Potential impacts of the EU's biodiversity strategy on the EU and global forest sector and biodiversity

A. Maarit I. Kallio[1a)] & Meley Mekonen Rannestad[1)]

1) Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, P.O.BOx 5003, N- 1432 Ås, Norway
a) Corresponding author: maarit.kallio@nmbu.no

Orcids:

Maarit Kallio: https://orcid.org/0000-0002-5393-761X

Meley Rannestad: https://orcid.org/0000-0002-1578-8078

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A. Maarit I. Kallio & Meley Mekonen Rannestad

Norwegian University of Life Sciences

Abstract

We analyzed the potential impacts of the EU Biodiversity Strategy 2030 (EUBDS) on forest sector production within the EU and Norway (EU+N) and globally using scenario analysis, quantified with a partial equilibrium model for the global forest sector. When EUBDS targets for 30% of terrestrial land under non-strict protection and 10% under strict protection by 2030 are applied at the country level, roundwood harvests in EU+N are projected to decrease by 25 Mm^3 in 2035 compared to harvest levels without EUBDS. Two-thirds of the EU harvest decrease is offset by increased production in other regions, replicating the phenomenon known as production leakage.

We compared biodiversity indicators in EU+N countries, which are expected to reduce harvests, with those in countries expected to increase their harvests. While harvests are projected to shift to countries with, on average, relatively large forest areas per capita, many of these countries perform worse on indicators associated with both direct and indirect risks of biodiversity degradation, e.g., forest governance, the representativeness of protected areas in relation to ecosystem or biome diversity, and the protection status of red-listed species. If forest conservation measures are implemented in North America alongside EUBDS, harvests in EU+N countries would decrease less, but biodiversity-rich tropical countries would face even greater pressure for intensified harvests. Additional policy measures are required to mitigate the negative environmental effects in these third countries.

Keywords: Forest protection, harvest leakage, biodiversity indicators, spillover effects, forest industries

1. Introduction

Several policies that will affect the utilization and management of forests in the European Union (EU) member states (MS) and Norway have been implemented or are under development. Many of them, for instance the regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change, and forestry (LULUCF) in the 2030 climate and energy framework (European Parliament and the Council 2018, 2023) and the EU Biodiversity Strategy (EUBDS) (European Commission 2020), emphasize a passive role of forests as a provider of environmental goods. EUBDS aims at halting the loss of biodiversity and reversing the degradation of ecosystems by 2030. It requires that 30% of the EU land area are protected by 2030, while 10% of the land area must be strictly protected. All primary and old-growth forests must be set under strict protection. The 30% goal aligns with global targets in The Kunming-Montreal Global Biodiversity Framework (The United Nations 2022a). Biodiversity, or biological diversity, refers to the vast variety of plants, animals, and microorganisms. It also includes genetic diversity within species and extends to the variety of ecosystems (Secretariat of the Convention on Biological Diversity 2000). Forests are among the most biologically diverse and species-rich habitats on Earth, accounting for more than 80% of terrestrial biodiversity (Aerts and Honnay 2011). The way forests are managed has significant implications for their ability to protect biodiversity. The impact of wood harvesting can have positive or negative effects on different species (Chaudhary et al. 2016).

The implementation of EUBDS should result in reduced harvests in most EU MS when compared to the projected future harvests without EUBDS (Dieter et al. 2020, Schier et al. 2022; Räty et al. 2023; di Fulvio et al. 2025). Schier et al. (2022) suggest that even a moderate implementation of EUBDS would cause a high decrease in the EU harvests and forest industry production also when compared to the present harvests. Also, di Fulvio et al. (2025) propose that EUBDS would result in decreased harvest levels in the EU, though less than what is projected by Schier at al. (2022). Räty et al. (2023) find that the prevailing harvest levels in Finland could be technically maintained up to next 100 years, while addressing the requirements in EUBDS. However, that would lead to higher costs of timber production. This would lead to higher production costs in the forest industries, and thereby to higher product prices and lower demand. When costs increase in one region, the producers in other regions with lower cost increase may gain market share and increase their production. Schier et al. (2022) and di Fulvio et al. (2025) confirm, in the context of EUBDS, the well-recognized phenomenon of 'leakage,' where unilateral policy actions that alter wood harvests or forest industry production in one region lead to opposing changes in other regions (e.g., Sohngen et al. 1999; Liu et al. 2008; Jonsson et al. 2012; Hu et al. 2014; Dieter et al. 2020; Kallio et al. 2006; Päivinen et al. 2022). Consequently, when the harvests and forest industry production decline in the EU due to the aim of enhancing biodiversity, that increases the environmental pressure elsewhere (Sohngen et al. 1999; Fischer et al. 2023, Rosa et al. 2023). This leakage of the environmental impacts weakens the efficiency of the policy. Also, due to increased costs of forest industry products, some of the forest product consumption may shift to products made of other materials (Hassegawa et al. 2022; Päivinen et al. 2022). In some cases, these alternative materials have higher environmental footprint than what the wood product replaced had (Sathre and Connor 2010).

Previous studies on EUBDS impacts do not accommodate the current geopolitical situation and trade embargoes that were imposed after Russia's invasion of Ukraine in 2022. The costs of energy and demand for fuelwood have increased since then (Martinez-Garcia et al. 2023), and the trade in wood and wood products between Russia and the EU and number of other countries has ceased due to trade embargoes. Russia had already earlier decided to stop the exports of coniferous roundwood in 2022. The markets for forest products have changed radically, making the forest industries in the EU and Norway (EU+N) more dependent on domestic roundwood production. Previous studies have assumed that, since Norway is not an EU MS, it would not participate in the EUBDS. However, due to European Economic Area agreement, Norway follows many of the EU policies. Also, it has its own national target for 30% areal conservation. Finally, it must be noted that EUBDS is not implemented in the vacuum. Also, Canada and the United States have signed the Kunming-Montreal Global Biodiversity Framework and have a goal to conserve at least 30% of their land and waters by 2030 (Environment and Climate Change Canada 2024; U.S. Department of State 2023). So, it is also worth exploring the potential impacts of EUBDS together with the assumption of increased forest protection in North America.

The objectives of this study are to (i) provide updated scenarios of the effects of EUBDS on EU+N forest sector and globally; (ii) to examine the magnitude and geographical direction of the leakage effect; and (iii) to consider the risk that leakage poses to biodiversity outside of the EU by examining the various environmental indicators in the countries affected. In pursuing the objective (iii), we follow the methodology of Dieter et al. (2020) and Fischer et al. (2023) and compare biodiversity indicators between EU+N countries and countries that are projected to increase their roundwood harvests due to EUBDS. Biodiversity indicators are important tool for assessing and monitoring the impacts of policies or management decisions on biodiversity (Jones et al. 2011; Martínez-Jauregui et al. 2021; Walpole et al. 2009). This is also relevant in the context of leakage, a situation where improvements to biodiversity in one area or region may unintentionally lead to negative impacts elsewhere. The projections of the policy impacts are carried out to year 2035 and they account for the significant changes in geopolitics and economics that occurred in 2022-2023.

2 Methods and data

This study employs scenario analysis and modelling for looking at the impacts of EUBDS on forest sector in EU+N and globally. The projected development with the policy is compared to the projected development without it. Moreover, to considerer potential leakage of environmental impacts due to EUBDS, we compare biodiversity-related indicators across the countries that will be affected by it. As to the scenarios, we develop the baseline (reference) scenario where the global forest sector develops without EUBDS and compare that to the scenario where the EU+N set aside new forest areas to strict or non-strict protection to achieve EUBDS conservation targets by 2030. The scenarios extend to the year 2035. In addition to the main scenarios, we explore three scenario variations: one where Norway is not joining EUBDS, and one where the trade embargoes due to Russian invasion to Ukraine are raised in 2030, and one where we consider the possibility that Canada and United States also set aside new forest protection areas. Additional sensitivity analyses are presented regarding harvest limitations under non-strict forest protection and the elasticity of roundwood supply in relation to growing stock volume and prices. The scenario paths are quantified by the global forest sector model FORMEQ (Kallio 2021; Päivinen et al. 2022, Kallio 2024). The remainder of this chapter is organized as follows. Section 2.1. presents the assumptions made on changes in protected forest areas under EUBDS. Section 2.2. discusses the global forest sector model FORMEQ and the scenarios considered. Section 2.3 provides information on indicators and their use in addressing the potential environmental leakage effects caused by EUBDS.

2.1 The assumptions on changes in protected forest areas under EUBDS

One of the key targets in the EU biodiversity strategy is that 30% of both the land and sea areas in the EU should be legally protected by 2030. One third of that area should be under strict protection and include all primary and old-growth forests. To raise the share of protected land areas in the EU from current 26% (Eurostat 2024a) to 30%, 16.4 M ha of additional land should be protected by 2030. It has not been decided how the area requirements will be divided between MS or between forests and other land types. Allocation of new protected areas among the land categories, regions and countries should account for the biodiversity potential in the alternative land parcels and consider the socio-economic consequences (Kallio et al. 2008; Peura et al. 2024). However, information on the current protection areas and their representativeness, neither the restrictions on harvests on these areas are not well available. Thus, we had to make simplified assumptions on the allocation of the new protected areas to model the effects of EUBDS in the forest sector. We assumed that set-asides for additional protection areas are based on hectares of land. Like Räty et al. (2023), Schier et al. (2022), and di Fulvio et al. (2025) in one of their scenarios, we require that the conservation targets are attained in each EU member states individually. We assumed that countries that already have 30% of their terrestrial area conserved do not add protected areas, unless they have old growth and natural forests outside of the current protected area network. The same was assumed to apply to 10% of strictly protected area goal.

