EUROPEAN FOREST INSTITUTE

Forest biodiversity in the spotlight

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Introduction

Forest biodiversity[1] is the basis for forest functioning, the provision of a multitude of forest ecosystem services and our insurance for the challenges of climate change adaptation and maintaining forest resilience. Forest biodiversity also has an intrinsic value that goes beyond any human measurable value.

Humans have been shaping European landscapes for thousands of years, partly even since the time when forests were just forming again after the last ice age. This altered the distribution and appearance of forests and the diverse plant and animal species assemblages associated with them (Ellis et al. 2021). This long history of human development has reduced forest area to currently 35% of the European land area (Forest Europe 2020) - compared to an assumed natural forest coverage of around 80% (EEA 2018). It has also reduced the area of primary and old-growth forests[2] to 3% of European forests (Barredo et al. 2021). At the same time, it has also allowed for the development of tremendously species-rich cultural landscapes.

In the 19th and 20th century the area of more intensively managed forests increased. Today, the direct and indirect effects of intensifying human actions including the impacts of climate change and increasing natural disturbances are putting ever bigger pressure on forest ecosystems and also on forest biodiversity. But there are also opportunities and examples of reversing the trend. For example, many previously intensively managed forests are now becoming more mature and mixed and are regaining biodiversity.

What do we know about the status of forest biodiversity?

Public awareness on the threats to biodiversity in general has markedly increased in recent years through a combination of local/regional studies and global assessments (e.g. IPBES 2019). Quite often it is assumed that a decline in biodiversity occurs across all land-use types. However, for European forests, an overall biodiversity decline cannot be verified, and several important indicators also point in the opposite direction.

Unfortunately, there are very few indicators in the important European forest assessment reports (i.e. EEA 2020, Forest Europe 2020, Maes et al. 2020, IPBES 2018, Rivers et al. 2019) that directly monitor forest biodiversity, e.g. common forest bird species protected under the Birds Directive, or other species protected under the Habitats Directive or IUCN Red List species. In addition, there are some structural, compositional and functional proxy indicators of (certain elements of) forest biodiversity such as tree species composition, deadwood, regeneration, naturalness, and forest fragmentation, indicators on pressures on biodiversity, e.g. alien species, and the indicator of protect forest areas. From these reports and assessments we can infer that in terms of average functional diversity European forests are doing well and show clear trends of improvement, but in terms of safeguarding rare/endemic and threatened species, the situation remains precarious (e.g. Rivers et al. 2019), although information on threatened species is also often fragmentary (Forest Europe 2020).

Forest birds

According to the latest State of Nature Report (EEA 2020), common forest bird species show an improving trend (2007-2018) in 34% of the cases, a stable trend in 37% of the cases and a deteriorating trend in 17% of cases. On average, the common forest bird index decreased by 3% between 1990 and 2016 in the EU (with a reversed trend over the last years), whereas the common farmland bird index decreased by 32%. Of non-bird species protected under the Habitats Directive, 6% show an improving trend, 37% a stable trend and 27% a decreasing trend (EEA 2020).

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[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.

Tree species diversity

Tree species diversity has been improving between 2005 and 2015, with the share of forests composed of 2-5 tree species slowly but steadily increasing (Indicator '4.1 Diversity of tree species', Forest Europe 2020). Since the diversity and abundance of other forest-associated species in European forests is related to tree species diversity (Ampoorter et al. 2020), this is an important indication of improvement. Overall, tree genetic diversity levels in European forests were found to be high across many traits and genes, showing no signs of decline (Erichsen et al. 2018; Eliades et al. 2011; Robledo-Arnuncio et al. 2004). Concerns raised by the 2019 IUCN European Red List of Trees (Rivers et al. 2019) about 42% of the 454 European tree species being threatened have to be carefully assessed. Among the 168 threatened species (not including slightly more than 20 data-deficient species assumed to be threatened), the vast majority (130) belong to the *Sorbus* genus which has a peculiar reproduction mode leading to an unusually high number of typically only locally occurring species. Threatened Sorbus species mainly occur in a few hotspots in Wales, England, the Carpathians and Hungary. Since these species typically occur in more open habitats, they are mainly threatened by tall forests or deforestation (Rivers et al. 2019).

