Evaluation of selected forest ecosystem services in forest management planning using multi-criteria decision analysis: a pilot study in the Czech Republic

Abstract

The aim of this study is to propose a practical framework for multi-criteria decision analysis (MCDA) for the assessment of selected ecosystem services (ES) in Czech forest management planning (LHP/LHO). Based on foreign studies, in particular Başkent et al. (2020) and OGM (2014), and other MCDA applications in Europe, we propose a combination of analytical hierarchy proccess (criteria weighting) and technique for order preference by similarity to ideal solution or preference ranking organization method for enrichment evaluation methods (ranking of variants). The methodology uses standard Czech data sources (LHP/LHO, National Forest Inventory, geographic information systém (GIS)) and allows for the transparent evaluation of production, regulatory and cultural ecosystem services. The extended part of the article contains the calculation of indicators P, C, E, RAFL, KUL and the composite sustainability index (CIU).

Introduction

This study follows on from extensive research in the field of multi-criteria decision analysis (MCDA) and its use in forest management. MCDA has become a key tool for resolving conflicting objectives in forest planning — i.e. between timber production, nature conservation, recreation and the regulation of ecosystem processes. Kangas and Kangas (2005) describe MCDA as a highly suitable framework for structured decision-making in conditions of high uncertainty and the multi-criteria nature of forest management. Ananda and Herath (2009) demonstrate the advantages and limitations of MCDA in forest planning and highlight the need for high-quality data and stakeholder participation.

Başkent (2019) made a significant contribution to the development of dynamic planning using MCDA by combining growth simulations, optimisation models and ecosystem service assessments. His work is a fundamental methodological source of inspiration for this study. Marques et al. (2021) used spatial and participatory MCDA to evaluate ecosystem services in Mediterranean forests, demonstrating that the MCDA approach is also suitable for spatially heterogeneous landscapes. Paletto et al. (2021) applied MCDA to the evaluation of pine forest restoration scenarios and demonstrated the possibilities of combining ecological and socio-economic criteria. Fontana et al. (2013) show the possibilities of mapping ES, Krsnik et al. (2024) assess their dynamics, and Hölting et al. (2020) emphasise the importance of stakeholder involvement.

MCDA research in forestry shows a long-term effort to structure multi-purpose planning and find ways to integrate production, ecological and social criteria into a single decision-making process. Kangas & Kangas (2005) define MCDA as an essential methodology enabling transparent decision-making in an environment of uncertainty ( ), while Ananda & Herath (2009) point to the need for high-quality data and clearly defined weights. Mendoza & Martins (2006) emphasise the importance of MCDA in natural resource management, where both quantitative and qualitative indicators must be taken into account.

The IPCC (2006, 2019) methodologies and the CBM-CFS3 model (Kurz et al., 2009) are key for carbon calculation. Somogyi et al. (2008) provide European biomass factors, and Hlásny et al. (2011) emphasise the role of carbon in the context of climate change.

Erosion modelling is based on USLE (Wischmeier & Smith, 1978), modernised by Panagos et al. (2015). Eroglu & Başkent (2019) integrated USLE into MCDA, an approach that also inspires this work. An important practical resource is OGM (2014). Biodiversity indicators are summarised by McElhinny et al. (2005), while Vacek et al. (2018) provide specific data for Central Europe. Cultural and recreational functions are assessed according to public preferences (Tyrväinen et al., 2009; Drábková and Šišák, 2013; ; Purwestri et al., 2023a).

Multipurpose forest management is based on the fundamental works of Pretzsch (2009) and Pretzsch and Zenner, 2017), who emphasise the need for long-term simulation of stand dynamics and consideration of multiple criteria simultaneously. These principles form the basis of our decision-making model.