2.1.1. Assumptions on additional forest protection to reach the 30% target on terrestrial areas

Bulgaria, Croatia, Germany, Greece, Luxembourg, Poland, Slovakia, and Slovenia have already at least 30% of their total land area under some kind of protection (Table A.1 in the appendix S.1). If the 30% goal was applied at country level, protected areas should be expanded in the rest of the countries. In five of the countries: Italia, Lithuania, Netherlands, Romania, and Spain - at least 30% of the forest areas are under protection already (Table A.1, in S.1.). We assume that in these countries, the additional protection will be implemented in other land types than forest. In the remaining countries, the additional non-strict protection was assumed to be assigned to forest land so that 30% of it would be protected. If 30% goal regards to the total land area is reached with a smaller increase in forest protection, the increase in protected forest areas in limited to that. Application of these rules give the increase of almost 18 M ha of non-strictly protected forest areas in EU+N (column C in the Table A.2 in the Appendix S.1). The highest increases take place in large, forested countries: Finland, France, Norway, and Sweden. Using this allocation rule implies that in some countries, the additions of conservation in non-forest land may be considerable. As the assumed additional protection area is more than sufficient to close the 16.4 M ha gap of land area protection to the 30% goal in the EU, we did not elaborate the problem of allocation conservation between forest vs. other land types further. Nor did we consider the financial burden associated with financing new land set-asides. As shown in Table 1, some countries would have a very high amount of new protected areas per capita. In 2024, EU MS are planning their measures for designating or better managing their protected forest areas to contribute to the 30% strategy target (European Environmental Agency 2024).

2.1.2. Assumptions on additional forest protection to reach the 10% strict-protection target

We assumed that the forest areas in the MCPFE classes 1.1 (no active intervention) and 1.2. (minimum intervention) as reported in Forest Europe (Forest Europe 2020; Schier et al. 2022) qualify as strictly protected (Table A.3 in the Appendix S.1, column C). In these areas, the main management objective is biodiversity conservation. The land areas reported to belong to IUCN classes Ia (strict nature reserves), Ib (wilderness areas), and II (national parks) were also taken to fulfil criterium of strict protection (Table A.3. column B). Countries that have 10% of the land area or forest area under strict protection then include Estonia, Finland, Italy, Norway, and Sweden. In the rest of the countries, new strictly protected forest areas were assigned in the following order until the 10% rule was met: (i) new protection areas (Column C of Table A.2) were allocated to strict protection assuming that these should also include previously non-protected old-growth and natural forests; (ii) the existing non-strictly protected forest areas were shifted to strict protection assuming that they could be expected to be more biodiversity rich than non-protected forests, (iii) new protection areas were added to fill the remaining gap if needed. In addition to these rules, additional information was used to elaborate the assumptions of new strict forest conservation in Germany, Finland, Norway, and Sweden. This information relates primarily to the amount of potentially non-protected natural and old-growth forests. Schier et al. (2022) suggest that there are old-growth forests outside of the current protected areas in Germany. Following their "Moderate Scenario", we assumed that the deficit of strictly protected forests areas of 1.1 Mha derives from completely from new protection areas. Nordic countries have relatively few intact forest areas. Jonsson et al. (2019) estimate that about 300 kha (1000 hectares) of forests outside the protection areas in Sweden have not been clearcut since 1955 and indicate that these areas provide opportunities for biodiversity conservation. Svensson et al. (2022) suggests even higher amount of such potentially high value new protection areas, 500 kha, which applied for new strictly protected forest area in Sweden. In "Double Scenario" of Räty et al. (2023), 600 kha of forests currently available for timber supply were strictly protected in Finland. A recent assessment by Syrjänen et al. (2024) suggests that most primary and old-growth forest land in Finland is already protected. Depending on the criteria for such forests, 31 - 63 kha remain in productive use. Some old forests can also be found in scrublands. To account for uncertainties regarding the eventual criteria, we assumed that 130 kha of new forest areas in Finland would be strictly protected. In Norway, the updated PEFC forest certification requires that 5% of the forest area in the properties that have at least 150 ha productive forests must be set-aside from roundwood production (PEFC 2022). We calculated that this could result in some 190 kha of new forest protection set-asides under strict protection and assumed that this might suffice to cover non-protected old-growth and natural forests in Norway, given that the extend of the non-protected old-growth forests is of similar magnitude to that in Finland and Sweden. Accounting for these details on protected areas in the Nordic countries and Germany, we got the assumed in the protected forest areas as shown in Table 1.

As Canada and the United States also aim at to conserving 30% of their terrestrial area by 2030, we provide a sensitivity analysis exploring a case where these plans are implemented simultaneously with EUBDS. Both countries cover vast terrestrial areas of which only one-third is forests. Canada reports to have 13.7%, United States 13% of terrestrial land under protection. We added non-strict protection areas to forest land, so that the share of protected areas lacking from the 30% target was assigned to all forest land in proportion to the share of forest land of the total land. This resulted to assuming 56 Mha additional land to forest conservation in Canada, and 53 Mha in United States.

	Deficit of protected forests	Deficit of strictly protected forest	New strictly protected forests	New non-strictly protected forests	Currently protected to strict protection	New protection area per capita
	A 1000 ha	B 1000 ha	C = min(A,C)* 1000 ha	D = A-C 1000 ha	E 1000 ha	F ha/capita
Austria	65	359	65	0	293	0.01
Belgium	27	51	27	0	24	0.00
Bulgaria	0	253	0	0	253	0.00
Croatia	0	140	138	0	2	0.04
Czechia	640	142	142	498	0	0.06
Denmark	57	55	55	3	0	0.01
Estonia	195	0	0	195	0	0.14
Finland	2983	0	130	2853	0	0.53
France	1081	1605	1081	0	524	0.02
Germany	0	1142	1142	0	0	0.01
Greece	0	226	*226*	0	0	0.02
Hungary	153	193	153	0	40	0.02
Ireland	85	78	78	6	0	0.02
Italy	0	0	0	0	0	0.00
Latvia	460	133	133	327	0	0.24
Lithuania	0	108	0	0	108	0.00
Luxembourg	0	8	0	0	8	0.00
Netherlands	0	1	0	0	1	0.00
Poland	0	882	0	0	882	0.00
Portugal	378	308	308	70	0	0.04
Romania	0	471	0	0	471	0.00
Slovakia	0	125	0	0	125	0.00
Slovenia	0	36	0	0	36	0.00
Spain	0	1319	0	0	1319	0.00

Sweden	6124	0	500	5624	0	0.58
Norway	2762	0	190	2572	0	0.50

Table 1. Assumed new areas of strict and non-strict forest protection and areas of non-strictly protected forests shifted to strict protection, and consequent expansion of protected forest land per capita. The entry in column B "Deficit of strictly protected forest" is zero if at least 10% of forest area or 10% of land area is under strict protection already.

2.2 Scenarios and quantification of the forest sector development in them.

2.2.1 On the global forest sector model used, FORMEQ

The FORMEQ model used for the scenario projections is a spatial partial market economic equilibrium model for the global forest sector. Like many other forest sector models since the development of the first global forest sector model, GTM, at IIASA forest project (Kallio et al. 1987), it mimics the market behavior of producers and consumers in the forest sector under the assumption of perfect competition. Like in the GTM and majority of the other forest sector models following it, the solution of the competitive market equilibrium is based on framework of Samuelson (1952), and uses non-linear mathematical (NLP) programming. FORMEQ is written under the General Algebraic Modelling System and solved by using MOSEK-solver for NLP. It divides world to 117 regions. The model and its main assumptions are detailed in Kallio (2021, pp. 4–6; doi: 10.1016/j.forpol.2020.102364; Kallio 2024, pp. 377-383). The description of how the roundwood markets and forest protection measures are modelled is, however, also provided in Appendix S.2. The base year for which the model was calibrated was updated to the year 2022, for which the most recent year for which FAOSTAT statistics (FAO 2024) were available. Relevant updates in the data were made to the forest industry production capacities, energy prices, labor costs, and assumed GDP growth in the countries. For the energy costs Eurostat (2024b) and various national statistics were used. For the labor costs, the data from ILOSTAT (International Labor Organization 2024) supplemented with GDP per capita data from the World Bank (2024) were employed. The recent GDP growth projections provided by the International Monetary Fund (2024) were used as assumptions for the real GDP growth up to 2029. For the years 2030-2035, the 2029 figures were repeated. The trade embargoes due to the Russian invasion into Ukraine were assumed to be in place for the whole period considered as in Kallio (2024). However, in an alternative baseline scenario, they were removed in 2030 (Table 2). Compared to the former studies on EUBDS, the scenarios presented in this study are based on more up-to-date picture of the world developments.

2.2.2. Scenarios and implementation on the forest protection measures to the model

We assumed that no roundwood production is allowed in strictly protected forest areas. Hence, the area and growing stock of roundwood in such areas is removed from timber production potential. Furthermore, we assumed that clear-cut forestry is no more allowed in non-strictly protected areas, whereas these forests could be cut selectively. No data exist, however, what this might mean in terms of restrictions on timber supply. In the long term, forests under uneven age management might be as productive in terms of roundwood supply as forests managed under clear-cut regime (Hanewinkel 2002; Kuuluvainen et al. 2012; Kellomäki et al. 2019). However, a shift to uneven age forest management regime requires a transitory period during which the timber supply will be restricted. We assumed that in the existing non-strictly protected forest areas, such transition had already taken place. In the forests shifted to non-strict protection, we assumed that 30% of the trees (area under trees) that would have previously been available for forest production would remain available. Such forests could not be revisited again during the 10-15 years period considered in this study to allow for the sufficient transitionary period or interval between the harvests.

Table 2 displays the scenarios addressed. In addition to the scenarios in Table 2, we provide a sensitivity analysis for the reference scenario Base compared to the EUBDS scenario Prot focusing on assumptions regarding roundwood markets. These include the elasticities of roundwood supply with respect to the growing stock and roundwood prices, and the proportion of land available for roundwood production in newly designated non-strictly protected forest areas (50% instead of 30%). More discussion on these assumptions is provided in the Appendix S.2.

Base	The reference scenario with no changes in protected forest areas. The EU, North America and group of other countries are not trading forest products with Russia and Belarus. Russia is not exporting coniferous roundwood due to its own policy decision of not doing so.
Prot	New protection areas as in Table 2 added in the EU and Norway. These will be established gradually during 2025-2030.
Scenario variations for sensitivity analysis	
Prot-N	As Prot but without Norway participating EUBDS.
Base-Embargo	As Base but the trade embargoes are removed in 2030.
Prot-Embargo	As Prot but the trade embargoes are removed in 2030.
Prot+NAm	As Prot but assuming non-strictly protected forest area increases in Canada and United States so that 30% of the terrestrial land area in these countries is conserved by 2030. New protection set asides are assigned to forests in proportion to forest area of these countries.

