND FOREST-OWNERSHIP LEVEL	
1. Retention of vegetation and large trees in logged areas on-site	Litter cover, vegetation diversity, soil disturbance, tree species diversity, deadwood volume and structure, lying deadwood, microhabitats, old/veteran trees, basal area, diameter diversity, distance to forest edge, forest/tree age, forest area, growing stock, stand diversity
2. Retention of deadwood	Deadwood composition, size of pieces of deadwood, deadwood diversity, deadwood amount, lying deadwood, standing deadwood, basal area

[85] Regulation (EU) 2021/240 of the European Parliament and of the Council of 10 February 2021 establishing a Technical Support Instrument.
[86] Maes, J. et al. (2023). Accounting for forest condition in Europe based on an international statistical standard. *Nature Communications, 14*, Article 3723. https://doi.org/10.1038/s41467-023-39434-0
[87] The legislative initiative on establishing a monitoring framework for resilient European forests by the European Commission is planned for Q3 2023.
[88] Zeller, L. et al. (2022). Index of biodiversity potential (IBP) versus direct species monitoring in temperate forests. *Ecological Indicators, 136*, Article 108692. https://doi.org/10.1016/j.ecolind.2022.108692
[89] after Oettel, J., & Lapin, K. (2021). Linking forest management and biodiversity indicators to strengthen sustainable forest management in Europe. *Ecological Indicators, 122*, Article 107275. https://doi.org/10.1016/j.ecolind.2020.107275

3.	**Variation of management practices and strategies in and between stands**	Natural regeneration, ground vegetation cover, vegetation diversity, tree composition, deadwood amount, canopy cover, canopy diversity, tree height
4.	**Provide habitat structures for specific species**	Standing deadwood, branchiness, cavities, microhabitats, protected species, deadwood amount
5.	**Use natural disturbance regimes as a template for logging activities**	Ground vegetation cover, water bodies, tree height, basal area, forest/tree age, stand diversity
6.	**Allowing natural regeneration**	Tree species diversity, water bodies, tree height, basal area, forest/tree age, stand diversity
7.	**Mixed-species stands**	Vegetation diversity, tree species composition, tree species diversity, stand diversity, management type, share of broadleaves, share of native species, share of coniferous trees, tree species composition, old/veteran habitat trees
8.	**Set-asides within production forests**	Litter cover, vegetation diversity, soil disturbance, tree species diversity, deadwood volume and structure, deadwood amount, lying deadwood, microhabitats, old/veteran trees, basal area, diameter diversity, distance to forest edge, forest/tree age, forest area, growing stock, stand diversity
9.	**Use of locally indigenous trees**	Share of broadleaves, share of native species, share of coniferous trees, tree species composition, old/veteran habitat trees
10.	**Protection of all primary and old-growth forests, and other sensitive land and aquatic habitats and species on-site**	Standing deadwood, cavities, microhabitats, stand diversity
11.	**Planning of road infrastructure**	Distance to forest edge, forest area growing stock
12.	**Strategies for control of invasive alien species**	Number of invasive alien species listed in EU Regulation 1143/2014
13.	**Control grazing by large ungulates**	Number of livestock units per hectare forest stand
14.	**Extensive management of biomass residues**	Deadwood amount
FOREST-LANDSCAPE LEVEL		
1.	**Establish new, uneven-aged, multi-species plantations as stepping stones**	Ground vegetation, vegetation diversity, deadwood diversity, standing deadwood, water bodies, basal area, distance to forest edge, forest/tree age, forest area growing stock, stand diversity, forest-road width, harvesting method
2.	**Spatial planning of cutover sites at landscape scale**	Ground vegetation, vegetation diversity, deadwood diversity, standing deadwood, water bodies, basal area, distance to forest edge, forest/tree age, forest area growing stock, stand diversity, forest-road width, harvesting method
3.	**Maintaining riparian corridors**	Ground vegetation, vegetation diversity, deadwood diversity, standing deadwood, water bodies, basal area, distance to forest edge, forest/tree age, forest area growing stock, stand diversity, forest-road width, harvesting method

Planning the transition

Forests have a comparatively long time delay between a management intervention and the response to that intervention. This makes it indispensable to adopt a forward-looking framework with a long-term vision of what could versus what should happen. This framework should consider different planning scales and contain concrete objectives, milestones and mid-term review points. Where applicable, such a framework should be part of strategic forest planning, which needs to adapt to unforeseen events and developments. Closer-to-nature forest management should be part of forest planning just like other components of sustainable forest management.

Adaptive management and climate change resilience

The implementation of closer-to-nature forestry practices is based on observations and detailed planning. This makes it possible to initiate operations (planting, thinning, pruning, final cuts, etc.) according to the twin objectives of increasing biodiversity and climate change resilience. It is an approach that allows for constant adjustments to be made. Based on continuous monitoring of precise indicators, closer-to-nature forestry makes it possible to adapt operations over time according to the dynamics in progress and unforeseen events.

Adaptive forest management of this sort increases the resilience of forests to rapidly increasing climate change impacts by reducing the risks associated with changes in temperature regimes, hydrological conditions and nutrient cycles. A significant share of Europe's forests is vulnerable to hazards such as fires, insect outbreaks and windthrows, or a combination of all three[90].

The boundaries of today's biogeographical regions will shift northwards and to higher altitudes, changing vegetation patterns and ecosystems, and triggering major shifts in forests and farmland. Trees and crops may not be able to keep up with such changes, especially when suitable habitats are fragmented. One solution is to make better use of genetic diversity and non-harmful plant genetic resources for adaptation, based on the latest science. This can be achieved, for example, by assessing and communicating to end users the climate suitability of specific trees and provenances and better integrating adaptation considerations into how forests are managed.

Resilient species and tree sub-species likely to cope with climate change should be favoured in selection and retention processes. It is important to note that forest resilience must also take into account the soil in which the forest is rooted. It is also essential to take actions to both increase the water retention capacity of stands and maintain stable within-stand climate conditions. In the same way, the continuous renewal of forests over time makes it possible to choose native species of local provenance. Such native species should be favoured. This gradual change over time in the proportion of species that are more resistant to droughts or pests makes it possible for the owner to build up a stand that is better able to face uncertainties.

Climate change increases uncertainty in forest management. It is therefore key to favour a balanced distribution of risks by creating finely mixed forests of well-established native species and cultivating stands that are more likely to be healthy and stable.

Taking account of forest fires

The biodiversity of forests has been shaped by fires for centuries. Nevertheless, the combined effects of climate change, land use change, forest management and socioeconomic drivers have led to changes in wildfire trends and patterns that challenge existing biodiversity[91]. The Commission guidelines on land-based wildfire prevention: principles and experiences on managing landscapes, forests and woodlands for safety and resilience in Europe provide an overview of wildfire trends, existing wildfire prevention concepts and good practices in Europe[92].

The management of forests after they have experienced wildfires should pay attention to soil conditions as one of the key factors for forest recovery and biodiversity-friendly afforestation. Even though post-fire salvage logging has historically been widely practised by forest managers, several

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[90] Forzieri G. et al. (2020). *Vulnerability of European forests to natural disturbances*. JRC PESETA IV project – Task 12. Publications Office of the European Union; Forzieri, G. et al. (2021). Emergent vulnerability to climate-driven disturbances in European forests. *Nature Communications, 12*, Article 1081. https://doi.org/10.1038/s41467-021-21399-7

[91] Kelly, L. T. et al. (2020). Fire and biodiversity in the Anthropocene. *Science, 370*(6519), Article eabb0355. https://doi.org/10.1126/science.abb0355

[92] Nuijten, D. et al. (Eds) (2021). *Land-based wildfire prevention: Principles and experiences on managing landscapes, forests and woodlands for safety and resilience in Europe*. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/695867

studies show that the felling and removal of burnt tree trunks may hamper forest regeneration by: (i) increasing soil erosion and compaction; (ii) reducing nutrient availability; (iii) damaging the seedling bank; or (iv) reducing species richness and diversity. As a result, there are increasing calls to implement less aggressive post-fire treatment policies and actions. Partial-cuts plus lopping (i.e. felling most of the trees, cutting the main branches and leaving all the biomass in situ) has been proven to be successful in Mediterranean forests[93], not only for physically protecting the soil but also for helping to recover soil fertility and nutrient availability. Mulching has also been proven to be successful in reducing post-fire run-off and erosion[94].

Heavily logged forest areas and plantations are prone to suffer more extensive fire damage than intact forests[95]. Fires of all types have dramatic implications on the condition of forest ecosystems. Clear-cut burnings are common practice in some areas of the EU. Clear-cutting followed by burning severely decreases the richness of soil species for at least 5 years, even for animals with good dispersal ability (Diptera, Coleoptera and Araneae), most likely due to food and habitat limitations. Such prescribed burnings do not improve biodiversity, but rather create profound disturbances that reduce the diversity of soil fauna over the long term[96].

PART V – CLOSER-TO-NATURE FORESTRY IN DIFFERENT REGIONS

The general principles of closer-to-nature forest management should be similar across all regions. Nevertheless, varying but related management approaches should be used in different regions of Europe[97]. Forests across the EU differ in their environmental characteristics, status, biodiversity and climate change challenges. The same is true for the forestry measures that have shaped these forests over time. Part V provides a short profile of the main forest types and management approaches in several EU biogeographical regions and how closer-to-nature forest management translates into their forestry reality. Regional profiles either present specific case studies, focus on specific parts of the region concerned or discuss the region as a whole. Region-specific challenges and experiences with closer-to-nature forest management are reflected in the varying emphasis and consideration of individual elements and principles of closer-to-nature forest management in each of them.

Biogeographical regions are not static over time. Because of climate change, climate and forest zones are shifting northwards and to higher altitudes, as illustrated in Figure 5. Pending the expected change in a specific location, management decisions could be helpfully informed by also consulting the regional examples for other zones.

[93] Castro, J. et al. (2011). Salvage logging versus the use of burnt wood as a nurse object to promote post-fire tree seedling establishment. *Restoration Ecology, 19*(4), 537-544. https://doi.org/10.1111/j.1526-100X.2009.00619.x

[94] Prats, S. A. (2012). Effectiveness of forest residue mulching in reducing post-fire runoff and erosion in a pine and a eucalypt plantation in north-central Portugal. *Geoderma, 191*, 115-124. https://doi.org/10.1016/j.geoderma.2012.02.009

[95] https://www.fs.usda.gov/psw/publications/documents/psw_gtr208en/psw_gtr208en_525-534_stone.pdf

[96] Malmström, A. et al. (2009). Dynamics of soil meso- and macrofauna during a 5-year period after clear-cut burning in a boreal forest. *Applied Soil Ecology, 43*(1), 61-74. https://doi.org/10.1016/j.apsoil.2009.06.002

[97] Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

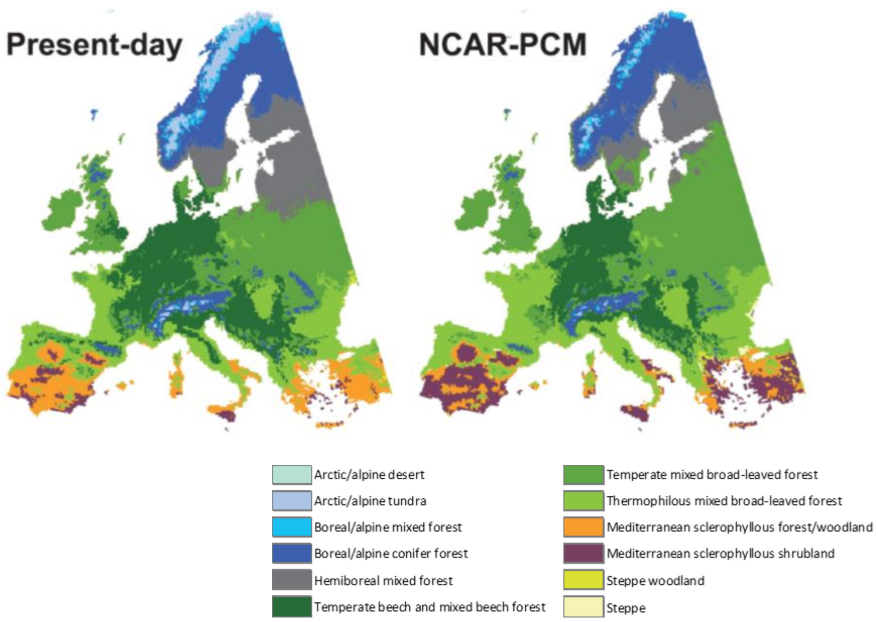

Figure 5: Modelled present-day (averaged for 1961-1990) and future (averaged for 2071-2100) potential natural vegetation (PNV) in Europe[98]

The Alpine region

Introduction

The Alpine region is, in general, a very varied biogeographical region with the following main mountain ranges in Europe: the Pyrenees, the Alps, the Apennines, the Carpathians, the Dinarides, the Balkans and the Scandes. Simply because of the great extent of forests in the Alpine region, they are an important landscape element contributing via their services to the area's economy and to the needs of people living in the Alpine region. In recent decades, countries in the region have developed their approach to forest management to preserve natural heritage and biodiversity, and to protect land from erosion. In this process, and taking into account the challenges of balancing forest management goals and forest ecosystem needs, natural dynamics have been partially harnessed to fulfil people's needs.

Compared to other mountain areas of the Alpine biogeographical region, the Alps are characterised by high population density and significant infrastructures (for transport, tourism and industrial production). Natural hazards therefore constitute a major risk for human activities. Across the Alpine mountain ranges, forests perform a protective function to varying degrees and in different ways. For example, they protect settlements, infrastructure and soil from severe natural hazards such as landslides, avalanches, floods and rock falls[99]. In addition, forests in the region serve other functions, such as preserving biodiversity, storing carbon, adapting to climate change, developing the bioeconomy, and providing opportunities for recreation and tourism. Protective functions go hand in hand with forest conservation and forest management efforts.

[98] Hickler et al. (2012). Projecting the future distribution of European potential natural vegetation zones with a generalized, tree species-based dynamic vegetation model. *Global Ecology and Biogeography, 21*(1), 50-63. https://doi.org/10.1111/j.1466-8238.2010.00613.x

[99] An international Treaty, the Alpine Convention (www.alpconv.org), includes since 1996 a specific Protocol on Mountain Forests (https://www.alpconv.org/fileadmin/user_upload/Convention/EN/Protocol_Mountain_Forests_EN.pdf) that recognises the importance of the protective function of forests. This approach has been replicated in 2011 for the Carpathian arc, which has also been the object of a dedicated international treaty (the Carpathian Convention) and a specific protocol on mountain forests since 2011 (http://www.carpathianconvention.org/protocol_on_sustainable_forest_management.html).

The Alpine range belongs to one of the most biodiversity-rich areas in the EU, with 33% of Alpine forests under different protection regimes. Higher-altitude forests in the Alps are mainly dominated by coniferous trees, mostly *Picea abies*, *Abies alba*, *Pinus sylvestris* and *Pinus mugo*. In addition to these conifers, there are other naturally dominant species, including *Larix decidua*, *Pinus cembra* and *Pinus nigra*, as well as the deciduous tree species beech (*Fagus sylvatica*) and sycamore maple (*Acer pseudoplatanus*). However, the composition of tree species varies because there are several vegetation belts at different altitudes, and these different vegetation belts all have their corresponding ecological conditions (such as soil type, sun exposure, length of snow cover, soil moisture, etc.). Lower-altitude Alpine forests are naturally dominated by oak and other broadleaf species, often covered by young successional forests following centuries of deforestation and then abandonment. An important Alpine habitat is riparian forests, although in several cases these are damaged by development in the valleys and by altered hydrology due to dams and flood defences. Other mountain ranges, such as the Carpathians or the Dinarides, are dominated by forests with a natural composition of tree species: mixed forests with beech (*Fagus sylvatica*), fir (*Abies alba*) and spruce (*Picea abies*) at lower altitudes and spruce at higher altitudes.

Closer-to-nature forestry in practice

Timber has been produced from forests in the Alpine region for hundreds of years. Heavy deforestation was common in the Alpine region until the 1850s. These practices of heavy deforestation for timber combined with pressure from pastoral farming to modify the natural distribution – and in some cases the state – of subalpine forests[100]. This has led to non-natural forests (e.g. forests of pure Norway spruce replacing mixed mountain forests), both in the montane and in the subalpine belts[101]. The current treeline in the Alpine region is not what it would naturally be since it has been affected by centuries of grazing and mining. At the same time, the long-term coexistence of forestry and grazing has created cultural landscapes that are currently disappearing[102]. Where and how to preserve the cultural landscape (e.g. how to preserve larch open stands) and where to allow natural dynamics to take place is subject to debate.

Depending on the countries and regions, some closer-to-nature forestry practices are already being implemented in Alpine forests. For example, in some locations in Austria, combining different closer-to-nature forestry measures has led to both: (i) a greater distribution area of beech forests; and (ii) the promotion of natural compositions of tree species (e.g. replacing monotypic Norway spruce at lower altitudes with native broadleaved tree species). This has been achieved while considering the changing site conditions due to climate change[103].

In the southern parts of the Alps, mainly in Italy, farmers working in the mountains began to face increasing difficulty in the 1970s in competing with agriculture in the plains. This led to a significant expansion of the forest area on marginal agricultural land in mountainous areas (pasture and meadows). At the same time, the growing cost of forest management reduced the pressure on forests. In some parts of the southern Alpine regions, these high costs of forest management and the small and fragmented ownership of forests is causing a complete abandonment of active forest management and monitoring. This has in some cases led to delays in taking measures against natural

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[100] European Environment Agency. (2006). *European forest types. Categories and types for sustainable forest management reporting and policy*. EEA Technical report No 9/2006. https://www.eea.europa.eu/publications/technical_report_2006_9

[101] Hilmers, T. et al. (2020). Assessing transformation scenarios from pure Norway spruce to mixed uneven-aged forests in mountain areas. *European Journal of Forest Research, 139*, 567-584. https://doi.org/10.1007/s10342-020-01270-y

[102] Garbarino, M. et al. (2011). The larch wood pasture: Structure and dynamics of a cultural landscape. *European Journal of Forest Research, 130*, 491-502. https://doi.org/10.1007/s10342-010-0437-5

[103] European Environment Agency. (2020). *State of nature in the EU. Results from reporting under the nature directives 2013-2018*. EEA Report No 10/2020, p. 66. https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020

risks (such as maintenance works on infrastructures and measures to monitor and prevent avalanches, landslides and rock fall).

The effects of climate change are particularly visible in the Alpine region. These effects have exacerbated the region's vulnerability to large-scale disturbances from windstorms, avalanches, rock fall, droughts, floods, fires, and – in recent times increasingly – bark beetle infestations. Temperatures are increasing almost twice as quickly in the Alps as in the rest of the northern hemisphere. The average temperature rise in the region is almost + 2°C since the late 19th century[104]. These disturbances reduce: CO_2 uptake by forests; forest growth; forest health; timber quality; and the status of natural habitats. Additionally, climate change is causing a gradual shift in the vegetation zones and represents a major threat to the ecosystems and the typical and unique biodiversity of the Alpine region. This also has negative impacts on socioeconomic aspects like tourism, timber production and the recreational functions of forests. Additional challenges include the higher costs of both timber harvesting and protecting against wildfires compared with other biogeographical regions. Forest management in the Alpine region has to aim for resilient compositions of tree species, and this requires closer-to-nature solutions such as supporting the natural regeneration of native species and creating mixed stands to support forest resilience[105]. Assisted 'migration' of forests can play a role with preference to provenances close to native species that adapt best to higher temperatures. Suitable management practices are necessary to adapt to these challenges and to preserve the precious functions of the forests.