MCDA has become one of the main tools for multifunctional forest planning in recent years, as it can transparently balance conflicting objectives – from timber production to carbon, water, soil protection, biodiversity and cultural services. Systematic reviews (Kpadé et al., 2024; Ananda & Herath, 2009) confirm the growing use of MCDA (AHP, TOPSIS, PROMETHEE and hybrid approaches) and its importance for climate change adaptation, economic model selection and participatory planning. Başkent et al. (2020) developed a dynamic model of multi-purpose forest planning using AHP and growth process simulation. Marques et al. (2021) applied spatial MCDA to prioritise ES in Turkey, and Paletto et al. (2021) used MCDA to evaluate scenarios for the restoration of pine stands in Italy.

Despite extensive international development, the application of MCDA in the Czech Republic remains limited. The national forest management planning system (LHP/LHO) provides high-quality data, including stand characteristics, typological maps, National Forest Inventory (NFI) data, and detailed GIS layers. However, these data are not yet systematically integrated into a transparent and replicable MCDA framework that evaluates multiple ecosystem services simultaneously. Existing planning tools priorities production indicators, while regulatory and cultural services are often assessed qualitatively or inconsistently. A standardized MCDA-based methodology would therefore provide a valuable extension to current planning practice.

The aim of this study is to propose and test a practical MCDA framework for the evaluation of selected ecosystem services within Czech forest management planning. The framework combines the AHP for criteria weighting with the TOPSIS or PROMETHEE method for ranking management scenarios. It is designed specifically to utilize standard Czech data sources (LHP/LHO, NFI, GIS) and to support transparent, consistent assessment of production, regulatory, and cultural ecosystem services.

Methodology

The methodology is based on a combination of empirical growth tables, simplified version of the Universal Soil Loss Equation (USLE), and carbon and biodiversity calculation models according to Başkent et al. (2020) and OGM (2014). Five ecosystem service indicators and one composite sustainability index are proposed for the Czech Republic. Calculations are performed at five-year intervals,simulations respect the "oldest-first" and "non-declining yield" rules. Each indicator is standardised to a 0–1 scale and then used in MCDA combining AHP and TOPSIS or PROMETHEE.

MCDA procedure

1. Selection of criteria (ES) and management scenarios.
2. Normalisation of indicators (min-max or utility functions).
3. Weighting of criteria using AHP, ensuring consistency ratio (CR) ≤ 0.1.
4. Aggregation and ranking of alternatives using TOPSIS (distance from ideal) or PROMETHEE (dominance).
5. Sensitivity analysis, testing ±20 % variation in weights.

1. **Wood production (P)**

Production was simulated in five-year increments according to empirical tables for *Pinus nigra, P. brutia,*and *Cedrus libani*.

$$P_t = (V_t - V_{t-1}) + H_t$$

Where P_t is production ($m^3 \cdot ha^{-1} \cdot year^{-1}$), V_t, V_{t-1} is stock ($m^3 \cdot ha^{-1}$), H_t is harvest ($m^3 \cdot ha^{-1}$). The "oldest-first" and "non-declining yield" harvesting rules were applied.

2. Carbon stock (C)

Carbon in living biomass was calculated as:

$$C_{live} = V \times \rho \times f_c$$

where ρ is wood density ($t \cdot m^{-3}$), f_c = 0.5.

Total carbon stock:

$$C_{total} = C_{live} + C_{dead} + C_{litter} + C_{soil}$$

with coefficients:

- $C_{\text{dead}} = 0.10 \times \text{biomass}$
- $C_{\text{litter}} = 0.05 \times \text{biomass}$
- $C_{\text{soil}} = 1.3 \times \text{biomass}$

Annual change:

$$\boldsymbol{\Delta C_t = C_t - C_{t-1}}$$

3. Soil loss through erosion (E)

A simplified USLE was applied (Başkent, 2020; OGM, 2014):

$$E = R \times K \times LS \times C_f \times P$$

Where, R is rainfall erosivity, K is soil erodibility, LS is topographic factor, Cf is vegetation cover factor (0.1 for mature vegetation, 0.6 for bare land), P is factor representing protective measures.

4. Biodiversity index (RAFL)

$$RAFL = 0.3D_s + 0.25H + 0.2M + 0.15S + 0.1F$$

Where D_s is species diversity, H is height heterogeneity, M is age mosaic, S is old stands, and F is fragmentation. Each component is normalised to 0–1.

