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Forest biodiversity in the spotlight – what drives change?

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Introduction

Forest biodiversity[1] is the basis for forest functioning, the provision of a multitude of forest ecosystem services and for maintaining forest adaptation and resilience to climate change.

Humans have been shaping European landscapes for thousands of years and therefore also the distribution and appearance of forests and the diverse plant and animal species assemblages associated with them (Ellis et al. 2021). This has led, amongst other things, to a reduction of the area of primary and old-growth forests[2] to 3% of European forests (Barredo et al. 2021) but has also allowed for the development of tremendously species-rich cultural landscapes.

What do we know about the status of forest biodiversity in Europe?

An overall decline in biodiversity of European forests cannot be verified according to existing European assessments reports (i.e. EEA 2020, Forest Europe 2020, Maes et al. 2020, IPBES 2018).

These reports show that in terms of average functional diversity European forests are doing well, e.g., forest birds mainly show a stable or even improving trend, and deadwood and tree species diversity have been improving – however for rare and endemic species, the situation remains precarious (e.g. Rivers et al. 2019).

Most forest indicators used in European assessments monitor the state/condition of the forest ecosystem or pressures on it (e.g. Maes et al. 2020, Storch et al. 2018).

However, it is not straightforward to derive general conclusions on forest biodiversity, because of the different demands and habitat requirements of the different forest species and their different susceptibility to change (Storch et al. 2019).

Future forest biodiversity assessments at European level need to be harmonized and find measurable, simple, financially feasible and reliable indicators. These should have elaborated thresholds or target ranges for the different European forest types (Oettel and Lapin, 2021), with a focus on functional indicator groups (de Groot et al., 2016) instead of single charismatic species and with genetic monitoring included.

1 The biological variety and variability of life including the genetic, species, and ecosystem level

2 Primary and old-growth forests are ecosystems where signs of past human use are absent or minimal and where ecological processes follow natural dynamics.

What are the key factors affecting forest biodiversity?

There is not a single key driver affecting forest biodiversity, but a range of pressures that affect forest biodiversity in different ways. Here we distinguish between external factors influencing forest biodiversity and internal, forestry-related factors.

External pressures

Climate change is one of the biggest current and future threats to forest biodiversity, impacting directly on species as well as their habitats. Climate change favours species with particular traits (e.g. favouring light-coloured insects), whereas other species at least locally may die out (e.g. Bässler et al. 2013; Zeuss et al. 2014). It also causes shifts of species to higher latitudes and elevations, in their attempt to stay in the temperature range they are adapted to (which is often unsuccessful due to the low migration velocity of e.g. plants or soil fauna) (e.g. Rosenzweig et al. 2007, Vitasse et al. 2021). Eventually, climate change will also cause changes in the composition and functional characteristics of entire species communities (e.g. Blondeel et al. 2020). Furthermore, range shifts of species and habitats across the landscape are often limited. For example, species found in the highest elevations of mountains cannot move further up (e.g. Barras et al. 2021).

Landscape fragmentation interacts with the effects of climate change. While landscape fragmentation has always impacted species requiring large habitats and affected the viability of small, isolated populations (due to inbreeding), range shifts driven by climate change (especially of low-mobility species) are hindered or even made impossible. Fragmentation has also been found to further reduce migration velocities (e.g. of forest floor plants) far below the migration rates that would be required to keep pace with the rate of climate change (Dullinger et al. 2015).

Atmospheric deposition continues to have serious effects on European forest biodiversity. While acidifying emissions have decreased over recent decades, sulfur dioxide (SO2) emissions, ammonia (NH3) and nitrogen oxide (NOx) emissions related to intensive livestock farming, industry and traffic respectively continue to be too high over large parts of West and Central Europe. Eu-

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trophication due to nitrogen deposition causes the loss of species specialised to nutrient-poor sites, in particular lichens and understorey plants (Dirnböck et al. 2018). With the loss of these species, other dependent species such as specialised insects lose their habitat (e.g. Eichenberg et al. 2021; Neff et al. 2021).