On possible conflicts over land use, agricultural land use generally does not conflict with protective forest use, as most protective forests are on land unsuited for agriculture. Although cattle grazing could still endanger the integrity of the ecosystem services provided by these forests in some areas, forests in other areas can benefit from extensive and well-managed cattle grazing, which can help diversify forest structure and reduce fire risk. Many Alpine forests suffer from increasing browsing damage by unnaturally high populations of game populations, while increasing year-round tourism and recreational uses require special management measures.

Ensuring suitable harvest conditions

Forest management systems and forest management practices in the Alpine region are often dominated by either: (i) selective cutting management (felling individual trees and individual groups of trees), which creates structural diversity; or (ii) partial cuts and the related shelterwood system. Clear-cutting (of areas larger than 0.5 ha) is used rarely – except for needs such as salvage logging after disasters – and is even prohibited in some countries due to the risk of soil erosion, landslides and avalanches.

Damage to forest ecosystems is often minimised by adjusting the placing, timing and methods of logging interventions and associated activities. Measures to this effect include adapting logging and associated activities to the requirements of wildlife, and especially to the requirements of rare and endangered species. Active nesting sites, dens or shelters and other important habitats of animal species must be avoided during the nesting/breeding season (this is a general requirement under Directive 2009/147/EC on the conservation of wild birds – the EU Birds Directive). The density of forest roads is often the subject of controversial debate.

'Calm zones' have been set up in some countries and these calm zones go beyond legal obligations resulting from the EU Birds Directive. The calm zones were created to protect the most vulnerable habitats and those species that are most sensitive to noise and other forms of disturbance. Setting

[104] https://www.alpconv.org/en/home/topics/climate-change/
[105] SWD(2023)61, part I, Chapter 1.3.4.

common basic rules for forest management across the region (not only in the Alpine region) would be beneficial. As an example, the formation of zones suitable as habitats for the chamois mountain goat is an important factor in some regions. Therefore, when planning harvesting, long forest edges and gradual transitions from non-forested areas to the forest should be established and maintained.

Promoting diversity and natural processes

The regeneration of forests is mostly natural in most of the mountains of central and southern Europe. Nevertheless, further promoting processes that mimic nature creates opportunities to both maintain species richness (including species associated with initial and transitional successional stages) and shape structural diversity at stand and forest landscape levels. Some projects, such as Austria's Naturpark Zillertaler Alps, aim to naturally regenerate lime trees and other rare deciduous trees (at the expense of spruce) to create more biodiverse forests and support nature-based and species-rich forests. In Italy, almost all Alpine forests are composed of natural species, because broadleaf species have been increasing their presence since the 1970s and all rare and sporadic species are usually protected in forest management.

The specific biodiversity associated with native species is on average higher than that associated with non-native species[106]. This phenomenon depends on the different taxonomic groups and the specific context. For example, lichens and mycorrhizal fungi appear to be particularly sensitive to the native character of tree species. However, in very specific cases and conditions, some non-native species adapted to the local soil, climatic and ecological context, and habitat conditions can play a role in fostering increased resilience to climate change. These specific cases should always be assessed through the lens of promoting greater biodiversity.

On diversity, much research shows that low-diversity silvicultures are especially prone to disease outbreaks, windthrow, drought, etc. The role of closer-to-nature forestry management in improving resistance and resilience should come to the fore in transitioning away from low-diversity silvicultures[107].

Maintaining ungulate species at natural carrying capacity

Over-grazing by excessive populations of ungulates is the main factor limiting the natural regeneration of forests. It also reduces species composition, and lowers timber quality. Therefore, improved management of ungulate grazing is needed. The main prevention measures are to keep their populations well balanced with the forest ecosystem through the balanced presence of ungulate predators (e.g. wolves), effective hunting methods, and other management measures (such as no or reduced feeding of ungulates in forests during the winter). Grazing can also be managed by locally limited stem or plot fencing or other protection measures where possible and compatible with biodiversity conservation objectives.

In Italy, where local communities hunt and where there are many hunters, damage caused by game mostly only occurs close to protected areas where hunting is prohibited.

Optimising deadwood retention

In most forests, the positive effects of retaining deadwood and habitat trees for biodiversity are well recognised, especially if the deadwood is evenly distributed in diameter classes, with standing and

[106] Kennedy & Southwood, 1984/Newton & Haigh, 1998 — Branch & Dufrêne, 2005 in Branquart & Liégeois, 2005.

[107] According to Messier et al. (2022): 'monospecific planted forests typically have less potential for providing ecosystem services other than timber or fibre and they often harbour lower associated biological diversity …. They are also more susceptible to pests and diseases, saturation or collapse of wood product markets, and climate change when compared to diverse planted forests' or in the case of this discussion, closer-to-nature forests. Source: https://doi.org/10.1111/conl.12829

lying trees of several species in various stages of decay. In the subalpine zone, deadwood retention is also an essential measure to promote biodiversity[108] and the natural regeneration of forests. Recent research also points to a positive correlation between deadwood and protection against avalanches and rockfall[109]. Lying deadwood can strengthen the surface roughness of the soil surface, reducing the risk of rock fall and grazing game[110].

Research also shows that coarse deadwood (lying and standing dead trees) helps to reduce the risk of wildfires, because coarse deadwood increases moisture and humidity. Conversely, fine deadwood could increase fuel load and therefore increase the risk of wildfires[111]. The moisture content of wood is a key factor in fire risk, and moisture content is typically always higher in old-growth forests, and closer-to-nature forestry. Moisture content should also increase as the amount of rotting deadwood in a forest also increases[112].

In some locations, deadwood is beneficial for microclimatic conditions and regeneration, as argued above[113]. For example, deadwood creates shade and provides moisture for seedlings in low-precipitation areas. Deadwood also acts as a shelter against high temperature and radiation in arid environments, and a cover of deadwood can sustain higher soil temperatures in cold regions during the night, increasing the survival rate of winter seedlings[114]. In Italy, the amount of deadwood in Alpine forests has increased in the last 30 years due to more extensive management in some areas and a lack of management in other areas.

Offsetting the effects of management interventions

The management of 'ecological corridors' are of special importance. These corridors are stepping stones between habitat patches, and they help to form a network of small-scale microhabitats for the conservation, restoration and connectivity of forest ecosystems. They provide a connection between widely spaced habitats and thus allow different species to migrate between them. In Austria, an important programme ('Connect Forest Biodiversity', 'Trittsteinbiotope – Programm')[115] aims at preserving and improving habitat networks by creating and setting aside forests as 'stepping stone' biotopes. These microhabitats could be a potential measure to minimise or offset the negative effects of different unavoidable management interventions.

In actively managed forests, set-aside areas can be created in addition to closer-to-nature forest management measures. These set-aside areas can be reserved only for the natural development of

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[108] Müller, J., & Bütler, R. (2010). A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. *European Journal of Forest Research, 129*, 981-992. https://doi.org/10.1007/s10342-010-0400-5

[109] Caduff et al. (2022), citing: McClung, 2001, Schweizer et al., 2003, Rammig et al., 2007, Wang & Lee, 2010; Fuhr et al. (2015); Wohlgemuth et al. (2017).

[110] BUWAL, 2000. Entscheidungshilfe bei Sturmschäden im Wald (Decision-making tool for wind-throw in forests.) Vollzug Umwelt. Bundesamt für Umwelt, Wald und Landschaft; Weiss, G. (2004). The political practice of mountain forest restoration—Comparing restoration concepts in four European countries. *Forest Ecology and Management, 195*(1-2), 1-13.

[111] Donato et al. (2006) point out the most likely fuel load is from 'fine' deadwood (up to 7.62 cm), not coarse deadwood (either standing or fallen) usually defined at 10 cm or more. They suggest that post-forest-fire salvage logging (possibly extrapolatable to other logging) actually increases the volume of fine deadwood, and that the idea that 'leaving woody material (dead trees) standing could result in lower fire hazard is a reasonable hypothesis'. Source: https://doi.org/10.1126/science.1126583

[112] Přívětivý, T., & Šamonil, P. (2021). Variation in downed deadwood density, biomass, and moisture during decomposition in a natural temperate forest. *Forests, 12*(10), Article 1352. https://doi.org/10.3390/f12101352

[113] For instance, on south-exposed dry sites in the Dolomites, deadwood fosters the natural regeneration.

[114] Leal Filho, W. et al. (Eds) (2020). *Climate change, hazards and adaptation options. Handling the impacts of a changing climate*. Springer. https://doi.org/10.1007/978-3-030-37425-9

[115] Projekt connectForBio – Trittsteinbiotope.at

forest ecosystems, and they can prohibit any kind of forestry use and anthropogenic influence (except for hunting to prevent game damage)[116].

Taking a scale-specific approach

In some parts of the Alpine region, it is important to: (i) take a scale-specific approach based on tree and landscape levels; and (ii) take into account essential factors such as altitude and accessibility[117]. At the tree, stand and landscape levels, forest management should aim to preserve the natural tree species composition of forest communities while taking climate change into account. Particular attention should be paid to preserve rare species of trees and shrubs in balance with the requirements of young trees in the understory. Should sanitary felling be required, the undamaged individual trees should be maintained to promote natural resistance and genetic diversity within tree species.

At stand level, a sufficient proportion of mature trees should be established and maintained in commercial forests, and trees of special shapes and varieties (habitat trees) should be preserved. In Austria, for example, the appropriate distribution and spatial structure of deadwood in line with the overall desired deadwood density are ensured. And dead and veteran trees are retained in stands following a mosaic approach. The aim is to stabilise or, if need be, increase the volume of deadwood and habitat trees, according to regional or structural circumstances and risk factors (e.g. flood protection), while simultaneously improving a network of 'deadwood islands'[118]. Italy is another instructive example. In Italy, it has been the norm since the 1970s to engage in selective cutting in the lower mountain areas and group selection in the subalpine areas. This has brought a mosaic of structures, an increase of mixed forests, an increase in the percentage of large trees (trees with a diameter of more than 50 cm), and the more widespread promotion of natural regeneration.

At the landscape level, the focus should be to preserve, maintain and restore the variety and extent of forest-stand structures and the diversity of forest habitats (such as forest edges, glades, sprouts, water pools, bushes and other minor ecosystems in the forest). Landscape elements, such as forest stands, riparian forests, or tree lines with a significant impact on the landscape and biodiversity (especially in the landscapes with low forest cover), should be preserved, especially those that are part of a connecting link between individual areas.

Other measures

Tourism and recreation are important economic sectors in some areas of the Alpine region, including its forested part. However, tourism and recreational uses may also act as a significant disturbing factor for biodiversity. Threats to forest biodiversity from tourism include the use of quad bikes, the creation of new ski runs, the construction of ski lifts with associated infrastructure, and the 24/7 presence of tourists on some of the ski runs (light pollution). Measures to minimise negative impacts on ecosystems and biodiversity include access limitations to sensitive nature conservation areas.

Critical enablers

It will be important to ensure that forest-related strategies – including targets – contain a sound legal framework and concepts for implementing closer-to-nature forestry with links to national/regional forest development programmes or plans. This should be carried out in tandem with targeted awareness raising among actors and stakeholders.

[116] The Platform on Sustainable Finance recommends 10% within closer-to-nature forest stands, and more for less biodiverse silvicultural approaches: Platform on Sustainable Finance: Technical Working Group. (2022). *Supplementary: Methodology and technical screening criteria*. Ch. 1.4 Forestry & Logging. https://finance.ec.europa.eu/system/files/2022-11/221128-sustainable-finance-platform-technical-working-group_en.pdf.

[117] Mayer, H., & Ott, E. (1991). *Gebirgswaldbau. Schutzwaldpflege*. Gustav Fischer.

[118] Austrian Biodiversity Strategy 2030+. https://www.bmk.gv.at/themen/klima_umwelt/naturschutz/biol_vielfalt/biodiversitaetsstrategie_2030.html

In addition, the further development of forest inventories to measure the state of forest ecosystems will be important to quantify relevant parameters (such as deadwood) for setting baselines and targets as well as for monitoring trends.

Forest owners and managers should be encouraged through incentives. Payment for ecosystem services provided by mountain forests make an essential contribution to closer-to-nature forestry. In this context, clear commitments enshrined in the Alpine Convention Protocol on mountain forests are relevant.

Articles 6 to 10 of this international treaty regulate: (i) the protective effect of mountain forests; (ii) the productive effect of mountain forests; (iii) the social and ecological effects of mountain forests; (iv) the need for haulage of timber; and (v) the obligation to designate natural forest reserves. Article 11 regulates funding and compensation (see text box below).

> Alpine Convention Protocol on mountain forests [119]
> Article 11 – Incentives and compensation
> 1. Considering the unfavourable economic conditions of the Alpine territory and bearing in mind the services of the mountain forest economy, the Contracting Parties shall undertake, within the framework of the existing political and financial conditions and for the period necessary to ensure such services, to provide sufficient incentives to the forestry activities, especially the measures stated in articles 6 to 10.
> 2. If the services requested on the mountain forest economy exceed those of the obligations of current laws, and their necessity is motivated on the basis of projects, the owner of the forest has the right to compensation commensurate to the services provided.
> 3. The Contracting Parties undertake to create the instruments necessary for financing the incentive and compensation measures and, when calculating the funds, taking account not just of the economic-political benefits for the entire population, but also the benefits to individuals.

The Atlantic region

Introduction

The Atlantic region stretches from the top of the United Kingdom (UK) and Ireland and from the central Norwegian coastline to the northern shores of Spain and Portugal, as well as all the Netherlands and parts of Belgium, Denmark, Germany and France. Including the UK, this region covers land areas across 10 countries or some 18% of the territory of the EU (pre-Brexit)[120,121].

Under natural conditions, and without human influence, deciduous broadleaf forests would have been the dominant forest type in the Atlantic region. However, native forests have been systematically cleared at least since the Middle Ages to make way for croplands, pasture and other land uses, including settlements as populations became denser and societies across the region became established[122]. Forests now make up around 13% of the land area of the Atlantic region[123] with sparse levels of forest cover along the western seaboard becoming generally more abundant moving eastwards towards the Continental region.

Although the Atlantic region is one of the most heavily populated and intensely managed biogeographical regions in Europe, areas of semi-natural and native forests with natural species composition still exist. Hopkins and Buck (1995) identify some 22 Annex I forest habitats occurring in

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[119] See page 8. https://www.alpconv.org/fileadmin/user_upload/Convention/EN/Protocol_Mountain_Forests_EN.pdf

[120] Sundseth, K. (2010). *Natura 2000 in the Atlantic Region*. European Commission, Directorate-General for Environment. Publications Office. https://data.europa.eu/doi/10.2779/82343

[121] Pinborg, U., & Larsson T. (2002). *Europe's biodiversity – Biogeographical regions and seas*. EEA Report No 1/2002. https://www.eea.europa.eu/publications/report_2002_0524_154909

[122] Kaplan, J. et al. (2009). The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews, 28*(27–28), 3016-3034, https://doi.org/10.1016/j.quascirev.2009.09.028

[123] Pinborg, U. and Larsson T. Europe's biodiversity – biogeographical regions and seas. The Atlantic region – mild and green, fragmented and close to the rising sea. EEA Report No 1. 2002 https://www.eea.europa.eu/publications/report_2002_0524_154909

the Atlantic region[124]. These include: (i) forests comprising native conifer species, such as the Caledonian (Scots) pine forests of Scotland; (ii) yew woodlands and old sessile oak woods, which are found only in Ireland and the UK; and (iii) the pine forests of France, comprising endemic Mesogean pines including *Pinus mugo* and *P. leucodermis*. However, the naturally dominant broadleaf deciduous forests of the Atlantic region comprise mainly beech (*Fagus sylvatica*), often mixed with sessile oak (*Quercus petraea*) and pedunculate oak (*Quercus robur*)[125] Remnants of floodplain forests in the region show a high richness in tree species with elm (*Ulmus* sp.), hornbeam (*Carpinus betulus*), ash (*Fraxinus excelsior*), alder (*Alnus glutinosa*), different lime species (*Tilia* spp.), maple (*Acer* sp.) and a rich variety of shrub species. The Sonian beech forest in Belgium is the only lowland beech forest representing the Atlantic region in the Beech Forest World Heritage[126].

In spite of significant levels of deforestation in the past, the forest area in the Atlantic region is increasing due to land abandonment[127,128] and because of the introduction of afforestation programmes on marginal agricultural lands by various EU Member States[129]. Afforestation since the 1800s has been dominated by the planting of conifer species on former agricultural lands, or on peat and heavy mineral soils in Ireland, or on sandy soils in Denmark, Germany, Spain, France, the Netherland and Portugal[130,131]. The new forests of the Atlantic region are primarily established and managed as commercial plantations for wood production. However, more recently, a wider range of conifer and broadleaf species are being established because of targeted financial incentives and greater focus on the importance of the carbon sequestration, climate resilience, biodiversity, water, landscape, heritage, recreation benefits and other ecosystem services provided by more diverse forests[132,133].

At 4.94%, the share of forest habitats reported under Article 17 of the EU Habitats Directive 92/43/EEC with good conservation status in the Atlantic region is the second lowest of all the other biogeographical regions in Europe[134]. Beech forests in particular need restoration in this region[135].

Existing forest management practices can vary substantially across the Atlantic region. These practices can include, but are not limited to: (i) no management due to land abandonment; (ii) management for nature protection and recreation (e.g. in parts of Denmark and France); (iii) shelterwood cuttings or partially close-to-nature deciduous forest management in Germany; (iv) traditional or 'cultural' landscape forest management by means of agroforestry, coppicing and silvopastoral systems (e.g. Spain and Portugal); (v) intensively managed short-rotation monoculture; and (vi) forests for producing timber, pulp and energy-related biomass under clear-fell systems (e.g. Ireland and Spain).