Table 2. Scenarios addressed

2.3. Data and methods for comparing indicators between EU+N and the rest of World

2.3.1 Indicators considered

Measuring the impacts of roundwood harvests on biodiversity in a country level alone is complex, and meaningful comparisons between countries are challenging. A practical approach to address this issue is to use indicators (Hagan and Whitman 2006). Biodiversity indicators are the most used tool to monitor biodiversity status, track changes over time, and assess the impact of management actions (Oettel and Lapin 2021). Ideal indicators are easy to measure and strongly correlate with multiple aspects of biodiversity, reducing the need to measure each element separately (Hagan and Whitman 2006). Forest biodiversity is impacted by both direct and indirect drivers of change in habitats and their biodiversity status.

In assessing the potential risk to biodiversity outside of the EU+N caused by forest harvest leakage due to EUBDS, we follow Fischer et al. (2023) and use four distinct groups of indicators: direct drivers, indirect drivers, forest status and change, and biodiversity (species and habitat) status and change in status. We adopted several biodiversity indicators within these categories from Fischer et al. (2023). Among them, forest coverage, rate of change in forest coverage, coverage of protected areas, protected area (PA) coverage in Key Biodiversity Areas and Red List Index are a widely used indicators (De Castro-Pardo et al. 2022; Jones et al. 2011). We added six indicators from the Environmental Performance Index (EPI 2022), and a share of planted (incl. plantations) forests of forest area to the indicator set. The EPI assesses 40 environmental performance indicators in 180 countries, with Biodiversity and Habitat being one of the key categories covered. This category assesses how effectively a country preserves natural ecosystems and protects biodiversity within its borders. Six of the seven indicators in this category are relevant and utilized in this study to complement and enhance the other indicators, particularly those related to PAs, which often provide an incomplete picture when considered alone.

Forest area per capita and forest governance can be regarded as indirect drivers for forest biodiversity status. Population density, especially in tropical, low-income regions, is among the primary drivers of deforestation (Geist and Lambin 2002). Governance measures are among key factors in determining the success or failure of forest biodiversity conservation (Fischer et al. 2021; Geist and Lambin 2002). The harmful effects of increased roundwood production on biodiversity are likely to be more severe when forest biodiversity is under significant pressure and governance quality is poor.

Forest area as a proportion of total land area, the rate of forest area change, and the proportion of planted forests within total forested areas are also linked to biodiversity. A country's relative forest coverage is commonly used as a structural indicator in forest biodiversity assessments at both global and regional scales (FAO 2020). Among the planted forests, plantations are widely regarded as essential for meeting the growing global demand for timber and other wood products. They may support natural forest conservation by reducing pressure on natural forests. Numerous studies have shown that the expansion of timber plantations is often associated with reduced degradation of natural forests (Pirard et al. 2016). However, plantation expansion may contribute to deforestation (e.g., Heilmayr 2014) and reduce habitats for forest species. Consequently, the negative effects of increased roundwood production on biodiversity are likely to be greater where forest cover is low, forest loss is high, or the proportion of plantation forests is low.

Forest areas under long-term management plans or certification schemes, areas located within legally established PAs, and forest areas managed primarily for biodiversity conservation - alongside the extend of PA and the inclusion of key biodiversity areas (KBAs) within these areas - are indirect drivers for biodiversity. Existence of long-term forest management plan that incorporates biodiversity conservation as one of its objectives is essential for sustainable forest management and has been associated with reduced deforestation (Tritsch et al. 2020). An increase in certified forest areas within a country reflects a commitment to sustainable management and biodiversity conservation. Studies have demonstrated the environmental benefits from certification, including reductions in biodiversity degradation (e.g., Burivalova et al. 2017). Moreover, although debates continue regarding the effectiveness of Protected areas in conserving biodiversity and reducing deforestation, numerous studies report positive outcomes from these efforts (Fischer et al. 2023). Also, the Kunming-Montreal Global Biodiversity Framework and EUBDS assume that protected areas are effective tools for biodiversity conservation. KBAs are essential for species and their habitats and play a crucial role in maintaining global biodiversity (Fischer et al. 2023). Considering these aspects, the harmful effects of increased roundwood production on biodiversity are likely to be more pronounced when a small proportion of forest area is under long-term management plans, when a low share of forest area is certified or managed for biodiversity conservation, or when coverage of land, forests, or KBAs within protected areas is limited.

Under the biodiversity status and change category, 12 indicators are considered: the Red List Index (RLI), terrestrial biome protection (national weights, TBPN), changes in TBPN, terrestrial biome protection (global weights, TBPG), changes in TBPG, the Protected Areas Representativeness Index (PAR), changes in PAR, the Biodiversity Habitat Index (BHI), the Species Protection Index (SPI), changes in SPI, and the Species Habitat Index (SHI). The RLI tracks extinction risk trends across species groups (United Nations 2019). The EPI's Biodiversity Habitat Index (BHI) assesses how effectively a country preserves natural ecosystems and protects biodiversity within its borders (Wolf et al. 2022). TBPN measures the proportion of each biome within a country that is protected, with more weight given to rarer biomes within the country. Similarly, TBPG measures the proportion of each biome within a country that is protected but gives greater weight to globally rare biomes. PAR assesses how well a country's terrestrial protected areas represent its ecological diversity, while BHI estimates the impact of habitat loss, degradation, and fragmentation on biodiversity retention. SPI measures the overlap between a country's protected areas and the ranges of its species, including vertebrates, invertebrates, and plants. Finally, SHI evaluates the proportion of suitable habitats for a country's species that remain intact compared to a 2001 baseline. The SHI weights species according to the proportion of their global range within the country. Harmful effects of increased roundwood production on biodiversity are likely to be higher when there is currently high risk of species extinction, low level of protection of species and habitat, or high level of decline in protected species and habitat.

Table 3 lists the indicators and their data sources. Most of the indicators have data across all countries, and their values align with the reference values of Aichi Target 11. The indicator values are available in Appendix S.3.

2.3.2 Analysis and interpretation of the potential impacts of EUBDS on biodiversity

Countries were divided into two groups: one comprising countries in EU+N and the other consisting of those countries in RoW, whose harvests were projected to be impacted by EUBDS. For both groups, we calculated the average value of each indicator to assess their vulnerability to biodiversity loss, based on that specific indicator. Here, vulnerability refers to the lack of capacity to prevent or mitigate potential damage (Fischer et al. 2023). We also computed the weighted mean for each indicator for both groups to derive risk values. A country's percentage share of projected changes in roundwood harvests were used as the weight. Here, risk is defined as the potential for adverse outcomes resulting from uncertain events and includes three key elements: vulnerability, exposure to threats, and the frequency or intensity of these threats. In this context, exposure refers to the countries that are affected by changes in roundwood production due to EUBDS, and the degree of threat is represented by changes in harvest levels. Exposure increases as more roundwood is sourced from outside the EU to compensate for the decreased production within the EU (Fischer et al. 2023). The significance of the differences between the means of the two regional aggregates and for each indicator was determined using t-test and weighted t-test.

Table 3. Indicators considered to assess the vulnerability and risk for the potential leakage of biodiversity degradation out of the EU due to EU Biodiversity Strategy 2030. The higher the indicator value the lower the vulnerability or risk of biodiversity loss.

Indicator	Values derivation and interpretation	Data source
Forest area per capita	Forest area divided by population estimate.	Forest area 2020 (FAO 2020) UN population estimate 2022 (United Nations 2022b)
Forest area as a proportion of total land area	The share of land area covered by forests.	FAO 2020
Forest area change rate	The change in the forest area from 2015 to 2020, relative to the 2015 value.	FAO 2020
Proportion of planted forests	The share of planted forests in total forest area (incl. plantations).	FAO 2020
Mean Governance	The average of six dimensions: Voice and Accountability, Political Stability, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. Composite governance measures follow a standard normal distribution (mean 0, standard deviation 1), ranging from about -2.5 to 2.5, where higher values indicate better governance.	Daniel and Aart 2023
Forest area under a long-term management plan	The share of forest area under a long-term management plan	FAO 2020
Forest under certification scheme	The share of forests under independently verified forest management.	FAO 2020
Conservation as primary management objective	The share of forests under primarily designated for conservation of biodiversity.	FAO 2020
Protected area (PA) coverage	The share of both terrestrial and inland waters under PAs.	FAO 2020

Forest in PA	The share of forest area within legally established PAs.	FAO 2020
Key Biodiversity Areas (KBAs) covered by PAs	The average share of KBAs covered by PAs.	United Nations 2019
Red List Index (RLI)	RLI ranges from 0 to 1, where 1 indicates that all species are classified as "least threatened" and 0 indicates that all species are "extinct".	United Nations 2019
Biodiversity and Habitat performance Indicators (BDH)	Category based on subcategories BHI, SHI, TBPN, TBPG, PAR & SPI. Assesses how well a country preserves ecosystems and protects biodiversity. A score of 100 reflects maximum effectiveness, while 0 indicates the least. Compiled by Yale Center for Environmental Law + Policy, Yale University and Center for International Earth Science Information Network, Columbia University	Earthdata 2022.
Biodiversity Habitat Index (BHI)	A score of 100 indicates no habitat loss, while a score of 0 indicates complete loss. Based on remote sensing and ecological diversity studies.	CSIRO 2024
Species Habitat Index (SHI)	A 100 score indicates no habitat loss since 2001, while a 0 score represents the most severe.	The Map of Life 2024
Terrestrial biome protection, national weights (TBPN)	A score of 100 indicates protection of at least 17% of each biome type, aligning with Aichi Target 11 of the Convention on Biological Diversity.	The World Database on Protected Areas. (The Protected Planet 2024)
Change in TBPN	The change in the TBPN from 2015 to 2020, and from 2017 to 2022, relative to the 2015 and 2017 values, respectively.	The World Database on Protected Areas. (The Protected Planet 2024)
Terrestrial biome protection, global weights (TBPG)	A score of 100 indicates protection of at least 17% of each biome type, aligning with Aichi Target 11 of the Convention on Biological Diversity.	The World Database on Protected Areas. (The Protected Planet 2024)
Change in TBPG	The change in the TBPNG from 2015 to 2020, and from 2017 to 2022, relative to the 2015 and 2017 values, respectively.	The World Database on Protected Areas. (The Protected Planet 2024)
Protected Areas Representativeness Index (PAR)	A perfect score (100) indicates near-perfect representation of ecosystem diversity, while a score of 0 signals very low representation.	CSIRO 2024
Change in PAR	The change in the PAR from 2015 to 2020, and from 2017 to 2022, relative to the 2015 and 2017 values, respectively.	CSIRO 2024

Species Protection Index (SPI)	A score of 100 indicates full coverage of species ranges by protected areas, while a score of 0 indicates no overlap. Based on remote sensing data and global biodiversity informatics.	The Map of Life 2024
Change in SPI	The change in the SPI from 2015 to 2020, and from 2017 to 2022, relative to the 2015 and 2017 values, respectively.	The Map of Life 2024

3. Results

In sections 3.1.1. and 3.1.2, we present the results for the cases where the forest protection is extended in EU+N or the EU only. In section 3.1.3, we draw in the possibility that also Canada and the United States increase the protected area cover in forest land. Section 3.2 considers the sensitivity of the results to technical assumptions. In section 3.3, we present the results from the biodiversity indicator comparison.

