FORESTRY STUDIES: EVALUATIONS FROM ECONOMIC, POLITICAL AND TECHNICAL PERSPECTIVES

Editors
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Chapter 1

Green Taxation Approaches in Forestry: Policy Perspectives for Türkiye

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Taxation can be defined as a mandatory financial obligation imposed by the state, based on its sovereign power, on individuals and legal entities without compensation, for the financing of public services. As the structure of economies and social needs changes, tax systems have also evolved. With the deepening of environmental problems, a new generation of financial instruments called green taxes has gained importance. Green taxes are a form of taxation designed to mitigate the environmental externalities resulting from anthropogenic activities. These taxes aim to reflect the social costs imposed on society by polluting entities in the form of prices, thereby incentivising behavioural change among economic actors. In this regard, scholars have demonstrated that they internalise environmental policy objectives alongside conventional fiscal objectives (OECD, 2023; European Commission, 2021).

Green taxes are a form of financial instrument that increases the cost of products or services with proven harmful environmental impacts. The purpose of this increase is to reduce consumption, thereby making public revenue available for environmentally friendly investments. These taxes have been shown to internalise negative externalities, correct market failures, encourage the adoption of environmentally friendly technologies, and contribute to the financing of ecosystem services (Ballet et al., 2007; İnan, 2023).

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The transition to a green tax approach directly reflects the acceleration of environmental degradation on a global scale. Since the 1960s, growth-oriented economic models have intensified crises such as excessive consumption of natural resources, biodiversity loss, and climate change. During the 1990s, European policymakers institutionalized environmental taxes and expanded carbon taxes and Emission Trading Systems, thereby accelerating the shift toward market-based instruments. The 2008 global financial crisis fostered strong awareness that economic recovery could only occur through environmental sustainability; consequently, sustainable development, green economy, and green finance have become the core axis of policy literature. In this context, fiscal authorities employ taxes, incentives, and public expenditures as critical instruments to guide environmentally friendly investments (Ağcakaya & Kaya, 2022).

The conventional growth model's structure, which consumes natural capital and disrupts ecological balance, along with the mounting environmental risks associated with climate change, underscores the imperative for a sustainable economic order, constituting the fundamental rationale for this transformation (Ağcakaya & Kaya, 2022). The green economy offers a development perspective that conserves resources, mitigates environmental risks, and ensures long-term sustainability and prosperity. Fiscal policy constitutes the most potent application area of this process. Governments employ a range of economic instruments, including taxes, incentives, and public spending, to internalise externalities and steer economic actors toward environmentally beneficial activities. Consequently, green taxation emerges as a pivotal policy instrument, playing a crucial role in safeguarding the environment while facilitating the implementation of sustainable development strategies.

The Importance of Green Taxation in Forestry

The worsening global climate crisis has compelled policymakers to integrate environmental policies into fiscal systems (World Bank, 2022). Since the 1990s, scholars have established green taxation as a specialised area within fiscal science (OECD, 2021a). By incorporating environmental externalities, researchers have positioned green taxation as a dual-purpose tool that advances both environmental and fiscal objectives (OECD, 2021a; World Bank, 2022). Tax economists design environmental taxes in accordance with the “polluter pays” principle, enabling governments to raise revenue while encouraging sustainable practices in production and consumption (OECD, 2021b). Consequently, experts argue that aligning fiscal instruments with environmental policies forms a cornerstone of low-carbon development strategies (OECD, 2021b; World Bank, 2022).

The forestry sector occupies a pivotal role within this integrated framework. Forests serve as natural carbon sinks, thereby helping to slow climate change. Additionally, they regulate the water cycle, preserve biodiversity, and reduce erosion (Aydın et al., 2018; Baç & Güneş Şen, 2025). However, the evaluation of forestry is frequently constrained to the assessment of timber production and the generation of raw material revenues. Consequently, the ecosystem services provided by forests remain inadequately visible through financial instruments. However, the utilisation of carbon markets, payments for ecosystem services (PES), and green fund mechanisms has emerged as a pivotal strategy for forestry to generate high added value, both environmentally and socioeconomically (Şen et al., 2019).

In the context of forestry, scholars identify three key mechanisms that enhance the importance of green taxation.

- Policymakers increase the financial attractiveness of carbon sequestration and reduction projects by implementing carbon pricing mechanisms, such as the Emissions Trading Scheme (ETS) and the carbon tax.
- Governments and environmental agencies recognise and acknowledge the economic value of forest services by providing payments for ecosystem services (PES).
- Fiscal authorities encourage the adoption of low-carbon production methods and environmentally friendly technologies by allocating financial resources through green funds and offering tax incentives.

This three-pronged approach ensures the integration of fiscal policies with the sustainable transformation of the forestry sector. However, since the distributional effects of carbon taxes may impose disproportionate burdens on low-income groups, the principles of income recycling—through refunds, transfers, or reductions in other taxes—are critical for achieving social acceptance (Cronin et al., 2017; European Court of Auditors, 2021). In Türkiye, a balanced reallocation of tax burdens from labor to pollution, combined with the earmarking of environmental revenues through dedicated funds, emerges as a complementary measure that would enhance overall effectiveness (Doğan, 2023).

International practices demonstrate that green taxation in forestry delivers not only ecological but also socio-economic benefits. For instance, Costa Rica has dramatically reduced deforestation by channelling revenues from fossil fuel taxes to forest owners through the PES system. Scandinavian countries have utilised carbon tax revenues to support the green transformation of industry, thereby reducing carbon intensity; meanwhile, the European Union has integrated carbon storage activities into the financial system through the Carbon Removals and Carbon Farming Certification Framework (CRCF). These examples demonstrate that aligning fiscal instruments with environmental governance yields robust policy outcomes. Similarly, “green fee” models implemented in tourism (Hawaii, Bali, New Zealand) are noteworthy for directing revenues toward nature conservation and infrastructure projects (Uyar Oğuz, 2025).

In Türkiye, the development of green taxation mechanisms has accelerated in recent years; however, their integration with forestry remains limited. The Climate Law and the national ETS, scheduled to take effect in 2025, represent a significant step toward incorporating carbon pricing into the Turkish economy. Nevertheless, institutional harmonisation is required to design these mechanisms in a way that finances forestry projects effectively. Tax incentives for forest villagers, ecosystem service funds, and local carbon projects have yet to be structured systematically, creating a critical policy gap for both climate targets and rural development.

Türkiye’s green economy performance further confirms this need. According to the Global Green Economy Index (GGEI) 2022, Türkiye ranks last among OECD countries, with a score of 0.399, whereas Sweden leads with a score of 0.799 (Ağcakaya & Kaya, 2022; Dual Citizen LLC, 2025). This finding underscores the urgency of aligning fiscal instruments with environmental objectives.

Green taxes are Pigovian fiscal instruments that incorporate environmental externalities into prices. When environmental costs resulting from production and consumption decisions (e.g., carbon emissions, habitat degradation) are internalised through taxation, resource allocation improves in favour of social welfare. Given the global public good nature of the environment (non-rival and non-excludable benefits), regional and global coordination is as crucial as national-level green taxes (Baumol & Oates, 1988; OECD, 2024a). Within this framework, green taxation serves not only to reduce carbon emissions but also as a fundamental policy tool for preserving natural capital and sustaining ecosystem services (Aydin et al., 2019).

Theoretical Framework: Economic and Fiscal Foundations of Green Taxation

Green taxation is one of the fundamental fiscal instruments designed to incorporate environmental externalities into the economic system. Environmental taxes play a crucial role in both financing climate policies and reducing activities that negatively impact the environment (OECD, 2024a; UNEP, 2022). From the forestry sector's perspective, these taxes provide an essential fiscal framework for preserving carbon sinks, ensuring the sustainability of ecosystem services, safeguarding biodiversity, and strengthening natural capital. Thus, green taxation in forestry evolves into a comprehensive policy tool that supports the financing of environmental public goods (Almansouri et al., 2020).

The scope of green taxes encompasses carbon taxes, energy taxes (on fuel and electricity consumption), pollution and waste taxes, water usage taxes, and transport-related levies. The objective is to increase the cost of harmful activities while making environmentally friendly alternatives-such as sustainable forest products and low-emission logistics-economically attractive (UNEP, 2022; OECD, 2024a).

Externalities and Market Failure

An externality occurs when an economic activity imposes costs or benefits on third parties without these effects being reflected in market prices. Consequently, environmental externalities lead to a failure of the market mechanism to achieve socially optimal resource allocation (Baumol & Oates, 1988). Public intervention addresses this failure through instruments such as taxes, subsidies, funding mechanisms, and regulatory standards (Stiglitz, 2019).

In the context of forestry, externalities manifest in both negative and positive forms. Illegal logging, soil erosion, land degradation, and habitat loss generate negative externalities. Conversely, carbon sequestration, regulation of the water cycle, soil conservation, and biodiversity enhancement create positive externalities (IPCC, 2022; Güneş Şen & Aydın, 2024; Çiloğlu & Güneş Şen, 2025). Therefore, forestry policies require financial instruments that incorporate both punitive and incentivising features.

Pigouvian Tax, Coase Theorem, and Modern Approaches

The theoretical foundation of environmental taxation is based on Pigou's (1920) approach to internalising externalities through fiscal instruments. A Pigouvian tax aims to reflect the social cost of activities that harm the environment. For instance, taxing high-emission production processes or imposing additional financial burdens on activities that cause forest degradation falls within this framework (Stern, 2006). Green taxes not only generate fiscal revenue but also encourage environmentally responsible behaviour among individuals and businesses; they reduce harmful activities by increasing their costs (İnan, 2023). The OECD framework structures this approach around four pillars: institutional arrangements, methods and instruments, accountability, and enabling environment (OECD, 2020).

Conversely, some perspectives argue that when property rights are clearly defined, parties can resolve externalities through bargaining (Coase, 1960). However, in forestry, the public nature of resources, the collective benefit dimension, and the complexity of ownership structures limit the applicability of Coasean solutions (Hanley et al., 2007; Perman et al., 2011). Therefore, Pigouvian fiscal instruments are generally more effective in the forestry sector.

Modern climate economics literature has advanced this theoretical framework. Nordhaus (2014) integrated carbon taxation with the concept of the 'social cost of carbon,' making the economic cost of climate change measurable, while Stern (2006) emphasised that carbon pricing cannot be effective without public intervention. Pairing Pigouvian taxation with incentive policies enables the simultaneous operation of a punitive signal that prices negative externalities and a supportive signal that makes green investment attractive. At the firm level, reputation, sales, and performance channels reinforce this combination (OECD, 1992; Durmuş & Arslan, 2023). Such fiscal and financial incentives not only enhance environmental performance but also play a pivotal role in economic transformation processes (UNEP, 2011; World Bank, 2020).

The Türkiye-focused framework defines the concept of green taxation as a tax that bases its assessment on a physical unit scientifically proven to have a negative impact on the environment. Current practices, such as the Special Consumption Tax (ÖTV) and Motor Vehicle Tax (MTV) applied to fuel and vehicles, have only limited effects on behavioural change; thus, a transition to an emission-based tax base and rate structure is emphasised as necessary (Olcay, 2024).

The Evolution of Fiscal Instruments in Environmental Policy

In the literature, green taxes are referred to as 'environmental taxes,' 'eco-taxes,' or 'green taxes,' and their primary function is to reduce negative externalities by incorporating the economic cost of environmentally harmful activities into prices. The theoretical foundation of this approach is based on Pigou's (2017) model, which argues that externalities should be internalised through taxation. Subsequently, this mechanism was expanded within the environmental economics literature, embedding the idea that producers or consumers should bear the social costs of environmental pollution at the core of modern environmental tax policies (Baumol & Oates, 1988).

Studies conducted in Türkiye define green taxes as fiscal instruments aimed at reducing environmental pollution; however, they emphasize that most existing taxes serve budgetary revenue rather than environmental objectives (Özkanca Andıç & Akça, 2019). Therefore, for green taxes to be functional, they must be designed in alignment with the Pigouvian fiscal framework and generate a strong price signal that incentivizes environmental behavioral change.

Since the 1990s, environmental taxes in Europe have been embedded within a strong institutional framework. Sweden, Norway, and Finland are pioneers of carbon taxation (OECD, 2021; Mideksa, 2024; OECD, 2024b). In these countries, carbon tax revenues are allocated to low-carbon production, the use of renewable raw materials, and the green transformation of the forest industry. The impact of these policies is also evident in consumer behaviour: consumers in the forest products sector prioritise environmental sensitivity and, within their economic constraints, support green marketing efforts and environmentally friendly products (Bayram & Üçüncü, 2022). According to the World Bank's Carbon Pricing Dashboard, as of 2024, 73 countries implement either a carbon tax or an ETS (World Bank, 2024). This finding demonstrates that green taxation has evolved into a mainstream policy instrument on a global scale.

Fiscal instruments related to forestry can be categorized into three groups:

1. Direct emission taxes (e.g., carbon tax, energy taxes)
2. Resource use and product taxes (e.g., timber, paper, waste management)
3. Payments for ecosystem services (PES) and environmental service charges

This model creates a significant impact when governments direct tax revenues toward ecosystem services. The table below categorises the primary fiscal instruments used in the forestry sector, explaining their functions and how they connect to forestry.

Table 1. Classification of Fiscal Instruments Used in Forestry

Instrument Type	Primary Function	Relation to Forestry	Application Example	Expected Impact	Source
Carbon Tax / ETS	Carbon pricing for emission reduction	Enhancing forests' carbon sink capacity, carbon credit generation and fund allocation	Sweden carbon tax, EU ETS	Reduction in emissions, development of carbon markets	OECD (2024a); World Bank (2024)
PES (Payments for Ecosystem Services)	Making ecosystem services economically visible	Payments for carbon, water, and biodiversity to forest owners and villagers	Costa Rica PES model	Reduction in deforestation, increase in local income	FAO (2023); UNEP (2022)
Green Funds and Grants	Providing financing for low-carbon investments	Grant support for carbon removal and ecosystem service projects	EU LIFE fund, GCF support	Reduction in investment costs, green innovation	UNEP (2022); FAO (2023)
Tax Incentives (VAT reduction, depreciation, etc.)	Encouraging environmentally friendly production and renewable raw material use	Sustainable forest products, use of wood materials, circular economy practices	Germany green depreciation, Sweden incentives	Increase in sustainable production, improved competitiveness	OECD (2024a); Durmuş & Arslan (2023)

When these instruments are considered collectively, they lay the foundation for a multidimensional and integrated green fiscal system for the forestry sector. However, the effective functioning of this system requires strong institutional coordination among finance, environment, and forestry authorities; regular and transparent monitoring of data related to ecosystem services; and, particularly, the institutionalisation of revenue allocation mechanisms at the local level (World Bank, 2024). Such a structure enables both the enhancement of carbon sink capacity and the redistribution of revenues generated from ecosystem services in favour of forest villagers and local communities.

The predominant factor contributing to the escalation in environmental taxes is the increasing incongruity between economic structures and ecological sustainability. The contemporary economic order is becoming increasingly fragile due to the interrelated challenges of climate change, resource depletion, and social inequalities. Consequently, the establishment of an economically viable and ecologically sustainable structure is contingent upon the transformation of fiscal policies (Ağcakaya & Kaya, 2022). This assessment demonstrates that the carbon tax and ETS applications, which gained momentum in Europe after the 1990s, represent not only a technical but also a structural policy transformation.

Sustainable Development, Green Fiscal Policy, and Institutional Integration

Green taxation constitutes one of the key economic instruments for sustainable development. The Brundtland Report (1987) and the United Nations Sustainable Development Goals (SDGs) emphasize the role of fiscal tools in safeguarding environmental public goods. In particular, SDG 13 (Climate Action) and SDG 15 (Life on Land) are directly linked to forestry. UNEP's (2022) "Green Finance" approach advocates aligning public budgets and tax systems with environmentally friendly investments. Türkiye's Climate Law of 2025 and preparations for an Emissions Trading System (ETS) reflect this orientation. However, the integration between forestry and fiscal policies remains incomplete. Achieving this integration is critical for enhancing carbon sink capacity and ensuring sustainable financing of ecosystem services. To achieve sustainable development, it is essential to implement a management strategy grounded in the principles of sustainability (Bayram, 2021).

International Experiences and Lessons Learned

Green taxation and carbon pricing mechanisms have produced effective outcomes in aligning environmental objectives with fiscal instruments across many countries. In particular, international practices offer valuable lessons for the forestry sector regarding the financing of ecosystem services, carbon removal, and the development of low-carbon production systems. This section examines examples from Costa Rica, the Nordic countries, and the European Union, and summarises key implications for Türkiye.

Costa Rica: The Payment for Environmental Services (PES) Model

Costa Rica has developed one of the most successful global models for financing ecosystem services in the forestry sector. Established under the 1997 Law on Forestry No. 7575, the Payment for Environmental Services (PES) system channels revenues from fossil fuel taxes, water usage fees, and hydromechanical energy into payments for forest owners and local communities (FAO, 2004).

The core principle of the model is "nature provides services, users pay." Forest owners who deliver ecosystem services such as carbon sequestration, watershed protection, biodiversity conservation, and recreation receive direct payments based on the environmental benefits they generate. According to World Bank (2024) data, the system's funding comes from fuel consumption taxes, water usage charges, and environmental funds. The program has also strengthened income stability for rural communities.

Implications for Türkiye:

- Allocating a portion of fossil fuel tax revenues to forest and carbon removal projects is feasible.
- Directly involving forest villagers in the financial process represents a powerful instrument for social sustainability.

Therefore, channelling part of the revenues generated from Türkiye's Emissions Trading System (ETS) into structures such as the National Forest Carbon and Ecosystem Services Fund (OKEHF) constitutes a key policy lesson derived from Costa Rica's experience.

Nordic Countries: Carbon Pricing and Industrial Integration

The Nordic countries have pioneered practices in green taxation, carbon pricing, and the integration of sustainable production. Sweden introduced the world's first comprehensive carbon tax in 1991, and by 2024 the tax rate had reached 130 USD per ton (Government Offices of Sweden, 2023). The Swedish experience demonstrates the importance of partially recycling carbon tax revenues through reductions in other taxes or social transfers, as this approach enhances both efficiency and public acceptance (Hildingsson & Knaggård, 2022).

Three Notable Features of the Nordic Model

i. Industrial Integration: Research and development support, tax reductions, and incentives are implemented for the forest products sector to promote sustainable production.

ii. Public Procurement: In Sweden, low-carbon wooden construction materials receive priority in public tenders.

iii. Circular Economy Linkage: Life cycle assessments (LCA) have been made mandatory for wood-based products, and a market focused on carbon footprint has emerged (European Commission, 2024).

Implications for Türkiye;

- Coordinating carbon pricing with industrial policies can accelerate the transition to green production.
- Green public procurement can steer domestic demand toward environmentally friendly products and services.

- Allocating carbon tax and ETS revenues to investments in the circular economy can enhance competitiveness.

European Union: Carbon Removal and the Carbon Farming Certification Framework (CRCF)

In 2024, the European Union standardised the certification of carbon removal through the Carbon Farming Certification Framework (CRCF) (European Commission, 2024). This framework encompasses both nature-based and product-based carbon storage, with forests and wood products playing a central role in the system.

Implications for Türkiye

- During the transition to ETS, a national certification mechanism aligned with the CRCF should be developed.
- Measuring the carbon storage capacity of wooden construction materials can provide a competitive advantage in exports.
- A system focused on the measurement, reporting, and verification (MRV) of carbon sinks will facilitate Türkiye's compliance with the Carbon Border Adjustment Mechanism (CBAM).

Common Lessons Derived from International Experiences

When the cases of Costa Rica, the Nordic countries, and the European Union are considered together, four essential conditions emerge for the successful implementation of green taxation policies in forestry. These conditions represent critical factors that determine both the alignment of fiscal policies with environmental objectives and the institutional capacity of the forestry sector. The table below summarises these conditions.

Table 2. Key Conditions for the Success of Green Taxation in Forestry

Condition	Description	Example of Implementation	Implication for Türkiye
Revenue Allocation Mechanism	Direct allocation of revenues from environmental taxes to environmental and forestry funds (FAO, 2023; UNEP, 2022)	Costa Rica: Fossil fuel tax revenues → PES fund	Allocation of ETS and energy tax revenues to the Forest Carbon and Ecosystem Services Fund
Institutional Integration	Regular coordination and joint strategy development among finance, environment, and forestry institutions (Government Offices of Sweden, 2023)	Finland: Collaboration between Ministry of Energy and Forest Agency	Establishment of a Green Finance Coordination Board among Treasury, Ministry of Environment, Urbanization and Climate Change (ÇŞİDB), and General Directorate of Forestry (GDF)
Market Infrastructure	Existence of market mechanisms such as carbon trading, certification, and MRV (measurement, reporting, verification) systems (European Commission, 2024)	EU: CRCF and ETS system	Harmonization of national carbon certification system and MRV infrastructure with ETS
Social Inclusiveness	Active participation of local communities, forest villagers, and small producers in financial processes (FAO, 2023; UNEP, 2022)	Costa Rica & Sweden: Community-based forest management	Income increase and social acceptance through PES-like payment systems for forest villagers

When we examine these four conditions together, we see that countries need to develop not only fiscal instruments but also institutional governance, market mechanisms, and social inclusiveness in an integrated manner. A lack of revenue allocation mechanisms undermines the effectiveness of fiscal tools; insufficient institutional integration fragments policies; missing market infrastructure renders carbon pricing ineffective; and neglecting social inclusiveness jeopardizes local acceptance and sustainability. In this context, governments can strengthen social inclusiveness by directing eco-tax revenues from tourism to local projects under a similar logic (Uyar Oğuz, 2025). Furthermore, green budgeting and green labeling improve implementation effectiveness by enabling transparent monitoring of environmental expenditures and institutionalizing the alignment of revenues with allocations (OECD, 2023; European Commission, 2021).

Redirecting ETS revenues to green funds, strengthening inter-institutional coordination, developing carbon certification infrastructure, and integrating forest villagers into financial mechanisms are imperative.

Current Status of Forestry and Green Taxation in Türkiye

Although Türkiye has taken significant steps in environmental taxation and climate finance in recent years, structural integration between the forestry sector and fiscal policies remains limited. The Climate Law, enacted in 2025, established a formal framework for carbon pricing and the Emissions Trading System (ETS); however, linking these mechanisms directly to the forestry sector has been limited in practice so far. To achieve Türkiye's net-zero target, strengthening the carbon sink capacity of forests is essential, and designing fiscal policies with a forestry focus is therefore of critical importance.

From a green budgeting perspective, Türkiye's environmental protection expenditures reached approximately 40 billion TL in 2020, with a GDP share of 0.8%, slightly below the EU average of 0.9%. The expenditure composition is as follows: 54.4% for waste management, 31.4% for wastewater, 4.3% for biodiversity/landscape, 3.2% for soil/water quality, and 6.7% for other purposes. This distribution clearly demonstrates the need for instruments that strengthen the institutional allocation of green tax revenues to environmental protection—such as the National Forest Carbon and Ecosystem Services Fund (OKEHF) (Ağcakaya & Kaya, 2022; TÜİK, 2021).

Legislation and Institutional Framework

Forestry policies in Türkiye have maintained a long-standing structure, and the General Directorate of Forestry (GDF) and the Ministry of Agriculture and Forestry coordinate their implementation. However, institutions still fail to achieve strong coordination in integrating environmental, fiscal, and forestry policies. The Ministry of Treasury and Finance, the Ministry of Environment, Urbanisation and Climate Change (ÇŞİDB), and GDF have not established a permanent mechanism for jointly designing green financial instruments.

Law No. 5491, enacted in 2006, introduced the "polluter pays" principle into legislation (Official Gazette, 2006). Nevertheless, this regulation has had an indirect influence on the forestry sector.

General Overview of the Green Tax System in Türkiye

In Türkiye, environmentally related taxes are applied broadly through indirect taxes, and in most cases, environmental protection remains a secondary objective. According to OECD (2024a) data, the share of environmental taxes in Türkiye's GDP is approximately 2.5%, with more than 90% originating from energy taxes (fuel, electricity, motor vehicles). This situation indicates that the scope of environmental taxes is limited and heavily energy-oriented. The central taxes that can be classified under green taxation include the Environmental Cleaning Tax (ÇTV), the Motor Vehicle Tax (MTV), and the Special Consumption Tax (ÖTV) on energy products. However, the design features of these taxes fall short of encouraging behavioural changes toward environmental sustainability (Özkanca Andıç & Akça, 2019).

Design Problems of Existing Taxes

- Environmental Cleaning Tax (ÇTV): The tax base relies on water consumption and building categories rather than waste quantity; therefore, it does not generate a price signal directly linked to environmental pollution.
- Motor Vehicle Tax (MTV): It is based on engine size and vehicle age, differing from a CO_2 emissions-based taxation model; as a result, its impact on carbon reduction remains limited (Kaplan, 2012).
- Special Consumption Tax (ÖTV): Applied to energy products; however, specific high-emission sectors (e.g., aviation jet fuel) are exempt, and chemical waste is not taxed (Gündüz, 2013).

These findings suggest that Türkiye's current tax structure prioritises revenue generation over serving as an effective instrument to mitigate environmental externalities.

Existing Fiscal Instruments Related to Forestry

- VAT withholding (rate reduction): Encourages registered production but is not conditional on environmental performance.
- Withholding tax (2–4%): Supports registered sales by forest villagers but does not link to sustainable production.
- Recreation and water service fees: Align with the "user pays" principle but lack adequate local allocation mechanisms.
- GDF revolving funds and special funds: Have a limited revenue structure and do not directly qualify as green financing instruments.

According to FAO (2023) assessments, effective green taxation in forestry requires channelling tax revenues toward ecosystem services, establishing transfer mechanisms for local stakeholders, and integrating carbon pricing systems with forestry. However, Türkiye's green tax system remains indirect, fragmented, and weak in institutional integration with respect to forestry. Therefore, conditioning carbon pricing and environmental taxes on forestry objectives is a fundamental requirement for accelerating the green transition.

The effectiveness of green taxation policies depends on aligning all components of fiscal policy with environmental objectives. To reduce environmental externalities, taxes, incentives, and public expenditures must be designed within a common policy framework (OECD, 2011; 2017). Foundational studies on the green economy approach (Quality of Life Policy Group, 2007) emphasise that environmentally friendly production processes can only become widespread through the guiding influence of fiscal instruments. In this context, eliminating fossil fuel subsidies, introducing tax reductions for low-carbon technologies, and making polluting activities financially deterrent constitute the core instruments of green finance (UNEP, 2011). Moreover, green growth policies not only enhance environmental performance but also strengthen economic resilience (Bowen & Hepburn, 2014).

For the forestry sector, this integrated fiscal framework is critical for preserving carbon sinks, ensuring sustainable timber production, and financing ecosystem services. Thus, green taxation becomes a multidimensional policy instrument with both environmental and economic significance.

Gap Analysis of Forestry-Related Fiscal Instruments in Türkiye

This analysis aims to reveal the extent to which existing fiscal instruments related to forestry in Türkiye align with environmental objectives. The goal is to identify which instruments integrate with sustainable forestry policies and which remain inadequate in terms of design or implementation. In doing so, the analysis clarifies priority areas for revision for policymakers.