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[124] Hopkins, J. J., & Buck, A. L. (1995). *The Habitats Directive Atlantic Biogeographical Region*. Report of Atlantic Biogeographical Region Workshop, Edinburgh, Scotland, 13th-14th October 1994. JNCC Report, No. 247. https://data.jncc.gov.uk/data/02c52cd8-62be-4de1-9ee0-8f99ad7e8dc8/JNCC-Report-247-FINAL-WEB.pdf

[125] Pinborg, U. and Larsson T. Europe's biodiversity – biogeographical regions and seas. The Atlantic region – mild and green, fragmented and close to the rising sea. EEA Report No 1. 2002 https://www.eea.europa.eu/publications/report_2002_0524_154909

[126] European Beech Forests - UNESCO World Heritage

[127] Perpiña Castillo C., et al. (2018). *Agricultural land abandonment in the EU within 2015-2030.* JRC113718, European Commission. https://joint-research-centre.ec.europa.eu/system/files/2018-12/jrc113718.pdf

[128] European Environment Agency. (2018). *Forest dynamics in Europe and their ecological consequences*. Briefing no. 16. https://www.eea.europa.eu/publications/forest-dynamics-in-europe-and

[129] Zanchi, G. et al. (2007). *Afforestation in Europe*. Specific targeted research project n°SSPE-CT-2004-503604. Impact of Environmental Agreements on the CAP. MEACAP WP4. European Forest Institute. https://ieep.eu/wp-content/uploads/2022/12/wp4_nd_afforestation_in_europe.pdf

[130] Heil, G. W. et al. (2007). *Environmental effects of afforestation in north-western Europe - From field observations to decision support*. Springer. https://doi.org/10.1007/1-4020-4568-9

[131] Farrell, E. P. (2012). Forests of Atlantic Europe 1: Forests of soft coasts. *Irish Forestry, 69*(1&2), 204-213. https://journal.societyofirishforesters.ie/index.php/forestry/article/view/10942

[132] DAFM. (2022b). *Ireland's Forest Strategy Implementation Plan*. Draft for public consultation. Department of Agriculture, Food and the Marine (DAFM). https://assets.gov.ie/237551/b0af026a-cc3a-4e92-a833-80ed6ae846fe.pdf

[133] Larsen, J. B. (2012). Close-to-nature forest management: The Danish approach to sustainable forestry. In J. J. Diez & J. M. García (Eds), *Sustainable forest management - Current research* (pp. 199-218). IntechOpen. doi:10.5772/1128

[134] Conservation status and trends of habitats and species — European Environment Agency (europa.eu)

[135] State of nature in Europe: a health check — European Environment Agency (europa.eu)

The closer-to-nature concept in practice – the example of CCF

Alternatives to clear-cut or clear-felling silvicultural systems have a long tradition in Europe[136,137]. More recently, considerable attention has been focused on new methods to avoid rotation, clear-fell, and rotational (or regular) forest management (RFM)[138,139]. In western Atlantic Europe, alternatives to RFM are widely known as CCF or as close-to-nature forestry. Table 3[140] provides estimates of the current percentage of forest area managed under CCF systems by country across the Atlantic region.

Table 3: Estimated percentage use of CCF compared to other silvicultural systems in high forests in the Atlantic region

Country	% CCF	Other[1]	Country	% CCF	Other[1]
Norway	6%	94%	France	25%	75%
Ireland	1%	99%	Netherlands	31%	69%
Germany	30%	70%	Denmark	13%	87%
Belgium	45%	55%	Spain	15%	85%
			Portugal	3%	97%

[1] 'Other' includes clear-fell, shelterwood, seed tree and other regeneration systems

Interest in the application of CCF has been increasing over time (e.g. in Denmark, Germany, Ireland and the Netherlands). This has been primarily prompted by a shift in public opinion as to how forests should be managed. As a consequence of this shift, there have been increasing requirements to consider the importance of structural and biological diversity, and the amenity and recreation values of forests, alongside timber production.

Of the Atlantic countries currently using CCF over larger areas, the percentage of forest area currently undergoing transformation to CCF is notable (e.g. Belgium, Denmark, Germany, France and the Netherlands) (see Mason et al., 2022). This indicates the relatively recent adoption of this system. Given the extent of forest area currently identified as being managed under clear-fell in the Atlantic region, the transformation of even-aged forests to CCF forests represents a challenge to forest owners and managers. There has been little research on this transformation process and there is limited practical information or guidance available[141]. A considerable proportion of the literature on CCF has come from the UK and central Europe. Although the UK literature has provided a valuable starting point for those engaged in transforming stands in Ireland, there is a need for further research to develop country-specific guidelines on the different stages of transformation[122]. For older beech forests, the management guidelines developed from the results of two, large, scientific projects in the lowlands of Germany are helpful. These guidelines give insights to forest managers on how to slowly transform homogenous beech forests into forests with more diverse uneven-aged structures with greater diversity of beech forest species[142].

If transformation to CCF is to be successful, it is important that forest managers have a vision of the type of forest structure they wish to develop during the transformation phase. For example, they need to decide whether the forest structure will involve selective or group felling in uneven-aged microhabitats, or whether it will be a structure with deadwood and biodiversity-rich forests covering

[136] Biolley, H. (1901): *Le traitement naturel de la forêt*. Bulletin de la société neuchâteloise des sciences naturelles. Tome XXIX-Année 1900-1901.

[137] Möller, A. (1922). *Der Dauerwaldgedanke. Sein Sinn und seine Bedeutung*. Springer.

[138] Pommerening, A., & Murphy, S. T. (2004). A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. *Forestry, 77*, 27-44. https://doi.org/10.1093/forestry/77.1.27

[139] Vítková, L., & Ní Dhubháin, Á. (2013). Transformation to continuous cover forestry – A review. *Irish Forestry, 70*(1&2), 119-140. https://journal.societyofirishforesters.ie/index.php/forestry/article/view/10105

[140] after Mason, W. L. et al. (2022). Continuous cover forestry in Europe: Usage and the knowledge gaps and challenges to wider adoption. Forestry: *An International Journal of Forest Research, 95*(1), 1-12. https://doi.org/10.1093/forestry/cpab038

[141] Vítková, L. et al. (2013). The practice of continuous cover forestry in Ireland. *Irish Forestry, 70*(1&2), 141-156. https://journal.societyofirishforesters.ie/index.php/forestry/article/view/10106

[142] Winter, S. et al. (2020). *Best practise handbook – Nature conservation in beech forests used for timber – Nature conservation objectives and management recommendations for mature beech forests in north-eastern Germany*. Land Brandenburg.

the complete forest life cycle. Such research has been carried out in Denmark, for example[143]. However, although forests are being transformed, and adaptive management practices are being employed in the pursuit of CCF, further guidance is needed for forest managers on how to achieve these CCF forest structures. Challenges to the wider adoption of CCF have also been identified by Mason et al. (2022). These challenges include: (i) a lack of awareness of CCF among forest owners; (ii) limited skills in CCF within the forestry profession and a scarcity of skilled forest workers to implement this approach; (iii) high ungulate populations damaging natural regeneration; (iv) a sawmilling sector geared to processing medium-sized logs; (v) subsidy regimes favouring practices associated with regular forest management; and (vi) a general lack of experience in transforming plantation forests to more diverse structures. All these issues are certainly pertinent in Ireland, for example, where: (i) most forests are newly established; (ii) a forest culture is still emerging; and (iii) the level of knowledge and skills in general forest management practices is generally low, meaning that the more exacting management requirements implied by CCF will be especially challenging. However, recent and ongoing initiatives in Ireland indicate a growing interest in – and application of – CCF and closer-to-nature forestry more generally. These initiatives are centred around: (i) relevant state supports for conversion to CCF and native forest or native woodland management; and (ii) the activities (including training and publications) of Pro Silva Ireland (www.prosilvaireland.com) and Woodlands of Ireland (www.woodlandsofireland.com).

CCF and close-to-nature forestry – a case study on challenges and opportunities in Ireland

Over the last 100 years, the Irish national afforestation policy, which has involved the planting of 690,000 ha of forest, has increased forest cover from c. 1-2% of total land in 1922 to 11.6% in 2022[144]. This represents the largest land use change since the foundation of the Irish State in 1922. However, unlike other EU Member States within the Atlantic region, most Irish forests are non-native, even-aged, conifer monoculture plantations planted and managed primarily under the clear-fell system. Sitka spruce, originally from the west coast of North America, is the most common species in Irish forests, occupying 44.6% of total forest area and over one quarter (27%) of the overall forest area containing broadleaf species including birch, ash, oak and willow. Most (70%) of Ireland's forests consist of trees 30 years old or less[144] Excluding mixed conifer and non-native broadleaf forest, around 100,000 ha of natural or semi-natural forest areas remain in Ireland. Of these, approximately 20,000 ha are defined as native ancient forest, i.e. forest dating from before the 1600s[145].

Although the practice of CCF or close-to-nature forestry has been applied in many forms for the past 120 years in Continental Europe, its application has been limited in Ireland (see Table 3 above). However, indications are that pressure to provide alternatives to the clear-fell system in Ireland will increase in the future, due to initiatives such as the EU's proposed nature restoration law and the public's increasing aversion to the visual impacts of clear-felling. As described above, interest in the application of CCF and closer-to-nature forestry is also increasing, due to the efforts of various initiatives and organisations.

It is relatively straightforward to apply closer-to-nature management principles to restore and improve biodiversity within Ireland's Annex I native oak, yew and bog forests, and for those forest areas that already have some elements of such biodiversity (e.g. ground flora consistent with native or semi-natural forest). For native and semi-natural forests, the measures and indicators that are effective in improving forest biodiversity (e.g. adaptive ungulate management, the exclusion of ungulates, the

[143] Larsen, J. B. (2012). Close-to-nature forest management: The Danish approach to sustainable forestry. In J. J. Diez & J. M. García (Eds), *Sustainable forest management - Current research* (pp. 199-218). IntechOpen. doi:10.5772/1128

[144] DAFM. (2022a). *Forest Statistics Ireland 2022*. Department of Agriculture, Food and the Marine (DAFM). https://assets.gov.ie/228969/78d3faac-d083-4660-bc04-1ca670df5007.pdf

[145] Perrin, P. M., & Daly, O. H. (2010). *A provisional inventory of ancient and long-established woodland in Ireland.* Irish Wildlife Manuals, No 46, Dublin: National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government. http://www.botanicalenvironmental.com/wp-content/uploads/2010/02/Perrin-Daly-2010-ALEW-IWM.pdf

removal of invasive or exotic species, increasing deadwood volume) have been identified and are readily qualifiable. However, this becomes increasingly challenging to achieve in existing production forests planted using non-native conifers on former agricultural land, as the elements of native forest biodiversity are severely limited. Therefore, achieving specific EU nature restoration indicators or targets may not be feasible within limited time frames in existing production forests of this sort. Ireland, like Denmark, the Netherlands and the UK, has had the highest gains in forest species diversity of all EU Member States due to the introduction of non-native tree species[146]. Therefore, there is a need for a matrix of indicators setting out both what should be achieved in forests already displaying elements of native forest ecosystems, and what should be achieved in forests that are far removed from what might be considered a 'native forest ecosystem'. For forests already displaying elements of native forest ecosystems, indicators and targets can realistically reflect native forest types and the species and ecosystem composition associated with each. For forests that are far removed from what might be considered a 'native forest ecosystem', indicators and targets might focus on more general principles of forest biodiversity (e.g. age and species diversification, edge habitat creation and strategic open spaces for biodiversity enhancement). Clearly, an appropriately designed Irish CCF model would facilitate the transformation and restructuring of newly established conifer and broadleaf forests at appropriate locations.

A significant impediment to the widespread adoption of CCF in Ireland is the Irish wind regime and the fact that much of the forest estate is highly fragmented and has been established on either peaty or wet mineral soils. Wind is the most important disturbance agent in European forest ecosystems[147]. In Ireland, however, wind damage to forests is of even more significance. Given the country's geographical position, it is subjected to more intense cyclones, extreme gales and precipitation than other European countries[148]. Therefore, large-scale, sudden or rapid changes to forest structure and canopy composition represent a significant risk to their stability if these changes are applied without undue attention, proper planning and appropriate site selection. This is especially true for fragmented, mid-rotation, monoculture crops established on peat soils. Thus, there is a strong argument to focus efforts to transform to CCF on those forest areas where stability makes this possible and where the capacity for significant biodiversity enhancement is greatest. Selective logging in an older stand could be used to initiate sheltered natural regeneration of the pioneer species. Alternatively, the clear-fell and replanting stage can be an opportunity to introduce CCF subsequently.

Given the current species, age class and geographic profiles for many of Ireland's forests, an opportunity for significant forest structural change in many areas of the country may only be possible at the reforestation stage. Any widespread adoption of closer-to-nature forestry for Ireland should thus reflect Ireland's current reliance on the clear-fell and reforestation cycle and seek to focus on what can be achieved at restock stage, when structural change can be achieved while minimising financial and environmental risk. Clearly, there are significant opportunities for restoration and improvement of biodiversity, both at the reforestation stage and in yet-to-be-established afforested areas.

Notwithstanding existing challenges and silvicultural management practices, progress can be seen in areas of low wind exposure, where existing forests have been established on mineral soils and can be characterised as mixed or more diverse multi-aged forests. In these areas, the level of engagement by forest owners with Pro Silva Ireland and participation in the current state-funded CCF grant scheme

146 Dimitrova, A. et al. (2022). Risks, benefits, and knowledge gaps of non-native tree species in Europe. *Frontiers in Ecology and Evolution, 10*. https://doi.org/10.3389/fevo.2022.908464

147 Gardiner, B. et al. (2010). *Destructive storms in European forests: Past and forthcoming impacts. Final report to European Commission - DG Environment*. European Forest Institute. p. 138. https://edepot.wur.nl/162053

148 McInerney, D. et al. (2016). A rapid assessment using remote sensing of windblow damage in Irish forests following Storm Darwin. *Irish Forestry, 73*(1&2), 161-179. https://journal.societyofirishforesters.ie/index.php/forestry/article/view/10850

indicates a strong interest and potential for transformation to CCF. There is great willingness among the public to pay for mixed forests in Ireland and there is a societal preference for mixed broadleaf and conifer forests in general[149]. This is reflected in recent afforestation statistics, with around 30-40% of the privately owned Irish forest estate now containing significant quantities of broadleaf species, compared to a much higher historic proportion of Sitka spruce.

Close-to-nature forestry – a case study from Germany

The Norway spruce (*Picea abies*) was considered until recently as the 'bread-and-butter' tree of German forestry, accounting for 25% of timberland with forest cover, a third of timber stock and over half of timber use. It has therefore long been the commercial backbone of many forestry enterprises and, largely for historical reasons, has been grown well beyond its natural range.

However, cultivating pure coniferous stands involves risks. Attention was already being drawn to these risks in the late 19th and early 20th centuries[150,151]. Since as early as the mid-1980s, in response to recent and widespread forest dieback, Germany's federal government and Länder launched funding programmes in Germany for the conversion of coniferous forests to mixed forests. Most of the Länder have decreed forest conversion measures in Länder-owned forests and funding measures for forest conversion in non-Länder-owned forests. Recent forest inventory findings confirm the positive outcome of these measures. Recent decades have brought a decrease in the share of Norway spruce and an increase in the share of mixed and deciduous forests in Germany. The overall goal in Germany is to establish mixed forests that are comprised of predominantly native tree species. The establishment of those forest stands meets the need for timber production and goes hand in hand with the needs for both future climate change adaptation and nature conservation targets. As climate change progresses, conditions are expected to deteriorate in Germany for Norway spruce (*Picea abies*)[152,153]. Some forest areas have already seen the species' large-scale dieback. Since 2018, damage caused by storms, drought stress and beetle infestations has focused attention on forest resilience, forest species composition and species selection and placed all these issues firmly on the political agenda. To a lesser extent, drought stress combined with secondary biotic damage has also affected other important tree species such as Scots pine (*Pinus sylvestris*) and common beech (*Fagus sylvatica*).

Critical enablers – focus on Ireland

A number of policy, education, economic and research-based requirements have been identified to advance the uptake and practice of CCF and close-to-nature forestry management in Ireland. Expert advice and technology transfer from outside Ireland can help to identify best practices for alternative silvicultural systems to RFM. This advice and technology transfer includes the establishment of: (i) relevant demonstration forests for monitoring progress; or (ii) test sites such those catalogued by the Association Futaie Irrégulière. Many of the private forest owners currently involved in CCF and their foresters are active members of Pro Silva Ireland (www.prosilvaireland.com/), which is used as a forum for discussion and informal training through field days and study tours.

[149] DAFM. (2021). *Public attitudes survey on forestry*. Department of Agriculture, Food and the Marine (DAFM). https://assets.gov.ie/233828/cb5d7a09-9981-44db-9e78-915aab222e0f.pdf

[150] Gayer, K. (1886). *Der Gemischte Wald*. Verlag Paul Parey.

[151] Wiedemann, E. (1925). *Zuwachsrückgang und Wuchsstockungen der Fichte*. Tharandt.

[152] Bolte, A. et al. (2009). Adaptive forest management in central Europe: Climate change impacts, strategies and integrative concept. *Scandinavian Journal of Forest Research, 24*(6), 473-482. https://doi.org/10.1080/02827580903418224

[153] Bugmann, H., & Pfister, C. (2000). Impacts of interannual climate variability on past and future forest composition. *Regional Environmental Change, 1*, 112-125. https://doi.org/10.1007/s101130000015

The Irish state offers financial support to Pro Silva-related and other CCF research projects to ensure the continued roll-out of research and knowledge transfer services. A more formalised CCF training system as well as the secondment of international experts to assist with Irish government policy on close-to-nature forestry management has also been proposed[154]. More recently, the forestry development section of Teagasc (Ireland's agricultural advisory agency) has partnered with the European Forest Institute (EFI), in collaboration with Coillte (Ireland's state-owned forestry company) and Pro Silva Ireland, to develop CCF training resources for Irish forest owners, foresters, students and other interested groups. The INTEGRATE Network forms part of a dynamic, Europe-wide EFI training network exchange, which aims to equip forest owners with the necessary skills to choose the most appropriate management systems for more diverse forests, including CCF forests[155].

In 2014, Ireland completed its COFORD state-funded research project focusing on low-impact silvicultural systems. COFORD was valuable in filling knowledge gaps in respect to CCF practice. A more recent research project, TranSSFor, which ran until the end of 2022, focused on the transformation of Sitka spruce forest in Ireland[156]. And the state-funded ContinuFOR project, which commenced in February 2022, seeks to collate the scientific evidence around the transformation of even-aged stands to CCF in Ireland. Within the time frame of the new Irish forestry programme for 2023-2027, ContinuFOR will identify the consequences of transformation to CCF for: (i) timber production (both quality and quantity); (ii) biodiversity; and (iii) climate change mitigation. In terms of practical tools and future research needs, there is still a need for appropriate yield models and actual financial comparisons between CCF and RFM for a range of forest conditions in Ireland[157]. These models and comparisons will enable forest managers and landowners to fully assess and operationalise the CCF forest model.