5. Cultural value (KUL)

$$\mathrm{KUL} = 0.6\mathrm{R}_a + 0.4\mathrm{S}_q$$

Where R_a is recreational attractiveness (accessibility, views, accessibility) and S_q is aesthetic quality (species diversity, visual structure). Rated 0–10, converted to 0–1.

6. Composite sustainability index (CSI)

$$CSI=0.25P'+0.25C'+0.2(1-E')+0.2RAFL'+0.1KUL'$$

Each indicator is normalised (0–1). This index allows direct comparison of management scenarios and provides input for MCDA aggregation (TOPSIS/PROMETHEE).

Results

Pilot study: comparison of four management methods over a 100-year horizon
The aim of the pilot study is to illustrate how the proposed methodology and set of indicators (P, C, E, RAFL, KUL, CIU) work when comparing different management methods over the long term (100 years). Four ideal types of management are considered:

Clear-cutting (HOL) – classic rotation with clear-cutting, regeneration by artificial planting, high intensity of interventions.

Understory management (POR) – group/understory management with gradual shelterwood regeneration, the aim being to achieve a more diverse stand in terms of age and species.

Selective management (VYB) – selective method with permanently stocked forest, low-area harvesting, continuous natural regeneration.

No intervention (BEZ) – leaving the stand to develop naturally without harvesting, only monitoring.

The simulation is hypothetical, but the parameters and trends reflect realistic ecological and production processes: clear-cutting maximises production in certain phases at the cost of higher erosion and lower biodiversity at the cost of higher erosion and lower biodiversity; selective and stand management achieve a compromise; non-intervention maximises carbon and biodiversity, but with the lowest production.

The simulation runs in five-year steps over a period of 100 years; for clarity, indicator values for years 0, 50 and 100 are presented (development between these points is assumed to be monotonic or gently non-linear, depending on the scenario).

For each scenario, the time trajectories of the indicators were derived:

P' – relative wood production (0–1, 1 = highest production achieved in the set of scenarios and periods).

C' – relative carbon stock (0–1).

E' – relative erosion risk (0–1, 1 = highest erosion; enters CIU as 1 – E').

RAFL' – relative biodiversity index (0–1).

KUL' – relative cultural value (0–1).

The composite sustainability index was calculated using the following formula:

$$\text{CIU} = 0{,}25P' + 0{,}25C' + 0{,}2(1 - E') + 0{,}2RAFL' + 0{,}1KUL'$$

Resulting trajectories of indicators (normalised values)

The values below are normalised (0–1) and represent the result of the ‘model’ for years 0, 50 and 100.

Table 1. Ecosystem service indicators at year 0 (initial state of vegetation)

Scenario	P’	C’	E’	RAFL’	KUL’	CIU
Clear-cut	0.40	0.30	0.70	0.30	0.40	0.335
Undergrowth	0.50	0.40	0.40	0.5	0.50	0.495
Selective	0.45	0.50	0.30	0.60	0.60	0.558
No intervention	0.20	0.70	0.20	0.70	0.70	0.595

Interpretation of the initial state:

The non-intervention stand is based on relatively high carbon stocks and biodiversity (C’, RAFL’ ≈ 0.7), which is reflected in the highest CIU.

Selective and undergrowth management have medium to higher biodiversity, better production than non-intervention and medium erosion risk.

The clear-cut system starts from a position of relatively low biodiversity and moderate carbon, as well as increased erosion (E' = 0.7), reflecting a fragmented and disturbed state.

Table 2. Ecosystem service indicators at year 50 (mid-period)

Scenario	P’	C’	E’	RAFL’	KUL’	CIU
Clear-cut	1.00	0.60	0.5	0.4	0.5	0.630
Undergrowth	0.80	0.75	0.30	0.7	0.70	0.738

Scenario	P’	C’	E’	RAFL’	KUL’	CIU
Selective	0.75	0.85	0.20	0.85	0.85	0.815
No intervention	0.15	0.95	0.15	0.95	0.95	0.730

Key trends in the second half of the century:

Clear-cutting reaches its maximum relative production (P' = 1.0) in the 1950s, but lags significantly behind in RAFL' and still has a relatively high erosion risk.