The analysis was conducted based on four key criteria:

(A) Goal Alignment: To what extent does the instrument align with forestry and climate policy objectives?

(B) Price Signal: Does it generate an economic signal that encourages environmental behaviour change?

(C) Revenue Allocation: Are the revenues directly directed toward forestry and ecosystem services?

(D) Institutional Framework: Does the necessary institutional and legal structure exist for implementation?

We conducted the assessment by considering a literature review (OECD, UNEP, FAO reports), Turkish legislation (Climate Law, GDF Communiqués), and international examples (Costa Rica's PES, EU ETS). We evaluated each instrument against the four criteria using the following symbols: ✔ Compliant (the instrument's design directly supports climate/environmental objectives), ◐ Partial (the instrument is related to the sector but does not fully align with sustainability, carbon, or ecosystem service metrics), ✖ Insufficient (does not create an environmental price signal or fails to serve forestry objectives), and ? Uncertain (we cannot assess the allocation of ETS revenues because secondary legislation will determine it). We added justifications to the table and summarised the analysis results in the table below.

Table 3. Gap Analysis of Forestry-Related Tax and Financing Instruments in Türkiye

Instrument / Regulation	A	B	C	D	Justification	Implication for Türkiye	Source
VAT Withholding (Forest Products)	◐	✖	✖	◐	Supports registered production; however, it lacks environmental performance or sustainability criteria.	Link withholding rates to sustainable production certification.	Durmuş & Arslan (2023); OECD (2023)
Withholding Tax (Payments to Forest Villagers)	◐	✖	✖	◐	Encourages registered sales; but lacks sustainability conditions and connection to environmental goals.	Differentiate withholding rates based on sustainable harvesting practices.	FAO (2023); UNEP (2022)
GDF Communiqués (Art. 31–35)	◐	✖	✖	✔	Strong institutional framework; however, no pricing based on carbon, biodiversity, or climate metrics.	Add carbon and ecosystem service metrics to the communiqués.	OGM (2023); OECD (2024a)
ETS (Climate Law, 2025)	✔	✔	?	◐	Carbon pricing is strong; however, allocation of ETS revenues to forestry is not regulated.	Redirect ETS revenues to the Forest Carbon and Ecosystem Services Fund.	OECD (2024a); World Bank (2024)
Water / Recreation Service Fee (PES)	✔	✔	◐	◐	Applies the “user pays” principle; but local allocation mechanisms are limited.	Establish watershed-based PES tariffs and local revenue allocation mechanisms.	FAO (2023); UNEP (2022)

This table clearly illustrates which instruments require revision to strengthen the integration of forestry and green fiscal policies in Türkiye. The gap is particularly evident in the revenue allocation (C) criterion. Directing a specific share of revenues generated through the ETS system to forestry and carbon sink projects represents a strategic step to close this gap.

Policy Solutions for Identified Gaps

The table below summarises policy solutions that address gaps in tax and financing instruments related to forestry in Türkiye. These solutions aim to align the environmental performance of existing fiscal instruments and establish new financing mechanisms to enhance environmental sustainability. Policymakers should incorporate green tagging and performance indicators into budgetary processes. At the firm level, companies should link tax incentives to green product design, R&D, and recycling investments (OECD, 2023; Durmuş & Arslan, 2023).

Table 4. Policy Solutions for Green Tax Gaps in Forestry

Gap	Policy Instrument / Design Parameter	Expected Impact	Priority for Türkiye	Source
Absence of environmental conditionality in withholding taxes	Apply reduced withholding rates for producers with sustainable production certification; impose higher rates on those failing to meet sustainability criteria	Reduction in informal practices; accelerated transition to sustainable harvesting	Short-term feasibility (2025–2026)	Durmuş & Arslan (2023); OECD (2023)
Lack of allocation of ETS revenues to forestry	Establish a National Forest Carbon and Ecosystem Services Fund (OKEHF); legally earmark a fixed share (%X) of ETS revenues	Permanent financing for forestry; improvements in carbon sequestration, biodiversity, and ecosystem service indicators	Critical in the medium term (2026–2028)	OECD (2024a); World Bank (2024); FAO (2023)
Non-systematic allocation of water and recreation revenues	Develop watershed-based environmental service fee tariffs; allocate a defined share of revenues to local governments and forest villagers	Strengthened local development; increased awareness of ecosystem services; transparency in watershed management	Short-to-medium-term feasibility (2025–2027)	FAO (2023); UNEP (2022)

Green Taxation and Institutional Coordination Challenges in Türkiye

The most significant barrier to integrating green taxation with the forestry sector in Türkiye is the lack of institutional coordination. Fiscal policies are primarily designed from a revenue stability perspective, while environmental policies operate within their own sectoral dynamics. This disconnect makes it difficult to implement a comprehensive "green fiscal" approach. As a result, the forestry sector's potential role in climate policy remains limited, and tax–fund mechanisms fail to align effectively with environmental objectives.

Strengthening institutional coordination at three levels;

- Strategic level: Establishing a Green Finance and Nature-Based Solutions Council that includes representatives from the Ministry of Treasury and Finance, the Ministry of Environment, Urbanisation and Climate Change, the GDF, and TÜBİTAK can provide the foundation for an integrated governance structure in policy design.

- Implementation level: Joint processes should be developed for allocating ETS revenues, managing PES-like funds, and monitoring local forestry projects.

- Data and monitoring level: Strengthening MRV systems, digital forest records, and GIS integration will ensure evidence-based decision-making.

These recommendations aim not only to transform the forestry sector but also to build a broader green economy architecture. Türkiye's 2053 net-zero target directly depends on the carbon sink capacity of its forests. Policymakers must align tax mechanisms, fund systems, and carbon market instruments with this vision because doing so is both strategically and operationally essential.

Current environmental taxes in Türkiye exhibit significant inconsistencies between their design principles and policy objectives. Authorities apply the Environmental Cleaning Tax (ÇTV), Motor Vehicle Tax (MTV), and Special Consumption Tax (ÖTV) primarily to secure fiscal revenues rather than to induce changes in environmental behaviour. Their base, exemptions, and rate structures severely limit their capacity to reduce externalities (Özkanca Andıç & Akça, 2019). This reality clearly demonstrates why next-generation green fiscal instruments proposed for the forestry sector—such as payments for ecosystem services, carbon-based tax differentiation, carbon-emission-linked pension systems (Şen et al., 2019), and fund mechanisms like OKEHF—are essential. To align Türkiye's green fiscal framework with environmental objectives, policymakers must redesign the tax system to reflect accurate price signals and channel revenues toward environmental priorities.

Future Perspective for Türkiye

Green taxation policies related to forestry in Türkiye still present a fragmented structure, and despite legislative progress, the system requires a comprehensive transformation to function holistically. This transformation should be structured around three key axes:

- Policy Integration: Policymakers must integrate environmental and fiscal policies under a shared sustainability vision and design tax regulations to achieve both ecological and fiscal objectives.

- Mechanistic Integration: Authorities should link ETS revenues, PES payments, and green funds within a unified revenue allocation system to improve resource efficiency and ensure investment continuity.

- Local Participation: Governments must ensure that forest villagers, municipalities, and local producers receive a direct share of green revenue streams to promote social equity and strengthen local ownership in ecosystem service protection. Provincial administrations should consolidate eco-tax practices in tourism under their budgets and allocate these revenues to environmental projects. They should also grant tax exemptions to businesses with Green Star certification to create strong incentives (Uyar Oğuz, 2025).

Green tax revenues in forestry should be allocated to the following areas:

- Combating forest fires and strengthening early warning infrastructure
- Increasing carbon sink capacity through industrial afforestation and natural forest restoration
- Monitoring biodiversity and controlling invasive species
- Supporting producers in obtaining sustainable forest product certifications (FSC/PEFC)

Policy design should consider the “polluter pays” principle together with “revenue neutrality” (maintaining the overall tax burden by offsetting through recycling or other tax reductions) (FAO, 2023; UNEP, 2022).

With Türkiye’s transition to an ETS system, green taxation is becoming not only a component of environmental policy but also a fundamental element of the country’s economic development strategy. In this context, the forestry sector is poised to become a strategic actor in Türkiye’s climate vision, both for increasing carbon sink capacity and for ensuring the effective use of climate finance.

Green Taxation and Sustainable Forest Investments: A Financing Perspective

The success of green taxation policies depends not only on achieving environmental objectives but also on directing investment flows. Within this framework, the forestry sector is evolving beyond its role in carbon sequestration and biodiversity conservation to become one of the financial pillars of the green investment ecosystem. Forest investments aligned with circular economy principles represent a tangible dimension of sustainable development and hold strategic importance for Türkiye’s long-term climate policies.

Empirical evidence (1990–2023) shows that Türkiye’s economic growth remains carbon-intensive and that green economy practices exert only a limited impact on income. This reality underscores the need for policymakers to design carbon pricing and green incentives more effectively (Güleç, 2025).

The Relationship Between Circular Economy and Forestry

The circular economy approach, which promotes resource reuse, minimises waste generation, and designs production processes based on closed-loop principles, aligns strongly with the forestry sector. Wood and its derivatives occupy a central position in the circular economy system due to their renewable and biodegradable nature (European Commission, 2024).

In Türkiye, forests cover approximately 29% of the total land area, and the sustainable management of these resources carries strategic value both environmentally and economically (OGM, 2023). However, a significant share of forestry investments still relies on traditional revenue streams. Investments in areas such as carbon storage, ecosystem services, biomass technologies, and green product innovation remain limited, making financial incentives essential for a transition aligned with circular economy principles.

Although investments in nature-based solutions and ecosystem restoration offer substantial contributions to social welfare, the private sector underfinances these areas (UNEP, 2011). High upfront costs and delayed returns reduce their attractiveness. This reality makes it imperative to support the transformation of the forestry sector through public-backed financial instruments, green taxation, payments for ecosystem services, and carbon-based financing models.

The Role of Green Tax Incentives in Forestry Investments

Green taxation is one of the most effective fiscal policy instruments for directing environmentally friendly investments. For Türkiye, three core incentive approaches stand out as mechanisms to strengthen forestry investments:

(i) Tax Incentives:

- Provide VAT and income/corporate tax reductions for businesses certified under FSC/PEFC standards.
- Grant special tax exemptions to producers using renewable raw materials.
- Include green buildings and the use of environmentally friendly materials within the scope of “green depreciation.”

Empirical evidence suggests that these incentives enhance reputation, drive sales, and strengthen a competitive advantage for enterprises. Researchers also show that matching design with certification criteria significantly increases effectiveness (Durmuş & Arslan, 2023). At the same time, market realities persist: forest product prices fluctuate seasonally, and sales revenues respond to market dynamics (Şen & Güngör, 2018a). Policymakers must incorporate these dynamics when designing green tax incentives to ensure resilience and impact.

(ii) Carbon Finance Integration:

- Use a portion of ETS revenues as a guarantee fund for green investments.
- Allocate resources directly to carbon removal projects.

OECD (2020) studies emphasise that such mechanisms reduce investment costs during the transition to low-carbon production and accelerate innovation.

(iii) Local Incentive Mechanisms:

- Expand payments for ecosystem services (PES) targeting forest villagers and local producers.

Güngör and Şen (2023) analysed sustainable rural development strategies and identified forest-based services such as ecotourism as strategic instruments for enhancing local welfare. They argue that financial mechanisms must support this potential to maximise its impact. FAO (2023) and UNEP (2022) demonstrate that models providing direct financial sharing with local stakeholders strengthen both social equity and environmental sustainability. Fiscal and financial incentives actively drive improvements in environmental performance and play a decisive role in economic transformation processes (UNEP, 2011; World Bank, 2020).

These policies have the potential to transform forestry from a traditional production sector into an innovative, low-carbon, and high-value investment domain. When green taxation promotes investments supporting low-carbon production, the forestry sector will serve as a strategic "bridge sector" that balances economic growth and environmental sustainability.

Strategic Orientations for Türkiye

Green taxation policies integrated with forestry in Türkiye succeed only when policymakers complement legislative development with a comprehensive transformation at the financial, institutional, and local levels. This transformation requires environmental and fiscal authorities to align their policies around a shared vision of sustainability. If they fail to achieve this coherence, the tax system cannot generate strong environmental performance, and incentive mechanisms lose their effectiveness. Policymakers must therefore transform the tax system from a mere fiscal revenue instrument into a strategic policy tool that actively drives environmental behaviour change.

International examples guide this transformation. In Germany, VAT refunds and depreciation advantages for renewable energy investments, in Sweden, carbon taxes and exemptions for renewable fuels, and in the United Kingdom, the Climate Change Levy demonstrate that the coordination of energy/carbon taxes with investment incentives accelerates the transition (Ağcakaya & Kaya, 2022). In Türkiye, the automatic allocation of a portion of ETS revenues to mechanisms similar to the Forest Carbon and Ecosystem Services Fund (OKEHF) could ensure permanent financing for forest-based carbon sequestration and ecosystem service projects.

The effectiveness of green financial instruments depends on integrating ETS, PES, and various green fund mechanisms into a unified revenue allocation structure, rather than applying them in isolation. The OECD (2020) emphasises that environmental fiscal instruments lose their impact without institutional coordination, while the UNEP (2011) underscores the necessity of publicly supported financing models for nature-based solutions. Findings from the World Bank (2020) reveal that financing models based on carbon sinks and ecosystem services strengthen the capacity for low-carbon development. Therefore, in Türkiye, green tax incentives for forest-based carbon projects, building material transformation, and sustainable raw material supply should become integral components of a comprehensive strategy. Industrial afforestation plays a pivotal role in this strategy; Şen and Güngör (2018b) emphasised the importance of the planning process, noting that selecting the most suitable species for industrial plantations optimises both economic and ecological outcomes.

At the local level, enabling forest villagers, municipalities, and local producers to benefit from green revenue streams directly will not only promote social equity but also strengthen local ownership in the conservation of ecosystem services. Payment schemes similar to PES, community-based forestry initiatives, and local carbon projects are among the instruments that can institutionalise this type of participation. Once such a transformation occurs, the forestry sector will become a cornerstone of Türkiye's sustainable development policy by enhancing carbon sink capacity, establishing low-carbon production chains, and increasing national competitiveness in the transition to a green economy. Green taxation will emerge not only as an environmentally friendly fiscal instrument but also as a key component of Türkiye's economic development strategy, aligned with its long-term climate objectives. These orientations are summarised in the table below.

Table 5. Strategic Green Taxation Orientations for Türkiye

Policy Area	Proposed Regulation / Instrument	Expected Outcome	Priority for Türkiye	Source
Tax Incentives	VAT reduction, green depreciation, certified producer support	Lower investment costs; increased private sector participation	Short-term feasibility (2025–2026)	Durmuş & Arslan (2023); OECD (2023)
Carbon Financing	Establishment of a green investment fund from ETS revenues	Increase in carbon storage and low-carbon project numbers	Critical in the medium term (2026–2028)	OECD (2024a); World Bank (2024)
Local Participation	Expansion of PES-like payment systems	Higher income for forest villagers; strengthened sustainable production	Short- to medium-term feasibility (2025–2027)	FAO (2023); UNEP (2022)
Public Procurement	Adoption of green product and sustainable material criteria	Domestic market shift toward environmentally friendly products	Medium-term (2026–2028)	European Commission (2024)

These strategic orientations define the priorities required to integrate green taxation and forestry policies within a comprehensive framework in Türkiye. Redesigning tax incentives to support environmental performance, strengthening carbon financing instruments, and enhancing local participation will not only increase the sector's transformation capacity but also facilitate progress toward achieving the Sustainable Development Goals. This approach suggests that forestry investments could become a core component of the green economy in the future.

Forest Carbon and Ecosystem Services Fund (OKEHF): An Integrated Financing Model Proposal

Forest ecosystems in Türkiye provide critical services, including carbon sequestration, water cycle regulation, soil conservation, and biodiversity, generating significant societal value. However, this value has not yet become a visible and compensated economic element within the financial system. To address this gap, the proposed Forest Carbon and Ecosystem Services Fund (OKEHF) aims to channel revenues from green taxation and carbon pricing into sustainable forest management through a comprehensive financing mechanism. The fund's core principle is to reallocate revenues generated under the Pigouvian tax approach, based on the "polluter pays" principle, to activities that enhance carbon sink capacity and produce ecosystem services (ÇŞİDB, 2024; Acet et al., 2025). In this respect, OKEHF becomes a structural instrument that aligns fiscal and environmental policies toward a common objective.

OKEHF pursues three primary goals:

(i) Determine the economic value of carbon sequestration and ecosystem services and integrate this value into the financial system.

(ii) Allocate a defined percentage of ETS and green tax revenues to forestry, ensuring permanent funding for sustainable forest management projects.

(iii) Strengthen social sustainability by enabling active participation of local communities—particularly forest villagers—through performance-based payments.

The fund's revenue structure relies on a diversified financial architecture. The table below summarises the sources of income and proposed allocation shares.

Table 6. Proposed Revenue Sources and Allocation Shares for OKEHF

Revenue Source	Share (%)	Description
ETS revenues	40	A defined percentage of auction revenues allocated to the fund.
Green tax share (Excise/Energy)	30	"Green share" derived from fossil fuel taxes.
PES and watershed revenues	15	Fees from recreation, drinking water, and hydropower use.
Voluntary carbon credits	10	Voluntary carbon payments from the private sector.
International fund contributions	5	External sources such as GCF, EU LIFE, and others.

Revenue diversity demonstrates that the fund can reach an annual financing capacity of approximately 8–10 billion TL. Analysts base this estimate on the ratio of similar EU funds to GDP (0.03–0.05%) (European Parliament & Council, 2023a, 2023b, 2023c). Planned ETS revenues and the potential for green bond issuance further strengthen this capacity. For example, if ETS sets a carbon price of USD 10–20 per tCO_2 and Türkiye maintains annual emissions of around 500 $MtCO_2$, ETS revenues alone will generate 10–25 billion TL (European DataWarehouse, 2023; World Bank, 2023). Additionally, the Turkish Treasury issued USD 2.5 billion in green bonds in 2023, and private sector bonds could potentially add another 3–4 billion TL to the fund portfolio. Policymakers should incorporate green bonds into the fund portfolio and enforce compliance and reporting standards to ensure transparency (European Parliament & Council, 2023a, 2023b, 2023c; European Data Warehouse, 2023).

OKEHF's institutional governance will operate as a semi-autonomous structure under the coordination of the GDF. The Board of Directors will include representatives from the Ministry of Treasury and Finance, the Ministry of Environment, GDF, TÜBİTAK, and civil society organisations to ensure integrated governance. Regional directorates will monitor performance at the local level. To ensure scientific accuracy and transparency, policymakers will establish a Scientific Advisory Board comprising experts in carbon accounting, biodiversity economics, and ecosystem services.

The fund will apply a performance-based payment mechanism to improve efficiency in resource allocation. Evaluators will score projects based on annual carbon sequestration, improvements in biodiversity indicators, and contributions to local employment. This scoring system will strengthen the fund's capacity to deliver both environmental and social outcomes.

Policymakers will implement OKEHF in three phases:

Phase I: Launch pilot projects in carbon-intensive regions (e.g., Bolu, Kastamonu, Artvin).

Phase II: Enact a legal framework that mandates allocating a defined percentage of ETS revenues to the fund.

Phase III: Scale the fund nationwide and develop co-financing models with international financial instruments.

This integrated model will transform forestry from a passive carbon sink into an active driver of Türkiye's green economy and climate policy.

Revenue Architecture and Allocation

OKEHF's revenue base consists of two groups: core sources (stable, high-volume) and optional sources (cyclical, scalable). In the EU, ETS auctions serve as a strong public revenue channel, and since 2023, legislation has reinforced the full allocation of these revenues for climate objectives (EEA, 2024). Germany has directed ETS revenues through the Climate and Transformation Fund (KTF) since 2012 (DEHSt/UBA, 2025). A similar "automatic share" arrangement in Türkiye will provide OKEHF with a predictable funding stream.

The revenue architecture and proposed allocation ranges appear in the table below. The annual target allocates 85–95% from core sources and 5–15% from optional sources.

Table 7. Proposed Revenue Sources for the Forest Carbon and Ecosystem Services Fund (OKEHF)

Revenue Source	**Proposed Share (Range)**	**Brief Rationale / Basis**
TR ETS auction revenues	40–55% (core)	EU ETS auctions generated €43.6 billion in 2023; Germany allocates to Climate and Transformation Fund (KTF). Automatic share regulation in Türkiye ensures predictability (EEA, 2024; DEHSt/UBA, 2025).
"Green share" in energy/carbon taxes	10–20% (core)	Earmarking carbon pricing revenues for climate purposes provides behavioral impact + stable financing (PwC/OECD, 2024).
Watershed service fees (PES)	5–10% (core)	Costa Rica's PES model funds watershed-based payments; similar tariffs in Türkiye strengthen local allocation (UNFCCC; Watershed Markets).
Recreation/protected area eco-fees	2–5%	National park entry fees and concessions contribute to ecosystem service funding; PES includes "landscape beauty" service (UNFCCC).
Voluntary carbon market (REDD/REDD+)	2–8%	Verra VM0048 and JNR (Jurisdictional and Nested REDD+) methodologies aligned with Integrity Council for the Voluntary Carbon Market (ICVCM-CCP); high-integrity credits boost revenue (Verra, 2024; ICVCM, 2024).
EU CRCF-compliant certificates	3–8%	Regulation (EU) 2024/3012 enables removal and carbon farming certification; Türkiye can generate certified revenues under a compliant framework (European Union, 2024).
Green bonds (EuGB)	5–15%	Regulation (EU) 2023/2631 standardizes use-of-proceeds and impact reporting; OKEHF windows align with EuGB criteria (European Union, 2023).
International funds (GCF/GEF, MDB)	5–10%	Amazon Fund and Indonesia's Environmental Fund Management Agency (BPDLH) examples; grants and results-based payments finance large-scale nature projects (BNDES, 2023; UNDP Indonesia, 2025).
Debt-for-nature swaps / SLB/SLL	0–5% (optional)	Debt relief and sustainability-linked financing provide long-term resources (UNFCCC IEF, 2025).
Private sector co-financing / CSR	1–3% (optional)	"Challenge window" with matching and guarantee mechanisms increases participation (UNDP Indonesia, 2025).

Brief explanations:

- ETS auction revenues: An automatic share arrangement under Türkiye's ETS will provide OKEHF with a predictable funding stream.

- Green share in energy/carbon taxes: Combines behavioural impact with permanent financing.

- PES and recreation fees: Strengthens local allocation under the "user pays" principle.

- Voluntary carbon market and CRCF certificates: Ensure revenue diversification through international standards.

- Green bonds and international funds: Increase long-term capital and co-financing capacity.

This revenue architecture will secure OKEHF's financial sustainability and ensure alignment with Türkiye's climate objectives.

Allocation Areas

The effectiveness of OKEHF resources depends not only on generating revenue but also on directing that revenue to the right areas. The priority spending domains and their strategic significance are defined as follows:

- Carbon Sink Capacity and Forest Restoration: Investments in industrial afforestation, natural restoration, and seedling infrastructure represent critical priorities for Türkiye's net-zero target. Determining appropriate afforestation strategies, particularly for the rehabilitation of degraded areas such as mining sites, directly influences the success of carbon sequestration (Güngör & Şen, 2024). Alignment with the EU's CRCF certification framework enables crediting in international carbon markets (European Union, 2024).
- Fire prevention and early warning: ETS revenues should finance risk mapping, remote sensing, and equipment investments to address the increasing fire risk driven by climate change (EEA, 2024).
- Biodiversity and invasive species control: Monitoring, rehabilitation, and genetic resource conservation will strengthen the resilience of forest ecosystems (BNDES, 2023).
- Local PES and social inclusion: Performance-based payments to forest villagers and cooperatives will enhance social equity and protect ecosystem services (UNFCCC, 2023).
- Certification and market integration: FSC/PEFC certifications and CRCF-compliant carbon removal certificates should be supported through green product criteria in public procurement, steering the domestic market toward environmentally friendly products (European Commission, 2025).

Governance, Transparency, and MRV

The success of the fund depends on a strong institutional structure and transparent monitoring mechanisms. The Board of Directors, comprising representatives from the Ministry of Treasury and Finance, the Ministry of Environment, GDF, TÜBİTAK, and civil society organisations, will govern OKEHF. A Scientific Advisory Board, comprising experts in carbon accounting and biodiversity economics, will provide scientific input to inform decision-making processes.

To ensure transparency, the fund will publish an annual report detailing its revenue and expenditure, as well as disclose project-level impact indicators to the public. MRV integrity will follow methodologies aligned with CRCF and ICVCM standards. Voluntary carbon projects will apply Verra VM0048/JNR and ICVCM-CCP labels (Verra, 2024; ICVCM, 2024).

Implementation Roadmap (2026–2030)

The implementation of OKEHF will follow a phased approach. The steps and stages planned for the 2026–2030 period are outlined below:

- Phase I (2026): Policymakers will draft the fund's charter, set an automatic share (%X) from ETS auction revenues, apply PES tariffs in pilot basins, and publish the EuGB-compliant bond framework.
- Phase II (2027–2028): Authorities will evaluate TR-ETS pilot results, launch a CRCF-compliant national certification system, and label REDD+ projects with ICVCM-CCP standards.
- Phase III (2029–2030): They will implement parametric insurance mechanisms to mitigate fire and disaster risks, introduce debt-for-nature swaps and de-risking windows, and establish carbon storage criteria in public procurement.

Risks and Mitigation Measures

The fund's success depends on effectively managing potential risks. Policymakers identify the following risks and implement corresponding mitigation measures:

- Revenue volatility: Policymakers will balance ETS price fluctuations through a multi-source architecture and green bond buffers.
- Integrity risk: They will mitigate quality risks in carbon credits by applying CRCF and ICVCM standards, enforcing independent verification, and implementing open data requirements.
- Social acceptance: They will allocate 25–40% of revenues to local performance-based payments to strengthen fairness and local ownership within PES models.

Expected Impacts

Implementing OKEHF will position the forestry sector as a strategic actor in Türkiye's green transition, generating multidimensional ecological, economic, and social impacts. These impacts will become measurable through tangible outcomes that serve both climate goals and rural development. The expected impacts are defined as follows:

- Ecological: Increase carbon sink capacity, reduce fire risk, conserve biodiversity, and regulate water cycles.
- Economic: Ensure predictable investment flows from ETS and green taxes, secure long-term capital through EuGB and certified carbon credits, and drive growth in the circular economy and timber markets.
- Social: Provide regular performance-based payments to forest villagers, expand green employment, strengthen local development, and promote social equity.

This framework integrates the EU's revenue allocation transparency, CRCF's certification quality, and the local inclusiveness of Costa Rica, Brazil, and Indonesia's fund models with Türkiye's TR-ETS roadmap, serving both climate objectives and rural development. OKEHF will emerge as a socially inclusive and economically sustainable financing model aligned with Türkiye's climate goals.

General Assessment

Strengthening sustainable forestry policies in Türkiye requires not only an approach focused on ecological goals but also a multi-layered transformation that incorporates fiscal, institutional, and governance dimensions. Green taxation represents one of the most critical instruments forming the financial foundation of this transformation. Environmental taxes do more than increase public revenues; they drive behavioural change, influence investment choices, and ensure that the economic system reflects environmental costs. The forestry sector, with its capacity for carbon sequestration, regulation of the water cycle, soil conservation, and rural employment, stands as a strategic domain that can occupy a central position in green taxation policies. However, in Türkiye, green taxation instruments remain concentrated in the energy and transport sectors, while fiscal mechanisms directly linked to forestry are still underdeveloped.