The Irish government recognises that the transformation of emergent and newly planted forests to CCF and closer-to-nature management represents both a technical and professional challenge. It therefore gave financial support under the last (2015-2022) national forestry programme to incentivise and facilitate the transformation to CCF of existing broadleaf and conifer forests, with 840 ha of private forests being assessed for funding for transformation under a woodland improvement scheme since 2019. Funding (e.g. for deer fencing, or for removing invasive or exotic species) is also provided by the Irish state under the native woodland conservation scheme for the restoration and protection of existing semi-natural or native forest areas. This scheme also funds the replacement of conifer stands with native woodland at replanting stage. Furthermore, a condition of Ireland's native woodland establishment scheme, which to date has funded the creation of more than 2,800 ha of new native woodland, is the requirement that future management must be CCF-based, ensuring such areas will not be clear-felled in the future. Periodic technical information notes produced by Woodlands of Ireland, and the publication *Management Guidelines for Ireland's Native Woodlands*[158], jointly

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[154] COFORD. (2007). Close To Nature Forest Management. A report on the morning session of the joint Pro Silva Ireland / IFA conference held on November 10th 2006 and supported by COFORD under the Workshops and Seminars, Networking and Knowledge Transfer Supporting Initiative. http://www.coford.ie/media/coford/content/funding/networkingandknowledgetransfer/Close%20To%20Nature%20Forest%20Management.pdf

[155] Teagasc. (2022). *The "marteloscope" training network. Enhancing forest owners' confidence and ability in managing diverse forests*. https://www.teagasc.ie/crops/forestry/advice/management/continuous-cover-forestry/the-marteloscope-training-network/

[156] Wilson, E. et al. (2020). Transforming Sitka spruce plantations. *TResearch, 15*(1), 32-33. https://www.teagasc.ie/media/website/publications/2020/32-Transforming-Sitka-spruce-plantations.pdf

[157] Purser, P. et al. (2015). Factors affecting the economic assessment of continuous cover forestry compared with rotation-based management. *Irish Forestry, 72*(1&2). https://journal.societyofirishforesters.ie/index.php/forestry/article/view/10301

[158] Cross, J. R., & Collins, K. D. (2017). *Management guidelines for Ireland's native woodlands*. Jointly published by the National Parks & Wildlife Service (Department of Arts, Heritage, Regional, Rural & Gaeltacht Affairs) and the Forest Service. Forest Service, Department of Agriculture, Food and the Marine. https://www.npws.ie/sites/default/files/publications/pdf/Management%20Guidelines%20for%20Ireland%27s%20Native%20Woodlands%202017.pdf

produced by the Irish government bodies principally responsible for nature conservation and forest policy in Ireland, provide much-needed information to inform this growing native woodland sector.
A further commitment has also been given by the Irish state in the new forestry programme for 2023-2027 for incentives to support landowners to: (i) establish new CCF forests (including new forests planted exclusively with native Irish species); (ii) transform existing even-aged forests; and (iii) replant former even-aged forests at clear-fell stage to create forest cover to be managed under CCF (see also Table 4, DAFM, 2022b[159]).

Table 4: Specific financial incentives supporting CCF and close-to-nature forestry measures under Ireland's forest strategy implementation plan (DAFM, 2022b)

Forest establishment measures	**Description**
Native forest	Creation of intimately mixed forests, comprised entirely of native species, reflecting local, native, forest and woodland type(s) and prioritising native provenance. Established primarily for biodiversity, with production also permitted where compatible. Areas planted to be managed under CCF.
Forests for water	Creation of native forests in targeted areas, with the specific objectives of protecting water from significant pressures and expanding Annex I Habitat 1E0 Alluvial Woodland, which is currently in bad overall status in Ireland.
CCF	Creation of production forests that are suitably structured to be managed as CCF from establishment.
Forest creation on public lands	Encourage public bodies to establish new native forests on suitable bare land, to be managed using CCF.
Emergent forest	Protection, enhancement and enrichment planting of existing emergent native forests.
Native Tree Area Scheme	Creation of tree native areas on agricultural lands (< 1 ha) for climate change, biodiversity and water quality objectives.
Ecosystem services payments	**Description**
Native woodland conservation	Restoring and protecting existing native forests.
CCF	Transformation/management of existing forests under CCF principles and agreed management plans.
Seed stand management	Open to forest stands included as 'selected' or 'tested' on the National Register of Forest Basic Material, including oak (sessile & pedunculate) registered in the category 'source identified' for the purposes of gene conservation.
Environmental enhancement scheme, including action for water habitats/species (targeting national or European designated sites)	Encouraging forest owners to undertake works within existing forests during the current rotation to achieve structural changes and to improve the environmental 'footprint' of those forests (e.g. reducing fragmentation, improving the composition of forest edge species, planting native trees and shrubs, and extending open forest areas).
Water protection	Operational measures focusing on water protection, including riparian tree planting with native species or, where necessary, premature felling and tree removal.

[159] DAFM. (2022b). *Ireland's Forest Strategy Implementation Plan*. Draft for public consultation. Department of Agriculture, Food and the Marine (DAFM). https://assets.gov.ie/237551/b0af026a-cc3a-4e92-a833-80ed6ae846fe.pdf

The Boreal region

Introduction

The Boreal forests are situated in the northern parts of Europe, in Scandinavia and around the Baltic Sea. The landscape in this area is characterised by forests, mires and lakes. The proportion of area classified as forest in the Boreal region varies from more than 70% in Finland to 35% in Lithuania. Within the Boreal biogeographical area, growing conditions and climate vary greatly from south to north. Boreal forests are mainly coniferous, with pine (*Pinus sylvestris*) forests prevailing at dry sites and spruce (*Picea abies*) forests dominating at more moist and nutrient-rich sites. The number of tree species in the Boreal region is naturally low, with most diversity in the hemi-Boreal region where broadleaved deciduous trees may also locally dominate. Typical trees in Boreal forests include mixed deciduous trees, such as birches (*Betula pubescens/pendula*), aspen (*Populus tremula*), goat willow (*Salix caprea*), alder (*Alnus glutinosa* and *A. incana*), and the rowan tree (*Sorbus aucuparia*). Old deciduous trees are very important for biodiversity.

Many of the boreal species have developed their traits in a fire-influenced landscape, and they are dependent on the structures and functions that develop after forest fires for their long-term survival. Wildfires have almost disappeared from Fennoscandia (the area covering Norway, Sweden, Finland and parts of Russia) due to efficient fire suppression, forest management and extensive forest-road networks. This means that species evolutionarily adapted to fire and post-fire forests are now threatened[160].

The Boreal region is a biodiversity hotspot for mosses, lichens and fungi and the species richness for these three taxa in the Boreal region is comparable to tropical regions[161]. Most threatened forest species in the Boreal region depend on habitats with a continuity of coarse, woody debris and very old trees. In addition, herb-rich forests and old peatland forests (like mires and bogs) are important for threatened species.

Forestry has long been – and continues to be – a part of the economy in Fennoscandia at country level and for individual companies, smallholders, and rural SMEs. Much of the forest in this area has been shaped by human intervention for hundreds of years. Before the era of even-aged RFM, which began in the mid-1900s, slash and burn agriculture impacted the forests for 2,000-3,000 years. Tar and charcoal production remained extensive in Boreal forests until the end of the 1800s, and the need for burning wood for heat has had a strong impact on these forests, especially in the southern parts of Fennoscandia. In combination with the more recent increase in commercial uses of wood (notably of timber and pulpwood), these historical practices have led to a significant change in the forest landscape of the Boreal region. These landscapes are not characterised by low levels of deadwood and the fragmentation of old-growth and natural forests, which are among the key aspects for biodiversity as critical habitats for wild fauna and flora. Nowadays, Boreal forests mainly consist of semi-natural, even-aged forests, in which it is important to improve structures to increase biodiversity.

Since the 1990s, measures to preserve and improve biodiversity have been taken. These measures include: (i) leaving retention/habitat trees; (ii) introducing deciduous trees into conifer stands; and (iii) forest legislation focused on improving forest biodiversity through legislative measures (e.g. protection of valuable small habitats, enhancing deadwood, etc.). For example, in Sweden, CCF was

[160] Lindberg H. et al. (2020). The challenge of combining variable retention and prescribed burning in Finland. *Ecological Processes, 9*, Article 4. https://doi.org/10.1186/s13717-019-0207-3

[161] Geffert, J. L. et al. (2013). Global moss diversity: Spatial and taxonomic patterns of species richness. *Journal of Bryology, 35*(1), 1-11. https://doi.org/10.1179/1743282012Y.0000000038

essentially banned in the Forestry Act of 1979, but a new forest policy was adopted in 1993 that implicitly lifted the ban on CCF by setting environmental objectives as a co-equal priority alongside forest production[162]. This has resulted in positive trends in the amounts of deadwood, and the numbers of large deciduous trees and old trees, for example.

However, according to the latest data from reporting for 2013-2018 under Article 17 of the EU Habitats Directive, 90% of the protected Annex 1 forest habitat types in the region still have an unfavourable conservation status. Forty-three per cent of the 90% show a deteriorating trend[163].

From a landscape perspective, the forest land in the Boreal region is a mosaic of: (i) managed forests, including retention; (ii) unmanaged low-productivity forests; (iii) protected forests; and (iv) voluntary set-asides, including for biodiversity and forest conservation (26% in Sweden). Nowadays, managed even-aged, semi-natural forests are often the most prominent part of the boreal landscape.

Natural disturbance dynamics in the Boreal region

Boreal forests are naturally characterised by diverse disturbance dynamics including partial, small-scale and large-scale disturbances[164,165,166]. Four types of disturbance dynamics have been identified in the Boreal region: (i) even-aged stand dynamics driven by stand-replacing disturbances; (ii) cohort dynamics driven by partial disturbances; (iii) patch dynamics driven by tree mortality at intermediate scales (> 200 m^2); and (iv) gap dynamics driven by tree mortality at fine scales (< 200 m^2)[167]. All types of disturbance dynamics can occur in both spruce-dominated forests and pine-dominated forests.

In naturally dynamic forest landscapes, disturbances often do not replace stands[168]. In the absence of forest fires, the prevailing natural dynamic in spruce forests is gap dynamics, where trees usually regenerate after infestations by insects, fungi or small patches of windthrow. This dynamic leads to an uneven age structure of stands. In spruce forests, fire dynamics create deciduous stands, which are later colonised by spruces.

The prevailing natural dynamics on dry soils are driven by fire, resulting in semi-open forests dominated by pine, birch and/or aspen. The dynamics that are based on repeating fires lead often to a stand structure with variable cohorts of understory, old trees and deadwood, all of which have survived several fires. Scarcity of fire (or other large-scale disturbances such as extensive windthrows) may change the natural composition of tree species, and the landscape may eventually become dominated by dense, spruce-rich forests that cannot host species adapted to open pine-dominated forests with the fire-created structures.

[162] Stens, A. et al. (2019). From ecological knowledge to conservation policy: A case study on green tree retention and continuous-cover forestry in Sweden. *Biodiversity and Conservation, 28*, 3547-3574. https://doi.org/10.1007/s10531-019-01836-2

[163] State of nature in Europe: a health check — European Environment Agency (europa.eu)

[164] Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

[165] Bauhus, J. et al. (2013). Close-to-nature forest management in Europe: Does it support complexity and adaptability of forest ecosystems? In C. Messier et al. (Eds), *Managing forests as complex adaptive systems: Building resilience to the challenge of global change* (pp. 187-213). Routledge. http://dx.doi.org/10.4324/9780203122808-12

[166] Kuuluvainen, T. et al. (2021). Natural disturbance-based forest management: Moving beyond retention and continuous-cover forestry. *Frontiers in Forests and Global Change, 4*. https://doi.org/10.3389/ffgc.2021.629020

[167] Kuuluvainen, T., & Aakala, T. (2011). Natural forest dynamics in boreal Fennoscandia: A review and classification. *Silva Fennica, 45*(5), Article 73. https://doi.org/10.14214/sf.73

[168] Beglund, H., & Kuuluvainen, T. (2021). Representative boreal forest habitats in northern Europe, and a revised model for ecosystem management and biodiversity conservation. *Ambio, 50*, 1003-1017. https://doi.org/10.1007/s13280-020-01444-3

Forest management methods

CCF methods like selective logging used to be common in Fennoscandia until the mid-20th century[169], when they were increasingly replaced by clear-cut harvesting methods[170]. Today, RFM is the prevailing management method in the Nordic and Baltic countries. Currently, around 55-60% of the forests in Finland and Sweden consist of tree stands younger than 60 years[171], representing an age-class distribution formed as a result of the historical use of forests.

Forests in the Boreal region are regenerated in several ways: (i) naturally; (ii) with planting and sowing/artificial regeneration; or often (iii) by a combination of both. However, in recent decades, the use of planting has considerably increased and natural regeneration has declined. More than half of the naturally regenerated area and most of the planted area in Boreal region forests are prepared with soil scarification[172]. This has positive effects for forest growth, resilience and natural regeneration, but it affects biodiversity by changing soil communities and reducing carbon storage[173]. Recent developments in soil scarification methods have benefited certain species, such as bilberry which is now abundant in Boreal forests. Ditching represents another adverse impact on Boreal forests.

The level of retention (single trees, retention patches, buffer zones) as well as the size and occurrence of clear-cuts vary throughout the region and between forest owners. On average, current retention levels are considered to be too low for a meaningful ecological benefit, in particular for declining and red-listed forest species[174]. However, the amount of retention trees has been constantly growing since the 1990s. The average area of individual clear-cuts in Boreal region forests is approximately 1.5 ha to 3 ha, not considering cumulating effects of clear-cuts in neighbouring areas. Family forest owners in Sweden voluntarily set aside about 5% of their land and take the environment into greater consideration than the law requires during harvest. This includes protecting waterways and other valuable forest areas. Nowadays, CCF methods are not common practice in the Boreal region, accounting for only 1% on average per country based on 2017 felling data[175]. However, interest in – and research on – the effects and applicability of CCF is increasing.

The Sámi people: an indigenous people within the EU

In the north of Norway, Sweden, Finland and Russia, the Sámi people are dependent on forests and reindeer husbandry for their subsistence. The forest provides shelter, food and materials for Sámi handicrafts.

Changes in habitats and habitat fragmentation due – directly or indirectly – to competing land use, including intense forestry, is negatively impacting Sámi culture, and reindeer husbandry in particular.

Increased connectivity between forests of importance for Sámi culture, notably for reindeer husbandry, could be achieved through more consultation and greater use of closer-to-nature forestry practices. Connectivity between lichen-rich forests and other forests of importance for reindeer

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[169] Östlund, L. et al. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. *Canadian Journal of Forest Research, 27*(8), 1198-1206. https://doi.org/10.1139/x97-070

[170] Lundmark, H. et al. (2013). The history of clear-cutting in northern Sweden – Driving forces and myths in boreal silviculture. *Forest Ecology and Management, 307*, 112-122. https://doi.org/10.1016/j.foreco.2013.07.003

[171] SLU. (2021). *Skogsdata 2021*. SLU Institutionen för skoglig resurshushållning. https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata_2021_webb.pdf

[172] Statistiska meddelanden Återväxternas kvalitet 2019-2020 (skogsstyrelsen.se)

[173] Jiménez Esquilín, A. E. et al. (2008). Soil scarification and wildfire interactions and effects on microbial communities and carbon. *Soil Science Society of America Journal, 72*(1), 111-118. https://doi.org/10.2136/sssaj2006.0292

[174] Kuuluvainen, T. et al. (2019). Low-level retention forestry, certification, and biodiversity: Case Finland. *Ecological Processes, 8*, Article 47. https://doi.org/10.1186/s13717-019-0198-0

[175] Mason, W. L. et al. (2021). Continuous cover forestry in Europe: Usage and the knowledge gaps and challenges to wider adoption. Forestry: *An International Journal of Forest Research, 95*(1), 1-12. https://doi.org/10.1093/forestry/cpab038

husbandry would make it easier for the reindeer to move over contiguous grazing areas. Connectivity of this sort has the potential to improve the availability of arboreal lichens in forests.

The steep decline of lichens is another major threat for reindeer husbandry. As a food resource, lichens are crucial for reindeer survival and therefore for the survival of all Sámi culture. In the past 60 years, lichen-rich forests have declined by 70%[176]. Reindeer grazing thrives in old-growth forests because of the vast amounts of beard lichens growing in this type of forest. In the drier and more sandy soils, there is also a very significant amount of reindeer lichens on the ground. Both these types of lichens are lacking in the young, even-aged stands of spruce or pine due to changed site conditions and soil scarification after harvesting. In Sweden, the earlier-planted plantations of the exotic and invasive tree species *Pinus contorta* is further undermining the conditions for Sámi reindeer husbandry by creating migrating barriers and poor reindeer forage. Therefore, it is of great importance to ensure that there is enough available lichen-rich forest in the landscape where reindeer husbandry takes place.

Consultation and cooperation with the Sámi people to obtain their free, prior and informed consent (FPIC)[177] before adopting and implementing measures that may affect them directly are key to protecting traditional subsistence living and for protecting biodiversity and ecosystems[178]. Continuous dialogue between the Sámi community and forest owners is crucial.

Closer-to-nature tools in practice in the Boreal region

Current good practices to implement closer-to-nature forest management in the Boreal region should be strengthened, and the implementation of these practices should take account of climate change effects. Climate change is likely to have many potentially profound effects on Boreal forests. For example, spruce might benefit in the medium term from a prolonged growing season and more precipitation due to climate change. However, spruce will likely be less resilient in the longer term to more frequent and more intense droughts, heat waves and pest outbreaks, as average temperatures continue to rise[179].

The most important principle is that expanding the use of closer-to-nature forest management will mean employing a variety of silvicultural methods to develop forest ecosystems that: (i) reflect local climatic conditions, forest types and site types; (ii) can sustain biodiversity and facilitate resilience; and (iii) can provide the desired range of ecosystem services.

Natural regeneration should be the first choice, considering its economic feasibility, site conditions and natural variation in the site type. Where it is assessed as leading to better forest growth, structural diversity, species diversity and resilience to climate change, natural regeneration could be combined with assisted planting or seedings of adapted native tree species. Native tree species should always be favoured. This is because lichens and mycorrhizal fungi, for example, appear to be particularly sensitive to the native character of tree species. The specific biodiversity potential associated with non-native species is on average lower than that associated with native species. Furthermore, exotic species raise a risk of being invasive and can spread undesired pathogens.

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[176] Sandström, P. et al. (2016). On the decline of ground lichen forests in the Swedish boreal landscape: Implications for reindeer husbandry and sustainable forest management. *Ambio, 45*(4), 415-429. https://doi.org/10.1007/s13280-015-0759-0

[177] Free, prior and informed consent (FPIC) is recognised in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

[178] This is set out in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). https://www.fao.org/indigenous-peoples/our-pillars/fpic/en/

[179] Kausrud, K. et al. (2022). *Impacts of climate change on the boreal forest ecosystem*. Scientific Opinion of the Panel on Alien Organisms and Trade in endangered species (CITES) of the Norwegian Scientific Committee for Food and Environment. VKM Report 2022:15. Norwegian Scientific Committee for Food and Environment (VKM). https://munin.uit.no/bitstream/handle/10037/28066/article.pdf?sequence=2&isAllowed=y

At the same time, in very specific cases and conditions (e.g. due to the climate change process, and the already observed changes in annual mean temperatures), new provenances of the same native species adapted to the local ecological context and habitat conditions (soil and climatic conditions prevailing on the site at local level) could be promoted to support natural adaptation to climate change. These specific cases should be assessed with the objective of promoting forest biodiversity and resilience.

No pesticides should be allowed, except biological pesticides for sanitary purposes to address emergency circumstances. In specific cases such as root rot, and in line with legal obligations, these pesticides may include preventive stump treatment in stands dominated by spruce and pine during felling. If used, these pesticides should be duly assessed and monitored. Fertilisation should only be used to address nutrition imbalances where it does not risk negative effects on biodiversity in the long term.