3.1 Impacts of EUBDS on the forest sector in the EU+N and globally

3.1.1 Roundwood harvests and trade

In the reference scenario Base, roundwood harvests in EU+N are projected to be at 558 Mm^3 in 2030 and rise further to 582 Mm^3 by 2035 (Fig. 1). This increase derives from higher production in the mechanical forest product industry (sawnwood and panel products), as well as from increased pulp production and exports of roundwood out of the EU.

In scenario Prot, the roundwood harvests in EU+N are 20 Mm^3 lower than in Base in 2030 after the completion of EUBDS (Table 1). By 2035, the difference between the two scenarios increases to 25 Mm^3 (-4%) . This happens after some initial stagnation in roundwood harvests due to annual additions of new land parcels to conservation. After the completion of the EUBDS targets, harvest growth in EU+N continues and exceeds current levels. The harvest decline is not uniformly distributed among the EU+N countries. The two countries that would bear the greatest economic burden to compensate forest owners for the additional land designated for conservation—Sweden and Finland—experience the largest harvest decreases under EUBDS compared to Base scenario (Table 4). Also Poland, Germany, and France are projected to decrease their harvests more than the EU+N average.

If Norway was not to follow EUBDS as assumed in scenario Prot-N, it would harvest more and replace both EU and RoW harvests. The difference in EU+N harvests between Prot-N and Base in 2035 decreases by about 1 Mm³, as Norway now harvest more. Removal of the trade embargos on forest products towards Russia/Belarus (Prot-Embargo) could be expected to magnify the impact of EUBDS in EU+N roundwood harvests, as forests products could be increasingly sourced from these countries. Because this would also happen without EUBDS, the decrease in EU+N roundwood harvest from Base-Embargo levels to Prot-Embargo is roughly same as in the case with trade embargoes. We assumed Russia to keep its export ban of coniferous roundwood, which also contributes to the small difference in the EU harvests in these two cases. Because the differences across the scenarios Prot, Prot-N, and Prot-Embargo are modest, we proceed by describing the impacts of EUBDS in the Prot scenario only.

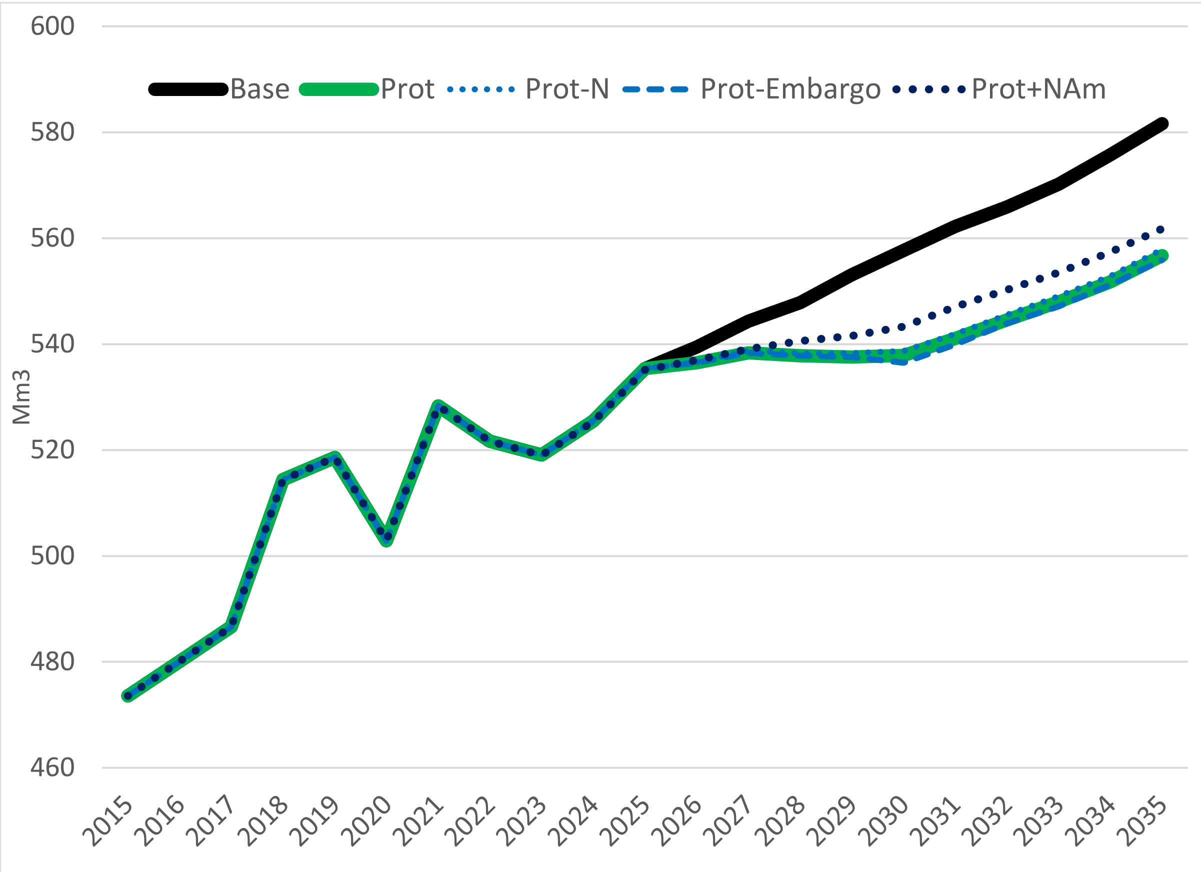

Fig. 1. Roundwood harvests as projected in the scenarios Base, Prot, and sensitivity analyses Prot-N, Prot-Embargo, and Prot+NAm. The values for 2015-2022 are from FAOSTAT (FAO 2024). Mill. m3 under bark.

EUBDS reduces wood supply in EU+N. The intensified competition for roundwood among forest industries raises roundwood prices not only in Europe but also globally, due to roundwood trade and shifts in forest industry production. The resulting costs increases put pressure on product prices, leading to eventual adjustments in the consumption of forest industry products in response to the new market conditions. After market adjustments, the global difference in the harvests between the Base and Prot scenarios is 8 Mm^3. Thus, two-thirds of the projected harvest decline in EU+N due to EUBDS is offset by an additional 17 Mm^3 harvests in RoW (Fig. 2, Table 4). The significant decrease in coniferous roundwood harvests, due to extensive conservation area set-asides in the Nordic countries (Table 1), particularly, creates opportunities for compensatory harvesting in North America, but also in other regions. This would also lead to an increased use of hardwood logs, which is reflected in the higher harvests, in Asia and South America, particularly (Fig. 2).

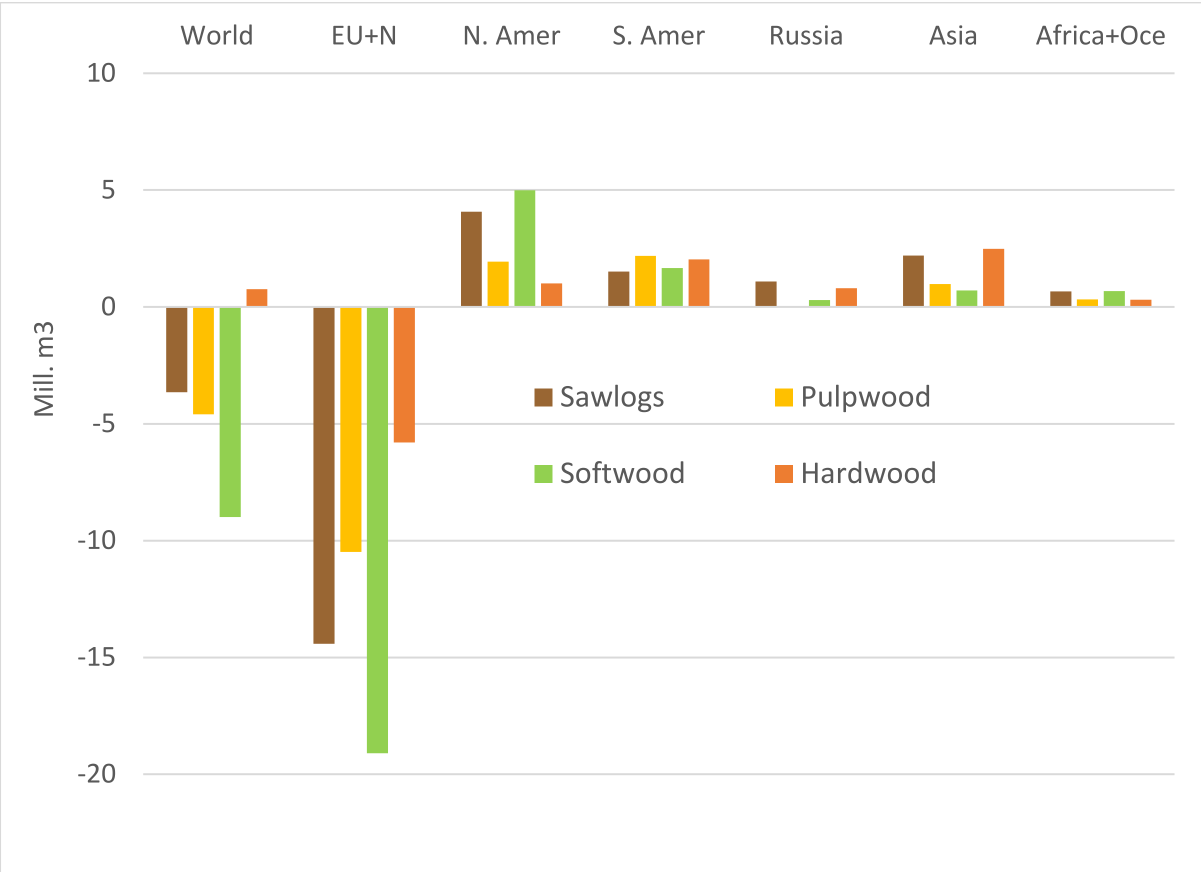

Fig 2. The projected change in roundwood harvests from scenario Base to scenario Prot in 2035 (mill. m3 over bark). EU+N = the EU27 + Norway; N.Amer = North America (Canada and the USA); Oce=Oceania.