Deadwood

Deadwood is a key structural attribute of forests that up to 4,000 species depend on (Stokland et al. 2012). Its occurrence in European forests has increased between 1990 and 2015, to varying degrees among regions and only with an opposite trend in Central-East Europe (Indicator '4.5. Deadwood' Forest Europe 2020). For the EU-28, deadwood amounts on average to 11.9 m^3/ha and 6.9% of the growing stock. Interestingly, the average volume of deadwood per ha, which is still lower compared to the 20-50 m3/ha proposed as minimum deadwood volumes (Müller and Bütler, 2010) and considerably lower compared to forests that have been strictly protected for a long time (Stokland et al. 2012), is unrelated to the percent of annual forest increment that is removed in fellings across European countries, pointing to other influences (Bauhus et al. 2017).

Forest habitats

While 31% of forest habitat assessments have a bad conservation status, forest habitats exhibit the highest proportion of improving trends among the assessments (13%) (EEA 2020). The conservation status of habitats, however, cannot be taken as an indicator for biodiversity per se, and its interpretation regarding biodiversity is complicated due to the differences in the assessment approach among countries. Four parameters must be assessed, (i) range, (ii) area, (iii) structure and functions and (iv) future prospects to yield the conservation status. The parameter 'structure and functions' is supposed to include some indicators directly associated with biodiversity. However, the countries define many different specific indicators and thresholds, and often the assessment does not even use indicators but is based on expert judgement (Alberdi et al. 2019), as is also the case for the parameter 'future prospects' of species and habitats.

Reflections on forest biodiversity indicators

Generally, 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). Typically, it is not possible to derive general conclusions on the impacts of changing indicators on forest biodiversity, because of the different demands and habitat requirements of the different forest species and the different susceptibility to change (Storch et al. 2019).

Some forest indicators may even contradict some specific conservation goals, for example high soil nutrient status/availability or soil carbon stocks would be counterproductive for the conservation of the typically highly diverse species assemblages on poor soils, including soils degraded by human activity like forest pasturage and litter raking (IPBES 2018). Indicators like increasing timber volumes or increasing stand productivity may mean more disadvantageous growing conditions for light demanding species (e.g. Sabatini et al. 2018). If there were more concrete targets defined for any of these indirect biodiversity indicators, they would have to be forest habitat specific and would often require target ranges rather than simple thresholds, for example even for forest area itself considering the competition with non-forest species and habitats.

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, and also a link to management measures to promote biodiversity indicators should be established (Oettel and Lapin, 2021). The focus should lie on functional indicator groups (de Groot et al., 2016) instead of single charismatic species and with genetic monitoring included. The concept of functional indicator groups encompasses their association with a particular habitat type or structure, thus better characterising the functional ecology of the habitat (Ricotta et al., 2015). In forests, the indicator groups under consideration include bryophytes (Mölder et al., 2015), lichens (Perhans et al., 2007), saproxylic Coleoptera (Gossner et al., 2013; Vanderwel et al., 2006), macrofungi (Dvořák et al., 2017), or tree-hole inhabiting aquatic organisms (Petermann et al., 2016, 2020).

What are the key factors affecting forest biodiversity?

Considering the information deficit on the state of forest biodiversity as shown above, the more relevant questions are on the drivers of biodiversity decline, the way forest management influences biodiversity, and management options to maintain and improve forest biodiversity.

Importantly, there is not a single key driver but a range of factors that affect forest biodiversity in different ways. In the following, we distinguish between internal, forestry related pressures and external pressures on forest biodiversity.