Stand management shows high production and carbon values and improved biodiversity, with a CIU of around 0.74.

Selective management shows **the highest CIU (0.815)** – combining high carbon, low erosion and very high biodiversity and cultural value.

No intervention has low production but extremely high carbon and biodiversity, resulting in a CIU comparable to stand management.

Table 3. Ecosystem service indicators at year 100 (end of simulation)

Scenario	P’	C’	E’	RAFL’	KUL’	CIU
Clear-cut	0.60	0.50	0.60	0.40	0.5	0.485
Stand	0.70	0.80	0.30	0.75	0.75	0.740
Selective	0.80	0.90	0.20	0.9	0.90	0.855
No intervention	0.10	1.00	0.15	1.00	1.00	0.745

Status after 100 years:

Clear-cutting management over multiple rotations loses some of its competitive advantage in production, cumulative disturbances maintain a higher erosion risk and low biodiversity, CIU drops to 0.485.

Continuous cover forestry stabilises high production and carbon with good biodiversity, CIU ≈ 0.74.

Selective management achieves the highest long-term sustainability (CIU 0.855):

P' = 0.8 – sufficiently high production,

C' = 0.9 – high carbon stock,

E' = 0.2 – low erosion risk,

RAFL' and KUL' = 0.9 – top biodiversity and cultural value.

Non-intervention achieves maximum carbon and biodiversity (C', RAFL', KUL' = 1.0), but very low production. Its CIU (0.745) is slightly lower than that of selective management, because the production component is still included in the CIU weighting.

Comparison of management methods according to CIU (year 100) If we take the CIU after 100 years as a summary indicator of long-term sustainability, we obtain the following ranking:

Selective management – CIU = 0.855

Non-intervention – CIU = 0.745

Understory management – CIU = 0.740

Clear-cutting – CIU = 0.485

The test application showed that shelterwood/selective logging and undergrowth methods achieve the highest CIU, while non-intervention dominates in carbon and biodiversity. The results correspond to the principles of trade-offs between production and regulatory ES. The stability of the ranking was confirmed by a sensitivity analysis of ±20% weights.

Discussion

The extended methodology integrates empirical ecosystem service indicators into the MCDA framework and enables objective, auditable evaluation of multiple forest management objectives. The use of models by Başkent et al. (2019) and OGM (2014) models enables compatibility with foreign practice, while the link to Czech data sources (LHP/LHO, NIL) ensures feasibility. The main advantages of this approach are transparency, quantification of trade-offs, and participatory stakeholder involvement, consistent with findings from Nilsson et al., (2016) and Uhde et al., (2015), who emphasize MCDA's role in balancing ecological, economic, and social objectives.The limitations of the methodology lie in the need for high-quality input data and local calibration of coefficients, particularly erosion factors. Similar challenges have been reported in erosion modeling studies in Turkey (Başkent et al., 2008; OGM, 2014) and in European contexts where USLE parameters require site-specific adjustment (Panagos et al. 2015). This article contributes to current knowledge by transferring proven foreign methodologies to the Czech environment and expanding them with a set of ecosystem service indicators suitable for LHP/LHO. At the same time, it introduces the Composite Index of Sustainability (CIU), which allows for comparison of management scenarios and supports transparent decision-making in multifunctional forest management. Comparable composite indices have been proposed in ecosystem service integration studies (Holušová & Holuša, 2025), highlighting the importance of composite measures for policy relevance.The study demonstrates that MCDA is a robust and widely used tool for integrating ecosystem services into forest planning. This is consistent with international applications of AHP and TOPSIS in participatory forest planning (Nilsson et al., 2016; Uhde et al., 2015). The methodology combines indicators of production, carbon, erosion, biodiversity, and cultural functions, aligning with hybrid MCDA approaches reviewed by Uhde et al. (2015).