3.1.2. Forest industry production and trade in forest industry products

When comparing EU+N forest industry production in Prot to that in Base, EUBDS is projected to have the greatest impact on the mechanical wood working industries in EU+N (Fig. 3). The production of sawnwood and panel products is 5 Mm³ lower (-3%) in Prot than in Base by 2035, leading to a reduction in net exports of these products from EU+N by 4 Mm³. Chemical pulp production is projected to decline only by 0.4 Mt/a by 2035. Approximately half (52%) of the decline in sawnwood, plywood, and panel production in EU+N is offset by increased production in RoW, with sawnwood production expected to grow in North America and Russia. Globally tightened roundwood supply heightens competition for sawlogs in some countries in Asia and South America, resulting in a slight decrease in aggregate sawnwood production in these regions. In the pulp and paper sector, high investment costs and large scale required combined with rising wood prices help limit production leakage from EU+N to RoW (Fig. 3). Globally, pulp production declines slightly more than the reduction in EU+N. The competition for wood with panel products contributes to this. However, changes in pulp production in any RoW country are modest.

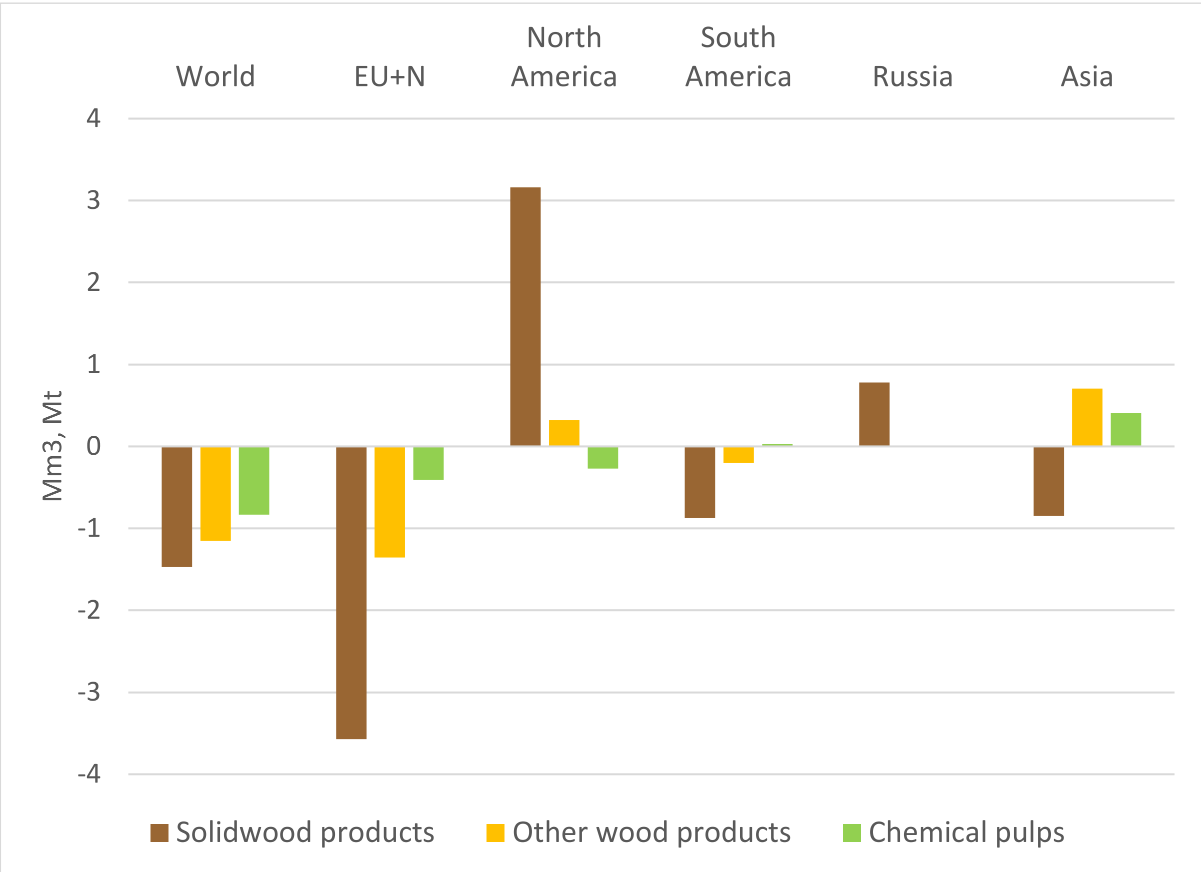

Fig. 3. The projected change in forest industry production from scenario Base to scenario Prot in 2035 (Mill. tonnes for pulp, Mill. m^3 for other products).

In scenario Base, market equilibrium prices for sawlogs and pulpwood are projected to be above the current levels in 2030 and 2035. The relative increase is projected to be more pronounced for hardwood than for softwood grades. The implementation of EUBDS (Prot) raises prices compared to Base across all regions. In EU+N, coniferous sawlog prices are projected to be 5% higher during 2030-2035, whereas coniferous pulpwood prices are 8% higher. For non-coniferous sawlogs and pulpwood, the respective price differences are 2% and 5%. Globally, the prices for roundwood increase less, as should be expected. The roundwood price increases in Prot make the turnover in roundwood sales in EU+N first increase slightly from the Base level in 2030, followed by a slight decline thereafter. While EUBDS makes forestry less attractive economically in EU+N, it boosts profitability in RoW. There the turnover from roundwood sales is projected to be nearly 5 x 10^9 euro higher than in Base in 2035.

Countries in the EU+N region		Countries in Rest of the World (RoW)	
Sweden	33.8%	United States	25.1%
Finland	14.0%	Brazil	12.5%
Poland	10.7%	Canada	10.9%
Germany	7.9%	Russia	10.5%
France	7.2%	China	6.6%
Norway	5.0%	Chile	5.4%
Latvia	4.1%	Indonesia	3.2%
Spain	3.4%	New Zealand	2.4%
Portugal	3.3%	Belarus	2.3%
Austria	3.2%	India	2.0%
Romania	2.0%	Turkey	2.0%
Slovak Republic	1.3%	VietNam	1.9%
Ireland	1.0%	Australia	1.8%
Estonia	0.9%	Argentina	1.6%
Hungary	0.8%	Mexico	1.2%
Bulgaria	0.8%	Malaysia	1.1%

Croatia	0.8%	Ukraine	1.0%
Belgium	0.7%	Thailand	0.9%
Lithuania	0.4%	United Kingdom	0.8%
Denmark	0.4%	Nigeria	0.7%
Greece	0.1%	Iran	0.6%
Luxembourg	0.1%	Switzerland	0.6%
Slovenia	0.0%	South Africa	0.5%
Cyprus	0.0%	Uruguay	0.4%
Netherlands	-0.1%		
Italy	-0.2%		
Czech Republic	-1.4%		
Total EU+N	100% of -24.9 Mm^3	Total	96% of the +16.7 Mm^3

Table 4. Percentages of the countries' shares of decreasing production in EU+N and percentages of the countries' shares of increasing production in the Rest of the World due to EUBDS. The decrease or increase refers to a change with respect to the baseline level in 2035. For RoW, countries that increased their harvests 50 000 m^3 or more from the baseline scenario are included.

3.1.3. Sensitivity analysis: Case of increased forest conservation in North America

In the scenarios above, the 30% conservation goal for terrestrial areas was achieved within the EU+N region only. Prot+NAm scenario explores the potential for similar forest conservation measures to be implemented in North America simultaneously with EUBDS.

In this scenario, the projected change in roundwood harvest volume in 2035 from the baseline scenario (Base) is -19.8 Mm^3 in EU+N (compared to -24.9 Mm^3 in the Prot scenario with EUBDS only), -11.7 Mm^3 in Nordic countries (-13.2 Mm^3), and -34.3 Mm^3 in North America (+6.0 Mm^3). Regions experiencing harvest increase from the Base scenario in 2035 show the following changes: Asia +10 Mm^3 (+3 Mm^3), South America +8.7 Mm^3 (+4.2 Mm^3), Russia +4.3 Mm^3 (+1.6 Mm^3), and Africa +0.8 Mm^3 (+0.4 Mm^3). The global change in roundwood harvest volume is -25.3 Mm^3 (-8.2 Mm^3). Figures in parentheses indicate the respective changes under the EUBDS-only scenario.

Harvest leakage to countries outside of North America and EU+N amounts to 28.8 Mm^3, reflecting a leakage rate of 53%. As anticipated, expanding conservation efforts to a larger region reduces overall harvest leakage. However, since an even greater portion of coniferous roundwood-producing land is excluded from potential supply, harvest leakage is directed more strongly toward tropical countries and hardwood species. The harvest of non-coniferous roundwood increases by 3.4 Mm^3 (compared to 0.8 Mm^3 previously) from baseline levels in 2035. While this scenario may be slightly more economically favourable for the EU, it could have stronger negative implications for global biodiversity, as increased harvesting occurs in biodiversity-rich regions with weaker forest governance than in EU+N or North America.

3.2. Sensitivity analysis regarding to wood supply parameters

Fig. 4 shows the EU+N roundwood harvests under alternative assumption of the 50% share of harvestable forest area under non-strict forest protection and the 30% share assumed earlier, and growing stock elasticity of roundwood supply 0.7 vs 1.0, and changing the price elasticity of wood supply to 1 from the earlier 0.5 and 0.7. The results are shown in the setting where the reference scenario Base is compared to EUBDS case Prot.

The assumption about the area restriction under non-strict protection (50% or 30%) has relatively small impact on the harvest projections in EU+N and harvest leakage. This is because a large share of the new forest conservation areas was assumed to be strictly protected (Table 1). However, the assumption is important for the Nordic countries which were assumed to set aside large areas of forests under non-strict protection. Under these modified assumptions, the EU+N roundwood harvests were projected to decline by 21.7 Mm3 instead of earlier projected 25 Mm3, when scenario Prot is compared to Base in 2035. The difference is mostly due to more harvest in the Nordic countries.