Despite the strong operational capacity of the GDF, the lack of coordination between the Ministry of Treasury and Finance and the Ministry of Environment, Urbanisation, and Climate Change limits the allocation of green tax revenues to forestry. This gap often results in environmental taxes being used primarily for budget balancing, creating only a limited environmental impact. Policymakers must incorporate the economic value of forest ecosystem services into the design of carbon pricing and environmental tax systems. Türkiye's 2053 net-zero emission target makes it imperative to integrate the carbon sink capacity of forests into the financial system.

In this context, policymakers propose the Forest Carbon and Ecosystem Services Fund (OKEHF) as a practical and effective policy instrument for Türkiye. They will allocate a defined share of ETS revenues and green taxes to this fund, creating a performance-based financing model for ecosystem services that goes beyond traditional budget mechanisms. This fund will deliver measurable contributions to afforestation, biodiversity conservation, and rural development projects. It will also transform forest villagers from mere implementers into direct stakeholders, thereby promoting social equity and equality. Through this approach, the forestry sector will gain an integrated financing structure that generates both environmental and social benefits.

Green tax incentives in forestry constitute a critical component of this transformation. Tax reductions for certified forest products, accelerated depreciation benefits for enterprises utilising renewable raw materials, and the adoption of sustainable product criteria in public procurement actively enhance the sector's green production capacity. With Türkiye's transition to an Emissions Trading System (ETS), the strengthening of carbon markets creates significant opportunities for forestry. Allocating a portion of revenues generated from carbon pricing to forestry activities establishes a financial bridge between the principles of "polluter pays" and "protector earns," thereby reinforcing the role of forests in climate policy.

However, the effectiveness of fiscal policies depends not only on tax design but also on institutional coordination capacity. Therefore, establishing a permanent Green Fiscal Coordination Board that brings together the Ministry of Treasury and Finance, the GDF, TÜBİTAK, and the Ministry of Environment is essential. This board can direct the allocation of green tax revenues, regularly monitor the economic value of ecosystem services, and ensure the development of indicators that assess the effectiveness of policies. Moreover, a robust data infrastructure supported by digital carbon accounting, remote sensing, and geographic information systems is a critical requirement for both transparency and performance tracking.

In this context, the proposed policy framework should be built on the following foundations:

- Reforming the Motor Vehicle Tax (MTV) and fuel taxes based on emissions;
- Establishing the Forest Carbon and Ecosystem Services Fund (OKEHF) and linking a defined share of green tax revenues to this fund;
- Introducing targeted environmental levies for products and activities exerting high pressure on forests (e.g., differential tariffs adjusted for unsustainable wood/paper imports);

- Implementing “revenue recycling” to support rural forestry cooperatives and balance the distributional impact on households (OECD, 2024a; UNEP, 2022).

In conclusion, the green taxation approach in forestry represents a comprehensive policy instrument that integrates environmental, economic, and social objectives. Institutionalizing this approach in Türkiye will not only ensure environmental sustainability but also strengthen fiscal discipline, support local economies, and enable the achievement of long-term development goals. Forests should no longer be perceived merely as natural assets to be preserved; they must be recognized as strategic ecosystem capital that generates economic value, stores carbon, and fosters rural development. Integrating green fiscal policies with forestry has the potential to position Türkiye as a regional leader in the low-carbon development process. Realizing this potential requires a long-term vision, strong institutional collaboration, and societal engagement. To institutionalize this integration, pollution-based tax base and rate design should be addressed alongside revenue recycling principles, while budgetary processes must reinforce the link between allocation and transparency through green tagging and performance frameworks (OECD, 2023; European Court of Auditors, 2021).

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Chapter 2

Forest Bathing and Health; The Health Function of Forests

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Until the mid-1960s, the global understanding of forestry focused solely on wood production. With the multi-purpose use of forest resources, the combined production of various products and services in addition to wood production from forests became a priority. The new century forestry approach, initiated by the Rio-Helsinki Process, evolved into modern forestry planning with the concept of "Sustainable Forest Management." The focus was on forest resource management, which considered all the economic, ecological, and socio-cultural functions of forest areas.

Global climate change, resulting from the rapid global population growth and the corresponding overexploitation of natural resources, has been the primary driver of this shift in forest management. The population living in urban areas accounts for more than half of the world's population. Urbanization, defined as the relative increase in the ratio of urban population to total population, brings with it social, economic, and psychological changes and affects social structure. While it contributes positively to economic development, it also exposes people to extreme stress, leading to various health problems (Kim and Shin, 2021). As the recreational needs of individuals under urbanization pressure increase, forest fire risks associated with global climate change create new challenges in forest access policies. For example, forest entry bans imposed during periods of high fire risk, while ensuring ecological safety, can create socio-economic constraints on rural tourism and recreational activities (Yeşilbaş and Güngör, 2025a). The Millennium Ecosystem Assessment (MEA, 2005) report categorizes the ecosystem products and services provided by forests under the main headings of provision, regulation, culture, and support. Within these classifications, the effects of forests on human health are included under the regulation heading due

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to their effects on air quality and microclimate regulation, and under the cultural services heading due to their contributions to recreation, therapy, and spiritual renewal (Yıldızbaş et al, 2025).

Humankind has lived in close contact with forests throughout history and has maintained a continuous relationship. This relationship extends not only to essential needs such as shelter and nutrition, but also to benefits for health, spiritual balance, and cultural significance. The functions of forests are classified under three main headings: economic, ecological, and sociocultural (Kapucu, 2004; Asan, 2013). Each functional group contributes differently to forest ecosystems and human life. In particular, current approaches highlight that ecotourism and recreational uses are the most important socio-cultural tools that combine the sustainability of forest resources with rural development strategies (Güngör and Şen, 2023). In this context, the ecosystem services provided by forests have been redefined. Health and recreation services, particularly within sociocultural functions, have emerged as nature-based solutions to the problems created by urbanization. The importance of these functions is determined over time and by regional differences. To this end, various international processes and monitoring mechanisms have been established. According to Türker (2003), sustainable forest management aims to prevent deforestation and forest degradation while increasing the direct benefits of forests to society and the environment. SFM focuses on the protection and management of forests and forest areas so that they can fulfill their ecological, economic, and social functions now and in the future (Gençay et al, 2018). Indeed, recent studies show that community-based management models and innovative approaches such as carbon management are strategic tools for strengthening the socio-economic functions of forests (Güngör and Yeşilbaş, 2025). In Türkiye, the forest management regulation was renewed in 2008 (OGM, 2008) based on the understanding of sustainable forest management, and the concept of forest functions has become the core process of our sustainable and multi-purpose (functional) forestry (Vatandaşlar, 2021).

This study will evaluate the effects of forest bathing practices on physical and mental health in light of current literature, and discuss how Türkiye's rich forest resources can be utilized within this perspective. Recommendations will be developed, particularly regarding the integration of health functions into forest management plans, the identification of pilot areas, and coordination with national health policies.

2.1. Literature on Forest Bathing

Forest bathing (Shinrin-Yoku) is an approach that aims to restore physical and mental integrity through contact with nature. Emerging in Japan in the 1980s, this concept was initially designed as a public health policy to combat the stress, burnout, and mental fatigue brought on by urban life. Over time, however, it has evolved beyond simply a relaxation method into a scientific field of research examining the biopsychosocial dimensions of human-nature interactions. Currently, forest bathing brings together various scientific disciplines, and through collaborative studies, it is being addressed holistically across social, health, and forestry sciences.

A review of the literature reveals that attempts have been made to determine changes in people's health patterns resulting from short-term or longer-term stays in forested areas. Studies have demonstrated that spending time in forest environments has measurable effects on human physiology. Both physiological and psychological effects have been found to contribute to significant well-being. Frequently repeated studies have found physiological effects such as decreased stress hormone levels, blood pressure, and heart rate, as well as significant improvements in negative emotions such as anxiety and anger, improved sleep quality, and improved ability to manage depression. This demonstrates that forest bathing is a holistic form of nature-based therapy that promotes not only mental relaxation but also physical healing.

Forests and nature have always served as shelter, a source of healing, and a source of nourishment for humanity. With developing technology, industrialization, and urbanization, humanity has gradually drifted away from nature. New lifestyles put pressure on human health and negatively impact quality of life. This awareness has led to the need to return to nature. The biophilia hypothesis (Barbiero, Berto, 2021) posits that humans have an innate interest in and a connection to nature and other living creatures. This natural attraction has become more pronounced with the negative emotions (such as burnout and chronic stress) brought on by stress factors such as air pollution, the heat island effect, and spatial congestion brought on by today's urban and modern life. Spending time in nature is not merely a recreational activity but is also being discussed as a right to a healthy life and an issue of environmental justice.

The "One Health" approach developed by the World Health Organization emphasizes the interconnectedness of human, animal, and environmental health within the ecosystem we live in (WHO, 2017). The health of forest ecosystems is also important for contributing to human health. However, biotic and abiotic factors such as storms, droughts, and insect damage, which are increasing due to climate change, threaten the capacity of forests to serve as carbon sinks and provide ecosystem services (health/recreation) (Yeşilbaş and Güngör, 2025b). Therefore, the 'One Health' approach should also include the preservation of the physical resilience of forests.A healthy forest ecosystem will improve the quality of the products and services it provides. This will directly contribute to public health, from purifying air and water to maintaining microbial diversity, balancing diseases within the natural ecosystem, and providing stress-reducing natural environments. Numerous scientific studies, such as those by Lee et al. (2011) and Li (2023), have established scientific findings that short-term forest visits have positive effects on the cardiovascular, nervous, and immune systems. Shinrin-Yoku, pioneered by Japan in the Far East, has been incorporated into national health policy and has given rise to a new discipline called "Forest Medicine." This discipline considers nature not only as a site of aesthetic experience but also as a health component that produces measurable biological responses (Li, 2023).

Forest bathing is increasingly attracting attention in the scientific community (Figure 1). A search of scientific publications reveals a significant increase in the use of the keywords "forest bathing" or "forest therapy." An examination of the distribution of articles published in the Web of Science database by year reveals that scientific production on forest bathing accelerated, particularly after 2015, and interdisciplinary collaborations in psychology, environmental health, and medicine became more evident during this period.

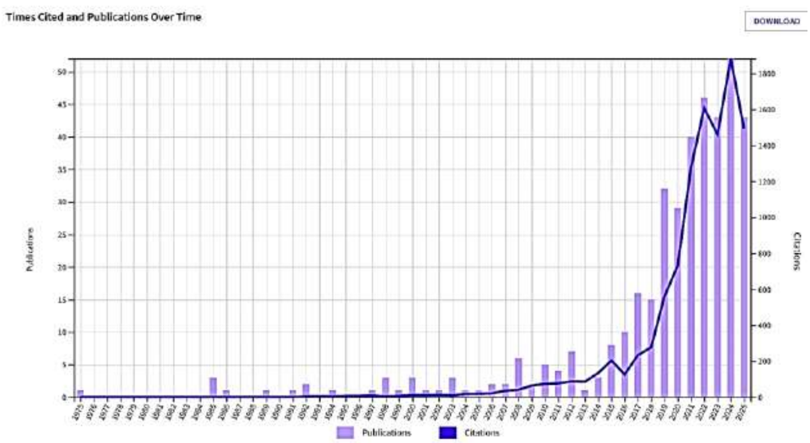

Figure 1. Distribution of scientific articles published with the keyword "Forest Bathing" by year (Web of Science, 2025).

2.2. Areas of influence of forest bathing

As mentioned above, studies on forest bathing are gaining increasing interest (Figure 1). Studies show that forest bathing is not merely a relaxing practice involving spending pleasant time in forest areas; it also has healing properties. Meta-analyses by Antonelli et al., 2021, and Kotera et al., 2020, indicate that forest areas have a complex influence, contributing simultaneously to both physiological and psychological processes in humans. Therefore, studies on forest bathing utilize a multidimensional approach to investigate the effects of forest areas on human health. Therefore, studies on forest bathing on human health will be discussed under two headings: psychological and physiological.

2.2.1. Psychological Effects

When the literature is examined, it is seen that the most studied part of forest bathing is the psychological effects. Studies by Hansen et al. (2017) and Lee et al. (2017) determined that short-term interaction with the forest reduces the level of stress hormones, lowers heart rate, and therefore provides a feeling of relaxation. A meta-analysis study by Kotera et al. (2020) determined that forest bathing reduces people's depression, regulates anger management, and reduces anxiety. Similar results have been seen in studies including short-term walking exercises and meditation exercises in the forest. For example, in the studies conducted by Furuyashiki et al. (2019) and Bielinis et al. (2019), spending two hours in the forest was found to have significant decreases in depression and decreases in stress levels in the participants. When studies conducted for shorter forest visits were examined; Song et al. (2019) and Takayama et al. (2019) concluded that a 15-minute walk in the forest increases people's happiness. These studies show that even short periods spent in the forest can lead to mental and spiritual well-being.

Studies on the effects of forest bathing on sleep quality have shown that forest bathing improves sleep quality and regulates mood disorders (Woo-Lee, 2020 Kim et al. 2019 and Shin et al. 2012). Lee and Choi (2017) have determined that forest bathing improves sleep quality and regulates mood disorders. These studies, particularly those that detect increases in melatonin levels, suggest that it helps individuals regulate their biological clocks, supporting deeper and healthier sleep.

Studies indicate that forest bathing offers significant support in the fight against and treatment of addiction. A study by Shin et al. (2012) on individuals with alcohol dependence found that individuals experienced decreased depression and a decreased tendency to use alcohol. Studies by Kotera and Rhodes (2020) and Poulsen et al. (2016) on individuals who had experienced trauma demonstrated improved self-understanding and accelerated recovery. Nature-based therapies involving forest bathing are considered more successful than art-based therapies (Vujcic, 2017).

Visual, auditory, and tactile awareness studies applied to the treatment of mental illnesses of individuals were determined to have positive results when their effects on participants participating in forest bathing studies were investigated (Bielinis et al. (2018, Yu et al. 2017)). Maple forests, as broad-leaved forests, were found to be the most successful in reducing anxiety (Guan et al. 2017

2.2.2. Physiological Effects

From a physiological perspective, the regulatory effects of forest bathing on the cardiovascular system are particularly notable. Comparative studies have shown that forest walks significantly reduce systolic and diastolic blood pressure, slow heart rate, and increase parasympathetic nervous system activity. These findings suggest that forest bathing functions as a mechanism that regulates the stress response not only psychologically but also at the neurophysiological level (Ideno et al., 2017; Rosa et al., 2021; Park et al., 2010).

Effects on the immune system are among the most striking findings in forest bathing research. Experimental studies by Li and colleagues (2007, 2008a, 2008b, 2009, 2010) have demonstrated that phytoncides present in the forest atmosphere—particularly compounds such as α-pinene and β-pinene—enhance natural killer (NK) cell activity and increase the production of anti-cancer proteins. Tsao et al. (2018) showed that this effect persists even after forest camping, while Lee and Choi (2017) reported that forest walks boost melatonin levels and strengthen immune responses. In a 12-week phytoncide diffusion study involving women survivors of gynecological cancer, Heo et al. (2023) observed decreased cortisol levels and increased NK cell counts. These findings indicate that forest bathing is not only a mental relaxation experience but also a health-enhancing practice that produces direct biochemical effects on the immune system.

Studies examining the effects of forest bathing on the metabolic and endocrine systems also yield promising results. Ohtsuka et al. (1998) and Li et al. (2016) reported that regular forest visits reduce the risk of metabolic syndrome by improving both acute glucose levels and long-term glycemic control. Lee et al. (2018) demonstrated that short-term forest therapy lowers stress levels and provides physiological relief in participants diagnosed with metabolic syndrome. These findings suggest that nature-based activities may exert an indirect yet lasting positive influence on hormonal and metabolic balance.

The effects of forest experiences on children and adolescents also occupy a distinct place in the literature. Lee et al. (2016) and Seo et al. (2015) reported reductions in attention-related difficulties and stress levels among children participating in nature camps, as well as improvements in allergic symptoms such as atopic dermatitis and asthma. These findings indicate that early exposure to nature may serve as a protective factor for both psychological development and immune functioning.

Forest bathing provides health benefits not only at the individual level but also at the societal level. Reports prepared by CJC Consulting et al. (2016) and the UK Government (2020) indicate that nature prescription programs implemented in countries such as Scotland, Japan, and New Zealand serve as cost-effective public health interventions. These studies suggest that forest-based practices can strengthen community well-being without placing additional burdens on public health budgets.

In general, the literature indicates that forest bathing produces significant effects on mental relaxation, stress reduction, immune activation, and physiological regulation—even in short-term applications. Systematic reviews conducted by Antonelli et al. (2021), Kotera et al. (2020), and Lew and Fleming (2024) show that these outcomes remain consistent across different age groups and cultural contexts. Thus, forest bathing represents a holistic approach that not only enhances individual well-being but also helps reestablish the balance between humans and nature while adding an ecological dimension to sustainable health policy.

These studies provide a new perspective on the future integration of nature-based therapies into public health strategies and their alignment with environmental sustainability principles.

3. Discussion

Research on forest bathing demonstrates that the effects of nature-based health approaches on the human organism extend beyond biophysiological processes; they constitute a multilayered experiential domain shaped by the interaction of psychological, neuroendocrine, and social factors. Findings in the literature show that forest environments regulate stress responses, restore attentional capacity, strengthen immune functioning, and stabilize biological rhythms. However, it is also noted that the durability, frequency, and persistence of these effects may vary across different cultural contexts.

Studies on the physiological effects of forest bathing generally highlight the activation of the parasympathetic nervous system. This is particularly significant for individuals living under the chronic stress of modern life, as parasympathetic activation shifts the body into a “rest-and-restore” state, reducing heart rate and blood pressure, lowering cortisol levels, and supporting cellular repair. Thus, the forest environment can be regarded not merely as a tranquil natural setting but as a "natural regulatory system" that helps reestablish human neurophysiological balance.

From a psychological perspective, forest bathing is a mindfulness-oriented practice that enhances individuals' emotional regulation skills. Participants' experiences of self-awareness, sensory grounding, and "being present in the moment" not only reduce stress but also strengthen psychological resilience. In this sense, forest bathing can be regarded as a nature-integrated form of the mindfulness approach in modern psychology. Thus, while supporting mental well-being at the individual level, it also functions as an ecological awareness practice that helps restore the human–nature relationship.

The multifaceted effects of forest bathing make it necessary to reconsider planning approaches within the discipline of forestry. Traditional forest planning has largely sought to balance production, protection, and recreation functions, with the health function typically incorporated only indirectly within this tripartite framework. However, in contemporary ecosystem services classifications, "health and well-being" is defined as a direct benefit category, and the biopsychosocial effects of forests are increasingly recognized as measurable planning criteria.

For this reason, the concept of "human health-focused planning" is at the forefront of contemporary forestry policies. Forest areas should be considered not only as carbon sinks or recreational areas, but also as living spaces that reduce stress, strengthen immunity, and support mental balance. In particular, incorporating health-related indicators such as air quality, noise levels, accessibility, and safety into the planning processes for forests surrounding cities, and developing new functional categories such as "green prescription trails" or "therapeutic forest zones" have become a contemporary necessity.

The integration of health functions into planning necessitates not only spatial but also managerial transformation. The functional planning system of the General Directorate of Forestry must define sub-classifications such as "health-based forest areas"; in these areas, biophysical indicators (e.g., air ionization, volatile compound concentration, noise level) and socio-psychological variables (e.g., user satisfaction, stress scales) must be monitored together. Such an integrated approach transforms the health function of forests from merely a scientific concept into a policy that can be implemented at the planning level.

At the societal level, forest bathing practices serve as an innovative tool for public health policies. Programs such as the "nature prescription" implemented in countries like Scotland, Japan, and New Zealand have developed models that support mental and physical well-being without imposing additional costs on the healthcare system. In Türkiye, this approach offers significant opportunities both for strengthening the social dimension of national forest policies and for promoting sustainable health tourism and recreation models in rural areas. To realize this potential at the institutional level, establishing interdisciplinary coordination between forest management, the health sector, and academia is of great importance.

In conclusion, forest bathing serves as a bridge that addresses the ecological and spiritual disconnections of modern society. It transforms the interaction between humans and nature beyond an aesthetic experience into a scientifically measurable health process. In this respect, forest bathing redefines not only individual well-being but also the concept of “ecological well-being,” highlighting the necessity of not separating human health from the health of the ecosystem.

4. Conclusion and Recommendations

Forest bathing, as one of the most holistic forms of nature-based therapies, offers an ecological response to the growing problems of stress, loneliness, and digital fatigue in contemporary society. Evidence in the literature indicates that this practice yields short-term mental relaxation, medium-term physiological balance, and long-term restorative effects on the immune and metabolic systems. This multi-layered health impact highlights that forest bathing is not only an ecological practice but also a public health–oriented approach that strengthens social well-being.

The health function of forests requires a fundamental shift in the planning paradigm of modern forestry. This new paradigm goes beyond the classic production–conservation–recreation triad, prioritizing a forest planning approach focused on ecological well-being and human health. Forests should be regarded not only as ecosystems that store carbon or provide economic resources, but also as nature-based health infrastructures that support human physical and mental well-being.

In this context, integrating criteria that reflect the health functions of forests into Türkiye's Ecosystem-Based Functional Planning (ETFP) model could be a fundamental step in this transformation. Taking into account indicators such as bioclimatic comfort, air quality, noise level, accessibility, and phytoncide density in the planning process could enable the classification of forest areas using a “health index.” Such an index would both increase the measurability of ecosystem services and make the relationship between public health and forestry visible.

Additionally, “forest therapy routes” can be defined in urban forests, incorporating criteria such as silence, safety, shade, and accessibility into planning standards. This approach will reduce the psychological strain caused by urbanization and transform forest areas into therapeutic ecosystems, not just recreational ones. In this regard, joint databases should be created between public health and forestry institutions so that the physiological and psychological effects of nature-based health activities can be scientifically monitored.

A multidimensional framework can be proposed for integrating forest bathing practices into public health policies:

• Scientific infrastructure: Universities and health and forestry institutions should collaborate to conduct interdisciplinary research aimed at measuring the physiological and psychological effects of forest bathing.

• Implementation areas: Pilot "forest therapy trails" should be established in national parks, urban forests, and nature parks, and joint training programs should be developed to support foresters, physicians, psychologists, and nature educators.

• Social awareness: Forest bathing should be promoted not merely as a tourism activity but as a nature-based lifestyle practice that enhances overall quality of life.

These recommendations enable forests to be planned not only as areas to be protected, but also as public health spaces where people can heal and regain their mental and physical balance. Such an approach is consistent with sustainable development goals and also highlights the social value of ecosystem services.

As a result, the concept of forest bathing has evolved beyond being merely an individual relaxation practice; it has become a symbol of the institutional recognition of human health functions in forestry planning. Embracing this understanding will enable us to view the forests of the future not only as carbon sinks but also as a fundamental component of social health infrastructure and ecological well-being. In this sense, the planning approach based on the health function of forests is the starting point for both an ecological and ethical transformation.

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Chapter 3

The Colorful Face of the Flora: An Overview of Geophytes

Hanife ERDOĞAN GENÇ[1]
Melike YAZAR[2]

Biodiversity studies has never become a global priority to the extent witnessed today. The pressures exerted by human activities in both rural and urban areas, when combined with the adverse effects of climate change, pose serious threats to biological diversity (Hesami et al., 2018). These processes smilarly manifest in Türkiye, particularly affecting fragile ecosystems, leading to species loss and degradation of habitat integrity. Türkiye, located at the intersection of biologically diverse regions such as the Caucasus, the Mediterranean Basin, and Iran-Turan phytogeographical zone, harbors remarkable species richness comparable to that of the entire European continent, with a total of 12,354 taxa (Terzioğlu et al., 2021). Relative to several European countries, Türkiye exhibits a higher level of endemism, containing 3,649 endemic taxa and an endemism rate of 31.82%. Recognized for its exceptionally rich flora, Türkiye is situated within the Mediterranean geophyte zone, one of the world's five major centers of geophyte diversity. The country hosts 1,056 naturally occuring geophyte taxa, of which 424 are endemic, correspondig to an endemisim rate of 40% (Özhatay, 2013). Geophytes therefore constitute a substantial component of Türkiye's biological richness (Koyuncu & Alp, 2014). Considering that approximately 4,300 geophyte species exist worldwide, Türkiye's remarkable richness in this plant group becomes evident (Giray, 2001).

Geophytes are plants characterized by specialized underground storage organs such as bulbs, tubers, rhizomes, and corms that function as reservoirs of nutrients (Giray, 2001; Selimov, 2008). The term geophyte'' was first introduced by the Danish botanist Christian Raunkiaer during his efforts to classify plant life forms (Ekim & Koyuncu, 1992). Etymologically derived from Latin, "geophyte" combines geo (earth) and phyta (plant), thus referring to "earth plants" or "hidden

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plants” (Akan et al., 2005; Avcı, 2005; Güner, 2006; Nemutlu & Çelik Çanga, 2021).

Geophytes, also known as natural flower bulbs (Kahraman & Özzambak, 2015), successfully endure periods of abiotic stress such as drought and extreme cold by storing reserves in their underground or ground-level storage organs (De Hertogh & Le Nard, 1993). While the aboveground organs of geophytes (stems, leaves, and flowers) wither and die after completing their growing season, the plants continue their life cycle through storage organs such as bulbs, tubers, rhizomes, and corms that remain protected underground during the summer months (Day, 2025). These organs serve as vital energy reservoirs that sustain the plant for the following year. Geophytes are particularly important due to their underground stems, which enable them to withstand unfavorable environmental conditions.

According to another classification, geophytes are grouped as “autumn-flowering bulbs’’ and “spring-flowering bulbs.’’ Autumn-flowering bulbs are planted in the fall and bloom in spring, whereas spring-flowering bulbs are planted in early spring and flower during the summer months (Topal et al., 2022; Olgaç, 2025; Yener and Seyidoğlu Akdeniz, 2020; Kılıçaslan and Dönmez, 2016). They thrive across a wide range of climatic conditions, from sea level to high-mountain environments. The leaf, flower, and stem morphologies of geophytes display remarkable diversity. Their flowers may be single, double, semi-double, or multi-flowered. Depending on the species, flowering may occur before, after, or simultaneously with leaf emergence (URL-1). The underground organs of some geophytes consist of scaly bulbs, while others possess solid corms, tubers resembling hardened storage organs, or rhizomes with elongated root-like structures (Nemutlu & Çelik Çanga, 2021). For example, species of *Allium, Gagea, Galanthus, Lilium, Muscari, Ornithogalum, Prospero ve Scilla* have bulbs; *Anacamptis, Arum, Cephalanthera, Coeloglossum, Corydalis , Cyclamen, Dactylorhiza, Gymnadenia, Ophrys, Orchis, Paeonia, Platanthera, Serapias ve Traunsteinera* possess tubers: *Colchicum* ve *Crocus* are corm-bearing; whereas some species of *Cephalanthera as well as Iris, Listera, Limodorum, Narthecium, Polygonatum, Polygonum, Ruscus ve Veratrum* are representative rhizomatous geophytes (Erdoğan Genç et al., 2022). These underground storage organs, concealed beneath the soil surface, allow the plants to regenerate after disturbances such as fire, drought, or excessive grazing, thereby contributing to habitat recovery (Almansouri et al., 2020; Çiloğlu & Güneş Şen, 2025). Examples of bulbs, corms, tubers, and rhizomes belonging to geophyte taxa are presented in Figure 1.