Long distance drift of pesticides from agriculture may be causing an alarming recent arthropod decline in forests that was not related to forest management intensity but to the management in the surrounding landscape (see e.g. Seibold et al. 2019).

Wildlife damage. Ungulate populations (e.g. deer) have strongly increased in European forests over recent decades. This causes heavy damage through browsing and fraying (rubbing the antlers against the stem of young trees) to young trees, particularly broadleaved and some native conifer tree species, and severely impacts the survival of these tree species in European forests. This is a huge problem not only for dependent species, but also in the light of climate change adaptation, for which more of the currently rare tree species are needed (e.g. Kunz et al. 2018).

Biological invasions are seen as a major driver of biodiversity loss worldwide, including in forests (Brondizio et al. 2019; Pyšek et al. 2020). The globalization of trade and travel continues to increase the spread of non-native species (Hulme 2021). In particular, invasive tree pests can trigger extinction cascades of many other species (e.g. Hultberg et al. 2020) and interactions with climate change are likely to worsen the impact of introduced pests and diseases on European forests (Seidl et al. 2018).

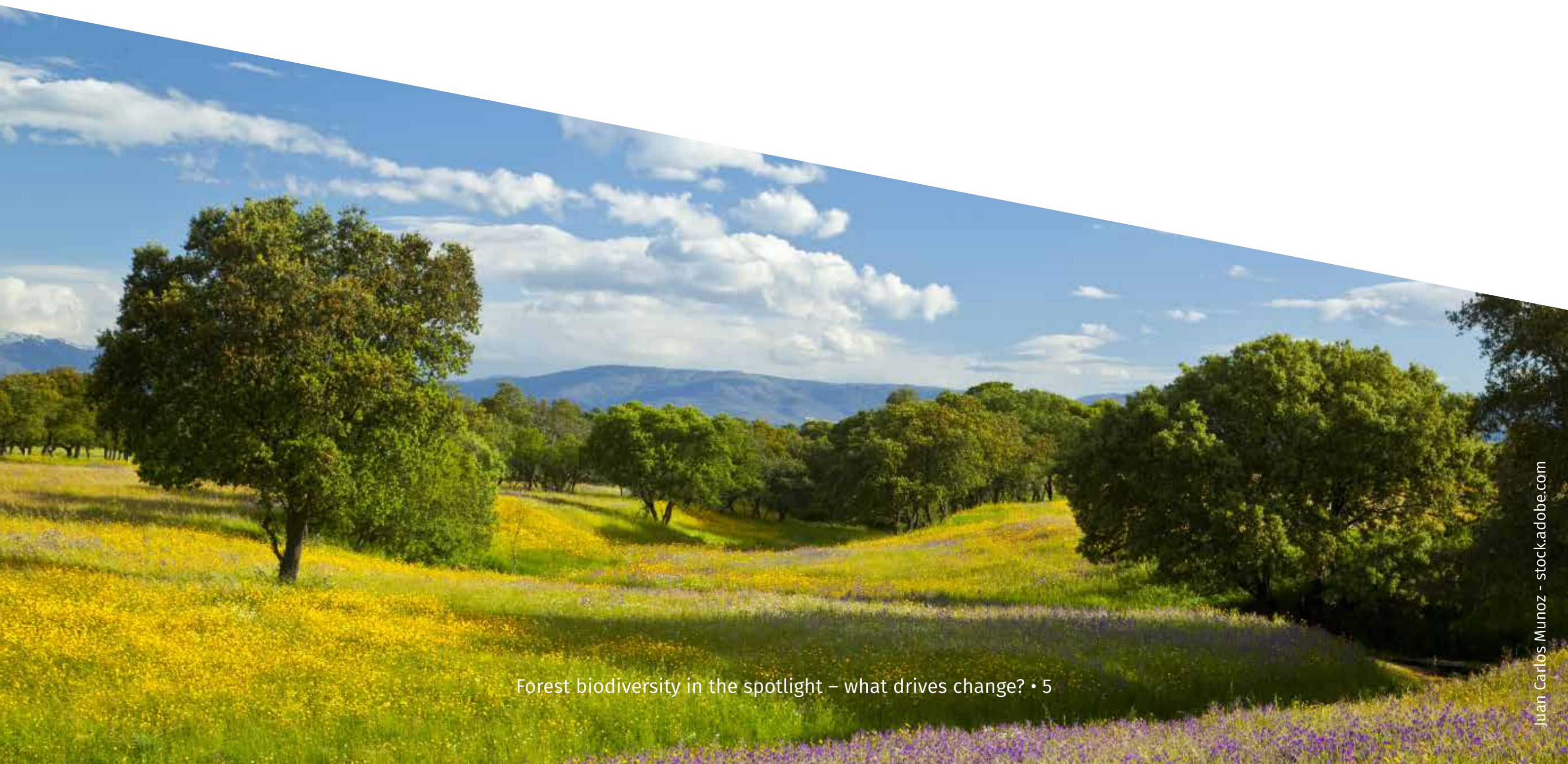
But also some herbal and woody invasive alien species can negatively impact native biodiversity, particularly since they may compete with native species, change the site (e.g. through nitrogen fixation) and alter food webs, transmit diseases or support the spread of native herbivores (e.g. Campagnaro et al. 2018; Krumm and Vitková 2016; Pötzelsberger et al. 2020).