In the analyses above, we assumed the elasticity of wood supply relative to the growing stock volume to be 0.7 for all countries (Appendix S.2). Thus, we assumed that the changes in stock are not fully reflected in wood supply, as the growth of forests occurs across all the age classes and, because all forest owners are not managing their forests for the purpose of roundwood supply. When the growing stock elasticity of wood supply was raised to 1.0, the forest growth stimulates the roundwood supply more. With the higher stock elasticity, the harvests in EU+N are projected to reach 595 Mm^3 in 2035 in the new Base scenarios, which is 13 Mm^3 above the earlier projected baseline harvest. Now, EUBDS is projected to reduce the harvests in EU+N by 6% from the baseline (35 Mm^3) in 2035, if 30% of non-strictly protected forests remain in roundwood production. Assuming 50% of non-strictly protected forests to remain in roundwood production reduces the EUBDS impact to -31 Mm^3. The baseline harvest is more sensitive to the change in elasticities that EUBDS scenarios.

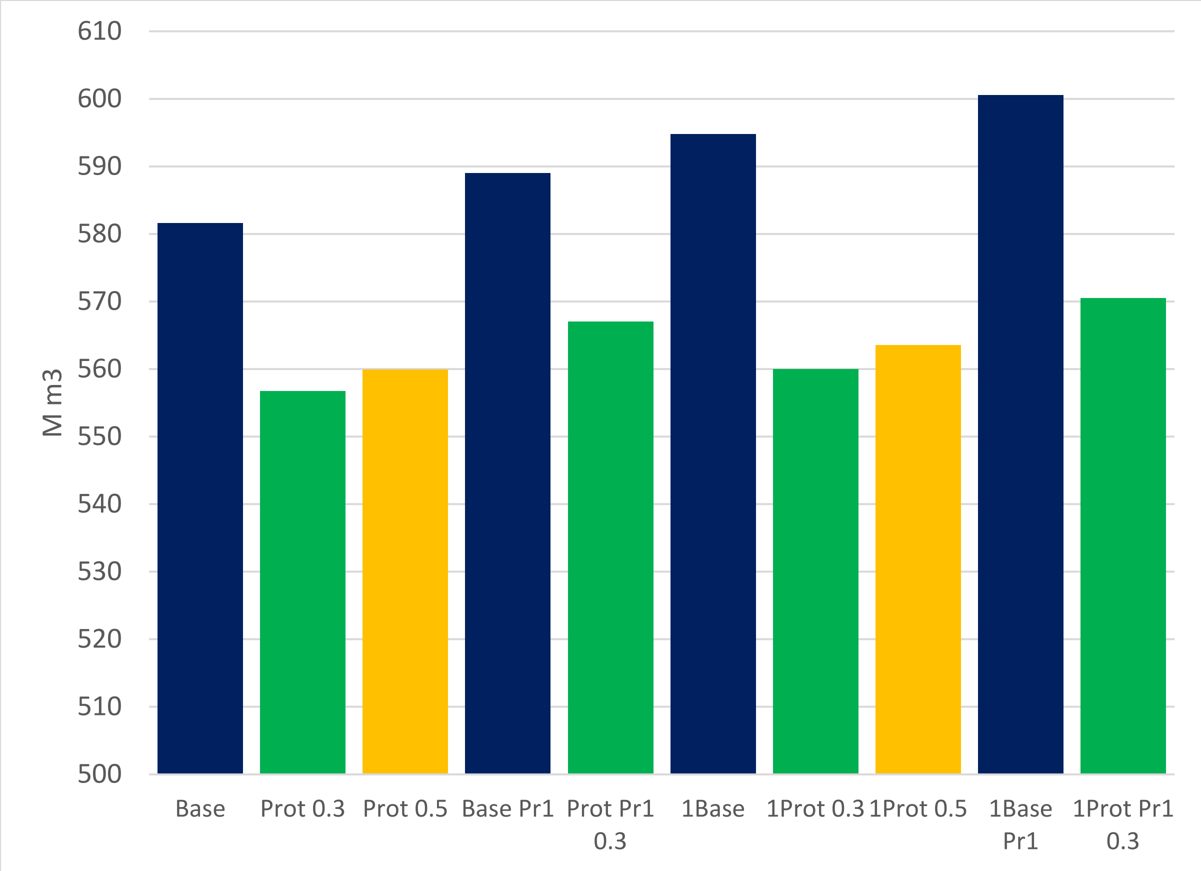

Fig. 4. Projected roundwood harvests in EU+N in 2035 under different baselines (Base) and EUBDS (Prot) cases when the elasticity of growing stock volume is 1 instead 0.7 used in the main analysis (the first label character is "1"); when the price elasticity of wood supply is changed to 1 from 0.5 for pulpwood and 0.7 for sawlogs in the main analysis ("Pr1" in the label), and when the share of area usable for roundwood supply in non-strictly protected areas is 50% instead of 30% (0.5 or 0.3 in the label). Base and Prot 0.3 refer to the the original Base and Prot scenarios. (Mill. m^3 u.b.)

3.3 Potential leakage of biodiversity risks under EUBDS based on indicator comparison

The means and weighted means of single indicator values for countries in the EU+N region and those in the RoW affected by EUBDS were compared to assess vulnerability and risk, respectively, for biodiversity degradation in RoW due to EUBDS (Table 5).

The EU+N countries most economically impacted by conservation set-asides typically have a larger share of forests and higher forest area per capita than the EU+N average. Similarly, harvest leakage was directed into the countries that, on average, had more forest area per capita than the EU+N countries. The countries receiving harvest transfers from EU+N had slightly higher deforestation rates, on average, but the differences compared to the EU+N average were not statistically significant.

Both the means (vulnerability) and weighted means (risk) were better for almost all indicators directly related to biodiversity in EU+N group of countries where harvests decreased compared to the group of countries in RoW receiving harvest transfers. The latter group performed better only in the Biodiversity Habitat Index, but the difference in means between the groups was not statistically significant for this indicator. While many of the biodiversity indicators have shown positive development in both groups over the last decade, the group of countries receiving harvest transfers from the EU+N perform worse, on average, in biodiversity protection, particularly with respect to the Species Protection Index ($p > 0.01$), Terrestrial Biome Protection ($p > 0.01$), KBAs covered by protected areas and Protected Area Representativeness ($p > 0.01$), and. On average, the target countries of harvest leakage not only performed weaker regarding PAR, but their performance in this indicator has shown a discouraging trend over the last decade. While the implementation of EUBDS should improve the biodiversity indicators in EU+N, the comparison suggests that this may come at the expense of indicators in RoW, unless additional policy measures are implemented to ensure positive development in biodiversity protection there.

Indicators	Vulnerability		Risk	
	EU+N	RoW	EU+N	RoW
Forest area per capita (ha/person)	0.73	1.28	1.78	2.37
Forest area as proportion of total land area (%)	**36.47**	**31.17**	**52.46**	**36.49**
Forest area change rate (%)	**0.13**	**-0.48**	**0.08**	**-0.10**
Proportion of planted forests (%)	**34**	**14*** **	**33**	**10*** **
Mean governance (index)	**1.00**	**0.11*** **	**1.28**	**0.31*** **
Forest area under a long-term management plan (%)	**69.42**	**51.89***	**78.73**	**61.91**
Forest under certification scheme (%)	**43.50**	**13.74*** **	**58.50**	**20.01*** **
Conservation as primary management objective (%)	8.39	29.53	11.47	12.25
Protected area (PA) coverage (%)	**25.60**	**13.75*** **	**23.37**	**15.37** **
Forest within legally established PA (%)	**18.12**	**15.03**	**15.28**	**15.08**
Key Biodiversity Areas covered by PAs (%)	**80.50**	**41.08*** **	**71.35**	**35.78*** **
Red List Index (RLI)	**0.93**	**0.82*** **	**0.96**	**0.82*** **
Biodiversity and Habitat performance Indicators	**79.46**	**49.42*** **	**76.58**	**52.91*** **
Biodiversity Habitat Index (BHI)	44.67	45.84	43.25	44.21
Species Habitat Index (SHI)	**81.20**	**75.48**	**77.72**	**72.91**

Terrestrial biome protection, national weights				
Index (TBPN)	**95.09**	**56.65*** **	**82.40**	**56.54*** **
Change 2015-2020 (%)	4.64	6.74	5.66	6.90
Change 2017-2022 (%)	0.83	5.62*	2.07	5.84
Terrestrial biome protection, global weights				
Index (TBPG)	**95.02**	**56.61*** **	**83.14**	**58.20*** **
Change 2015-2020 (%)	4.58	5.92	5.33	5.71
Change 2017-2022 (%)	0.77	5.71	1.83	4.99
Protected Areas Representativeness (PAR)				
Index	**46.09**	**26.00*** **	**42.76**	**23.76*** **
Change 2015-2020 (%)	**12.41**	**-4.20** **	**11.65**	**-8.30*** **
Change 2017-2022 (%)	**8.76**	**-6.45** **	**8.24**	**-8.76*** **
Species Protection Index (SPI)				
Index	**75.62**	**43.96*** **	**75.15**	**47.78*** **
Change 2015-2020 (%)	7.19	4.21	4.36	4.52
Change 2017-2022 (%)	6.65	16.18	4.64	14.13**

Table 5. Vulnerability and risk of biodiversity loss in the EU and Norway (EU+N) versus the Rest of the World (RoW) countries increasing their harvests due to EUBDS. Vulnerability is the average indicator value, while risk is the weighted average based on countries' harvest change shares. For all indicators, lower value indicates lower vulnerability or lower risk. Results showing higher vulnerability or risk in RoW are bolded. *, **, and ***, indicate statistical significance at P<0.1, P<0.05, and P<0.01, respectively.

4. Discussion

Our results suggest a milder effect of EUBDS than what was indicated by the 'moderate conservation scenario' of Schier et al. (2022). They projected a decline in EU roundwood harvests from the reference level of 539 Mm^3 to 490 Mm^3 (-65 Mm^3) by 2030 due to EUBDS. In the corresponding setting in our study (Prot-N), EU harvest declines by 19 Mm^3 to 526 Mm^3 in 2030 but exceeds current levels also under EUBDS. The differences in the results can be attributed to the scope of new conservation measures, which were assumed to be less extensive in our study. Additionally, we used a different model, up-to-date GDP forecasts, and considered the impacts of the war in Ukraine on trade of forest products. However, the profile of countries most affected by leakage of roundwood harvests from EU to RoW is similar in both studies.