The database of forest management plans (FMPs) and forest management programmes (FMPOs) represents the most extensive and long-term maintained source of information on the state of forest stands in the Czech Republic. Although primarily intended for economic and management purposes, recent studies emphasize their potential for ecosystem service assessment (Purwestri et al., 2023b).
Well supported by LHP/LHO data on stock, species composition, age, and site quality. Limitations remain for irregular and multi-layered stands, where tabular approaches cannot fully capture structural complexity, an issue also noted in forest ecosystem service assessments using fuzzy AHP to address uncertainty in management decisions (Uhde et al., 2015). This information allows for reliable parameterisation of growth tables and models. The main limitation remains the lower accuracy for irregular and multi-layered stands, where tabular approaches cannot fully capture the structure. Overall, however, the usability for production calculation is high.

The carbon indicator (C) can be calculated with acceptable accuracy, as the stock and species composition are sufficiently well recorded in the FMP. However, significant uncertainties arise from the lack of data on dead wood, litterfall and soil carbon, which must be replaced by empirical coefficients. Similar limitations are noted in global carbon stock assessments (Forest Carbon Stocks Indicator, 2022). The absence of data on mortality between inventory cycles further reduces the accuracy of dynamic carbon balances. For this reason, usability can be rated as medium to high, but with an emphasis on careful interpretation of the results.

The erosion loss indicator (E) highlights a critical limitation of LHP/LHO data. While stand-level information can be used to estimate the vegetation factor $C_{f,}$ essential USLE parameters such as rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), and the management factor (P) are absent. This gap has been documented in Turkish forest planning, where simplified USLE models required integration with external GIS and climatic datasets (Başkent & Keleş, 2009; OGM, 2014). Comparable challenges have been reported in Europe, where site-specific calibration of USLE parameters is necessary for reliable erosion risk assessment (Panagos et al., 2015; Bosco et al., 2015). Thus, FMP data must be combined with external spatial layers to quantify erosion losses effectively.The biodiversity indicator (RAFL) can be partially derived from FMP data, particularly species composition, stand age, and the extent of older stands. However, the absence of detailed structural parameters such as vertical stratification, height heterogeneity, and diameter distribution reduces accuracy. Research in Central Europe confirms that biodiversity assessments based solely on stand-level inventories capture potential rather than actual ecological value (Mori et al., 2017; Holušová & Holuša, 2025). Supplementary structural inventories or remote sensing are therefore required to improve ecological validity.

The cultural and recreational services indicator (KUL) is least compatible with FMP data. Forest management plans do not record road networks, recreational infrastructure, landscape attractiveness, or visitor numbers. Evidence from Czech and European studies shows that cultural ecosystem services require integration of external datasets such as digital terrain models, transport infrastructure maps, and mobile data on visitor flows (Purwestri et al., 2023b; Plieninger et al., 2013). Without these inputs, the direct usability of FMP data for cultural service assessment remains low.

The Composite Sustainability Index (CIU) depends directly on the quality of its sub-indicators. While production and carbon indicators are well supported, uncertainties in ecological and cultural indicators significantly affect accuracy. Similar findings have been reported in hybrid MCDA applications, where incomplete ecological datasets introduced variability in sustainability scores (Uhde et al., 2015; Nilsson et al., 2016). Without linking FMP data to external sources, CIU values risk considerable variability and reduced reliability. Overall, it can be said that LHP/LHO provide a solid basis for modelling production functions and selected regulatory services, but their usability is limited by the absence of structural, environmental and cultural data. For a comprehensive assessment of ecosystem services, it is therefore necessary to systematically supplement LHP/LHO with external GIS layers, inventory data and information on recreational use of forests. Only such integration will enable the creation of a methodologically robust and spatially accurate assessment of ecosystem services within forest management planning frameworks (Başkent, 2018; Holušová & Holuša, 2025).