In the Boreal region, the management approach should consider soil conditions. CCF can be applied, especially in fertile and wet habitats. It can promote greater humidity, for example, in drained forested peatlands[180], and therefore improve drought resilience and fire resistance while potentially also reducing soil CO_2 emissions. If the decision to adopt CCF practices is taken towards the end of a rotation period, the focus should be on ensuring respectful harvest conditions by felling trees individually or in small groups.

Especially on drier and less fertile soils, retention forestry combined with prescribed burning can be an alternative starting point for increasing structural complexity and tree species diversity. Retention forestry can promote biodiversity, but its benefits for individual species depend on what these species need to ensure their habitats are not excessively disturbed. Protected areas are also needed, and in some cases they may be the only way to safeguard certain habitats and species, such as highly specialised species. Retention patches and trees should be permanent, and their distribution and volume should be at science-based levels that are sufficiently high to: (i) obtain tangible ecological benefits; and (ii) contribute in particular to the objective of halting the decline of rare and red-listed species that depend on large and old living trees and coarse woody debris. According to available scientific evidence, 5-10% should be the strict minimum percentage of forest dedicated to retention patches, noting that considerably more will likely be needed in many cases to achieve the desired ecological objectives[181]. Overall, the ecological aim should be to safeguard some of the key structural, functional and compositional diversity characteristics of natural forest ecosystems[182]. Other studies suggest that retention levels of more than 15% are needed to effectively retain sensitive plants and animals, improve harsh microclimatic conditions and gain public acceptance of retention harvests in forests[183].

Harvesting techniques and planning should prevent soil damage and take full account of biodiversity, water, cultural values and other forms of use. Harvesting techniques and planning should also: (i) identify science-based levels for buffer zones; (ii) identify water considerations; (iii) identify minimum levels of nature conservation and restoration measures; and (iv) increase the resilience of the managed area. Soil scarification should only be used in exceptional cases if required to achieve

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180 Laudon, H., & Maher Hasselquist, E. (2023). Applying continuous-cover forestry on drained boreal peatlands; water regulation, biodiversity, climate benefits and remaining uncertainties. *Trees, Forests and People, 11*, Article 100363. https://doi.org/10.1016/j.tfp.2022.100363

181 Gustafsson L. et al. (2012). Retention forestry to maintain multifunctional forests: A world perspective. *BioScience, 62*(7), 633-645. https://doi.org/10.1525/bio.2012.62.7.6

182 Kuuluvainen, T. et al. (2019). Low-level retention forestry, certification, and biodiversity: Case Finland. *Ecological Processes, 8*, Article 47. https://doi.org/10.1186/s13717-019-0198-0

183 Aubry, K. B. et al. (2009). Variable-retention harvests in the Pacific Northwest: A review of short-term findings from the DEMO study. *Forest Ecology and Management, 258*(4), 398-408. https://doi.org/10.1016/j.foreco.2009.03.013

sufficient regeneration. The lightest soil scarification method should be used to minimise impacts on soil and lichen communities. Shelterwood systems or gap-cutting may be used to both minimise impacts of the intervention and support light-demanding species, for example. During pre-commercial and commercial thinning operations, it is important to promote a mixture of tree species in the forest. The risk of damage caused by certain pests such as bark beetles, outbreaks of which are forecasted to increase with climate change, can be reduced with increasing species diversity, notably with broadleaved tree species[184].

Independent of the forest management regime, interventions should aim to optimise deadwood retention considering both: (i) biodiversity needs across different species, in particular threatened species; and (ii) risk mitigation for fires and pests. Current levels of deadwood are increasing in all European forests, but they tend to be rather low on average in the Boreal region. As an example, ranges of 10-80 m^3 of deadwood per hectare with a peak at 20-30 m^3 per hectare have been proposed as a baseline for management decisions for boreal coniferous forests[185]. To increase deadwood levels, possible measures that respond to the varying needs of different species include: (i) retention of dying trees and existing coarse woody debris; and (ii) active creation of deadwood through, for example, artificial snags ('high stumps').

Other measures include set-aside areas. Set-aside areas are important for preserving specific high-conservation-value habitat types (including key woodland habitats). These habitats are important for rare, habitat-specialist species and can be crucial in improving habitat connectivity. In turn, improved habitat connectivity can help to secure a functional network of habitats with high conservation value. In any forest management activity, it is recommended to minimise the removal and disturbance of ground vegetation, needed for food supply, nesting, and cover by other flora and fauna.

Large herbivores (ungulates) are an indispensable part of Europe's Boreal forests. However, in some local areas high numbers of a few wild ungulate species prevent the establishment of more diverse stands. The densities of large herbivores have been falling sharply in the forests of the Boreal region for many years with only a few exceptions. One exception to this general trend is species like fallow deer and white-tailed deer, both of which have increased locally in certain parts of the Boreal region. Under such circumstances, efficient countermeasures are necessary: focused hunting[186], deer repellents and the fencing of young forest cultures. In general, a balanced forest ungulate system needs to consider both the economic and the ecological point of view.

Landscape-level considerations are crucial for: (i) cost-efficient forest management; (ii) the conservation of species and habitats; and (iii) increasing the heterogeneity of forests, particularly in terms of age structure and structural features. The development of uneven-aged forests both at stand and landscape levels is an important element in fostering structural diversity and it also benefits forest-dependent species[187]. Many species depend on large-scale patterns and processes, but so far almost all surveys and experiments have been carried out at the stand level[188]. Important elements to consider at the landscape scale are:

[184] Berthelot, S. et al. (2021). Tree diversity reduces the risk of bark beetle infestation for preferred conifer species, but increases the risk for less preferred hosts. *Journal of Ecology, 109*(7), 2649-2661. https://doi.org/10.1111/1365-2745.13672

[185] Müller, J., & Bütler, R. (2010). A review of habitat thresholds for dead wood: A baseline for management recommendations in European forests. *European Journal of Forest Research, 129*, 981-992. https://doi.org/10.1007/s10342-010-0400-5

[186] Cromsigt J. P. G. M. et al. (2013). Hunting for fear: Innovating management of human–wildlife conflicts. *Journal of Applied Ecology, 50*(3), 544-549. https://doi.org/10.1111/1365-2664.12076

[187] Savilaakso, S. et al. (2021). What are the effects of even-aged and uneven-aged forest management on boreal forest biodiversity in Fennoscandia and European Russia? A systematic review. *Environmental Evidence, 10*(1). https://doi.org/10.1186/s13750-020-00215-7

[188] Gustavsson, L. et al. (2020). Research on retention forestry in northern Europe. *Ecological Processes, 9*, Article 3. https://doi.org/10.1186/s13717-019-0208-2

- different types and amounts of structural characteristics, e.g. very old trees and coarse woody debris in different landscapes;
- environmentally and culturally important areas;
- the effects of roads and other infrastructure made by humans;
- the distribution of forestry activities in time and space;
- different requirements for the occupancy and abundance of especially rare and red-listed species;
- greater forest-landscape connectivity to facilitate movements of species and their genes.

Landscape-scale management can be considered easier by some landowners who own or administer very large areas, such as state forests and large forest companies. But private forest owners can also be encouraged to: (i) better account for biodiversity and other ecosystem services with new participatory processes and access to open data to cooperate (for example, in nature management projects); or (ii) collaborate with public authorities and other forest owners at landscape level.

Critical enablers in the Boreal region

Forests in the Boreal region are mostly privately owned. This point should not be neglected, since the uptake of closer-to-nature forestry practices is highly dependent on the motivation of private owners and on the support and incentives that they are offered to implement these practices. Private forest owners with an interest in closer-to-nature forestry should either be skilled and knowledgeable in the relevant practices or have access to advisory/support services based on closer-to-nature forestry. Education and awareness raising are critical to spread best practices widely. Forest owners and forest professionals who plan, manage, harvest or buy wood play a key role in spreading best practices widely. Providing targeted information and planning tools for them plays a key role in spreading closer-to-nature forestry practices. For example, using geographic data in planning opens more possibilities for targeting biodiversity and climate adaptation measures to where they are most cost-efficient.

Most of the forests in the Boreal region are in non-industrial private ownership[189]. It is important to provide incentives, including information and financial incentives, for the forest owners to promote voluntary measures. These incentives could include alternative income options such as payment-for-ecosystem-services schemes. A good example of an alternative income option is the Metso programme[190] in Finland, which rewards private forest owners for setting areas aside for biodiversity. However, in the end, closer-to-nature management should be profitable by itself and without public subsidies, in particular, if respective value chains are strengthened.

The Continental region

Introduction

The Continental region covers over a quarter of the EU. It starts in central France and stretches beyond the eastern border of Poland. The forests of the Continental region consist of approximately 40 native tree species with various life-history strategies, biological properties and ecological requirements[191]. Over the last two centuries, there has been a focus on the production function of forests in this area. This focus has, combined with harsh environmental conditions (low precipitation, poor soils) in extensive areas of the region (especially in its northern and eastern parts), resulted in rather simple

[189] https://efi.int/forestquestions/q2
[190] https://metsonpolku.fi/en/metso-programme
[191] Brzeziecki, B., & Kienast, F. (1994). Classifying the life-history strategies of trees on the basis of the Grimian model. *Forest Ecology and Management, 69*(1–3), 167-187. https://doi.org/10.1016/0378-1127(94)90227-5

tree species composition and structures in many current Continental forest stands[192]. As a result of this, the Continental forests, especially conifer stands established on former agricultural lands[193], are constantly threatened by several factors, including abiotic factors (hurricane winds, droughts, wet-snow loads), biotic factors (bark beetles and other insects, infectious fungal diseases, excessive numbers of ungulates, mistletoe), and anthropogenic factors (air and soil pollution, forest fires).

The share of forest habitats reported under Article 17 of the EU Habitats Directive 92/43/EEC with a good conservation status in the Continental region is rather low (20.79%), but still slightly higher than the average across all biogeographical regions (20.32%)[194]. Introduced tree species (e.g. Douglas fir, Sitka spruce) are in general rare in the Continental forests, covering about 3% of the forest area. Nevertheless, in some areas of the region the expansion of invasive alien species (black locust, tree of heaven, ash-leaved maple, black cherry, northern red oak, etc.) can be observed[195].

Over the last 30 years, the general state of Continental forests has been slowly improving from both an ecological and an economic point of view. This can be seen in increasing trends in several key forest indices (forest coverage, standing tree volume, age class structure, share of broadleaved species, amount of deadwood, amount of harvested timber, forest bird populations[196])[197] thanks to local forest managers and the timber industry. They play a significant role in climate change mitigation and in the European transformation process towards a circular bioeconomy[198]. Likewise, despite the long-lasting history of human use and human-induced transformation of most – if not virtually all – natural ecosystems[199], the Continental region is still rich in biodiversity[200,201].

The current approach to the use and protection of forest resources and values in the Continental region is largely a result of several breakthrough initiatives and processes at the global, European and national levels. These initiatives and processes were mostly started in the early 1990s[202]. Different closer-to-nature practices are currently being applied in the Continental region[203], and these practices have also been enshrined in official silvicultural guidelines and other similar documents. Examples of such practices are closer-to-nature silviculture in central Europe[204,205] or CCF in several other countries

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[192] The natural vegetation in the Continental region is mixed deciduous forests or mixed conifer-deciduous or conifer-dominated forests (depending on local soil conditions). In many places, however, natural woodland communities were replaced by single-species, even-aged Norway spruce and/or Scots pine forest stands in the past due to their fast growth rates and desirable timber properties.

[193] In Poland alone, after the Second World War, roughly 2.8 million ha of forests were established on post-agricultural lands. Statistics Poland / Topics / Statistical yearbooks / Statistical Yearbooks / Concise Statistical Yearbook of Poland 2022

[194] Conservation status and trends of habitats and species - European Environment Agency (europa.eu)

[195] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[196] Over the past four decades, there was an improving or stabilising trend in most forest-bird populations. Source: European Environment agency. (2020). *State of nature in the EU. Results from reporting under the nature directives 2013-2018*. EEA Report No 10/2020, p. 134. https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020

[197] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[198] Brief on the role of a forest-based bioeconomy in mitigating climate change. 2021. The European Commission's Knowledge Centre for Bioeconomy.

[199] In the Continental region, the share of undisturbed (primary and old-growth) forests is much less than 1%. Source: Barredo, J. I. et al. (2021). *Mapping and assessment of primary and old-growth forests in Europe*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/797591

[200] Schulze, E. (2017). Effects of forest management on biodiversity in temperate deciduous forests: An overview based on Central European beech forests. *Journal for Nature Conservation, 43*, 213-226. https://doi.org/10.1016/j.jnc.2017.08.001

[201] Sundseth, K. (2005). *Natura 2000 in the Continental region*. European Commission.

[202] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[203] Many closer-to-nature silviculture concepts have emerged in the Continental part of Europe, including 'Dauerwald' in the early 20th century and CCF concepts promoted by Pro Silva, which was founded in 1989 in Slovenia. Source: Jacobsen, M. K. (2001). History and principles of close to nature forest management: A Central European perspective. In K. Alexander (Ed), *Tools for preserving woodland biodiversity* (pp. 56-60). Naconex.

[204] Bernadzki, E. (2000). Close-to-nature silviculture (in Polish). *Bibl. Leśn, 129*. SITLiD. DGLP.

[205] Brzeziecki, B. (2008). Ecosystem approach and close-to-nature silviculture (in the context of the forest multifunctionality principle) (in Polish with English Summary). *SiM CEPL w Rogowie, 19*(3), 41-54.

of the region[206,207]. Both approaches are based on common silvicultural principles such as: (i) avoidance of large clear-cuts; (ii) preferential use of natural regeneration and native tree species; (iii) an emphasis on diversity of stand structures at small scales; (iv) the promotion of mixed-species stands; and (v) the avoidance of intensive forest operations[208]. Thanks to this, many forest stands in the Continental region are now closer-to-nature than they were just 20-30 years ago. However, replacing a conventional forestry model – typically based on even-aged forestry – with alternative, more ecologically oriented approaches is a long-term process, needing continuity and reinforcement.

Forests in the Continental region face many problems and challenges, such as: (i) the biodiversity crisis; (ii) climate change impacts; (iii) nitrogen deposition[209]; and (iv) high ungulate densities. It is highly likely that the spatial distribution of the main forest types will change under future climatic conditions, with species currently important for wood production in the Continental region (Norway spruce, Scots pine) being replaced with other, less productive species[210]. Thus, closer-to-nature forestry management measures should be further promoted since they can greatly contribute to addressing these challenges. These measures help to safeguard biodiversity and support the potential of Continental forests to adapt to current and future environmental changes. Of particular importance in promoting this potential are the following key 'adaptation rules'[211]: (i) increase tree species richness (including in specific cases the introduction of pioneer species that are more resilient and better adapted to long-term climate change); (ii) increase structural diversity; (iii) maintain and increase genetic variation within tree species; (iv) increase the resistance of individual trees and stands to biotic and abiotic stress; (v) transform high-risk stands; and (vi) keep growing stock volume low[212].

Closer-to-nature forestry in practice in the Continental region

For several decades, one of the highest priorities of silvicultural practice in the Continental region has been the promotion of natural regeneration[213]. In closer-to-nature forestry management, natural regeneration is the first choice and it should be further promoted and widely used. Where this is not possible (for example, due to: (i) insufficient silvicultural quality, diversity and vigour of mature stands; or (ii) the lack of appropriate seed trees), artificial regeneration, including enrichment or improvement planting, will remain a relevant measure for transitioning towards closer-to-nature forestry operations[214,215]. Artificial regeneration can also help to create more diverse compositions of tree species in areas where competitive ground vegetation (grasses, herbs and shrubs) or a thick layer of forest litter prevents seedling establishment and cannot be dealt with through other means. It is important, however, to avoid creating monospecific stands. It is also important to use planting and/or

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206 Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

207 Pommerening, A., & Murphy, S. T. (2004). A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. *Forestry, 77*, 27-44. https://doi.org/10.1093/forestry/77.1.27

208 Puettmann, K. J. et al. (2015). Silvicultural alternatives to conventional even-aged forest management - What limits global adoption? *Forest Ecosystems, 2*, Article 8. https://doi.org/10.1186/s40663-015-0031-x

209 The atmospheric deposition of nitrogen in central Europe has been growing in recent decades, exceeding the buffer capacity of forest ecosystems and leading to noticeable site eutrophication. Sources: 1) Churkina, G. et al. (2010). Interactions between nitrogen deposition, land cover conversion, and climate change determine the contemporary carbon balance of Europe. *Biogeosciences, 7*, 2749-2764; 2) Pretzsch, H. et al. (2014). Forest stand growth dynamics in Central Europe have accelerated since 1870. *Nature Communications, 5*, Article 4967.

210 Hanewinkel, M. et al. (2013). Climate change may cause severe loss in the economic value of European forest land. *Nature Climate Change, 3*, 203-207. https://doi.org/10.1038/nclimate1687

211 Brang, P. et al. (2014). Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. *Forestry: An International Journal of Forest Research, 87*(4), 492-503. https://doi.org/10.1093/forestry/cpu018

212 While keeping low growing-stock density might be seen as an adaptation strategy, there are limitations to applying it fully in single-tree and group selection systems, as explained in the cited study.

213 In Poland, the share of natural regeneration in managed forests has increased from nearly none in the 1980s to the current 15-20% on average.

214 Puettmann, K. J. et al. (2015). Silvicultural alternatives to conventional even-aged forest management - What limits global adoption? *Forest Ecosystems, 2*, Article 8. https://doi.org/10.1186/s40663-015-0031-x

215 Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

direct seeding to create forests that are as diverse as possible[216] under constraints imposed by local environmental conditions. In Continental Europe, some forestry management practices merge artificial regeneration and natural regeneration within the same stand. This leads to so-called combined regeneration[217]. It can also include assisted migration with suitable provenances and/or ecologically adapted species to promote climate change adaptation[218]. In any case, the regeneration method can't be treated as an end in itself, but merely as a means to promote tree species diversity and composition in line with local natural conditions[219].

Yet another important priority in the region is the promotion of respectful harvest conditions. Uneven-aged systems are gaining steadily in significance and should be further promoted by respectful harvest conditions. These uneven-aged systems include single-selection, group-selection and irregular shelterwood regeneration cuttings, all of which encourage high levels of within-stand structural diversity (Figure 6). Nevertheless, there may be a justification for also using some forms and variants of variable retention systems[220] (Figure 7). This is mainly to accommodate the high need for light of several tree species, characteristic for the Continental region (e.g. aspen, birch, larch, pine, oak and alder), as well as many other forest-dwelling wildlife species (such as vascular plants and insects, including rare and red-listed species[221]). When using these forms and variants of variable retention systems, retaining important residual structures and organisms occurring in the original stand (so-called biological legacies[222], such as seed and habitat trees[223]) will help to restore key structural, functional and compositional diversity. Diversity of this sort is typical for natural forest ecosystems[224].