Our projection for the EUBDS impacts aligns more closely with those in di Fulvio et al. (2025). In their most comparable scenario, where EUBDS targets are achieved individually by each country in region EU+N & the UK, roundwood harvests are projected to decrease from the reference level by 17 Mm³ (o.b.) in 2030 and 25 Mm³ (o.b.) in 2040 due to EUBDS. Our respective figure for 2035 was 25 Mm³ (u.b.). Based on a reported increase in total biomass harvests from about 625 Mm³ in 2020 to around 750 Mm³ in 2040 in di Fulvio et al. (2025), their baseline roundwood harvests were likely higher than in our study.

Räty et al. (2023) suggest that prevailing harvest levels in Finland could be technically maintained in the future even under EUBDS. Our results indicate that this could also be economically feasible.

Compared to studies assessing the impacts of the LULUCF regulation on forest carbon sinks, harvest levels under EUBDS are projected to be well above those calculated by Päivinen et al. (2022) for the case where countries' harvests were restricted to those assumed to be compatible with their forest reference levels 2021-2030 for carbon sinks. EU appears unlikely to meet its LULUCF target for 2021-2025 (Korosuo et al. 2023), while the 2026-2030 targets are expected to be even stricter (European Parliament and the Council 2023). Also, EUBDS might not reduce harvests in areas with high carbon accumulation potential. Räty et al. (2023) project that implementing EUBDS in Finland would lead to lower growing stock volumes and reduced carbon stocks in forests by 2050.

Among forest industries, the increased forest conservation in Europe is projected to impact the mechanical forest industry most significantly. This aligns with previous studies (Bolkesjø et al. 2005; Hänninen and Kallio 2007; Schier et al. 2022). Investments in plants for sawnwood and panel products require less capital, technical expertise, and smaller production scale than new pulp and paper mills. The substantial investment costs and raw material requirements for large-scale production provide the pulp and paper sector in the EU some protection from new entrants in RoW. However, this advantage may not persist in the longer-run when the existing production facilities need to be upgraded. Also, while our assumptions did not detail the shares of pulpwood and sawlogs in areas designated for conservation, conserving old-growth forests should impact sawlog supply more than that of pulpwood, as pulpwood is also sourced from forest thinning activities years before final harvesting. Beyond the timeframe of this analysis, the situation could shift in favour of sawlogs over pulpwood, as uneven-aged forestry would likely yield more valuable large-dimension wood.

Biodiversity indicators have both advantages and drawbacks. They help in uniformly tracking impacts across regions and understanding trends related to species loss or habitat alterations. They also serve as early warning systems for biodiversity loss due to displacement effects, alerting when there is a need for policy adjustments to mitigate unexpected biodiversity impacts (Martínez-Jauregui et al.

2021). One drawback in using indicators to assess the leakage of biodiversity degradation is their sensitivity to spatial and temporal scale mismatches, which can obscure the true effects of policy leakage. Indicators often fail to capture indirect or delayed impacts that result from policy-driven activity shifts. Furthermore, the data used to build indicators may have gaps in geographic coverage or in ecosystem-specific data that weaken the overall reliability of impact assessments.

Most biodiversity indicators suggest a risk of biodiversity degradation leakage from EU+N to RoW due to EUBDS. These risks could be exacerbated by weak governance. Countries in RoW that are projected to increase their harvests due to EUBDS have, on average, made improvements in species and biome protection during 2015–2022. The values of these indicators have, however, remained lower than those in EU+N on average. Notably, these figures reflect past developments and do not capture the situation following EUBDS implementation. While EUBDS is expected to improve biome, habitat, and species protection, as well as the protected area representativeness in the EU, additional measures will be needed in other countries to mitigate the risk of biodiversity degradation resulting from increased harvests there. This is especially true for Brazil, which accounts for around 12.5% of the projected increase in roundwood harvest following EUBDS. Brazil is widely recognized not only as a biodiversity hotspot country, but also for its substantial effort to establish PAs. Currently, it has the largest network of protected areas globally, comprising approximately 12.4% of the world's total PAs (Marina et al., 2018). 30% of its forests are within the PAs. However, it faces challenges such as weak governance, which puts it at risk of biodiversity loss leakage due to EUBDS. Among the 25 non-EU countries expected to increase roundwood harvest due to EUBDS, Brazil is one of the 11 nations with a particularly low mean governance index. Similarly, in Russia, where the fourth-largest share of increase (10.5%) in RoW harvests is expected, several indicators suggest a risk of biodiversity leakage. These indicators include a low mean governance index (-1), low coverage of forest under certification schemes (8%), and PA coverage of only 12% with forests accounting for just 2% of that area.

In Canada and the USA, which have 36% share of projected harvest transfer from EU+N, indicators suggest that leakage of biodiversity degradation is less likely. Although PAs cover about 12% and 13% of these countries, with 8% and 10% being forests, respectively, these areas represent roughly 31% and 45% of key biodiversity areas. Both countries have high mean governance indicators, which would reduce the risk of leakage of biodiversity degradation. Similarly, the risk of leakage impacts is likely low in China and Chile, which together account for around 11% of the projected increase in roundwood harvest due to EUBDS. One of the reasons reducing the risk is the high proportion of plantation forests in these countries, representing 39% and 17% of their forests, respectively. The Chinese government have banned commercial logging from all its natural forests and prioritized the establishment of plantation forests through several large-scale afforestation programs (NFGA 2019).

As of 2019, plantations in China covered an area of 80 M ha, with a stock volume of 3.39 x 10^9 m^3 (Farooq et al. 2021). The projected 1 Mm^3 increase in roundwood harvests in China due to EUBDS is modest considering the country's growing forest resources. Similarly, Chile has a strong forest sector based on plantation forests. With 2.9 M ha dedicated to this use, Chile ranks among the top 10 countries globally in terms of land area devoted to plantation forests (Salas et al. 2016).

However, it is important to note that despite some possibilities to increase production on existing plantation land, expanding plantation area takes time. The increase in roundwood demand due to EUBDS represents an external shock that is unlikely to be accounted for in current plantation programs. Even if new plantations were established today, they would hardly produce sawlogs within the timeframe considered in this analysis. The additional sawlog harvests could come from existing plantations only using increasing the rotation times.

Conclusions

This study provides updated information on the potential impacts on the global forest sector of implementing the European Biodiversity Strategy 2030, in the context where EU member states protect at least 30% of their land area, with a minimum of two-thirds of this under strict protection. The same minimum shares were applied to forest protection, up to certain extent. Biggest additions to non-strictly protected forest areas was assumed to be made in Nordic countries, while the largest increases in strictly protected areas was assumed to occur in France, Germany and Sweden.

When these new land-area set-asides were gradually implemented between 2025 and 2030, they initially led to stagnation in roundwood harvests in the EU+N. However, harvests continued to increase thereafter. However, harvest levels remained below baseline projection. By 2035, the projected decline in harvests due to the assumed implementation of EUBDS was 25 Mm^3 compared to harvests without EUBDS. The decline in harvests was not distributed evenly in EU+N. The forest sector was hardest hit in a few countries that can also be assumed to bear a significant economic burden in establishing new conservation areas. Since harvest levels are driven by market demand, the decline in harvests in EU+N led to compensatory harvests in RoW. This harvest leakage amounted to 17 Mm^3 in 2035, corresponding to a leakage rate of 67%. Due to significant harvest reductions in Nordic countries, a particularly large portion (77%) of the harvest reduction in the EU+N was composed of coniferous wood. Consequently, an increase in harvests in North America is projected to offset a significant portion of the harvest decline in EU+N, with Russia following. The expected increase in roundwood harvest in non-EU countries is likely to harm biodiversity in some areas, especially in Brazil, which has the second highest projected harvest increase, rich biodiversity, and weak governance limiting effective protection.

If Canada and the United States also achieve 30% area protection target by 2030 and set aside significant forest areas to protection, global harvest leakage declines from the case where only EUBDS was implemented. Also, the EU+N would then harvest more roundwood than under EUBDS alone. However, the simultaneous implementation of conservation measures in North America and the EU results in intensified harvesting in biodiversity-rich tropical regions. Harvests of hardwood grades increase even more, as coniferous wood is substituted with non-coniferous grades.

Even if EU harvests declined, global roundwood harvests are increasing, driven by rising demand for forest products. This trend poses significant risks to biodiversity worldwide. The planned expansion of conservation areas in the EU and North America could potentially amplify these risks beyond their borders. Policymakers should take this into account when designing conservation and trade policies. The EU's regulation of deforestation-free products may have limited impact, as the highest growth in demand for forest products is occurring outside the EU, and the EU can only regulate wood products entering or leaving its territory. Greater attention should be given to addressing the drivers of this growing demand and implementing measures to promote more efficient and sustainable use of wood resources. For instance, a substantial portion of wood harvests is currently used for energy production, such as heating and cooking, despite the availability of alternative renewable energy sources.

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Conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Contributions

MK (forest sector modelling): Methodology, Data on forest sector, Scenario definitions and assumptions, Formal analysis, Writing -original draft, review and editing, Funding acquisition, Project administration, Resources; MMR (indicator analysis): Methodology, Data on indicators, Formal analysis, Writing - original draft, review and editing.

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APPENDIX S.1

Background data for forest protection area assumptions

	Total area EEA, Eurostat 1000 ha	Forest Area UNECE, FRA2023 1000 ha	Protected surface area EEA, Eurostat 1000 ha	Protected forest area UNECE, FRA2023 1000 ha	Protected surface area, Share %	Protected forest area Share %
Austria	8388	3899	2451	882	29%	23%
Belgium	3067	689	451	180	15%	26%
Bulgaria	11100	3893	4546	715	41%	18%
Croatia	5659	1939	2152	56	38%	3%
Czechia	7887	2677	1726	147	22%	5%
Denmark*	4293	628	644	131	15%	21%
Estonia	4534	2438	948	536	21%	22%
Finland*	33841	22409	4478	3740	13%	17%
France	54906	17253	15391	4018	28%	23%
Germany	35757	11419	13371	3306	37%	29%
Greece**	13169	3902	4606	164	35%	4%
Hungary	9301	2053	2069	463	22%	23%
Ireland	6995	782	971	150	14%	19%
Italy	30207	9566	6443	3360	21%	35%
Latvia	6459	3411	1173	563	18%	17%
Lithuania	6528	2201	1113	688	17%	31%
Luxembourg	260	89	145	1	56%	1%
Netherlands	3738	370	992	220	27%	60%
Poland	31193	9483	12355	3112	40%	33%
Portugal	9223	3312	2055	616	22%	19%
Romania	23840	6929	5589	2616	23%	38%
Slovakia	4904	1926	1835	573	37%	30%
Slovenia	2027	1238	821	242	40%	20%
Spain	50598	18572	14162	7414	28%	40%
Sweden*	44742	27980	6752	2270	15%	8%
Norway*	30413	12180	5674	892	19%	7%
EU+Norway	443027	171238	112909	35683	25%	21%
EU	412614	159058	107236	35072	26%	22%

Table A.1. Total land and forest area, and the surface of protected terrestrial areas and protected forest area. The latter comprises nationally designated protected areas and Natura 2000 sites. Sources: Eurostat (2024) and UNECE 2024. Data on protected forests in the Nordic countries is from Hannerz and Ekström (2023).