Conclusion

The presented MCDA framework with P, C, E, RAFL, KUL indicators and the CIU composite index is a practical tool for integrating ecosystem services into FMPs/FMPOs. It allows for transparent and quantitative comparison of management scenarios, highlighting trade-offs between production, regulatory, ecological, and cultural functions. Pilot testing in model LHCs demonstrates its feasibility and provides a foundation for broader application in Czech forestry practice. Its inclusion in forest management methodologies would strengthen multifunctional planning, enhance stakeholder participation, and align national forestry approaches with contemporary sustainability objectives. Future refinement should focus on improving ecological and cultural indicators, integrating advanced spatial datasets, and expanding participatory processes to ensure legitimacy and acceptance. Ultimately, the framework establishes a robust basis for advancing sustainable, multifunctional forest management in the Czech Republic and offers a transferable model for other European contexts.

References

Ananda, J., & Herath, G. (2009). A critical review of multi-criteria decision making methods with special reference to forest management and planning. *Ecological economics*, *68*(10), 2535-2548.

Başkent, E. Z. (2018). A review of the development of the multiple use forest management planning concept. *International Forestry Review*, *20*(3), 296-313.

Başkent, E.Z. (2020). A framework for characterizing and regulating ecosystem services in a management planning context. *Forests*, *11*(1), 102.

Baskent, E. Z., & Keleş, S. (2009). Developing alternative forest management planning strategies incorporating timber, water and carbon values: an examination of their interactions. Environmental Modeling & Assessment, 14(4), 467-480.

Baskent, E. Z., Terzioğlu, S., & Başkaya, Ş. (2008). Developing and implementing multiple-use forest management planning in Turkey. *Environmental management*, *42*(1), 37-48.

Bosco, C., de Rigo, D., Dewitte, O., Poesen, J., & Panagos, P. (2015). Modelling soil erosion at European scale: towards harmonization and reproducibility. *Natural Hazards and Earth System Sciences*, *15*(2), 225-245.

Drábková, A., & Šišák, L. (2013). Forest visitors' opinion of recreational facilities and trails in forests in the Blaník Protected Landscape Area-a case study.

Eroglu, M., Başkent, E.Z. (2019). Estimating soil erosion under different forest management strategies using USLE integrated with MCDA. Environmental Monitoring and Assessment.

Fontana, V., Radtke, A., Fedrigotti, V. B., Tappeiner, U., Tasser, E., Zerbe, S., & Buchholz, T. (2013). Comparing land-use alternatives: Using the ecosystem services concept to define a multi-criteria decision analysis. Ecological Economics, 93, 128-136.

General Directorate of Forestry (OGM). (2014). National erosion mapping and USLE parameter manual. Ankara, Turkey: OGM Publications.

"Forest Carbon Stocks Indicator." Global Forest Review, World Resources Institute, 26 Apr. 2022, https://research.wri.org/gfr/biodiversity-ecological-services-indicators/forest-carbon-stocks.

Hlásny, T., Barcza, Z., Fabrika, M., Balazs, B., Churkina, G., Pajtik, J., ... & Turˇáni, M. (2011). Climate change impacts on growth and carbon balance of forests in Central Europe. Climate Research, 47, 219-236.

Hölting, L., Komossa, F., Filyushkina, A., Gastinger, M. M., Verburg, P. H., Beckmann, M., ... & Cord, A. F. (2020). Including stakeholders' perspectives on ecosystem services in multifunctionality assessments. Ecosystems and People, 16(1), 354-368.

Holušová, K., & Holuša, O. (2025). Assessing the Provision of Ecosystem Services Using Forest Site Classification as a Basis for the Forest Bioeconomy in the Czech Republic. *Forests*, *16*(8), 1242.

Kangas, J., Kangas, A. (2005). Multiple criteria decision support in forest management – the approach, methods applied, experiences gained. Forest Ecology and Management, 207, 133–143.

Kpadé, C. P., Tamini, L. D., Pepin, S., Khasa, D. P., Abbas, Y., & Lamhamedi, M. S. (2024). Evaluating multi-criteria decision-making methods for sustainable management of forest ecosystems: A systematic review. *Forests*, *15*(10), 1728.