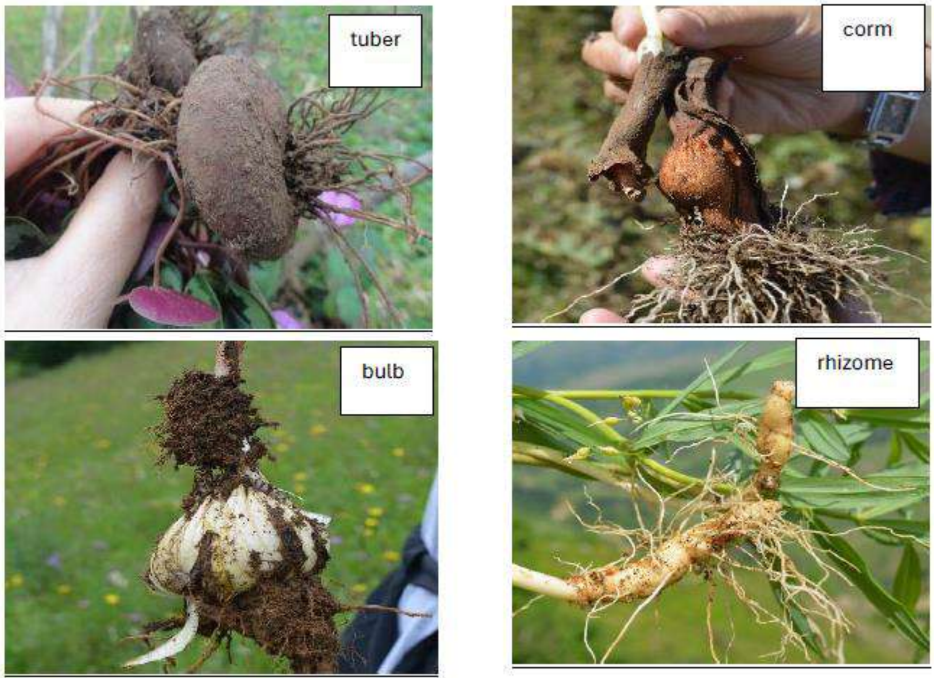

Figure 1. Examples of bulbs, corms, tubers, and rhizomes belonging to geophyte taxa.

The majority of geophyte species bloom during the early weeks of spring, while some flower in October (Özuslu & İskender, 2009). Spring-flowering geophytes emerge immediately after snowmelt and are among the first plants to colour the landscape. They commonly occur at high elevations and along snow lines, where many species may appear together, adorning the natural scenery. In contrast, autumn-flowering geophytes begin to bloom following the dry and hot conditions of summer. These species create a vivid visual display particularly in upland and subalpine zones with cool and humid microclimates colouring extensive meadows in shades of purple, yellow, blue, and pink. In some species, flowering occurs prior to leaf emergence, a characteristic especially evident in *Colchicum* and *Crocus*. This phenomenon can be observed in various regions of Türkiye and is particularly striking in the high-altitude plateaus of the Black Sea region. Geophytes that emerge immediately after snowmelt are regarded as heralds of spring. Examples illustrating the spectacular displays created by geophytes in the Black Sea highlands are presented in Figures 2 and

Figure 2. Spring flowering geophytes

Figure 3. Autumn flowering geophytes

Geophytes of Medicinal and Economic Value

Species belonging to petaloid monocots presented in Volume 8 of the Flora of Turkey, along with *Cyclamen* in Volume 6 and the genera *Anemone* and *Eranthis* in Volume 1, naturally occur in Türkiye, and many of them possess significant medicinal and economic value (Ekim & Koyuncu, 1992; Koyuncu, 1994; Özuslu & İskender, 2009; Demir et al., 2013). The plant families in which geophytes are particularly rich in Türkiye include Orchidaceae, Asparagaceae, Liliaceae, Amaryllidaceae, Iridaceae, and Colchicaceae (Fırat et al., 2015; Erdoğan Genç et al., 2022). In general, geophytes occur in dicot families such as Primulaceae, Ranunculaceae, Paeoniaceae, and Geraniaceae, and in monocot families such as Orchidaceae, Liliaceae, Amaryllidaceae, Iridaceae, Colchicaceae, Asparagaceae, and Araceae. Owing to their medicinal and aromatic constituents, many geophyte species possess high economic value and are utilized in various fields, including herbal pharmaceutical raw materials, ornamental horticulture, food, and the cut-flower industry (Baytop, 1999; Erdoğan Genç et al., 2022; Topal et al., 2022; Olgaç, 2025).

Numerous species from genera such as *Anemone*, *Crocus*, *Colchicum*, *Cyclamen*, *Eranthis*, *Fritillaria*, *Galanthus*, *Iris*, *Leucojum*, *Muscari*, *Ornithogalum*, *Orchis*, *Arum*, and *Scilla* exhibit medicinal and aromatic properties (Seyidoğlu & Yayım, 2009; Sargın et al., 2013). For example, species belonging to the Amaryllidaceae family contain important alkaloids. In particular, the alkaloid galanthamine is used in the treatment of Alzheimer's disease, poliomyelitis, and neuromuscular disorders (Arslan et al., 2002; Karaoğlu, 2010). *Colchicum* species are utilized in the pharmaceutical industry due to the colchicine alkaloids found in their corms and seeds (Koçoğlu et al., 2018; Düşen & Sümbül, 2007; Küçüker, 1995). These alkaloids have long been used in the treatment of gout, Behçet's disease, and familial Mediterranean fever (Baltacı et al., 2022; Akbulut, 2009). Sand lilies (*Pancratium maritimum*), known for their pleasant fragrance and attractive appearance, are important ornamental plants; however, the presence of more than 150 alkaloids also endows them with pesticidal and medicinal potential. Owing to these properties, this species which is also utilized in antineoplastic drugs holds a significant place in cancer treatment (Ioset et al., 2001; Dayıoğlu et al., 2019). Similarly, the bulbs of *Fritillaria roylei* (Liliaceae) are used as a febrifuge and expectorant in respiratory ailments (Sharma, 2009; Dayıoğlu et al., 2019). In Türkiye, tubers of *Crocus* species are consumed raw or cooked in ashes, and their flour is also prepared. Certain *Crocus* species have historically been used as dyes, medicines, and perfumes (Brighton et al., 1980; Fırat et al., 2015).

Geophyte plants also hold a special place in ecotourism due to their showy and aesthetically appealing flowers. Geophyte taxa that stand out due to characteristics such as endemism or rarity are important attractions for ecotourism activities aimed at photographing these species in their natural habitats and exploring the ecological features of their regions. For this reason, designing ecotourism routes based on the flowering periods of geophytes and supporting these routes with photosafaris and botanical tours is of great significance. For instance, Kadıralak Plateau in the Tonya district of Trabzon becomes a center of tourist attraction in the spring due to the striking displays created by *Scilla siberica* var. *armena*, commonly referred to as "blue star" by locals (Figure 4). Although flowering times vary among species, the peak flowering period for geophytes generally occurs between April and July (Erdoğan Genç et al., 2022). Flowering commonly begins in mid-winter, reaches its maximum in spring, and continues until late October. Establishing flowering calendars for geophyte species across different regions and applying these calendars particularly in ecotourism and flora-tourism activities is essential.

Figure 4. The visual spectacle created by *Scilla siberica* var. *armena* on Kadıralak Plateau.

They also bloom during winter and early spring and are highly ornamental in parks and gardens, where they are widely used for landscaping purposes (Seyidoğlu, 2009). The flowering periods of geophytes vary among species, and by planning designs so that these flowering times are distributed across the entire year, aesthetically pleasing landscapes can be achieved in all seasons (Yener & Seyidoğlu Akdeniz, 2020). Geophytes also serve as valuable ornamental plants owing to their attractive flowers, suitability as cut flowers, and pleasant fragrance (Çakır, 2017). Bulbous plants are used as ornamentals in parks and gardens, as well as in interior decoration as cut flowers and as motifs in the decorative arts (McHoy, 2008). The use of geophytes as ornamental plants in landscape design projects would provide economic benefits at the national scale. However, the limited access to natural taxa is the main restrictive factor preventing their broader use in landscape applications. In this context, bringing natural geophyte taxa suitable for landscape designs into cultivation and organizing the reliable supply of sufficient plant material, together with the rapid implementation of adaptation studies with these taxa, will support the conservation of our natural resources and enable the realization of sustainable landscape designs (Tanrıverdi, 2019).

Major Threats to Geophytes and Conservation Measures

The remarkable richness of Türkiye's flora has long attracted the attention of foreign botanists, who have shown particular interest in geophytes due to their conspicuous and ornamental flowers. This circumstance has positioned the country as an appealing source of natural ornamental plants and has consequently increased international demand (Ekim et al., 1991; Kaya, 2016). Geophytes have been exported since the Ottoman era (Çelik et al., 2004). For instance, *Crocus sativus* was an important cultivated species during the Ottoman period, a substantial portion of which was exported (Arslan, 1986; Fırat et al., 2015). In addition to large-scale collection of bulbs from the wild for export, numerous foreign breeders obtain their breeding materials directly from Türkiye's flora (Kaya, 2016). Among the geophyte species harvested in Türkiye, *Galanthus* species are those most frequently collected and exported. It has been reported that *Galanthus* populations in the Mediterranean Region have declined and that excessive harvesting has caused habitat degradation (Ekim et al., 1991). Moreover, the populations of *Galanthus* and *Sternbergia* species have suffered adverse effects due to excessive collection, as reported by Çelik et al. (2004) and Ergun et al. (1997). It has also been documented that many of the geophytes of commercial importance are collected predominantly from the Toros Mountains, as well as from the Ege Region, Eastern Black Sea Region, and the uplands of Eastern Anatolia (Ekim et al., 1991; Seyidoğlu, 2009).

Geophyte species are increasingly experiencing habitat loss due to the conversion of natural areas into agricultural land, expanding urbanization driven by rapid population growth, road-widening and new road construction projects (Ekim et al., 2000), reclamation of barren and marshy areas, watershed rehabilitation initiatives, the construction of hydroelectric power plants (HPPs) and dams, forest fires, agricultural activities (such as tea and hazelnut cultivation in the Black Sea Region), and the impacts of climate change. Therefore, in regions where geophyte taxa are densely distributed, public awareness must be raised and local communities educated to mitigate the threats these species currently face (Aydın et al., 2018; Aydın et al., 2019; Güneş Şen & Aydın, 2024). Additionally, during the permitting processes for development activities such as dam construction, HPPs, quarrying, mining, and road building, the presence of geophyte species within the project area must be carefully considered. When necessary, these species should be translocated to ecologically suitable and comparable habitats in accordance with their biological requirements to ensure their long-term conservation.

Another significant threat to geophytes is excessive grazing and mowing. Geophyte species, particularly those distributed in moist meadows, are unable to survive until seed formation when mowing occurs at very early growth stages. Consequently, their populations decline and their long-term survival becomes jeopardized. As Türkiye is a country rich in geophyte biodiversity, it also faces substantial risks such as biotrafficking. It has been reported that bulbous plants constitute the majority of illegally exported flora, with species such as *Fritillaria* spp., *Galanthus* spp., *Narcissus* spp., *Sternbergia* spp., *Cyclamen* spp., *Muscari* spp., *Iris* spp., *Lilium* spp., and *Anemone blanda* being the most targeted taxa (Gökyiğit, 2014). To combat biotrafficking, measures should be identified and implemented at border checkpoints; customs personnel should be trained and made aware of the issue; qualified botanists should be appointed, the public should be informed; and necessary legal regulations should be established to ensure the conservation of species diversity (Yılmaz et al., 2019).

Orchid species, which are among the most prominent and striking geophytes, are also under threat due to harvesting for salep production. Unregulated goat grazing, conversion of natural habitats into agricultural land, and their use as ornamental plants further damage orchid populations (Kayıkçı & Oğur, 2012). Orchids in Türkiye occur across remarkably diverse habitats and are found almost throughout the entire country. Conserving these species in their natural environments is of critical importance. Unfortunately, orchids in Turkiye are now on the brink of extinction, and without urgent, long-term conservation planning, many orchid species will face severe risk, while rare and highly endemic taxa restricted to only a few sites may completely disappear (Kreutz & Çolak, 2009). Therefore, conservation–utilization based management plans should be developed for the collection and propagation of such species (Özhatay et al., 1997). Examples of significant orchid species distributed in Türkiye are presented in Figures 5 and 6.

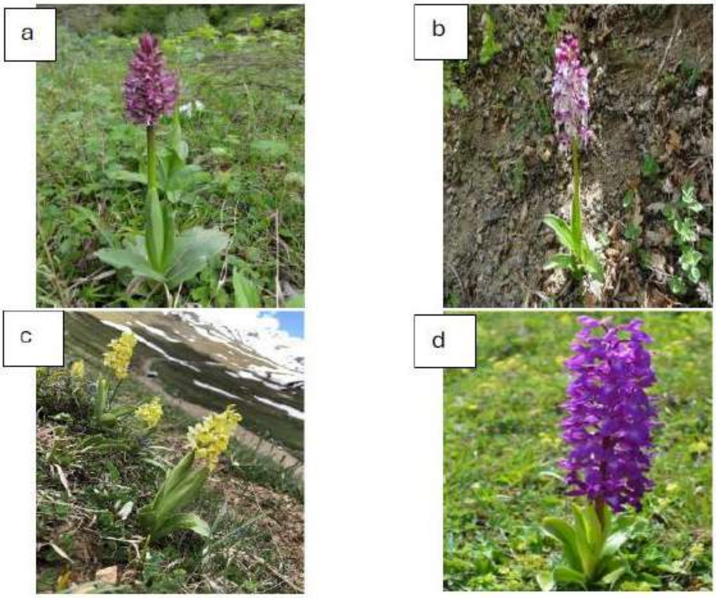

Figure 5. *Orchis simia* (a), *Orchis purpurea* (b), *Orchis pallens* (c) and *Orchis mascula* subsp. *longicalcarata* (d)

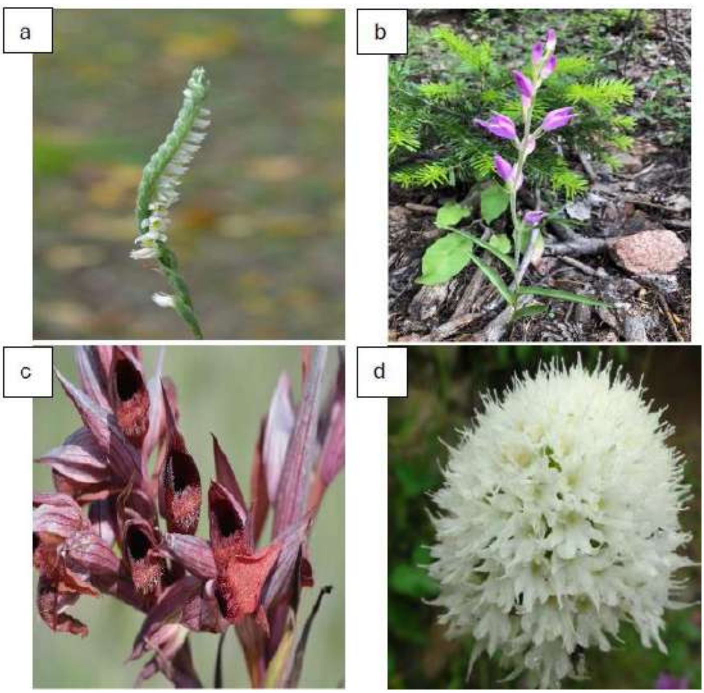

Figure 6. *Spiranthes spiralis* (a), *Cephalanthera rubra* (b), *Serapias orientalis* subsp. *orientalis*(c)and *Traunsteinera sphaerica* (d)

The most effective conservation strategy is to identify the distribution ranges and population sizes of species and to implement conservation measures in accordance with these plans. In Türkiye, numerous studies have been conducted on determining the distribution areas of geophytes, their areas of use (landscape, food, ethnobotany, etc.), their IUCN threat categories, and their conservation requirements (Koyuncu & Demirkuş, 2000; Mammadov & Sahranç, 2003; Çelik et al., 2004; Pınar et al., 2008; Selimov, 2008; Yıldırım & Gemici, 2008; Yüzbaşıoğlu et al., 2008; Kreutz & Çolak, 2009; Sandal, 2009; Akan, 2012; Kayıkçı et al., 2012; Kayıkçı & Oğur, 2012; Şekeroğlu et al., 2012; Sargın et al., 2013; Sarıhan & Asil, 2013; Avcu et al., 2016; Akbaş & Varol, 2017; Sefalı & Gıdık, 2019; Tanrıverdi, 2019; Yener & Seyidoğlu Akdeniz, 2020; Alhasan & Akan, 2021; Bozkurt, 2021; Tel & Akan, 2021; Erdoğan Genç et al., 2022). In light of the recommendations emphasized in these studies, conservation measures for geophytes the vibrant elements of our flora should be strengthened.

To ensure the conservation of geophyte species facing numerous threats, Türkiye has undertaken responsibilities through both national legislation and international conventions. The Ministry of Agriculture and Rural Affairs issued a regulation in 1989 concerning the harvesting, cultivation, and export of natural flower bulbs. Under this regulation, the export of certain flower bulbs was prohibited, while quotas were established for both wild collection and cultivated production for those permitted for export. Moreover, the minimum bulb sizes eligible for export were also defined (Çelikel, 2014; Çelikel, 2015). Geophyte species subject to trade are monitored in situ by scientists and technical personnel assigned by the Ministry of Agriculture and Forestry across different regions. The necessary reports are submitted to relevant authorities, and quotas are subsequently determined. These quotas are allocated to exporting companies as either production quotas or wild-harvesting quotas and are revised annually. For example, the quotas allocated for natural flower bulbs for 2025 are presented in the export list table (Table 1) (URL-1).

Table 1. Export list of natural flower bulbs for 2025

Ek-1 **2025 YILI DOĞAL ÇİÇEK SOĞANLARININ İHRACAT LİSTESİ TABLOSU**

(I)	(II)				(III)
Doğadan Toplanmak Suretiyle İhraç Edilmesi Yasak Olan Çiçek Soğanları	İhracatı Kotaya Tabi Olan Çiçek Soğanları				İhracatı Üretimden Serbest Olan Çiçek Soğanları
Tür İsmi	Tür İsmi	Yıllık Limit (Adet)		Çevre Uzunluğu(cm)	Tür İsmi
		Doğa	Üretim		
1. *Allium* (Soğan) türleri	1.*Cyclamen cilicium* (Sıklamen)	-	1.000.000	8+	1.*Lilium candidum* (Akzambak)
2. *Anemone* (Yoğurtçiçeği) türleri	*Cyclamen coum* (Sıklamen)	200.000	1.000.000	8+	2.*Lilium martagon* (Türkzambağı/Sultanzambağı)
3. *Crocus* (Çiğdem) türleri	*Cyclamen hederifolium* (Sıklamen)	-	5.000.000	10+	3.*Iris tuberosum* (Süsen)*
4. *Fritillaria* (Terslale) türleri	2. *Galanthus elwesii* (Toros kardeleni)	-	8.000.000	4+	4.*Calla aethiopica* (Kalla)*
5. *Lilium* (Zambak) türleri	*Galanthus woronowii* (Karadeniz kardeleni)	1.500.000	7.000.000	4+	5.*Polianthes tuberosa* (Sümbülteber)*
6. *Muscari* (Müşkürüm) türleri	3. *Eranthis hyemalis* (Sarıkokulu)	-	3.000.000	3,5+	6.*Fritillaria persica* (Adıyaman lalesi/Kırklale)
7. *Sternbergia* (Karaçiğdem) türleri					7.*Fritillaria imperialis* (Ağlayangelin)
8. *Tulipa* (Lale) türleri					8.*Anemone blanda* (Dağlalesi)
9. *Eminium* (Yılanbacağı) türleri					9.*Geranium tuberosum* (Çakmuz)
10. *Biarum* (Yılanpancarı) türleri					10.*Sternbergia lutea* (Karaçiğdem)
11. *Geranium tuberosum* (Çakmuz)					11.*Dracunculus vulgaris* (Yılanbıçağı)
12. *Dracunculus vulgaris* (Yılanbıçağı)					12.*Arum italicum* (*Yılanyastığı*)
13. *Nymphaeaceae* (Nilüfergiller) türleri					13.*Arum dioscorides* (*Tirşikpancarı*)
14. *Orchidaceae* (Salepgiller) türleri					14. *Drimia maritima* (=*Urginea matima*: Adasoğanı)
15. *Arum* (Yılanyastığı) türleri					15.*Leucojum aestivum* (Gölsoğanı)
16. *Pancratium maritimum* (Kumzambağı)					16.*Crocus sativus* (Safran)
17. *Hyacinthus orientalis* (Şarksümbülü)					
18. *Gentiana lutea* (Censiyan)					
19. *Cyclamen* (Sıklamen) türleri (*C. coum.* hariç)					
20. *Galanthus* (Kardelen) türleri (*G. woronowii* hariç)					
21. *Iris* (Süsen) türleri					
22. *Paeonia* (Şakayık) türleri					
23. *Eranthis hyemalis* (Sarıkokulu)					
24. Diğer yumrulu ve soğanlı türler					

* Üretimi yapılan egzotik türler.

Türkiye signed the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) on 20 February 1984 with the aim of conserving its natural flora and fauna and their habitats. The Bern Convention employs the Annex I list for plant species. According to this list, many bulbous taxa such as *Cyclamen coum*, *Steveniella satyrioides*, *Orchis punctulata*, *Ophrys oestrifera*, certain species of *Colchicum*, and several species of *Fritillaria* are designated under protection (URL-2). In addition, Türkiye became a party on 22 December 1996 to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which entered into force in 1975 to monitor international trade in species that are or may become threatened with extinction, to prevent the exploitation of ecological balance through international trade, and to ensure the sustainable use of countries' biological resources. *Cyclamen* spp., *Orchidaceae* spp., *Galanthus* spp., and *Sternbergia* spp. are listed in CITES Appendix II as taxa requiring protection (URL-3).

Another major authority responsible for the global conservation of biological diversity is the International Union for Conservation of Nature (IUCN). The risk categories of species considered to be threatened in the wild are classified by the IUCN. Threatened taxa are categorized as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC) (IUCN, 2001). Countries prepare their national Red Lists primarily for endemic and rare species based on these criteria (Ekim et al., 2000). According to these assessments, many endemic and rare geophyte species are also classified as threatened.

Despite the significant progress achieved through laws and regulations governing the controlled collection and export of natural bulbous plants which constitute an important component of Türkiye's biological richness numerous shortcomings remain regarding the conservation of these species and the need to utilize them without compromising their future sustainability. The conservation of biodiversity, particularly endemic and rare taxa, is both a national and international obligation. Türkiye continues to implement the necessary legal arrangements and initiatives in this regard (Erken et al., 2022).

There is an urgent need to conserve geophyte diversity to prevent the depletion of our rich biodiversity and to ensure the sustainable use of geophyte plant material by current and future generations. The most effective method for conserving plant diversity is in situ conservation, which prioritizes the protection of species within their natural habitats (Fenu et al., 2019). In situ conservation, which focuses on maintaining populations within their natural habitats, is widely recognized as the primary and most appropriate conservation strategy (Fenu et al., 2019; Coelho, 2020; Godefroid et al., 2011). For endemic geophyte species with restricted distributions and threatened by habitat loss, monitoring their populations in native habitats, reinforcing them when necessary, and integrating these species into the management plans of relevant institutions constitute the most effective in situ conservation actions that contribute to the long-term survival of the species.

Although efforts are made to protect plants in their natural habitats, increasing demand for natural resources and habitat degradation continue to disrupt these environments. This situation will inevitably lead to the extinction of numerous plant species (Dhyani & Abeli, 2022). As anthropogenic pressures on ecosystems and species increase, the practice of relocating threatened taxa for biodiversity conservation purposes has become more widespread (Silcock et al., 2019). Consequently, ex situ conservation methods have become unavoidable. Ex situ approaches include cultivating material collected from threatened populations under controlled conditions in greenhouses or botanical gardens and subsequently transferring them back to their natural habitats or to suitable new sites (Maunder et al., 2001; Whitehead et al., 2023). Botanical gardens play a critical role in cultivating rare and threatened plants under controlled conditions, establishing ex situ collections, and safeguarding the genetic diversity of species (Heywood, 2017; Maunder et al., 2001). Within the scope of ex situ conservation, seed and gene banking represent essential strategies that secure the genetic material of species, enabling their reintroduction into nature should wild populations be lost.

Therefore, the strengthening of national and international seed banks is of great importance for the conservation of geophytes.

One of the most critical measures for the conservation of geophyte plants is to ensure the sustainability of species particularly endemic and rare geophytes by identifying appropriate propagation and cultivation methods. Among the pioneering studies on the cultivation of geophytes is the project titled "Cultivation of Certain Wild Plants and Introduction of New Species and Varieties to the Ornamental Plant Sector-I (TÜBİTAK 1007)". Within the scope of this project, at least one population of 1,045 geophyte taxa, which represent some of the most valuable components of the Turkiye flora, was identified. Subsequently, ten individuals from each population were collected following appropriate procedures and conserved ex situ in the "Turkish Geophytes Garden." This project marked a significant step toward cultivating several perennial plants native to Türkiye including *Colchicum* spp., *Lilium* spp., *Nectaroscordum* spp., and *Polygonatum* spp. and establishing the "Turkish Geophytes Garden" (Kaya et al., 2009).

Geophytes are generally propagated through both vegetative and generative methods, with vegetative propagation being primarily preferred for large-scale production. However, in the mass propagation of narrowly distributed endemic and rare geophytes, generative propagation should be prioritized where seed production is biologically feasible in order to avoid adverse impacts on natural populations. For example, *Lilium ciliatum*, an endemic geophyte species of Türkiye classified as Endangered (EN) by the IUCN, has been successfully propagated from seed under greenhouse conditions, yielding bulbs sufficient for transfer to ex situ collections (Erdoğan Genç et al., 2025). Transferring plant material of such species to protected areas or their original habitats will contribute directly to habitat restoration, long-term species conservation, and broader biodiversity sustainability goals. Vegetative propagation methods include production with bulblets, production by dividing tubers, rhizomes, and bulbous tubers (Saharma et al., 2011), production with axillary bulbils, production from bulb scales, chipping and twin-scaling, production by cutting the bulb base (Day, 2025), and production through tissue culture (Dhyani et al., 2014; Javaheri et al., 2022; Eskimez et al., 2024).