External pressures

Climate change is one of the biggest current and future threats to forest biodiversity. It impacts directly on species as well as their habitats. Climate change favours species with particular traits (e.g. favouring light-coloured insects), whereas other species may be reduced in their abundance or even die out, at least locally (e.g. Bässler et al. 2013; Zeuss et al. 2014). As tree pests and diseases may also benefit from climate change, e.g. through increased winter temperature or prolonged vegetation periods, impacts on tree species will increase, what may lead to a transformation of major forest types (Hole et al. 2009). Climate change 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). In this regard we should also consider, that species ranges and habitats cannot be freely moved across the landscape. For example, species found in the high elevations of low mountains cannot move to higher elevations as warming progresses (e.g. Barras et al. 2021). Eventually, climate change will also cause changes in the composition and functional characteristics of communities (e.g. Blondeel et al. 2020). Therefore, there will inevitably be a recombination of species in emerging communities, with little predictability for the outcome of new interactions for individual species.

Landscape fragmentation also interacts with the effects of climate change. While landscape fragmentation has always impacted species requiring large habitats, affected the viability of small, isolated populations (e.g. due to inbreeding) and can cause the extinction of populations (Fahrig 2001), 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, especially sulphur dioxide (SO_2) emissions, ammonia (NH_3) and nitrogen oxide (NO_x) emissions related to intensive livestock farming and industry/traffic respectively continue to be too high over large parts of West and Central Europe. Eutrophication 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 (see e.g. Eichenberg et al. 2021; Neff et al. 2021). Forest soil acidification due to atmospheric inputs has affected complete forest food webs, e.g. linking decreasing snail populations with unsuccessful bird reproduction (Graveland et al. 1994).

Long distance drift of pesticides from agriculture. A much-cited recent study showed that there is an alarming recent arthropod decline in forests, similar in magnitude to that observed in agriculture. This study showed that arthropod decline in forests was not related to forest management intensity but to the management in the surrounding landscape. It is not entirely clear what is causing this decline, but a likely explanation is the wide-spread use of agrochemicals (see e.g. Seibold et al. 2019).

Wildlife damage. Ungulate populations (e.g. deer) have strongly increased in European forests over recent decades due to several factors. This causes heavy damage and often mortality through browsing and fraying (rubbing the antlers against the stem of young trees) to young trees, particularly of broadleaved and some native conifer tree species. 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 particularly susceptible to browsing are needed (e. g. Kunz et al. 2018).

Biological invasions are seen as a major driver of biodiversity loss worldwide, including in forests (Liebhold et al. 2021) and cause damage through parasitism, competition with native species, physical changes of the environment, and pathogen transfer (Riccardi et al. 2013). The globalization of trade and travel continues to increase the spread of non-native species (Hulme 2021). In particular, invasive pests and pathogens such as those that cause Dutch Elm disease or Ash dieback can trigger extinction cascades for all the other species that depend on these tree species (e.g. Hultberg et al. 2020). Interactions with climate change are likely to worsen the impact of introduced pests and diseases on European forests (Seidl et al. 2018).

Some herbal and woody invasive alien species such as Black locust (*Robinia pseudoacacia*), Boxelder maple (*Acer negundo*), Tree of heaven (*Ailanthus altissima*), or wattles (*Acacia sp.*) can also 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 habitat 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. For example, some light-demanding species formerly thriving in traditional forest management systems such as coppice forests became rare as a result of transformation to high forests.

Because of the differing demands, specialisations and connections of the myriad of forest dwelling species, **no one-size-fits-all solution for optimising forest biodiversity** exists, but forest heterogeneity 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 internal factors 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 getting more mature, and thus offer opportunities to (actively) restore old-growth habitats (see e.g. Sabatini et al. 2020).

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 red-listed today actually depend on more open and heterogeneous forest conditions, which were historically maintained through a diversity of forest and agroforestry management systems characterised by high anthropogenic disturbance levels. These transitional systems have been largely abandoned and replaced, either by more intensive and homogenous agricultural production systems or by closed high forests. Therefore, more open forests are today often the focus of nature protection (see e.g. Bengtsson et al. 2000). The current ongoing massive land abandonment in southern and eastern Europe is a big concern for these forest management-dependent conservation values. Utilising potential win-wins between circular bioeconomy development, fire prevention and biodiversity conservation has been proposed to reverse this trend (Varela et al. 2020).