	Additional land to be protected for 30% goal 1000 ha A	Additional forest to be protected For 30% goal 1000 ha B	Applied increase in (non-strict) forest protection 1000 ha C = min [A,B]	Reruired increase in protection of other land 1000 ha D = (A-C)
Austria	65	288	65	0
Belgium	469	27	27	442
Bulgaria	0	453	0	0
Croatia	0	526	0	0
Czechia	640	656	640	0
Denmark	644	57	57	587
Estonia	412	195	195	217
Finland	5674	2983	2983	2692
France	1081	1158	1081	0
Germany	0	120	0	0
Greece	0	1007	0	0
Hungary	721	153	153	568
Ireland	1128	85	85	1043
Italy	2619	0	0	2619
Latvia	765	460	460	304
Lithuania	845	0	0	845
Luxembourg	0	26	0	0
Netherlands	129	0	0	129
Poland	0	0	0	0
Portugal	712	378	378	334
Romania	1563	0	0	1563
Slovakia	0	5	0	0
Slovenia	0	129	0	0
Spain	1017	0	0	1017
Sweden	6671	6124	6124	547
Norway	3450	2762	2762	688
EU+N, from above	28606	17590	15010	13598
EU+N, from statistics 30%	19999	15698	12646	

Table A.2. Additional protection areas allocated to forest area if we assumed that 30% of the forest area could be under protection eventually. However, the additional protection should not increase the areal protection share above 30%. Source: own calculations.

	OECD Terrestrial area IUCN classes Ia, Ib & II A 1000 ha	MCPFE Forest area managed for biodiversity 1.2, 1.2 B 1000 ha	Higher of A and B C=max(A,B) 1000 ha	EEA, Eurostat Land area D 1000 ha	UNECE, FRA2023 Forest area E 1000 ha	Strictly protected land area F=C/D %	Strictly protected forest area H=B/E %
Austria	212	30	212	8388	3899	2.5%	0.8%
Belgium	0	18	18	3067	689	0.6%	2.6%
Bulgaria	224	135	224	11100	3893	2.0%	3.5%
Croatia	0	54	54	5659	1939	1.0%	2.8%
Czechia	89	127	127	7887	2677	1.6%	4.7%
Denmark	8	8	8	4293	628	0.2%	1.3%
Estonia	162	311	311	4534	2438	6.9%	12.8%
Finland	3185	2542	3185	33841	22409	9.4%	11.3%
France	440	129	440	54906	17253	0.8%	0.7%
Germany	193	0	193	35757	11419	0.5%	0.0%
Greece	93	164	164	13169	3902	1.2%	4.2%
Hungary	216	13	216	9301	2053	2.3%	0.6%
Ireland	0	0	0	6995	782	0.0%	0.0%
Italy	1550	1761	1761	30207	9566	5.8%	18.4%
Latvia	365	207	365	6459	3411	5.7%	6.1%
Lithuania	176	113	176	6528	2201	2.7%	5.1%
Luxembourg	9	1	9	260	89	3.6%	1.1%
Netherlands	128	36	128	3738	370	3.4%	9.7%
Poland	198	63	198	31193	9483	0.6%	0.7%
Portugal	82	22	82	9223	3312	0.9%	0.7%
Romania	318	220	318	23840	6929	1.3%	3.2%
Slovakia	148	68	148	4904	1926	3.0%	3.5%
Slovenia	87	88	88	2027	1238	4.3%	7.1%
Spain	874	530	874	50598	18572	1.7%	2.9%
Sweden	4650	1976	4650	44742	27980	10.4%	7.1%
Norway	3890	610	3890	30413	12180	12.8%	5.0%

Table A.3. Terrestrial forest areas belonging to the IUCN classes 1a, Ib and II (Column A), forest areas belonging to the MCPFE classes 1.1.-1.3. (Column B), and the share of these from land area (Column C) and forest area (Column D). Sources: OECD(2024), Schier et al. (2022) and Forest Europe (2020), Eurostat (2024a), UNECE (2024), Hannerz and Ekström (2023).

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APPENDIX S.2

Modelling the roundwood supply in FORMEQ

Roundwood supply is represented by functions that assume that supply is a function of price, which is endogenous in the model, and other parameters that are exogenous in a given calculation period. The inverse supply function for roundwood category *w* in region *i* is specified by Equation 1:

$$P_w^i = \alpha_w^i {H_w^i}^{\beta_w^i} \qquad (1)$$

where P_w^i is a timber price per cubic meter at the roadside, H_w^i is the harvest level, β_w^i is the inverse of the price elasticity of supply, and α_w^i is a shift parameter that accounts for the impact of non-price factors affecting the supply. The latter include for instance interest rate and the amount of wood stock available for timber supply (Tian et al. 2017). In the first period, the initial values for the parameters α_w^i are determined using the observed values $\hat{H}_w^i$ and $\hat{P}_w^i$ along with the assumed value for β_w^i in Eq. (1).

Roundwood supply is classified into 8 roundwood categories as in FAOSTAT (FAO 2024a): coniferous and non-coniferous sawlogs, pulpwood, fuelwood and other industrial roundwood. In the current model application, the supply of fuelwood and other industrial roundwood is kept constant over time.

Growing stock volumes $V_{W,t}^i$ in the land available for roundwood production are specified for two species types W, one including all coniferous and the other including all non-coniferous species. After each period (year) calculated by the model, the growing stock volumes are adjusted by adding the net the growth after the harvests into it and deducting the volume that is shifted under biodiversity protection. This is represented by Eq (2).

$$V_{Wt}^i = V_{W,t-1}^i + g_W^i V_{W,t-1}^i - \sum_{w \epsilon W} H_w^{i,} - (1-r) C_{W,t-1}^{i,nsp} - C_{W,t-1}^{i,stp}. \qquad (2)$$

where g_W^i is the growth rate of the growing stock, $C_{W,t}^{i,nsp}$ denotes the stock in the land shifted to non-strict protection, $C_w^{i,stp}$ denotes the stock in the land assigned to strict protection. Parameter *r* gives the assumed share of stock that remains available to roundwood supply in the coming two decades when, for instance, the transition from even-aged forestry to uneven aged forest practices takes place. Our default assumption was r=0.30, but sensitivity analysis is provided with value r=0.5. The forest areas shifted to strict protection and their respective growing stocks are removed from the timber supply entirely. The shift parameter α_w^i in timber supply Eqs (1), is updated after each period applying the growing stock elasticities δ_W^i of timber supply to the stock change $(V_{Wt}^i)/(V_{Wt-1}^i)$.

Ideally, the growing stocks V_{W0}^i in the start of the simulations would be defined by using the data for forest available for timber supply only. This data was available for most European countries in the end of 2020 from FAO (2024b). For the rest of the countries, or in the case of missing data, the latest available values from Forest Resource Assessments by FAO (2024c) or Eurostat (2024) were used in defining the growing stock. Then these data were mostly referring to all forests. When the division of the stock to non-coniferous and coniferous grades was not available for forests available for wood supply or for all forests, the respective data for all forests, in the former case, older FRA data from 2015, or the shares of these wood grades in the countries' roundwood supplies (FAO 2024a) were used as a proxy to divide the stock to coniferous and non-coniferous. The growth rate of the growing stock was elaborated by using the data on growing stock development over time in FRA2023 (FAO, 2024c) and the reported harvests in the

FAOSTAT (FAO 2024a) and searching for the growth rates that aligned the stock development before harvests. For some countries this give negative values and for some countries unlikely large values to be persisted over longer time. Therefore, the eventual figures used were limited to the range of 1.5% - 4.5% annually.

We assumed that sawlog supply is more elastic than pulpwood supply, as the latter is often a byproduct of sawlog production. Sawlogs are the roundwood category that influences the forest owners' income most and, therefore, is thus most crucial for determining forest maturity. For sawlogs, we assumed an inverse supply elasticity $\beta_w^i = 1/0.7$, and for pulpwood, we assumed β_w^i=1/0.5. The magnitude of these elasticities is in line with the former studies (e.g., Devadoss 2008; Borzykowski 2019; Rørstad et al. 2022, Tian et al. 2017) The elasticity of wood supply relative to the growing stock was assumed to be 0.7 across all countries. Consequently, changes in timber stock are not assumed to be fully reflected in wood supply, as not all forest growth occurs in the age classes that are mature for harvesting.

In countries where establishment of new forest plantations are likely, these plantation areas were not included in the growing stocks. Instead, such short-rotation plantations were treated like production facilities with certain annual wood production capacity (hectares x mean annual increment m^3/ha).

While roundwood supply functions were calibrated to the most recent harvests data $\hat{H}_w^i$ from FAOSTAT that was available at the time of doing this study, year 2022 (FAO 2024a), it must be acknowledged that these data contain some significant errors for some countries. These errors come with a consequence that there is significant over or under harvesting of roundwood compared to what would be needed to produce the reported forest industry production (Buongiorno 2018; Kallio and Solberg 2018). Ignoring them would cause problems in calibrating the model. Therefore, some adjustments were done in these data. Sometimes these included the shift of the harvests between wood categories other, e.g., other industrial roundwood to sawlogs or vice versa (e.g. China, Canada, Indonesia, India, Russia, United States), or some roundwood production was added some cases (India, Iran, Thailan) to match the reported apparent consumption of roundwood and chips in the countries' forest industry production in 2022. For the roundwood prices $\hat{P}_w^i$ in 2022, the default assumptions were 110 €/m3 for sawlogs, and 45 €/m3 for pulpwood. These data were supplemented with more detailed data for the countries such data were available.

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