The information and data presented in this study highlight that Türkiye is rich not only in terms of floristic composition but also in geophyte diversity. The sustainability of this biological wealth can be ensured only through strengthened scientific research, the determined implementation of conservation policies, and heightened public awareness. Geophytes, which represent the colorful face of our national flora, are threatened by various biotic and abiotic factors, and these pressures impose irreversible negative effects on species with significant ecological and economic value. Increasing habitat loss, climate change, biotrafficking, and uncontrolled harvesting exert substantial pressure on geophyte populations. Accordingly, it is essential for researchers, ecologists, conservation biologists, local authorities, and local communities to act with shared responsibility. Effective monitoring is required to protect natural habitats, improve degraded ecosystems, and prevent illegal harvesting (Baç & Güneş Şen, 2025). Moreover, enhancing educational and awareness-raising activities will help ensure that these natural assets are safely preserved for future generations. Increasing both in situ and ex situ conservation efforts is of critical importance, particularly for the sustainable future of rare and endemic species. Through such efforts, the conservation of geophyte species nature's vibrant elements can be secured, ensuring the long-term maintenance of biodiversity in harmony with conservation–utilization principles.

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Chapter 4

Forest Fragmentation: Causes, Ecological Consequences, and Restoration Strategies

Osman TOPAÇOĞLU[1]

Forests are among the world's most important ecosystems, providing numerous products and services essential to the economy, in addition to their functions such as carbon storage, regulating the water cycle, conserving soil, and providing habitat for biodiversity. However, in today's world, where anthropogenic pressures are rapidly increasing, the spatial integrity of forest ecosystems is being severely disrupted, and forests are becoming smaller, more fragmented, and increasingly isolated. This process is defined in ecological literature as "forest fragmentation" and is considered a multidimensional environmental threat that affects both the area and connectivity of natural habitats. Fahrig (2003) defines forest fragmentation as the process by which large, continuous forest areas are transformed over time into small, isolated, and ecologically non-functional patches due to human activities or natural factors. This phenomenon alters the landscape configuration and has a significant impact on biodiversity, ecological dynamics, and overall forest health.

As a result of forest fragmentation, changes in microclimatic conditions within and at the edges of forest patches are extremely important. Pinto et al. (2010) state that the formation of edges leads to significant changes in vegetation dynamics, such as the prevalence of pioneer species. At the newly formed forest edges, the natural habitats of species are changing, and those adapted to the original natural forest conditions are affected, leading to a decrease in biodiversity (Vergara & Simonetti, 2004). Changes in the microclimate, the new conditions created in isolated small areas that do not support natural reproduction, also negatively affect the reproductive patterns and survival rates of forest-dwelling species (Schmiegelow et al., 1997).

The impact of forest fragmentation on wildlife populations is particularly significant, especially for large mammals and sensitive species. Sampaio et al. (2010) report that the life of these species is largely dependent on the size of forest

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fragments. Additionally, Vergara and Simonetti (2004) state that the abundance of various bird species in fragmented forest areas has decreased, indicating that fragmentation reduces species richness and affects the ecological balance of these communities.

A significant impact of fragmentation in forested areas is also seen in natural ecological processes such as seed dispersal and nutrient cycling. Studies have shown that forest fragmentation disrupts these processes (Girão et al., 2007; Šipek et al., 2022). The inability of species carrying plant seeds to survive due to fragmentation significantly hinders the natural regeneration of forests (Klein, 1989).

In summary, forest fragmentation poses significant threats to biodiversity, alters ecological dynamics, and impacts the functional capacity of forest ecosystems. Addressing forest fragmentation through conservation strategies, maintaining connectivity between fragments, and restoring larger contiguous forest areas is crucial for preserving biodiversity and the ecological integrity of forested landscapes. This book chapter was prepared to comprehensively address the causes of forest fragmentation, their ecological consequences, detection methods, and restoration approaches.

Causes of Forest Fragmentation

One of the main causes of forest fragmentation is the expansion of agricultural lands. The conversion of forests into agricultural land is a significant cause of fragmentation, especially in developing tropical countries where land pressure is high (Abdullah & Nakagoshi, 2007). This process not only involves the direct clearing of forested areas but also the establishment of pastures for grazing animals, which have been shown to be a significant factor in deforestation and fragmentation in regions like the Amazon (Armenteras et al., 2013). As observed in areas like the Zagros Mountains ecoregion, nomadic agriculture, often practiced for illicit products, further increases fragmentation by periodically clearing small patches of forest (Chadid et al., 2015).

Infrastructure projects are also a significant contributor to forest fragmentation. Roads, urbanization, and industrial activities create barriers within ecosystems, leading directly to forest loss and generating "edge effects" that can radically alter the microclimate and biological dynamics within remaining forest fragments (Riitters et al., 2000). Roads not only facilitate access for logging and agricultural expansion but also increase the vulnerability of forest habitats along forest edges to invasive species and hunting pressures (Brinck et al., 2017).

Mining activities represent a critical but often overlooked cause of forest fragmentation. The conversion of large forested areas into mining sites further exacerbates fragmentation, especially in rapidly developing regions. The transformation of natural landscapes into mining areas not only involves removing forest cover but also frequently leads to ecological degradation, impacting surrounding ecosystems (Nasir et al., 2023).

Urbanization also plays a significant role in forest fragmentation. The expansion of cities and towns leads to the loss of natural habitats and the disruption of wildlife. The construction of urban infrastructure has a negative impact on natural hydrological patterns.

Natural disturbances such as forest fires, landslides, and severe weather events can further complicate this situation by accelerating fragmentation in already stressed forested areas. These events are exacerbated by environmental changes linked to human activities and can create a feedback loop that increasingly affects the sustainability of forests (Batar et al., 2021).

Additionally, changes in temperature and precipitation patterns resulting from climate change are affecting forest health and resilience. For example, it is reported that rising temperatures can contribute more to fragmentation by promoting more frequent and intense forest fires (Jaroensutasinee et al., 2024).

In summary, the causes of forest fragmentation are multifaceted and stem from a combination of agricultural expansion, infrastructure development, mining, urbanization, and natural disturbances, all of which are exacerbated by climate change. Understanding these factors is crucial for developing effective conservation strategies that mitigate the impacts of fragmentation on biodiversity and ecosystem integrity.

Ecological Consequences of Fragmentation

The ecological consequences of forest fragmentation significantly alter habitat quality and connectivity, impacting biodiversity, ecosystem functioning, and overall landscape dynamics. The main ecological consequences of forest fragmentation can be listed as follows:

Loss of Biodiversity: Forest fragmentation leads to a decrease in biodiversity. When forests are divided into smaller pieces, the available natural area for species to live in decreases, leading to the extinction of sensitive species that require larger areas. Research has shown that fragmentation affects both taxonomic and functional diversity, and higher β-diversity is often observed in edge-effect forests due to changes in species composition (Sfair et al., 2016). The emergence of edge effects can lead to microclimate changes that favor some species while disadvantaging others, potentially exacerbating biodiversity loss (Fischer et al., 2021).

Disrupted Species Interactions and Movement: The physical fragmentation of habitats restricts species' ability to find mates, locate food, and migrate between patches by hindering their movement. Even narrow breaks in the forest constantly significantly hinder the movement of numerous bird and insect species (Debinski & Holt, 2000). This deterioration threatens the genetic health of populations by leading to reduced gene flow and increased inbreeding.

Changes in Ecosystem Functions: Ecosystem functions are negatively affected by forest fragmentation. It is crucial that the decrease in space and connectivity in this regard impacts the patches' ability to deliver basic services. Fischer et al. (2021) stated that the increase in edge area due to fragmentation leads to altered habitat quality, which in turn affects processes such as nutrient cycling, carbon sequestration, and water regulation. As functional diversity decreases, the ability of ecosystems to maintain multiple functions becomes even more endangered in isolated fragments (Hertzog et al., 2019).

Increased Sensitivity to Invasive Species: The formation and development of invasive species in fragmented areas is easier because these species can more readily utilize the edge habitats created by fragmentation. The development of non-native species can lead to changes in community dynamics by eliminating native plant and animal species, thereby reducing biodiversity (Scariot, 1999). The newly formed forest edges can create microhabitats that support invasive species, resulting in a decline in local biodiversity and ecosystem resilience (Šipek et al., 2022).

Altered Microclimate Conditions: Forest fragmentation leads to significant changes in microclimate factors, including temperature, humidity, and light penetration. These changes could create unfavorable conditions for species that have adapted to specific climate conditions found in natural forests. Studies have shown that the destruction of natural habitats not only leads to increased solar radiation at the edges but also results in higher temperatures and wind exposure (Šipek et al., 2022). This microclimatic change can profoundly affect seed dispersal mechanisms, plant growth, and overall ecosystem health.

Ethical and Social Impacts: It is stated that the ecological consequences of fragmentation can exacerbate problems related to climate change (Debinski & Holt, 2000). However, the social and ethical consequences of forest fragmentation are also noteworthy. The loss of forested areas can have a negative impact on local communities, whose livelihoods and cultural practices depend on forests.

Consequently, the ecological consequences of forest fragmentation manifest as significant biodiversity loss, disruption of species interactions, reduced ecosystem functions, increased vulnerability to invasive species, and altered microclimates.

Detection and Monitoring of Fragmentation

The detection and monitoring of forest fragmentation have become indispensable for understanding ecological dynamics and conservation practices. Various methods and technologies are employed to assess fragmentation patterns, which are largely driven by advancements in remote sensing, geographic information systems (GIS), and landscape metrics.

Remote Sensing Technologies: Remote sensing plays a critical role in detecting and monitoring forest fragmentation. High-resolution satellite imagery, such as Landsat data, allows for comprehensive spatial coverage and temporal analysis of forest cover changes. These images are often analyzed to monitor land use and land cover (LULC) changes, which reflect fragmentation processes. Studies are being conducted using satellite-based evidence to highlight the increase in global forest fragmentation from 2000 to 2020 and the potential of remote sensing for large-scale assessments (Zou et al., 2025). Additionally, Ma and colleagues (2023) discussed the impact of land policies on forest fragmentation and demonstrated the benefits of using satellite imagery to monitor such changes. Additionally, similar studies on this topic can evaluate the calculation of various fragmentation metrics, such as patch size, shape, edge density, and inter-patch distances, which characterize the spatial structure of forests (Zhen et al., 2023; Riitters et al., 2000). With advancements in image classification techniques, remote sensing now offers tools for generating fundamental data and effectively monitoring ongoing changes.

Geographic Information Systems (GIS): GIS is an important tool for analyzing spatial data related to forest fragmentation. The integration of CBS's remote sensing data facilitates the mapping and analysis of changes in forested areas. Studies have utilized GIS in conjunction with Landsat imagery to monitor changes in forest cover over time, providing insights into the dynamics of fragmentation in specific regions (Çakır et al., 2007). CBS allows for a robust examination of landscape patterns and can integrate various data layers, including land use, hydrology, and topography, to better understand the effects of fragmentation.

Landscape Metrics: Landscape metrics serve as quantitative indicators to assess forest fragmentation. Metrics such as Number of Peaks, Total Area, Edge Density, and Average Shape Index are frequently used for fragmentation analyses (Ersoy, 2019; Midha & Mathur, 2010).

Change Detection Methods: Change detection methods are vital for assessing forest fragmentation over time. Techniques such as post-classification comparison and image differencing allow researchers to measure the extent and type of changes occurring in the field. For example, as stated in a study on forest fragmentation in the La Union region, the cross-tabulation method was effectively used to assess land cover changes over specific periods (Encisa-Garcia et al., 2020). Monitoring change using these methods provides fundamental insights into the dynamics of forest fragmentation (Mehta et al., 2022).

Spatial Pattern Analysis: Spatial pattern analysis, conducted using software tools such as FRAGSTATS, enables a detailed examination of fragmentation metrics at the patch, class, and landscape levels. These analyses can characterize forest cover patterns and assess the impacts of fragmentation on biodiversity and ecosystem functioning (Malhi et al., 2020). By using these types of vehicles in research, trends have been identified showing a decrease in forest cover and an increase in fragmented landscapes (Malhi et al., 2020).

Integrated Monitoring Approaches: Emerging practices involve integrating multiple approaches to create comprehensive monitoring frameworks. For example, methods that combine remote sensing, GIS, and landscape metrics facilitate a holistic assessment of fragmentation patterns, enabling both local studies and broader ecological evaluations. By utilizing various data sources and analytical techniques, researchers are providing practical solutions for conservation planning (Roy & Inamdar, 2019; Gillanders et al., 2008).

Conclusion: In summary, detecting and monitoring forest fragmentation necessitates a multifaceted approach that utilizes remote sensing, GIS, and landscape metrics. These technologies and methodologies collectively inform conservation efforts by enhancing the dynamics of fragmentation and facilitating more effective management of forest ecosystems. By integrating various data sources and analytical frameworks, researchers can assess the ecological impacts of fragmentation, identify areas for conservation, and develop strategies to maintain forest connectivity and resilience.

Prevention of Fragmentation and Restoration Strategies

Preventing forest fragmentation and promoting ecological restoration are critical for conserving biodiversity and maintaining ecosystem resilience. Various strategies have been proposed and implemented in different areas. Generally, prevention strategies can be categorized into three main groups: preventive measures, restoration practices, and integrated management approaches.

Prevention Strategies

Establishing Protected Areas: Identifying protected areas plays a vital role in preventing fragmentation, as these areas can serve as critical habitats for many species. Effective management of these areas ensures that ecosystems remain intact and human intervention is minimized (Cameron et al., 2022). Creating well-connected protected area networks can conserve biodiversity while allowing species to evolve.

Habitat Corridors: Creating habitat corridors is a good strategy for maintaining connectivity between fragmented landscapes. The inclusion of corridors in conservation planning to allow for species movement and gene flow is essential for the population's existence and health (Beier & Noss, 1998). The negative effects of isolation can be mitigated, dispersal facilitated, and genetic distance between populations reduced by connecting fragments with corridors (Cushman et al., 2018). Land Use Planning and Zoning: Implementing sustainable land use policies and zoning regulations can significantly reduce fragmentation. This includes limiting agricultural expansion in forested areas and promoting sustainable practices (Gelmi-Candusso et al., 2025). Land use planning can protect critical ecological functions and connectivity within landscapes by directing development away from sensitive habitats (Cushman et al., 2018).

Urban Planning for Wildlife Connectivity: As urban areas expand, urban planning that prioritizes wildlife corridors and green spaces is essential. Strategies such as green roofs, permeable surfaces, and park networks can facilitate wildlife movement and reduce fragmentation effects by increasing habitat connectivity in urban environments (Gelmi-Candusso et al., 2025; Serret et al., 2022).

Community Participation and Management Programs: Involving local communities in conservation efforts is crucial. Programs that promote governance and sustainable practices among landowners can reduce fragmentation by fostering an understanding of the ecological value of intact ecosystems (Cameron et al., 2022; Gelmi-Candusso et al., 2025). Initiatives that involve the local population in conservation efforts can lead to more successful outcomes.

Restoration Strategies

Afforestation and Reforestation: Afforestation of degraded areas not only restores lost habitats but also strengthens connectivity in fragmented landscapes

(Aronson et al., 2006; Aars & Ims, 1999). However, in restoration efforts, native species should be prioritized to protect ecological integrity and resilience.

Restoration of Natural Matrix Habitats: Incorporating natural matrix habitats adjacent to forest patches can facilitate connectivity, increase biodiversity, and protect the patches from degradation. Rich matrix habitats can serve as valuable resources and refuge areas for wildlife (Olivier & Aarde, 2016; López-Mendoza et al., 2022). The restoration of such habitats can be particularly effective in mitigating the effects of fragmentation.

Managing Invasive Species: Controlling invasive species is often critical in restoration efforts because they put pressure on native flora and fauna in fragmented areas. Active management and removal of invasive species can increase the success of afforestation and habitat restoration initiatives (Yumnam et al., 2014).

Monitoring and Adaptive Management: Continuous monitoring of restored areas is crucial for evaluating the effectiveness of restoration strategies. Adaptive management practices ensure more effective conservation outcomes by allowing for timely adjustments based on ecological responses (Molofsky & Ferdy, 2005).

Integrated Approaches Landscape Connectivity Planning: Effective conservation strategies must integrate both habitat protection and restoration efforts into comprehensive landscape connectivity planning. This involves a multi-scale assessment of ecological networks to prioritize areas that provide the most significant ecological benefits for conservation and restoration efforts (Cushman et al., 2018).

Stakeholder Collaboration: The involvement of various stakeholders, including government organizations, NGOs, scientists, and local communities, is vital for the successful implementation of conservation strategies. Collaborative approaches promote shared goals and lead to the efficient use of resources, thereby preventing fragmentation and restoring ecosystems (Cameron et al., 2022; Jones et al., 2012).

Research and Innovation: Continuous research on the dynamics of forest fragmentation and restoration techniques is crucial for identifying best practice methods. Innovative approaches, such as utilizing technology to monitor and assess habitat connectivity and forest health, can lead to more effective management strategies (Cisneros-Araújo et al., 2021; Noss, 1987).

In conclusion, preventing forest fragmentation and restoring fragmented landscapes necessitates a multifaceted approach that combines protective, restorative, and integrative strategies. Implementing these measures can significantly enhance ecosystem resilience, conserve biodiversity, and deliver sustainable benefits for both the environment and local communities.

Results and Evaluation

Forest fragmentation is one of the significant environmental processes that threatens ecosystem resilience on a global and national scale. The disruption of the forest's holistic structure not only leads to habitat loss but also profoundly impacts the microclimate, species interactions, population dynamics, ecosystem processes, and the sustainability of biodiversity. The topics covered in this chapter of the book clearly demonstrate that fragmentation is a complex, multi-layered, and difficult-to-reverse process.

When examining the main causes of fragmentation, it is evident that factors such as the expansion of agricultural areas, infrastructure development, urbanization, mining activities, and forest fires have a direct impact. These anthropogenic and semi-natural processes are increasingly fragmenting forest integrity, placing intense pressure on it, especially in developing regions. In addition, climate change is exacerbating the disruptive effects through rising temperatures, drought, and extreme weather events. As a result of the process, the natural regeneration capacity of degraded and fragmented forest areas decreases. Therefore, the assessment of forest fragmentation must be addressed not only in conjunction with local land-use dynamics but also in relation to global environmental change processes.

When examining the ecological consequences, it is evident that fragmentation has far-reaching effects, including biodiversity loss, changes in functional ecology, a decrease in genetic diversity, and the disruption of ecosystem services. Habitat loss and isolation, particularly for mammal species requiring large areas and sensitive bird and insect communities, carry the risk of an irreversible population collapse. Research again shows that edge effects alter the microclimate, promote the growth of invasive species, and degrade the ecological quality of forest habitats. Restriction in gene flow reduces the species' adaptive capacity in the long run, leading to both genetic erosion and the risk of local extinction. These results demonstrate that fragmentation is not merely a spatial issue, but also a process that profoundly impacts ecosystem functionality.

The monitoring methods presented in this study demonstrate that the methods described have become a crucial tool for understanding the spatial patterns of fragmentation using modern technologies. Remote sensing, GIS-based analyses, landscape metrics, and change detection algorithms make it possible to objectively assess both the temporal trajectory and spatial characteristics of fragmentation. These technologies provide critical information for decision-makers, ensuring that conservation planning, risk assessment, and ecological restoration efforts are based on sound scientific foundations.

Preventing fragmentation and restoring degraded landscapes is not a process that can be solved with a single intervention. In this context, the expansion of protected area networks, the creation of ecological corridors, the adoption of sustainable land use policies, the management of invasive species, the application of restoration ecology techniques, and the active participation of local communities in decision-making processes are of great importance. Ecological corridors, by increasing connectivity in fragmented landscapes, support the mobility of species and gene flow, thereby contributing to the maintenance of ecosystem functions.

Overall, forest fragmentation is an environmental issue that requires multidisciplinary, multi-scale, and long-term approaches. The effects of fragmentation are not only ecological, but also have social, economic, and cultural dimensions. Therefore, for strategies aimed at reducing fragmentation to be successful, the disciplines of forestry, ecology, geography, urban planning, environmental engineering, sociology, and economics must collaborate.

In conclusion, reducing forest fragmentation is a critical goal that requires holistic landscape management, science-based policy development, resilient ecosystem design, and community engagement. The effective implementation of conservation and restoration strategies will not only safeguard biodiversity but will also make significant contributions to combating the effects of climate change, achieving sustainable development goals, and ensuring the continuity of ecosystem services. The long-term sustainability of forest ecosystems depends on developing scientifically based interventions by accurately understanding both the causes and consequences of fragmentation.

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Chapter 5

Statutory Rights Accorded to Forest Villagers in The Utilization of Non-Wood Forest Products: Evidence from Kastamonu Province

Gökçe GENÇAY[1]
Zeynep Nursima YILDIZOĞLU[2]

The utilization of forests by humans, or the human–forest relationship, begins with the appearance of humankind on Earth 2.5–3 million years ago. Human beings first began living in forests and in tree hollows before caves, sustained their lives in the forest through hunting and gathering, and later settled on lands acquired by clearing forest areas and started to cultivate the soil (Günay, 2003).

During this period, in addition to hunting, gathering became an important method of nutrition, and especially non-wood forest products, wild fruits, nuts, and root plants obtained from forests became one of the fundamental sources of livelihood for humans. Although this situation has varied between periods since primitive tribes, there has been an increasing tendency to obtain more products from forests (Aydın & Yıldızbaş, 2023). For example, the use of plants for healing purposes is as old as the earliest formation of humanity (Doğan, 2020). Thousands of years ago, people recognized the therapeutic power of plants and benefited from it in order to live healthily (Faydaoğlu & Sürücüoğlu, 2011).

Non-wood products obtained from forests were used not only in the fields of nutrition and health but also in transportation and defense technologies. For example, in the period when ships were made of wood, forest products such as tar, pitch, and resin were among the primary strategic materials. In addition, products such as acorn, pine bark, and dye plants were indispensable raw materials for the leather industry and other sectors (Kılıç, 2018). In the present day, natural resins, which are among the most prominent of these products, continue to serve as a strategic raw material in modern industries due to their intensive use in paper and packaging technologies and their ability to provide

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water resistance (Tulukcu Yıldızbaş & Bildik Dal, 2024; Bildik et al., 2019; Bildik Dal et al., 2020).

Non-wood forest products (NWFPs), which serve as an important source of both food and income for rural communities (Güngör et al., 2018), refer to naturally occurring forest products and services other than timber. A portion of these products, due to the high demand they receive, are domesticated and produced through agricultural activities (Ok & Tengiz, 2018). NWFPs are economically, ecologically, and socially important resources, and their significance has become clearer through studies showing how community-based forest management contributes to rural development (Güngör & Yeşilbaş, 2025).

Regarding the utilization of non-wood forest products, the general trend in the world is to allow free use for personal needs while subjecting commercial use to permission. For example, in Spain, a monetary limit has been set; uses below this value are allowed freely, whereas those above it are subject to authorization (Coşkun Aydın, 1999). Estonia and Lithuania, on the condition that the forest ecosystem is not harmed, have completely allowed the free utilization of non-wood forest products (Bauer et al., 2004, cited in Türker, 2011). When looking at the Ottoman period, the Forest Regulation allowed free use of forests for the purpose of meeting personal needs. Commercial uses, however, were possible only with permission. Such uses were subject to obtaining a license and various contractual conditions (Gümüş, 2018).

In Türkiye, according to Article 14 of the Forest Law, the utilization of the listed non-wood forest products is prohibited. However, it is possible to make use of these products by obtaining permission from the forest administration. The prevailing view on the subject is that, as in many other European Union countries, only commercial uses in Türkiye are subject to authorization, while the utilization of such products for personal needs is freely permitted. The basis of this view is the belief that the utilization of non-wood forest products for personal needs creates a right for individuals based on customary law (Türker, 2011).

The use of non-wood forest products in our country is carried out either to meet personal needs or through the sale of the collected products by individuals using their own means (Gedik, 2014). When the legislation on the use and sale of NWFPs is examined, it is seen that Article 14/C of the Forest Law No. 6831 of 1956 states that "collecting and removing acorn, linden flowers, all kinds of forest cover, galls, medicinal and industrial plants, or forest seeds" is prohibited. Therefore, activities related to the utilization of non-wood forest products are essentially subject to this fundamental prohibitive framework and may only be carried out in cases where explicit permission is granted by the law or relevant regulations and when such use is undertaken with duly obtained authorization.

According to the provisions of the "Regulation on Permits to be Granted to Those Who Wish to Benefit from Forest Products," published in the Official Gazette No. 22456 dated 1995, those who wish to benefit from forest products must apply directly to the provincial units of the General Directorate of Forestry, and the area, quantity, method of collection of the requested product, and whether the activity will endanger the continuity of the forest are evaluated by a committee (OGM, 1995).

For example, it is essential not to grant permission for the utilization of species that are strictly protected under national legislation or the international agreements to which we are a party, as well as for species with a distribution rate below 5% or for species that are biologically vulnerable to harm (OGM, 2016). In order for the collected NWFPs to be removed from the forest and transported, a transport permit must be issued; this document is the official transport permit used for transporting non-wood products produced from State forests (OGM, 2024).

The sales process of NWFPs, on the other hand, is carried out within the framework of market sales procedures in accordance with Circular No. 302 of 2016. Within this framework, natural forest products such as seeds, cones, flowers, leaves, tubers, bulbs, and similar items are priced by taking into account the estimated value determined by the Forest Management Directorates, tariff value, actual costs, and sales expenses, and are offered for sale through auction, allocation, or negotiation methods. The supply of these products to the market is under the control of the administration, and for transport outside the forest boundaries after the sale, the issuance of an additional transport permit is mandatory. On the other hand, the literature shows that authorization procedures related to NWFPs are not always sufficiently understood by local communities, and that socio-economic difficulties and the perception of traditional use may influence unauthorized harvesting behaviors (Durkaya et al., 2020; Durkaya et al., 2017).

Naturally, it is desirable for individuals who wish to benefit from NWFPs to be familiar with the relevant legal provisions and to act in accordance with them. However, a lack of knowledge or attention does not exempt individuals from responsibility. For this reason, assessing the public's level of awareness regarding the collection and sale of NWFPs, and analyzing their overall understanding of these practices, will contribute to future training programs and collaborative efforts to be carried out by forest enterprises in cooperation with local communities. Kastamonu, selected as the study area, is one of Türkiye's provinces rich in NWFP resources. Accordingly, the survey aimed to measure both the local population's knowledge of NWFP varieties and their awareness of associated legal rights.

Data Collection Process in the Kastamonu Case

Kastamonu is a province situated in the Black Sea Region of Türkiye. The province has a relatively small population, with approximately 100,000 residents in its central area. Notably, the region is endowed with abundant forest resources, contributing to its ecological diversity and natural beauty (Bayram et al., 2015). Kastamonu province experiences two distinct climatic zones due to the mountain ranges that extend along its east–west axis, and therefore possesses a highly diverse and rich forest ecosystem (Özden & Erkan Buğday, 2015). Walnuts, mushrooms, St. John's wort, chestnuts, rosehip, and linden are among the prominent NWFPs in the region. These income-generating products are known and used by certain segments of the local population. Particularly in villages located near, adjacent to, or within forest areas, households with lower income levels tend to use NWFPs either for subsistence or as a means of generating income.

However, a critical point is whether local residents are aware of the rules governing the collection and use of NWFPs. Equally important is whether they know that failure to comply with these rules may result in administrative sanctions.