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). This also applies to strict forest reserves, where in the first decades following cessation of harvesting (and hence owing to the lack of disturbances) the habitat quality for species requiring more open conditions and high structural diversity can decline (e.g. Braunisch et al. 2019; Neff et al. 2021). 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. 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).

Increased wood removals, 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).

What measures can we take?

To ensure the conservation and restoration of forest biodiversity it will be crucial to deal with all the external and internal pressures mentioned above. Here, we restrict our discussion to those important forestry-related measures to support biodiversity 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 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 and at landscape level through 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. 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).

It is imperative that restoration practice apply multidisciplinary approaches that consider important but previously neglected factors like the genetic composition (diversity and adaptedness) of tree populations to ensure both the short and the long-term success.

So called 'integrative forest management approaches' that allow for the retention and active restoration of old-growth attributes, 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, but in turn sustainable forest management also needs to consider genetic diversity at all levels. The use of forest reproductive material that is genetically suited for a specific site requires a sound knowledge about its identity, adaptive traits and adaptation potential. Work still needs to be done on the identification and characterization of forest reproductive material, and science-based tools should be further developed and made available broadly to support end-users and the regulating framework in the decision making, e.g. with recommendations on suitable provenance, indicators for genetic diversity and results of genetic tests (Gömöry et al. 2021).

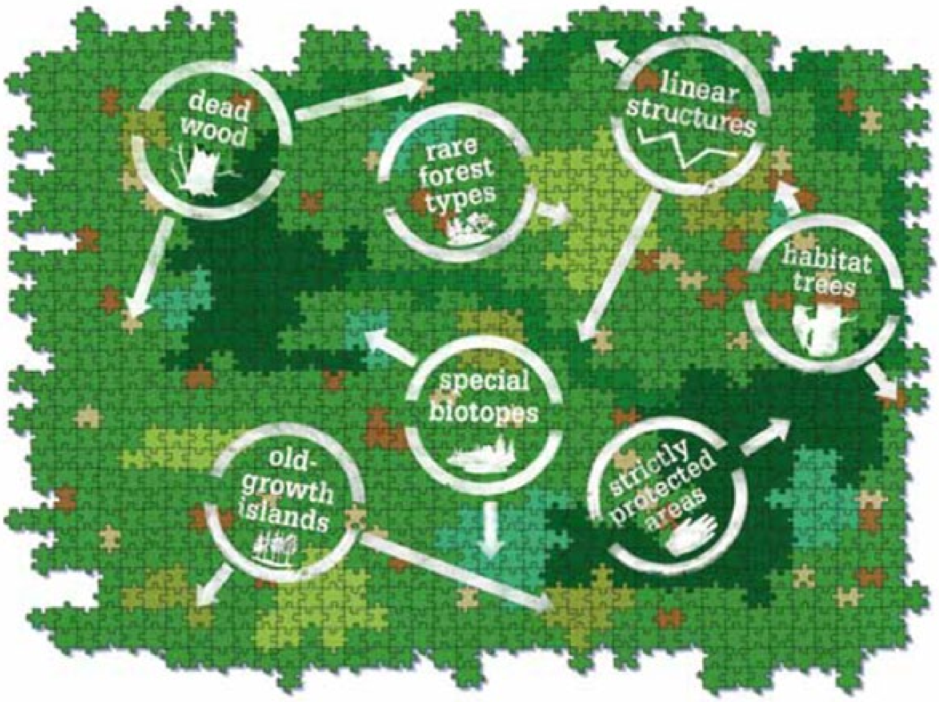

Figure: Idealised integratively managed forest landscape that integrates segregative elements such as special biotopes, strict reserves, old-growth/old forest islands, linear structures but also habitat trees and deadwood that are spatially embedded within a matrix of managed forests (taken from Krumm et al., 2013). The forest matrix may be managed by close-to-nature management principles, or by other forms of sustainable forest management that would allow for different forest development stages including the more open regeneration phase to co-exist next to each other at landscape level (development stages for simplicity not separately shown).