Forestry-related (internal) pressures

Forest management practices influence forest structure and biodiversity in many ways, e.g., size of canopy openings, amount of deadwood left in the forest, tree species selection and mixture, rotation length and number of old trees left, landscape pattern of different forest types/patches, etc. (e.g. Pötzelsberger et al. 2021). Similar to agriculture, the biggest overall problem arises in areas of significant intensification of forest use and homogenisation of forest structure and composition.

Still, with the differing demands, specialisations and connections of the myriad of forest dwelling species, **no one-size-fits-all solution for optimising forest biodiversity** exists. Forest heterogenity across the landscape is key to host a high diversity of species. Therefore, depending on the circumstances and the forest management approach (e.g. coppice forest vs. whole tree harvesting), synergies and trade offs between e.g. bioenergy production and biodiversity enhancement will vary. Some major forestry-related pressures influencing forest biodiversity include:

Loss of old growth-forests, which harbour unique structures with their plentiful associated species. This is a process that is unfortunately ongoing in some eastern European countries and parts of Northern Europe. However, in the majority of Europe, forest structures are becoming more mature, and thus offer opportunities to (actively) restore old-growth habitats (see e.g. Sabatini et al. 2020).



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Loss of ancient forests that are characterised by long-term **forest continuity**, with associated species that need this long forest continuity to colonize the area (Hermy et al. 1999; Janssen et al. 2019). Although these forests with unique biodiversity features are not well mapped in Europe, overall the low deforestation rates in Europe keep them currently well conserved. However, intensive forestry methods including monoculture management, stump extraction and soil preparation pose a threat to these values.

Loss of historical forest management systems such as coppice, coppice with standards (coppice forest with some trees allowed to grow large) and silvo-pastoral systems. Many forest dwelling species that are rare and threatened today actually depend on more open and heterogeneous forest conditions, which were historically maintained through a diversity of forest and agroforestry management systems (e.g. Bengtsson et al. 2000). These transitional systems have been largely abandoned and replaced, either by more intensive and homogenous agricultural production systems or by closed forests including after land abandonment.

The increasing growing stocks in European forests do not necessarily lead to an increase in biodiversity. While some species benefit from older forests with more biomass, other species that require more open and light conditions are clearly disadvantaged. This shows that strict protection of forests is not helpful as a universal solution, and a more tailored legacy-based approach to biodiversity conservation in European forests is needed (Van Meerbeek et al. 2019). But also the much praised close-to-nature forest management (continuous cover forest management) leads to denser forests where such light-demanding species decline in abundance (Bauhus et al. 2013). This may lead to potential negative consequences on dependent herbivores, which becomes a particular issue if continuous cover forestry is promoted across large landscapes as an optimal solution (compare e.g. Neff et al. 2021; Schall et al. 2018).