[216] Messier, Ch. et al. (2021). For the sake of resilience and multifunctionality, let's diversify planted forests! *Conservation Letters, 15*(1), Article e12829. https://doi.org/10.1111/conl.12829

[217] An example is planting oaks in wide-spaced clusters, which allows for a natural regeneration of accompanying tree species in free spaces between oak clusters and leads to a high species diversity of newly established stands. Source: Rock J. et al. (2003). Vegetation diversity of thicket stage oak stands planted in different schemes. *Beitr. Forstwirt. Landschafts, 37*, 11-17. Another example is so-called Sobański's method, widely used in western Poland, which involves a direct seeding of oak, beech, hornbeam, lime, sycamore and other broadleaved tree and shrub species during establishment of Scots pine-dominated stands. Source: Niemiec, P. (2003). Sobański's method (In Polish). *Las Polski, 19*, 19-21.

[218] Commission Staff Working Document on Guidelines on Biodiversity-Friendly Afforestation, Reforestation and Tree Planting (SWD (2023) 61).

[219] Bernadzki, E. (2000). Close-to-nature silviculture (in Polish). *Bibl. Leśn, 129*. SITLiD. DGLP.

[220] Gustafsson, L. et al. (2012). Retention forestry to maintain multifunctional forests: A world perspective. *BioScience, 62*(7), 633-645. https://doi.org/10.1525/bio.2012.62.7.6

[221] Sebek, P. et al. (2015). Does a minimal intervention approach threaten the biodiversity of protected areas? A multi-taxa short-term response to intervention in temperate oak-dominated forests. *Forest Ecology and Management, 358*, 80-89. https://doi.org/10.1016/j.foreco.2015.09.008

[222] Lindenmayer, D. B. et al. (2012). A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. *Conservation Letters, 5*(6), 421-431. https://doi.org/10.1111/j.1755-263X.2012.00257.x

[223] Habitat tree: a standing live or dead tree providing ecological niches (microhabitats). The concept of habitat tree in a broader sense also includes trees characterised by unusual shape, age and size, as well as trees representing rare, minor, nectareous and fruit-bearing species (e.g. aspen, birch, willow, lime, wild cherry, wild apple, wild pear and rowan).

[224] Retention patches and trees should be permanent, and their distribution and volume should be at science-based levels that are high enough to: (i) obtain tangible ecological benefits; and (ii) contribute in particular to the objective of halting the decline of rare and red-listed species that depend on large and old living trees and coarse woody debris. Available scientific evidence states that 5-10% should be a strict minimum percentage of forest dedicated to retention patches noting that considerably more will likely be needed in many cases to achieve the desired ecological objectives.

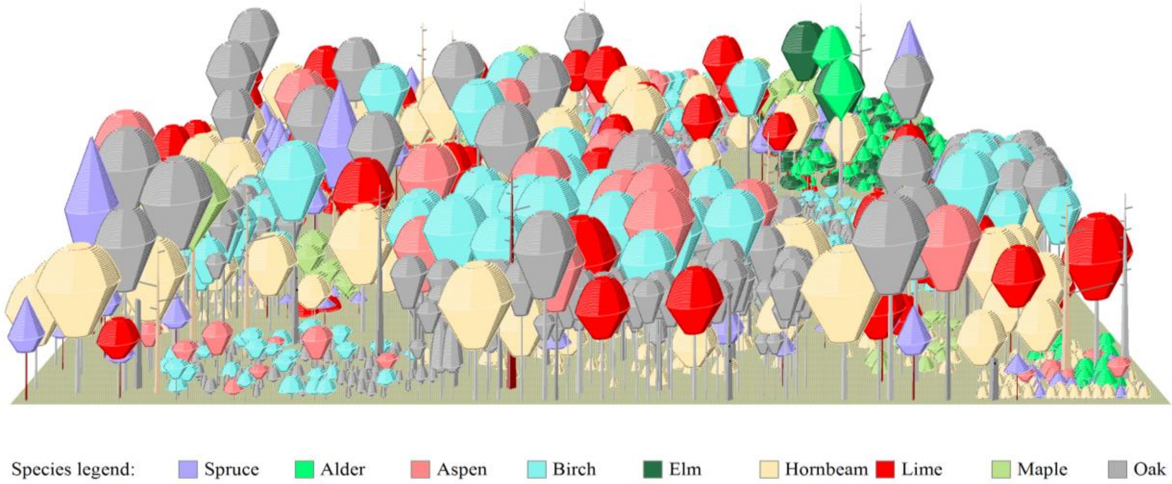

Figure 6: Example of a structurally and compositionally diverse stand consisting of mesotrophic tree species occupying rich sites, managed by a group-selection system

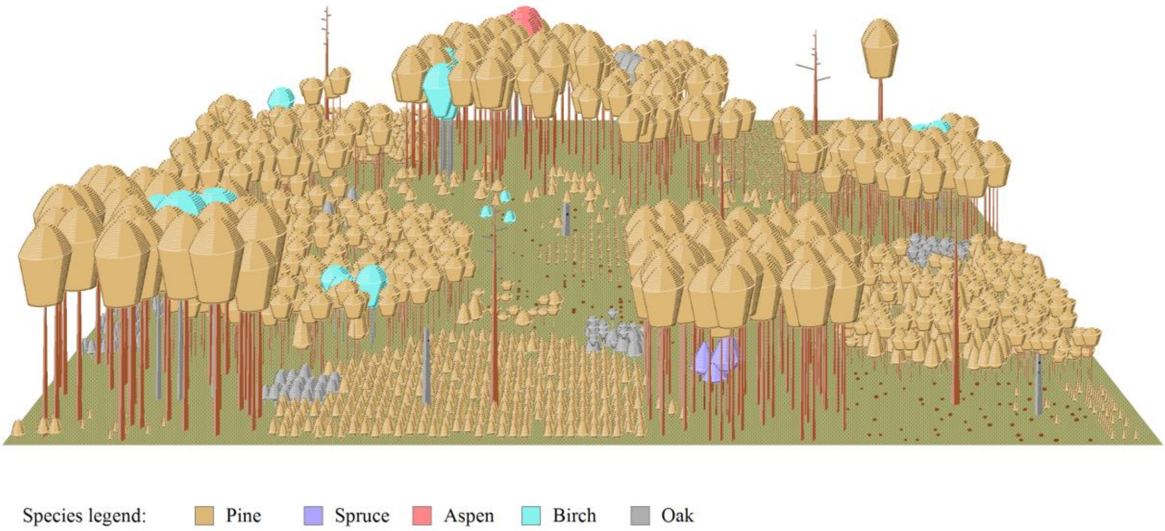

Figure 7: Example of closer-to-nature forestry structures in Scots pine stands occupying low-productive forest sites managed by a patch-cut system

To support diverse stand structures and composition, harvest regulation methods based on the concept of equilibrium diameter distribution should always be strongly preferred[225]. A wide application of such methods will help to preserve the spatio-temporal continuity of forest cover and ensure the demographic stability of particular tree species within relatively small (ca. 5-30 ha) units.

Preserving healthy forest soils is an additional important concern in closer-to-nature approaches. In this context, it is important to recognise that the success of either artificial or natural regeneration is

[225] Examples of such methods include: the Liocourt-Meyer model, the BDq method, and the demographic equilibrium approach. Sources: Schütz, J.-Ph. (2001). *Der Plenterwald und weitere Formen strukturierter und gemischter Wälder*. Parey; O'Hara, K. L. (2014). *Multiaged silviculture. Managing for complex forest stand structures*. Oxford University Press; Brzeziecki, B. et al. (2021). A demographic equilibrium approach to stocking control in mixed, multiaged stands in the Białowieża Forest, northeast Poland. *Forest Ecology and Management, 481*, Article 118694. https://doi.org/10.1016/j.foreco.2020.118694

usually a matter of proper soil management[226,227]. Many failures in regeneration can be traced to insufficient attention to soil health or the treatment of seeding and planting sites. In closer-to-nature forest management, it is always crucial to select the methods that are best suited for a given situation and are most friendly for the soil environment and the whole forest community[228]. 'Partial' methods, which affect only a small percentage of the soil surface (point-wise and row-wise methods), should always be preferred[229]. Under favourable conditions (missing and/or weakly developed ground-cover vegetation or thin layers of forest litter), natural regeneration without earlier soil treatment would be the obvious choice. For peaty soils, distinguished by a high groundwater table level, soil treatment should be avoided.

Considering that extensive areas in the Continental region are distinguished by low, variable precipitation and by scarce water resources, a major task of closer-to-nature forestry practice in the region is the efficient protection of existing wetlands and restoration of degraded wetlands and natural water bodies occurring within forested areas. This helps to: (i) slow down water outflow; (ii) retain water in soils as well as in open, natural and/or artificial reservoirs; and (iii) establish specially managed buffer zones around and along water bodies and courses[230]. Converting monoculture conifer forests to mixed-species forests with a higher proportion of broadleaved species is also a suitable closer-to-nature forestry tool for improving soil water budget[231].

Yet another important component of closer-to-nature forestry management is optimising balanced deadwood retention. Many studies have shown that leaving enough deadwood in the forest in all stages of decomposition is an important measure for biodiversity restoration and conservation[232]. For this reason, as early as two decades ago, the volume of deadwood, both standing and lying, was included in the list of quantitative indicators for Criterion 4 of sustainable forest management[233]. The volume of deadwood has also been incorporated in national forestry legislation (official guidelines, manuals and instructions)[234]. In the past 20 years, and as measures were implemented to promote deadwood, the average amount of deadwood in Continental forests has increased from practically none to current levels that approach 15 m^3/ha on average (and even more in some regions)[235]. Maintaining enough deadwood remains an important commitment of contemporary forest management. Nevertheless, the type and quantity of deadwood left in managed stands needs to

226 Löf, M. et al. (2012). Mechanical site preparation for forest restoration. *New Forests, 43*, 825-848. http://dx.doi.org/10.1007/s11056-012-9332-x

227 Aleksandrowicz-Trzcińska, M. et al. (2014). Effects of different methods of site preparation on natural regeneration of *Pinus sylvestris* in Eastern Poland. *Dendrobiology, 71*, 73-81.

228 Multi-aged, closer-to-nature silviculture is often associated with more natural forms of management. However, artificial regeneration and cultural treatments, such as site preparation and vegetation control, are also appropriate for creating multi-aged, structurally diverse stands. Source: O'Hara, K. L. (2014). Multiaged silviculture. *Managing for complex forest stand structures*. Oxford University Press. Chapter 8.3-5. Artificial regeneration.

229 Bernadzki, E. (2000). Close-to-nature silviculture (in Polish). *Bibl. Leśn, 129*. SITLiD. DGLP.

230 For example, in the period between 1998 and 2020, in Polish state-owned forests, over 17,000 objects of so-called small water retention were ecologically restored or newly built. Together, they store over 55.5 million m^3 of water. It is very important to continue such activities considering their positive impacts on water storage, carbon storage and biodiversity.

231 Müller, J. et al. (2002). Quantifizierung der ökologischen Wirkungen aufwachsender KiefernBuchen-Mischbestände im nordostdeutschen Tiefland. *Beiträge für Forstwirtschaft und Landschaftsökologie, 36*(3), 125-131. www.waldwasser.de/dload/waldwasser_vortrag1.pdf

232 Bernadzki, E. (1993). Enhancement of biodiversity through silviculture treatments (in Polish with English Summary). *Sylwan, 137*(3), 29-36.

233 Criterion 4 of sustainable forest management: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems. Source: Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

234 A good example is the sectoral 'Forest Protection Manual' of the State Forests in Poland, which contains detailed guidelines related to leaving biocenotic trees until their biological death and natural decomposition, p. 28. https://www.lasy.gov.pl/pl/publikacje/copy_of_gospodarka-lesna/ochrona_lasu/instrukcja-ochrony-lasu/instrukcja-ochrony-lasu-tom-i/view

235 Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

balance biodiversity considerations with the risk of fire, the risk of insect outbreaks and safety considerations.

In the past 30 years, the Continental region has seen the same trend that was visible elsewhere in Europe of excluding ever-growing forest areas from timber utilisation and subjecting them to strict protection. Examples of this include: (i) strict forest reserves; (ii) 'ecological spots'; (iii) all-year-round buffer zones around permanent nests of birds of prey; (iv) 'old-growth islands'; (v) 'reference forests'; and (vi) 'xylobiont refugees'. In each case, any decision to set a given forested area aside should be accompanied by measures to address possible conflicts and threats[236].

Large herbivores (ungulates) are an indispensable part of Europe's Continental forest ecosystems. However, excessive numbers of wild ungulates (deer overabundance) prevent the establishment of more diverse stands. They also strongly impair the ability of forests to fulfil their wood production function and have several negative cascade effects for the whole woodland community[237]. Since decades, the densities of large herbivores (roe deer, red deer, fallow deer and elk) have been increasing in forests of the Continental region[238]. This increase has been caused by many factors, including changes in overall environmental conditions, trends in agriculture and inadequate hunting strategies. Under such circumstances, efficient countermeasures are necessary. These efficient countermeasures can include: focused hunting[239], the application of deer repellents and the fencing off of young forest cultures. These countermeasures must consider their impacts and consequences from both an economic and an ecological point of view.

Critical enablers

It will be necessary to both: (i) maintain high levels of biodiversity in managed forests; and (ii) ensure the long-term productivity, multifunctionality and resilience to climate change of these forests. Achieving this requires the creation of forests that are as diverse as possible (in terms of composition and structure) and at both stand scale and landscape scale[240]. This process is underway in the Continental region. However, to further promote this process, several additional actions are needed. Some examples of these additional actions include: (i) environmental education to increase awareness of the benefits and practical options of closer-to-nature forest management, in particular among forest owners and managers; (ii) a sound impact/feasibility analysis of the closer-to-nature forestry measures; (iii) the integration of the main ideas and voluntary principles of closer-to-nature forestry in documents (such as national forestry legislation, official silvicultural guidelines, forest protection manuals, instructions on forest management, etc.); (iv) developing new forest-based products and services, including wood products derived from many different tree species not yet in wide use; (v) dialogue with the downstream value chain on the possible impacts of changing forest compositions on future timber markets; (vi) better integration of forestry issues into spatial planning at the landscape level; and (vii) investing in research to assess the landscape benefits of diverse forests for functional connectivity and resilience to climate change.

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[236] This is illustrated by the case of the Białowieża Forest in north-east Poland, where such a decision (to immediately stop management on the prevailing area of the forest, i.e. an area of about 50,000 ha) led to a massive outbreak of bark beetle. During a relatively short period (2012-2018), this outbreak killed approximately 2 million m^3 of Norway spruce trees. See: Brzeziecki, B. et al. (2018). Problem of a massive dying-off of Norway spruce in the 'Białowieża Forests' Forest Promotional Complex (In Polish with English Summary). *Sylwan, 162*(5), 373-386. https://doi.org/10.26202/sylwan.2017129

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[239] Cromsigt, J. P. G. M. et al. (2013). Hunting for fear: Innovating management of human–wildlife conflicts. *Journal of Applied Ecology, 50*(3), 544-549. https://doi.org/10.1111/1365-2664.12076

[240] O'Hara, K. L. (2014). *Multiaged silviculture. Managing for complex forest stand structures*. Oxford University Press.

When planning management interventions, and especially when planning harvesting operations, it is also important to consider potential public perceptions. One should note that even low-impact timber harvesting may create a negative impression among members of the public visiting forests located in densely populated areas, e.g. around cities, and in areas that are attractive for tourism and recreation. Institutions and organisations responsible for forest management planning and implementation should conduct effective environmental education, aimed at increasing public awareness and acceptance of closer-to-nature forestry measures in the field.

In general, the diversity of settings in which the principles of closer-to-nature forestry are applied is reflected by the diversity of possible challenges that may limit their wider implementation. This diversity of setting is typical even for relatively small biogeographical regions (such as the Continental region). Under such circumstances, the best strategy is to treat the closer-to-nature forestry concept in a flexible way, and to apply different closer-to-nature forestry measures in combinations to accommodate a wide variety of local, ecological, economic and social conditions[241,242]. Such combinations, complemented by clear targets for closer-to-nature results and regular performance monitoring, will ensure that the overall principles and objectives are achieved.

The Mediterranean region

Introduction

The Mediterranean basin is one of 36 global biodiversity hotspot centres for plant diversity and one of the richest in endemic species[243]. It also hosts 20% of the world's flowering plants and fern species, of which 50% are endemic[244]. The current Mediterranean landscape is the result of a long-term interaction between forest ecosystems and human populations that developed over millennia, creating a biocultural diversity recognised by the EU: of the 199 habitats of community importance (Directive 92/43/EC), 117 are in the Mediterranean region, and 93 of them are exclusively found there.

However, the prevailing ecological conditions in this area are quite diverse due to its varied terrain. This varied terrain gives rise to many bioclimates, defined by: (i) diverse orientations, slopes and ranges of altitude; (ii) the diversity of soils; and (iii) the greater or lesser degree of influence of other bioclimates (oceanic in the west/north-west, continental in the north, and arid in the south and east)[245]. Forest in the Mediterranean region is part of a landscape mosaic with different land uses (agriculture, agroforestry, forestry and grazing) and different patches of vegetation type and vegetation structure.

The long-term use of land for agriculture and timber production in the region has resulted in the loss of forest area. In addition, the profound alteration of natural fire regimes resulted in some regions in a progressive change in vegetation cover followed by soil degradation and fertility loss up to the early 20th century[246]. Urban expansion has recently damaged several of the region's forest ecosystems,

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[241] Puettmann, K. J. et al. (2015). Silvicultural alternatives to conventional even-aged forest management - What limits global adoption? *Forest Ecosystems, 2*, Article 8. https://doi.org/10.1186/s40663-015-0031-x

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[243] Blondel, J. & Médail, F. (2009). Biodiversity and conservation. In J. Woodward (Ed.), *The physical geography of the Mediterranean* (pp. 615-650). Oxford University Press.

[244] Gauquelin, T. et al. (2018). Mediterranean forests, land use and climate change: A social-ecological perspective. *Regional Environmental Change, 18*, 623-636. https://doi.org/10.1007/s10113-016-0994-3

[245] Coello, J. et al. (2022). *Adaptive and close-to-nature management in mixed sub-humid Mediterranean forests: Holm oak, chestnut, common oak and pine woods*. Forest Science and Technology Centre of Catalonia, Solsona (Lleida, Spain), Forest Ownership Centre, Santa Perpètua de Mogoda (Barcelona, Spain).

[246] Hill, J. et al. (2008). Mediterranean desertification and land degradation: Mapping related land use change syndromes based on satellite observations. *Global and Planetary Change, 64*(3–4), 146-157. https://doi.org/10.1016/j.gloplacha.2008.10.005

especially coastal ones. The intense land use – both historical and ongoing – and the high population density have been key drivers in reducing primary and old-growth forests. Primary forests cover only 0.26% of the total forest surface in the region[247]. The current conservation status for Mediterranean forest ecosystem habitats assessed is 'favourable' (30%), 'unfavourable/unknown' (32.6%) and 'deteriorating' (34.8%)[248].