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, it is necessary to allow for potential shifts in species ranges, communities and habitats across the landscape as environmental conditions change, and to identify and protect 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 (Bengtsson et al. 2003), and the selection of reserve areas has not been made with climate change in mind (Haslet et al. 2010). 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 estimated that in temperate deciduous and mixed forests globally, approximately 45% of all protected areas will experience unprecedented climatic conditions by 2070 (Hoffmann et al. 2019). In most cases, the expected range shifts of species due to climate change cannot occur within protected area boundaries (Araujo et al. 2011).

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 of the biotope network 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 (Fahrig 2013, 2019, Krosby et al. 2010). In Europe, such an ecological network can only be developed if forests of all tenure types can be included. Incentives for private, communal or municipal forest owners need to be provided to ensure the future development and adaptation of their forests occurs in support of such a biotope network.

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 intrinsic motivation diverse European forest owners have to fully consider biodiversity conservation beyond the kind of biodiversity required for a healthy production forest. Satisfying additional biodiversity demands may lead to income losses, i.e. opportunity costs of foregoing profits in less diverse yet profitable systems through different choices of tree species, harvesting decisions, or the set-aside for conservation of old-growth. There may also be other provision costs, e.g. controlling access to the forestland for external agents potentially degrading biodiversity through signposting, fencing, or monitoring.

Extrinsic incentives can cover these opportunity costs of biodiversity conservation measures. The classical tool is **state subsidies for reforestation**, which may require e.g. a certain level of tree species diversity. This has in recent decades been developed further into the concept of **payments for environmental services** (PES) to encourage forest owners to be proactive in enhancing forest biodiversity (Engel et al. 2008, Ferraro and Kiss 2002; Wunder and Wertz-Kanounnikoff 2009). PES has been applied in public PES schemes e.g. in China, Costa Rica, Ecuador, and Peru, and by private conservation NGOs and international organisations in North America and in the Global South (Barbier et al. 2018; Salzman et al. 2018). Impact evaluations have also shown that PES interventions globally seem to be successful (Wunder et al. 2020).

In Europe, forest biodiversity PES schemes have been rare. 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), whereas multiple experiences exist with the use of agri-environmental payments to safeguard biodiversity on private productive lands (Hanley and White 2014). 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, changing forest management towards greater provision of recreational and biodiversity-related benefits. For instance, the Forest Biodiversity Programme for Southern Finland (METSO)[3] has paid compensations to voluntarily enrolled forest owners since 2008 to take concrete management measures to enhance biodiversity. METSO's aim is to halt the ongoing decline in the biodiversity of forest habitats and species. By 2025, about 82,000 hectares of high-value forest habitats in private, commercially managed forests will be protected by fixed-term PES agreements.

The way in which biodiversity PES contracts are allocated also matters for cost efficiency. A promising pilot has recently been carried out in Central Jutland, Denmark[4], where PES contracts have been granted using

[3] https://www.metsonpolku.fi/en-US/METSO_Programme

[4] https://sincereforests.eu/wp-content/uploads/2019/11/DenmarkCS_factsheet_SINCERE.pdf

reverse auctions: landowners with the lowest bids offering their forests for specific conservation action will 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 through reverse auctions will be tested in Belgium[5]; both cases form part of the H2020 project SINCERE.

At the EU level, dedicated funds for landowner incentives 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. A more extensive use of an EU-based forest PES scheme should be aimed for in the future, to 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. Another tool can be **biodiversity offsets**, which accept losses of biodiversity in a place of (high-value) economic development, but provide resources for compensatory biodiversity conservation and restoration in other sites (Vaissiere et al. 2020). Finally, **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).

[5] https://sincereforests.eu/reverseauction/

Selected Literature

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