The main data collection method of the study is a survey. A questionnaire was prepared for forest villagers living in the rural areas of Kastamonu Province who benefit from non-wood forest products, and it was completed through face-to-face interviews. The questionnaire consisted of questions aimed at determining the socio-demographic characteristics of the participants—such as age, gender, and occupation—their level of knowledge about non-wood forest products, their awareness of the legal regulations, and how they economically benefit from these products. The sample group of the survey was determined using the random sampling method. A specific group of forest villagers in Kastamonu Province was selected for the survey, and it was aimed to reach at least 96 participants.

Since the entirety of Kastamonu Province constitutes a limited population, the minimum number of individuals with whom the survey must be conducted—so that the results can represent the population—was calculated according to the formula used for determining sample size in limited populations (Daşdemir, 2016), as shown below.

$$n \geq \frac{Z^2 \times N \times p \times q}{(N \times D^2) + (Z^2 \times p \times q)}$$

The expressions used in the formula are explained below:

n: Sample size

N: Population size (According to TUIK 2022 data, the population of Kastamonu Province has been determined as 378,115 people (URL-1).

Z: Confidence coefficient (1.96 for a 90% confidence level)

D: Accepted sampling error rate (taken as 10% in forestry and social research)

According to this formula, the sample size was calculated as 96. In other words, if surveys are conducted with at least 96 individuals, a sample size that statistically represents the population will be reached without spending additional labor, time, and resources. Taking into account that some questionnaires may be incomplete or incorrectly filled out and therefore unusable, the calculated sample size was set at 200 and implemented accordingly.

Survey-Based Assessments on NWFPs

The utilization of non-wood vegetal forest products has become important particularly due to the increasing demand of people living in urban settlements. Forest products of vegetal origin obtained from nature encounter certain difficulties both during the collection process and in marketing (Gedik, 2014).

Based on the research conducted in Kastamonu Province, the findings obtained regarding the forest villagers' level of utilization of NWFPs, their awareness levels about these products, the problems they encounter in marketing processes, and their level of knowledge about legal rights are presented. Through the survey method used in the study, data were collected from 200 participants on various demographic, economic, and legal awareness issues.

According to the survey conducted in Kastamonu Province, when the demographic and socio-economic characteristics of the participants are examined (Table 1), 61% of the participants are male and 39% are female. This distribution reveals that activities related to forest products are carried out more intensively by men. When the age distribution of the participants is examined, 25% are in the 18–30 age range, 39.5% are in the 31–50 age range, 22% are in the 51–60 age range, and 13.5% are 65 years and over, indicating that the great majority consists of individuals of active working age. In terms of education level, 48.5% of the participants are high school graduates and 30.5% are undergraduate (bachelor's) graduates. These data show that the education level among forest villagers is generally at a medium level. When income sources are examined, 30% of the participants earn their livelihood from trade, 16% from wage labor, 14.5% from retirement pensions, 10.5% from agriculture, 4.5% from forestry, and 4% from animal husbandry. In terms of household size, 68.5% of the participants have a family structure of 3–6 persons. As for the monthly income distribution, it is seen that 67% of the participants have an income above 30,000 TL.

Table 1. Distribution of General Information of Survey Participants

General Information Table

		Freq.	%			Freq.	%
Occupation	Public sector	16	8,0	Education Level	Illiterate	1	,5
	Private sector	57	28,5		Literate	11	5,5
	Retired	31	15,5		Primary school	25	12,5
	Not working	43	21,5		Middle school	4	2,0
	Student	16	8,0		High school	97	48,5
	Worker	37	18,5		Associate degree	-	-
Age	18-30	50	25,0		Bachelor's degree	61	30,5
	31-50	79	39,5		Postgraduate	1	,5
	51-60	44	22,0	Gender	Female	78	39,0
	65 +	27	13,5		Male	122	61,0
Income Source	Agriculture	21	10,5	Additional Income Source	Agriculture	26	13,0
	Animal husbandry	8	4,0		Animal husbandry	18	9,0
	Forestry	9	4,5		Forestry	10	5,0
	Trade	60	30,0		Trade	12	6,0
	Retired	29	14,5		Worker	1	,5
	Worker	32	16,0		Other	1	,5
	Other	39	19,5		None	132	66
Househ old Size	1-2	40	20,0	MonthIy income	15000- 20000 TL	13	6,5
	3-6	137	68,5		25000- 30000 TL	53	26,5
	7 +	23	11,5		30000 + TL	134	67,0

After these general questions, the local community was asked about their opinions regarding training programs related to NWFPs. Upon examining the responses, it was observed that only 30% of participants were willing to attend such training sessions. When this relatively low proportion was further analyzed through a crosstabulation comparing NWFP income status and willingness to participate in training, it was found that a large majority (76%) of those who do not earn income from NWFPs were unwilling to participate. Conversely, willingness to attend training increased in parallel with income levels. Therefore, it can be inferred that the primary target group of the question—those who benefit economically from NWFPs—are indeed interested in receiving training.

When participants were asked whether they experience any difficulties during the NWFP marketing process, 27% reported experiencing "a few" difficulties, 28% "moderate" difficulties, 8.5% "a lot," and 3% "very many" difficulties. A crosstabulation conducted for individuals who derive income from NWFPs showed that those who do not earn income from these products predominantly selected the option "I do not experience difficulties," whereas individuals with higher NWFP income tended to report experiencing moderate levels of difficulty.

The next question posed to the local community concerned whether they would be willing to increase production if government incentives were provided.

The responses revealed a striking level of interest: 46% stated they would produce "much more," while 26% indicated they would produce "more." These findings clearly demonstrate that government incentives have a strong influence on the local population and play a key role in enhancing the production potential of income-generating NWFP species.

Another Likert-scale question asked participants to evaluate their level of knowledge regarding NWFPs. According to the results, 41% reported possessing a moderate level of knowledge, 25% a high level, and 18.5% a very high level. These relatively strong indicators suggest that lack of knowledge about NWFPs may not be a primary issue among the local population. However, when participants were immediately afterward asked about their knowledge of legal rights, 38% stated they had a moderate level of knowledge, whereas 17% reported having no knowledge at all. This reveals a significant gap in awareness regarding legal rights and obligations.

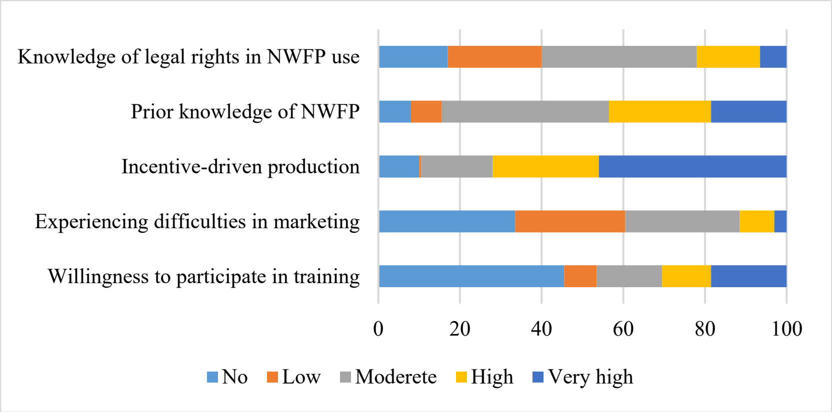
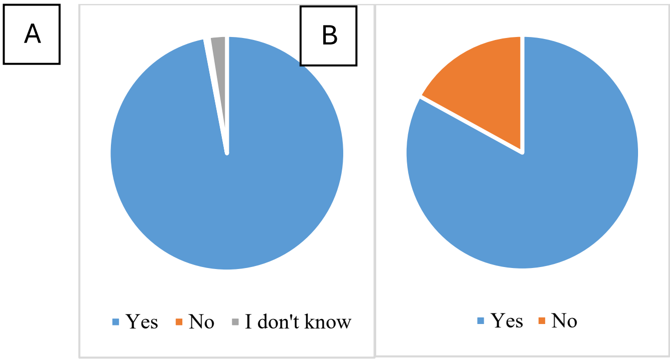


Figure 1: Awareness and Participation Levels Related to NWFPs

Following the Likert-scale questions, the local community was asked whether they considered the Kastamonu region to be rich in NWFPs, and an overwhelmingly high proportion of 97% responded "yes." This indicates that the local population is aware of the strength of the forest resources in the region in which they live. As for the remaining 2.5%, their response of "no knowledge" suggests not that they believe the region is not rich, but rather that they simply lack sufficient information to make an assessment.

When the responses to the question "Have you or any of your family members ever generated income from non-wood forest products?" were examined, 83% of the participants stated that they or their family members had previously generated income from NWFPs (Figure 2). This rate indicates that the local population has an economic connection with these products and that NWFPs may be an important source of income for the regional economy. However, 16.5% of the participants stated that they had not generated income from such products. This situation shows that although the rate of benefiting from NWFPs is high, certain segments of the population have not yet been able to sufficiently utilize this potential.



A- Is the region rich in NWFP?

B- Have you or your family earned income from NWFP before?

Figure 2: Income Generation Status from NWFPs in the Kastamonu Region

When the responses to another survey question, "From which non-wood forest products have you generated income?", were examined, it was revealed that mushrooms are the non-wood forest product with the highest market demand in the region. Among the main reasons for this situation are the wide distribution area of various mushroom species throughout the province, the ease with which forest villagers can access this product, and the collective mushroom-gathering activities carried out during certain periods. In addition, the extensive market network formed in response to the high demand for mushrooms stands out as an important factor that increases the economic value of this product (Figure 3).

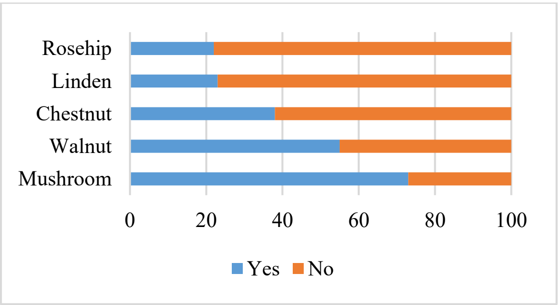


Figure 3. From which non-wood forest products did you earn income?

When the responses to the multiple-choice survey question "Which non-wood forest products have you heard of before?" were examined, it was observed that certain NWFP types have a very high level of public recognition (Figure 4). In particular, products such as chestnut (99.0%), walnut (97.5%), mushrooms (96.5%), and rosehip (95.0%) are known by the vast majority of participants, while some species—such as strawberry tree (68.5%) and St. John's wort (86.0%)—have comparatively lower recognition rates.

The data obtained show that forest products traditionally valued for their food, medicinal, and economic importance stand out in terms of social awareness. Especially products such as chestnut, walnut, and mushrooms are more widely known in society because they are commonly used both for direct consumption and economic activities. In addition, medicinal and aromatic plants such as bay leaves (89.0%), thyme (90.5%), and sage (89.5%) also have high recognition rates.

When the products with lower recognition levels are examined (such as strawberry tree at 68.5%), this may indicate that these species are not yet well known in the region or that market demand and sales opportunities for these products have not sufficiently developed. In this context, in addition to well-known species, it is important to promote other locally occurring species with high economic value and introduce them for public use.

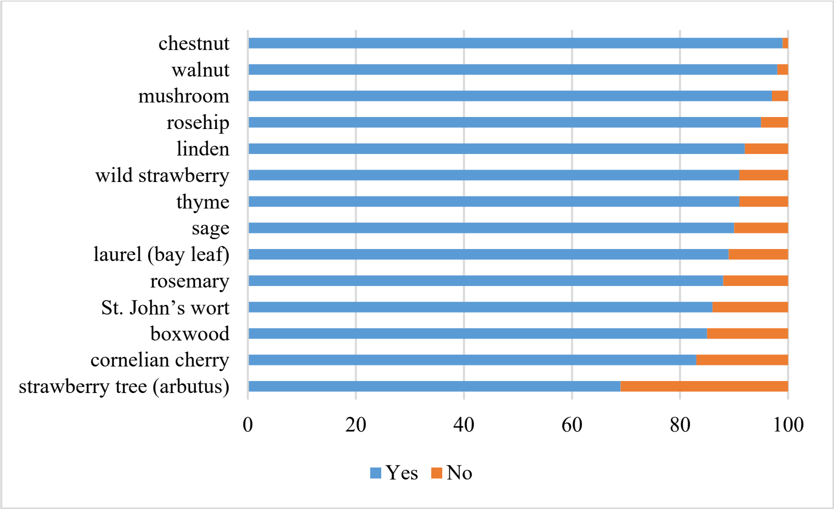


Figure 4. Which of the following non-wood forest products have you heard of before?

First, the local community was asked whether they were aware of the penalties imposed for collecting NWFPs without authorization, and subsequently whether they or any of their relatives had previously been subjected to such sanctions. An evaluation of the responses shows that the level of knowledge regarding penalties is quite high (%78), indicating that most residents are aware that unauthorized collection would result in a legal sanction. In this sense, it can be suggested that the community's awareness of the penalties associated with unauthorized NWFP collection—and their avoidance of such behavior in order not to face sanctions—reflects a high level of legal effectiveness. However, awareness of penalties does not always suffice to prevent offenses, and in some cases full compliance with the rules may not be achieved. This may suggest that the effectiveness of law enforcement is not always adequate. Therefore, it is important to examine the relationship between awareness and actual practice in greater depth.

Finally, when the proportion of individuals who have been subjected to administrative procedures due to unauthorized NWFP collection (either themselves or their relatives) is examined, a very low figure of 14.5% is observed. The fact that a large majority (85.5%) stated that they had not encountered any sanctions may, at times, result from individuals' reluctance to disclose involvement in an offense or from their lack of knowledge regarding whether their relatives have faced such situations. Human nature may lead individuals to avoid revealing actions associated with guilt or remorse. For this reason, it is considered necessary to compare the responses to this question with official records in order to obtain an accurate assessment.

General Evaluation and Recommendations

This study aimed to evaluate the level of utilization of NWFPs by forest villagers living in Kastamonu Province, their awareness of these products, and their knowledge of existing legal regulations. The data obtained within the scope of the research revealed that NWFPs constitute an important economic resource for the local population; however, they also indicated that legal awareness and knowledge levels in this field are not at a sufficient level. The survey results confirm that the Kastamonu region possesses high biodiversity and significant economic potential in terms of NWFPs. A large proportion of the participants stated that they generate income from these products either directly or indirectly. In contrast, it was determined that the willingness to participate in training programs related to NWFPs is low, and awareness regarding legal regulations and sanctions remains limited. This situation emerges as a significant gap in terms of the sustainability of NWFP use in the region and compliance with the legal framework, which is on par with the findings of another research: Bayram (2021) noted that Türkiye prioritizes the sustainability of wood and wood products over other sustainability indicators and aspects.

In line with the findings obtained from the study, the following recommendations have been developed. The first of these is the establishment of education and awareness-raising programs. Comprehensive training programs should be implemented to increase forest villagers' knowledge regarding the ecological and economic value of NWFPs and to strengthen their awareness of the legal framework. Seminars, workshops, and informational activities organized in cooperation with local administrations and relevant public institutions would serve as effective tools for achieving this objective. In addition, for forest villagers who are unwilling to participate in informational activities, certain incentives should be employed to encourage their participation in training programs.

A significant portion of the participants stated that they did not have sufficient knowledge about the existing legal regulations. In this context, informational brochures, guide booklets, and public service announcements to be broadcast through local media channels should be prepared in order to communicate the legal framework to the public in a clear and accessible manner. Another problem for forest villagers is that the economic potential of NWFPs is not fully realized; therefore, it is necessary to strengthen the marketing capacities of villagers to ensure more effective utilization of these products. Encouraging cooperative initiatives among local producers and increasing market access opportunities will play a critical role in this regard. To prevent illegal harvesting and unauthorized sales activities, enforcement processes should be made more effective. Indeed, it is well known that administrative restrictions—such as bans on entering forest areas—can place direct socio-economic pressure on forest villagers who rely on non-wood forest products for income (Yeşilbaş & Güngör, 2025). Increasing field inspections by relevant institutions and developing mechanisms that ensure the applicability of legal sanctions will support sustainability in this area.

Finally, as demonstrated by the survey findings, the incentive programs that forest villagers need most should be financed by the state in order to strengthen the economic activities of NWFP collectors and producers. Providing tax advantages and grant opportunities for small-scale NWFP enterprises would be an important step toward contributing to the local economy.

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Chapter 6

Social Sustainability and the Role of Trees in Urban Ecosystems: An Urban Forestry and Social Participation Perspective

Hasan Emre ÜNAL[1]

Recent research has revealed that urban trees play a crucial role in enhancing the environmental quality of cities and towns globally (Livesley et al., 2016). These trees contribute to urban sustainability by providing essential ecosystem services that benefit the environmental, economic, and social well-being of urban communities (Ordóñez et al., 2023). While urban forests offer numerous ecosystem services and values to cities and their residents, they also come with certain economic and environmental costs. These costs include financial burdens associated with tree maintenance and restoration, property damage, reduced visibility, and safety concerns (Turner-Skoff & Cavender, 2019; Novak et al., 2016). Green space research holds significant potential in addressing the complex environmental and social challenges faced by urban areas worldwide. For instance, green infrastructure is explicitly included in Goal 11.7 of the United Nations Sustainable Development Goals. This goal aims to ensure universal access to safe, accessible, and public green spaces for vulnerable groups such as women, children, the elderly, and individuals with disabilities by 2030 (UN, 2015).

The health and vitality of tree populations in urban green spaces are paramount for supporting ecological sustainability and community well-being. Parks, street trees, and green belts serve multiple functions, including aesthetics, carbon sequestration, public health, and social cohesion (Wang et al., 2023; Novak et al., 2016; Woodward et al., 2023). Urban forests are inherently systems composed of both natural components (trees, etc.) and human components (people living in urban areas). Therefore, it is crucial to consider both the biophysical characteristics of the trees and forested areas that make up urban forests and the human elements of the urban forest (Vogt, 2020).

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Urbanization is a rapidly increasing trend, with over half of the world's population now living in urban areas. According to the United Nations (UN), projections for 2050 suggest that 64% of developing countries and 86% of developed countries will be urbanized (Luettge & Buckeridge, 2023).

Urbanization significantly transforms natural landscapes and often leads to the degradation of existing green spaces. In this context, strategic management and community participation in urban tree care are crucial for promoting the resilience and longevity of urban forestry (Czaja & ark., 2020). Research shows that involving local communities in the management of urban green spaces not only raises awareness of their importance but also fosters a sense of ownership and responsibility among residents. This sense of ownership can lead to increased commitment and support for greening efforts (Guzman & ark., 2018; Lachmund, 2022). Communities are in a key position to support greening efforts. Raising public awareness of the health, social, environmental, and economic benefits of trees and green spaces can be achieved through public education campaigns and community programs (Woodward & ark., 2023).

Education initiatives can illustrate the intricate connections between trees and their surroundings, resulting in various benefits such as improved air quality, reduced urban heat island effect, and enhanced human emotional well-being. These initiatives can also cultivate an appreciation for tree ecosystems (Huang et al., 2017; Ababneh, 2023). For instance, research indicates that resident participation significantly contributes to the sustainability and survival of newly planted trees, underscoring the pivotal role of social engagement in the overall health of urban green spaces (Roman et al., 2015). Moreover, systematic planning and access to education are crucial for the most effective management of urban green spaces. Integrating technologies like Geographic Information System (GIS) and remote sensing can enhance strategic decision-making by identifying areas requiring tree planting, maintenance practices, and ecological monitoring (Yu et al., 2017; Song et al., 2020). By combining these technological advancements with active community participation, we can foster an informed citizenry that ensures the sustainability of urban ecosystems (Olivero-Lora et al., 2019; Egerer et al., 2024).

The Importance of Trees in Social Sustainability and Urban Life

Cities, as centers of knowledge, culture, science, and economic activity, provide individuals with diverse employment, educational, and lifestyle opportunities. However, the rapid urbanization and population density that accompany this growth pose significant challenges to urban life. Environmental degradation, increased resource demands, and unemployment are among the key factors threatening the quality of urban life. The lack of high-quality public spaces essential for socialization and recreation further exacerbates these issues, negatively impacting social well-being (Shakunthala, 2017). In response to these problems, society has begun to reconsider the environmental aspects of urban life. In recent years, the increasing rates of urbanization and the resulting degradation of urban environments have drawn public attention to the natural environment, urban forest ecosystems, and other urban green infrastructure (Oliveira et al., 2022).

Urban trees offer numerous benefits to societies, including ecological advantages such as enhancing air quality, providing habitats for urban wildlife, filtering rainwater, and contributing to various ecosystem services (Elmqvist et al., 2015). They also provide social value by beautifying concrete landscapes and offering residents privacy from neighbors (Barona et al.,2022). Moreover, urban trees mitigate climate impacts and generate economic assets (Myers et al., 2023). However, the increasing demand for urban woodlands, parks, and other green spaces is countered by ongoing urbanization, urban densification, and urban sprawl, which often lead to the loss and fragmentation of urban natural areas (UN, 2021a).

This paradoxical situation necessitates a strategic approach to sustainable urbanization. In recent years, driven by economic, social, and environmental pressures, the drive toward sustainability has surged, leading to a proliferation of sustainability plans and programs at local and global scales. A sustainable urban forest encompasses all the elements that ensure the forest ecosystem's long-term health and structure, providing the anticipated benefits and ecosystem services.

Although this definition is limited to urban forest resources, it's important to consider urban forests within the broader context of sustainability and a sustainable society. This broader context encompasses various interconnected areas, such as waste management and recycling, rainwater management, energy consumption, air and water quality, wildlife habitat protection, public health, economic vitality, social justice, and urban livability. Within this framework, sustainable urban forests clearly fit holistically (Leff, 2016).

The United Nations Sustainable Development Goals (SDGs) explicitly recognize the significance of urban green spaces. Goal 11, target 11.7, emphasizes the need for universal access to safe, inclusive, and accessible green and public spaces, particularly for vulnerable groups like women, children, older people, and individuals with disabilities (UN, 2021b). The 2030 Agenda further recognizes urban sustainability as a crucial component of sustainable development, with a specific target for urban development (SDG 11): "Make cities and human settlements inclusive, safe, resilient, and sustainable." Approximately one-third of the 231 indicators in the Sustainable Development Goals Global Monitoring Framework directly impact cities and human settlements and are measurable at the local level (Borelli et al., 2018). Sustainable cities are defined as those that develop environmentally sensitively and meet their own needs. Green spaces play a vital role in urban ecological sustainability, aiming to foster social, economic, and ecological development (Ekren, 2017). Urban forestry is a fundamental aspect of sustainable urban development, and its importance cannot be overstated. This field encompasses the cultivation, management, and protection of trees and green spaces within urban areas. One of the most significant contributions of urban forestry is its positive impact on environmental sustainability (Brito, 2023). However, it is essential to consider not only environmental but also social aspects of urban sustainability.

Social sustainability, a dynamic process, promotes interaction among diverse community groups at the neighborhood and regional levels. It fosters social solidarity by supporting the quality of cultural life. This process ensures the long-term development of societies through fundamental principles such as social equality, inclusiveness, and social justice (Nasrabadi, 2023).

Planting and maintaining the right types of trees in suitable areas is a highly effective strategy that promotes public health and well-being. Urban afforestation plays a crucial role in reducing greenhouse gas emissions by sequestering carbon through photosynthesis, actively contributing to the fight against climate change. Moreover, it constitutes a long-term public investment that yields progressively increasing ecological and societal benefits as trees mature (Woodward, 2023).

Urban forests, as per current research, can significantly contribute to the physical and mental well-being of individuals. Incorporating trees and forest landscapes into school classrooms and public spaces can enhance academic performance, foster social cohesion, and even reduce crime rates in certain areas. While urban forests offer a multitude of social advantages for city dwellers, workers, and visitors, it's important to acknowledge that these benefits are not evenly distributed across society. Inequalities in access to trees and green spaces are often associated with socioeconomic factors, ethnicity, race, and education levels. For instance, urban tree cover and open spaces tend to be more limited in low-income neighborhoods (Hanson & Frank, 2016).

Perception of Urban Forestry and Social Participation in Urban Forest Management

In recent years, trees and urban forests have been recognized as pivotal in reshaping the relationship between society and the natural environment (Nocentini et al., 2021). Research on urban and peri-urban forests has primarily focused on individuals' perceptions of the advantages provided by these green spaces. It has been found that urban residents are cognizant of the environmental and social significance of these areas (Beckmann-Wübbelt et al., 2021). These studies underscore the potential influence of urban residents' perceptions and expectations on the future management of these areas.

Various studies have investigated individuals' attitudes towards urban and peri-urban forests, as well as the factors that influence these attitudes. For instance, a study conducted in Bari, Italy, revealed that many citizens expressed a strong desire for both an increase in the number and improvement in the quality of green spaces. They also demonstrated a high level of interest in participating in urban design processes (Sanesi & Chiarello, 2006). Similarly, in Kosice, Slovakia, an urban forest designated for sale was canceled due to strong public opposition. Consequently, the area was protected under municipal regulations (Kozová et al., 2018). Another study conducted in Lalitpur, Nepal, indicated that individuals with higher education and social status possessed greater knowledge of ecosystems and perceived urban forests as crucial components of sustainable urban landscapes (Gurung et al., 2012).

Governance in urban forests involves the implementation of policies, regulations, and strategies by individuals and institutions, both formal and informal, to plant, maintain, and protect trees. This collaborative effort between local governments, civil society organizations, and citizens is crucial for ensuring the health and resilience of urban forests. An effective governance model ensures that the benefits of urban forests, such as clean air, cooling, and aesthetic value, are equitably accessible to all urban residents (Abdulai, 2025). However, one significant challenge in this process is limited public participation due to a lack of understanding of the environmental services forests provide (Lima et al., 2023).

At this point, participation becomes a crucial aspect of managing urban areas, especially those that individuals have direct interaction with. Participation involves the active involvement of the public in various processes, such as decision-making, implementation, use, and evaluation of outcomes (Igor, 2018). Public participation has emerged as a novel and more direct mechanism for enhancing the sustainable management of urban trees (Arabomen et al., 2020). However, it remains uncertain whether individuals' intention to participate in urban forestry initiatives is influenced by their perceptions of the natural environment. This perception, in turn, impacts their inclination to adopt environmentally friendly behaviors, including resource allocation for the protection of urban green spaces (Huang et al., 2021). Nevertheless, inadequate awareness and effectiveness of environmental education programs, coupled with challenges in maintaining and covering the costs of tree care, are among the primary factors that negatively affect citizens' willingness to participate in urban forestry projects (Galati et al., 2023).

From a citizen's perspective, participation in the forest sector should not be seen as a prerequisite for forest management, but rather as a widely adopted method by all forest organizations (Atmış et al., 2007). Time and financial resources are crucial in the development of participatory urban forestry. While some individuals prefer financial support over direct participation, the success of sustainable forestry policies hinges on the public's involvement at both material and physical levels (Ajewole, 2015). This becomes even more critical considering that a significant portion of urban green spaces is privately owned and should be protected as much as public lands (Woodward et al., 2023).