According to the Global Forest Resources Assessment[249], the area occupied by Mediterranean forests has been slightly increasing since 1990. This increase was mainly due to natural forest expansion on abandoned agricultural and grazing areas and, to a minor degree, to reforestation. However, recent socioeconomic processes (rural abandonment, the ageing of rural populations, the intensification of production systems in certain areas such as Galicia and Portugal, globalising trends in wood production, etc.) have exposed forest landscapes to varying pressures causing continuous changes in vegetation structure[250]. As a result, Mediterranean forests are currently very vulnerable to a variety of risks such as: (i) changes in natural fire regimes; (ii) over-exploitation in some areas; (iii) degradation of water and soil ecosystems; (iv) desertification; and (v) climate change more broadly[251]. Several areas of the Mediterranean region face severe degradation due to the removal of forest cover and soil degradation processes. Many areas were largely deforested with progressive replacement by scrublands in the past. The over-exploitation and depletion of forest resources have profoundly impacted ecosystems throughout the Mediterranean region. These threats could compromise critical ecosystem services, such as the provision of strategic water resources for this region[252].

Existing main practices and trends in forest management in the Mediterranean region

Some Mediterranean forests have a long history of coppicing. However, several previously managed coppices are currently under conversion into high forests[253], which provides a greater yield per unit area and is more economically profitable[254].

There is a relatively low incidence of broadleaved high forests in the region, especially if compared with other European biomes. There are native conifer forests (coniferous forests of the Mediterranean, Anatolian and Macaronesian regions) and planted conifer forests that are locally managed with a wide range of silvicultural approaches. Management of forests is nowadays directed towards pursuing multiple functions[255].

Unique features of the Mediterranean bioregions include its cultural, silvopastoral and agroforest systems shaped by humans. These systems include holm oak, cork oak, chestnut and stone-pine forests. A remarkable case, accounting for nearly 3 million ha, are the Dehesa/Montado systems in Spain and Portugal, an open-canopy system combining trees with natural pasture, enabling production

[247] Forest Europe. (2015). *State of Europe's forests 2015*. Ministerial Conference on the Protection of Forests in Europe. https://foresteurope.org/wp-content/uploads/2022/02/soef_21_12_2015.pdf

[248] https://www.ecologic.eu/sites/default/files/publication/2015/state_of_nature_in_the_euv2_0.pdf

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[250] Quintas-Soriano, C. et al. (2022). Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: A review. *Land Use Policy, 116*, Article 106053. https://doi.org/10.1016/j.landusepol.2022.106053

[251] FAO, & Plan Bleu. (2018). *State of Mediterranean forests 2018*. Food and Agriculture Organization of the United Nations (FAO) and Plan Bleu. https://planbleu.org/wp-content/uploads/2018/11/somf2018.pdf

[252] Birot, Y. et al. (Eds.) (2011). *Water for forests and people in the Mediterranean – A challenging balance. What Science Can Tell Us 1*. European Forest Institute. https://efi.int/publications-bank/water-forests-and-people-mediterranean-challenging-balance

[253] In some cases, in landscape mosaics, coppicing may provide biodiversity, protection and non-wood forest products (Radtke et al., 2014; Scheidl et al., 2020; Vymazalová et al., 2021; Weiss et al., 2021). In some particular sites (e.g. deep and rocky slopes), coppicing might have a special protection role (Scheidl et al., 2020).

[254] Hubert, M. (1999). *Les terrains boisés, leur mise en valeur*. IDF, p. 254.

[255] Spiecker, H. et al. (2009). *Valuable broadleaved forests in Europe*. EFI Research Report 22, European Forest Institute, p. 276. https://efi.int/publications-bank/valuable-broadleaved-forests-europe

of livestock or crops. These silvopastoral systems are characterised by an open canopy, low tree cover, and often simplified stand composition and structure. These agroforest types have essential socioeconomic and cultural roles. In addition, they support a high diversity of plants and animals associated with the grass-shrub layer components and originate specific habitats under the Natura 2000 network. However, they face a number of ecological problems, such as lack of natural regeneration, tree decline, soil degradation, carbon loss and disease[256].

Over the last century, afforestation has been one of the central policies for the environmental management of forest landscapes in Mediterranean areas to restore the water regulation system, prevent floods and restore degraded land. However, in some forests, throughout the 20th century, afforestation led to extended use of pioneer conifers (e.g. maritime pine, Aleppo pine, stone-pine, Scots pine and black pines, but also some broadleaves such as eucalyptus). The spontaneous forest expansion following the rural exodus in the 1950s to 1970s also led to abandonment of land. In the absence of silvicultural tending or thinning to reduce stem density and increase structural heterogeneity, these relatively young and homogeneous forest structures are driving major changes in fire regimes towards stand-replacing fires[257]. In most cases, forest management practices in these afforestations include reducing fire hazards, increasing stand resistance to fire disturbance[258] and mitigating fire intensity to support firefighting in shaded fuel breaks[259]. These forest management practices should be seen in the overall context of promoting less vulnerable and more fire-resilient landscapes[260].

Fire is a natural occurrence in forests, particularly in the Mediterranean region. However, humans have changed the nature, seasonality, frequency and intensity of the natural disturbance regime, which today is mainly driven by anthropogenic factors[261]. Some studies show that the existence of natural fires, caused by lightning, account for less than 5% of ignitions[262]. Fire regimes exceeding the natural range, particularly fires that are more frequent than they would be naturally, have several effects on the forest ecosystem. Firstly, they expose the soil to erosion, affecting physical, chemical and biological soil properties and leading to a decrease in water infiltration and to an increase in surface run-off[263]. They also lead to a loss of soil and to: (i) a degradation of soil characteristics; (ii) the loss of soil organic matter; (iii) a deterioration in soil surface and structure; and (iv) changes in microbial activity, affecting soil fertility[264]. These unnaturally frequent fires affect the availability and quality of the forest habitat, which may eventually lead to a change in the type of vegetation and of the ecosystem[265]. Water quality is also affected by more frequent fires, as a result of the particles, ash and chemicals that flow into

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[256] Brasier, C. M. (1996). Phytophthora cinnamomi and oak decline in southern Europe. Environmental constraints including climate change. *Annales des sciences forestieres, 53*(2-3), 347-358. https://hal.science/hal-00883057

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[259] Musio, L. et al. (2022). Prevenzione di incendi di chioma. Prescrizioni selvicolturali per boschi montani di conifere. Sherwood. Foreste ed alberi oggi 260, pp. 13-17.

[260] Moreira, F. et al. (2011). Landscape – wildfire interactions in southern Europe: Implications for landscape management. *Journal of Environmental Management, 92*(10), 2389-2402. https://doi.org/10.1016/j.jenvman.2011.06.028

[261] Agee, J. (1981). *Fire effects on Pacific Northwest forests – Flora, fuels and fauna*. In Proc. Conference Northwest Forest Fire Council, Nov. 23-24, Portland, pp. 54-66.

[262] Moreno, J. et al. (1998). Recent history of forest fires in Spain. In J. Moreno (Ed.), *Large forest fires* (pp. 159-185). Backhuys.

[263] Murphy, J. D. et al. (2006). Wildfire effects on soil nutrients and leaching in a Tahoe Basin watershed. *Journal of Environmental Quality, 35*(2), 479-489. https://doi.org/10.2134/jeq2005.0144

[264] Hebel, C. L. et al. (2009). Invasive plant species and soil microbial response to wildfire burn severity in the Cascade Range of Oregon. *Applied Soil Ecology, 42*(2), 150-159. https://doi.org/10.1016/j.apsoil.2009.03.004

[265] Malak, D. et al. (2015). Fire recurrence and the dynamics of the enhanced vegetation index in a Mediterranean ecosystem. *International Journal of Applied Geospatial Research, 6*(2), 18-35. https://doi.org/10.4018%2Fijagr.2015040102

water[266], and as a result of air pollution[267]. Large wildfires have a strong negative impact on the landscape and economic sectors such as recreational activities and tourism[268].

The potential for the combustion and propagation of a fire is related to weather conditions, terrain features and forest type. Broadleaf trees are more effective in changing the behaviour of fire, reducing or slowing down its spread[269]. Weather conditions, such as temperature, dryness and wind speed can have the greatest influence regardless of management treatment, contributing to big fires[270]. Prevention is essential and involves aspects such as land use planning, forestry management, awareness raising, surveillance and accountability[271].

Landscape planning plays an important role in preventing the spread and impact of wildfires. This involves measures like 'mosaics' of land use (e.g. crop production areas next to pasture areas next to forest areas), and the use of tree species that are less prone to fire and to fire spread.

Forest holdings are extremely small in many regions in the Mediterranean and fragmentation makes forest investments less profitable. There is a lack of a tradition of forest practice, including harvesting, in increasingly urban societies that lack a forest 'culture'. This makes it difficult to incorporate sustainable forest management. Forest value chains are not well developed locally in many European Mediterranean forests, so markets for forest products are also not well developed, limiting forest activity.

Closer-to-nature as a concept

Even though there is significant variability within the closer-to-nature concept, some aspects are shared among all Mediterranean forest types and management approaches that implement closer-to-nature forestry management. These aspects are set out in the bullet points below.

- Emphasis on increasing the retention of live and dead trees (single tree, group or patch retention) and coarse woody debris. Even though closer-to-nature forests in Mediterranean countries currently have a lower average amount of deadwood than other EU regions (linked to their predominantly young age and slow growth), there is a broad stakeholder recognition, supported by government and regional regulations, of the value of retaining deadwood. Therefore, the increment of deadwood has to be carefully evaluated site by site according to vulnerability to forest fires, vulnerability to drought and the need to prevent phytosanitary diseases.
- Progressive increase in the rate of mixed and naturally regenerated forests, even though: (i) most Mediterranean forests are regenerated naturally; and (ii) the rate of mixed forests in Mediterranean countries is generally high (except in plantations).
- Importance of increasing the presence of secondary tree species that could incorporate a lot of value to the forest stand, such as *Sorbus* sp., *Prunus* sp. or others.
- The role of natural disturbances with special reference to droughts and forest fires. Depending on the forest ecosystem, forest fires may play an essential ecological role in biodiversity conservation, but this role should be carefully managed to adopt an integrated approach to managing forest

[266] Mast, M. A., & Clow, D. W. (2008). Effects of 2003 wildfires on stream chemistry in Glacier National Park, Montana. *Hydrological Processes, 22*(26), 5013-5023. https://doi.org/10.1002/hyp.7121

[267] Kenward, A. et al. (2013). *Wildfires and air pollution. The hidden health hazards of climate change*. Climate Central, Princeton.

[268] Giovannini, G. et al. (2001). Effects of land use and eventual fire on soil erodibility in dry Mediterranean conditions. *Forest Ecology and Management, 147*(1), 15-23. https://doi.org/10.1016/S0378-1127(00)00437-0

[269] González, J. R. et al. (2006). A fire probability model for forest stands in Catalonia (north-east Spain). *Annals of Forest Science, 63*(2), 169-176. https://doi.org/10.1051/forest:2005109

[270] Keeley, J., & Zedler, P. (2009). Large, high-intensity fire events in southern California shrublands: Debunking the fine-grain age patch model. *Ecological Applications, 19*(1), 69-94.

[271] Leone, V. (1997). Sociological aspects in the phenomenology of forest fires. In O. Ciancio (Ed.), *The forest and man* (pp. 305-323). Accademia Italiano di Scienze Forestali.

fires, including, in some locations, prescribed burning[272]. Measures to adapt to fire disturbance in several southern European forest types rely on an ecological understanding of the species' fire ecology and on the specific effects of fire on the forest structure, soils and regeneration processes[273].

- The role of grazing in Mediterranean landscapes, by both domestic and wild animals, the need to allow managed grazing in forests, and the need for more dynamic management of deer and boars through hunting.
- Increasing the diversity of productions and types of crown covertures and species compositions to manage the production of non-wood forest products, particularly: cork, resin, nuts, berries, medicinal plants, truffles and wild mushrooms.

Specific challenges

Even though there are districts with valuable wood production, some Mediterranean forests are characterised today by low growth rates and low-quality wood assortment as a result of the degradation of forest conditions due to use over many hundreds of years[274]. Non-wood products (i.e. cork, resin, mushrooms, pine nuts, medicinal and aromatic plants, and forage) are becoming more important aspects of forest management – partly for economic reasons – and there is a high social demand for environmental services. Nevertheless, there are no appropriate schemes for the economic recognition of – or compensation for – these services/products on a larger scale[275].

The Mediterranean region also has several weaknesses in forest management that require greater attention and support[276]. With some exceptions, Mediterranean forests are less likely to be covered by 'forest management plans' than other EU forest bioregions[277]. The lack of a long-term plan can jeopardise the provision of forest products and forest ecosystem services, and can also prevent the application of adaptive management. This challenge is made more acute by the small scale of private ownership, which limits the aggregation of the forest land surface needed to achieve economies of scale when planning and implementing sustainable forest management.

Forest management lacks both staff (due to rural depopulation) and profitability (high costs and low timber prices). The vicious circle of low profitability, land abandonment, and increased vulnerability to disturbances (drought and fire above all) makes the creation of large and sustainable management units a political priority (e.g. in Italy and in Spain[278]). However, even though it is now rising up the political agenda, there has been little impact on-the-ground. This situation has resulted in forest land abandonment in some parts of the region due to public and private owners having little interest in cultivating and maintaining their forests[279].

[272] Moreira, F. et al. (2020). Wildfire management in Mediterranean-type regions: Paradigm change needed. *Environmental Research Letters, 15*(1), Article 011001. https://doi.org/10.1088/1748-9326/ab541e

[273] Raftoyannis, Y. et al. (2014). Perceptions of forest experts on climate change and fire management in European Mediterranean forests. *iForest – Biogeosciences and Forestry, 7*(1), 33-41. https://doi.org/10.3832/ifor0817-006

[274] Mediterranean forests might develop extraordinary wood value, with the presence of highly valuable species, like Quercus, Juglans, Taxus, Juniperus and others.

[275] There is one exception to this: in Croatia there are payment schemes for ecosystem services. According to Croatia's forest law, all natural and legal persons conducting economic activities with over EUR 400,000 in annual profit are obligated to pay 0.0265% of their income to benefit forest ecosystem services. Most of this money is allocated to forest owners for forest management activities prescribed by forest management plans in protection forests that are mostly represented in the Croatian Mediterranean region.

[276] Larsen, J. B. et al. (2022). *Closer-to-nature forest management. From science to policy 12*. European Forest Institute. https://doi.org/10.36333/fs12

[277] Forest Europe. (2020). *State of Europe's Forests 2020*. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[278] In Spain, the Horizon 2050 Spanish forestry strategy, recently revised in 2022, is committed to the grouping of forest properties and to recognising forest owners and managers for the activation of forest management in private forests at risk of abandonment.

[279] Palahí, M. et al. (2010). Mediterranean forests under focus. *International Forestry Review, 10*(4), 676-688. https://doi.org/10.1505/ifor.10.4.676

Mediterranean forests are critical for the genetic diversity of European tree species, providing essential adaptive capacity to Mediterranean and other European forests. The conservation of genetic diversity in Mediterranean forests has become urgent in light of the challenges posed by climate change and the need to maintain a resilient forest ecosystem. Effective conservation strategies must be implemented across the Mediterranean basin within species' distribution ranges to safeguard genetic diversity. This requires the development of appropriate forest reproductive material and the enforcement of stringent protocols, both of which will make reproductive material more available for forest landscape rehabilitation and the regeneration of degraded forests.

Land abandonment and cascading rewilding processes might be an opportunity to regenerate Mediterranean forests, but these must be monitored and managed carefully. Most Mediterranean forests are currently outside of their natural range of variability, and after the abandonment the dynamics are uncertain and affected by climate change. In many cases, therefore, abandonment causes the loss of traditional cultural landscapes[280] and does not result in a rewilding but in a deterioration in both biodiversity and ecosystem services provision[281]. For Mediterranean forests, mostly located in densely inhabited areas with high land use pressure, restoring the attributes of primary forests remains challenging[282].

Closer-to-nature tools in practice

Recent decades have seen the development and application of different new silvicultural and silvopastoral tools. These tools are based on changes in conventional silvicultural principles to make traditional systems management and conservation more sustainable while simultaneously meeting the growing social demands for ecosystem services. A variety of silvicultural systems have been applied in different Mediterranean regions for decades, bringing the benefits of predominantly mixed-stand composition. These systems include: mixed-stand silviculture[283]; single-tree silviculture[284]; irregular management[285]; mixed regeneration[286]; sporadic species valorisation and enhancement[287]; and many others[288].

All these silvicultural systems, including new management rules for coppicing, show an emphasis on tree retention and are implemented to develop mixed and often multi-layered forests in line with closer-to-nature principles. Another important step towards a closer-to-nature approach is recognising the role of natural disturbances[289]. Unfortunately, reconstructing the natural disturbance

[280] Knight, T. (2016). Rewilding the French Pyrenean landscape: Can cultural and biological diversity successfully coexist? In M. Agnoletti & F. Emanueli (Eds), *Biocultural diversity in Europe* (pp. 193-209). Springer International Publishing.

[281] Quintas-Soriano, C. et al. (2022). Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: A review. *Land Use Policy, 116*, Article 106053. https://doi.org/10.1016/j.landusepol.2022.106053

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[283] Pach, M. et al. (2018). Silviculture of mixed forests: A European overview of current practices and challenges. In A. Bravo-Oviedo et al. (Eds), *Dynamics, silviculture and management of mixed forests* (pp. 185-253). Springer International Publishing.

[284] Mairota, P. et al. (2016). Opportunities for coppice management at the landscape level: The Italian experience. *iForest - Biogeosciences and Forestry, 9*(5), 775-782. https://doi.org/10.3832/ifor1865-009

[285] Berretti, R. et al. (2014). Trattamenti irregolari per la valorizzazione delle faggete. Criteri per la redazione di un piano dei tagli e primi casi applicativi in una proprietà regionale. Sherwood - Foreste ed Alberi Oggi, pp. 5-9.

[286] Motta, R. et al. (2015). Il governo misto. Sherwood - Foreste ed Alberi Oggi 211, pp. 9-13.

[287] Bianchetto, E. et al. (2014). Selvicoltura per le specie arboree sporadiche. Manuale tecnico per la selvicoltura d'albero proposta dal progetto LIFE+ PProSpoT. Compagnia delle Foreste, Arezzo.

[288] https://www.lifegoprofor-gp.eu

[289] Aszalós, R. et al. (2022). Natural disturbance regimes as a guide for sustainable forest management in Europe. *Ecological Applications, 32*(5), Article e2596. https://doi.org/10.1002/eap.2596

regime in Mediterranean forests is almost impossible since the disturbances themselves have been profoundly altered (e.g. fire) or suppressed by human activities for thousands of years[290].

Nevertheless, the recent development of disturbance ecology and palaeoecological studies have allowed recognition of the critical role of disturbances and past land use in tree regeneration and biodiversity conservation in Mediterranean forests[291]. As observed in some ecosystems, suppressing natural disturbances can lead to biodiversity and habitat loss. Some Mediterranean species (animals and plants) depend on – or benefit from – natural disturbances. On fire disturbance, biodiversity can benefit from fire regimes tailored to suit specific habitat and species requirements in terms of seasonality, the spatial distribution of fire severity and frequency[292].

The use of prescribed burning to maintain or reintroduce appropriate fire regimes in southern European ecosystems is increasingly being understood and implemented, particularly for pasture regeneration goals. However, the use of wildfire under planned conditions as a regulator of ecological processes at the landscape scale (e.g. biomass accumulation, mosaic creation), as implemented in several natural landscapes worldwide[293], is currently not encouraged in southern Europe mainly due to risk averse policies in densely populated areas[294].