Replacement of native forests by homogeneous (conifer) plantation forests has certainly led in the past to much habitat loss. However, this is in most parts no longer occurring and we actually see an opposite trend in most parts of Europe, where restoration and conversion of conifer plantations leads to more mixed species forests and natural habitats. This process is currently accelerating through the wide-spread drought damage in these plantations (Schuldt et al. 2020).

Intensification of biomass extraction, often connected to bioenergy production. There are many European countries in which harvest levels are considerably lower than the current wood increment and where therefore more intensive forest use may be considered to provide more resources for a forest-based bioeconomy (Bauhus et al. 2017). If the additional biomass extraction includes the removal of residues (harvesting slash and stumps) or whole trees, not only nutrient depletion of these stands becomes an issue, but also deadwood-dependent species may be negatively affected (Bouget et al. 2012).

How can forestry ensure the conservation and restoration of forest biodiversity?

To ensure the conservation and restoration of forest biodiversity it will be crucial to deal with all the above-mentioned external and internal pressures. Here, we want to highlight important forestry-related measures that we regard as the most effective from a policymaker's as well as forest practitioner's perspective.

Targeted forestry measures

There is now a good body of evidence for a range of approaches to better integrate biodiversity conservation into forest management e.g. through adopting natural processes, diversifying forest structure and composition and integrating old-growth forest elements (Krumm et al. 2020) or through special treatment and conservation of genetic conservation units across Europe, following the pan-European strategy for genetic conservation of forest trees (De Vries et al. 2015).

Emphasis should be given to ensure a **diversity of forest conditions both at stand and landscape level**. At stand level diversity of conditions and structure can be promoted through e.g. the tree species mixture, veteran trees, the shrub, tree and herbal understorey, and standing and lying deadwood. At landscape level a variety of forest management and forest development stages (including the sapling/regeneration stage preferred by e.g. less shade-tolerant plants or free breeding birds) and no-intervention areas are needed. Together, this maximises within-stand, across-stand and landscape diversity (alpha, beta, gamma diversity) benefiting a wide variety of species groups (Hilmers et al. 2018; Schall et al. 2018).

So-called 'integrative forest management approaches' that allow for the retention and active restoration of old-growth attributes such as deadwood, old-growth islands and rare forest types in sustainably managed forests should receive more attention in the current political debate as a complementary measure for biodiversity protection (Aggestam et al. 2020). These forests will also provide important corridors among strictly protected areas.

Due to the fundamental changes in site conditions that climate change is causing, it will also be important to **connect biodiversity restoration with forest adaptation** – applying 'prestoration' (Butterfield et al. 2017) – as a dynamic approach to ensure continued ecosystem functioning and habitat provision under changing climatic conditions. Furthermore, it is imperative that restoration practices consider **genetic composition (diversity and adaptedness) of tree populations**, which impacts on forests' survival, adaptation and evolution under changing environmental conditions, ecosystem stability and forest resilience (Alfaro et al. 2014, Bozzano et al. 2014). Future management options to adapt forests to climate change heavily rely on the availability of appropriate forest genetic resources with known identity, adaptive traits and adaptation potential and therefore science-based decision support tools, but in turn sustainable forest management also needs to consider genetic diversity at all levels (Gömöry et al. 2021).

Rethinking reserves

There are different forest protection approaches with differing protection goals, ranging from the protection of single veteran trees up to large wilderness regions where natural processes can take place freely. **Today, the remaining primary and old-growth forests in Europe receive particular attention, and deserve strict protection** due to their very low remaining coverage and the rare habitat types they offer (Sabatini et al. 2020). While the current value of other protected forest areas for the conservation of biodiversity, like the Natura 2000 network, is also largely undebated, to maintain biodiversity long-term, we need to allow for potential shifts in species ranges, communities and habitats across the landscape as environmental conditions change, and to identify species, habitats and regions most at risk (Thomas et al. 2004; Willis and Birks 2006).