Citizen participation in urban forest planning and management is influenced by various factors, as highlighted by Galati et al. (2023). For instance, a study in Florina, Greece, revealed that individuals are willing to contribute financially to projects protecting green spaces because they recognize the significance of ecosystem services (Kalfas et al., 2020). Similarly, citizens in Guangzhou, China, were found to be more inclined to participate in green space planning and management due to their understanding of their role in urban life (Shan, 2012). However, these examples don't necessarily indicate equal participation among all individuals. Community participation in urban forest management varies across neighborhoods, underscoring the need for further research on the impact of local participation on urban forest conservation (Conway et al., 2011; Carreiro & Zipperer, 2008).

Understanding what motivates community participation in urban forest management and the role of knowledge in this process enables both municipalities and participants to act more effectively and in a more targeted manner when implementing community programs (Butt & ark., 2021).Public participation in governance processes allows citizens to interact with local governments, which in turn benefit local governments in several ways. These benefits include gaining new perspectives and knowledge, making decisions that align with public needs, and informing citizens about public programs. Additionally, public participation fosters communication and interaction within the community (Asah & Blahna, 2012).Urban forestry activities offer a low-risk participation model for urban residents, enabling community groups to organize around shared environmental improvement goals and develop collective action capacity. This participation not only fosters community engagement but also creates opportunities for building public trust and institutionalizing environmental awareness at the local level (Ajewole, 2015).

Education and Awareness Studies in Terms of Sustainability

Urban forests play a vital role in enhancing the quality of life for city dwellers and significantly contributing to the sustainability of cities. However, the sustainability and well-being of these ecosystems depend largely on the environmental awareness, responsible behaviors, and active participation of individuals who visit them. (Erfanian et al., 2024) Visitors' environmentally responsible actions directly impact the conservation and resilience of urban forests in the face of increasing urbanization and environmental challenges. Moreover, they ensure that these areas remain accessible and livable for future generations. Environmental behavior in urban forests is also crucial for raising environmental awareness and consciousness among urban populations. This heightened awareness can lead to increased support for urban forest conservation initiatives, strengthened public participation in environmental protection activities, and strengthened connections between individuals and nature. (Maleknia & ChamCham, 2024).

In this context, institutions involved in natural resource management increasingly employ processes that foster public participation. These processes primarily aim to enhance communication and consultation through various means, including public information dissemination, public meetings, conferences, and the establishment of advisory groups (Janse & Konijnendijk, 2007).

Urban forests serve as an invaluable learning environment for environmental education, providing concrete tools to teach ecological processes. For instance, observing wildlife and their habitats allows us to witness the competitive, interdependent, and cyclical nature of ecosystems. Additionally, assessing the effects of soil compaction on water flow and tree health, and analyzing the structure of urban green infrastructure through spatial maps showing the distribution of different tree species and their canopy density, enables us to gain insights into these processes. These practices not only enhance environmental awareness but also contribute to the understanding of urban ecosystem services (Seitz et al., 2008). For urban forestry to be successful, it is crucial to comprehend individuals' views, contributions, willingness to pay, and needs. Furthermore, it is essential to recognize not only the services provided by urban forests and trees but also the negative impacts they may have (Opoku et al., 2024). Historically, experts in urban and peri-urban forestry have primarily focused on informing politicians and raising public awareness about the significance of urban trees and forests (Konijnendijk et al., 2018).

Societies play a crucial role in protecting and developing green spaces. Effective public education campaigns and public information programs can raise public awareness about the health, social, environmental, and economic benefits of trees and green spaces. These campaigns can influence societal attitudes and expectations, driving the success of policies aimed at improving access to quality green spaces (Woodward et al., 2023).The preference for plant species in cities is largely shaped by individuals' cultural, aesthetic, and functional expectations. In this context, citizens can actively participate in the planning and sustainability of urban green spaces. However, raising public awareness is essential to effectively utilize this potential. Developing environmental education encompassing all age groups is a fundamental cornerstone of this process. Numerous studies demonstrate that environmentally based education programs enhance individuals' sensitivity to nature, indirectly influencing the knowledge base of urban planners and decision-makers (Menconi et al., 2025).

Civil society actors are increasingly playing a crucial role in promoting the potential benefits of forests in urban and semi-urban areas. By conducting applied research, providing policy recommendations, and building institutional capacity, intergovernmental and non-governmental organizations (NGOs) address knowledge gaps. These organizations also foster communication among countries, cities, and civil society to raise global awareness of the need for sustainable lifestyles (Ordóñez, 2021). Environmentally focused NGOs and international organizations, such as the World Wildlife Fund, the International Union for Conservation of Nature, the Nature Conservation Foundation, and the International Federation for Conservation of Nature, are increasingly playing a significant role in managing urban and peri-urban forests (Duinker et al., 2014). Raising awareness of the role of urban forests in sustainable urban development and developing effective educational strategies in this area are essential for achieving global sustainability goals. In this context, collaborations between cities and interdisciplinary networks that foster knowledge and experience sharing offer valuable opportunities for learning and interaction. Networks like the C40 Cities Climate Leadership Group, the Local Governments Network for Sustainability, the Urban Development Network Program, and the Carbon Neutral Cities Alliance operate effectively at national, regional, and global scales, contributing to sustainable urbanization processes. They conduct joint projects and share experiences to highlight the fundamental role of urban forests and green spaces in this process. These platforms provide significant opportunities for training, capacity building, and public awareness for all stakeholders, particularly local governments (Borelli et al., 2018).

Policy Development and Management Approaches in Urban Forestry

As the effects of global population growth and extreme weather become more pronounced, the ecological, social, and economic advantages of urban forests are gaining increasing recognition both domestically and internationally. However, in increasingly crowded urban areas, relying solely on tree conservation is insufficient for effective urban forest management. This necessitates the development and implementation of innovative and comprehensive strategies and policies (https://www.belmont.wa.gov.au, 2014).

Many urban governments are currently developing urban forest management plans, often referred to as "strategy documents," "policies," "master plans," or "action plans" (Barona et al., 2022). However, these plans are often structured at a sectoral level, which can lead to conflicts and incompatibilities with policies from other sectors regarding the use of urban open space. This underscores the need for a holistic and participatory approach to green space management. An effective urban and peri-urban forestry policy requires fostering intersectoral dialogue among different stakeholders, balancing diverse interests, and establishing a common vision for green infrastructure in and around cities (FAO, 2016).

Sustainable urban forestry plays a vital role in various sectors, including urban planning, public health, public education, climate action, land use, forestry policies (including rural areas), agricultural policies, and economic development (United Nations, 2021a). Integrating urban forestry with other sector policies is crucial to create administrative synergies, optimize resource utilization, and develop practices that align with sustainability principles.

The concept of sustainability in urban forest management has been integrated into urban forest planning processes for a long time. Today, these plans prioritize preserving and enhancing the benefits and services that urban forests provide (Steenberg et al., 2013). However, a sustainability-focused approach requires a holistic effort involving all segments of society, not just preserving tree stock in specific areas. This holistic effort encompasses complementary processes such as information exchange, benefit prioritization, setting management objectives, coordinating activities, monitoring results, and evaluating progress (Dwyer & Novak, 2003).

To manage their urban forests sustainably and effectively, cities need assessment processes that accurately define the structure of this ecosystem and provide a qualitative account of its current status (Pregitzer et al., 2019). These assessments are crucial not only for policymaking processes but also for determining the most effective implementation strategies.

Urban forestry, a holistic discipline, encompasses the maintenance and management of all green elements in urban areas to enhance the urban environment. It simultaneously focuses on planning and management to preserve urban forests, recognizing their significance as a crucial component of green infrastructure (Dutta, 2023). The primary objective of urban forest management plans is to ensure that society sustainably benefits from the environmental, social, and economic advantages provided by trees. These plans identify strategic priorities for urban forest management and systematically outline the activities and services required to achieve these priorities (American Public Works Association, 2007).

Urban forests play a multifaceted role in cities, and their sustainability should be considered not only from an ecological perspective but also from a social one. In the context of social sustainability, the role of trees and forested areas in urban ecosystems is crucial in determining the livability of contemporary cities. Urban forests contribute to social sustainability in several ways. Firstly, they provide environmental benefits, such as reducing air pollution and mitigating climate change. Secondly, they have a positive impact on social well-being, health, identity, and solidarity. Therefore, urban forestry should be recognized as a multidisciplinary field that encompasses social, cultural, and economic dimensions, beyond being merely an ecological activity.

The success of urban forestry depends significantly on the extent to which society actively participates in these processes and the level of awareness it fosters. By involving the public in decision-making and implementation, urban forests can achieve sustainability while fostering a sense of belonging and responsibility among residents for the environment they inhabit. In this regard, participatory governance models are crucial for urban forestry to progress in alignment with social sustainability objectives.

Education and awareness campaigns are crucial tools for strengthening urban residents' connection with nature, promoting environmental consciousness, and cultivating a culture of sustainability that can be transmitted to future generations. Collaborating with local governments, civil society organizations, and academic institutions to support these efforts will not only enhance the environmental resilience of urban ecosystems but also contribute to the overall well-being of the community.

In conclusion, urban forests play a crucial role in ensuring social sustainability by serving as ecological elements. They also act as strategic assets, strengthening the social fabric of urban life. To build healthier, more inclusive, and more resilient cities, it is essential to increase public knowledge, awareness, and participation in the planning, management, and protection of these area.

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Chapter 7

The Role of Camera Trapping in Wildlife Ecology and Management

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For many years, wildlife inventories were limited by the physical limitations of the human observer. To study a species, it was necessary to observe it directly or identify it through indirect observation. This limitation was particularly pronounced for large carnivores, nocturnal mammals, and shy species. Traditional methods, such as tracking or direct visual counting, often yielded estimates closer to those of unmeasurable bias (Karanth and Nichols, 1998). The observer's presence in the field inevitably altered the behavior of the species being observed, creating uncertainty in the ecology (Silveira et al., 2003).

The advent of the camera trap, a remotely triggered device capable of capturing images without the researcher's active presence, removed this obstacle. Early experiments by George Shiras III in the late 19th century using trigger wires and magnesium flashes offered the first glimpses of this potential (Kucera and Barrett, 2011), while the integration of passive infrared (PIR) sensors and digital storage in the late 20th and early 21st centuries triggered a revolution (Swann et al., 2004). Today, camera traps serve as noninvasive sentinels in the forest, continuously collecting data across previously unimaginable spatial and temporal scales (O'Connell et al., 2011).

The Technological Evolution

The development of camera traps is directly linked to the evolution of technology. Early studies used film-based systems, which were logistically problematic, limited to a single 36-exposure roll, and prone to mechanical failure (Cutler and Swann, 1999). The transition to digital systems resolved data storage bottlenecks, allowing researchers to leave their camera traps in the field for

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months and collect thousands of images (Rovero et al., 2013). This change also expanded the range of questions ecologists could ask.

Modern units, characterized by fast trigger speeds and "no-glow" infrared flashes, have significantly reduced disturbance to timid species (Meek et al., 2014). Newey et al. (2015) have argued that the detection zone, the specific area within which a sensor can be triggered, is not a static variable but fluctuates with ambient temperature and animal size. The ability to randomly place camera traps along a trail or within a habitat has allowed for greater statistical inference, a methodological distinction that distinguishes abundance estimation from biodiversity inventories (Burton et al., 2015).

The architecture of the modern camera trap shown in Figure 1 addresses many of the logistical challenges facing early ecological studies. The central component for autonomous operation is the Passive Infrared (PIR) Motion Sensor, which detects the thermal differential of passing animals (Welbourne et al., 2016). It is important to note that the detection zone governed by this sensor is not static, but fluctuates in response to ambient temperature and animal size (Newey et al., 2015). Once triggered, the Camera Lens captures data; for nocturnal imagery, the unit relies on the IR LED Array and IR Flash Filter to minimize behavioral disturbance (Meek et al., 2014).

Figure 1. External components of a modern digital camera trap

The Statistical Renaissance: Moving Beyond Indices

In ecological studies, camera traps are important not only for species identification but also for the quantitative data they provide. In this context, the

Relative Abundance Index (RAI) has been established in the literature as a standardized method based on the number of records per 100 trap-nights (Carbone et al., 2001). However, Sollmann et al. (2013) and Anderson (2001) have raised methodological concerns regarding the use of the RAI index. These researchers emphasized that the index confounds the abundance parameter with the probability of detection; therefore, high record numbers may not directly reflect population density but rather may be due to the frequency with which particular individuals are caught in traps.

Spatially Explicit Capture-Recapture (SCR)

In species with unique coat patterns, such as tigers (*Panthera tigris*), jaguars (*Panthera onca*), and ocelots (*Leopardus pardalis*), camera traps have functioned as a non-invasive marking system, allowing for the identification of individuals (Karanth, 1995; Silver et al., 2004). Although this technical capacity has paved the way for Capture-Recapture (CR) analyses, traditional CR models have methodological limitations due to the “edge effect” problem, where the effective sampling area cannot be clearly defined (Otis et al., 1978). This limitation was overcome by the Spatial Capture-Recapture (SCR) models developed by Borchers and Efford (2008) and expanded by Royle et al. (2013).

SCR models integrate the spatial location data of the stations with their capture histories to estimate the “activity centers” of individuals. Instead of just the abundance value, the density (D) is directly used. This approach, which allows the calculation of the parameter, provides more sensitive results, especially in the monitoring of endangered carnivores (Sollmann et al., 2011). Recently, SCR has been considered the most reliable method in population ecology studies of patterned species due to the consistent estimates it provides even at low population densities (Tobler and Powell, 2013).

Occupancy Modeling

Counting individuals for species such as deer and bear, which lack unique patterns that allow for individual identification, is methodologically limited. Therefore, the focus in studies on these species is shifting from population size ("how many?") to the species' spatial distribution ("where?"). In this context, MacKenzie et al. (2002) developed the "Occupancy Modeling" framework, which estimates the probability of an area being used by a species by statistically accounting for the probability of missing detection.

Camera traps are the most suitable data collection tool for this modeling approach because they provide the temporal replication necessary for calculating detection probability, eliminating the need for physical revisiting of the site

(MacKenzie et al., 2017). This method allows for high-precision mapping of species distributions by correlating them with environmental variables (covariates) such as elevation and forest cover (Bailey et al., 2014). For example, Ahumada et al. (2011) presented the first global standard assessment of tropical mammal diversity using Tropical Ecology Assessment and Monitoring (TEAM) network data in this framework. They demonstrated the effectiveness of the method in large-scale biosphere monitoring studies.

Use of Camera Traps for Understanding Behavioral Ecology

Beyond inventory studies, camera traps provide critical data on the behavioral ecology and daily activity patterns (circadian rhythms) of wild animals. Ridout and Linkie (2009) used timestamps in digital records to develop circular statistical methods, enabling the quantitative analysis of activity overlap between prey and predator species (Figure 2).

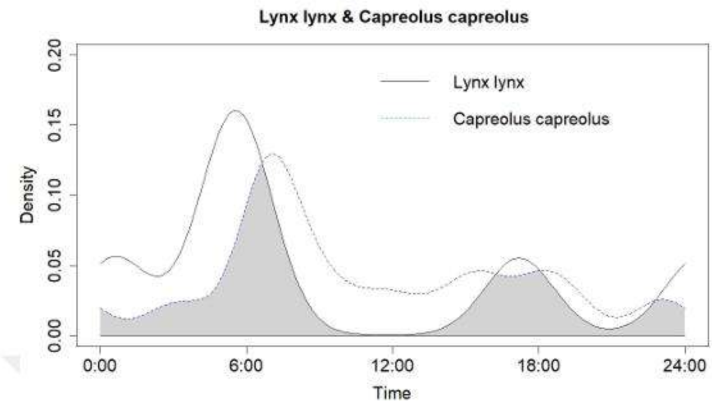

Figure 2. The prey and predator activity of Eurasian lynx (*Lynx lynx*) and roe deer (*Capreolus capreolus*) (Tekşen N. Z., 2024)

These analyses reveal complex behavioral adaptations of species; for example, Di Bitetti et al. (2010) found that sympatric felids in the Neotropics partition their activity times (temporal partitioning) to avoid direct competition. Gaynor et al. (2018) conducted a global meta-analysis, demonstrating that mammals are exhibiting more nocturnal behavior in response to human pressure, and that this may have evolutionary consequences. In addition to temporal analyses, continuous observations have enabled the recording of rarely observed behaviors, such as reproductive behaviors and interspecific interactions (Zimmermann et al., 2013).

Management and Conservation Applications

In recent years, camera traps have become an indispensable tool for collecting data on wildlife. This technology serves purposes such as apprehending criminals and detecting crime, in addition to specifically detecting poaching (Figure 3).

Figure 3. People who stole electrical cables were detected using a camera trap and arrested by the Turkish Gendarmerie (URL-1)

Hossain et al. (2016) demonstrated that camera trap data facilitates the optimization of patrol routes and the identification of illegal activity hotspots in tiger reserves. In Türkiye, the General Directorate of Nature Conservation and National Parks (DKMP) actively uses camera traps to protect and monitor endangered species such as the Anatolian Leopard (*Panthera pardus tulliana*). Beyond mere presence data, these devices provide concrete forensic evidence necessary to initiate legal action against poachers.

Sawaya et al. (2013) employed genetic sampling and camera traps to assess the effectiveness of crossing structures in Banff National Park, and similar practices are also observed in Türkiye. For example, Tuttu et al. (2023) installed camera traps on the ecological bridges of the İzmir-Çeşme North Marmara Highway, providing important confirmation that these infrastructures serve as functional corridors for species such as wild boar, thus justifying infrastructure investments with empirical evidence.

Camera traps are also a powerful tool for the early detection and management of invasive species. Glen et al. (2013) have highlighted the effectiveness of their approach in detecting or confirming the eradication of alien species in island ecosystems. This methodology has significant potential for Turkish wetlands, for example, in monitoring the spread of the invasive coypu (*Myocastor coypus*)

(Figure 4), particularly in areas such as Iğdır and Edirne, where dense vegetation often prevents direct observation.

Figure 4. A coypu captured with cameratraps in Türkiye (URL-2)

Challenges, Ethics, and the Future

The widespread use of camera traps presents a complex set of operational and ethical challenges. The exponential accumulation of photographic data, often exceeding tens of thousands of images per project, has led to a "data dump" for researchers (Harris et al., 2010). Because processing such a large amount of data is time-consuming, the integration of Artificial Intelligence and Machine Learning has become necessary for automated taxonomic classification of species. In addition to the logistical unsustainability of manually processing such terabytes of data, ethical concerns regarding incidental surveillance of human populations pose a significant normative challenge (Sandbrook, 2015; Norouzzadeh et al., 2018; Sharma et al., 2020). Especially in areas with a high concentration of indigenous people, researchers must maintain a delicate balance between monitoring illegal poaching and respecting the privacy rights of local villagers (Figure 5) and pastoralists engaged in legal activities. Additionally, camera trap theft poses a high risk, especially in areas experiencing resource conflicts, and this remains a security vulnerability, even though SIM card camera traps are becoming more widespread (Meek et al., 2015).

Figure 5. Image of roe deer and local people using the same area captured by a camera trap

In addition to the logistical burden and ethical concerns associated with camera trap monitoring, there are further challenges, including data security and ownership. In many regions, there are no clear legal or ethical guidelines regarding how camera trap footage should be stored, who can access it, or how it can be used, creating the risk of misuse or unauthorized distribution. At the ecological level, some species may alter their behavior in response to the devices' odor, light reflection, or faint mechanical noises, which can impact sampling results, particularly for rare or disturbance-sensitive wildlife. Furthermore, large-scale camera trap projects require intensive and long-term maintenance. Frequent battery changes, device repairs, and safe handling of SD cards are time-consuming and costly, especially in remote areas. Furthermore, local residents may perceive the devices as surveillance tools rather than scientific instruments, which can lead to distrust if proper communication and consent processes are not implemented. These factors highlight the importance of careful planning, transparent data management, and community participation in camera trap research.

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Chapter 8

Mushroom-Based Rural Development Strategıes for Local Communıtıes in Protected Areas

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Perhaps the most important issue for economies today is increasing individual and societal welfare; that is, ensuring economic development and its sustainability, with rural development being considered the most important component (Ata and Dallı, 2024). Rural development has become multidimensional, encompassing various elements such as the conservation of natural resources and the sustainable management of ecosystem services. Forest ecosystems and forest products play a particularly important role in achieving rural development due to their impact on both the livelihoods and quality of life of low-income groups living in rural areas. Forests provide numerous benefits to society, ranging from timber production to oxygen supply, clean water production, and the diversity of non-timber products (Gençay & Çelik, 2025).

In addition to timber production from these ecosystems, non-wood forest products (NWFPs) also have strategic importance in terms of both conserving biological diversity and strengthening rural economies. The demand for NWFPs worldwide is increasing, depending on current trends in individuals' lifestyles and consumption (Toksoy et al., 2010; Vacik et al., 2019; Wolfslehner et al., 2019; Arslan et al., 2021). Natural resources such as edible mushrooms, which are non-timber forest products collected from forest ecosystems, are at the center of sustainable development approaches, particularly in rural communities in developing countries, because they can be produced with low capital, provide high nutritional value when consumed, and have commercial importance. Mushrooms have a wide range of applications due to both their important ecological role and their use in food and medicine (Wani et al., 2010). Studies have found that mushrooms are effective against various diseases such as cancer, asthma, allergies, and diabetes (Bahl, 1983; Turp and Boylu 2018; Antmen and

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Ögenler, 2021; Yavuz and Gül, 2022). This resource, one of the world's largest food sources and one of the delicious foods of the future (Wani et al., 2010), offers income opportunities to rural communities without harming the ecological balance when managed correctly. In this context, mushroom gathering and related activities serve as a bridge between the environmental and socio-economic goals of rural development.

According to the Millennium Ecosystem Assessment Report (Millennium Ecosystem Assessment, 2005), ecosystem services are: products obtained from ecosystems (Provisioning Services) (Food, Fresh water, Fiber, Fuelwood, Biochemicals, genetic resources); benefits derived from the regulation of ecosystem processes (Regulating Services) (Climate, disease and water regulation, water purification, pollination); non-material benefits derived from ecosystems (Cultural Services) (Spiritual and religious, recreation and ecotourism, aesthetic, inspirational, educational, sense of place, cultural heritage) and services necessary for the production of all other ecosystem services (Supporting Services) (Soil formation, Nutrient cycling, Primary production) (MEA, 2005). Globally, forests play an important role in sustainable development due to their functions such as carbon storage, regulation of the water cycle, mitigation of climate change, soil protection, and maintenance of biological diversity (FAO, 2022; IPCC, 2023). In addition to these functions, the economic contributions provided, particularly through non-wood forest products, demonstrate that forests are critical not only for ecological but also for socioeconomic sustainability. A study by Mızraklı et al. (2008) estimated that the value of the ecological functions of forests, which include products and services that form the basis of human life, is 2,000 times greater than the value of their timber production function. Recent studies show that forests are under threat from biodiversity loss, land use change, climate pressures, and overexploitation; therefore, sustainable management principles have become even more important (Seidl et al., 2017; Seddon et al., 2021). NWFPs, including fungi, is part of the natural cycle of these ecosystems and is directly related to climatic, physiographic, and edaphic factors. Therefore, the evaluation of fungal resources requires sustainable use models that not only constitute an economic activity but also contribute to the preservation of forest ecosystem health. This situation demonstrates that mushroom-based rural development is an area compatible with environmental sustainability principles.

Mushroom-based rural development strategies are gaining importance worldwide as a model integrated into analyses aimed at diversifying the production, culture, and livelihood activities provided by NWFPs from an economic perspective. The high nutritional value of mushrooms, their low collection costs, and their high market demand (Wani et al., 2010) make them both accessible and a source of income for rural communities (Güngör et al., 2018). Research conducted in different regions of Europe has revealed that mushroom gathering is not merely a food activity; it also plays a critical role in regional development, tourism, and the preservation of cultural heritage. For example, mushroom festivals, guided nature walks, and gastronomic events organized under the name of "mycotourism" in regions such as Castile and León in Spain directly contribute to the local economy and revitalize rural tourism (de Román and Boa, 2006; Bonet et al., 2014; Suazo and Viana-Lora, 2022). Similarly, in Italy, mushroom collection and marketing activities have been supported by cooperative models; thus, local producers have been involved in drying, packaging, and branding processes, enabling them to achieve higher added value (Sitta and Floriani, 2008). In Asia, China in particular has become a world leader in both cultivated mushroom production and the sustainable harvesting of wild mushrooms; mushroom cultivation has been highlighted as a strategic tool for reducing rural poverty (Zhang et al., 2014). In Japan, local mushroom species and other wild edible products in regions such as the Noto Peninsula (Ishikawa Prefecture) have become an important element of regional branding processes by being combined with gastronomy, education, and cultural heritage components (Chen and Qiu, 2012). These examples demonstrate that mushrooms are not only an NWFPs but also a multifaceted development tool for sustainable income, cultural vitality, and nature-based tourism in rural economies. Therefore, mushroom-based activities constitute a concrete example of sustainable development activities that contribute to the conservation of biological resources and create new economic opportunities for rural communities.

Turkey possesses significant potential in terms of NWFPs due to its biological diversity and distinct ecological regions. According to OGM data, approximately 300 NWFPs species in the country can be economically evaluated; these products play an important role in the income diversity of rural communities (OGM, 2016). In addition to high-value export products such as laurel, thyme, sage, and chestnuts, wild mushrooms have also gained importance both in local consumption and in the market. Wild mushroom gathering is particularly widespread in the Black Sea, Marmara, and Aegean regions of Turkey, providing seasonal income for rural households. A study conducted in the Istranca Mountains revealed that wild mushroom gathering contributes significantly to the family economy in many villages, but this potential cannot be fully realized due to a lack of cooperatives, processing, and marketing (Yılmaz, 2024). In addition, Circular No. 302 regarding NWFPs management aims to protect resources by determining the necessary permit and control processes for the sustainable harvesting of wild mushrooms (OGM, 2016). Studies on Turkey's natural mushroom diversity show that it offers significant opportunities for both scientific research and rural development applications, particularly due to the rich macrofungus flora of the Black Sea Region (Sesli et al., 2020). Therefore, mushroom resources in Turkey are a strategic area where biodiversity policies and rural development approaches intersect.

The Context of Küre Mountains National Park

Küre Mountains National Park (KDMP) is an important protected area located within the borders of Kastamonu and Bartın provinces in the Western Black Sea Region, which was declared a national park in 2000. With a core area of approximately 37,753 hectares and an extensive buffer zone, it is considered one of Turkey's richest areas in terms of biological diversity (Öztürk, 2005). Its designation as "One of Europe's 100 Forest Hotspots" by the World Wildlife Fund (WWF) in 1998 contributed to the area's international significance (WWF, 1998). Furthermore, by obtaining PAN Parks certification in 2012, it became the 13th protected area in Europe with PAN Parks certification, attracting attention with its high protection quality and unspoiled wildlife habitats. KDMP, with its karstic structure, caves, deep canyons, waterfalls, and forest ecosystems, is among the areas cited as examples in Turkey in terms of both protected area management and sustainability.