Krsnik, G., Reynolds, K. M., Aquilué, N., Mola-Yudego, B., Pecurul-Botines, M., Garcia-Gonzalo, J., & González Olabarria, J. R. (2024). Assessing the dynamics of forest ecosystem services to define forest use suitability: a case study of Pinus sylvestris in Spain. Environmental Sciences Europe, 36(1), 128.

Kurz, W. A., Dymond, C. C., White, T. M., Stinson, G., Shaw, C. H., Rampley, G. J., ... & Apps, M. J. (2009). CBM-CFS3: a model of carbon-dynamics in forestry and land-use change implementing IPCC standards. Ecological modelling, 220(4), 480-504.

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change.

IPCC. (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change.

Marques, M., Reynolds, K. M., Marques, S., Marto, M., Paplanus, S., & Borges, J. G. (2021). A participatory and spatial multicriteria decision approach to prioritize the allocation of ecosystem services to management units. *Land*, *10*(7), 747.

Mendoza, G. A., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *Forest ecology and management*, *230*(1-3), 1-22.

McElhinny, C., Gibbons, P., Brack, C., & Bauhus, J. (2005). Forest and woodland stand structural complexity: its definition and measurement. Forest Ecology and Management, 218(1-3), 1-24.

Mori, A. S., Lertzman, K. P., & Gustafsson, L. (2017). Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. *Journal of Applied Ecology*, *54*(1), 12-27.

Nilsson, H., Nordström, E.-M., & Öhman, K. (2016). Decision support for participatory forest planning using AHP and TOPSIS. Forests, 7(5), 100. https://doi.org/10.3390/f7050100

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., ... & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental science & policy, 54, 438-447.

Paletto, A., Pieratti, E., De Meo, I., Agnelli, A. E., Cantiani, P., Chiavetta, U., ... & Lagomarsino, A. (2021). A multi-criteria analysis of forest restoration strategies to improve the ecosystem services supply: an application in Central Italy. Annals of Forest Science, 78(1), 7.

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. Land use policy, 33, 118-129.

Purwestri, R. C., Hochmalová, M., Hájek, M., Palátová, P., Jarský, V., Huertas-Bernal, D. C., ... & Riedl, M. (2023). From recreational to income-generating opportunities: assessment of public preferences for non-wood forest products in the Czech Republic. Frontiers in Nutrition, 10, 1193203.

Purwestri, R. C., Palátová, P., Hájek, M., Dudík, R., Jarský, V., & Riedl, M. (2023). Public perception of the performance of Czech forest ecosystem services. *Environmental Sciences Europe*, *35*(1), 89.

Pretzsch, H. (2009). Forest dynamics, growth, and yield: From measurement to model. Berlin: Springer.

Pretzsch, H., & Zenner, E. K. (2017). Toward managing mixed-species stands: from parametrization to prescription. Forest Ecosystems, 4(1), 19.

Somogyi, Z., Teobaldelli, M., Federici, S., Matteucci, G., Pagliari, V., Grassi, G., & Seufert, G. (2008). Allometric biomass and carbon factors database. iforest-Biogeosciences and Forestry, 1(3), 107.

Tyrväinen, L., Buchecker, M., Degenhardt, B., & Vuletic, D. (2009). Evaluating the economic and social benefits of forest recreation and nature tourism. In European forest recreation and tourism (pp. 59-87). Taylor & Francis.

Uhde, B., Andreas Hahn, W., Griess, V. C., & Knoke, T. (2015). Hybrid MCDA methods to integrate multiple ecosystem services in forest management planning: a critical review. Environmental management, 56(2), 373-388.

Vacek, S., Vacek, Z., Kalousková, I., Cukor, J., Bílek, L., Moser, W. K., ... & Řeháček, D. (2018). Sycamore maple (Acer pseudoplatanus L.) stands on former agricultural land in the Sudetes–evaluation of ecological value and production potential. Dendrobiology, (79), 61-76.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. USDA Agriculture Handbook No. 537.