It is important to recognize that the habitat types we have designated to date are a construct and will not persist unchanged in the future. Protected areas mostly have not been designed to account for the long-term and large-scale dynamics of ecosystems as part of dynamic landscapes and the changes caused by climate (Bengtsson et al. 2003). Particularly in Europe's distinct cultural landscape, strictly protected areas account for only a small proportion of land, and **climate change limits protected areas' ability even more to capture the dynamic development of ecosystems.**

It is therefore key to think and plan species and habitat conservation across the entire forested landscape and all types of forest tenures. **Only a functioning ecological network will allow climate-induced distribution shifts to preserve biodiversity** (Fuchs et al. 2007, 2010; Jongman et al. 2004). Key elements include appropriately sized high-quality core areas, stepping stones and corridors (climatically suitable habitats that provide migration options), but also the surrounding forest matrix should be developed to optimize permeability for migration, i.e. through integrative forest management (Fahrig 2013, 2019).

Landowner incentives

Forest owners are key stakeholders for the restoration and conservation of forest biodiversity. As well as the issue of capacity, a crucial question is what motivation diverse European forest owners have to fully consider biodiversity conservation beyond the kind of biodiversity required for a healthy production forest.

Incentives to encourage forest owners to be proactive in enhancing forest biodiversity can be developed via **payments for environmental services** (PES) (Engel et al. 2008; Ferraro and Kiss 2002; Wunder and Wertz-Kanounnikoff 2009). So far, we have seen more forest PES initiatives focused on watershed, landslide and avalanche protection (e.g. in Switzerland, Austria, Italy, Germany) (Viszlai et al. 2016). Good examples for PES for biodiversity, however, do exist, starting with smaller pilots like protecting 'singular' (old) forests in Catalonia, to larger programmes in Finland and Sweden. For instance, the Forest Biodiversity Programme for Southern Finland[3] (METSO) has paid competitive compensation to voluntarily enrolled forest owners since 2008, to take concrete management measures to enhance biodiversity. **By 2025, about 82,000 hectares of high-value forest habitats in private, commercially managed forests will be protected by fixed-term PES agreements through METSO.**

The way in which biodiversity PES contracts are allocated also matters for cost-efficiency. **PES contracts have recently been granted using reverse auctions**, in a promising pilot in Central Jutland, Denmark[4]. There, landowners who offer their forests for a specific conservation action and have the lowest bid win the contract. In this way, more biodiversity benefits can be bought for each unit of taxpayer money. Similar voluntary competitive mechanisms to improve biodiversity protection outcomes are currently being tested in Belgium[5].

Such PES are important because in the past dedicated funds under Natura 2000, LIFE+, and Rural Development Programme have mostly been under-utilized, mainly due to landowner-perceived transaction costs and the bureaucratic difficulties of accessing them. **An EU-based forest PES scheme could encourage better forest management to control a range of threats to forest resilience, e.g. extreme forest wildfires, which in turn also threaten forest biodiversity.**

Beyond PES, other financing and incentive tools exist to enhance forest biodiversity. **Forest certification**, for example, aims to have final consumers pay price premiums to reward labelled producers undertaking biodiversity-friendly forest management. **Biodiversity offsets** accept losses of biodiversity in a place of (high-value) economic development, but provide resources for compensatory biodiversity conservation and restoration in other sites (Vaissière et al. 2020). **Green bonds** are another tool for investors to pay for frontloaded forest management actions, which environmental service beneficiaries will pay back only later, but this tool has more been used for e.g. wildfire-preventing forest management, rather than directly focused on biodiversity actions (Ehlers and Packer 2017).

3 https://www.metsonpolku.fi/en-US/METSO_Programme
4 https://sincereforests.eu/reverse-auctions-pilot-for-biodiversity-protection/
5 https://sincereforests.eu/reverseauction/

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