Critical enablers

Among all European bioclimatic regions, the Mediterranean appears to be the most vulnerable to global change and the one that requires the most intensive scientific and training effort[295]. Currently, there are already established training[296] and model forest[297] networks. However, these activities should be strengthened and improved in all Mediterranean regions[298]

In line with the EU biodiversity strategy and the new EU forest strategy for 2030, it will be crucial to: (i) develop value chains from non-wood forest products; and (ii) develop payment schemes for ecosystem services[299]. This is necessary given the social and community role of forest systems, and the deep involvement of stakeholders. Closely related sectors that benefit directly from forest goods and services (e.g. agriculture, water, energy, tourism, mining and health) rarely recognise the value of forest goods and services. All these sectors have to raise awareness of the importance of the Mediterranean forest and contribute to healthy forests through investment for sustainable management[300]. Payment-for-ecosystem-services schemes should increasingly apply to forests, which protect communities from natural hazards such as landslides, floods and wildfires, and which improve the quality of drinking water. In this sense, natural systems that increase forest resistance and

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[293] Pausas, J. G., & Keeley, J. E. (2019). Wildfires as an ecosystem service. *Frontiers in Ecology and the Environment, 17*(5), 289-295. https://doi.org/10.1002/fee.2044

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[295] Peñuelas, J., & Sardans, J. (2021). Global change and forest disturbances in the Mediterranean Basin: Breakthroughs, knowledge gaps, and recommendations. *Forests, 12*(5), Article 603. https://doi.org/10.3390/f12050603

[296] http://www.integrateplus.org/home.html

[297] https://www.medmodelforest.net/en/

[298] https://vii-med.forestweek.org/sites/default/files/editor/antalya-declaration_final.pdf

[299] Varela, E. et al. (2020). Targeted policy proposals for managing spontaneous forest expansion in the Mediterranean. *Journal of Applied Ecology, 57*(12), 2373-2380. https://doi.org/10.1111/1365-2664.13779

[300] Winkel, G. et al. (2022). Governing Europe's forests for multiple ecosystem services: Opportunities, challenges, and policy options. *Forest Policy and Economics, 145*, Article 102849. https://doi.org/10.1016/j.forpol.2022.102849

resilience to disturbances should receive economic support under payment-for-ecosystem-services schemes and certification programmes.

The restoration of degraded natural forests, namely broadleaved woodlands, should be supported in order to recover their functional condition and their capacity to resist wildfires. When they are well developed, these forests provide a wide range of goods and ecosystem services, but when they are degraded they become vulnerable to disturbance factors[301].

[301] Spiecker, H. et al. (2009). *Valuable broadleaved forests in Europe*. EFI Research Report 22, European Forest Institute, p. 276. https://efi.int/publications-bank/valuable-broadleaved-forests-europe

GOOD PRACTICE EXAMPLES

Integrative forest management in Ebrach, Germany	
Introduction	The Ebrach Forest is owned by the Bavarian State. The overall management aim for the Ebrach state forest is to optimise the total value of all ecosystem services provided by the forests rather than maximising a single service. The main management types in Ebrach are irregular group shelterwood, group selection and single-tree selection systems. Around 90% of the broadleaved timber is marketed in the region and 20,000 m^3 of fuelwood is sold to local commercial and private customers. The state forests are also a major provider of high-quality drinking water for the surrounding communities and provide recreational opportunities such as hiking and camping in the area. Roughly 60-70 hunters have temporary hunting permits, and more than 1,000 hunters attend the 40 driven hunts every year.
Type/ Mandate	Ebrach State Forest Enterprise
Forest characteristics	16,500 ha (1,200 ha set-aside area; timber production on 15,300 ha) of beech (*Fagus sylvatica*) forest composed of: (i) 75% broadleaved species – beech ca. 44%, oak (*Quercus* spp.) ca. 21%; and (ii) 25% coniferous species – Scots pine (*Pinus sylvestris*) being the main species accounting for roughly 13%.
Scope and objectives	The main silvicultural aim in Ebrach is to preserve the beech-dominated character of the Steigerwald region and at the same time to maintain the climate resilience of forest ecosystems. Single-tree harvesting and natural regeneration are the basis for developing structurally diverse and uneven-aged forests. <u>Main objectives:</u> ○ preserving and maintaining the character of the forests of the Steigerwald based on working with nature, not against it; ○ safeguarding public welfare for the highest overall benefit for society; ○ economic efficiency based on the highest added value possible through minimal effort; ○ resilient and adaptive forest ecosystems in the context of climate change to safeguard ecosystem services for future generations. <u>Main targets:</u> ○ increase the amount of deadwood to 20 m^3/ha in forests older than 100 years and 40 m^3/ha in forests older than 140 years; ○ retain 155,000 permanent habitat trees (10 trees/ha) in the productive forest area.
Structure and governance	The Ebrach State Forest Enterprise is made up of the state forests of the former forest districts of Ebrach, Gerolzhofen, Eltmann and Burgebrach. It provides employment for 60 forest employees and 12 local contractors and their staff.
Challenges	Identification of thresholds at which productive functions can be maintained and, at the same time, biodiversity protected. Seizing future market and product opportunities based on the estimated total economic value of all ecosystem services.
Enabling conditions	Although focusing on forest biodiversity and practising integrative forest management, the Ebrach enterprise primarily generates income from timber and ancillary uses (e.g. game meat or hunting leases), while receiving only a rather small amount of compensation for set-aside areas.
Outcomes	On average, annual profit of approximately EUR 1 million is generated from forest management, of which 95% comes from timber sales and 5% from hunting permits

	and marketing of game. Around EUR 67/m³ is the average income from timber across all assortments. The annual total economic value provided by all ecosystem services is estimated at over EUR 2.4 million, with 43% provided by biodiversity and related services, 31% by wood and ancillary uses, 16% by climate protection and 10% by water protection services. The deadwood-enrichment strategy seeks to only harvest sawn wood (and industrial timber to a lesser degree) and leave the complete tree crowns on-site has proven economically efficient.
Outlook and next steps	Closer-to-nature silviculture has been the main strategy in Ebrach since 1973. Securing and improving habitat diversity for forest species has led to a rethinking of management principles and a transition to managing the Ebrach forests as complex adaptive systems.
Lessons learned	From a conservation perspective, it is far more important to focus on the strategic planning of conservation instruments than on the total protected area. The habitat requirements and thresholds of target species must be considered for the development and cross-linking of conservation instruments. Constant monitoring is key for efficiency assessments. Three excellent indicators of conservation success are: (i) species groups linked to old-growth structures; (ii) deadwood; and (iii) natural disturbances. A diversity of silvicultural systems and strategies across the landscape is needed to increase diversity in structures, functions and biota, and therefore to support a broad range of other ecosystem services.
Optional	Based on: Learning from nature - Integrative forest management in Ebrach, Germany. U. Mergner, D. Kraus in “How to balance forestry and biodiversity conservation? A view across Europe” (pp. 196-213). Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf (2000).

Stadtwald Lübeck, Germany Management of a 4,600 ha municipal forest, 10% of which is not managed. This unmanaged portion is used as a reference point to monitor natural processes.	
Introduction	Closer-to-nature forestry has been practised for over 20 years in Lübeck. Foresters rarely intervene for maintenance and refrain from any actions that might harm the natural processes of the forests. As a point of reference, 10% of the total area is used to monitor and compare the development of forests without any management with the forests that are managed with closer-to-nature forestry practices. This makes it possible to adapt closer-to-nature forestry practices to come as close as possible to the development of forests that are not managed. Selling wood at higher prices is made possible due to the increased quality of trees that are felled. This is beneficial for the City of Lübeck, but also for its residents. The forests provide opportunities for recreational and educational activities and hunting. They also provide valuable ecosystem services such as clean water and biodiversity protection.
Type/ Mandate	Municipality-owned forests managed by the city’s forest office. A citizen’s referendum approved of the implementation of closer-to-nature forestry practices in 1994.
Forest characteristics	The main species are beech and oak trees, mixed with ash, maple, hornbeam, elm, birch and alder. They are structurally diverse and unevenly aged forests.
Scope and objectives	Closer-to-nature forestry practices are aiming to replicate the natural dynamics of the forest’s development (and protect its natural processes) to achieve closer-to-nature management.

	Main objectives: - support natural forest development for recreational and educational purposes; - meet the commercial needs of the forest industry through sustainable management, with a focus on felling large trees; - contribute to the conservation of nature, improving biodiversity through the preservation of natural habitats; - increase carbon sequestration in the forest.
Structure and governance	Closer-to-nature practices were developed in collaboration with scientists and nature conservationists. In a referendum, Lübeck's residents greatly supported the proposal. The chief forester oversees the work of 30 district foresters and forest workers, who harvest mature trees while working to bring the forests closer to nature and raise the quality of the remaining trees.
Timeline/ Rotation	Started in 1994, and closer-to-nature forestry practices have been ongoing since then.
Enabling conditions	Strong public support and social acceptance by environmental organisations and by the people of Lübeck. The successful demonstration of an ecological business case with benefits along various dimensions (social, ecological, economic).
Outcomes	Environmental: - protected forest soils by avoiding the use of large machines; - stable and diverse forests are developed; - no use of toxins or fertilisers; - no work during ecologically sensitive seasons (spring and summer); - increased timber stock: in 1996, timber stock was 315 m^3/ha, whereas in 2018 it was 429 m^3/ha; - timber certified by the Forest Stewardship Council (FSC) and Naturland (Naturland is a stricter standard than the FSC). Social: - educational activities (120 events per year); - 250 km of hiking, equestrian and cycling trails. Economic: - increased added value by marketing high-quality timber; - a minimum of manpower, energy and capital is used; - reduced financial risk of operations through closer-to-nature forestry practices that support the natural distribution of native, site-appropriate tree species that are more resistant to disturbances such as storms, drought and insect infestation.
Outlook and next steps	Continuous monitoring, including laser scans, is used to assess changes in woody biomass and carbon sequestration levels. This helps to monitor the development of the whole forest area and also the subparts of the forest. The 'citizen's forest' is supported by an independent scientific organisation.
Lessons learned	Closer-to-nature practices have proven to be beneficial for nature conservation, for ecosystem services and for those living in this municipality. The forests have provided stable incomes.
Optional	English weblink: https://yellowpointecologicalsociety.ca/2019/01/30/lubeck-another-way-of-logging/ German weblinks:

	https://www.luebeck.de/de/rathaus/verwaltung/stadtwald/index.html https://naturwald-akademie.org/wp-content/uploads/2019/04/Factsheet-Naturnahe-Wirtschaft-Politik_WEB-NEU19.pdf

Integration of nature conservation into forest management by the strategic and long-term 'Ecology & Economy' project/Austrian Federal Forests plc (Österreichische Bundesforste (ÖBf)), Austria	
Introduction	ÖBf launched the strategic, long-term 'Ecology & Economy' project in 2015. As part of this project, experts developed measures to improve the state of nature protection in woodlands while still considering economic aspects. 'Integrative forestry management' means that environmental protection and timber harvesting are integrated in harmony with the entire forest area. ÖBf implemented measures from 2015 until 2020 and these measures became considered as 'business as usual'. In addition, ÖBf produced a guidebook called *Forest management for nature* (*Naturschutzpraxisbuch*), with sections dedicated to endangered habitats and species and guidelines for conservation measures. The guidebook is aimed at all forest managers and encourages the measures to be implemented across the whole state forest area, including both the 50% that is subject to nature protection regulations (Natura 2000 and/or other protection status) and the rest of the area.
Type/ Mandate	Project
Forest characteristics	All types of forests found in Austria in different growing areas as officially described by the public law institution BFW (see https://www.bfw.gv.at/die-forstlichen-wuchsgebiete-oesterreichs/) covering 510,000 ha of forested area.
Scope and objectives	Improving habitats and biodiversity in economically productive forests is one of the main goals of the implemented measures. Some of the most important approaches include: (i) the management of deadwood and old-habitat trees; and (ii) the planting of regional rare tree species and shrubs. This is typically carried out by leaving 5 habitat trees/ha in the course of final cutting. These five habitat trees are permanently marked, leaving deadwood of 25 m^3/ha on average (result of sample inventories 2017-2019: 29 m^3/ha), planting 150 rare tree and shrub species annually per forest district. In addition, ÖBf has left 35,000 ha of forest unmanaged so that it can follow natural dynamics.
Structure and governance	The strategy was developed on a broad basis with internal and external experts and is implemented by the forest district managers. Adherence to the directives is regularly monitored.
Timeline/ Rotation	Launched in 2015 and still ongoing.
Challenges	Considerable time is needed to disseminate the results. There is also a need to create awareness of the importance of thinking beyond management periods, and for persevering when implementing measures.
Enabling conditions	Human factors: (i) commitment by the owner (Republic of Austria); (ii) support from the management and the supervisory boards; (iii) acceptance by the employees implementing the measures – in combination with own, current, reliable data; and (iv) intensive cooperation with NGOs.
Outcomes	Based on the above-mentioned guidebook, voluntary nature conservation activities are currently implemented all over the ÖBf area. In 2021, about 1,780 activities were registered. Many of these measures (nearly 30%) involve the protection of species and habitats (e.g. establishment of biodiversity islands for

	bird protection, a Ural owl conservation project and measures to save forest bees). Forty-three per cent of the voluntary activities were related to biodiversity management, including the promotion of deadwood and habitat trees, and the planting of rare species of trees and shrubs. Roughly a fifth of the measures were dedicated to open land management. Meadows were mown and measures were taken to actively combat invasive neophytes such as giant hogweed. For species conservation, ÖBf employees cleared mountain pastures and created habitats for black grouse or the rare violet copper butterfly. Small bodies of water were also created for amphibians, and the monitoring of lynx and wildcats continued.
Outlook and next steps	The project is ongoing and is evaluated on a yearly basis, so that further development is guaranteed.
Lessons learned	Cooperation with NGOs and science bodies – above all the University of Life Sciences, Vienna – has been crucial for success.

Ecological land use management as an important part of the strategic, long-term 'Ecology & Economy' project/ ÖBf, Austria	
Introduction	In the ecosystem management segment, 2019 saw the beginning of a pioneering project for the entire forestry industry: following intensive preparations, traditional forestry planning in all forest districts was expanded to include ecological land use management.
Type/ Mandate	Project
Forest characteristics	510,000 ha of forested area covered with all types of forests in different growing areas in Austria were officially described by the public law institution BFW (see https://www.bfw.gv.at/die-forstlichen-wuchsgebiete-oesterreichs/).
Scope and objectives	As an integrative part of forest management planning, the forest district managers receive an eco-plan, which sets out specific nature conservation measures to preserve and improve biodiversity. These measures include promoting rare types of trees or setting up species-rich forest edges along forest roads. The eco-plan also includes areas worthy of protection, such as nature reserves, stepping stones and habitat networks. After its successful introduction, ecological land use management will be expanded in the coming years to all 120 forest districts, including cartographic representation.
Structure and governance	Developed within approved project management structures and monitored as part of forest monitoring.
Timeline/ Rotation	Launched in 2019 and still ongoing.
Challenges	Long-term commitment, combination of long-established forest planning tools and new tools providing information on biodiversity.
Enabling conditions	The design and implementation of the project took place in close cooperation with WWF Austria.
Outcomes	Eco-plans for 120 forest districts.
Outlook and next steps	Further regular development and implementation of eco-plans, based on long-term commitments.
Lessons learned	Cooperation with NGOs and acceptance by colleagues implementing the measures are crucial for success.

Member State experts and key stakeholders

Member State experts

Austria	Federal Ministry for Agriculture, Forestry, the Regions and Water Management
	Federal Ministry for Climate Action, the Environment, Energy, Mobility, Innovation and Technology
Belgium	SPW Agriculture, Ressources naturelles et Environnement
	Forêt Nature
	Research Institute for Nature and Forests (INBO)
	Sonian Forest Foundation
Bulgaria	Executive Forest Agency
	Ministry for Agriculture
	Ministry for the Environment and Water
Croatia	Ministry for Agriculture
	Ministry for the Economy and Sustainable Development
Cyprus	Ministry for Agriculture, Rural Development and the Environment – Department of Forests
Czechia	Ministry for Agriculture
	Ministry for the Economy and Sustainable Development
Denmark	Ministry for the Environment and Food
	Danish Environmental Protection Agency – Landscape and Forest
Estonia	Ministry for the Environment: Department of Forest & Department of Nature Conservation
Finland	Ministry for Agriculture and Forestry
	Finnish Environment Institute
	Ministry for the Environment
	Natural Resource Institute of Finland
France	Ministry for Agriculture
	Ministry for the Environment
	Ministry for Europe and Foreign Affairs

Germany	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
	Federal Ministry for Food and Agriculture
	Federal Agency for Nature Conservation
Greece	Ministry for the Environment and Energy, Directorate-General for Forests and the Forest Environment
Hungary	Ministry for Agriculture, Department of Forest Management
Ireland	The National Parks and Wildlife Service – Department for Housing, Local Government and Heritage
	The Forest Service – Department of Agriculture, Food and the Marine
Italy	Institute for Environmental Protection and Research
	Ministry for Agriculture, Food Sovereignty and Forests
	Ministry for the Environment and Energy Security
	UNIFI - Università degli Studi di Firenze
Latvia	Ministry for Agriculture
	Ministry for Environmental Protection and Regional Development
Lithuania	Ministry for the Environment
Luxembourg	Ministry for the Environment, Climate and Sustainable Development
Malta	Ministry for Agriculture, Fisheries and Animal Rights
	Ministry for the Environment, Energy and Enterprise
	Ambjent Malta
	Parks Malta
Netherlands	Ministry for Agriculture, Nature and Food Quality
Poland	Ministry for Climate and the Environment
	Directorate-General for the State Forest
Portugal	Institute for the Conservation of Nature and Forests
	Ministry for the Environment and Climate Action
Romania	Ministry for the Environment, Waters and Forests – General Directorate of Forests and Strategies in Forestry
Slovakia	National Forest Centre
	Ministry for the Environment

Slovenia	Ministry of Agriculture, Forestry and Food
Spain	Ministry for Ecological Transition and Demographic Challenge – Directorate-General of Biodiversity, Forests and Desertification
Sweden	Swedish Forest Agency
	Swedish Environmental Protection Agency

Forest stakeholders, civil society organisations and others

CEPF - Confederation of European Forest Owners
CEPI - Confederation of European Paper Industries
COPA/COGECA - Farmers and Forest-Cooperatives Organisations
EFNA - European Forestry Nursery Association
ELO - European Landowners Association
EOS - European Organisation of the Sawmill Industry
EUSTAFOR - European State Forest Association
FSC – Forest Stewardship Council International
PEFC - Programme for the Endorsement of Forest Certification
USSE - Unión de Selvicultores del Sur de Europa
BirdLife Europe and Central Asia
EEB - European Environmental Bureau
Euronatur
Fern
Protect the Forests
Wild Europe Foundation
WWF European Policy Office
EFI - European Forest Institute
EURAF - European Agroforestry Federation
FACE - European Federation for Hunting and Conservation
Pro Silva
SAAMI Council