The Küre Mountains and their immediate surroundings are considered one of Turkey's important regions in terms of macrofungus diversity. The Turkey macrofungus list published by Sesli et al. (2020) emphasizes that the region has a high diversity of fungi, thanks to its humid forest habitats and old-growth beech (Fagus orientalis) and hornbeam (Carpinus betulus) communities. Studies conducted in the KDMP and its surrounding area have reported 104 macrofungi (Yeşilbaş, 2015; Oğuz, 2015; Özkazanç et al., 2018), as well as 17 microfungi species identified on Carpinus species (Erdoğdu and Hüseyin, 2011). The edaphic and physiographic characteristics of the region contribute to the enrichment of fungal habitats. In this context, KDMP is not only a protected ecosystem but also an important natural area for fungal ecology and biodiversity research.

Rural life in the villages surrounding KDMP largely depends on activities such as forestry, traditional agriculture, animal husbandry, beekeeping, and the collection of non-timber forest products. As the region faces structural problems such as an aging population and the migration of young people to cities, the diversification of income sources is important for rural development (İnan and Konyalı, 2021). Ecotourism has emerged as an alternative activity to be developed in rural settlements around the national park in recent years. The rich flora and fauna diversity, cultural landscape, and hiking trails of the Küre Mountains hold significant potential for rural tourism (Öztürk, 2005). However, obstacles such as infrastructure deficiencies, marketing inadequacies, and low levels of organization stand in the way of sustainable rural development. Therefore, development strategies around the KDMP must be approached within a framework that protects natural resources, values the knowledge and experience of the local community, and increases income diversity.

Mushrooms have long been considered an important natural resource in the villages around KDMP, both economically and culturally. The local people collect wild mushrooms in the spring months and use this product for household consumption and also sell it in markets to earn seasonal income. Turkey's macrofungus literature reports that species recognized by the public and having economic value in the KDMP area include Cantharellus cibarius, Boletus edulis, and Morchella spp. (Sesli et al., 2020). Mushroom gathering activities are particularly important for providing additional income for women and the elderly, thus serving a strategic function in terms of gender equality (Yılmaz, 2024). Furthermore, as mushroom gathering is an activity based on traditional ecological knowledge passed down from generation to generation, it contributes to strengthening local culture and maintaining the human-nature relationship. However, issues such as collecting the wrong species, overharvesting, and inadequate market channels make the sustainable use of mushroom resources difficult. Therefore, mushroom-based activities must be managed in terms of both their ecological and socioeconomic dimensions.

Sustainability

Rural development processes are no longer defined solely by economic growth; they are now addressed within a framework that encompasses multiple dimensions, including social content, environmental protection, and institutional governance. This multidimensional approach to sustainability also provides a fundamental framework for evaluating mushroom-based activities in protected areas such as KDMP. In this context, sustainable development requires equal consideration of environmental, economic, social, and governance (institutional) dimensions (Cachipuendo et al., 2025). Within this multidimensional approach, mushroom-based rural development activities are seen as a strategy that bridges the social and economic benefits of renewable natural resources with the sustainability of forest ecosystems. Therefore, activities such as mushroom collection, processing, and marketing, when planned with consideration for all four dimensions of sustainability, will offer solutions that can be integrated into rural development.

Mushroom harvesting activities require a delicate balance in natural forest ecosystems; excessive and uncontrolled harvesting can lead to habitat destruction, disruption of micro-ecosystems, and a decline in mushroom populations. Mushroom harvesting without consideration for the carrying capacity of forest ecosystems can cause ecological pressure. Such activities carry the risk of a “conservation-use” conflict in the context of a national park, which is a protected area. For example, a study examining the relationship between forests and sustainable development highlighted the critical importance of synergies and trade-offs between the social and environmental functions of forests and their product production potential; it emphasized that carrying capacity and regeneration processes must be considered for sustainable forest management (Nurrochmat et al., 2022). Therefore, mushroom harvesting strategies should be planned and implemented not only for economic benefit but also for ecosystem health.

From the perspective of local communities, mushroom-based activities are not only an economic livelihood but also of great importance in terms of cultural knowledge, community solidarity, and the sustainability of traditional knowledge practices passed down from generation to generation. While issues such as migration, aging populations, and limited job opportunities for young people are prevalent in rural areas, such local activities can contribute to strengthening community ties and developing participatory governance (Barbir, 2012). In this context, the social dimension of mushroom use, such as the place of mushrooms in local culinary culture, the sharing of common knowledge during nature walks, and the activation of local groups in festivals or the marketing process, should be addressed within the framework of sustainable development.

Mushroom-based activities are particularly noteworthy in rural areas for their capacity to generate seasonal additional income. However, as in many countries, mushroom prices in Turkey can vary depending on the species, season, availability, and market demand, leading to fluctuations in producer income. Studies examining European rural areas emphasize that mushrooms and other non-wood forest products can contribute 10–30% to household income, and that processes such as cooperatives, processing, packaging, and branding can further increase this value (Lovrić et al., 2020). Similarly, in regions where mushroom picking and mushroom-based tourism practices converge, it is reported that local product sales, guiding services, and gastronomy events directly contribute to the local economy (Rovira et al., 2022). In this respect, mushrooms can be considered not only as a raw material but also as an integrated product that generates added value in the rural economy.

Governance capacity, legal framework, and inter-institutional cooperation are of critical importance in all activities carried out in protected areas such as the Küre Mountains. Natural mushroom collection, production, and sales processes in Turkey are regulated by the General Directorate of Forestry's legislation on non-timber products and Circular No. 302; permit, inspection, and registration processes are implemented to ensure sustainable use (OGM, 2016). Specifically for protected areas, the General Directorate of Nature Conservation and National Parks (DKMP) operates mechanisms for balancing use and conservation, educational activities, monitoring activities, and local stakeholder participation within the scope of the National Park Long-Term Development Plan. International literature emphasizes that stakeholder participation, information sharing, and joint decision-making processes in protected area management increase the support of rural communities and that this is decisive for long-term sustainability (Borrini-Feyerabend et al., 2014). Therefore, mushroom-based rural development practices must be addressed within a strong and inclusive governance framework.

The AHP Approach and Analytical Framework

The Analytic Hierarchy Process (AHP) is one of the most widely used methods among multi-criteria decision-making (MCDM) approaches and aims to systematically analyze complex decision problems within a hierarchical structure. This method, which is essentially a measurement theory based on priorities obtained from pairwise comparisons of elements (Daşdemir, 2022), was developed by Thomas Saaty (1980). Saaty developed AHP as a contemporary method for addressing intricate decision-making challenges, enabling decision-makers to prioritize options for better outcomes (Bayram, 2021). AHP has a wide range of applications in areas such as forest management, rural development, ecotourism planning, and the sustainable assessment of natural resources. In recent years, studies have shown that AHP has been effectively used in weighting sustainability criteria, evaluating alternative policy options, and incorporating stakeholder views into decision-making processes (Güngör and Şen, 2024; Grošelj et al., 2024; Dissanayake et al., 2025; Güngör and Yeşilbaş, 2025a; 2025b). In this respect, AHP is used as a flexible and reliable tool in both scientific and applied decision-making processes (Ezquerro et al., 2019).

In a multidimensional area such as Küre Mountains National Park, where ecological, economic, and social elements must be evaluated together, the AHP method is a suitable method that can be used for mushroom-based rural development. AHP can systematically weight many interrelated criteria, such as the protection of mushroom resources, the development of income-generating activities, the strengthening of social acceptance, and the enhancement of institutional capacity, to show which activities are more sustainable. AHP can be used with versatility in decision-making processes (Bayram et al., 2018). The literature also emphasizes that AHP is an effective decision support mechanism, particularly in protected areas, for sustainable use, determining rural development strategies, resource allocation, and tourism planning (Kangas et al., 2008). Therefore, there is a natural methodological fit between the subject of this study and AHP.

In this research, the AHP hierarchy is structured based on the four fundamental dimensions of sustainable development: environmental, economic, social, and institutional criteria. Environmental criteria include elements such as the protection of mushroom habitats, biodiversity, and ecosystem health, while economic criteria encompass income level, added value, market access, and cost elements. Social criteria include qualities such as social acceptance, traditional knowledge, employment impact, and the participation of vulnerable groups; while the institutional dimension includes governance elements such as legislation, monitoring and control capacity, local organization, and stakeholder cooperation. These criteria were selected based on both the international frameworks for sustainable development (UN-SDGs) and local conditions, creating a structure consistent with similar studies (Diaz-Balteiro et al., 2017).

The AHP application was carried out by following a four-stage systematic process (Figure 1). In the first stage, a hierarchical structure was developed with the aim of selecting KDMP sustainable mushroom-based development strategies. This structure is based on the four fundamental dimensions of sustainable development—environmental, economic, social, and institutional criteria—and includes four sub-criteria and four alternative strategies under each main criterion.

In the second stage, Saaty's 1-9 scale was used to create pairwise comparison matrices. In this scale, a value of 1 indicates that two criteria are of equal importance, a value of 3 indicates that one criterion is slightly more important than the other, a value of 5 indicates a strong superiority, a value of 7 indicates a very strong superiority, and a value of 9 indicates absolute superiority. Intermediate values (2, 4, 6, 8) provide ratings between these basic values.

In the third stage, the data required for the AHP analysis was provided by a decision-maker group (DM) consisting of 10 experts in the field. This group consisted of 2 experts from the General Directorate of Nature Conservation and National Parks (DKMP), 2 personnel from the General Directorate of Forestry

(OGM), 2 representatives from local cooperatives, 2 village heads from the region, and 2 academics conducting research on the subject. Care was taken in selecting participants to ensure a balance representing both conservation policies and local practices.

In the fourth and final stage, weight calculations were performed on the collected data, and consistency analyses were conducted. The eigenvector method was used for all calculations, and consistency ratios (CR) below 0.10 were required.

The strategies to be evaluated in the AHP analysis were determined under four headings, taking into account field conditions and local stakeholder opinions.

1. Controlled Mushroom Harvesting

This strategy aims to develop sustainable harvesting techniques and implement usage models appropriate to transport capacity.

2. Mushroom Processing and Cooperative Marketing

The goal is to organize local producers and enable them to add value through drying, packaging, and branding processes.

3. Mushroom-Based Ecotourism

This strategy offers a nature-based income model that includes activities such as mushroom observation walks, gastronomic events, and guided tours.

4. Cultivation of Edible or Medicinal Mushrooms

This is considered an option for creating sustainable year-round income based on controlled production in buffer zone villages.

These four strategies have been included in the scope of the study in terms of their suitability for both the demands of local communities and the conservation principles of the national park.

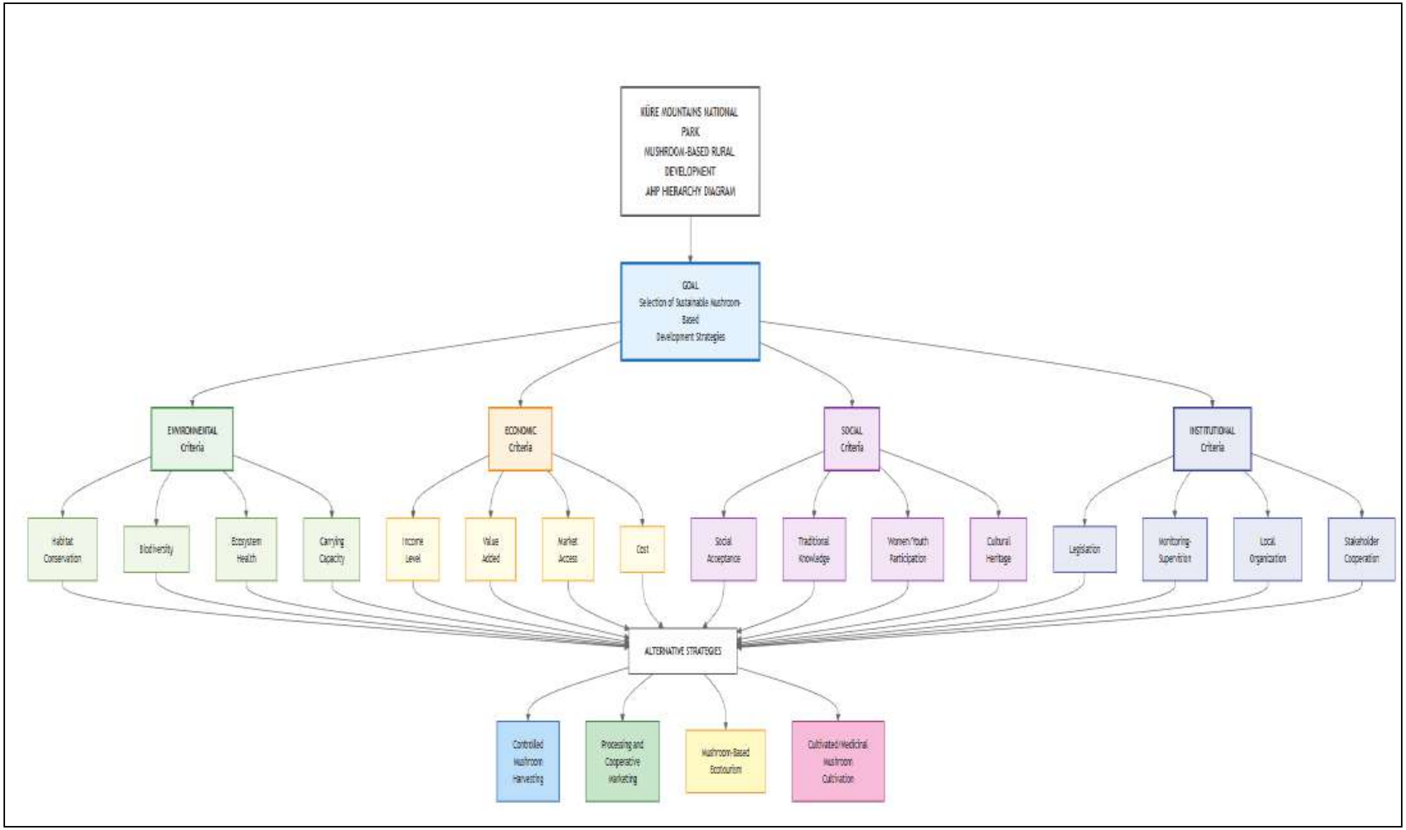

Figure 1. AHP Hierarchy

Application, Evaluation, and Interpretation

The results of the AHP analysis show that environmental criteria have the highest weight. In the evaluation conducted at the main criteria level, the environmental dimension ranks first with a weight of 32.1%, followed by economic criteria with 28.3%, social criteria with 22.7%, and institutional criteria with 16.9%. This distribution clearly demonstrates the priority given to ecosystem integrity and the sustainability of natural resources in a protected area such as KDMP.

In the assessment of environmental sub-criteria, habitat protection had the highest weight at 30.2%, followed by biodiversity (25.6%), ecosystem health (22.4%), and carrying capacity (21.8%). In economic sub-criteria, income level was determined as the most important factor at 33.5%, followed by added value (25.9%), market access (24.4%), and cost (16.2%). In the social dimension, social acceptance stands out with a weight of 32.1%, while in the institutional dimension, compliance with legislation is considered the most important sub-criterion with 31.8%.

The final evaluation of alternative strategies shows that controlled mushroom harvesting activities have the highest performance with 0.311 points. This strategy was followed by mushroom-based ecotourism with 0.266 points, processing and cooperative marketing with 0.222 points, and cultural or medicinal mushroom cultivation with 0.201 points. The prominence of controlled mushroom harvesting stems from this strategy being the option that best balances environmental sustainability and economic benefit.

The methodological validity of the AHP analysis was tested through consistency analyses conducted at all decision levels. The consistency ratio (CR) at the main criteria level was calculated as 0.015. At the sub-criterion level, the CR was determined to be 0.019 for the environmental dimension, 0.021 for the economic dimension, 0.023 for the social dimension, and 0.021 for the institutional dimension. In the evaluation of alternative strategies, the CR value was calculated as 0.018.

All these values are well below the 0.10 threshold value recommended by Saaty. This indicates that the decision-makers' assessments are highly consistent, that the pairwise comparisons were performed reliably, and that the results obtained are methodologically valid. In the AHP literature, CR values below 0.10 indicate that the analysis results are at an acceptable level of consistency.

The calculation of the overall consistency ratio as 0.019 proves that this study applied the AHP methodology correctly and systematically. When compared to consistency ratios obtained in similar studies (Kangas et al., 2008; Diaz-Balteiro et al., 2017), this value remains at a very low level.

The results of the AHP analysis show that environmental sustainability plays a central role in determining mushroom-based rural development strategies in Küre Mountains National Park. The high weight value of 30.2% assigned to environmental criteria indicates that decision-makers have adopted the ecosystem-focused approach required by protected area status. This finding is consistent with the results of similar studies conducted by Bonet et al. (2014) in protected areas in Spain.

The ranking of alternative strategies indicates that controlled mushroom harvesting is the most suitable option. The main reason this strategy stands out is that it is based on carrying capacity and sustainable harvesting principles, thus best ensuring the balance between conservation and use. Mushroom-based ecotourism, which ranks second, reflects the potential contribution of nature-based tourism activities to rural economies. Studies conducted in Spain by De Román and Boa (2006) and Suazo and Viana-Lora (2022) similarly emphasize that mushroom tourism can be an important tool for rural development.

The fact that processing and cooperative marketing strategy ranks third indicates that, despite the economic added value potential of this activity, it is subject to a more cautious assessment in terms of environmental suitability in the context of protected areas. The fact that mushroom cultivation for culinary or medicinal purposes received the lowest score indicates that this activity requires controlled conditions even in buffer zones and may potentially exert pressure on natural ecosystems.

In light of the findings, a series of recommendations can be made for the development of mushroom-based rural development policies in KDMP:

• Controlled mushroom collection activities should be regulated within the framework of carrying capacity and sustainable harvesting techniques, and the local population should be educated on this subject.

• Ecotourism activities should be integrated with controlled collection to develop an integrated model that provides both environmental protection and economic gain.

• Cooperative models for processing and marketing should be supported, and local producers should be encouraged to develop value-added products.

• Institutional capacity must be strengthened to ensure that all these activities can be carried out sustainably.

Effective implementation of legislation, development of monitoring and control mechanisms, and ensuring the active participation of local stakeholders in decision-making processes are fundamental conditions for long-term sustainability. As emphasized by Borrini-Feyerabend et al. (2014), stakeholder participation and joint decision-making processes in protected area management increase the support of rural communities and strengthen sustainability.

This study has demonstrated that the AHP methodology can be used as an effective decision support tool in evaluating natural resource-based rural development strategies in protected areas. The results obtained are instructive not only for KDMP but also for similar protected areas.

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Chapter 9

Invisible Architects of Forest Ecosystems: Fungi

Mertcan KARADENİZ[1]
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Forest ecosystems are far more than just the visible canopy of trees; they function as a dynamic mosaic of complex biotic and abiotic interactions. While often overlooked, fungi play a fundamental and critical role in the sustainability and resilience of these systems. Although fungi have historically been overshadowed by the study of plant and animal biology, revolutionary advancements in molecular techniques over the last two decades have thoroughly illuminated their fundamental and unique roles in ecosystem processes (Peay et al., 2016).

The post-2010 era marks a turning point in fungal ecology studies. The widespread adoption of advanced molecular techniques, such as next-generation sequencing (metagenomics, metatranscriptomics), has revolutionized our understanding of the biodiversity and functions of subterranean fungal communities (Lindahl et al., 2013). Unlike traditional morphological identification methods, these techniques have enabled the simultaneous identification of thousands of fungal species within soil and dead wood, while also determining their active roles through transcriptomic analyses (Baldrian, 2019). Current estimates suggest that fungal biodiversity may encompass tens of millions of species, indicating that the functional integrity of forest ecosystems depends largely on the activities of these microscopic fungal networks, far beyond the influence of macroscopic organisms.

Regarding the sustainability and health of forest ecosystems, three primary ecological functions of fungi are vital: Decomposition (Saprotrophy), Symbiosis (Mutualism), and Pathogenesis (Parasitism) (Boddy et al., 2008). Current studies in fungal ecology have demonstrated that these roles not only regulate biological interactions at the local level but act as major drivers controlling carbon and nutrient cycles on a global scale (Treseder and Holden, 2013). For instance, in Boreal forests (Taiga), the key role of fungi in decomposition processes and

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carbon storage is considered a determinant factor for global climate dynamics, as it directly influences the amount of CO2 released into the atmosphere (Clemmensen et al., 2013; Aydin et al., 2019).

Fungi exhibit immense morphological and genetic diversity. This diversity is a fundamental factor ensuring functional redundancy within the ecosystem (Allison and Martiny, 2008). Functional redundancy implies that if one fungal species is lost, another species with a similar ecological role can sustain that function. This characteristic significantly increases ecosystem stability and resilience against stress factors such as climate change and habitat fragmentation (Crowther et al., 2019). Furthermore, species richness across different mycorrhizal types maintains forest productivity by adapting to varying environmental conditions such as temperature, humidity, and pH (Tedersoo et al., 2014).

This chapter will examine the broad ecological roles of fungi—ranging from decomposition processes to the complex biotic interactions they establish with plants and insects—and adopt a holistic approach to discuss how they, as the 'invisible architects of the forest,' shape biological diversity and ecosystem resilience. Specifically, the roles of fungi in breaking down recalcitrant polymers like lignin (Decomposers), connecting plants via mycorrhizal networks (Symbionts), and regulating ecosystem dynamics as pathogens (Pathogens) sit at the center of processes occurring both above and below the forest floor (Floudas et al., 2012).

The "Omics" revolution in biology during the late 2000s allowed fungal ecology to evolve from a sub-discipline into a central focus of ecosystem biology (Martin, 2014). While classical ecology relied mostly on observable fruiting bodies (caps) or laborious laboratory isolation and culture-based methods for fungal detection (Bridge and Spooner, 2001), next-generation sequencing techniques (particularly ITS region sequencing) now allow for the extraction of genomic footprints of tens of thousands of fungal taxa from a single teaspoon of soil (Schoch et al., 2012)

1. **True Level of Biodiversity:** It is now understood that fungal species diversity is many times greater than previously estimated, with most species being microfungi that live entirely underground without producing fruit (Hawksworth and Lücking, 2017).
2. **Determination of Functional Status:** Metatranscriptomic analyses show not only the presence of fungal species in an ecosystem but also which genes they are actively using at that moment (e.g., genes for lignin degradation or nutrient exchange). This has provided a functional understanding of how

fungal communities respond to seasonal and environmental stresses (Baldrian et al., 2012)

3. **Large-Scale Mapping:** Molecular data have made it possible to map the geographic distribution patterns of fungal communities on a global scale. Researchers such as Tedersoo et al. (2014) have identified continental-scale differences in the roles of saprotrophic and mycorrhizal fungi in carbon and nitrogen cycles across diverse biomes, from Boreal to tropical forests. The fact that a large portion of fungal biomass is concentrated in the soil has shown that assessing forest health by looking solely at the condition of trees is insufficient. The structure and function of fungal communities are now accepted as primary indicators of the forest's long-term stability and ecosystem services (Orgiazzi et al., 2016; Bar-On et al., 2018; Baç & Güneş Şen, 2025).

Masters of Recycling: Saprotrophic Fungi

Saprotrophic (decomposing) fungi are the most important recycling agents of the biosphere within the forest ecosystem (Boddy et al., 2008). By breaking down dead wood, leaf litter, and animal remains, these fungi release essential nutrient elements bound in these materials (Nitrogen, Phosphorus, Sulfur) and return them to the soil (Schimel and Bennett, 2004). This process is a prerequisite for plant growth, soil fertility, and nutrient flow throughout the entire ecosystem (Wardle et al., 2004). What makes saprotrophic fungi unique is that they are the only eukaryotic organisms capable of breaking down complex aromatic polymers like cellulose and, specifically, lignin, which are the main structural components of wood (Cragg et al., 2015). This critical ability is achieved through powerful extracellular enzyme systems such as Laccase, Manganese Peroxidase (MnP), and Lignin Peroxidase (LiP) (Ruiz-Dueñas and Martínez, 2009). The decomposition roles of fungi can be classified based on the wood components they target: White-Rot Fungi, Members of the Basidiomycota, these fungi degrade lignin and cellulose simultaneously, or primarily lignin, causing intensive decay of the entire wood structure. Due to their ability to completely mineralize lignin, they represent one of the most significant control points in the global carbon cycle (Cornwell et al., 2008). Floudas et al. (2012) demonstrated their importance in controlling the carbon budget of forest ecosystems by examining the carbon cost these fungi incur to break down lignin. In contrast, Brown-Rot fungi primarily target cellulose and only modify lignin. Rather than completely breaking down lignin, they leave it behind as a dark, amorphous residue that is difficult to decompose (Goodell, 2003). This residue forms a significant pool of soil organic matter (Humus), contributing to long-term carbon accumulation in forest soils (Clemmensen et al., 2013; Almansouri et al., 2020).

Preston and Lenton (2013) argued that the role of these decomposers was a fundamental factor in the evolution of the terrestrial carbon cycle.

The breakdown of lignin and cellulose brings with it the mineralization of nutrients such as Nitrogen (N) and Phosphorus (P), which can be limiting factors for plant growth (Manzoni et al., 2010). Fungi initially uptake these nutrients into their own biomass (immobilization). Subsequently, the decomposition of this biomass (via death of fungal hyphae or consumption by microfauna) allows for the release of nutrients in forms accessible to plants (e.g., ammonium) (mineralization) (Hodge et al., 2000) (Figure 1).

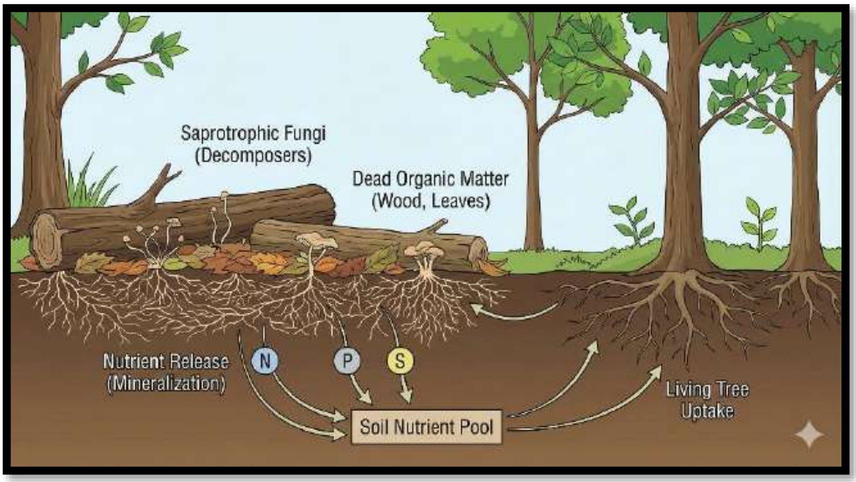


Figure 1. Diagram of the nutrient recycling and mineralization process occurring through saprotrophic fungi in the forest ecosystem. (Google Gemini, 2025a)

Lindahl and Clemmensen (2017) highlighted the key role of fungi in regulating the movement and availability of nitrogen in forest soils. Fungal biomass represents one of the largest nitrogen pools in the soil due to rapid nitrogen cycling. Current research indicates that the impact of decomposer fungi on the ecosystem is not limited to decomposition rates alone but also controls the balance between carbon transfer to the soil and its long-term storage (Averill et al., 2014). Under global pressures such as climate change and land-use changes, shifts in the structure and function of decomposer fungal communities threaten the stability of the global carbon cycle (Treseder et al., 2016).

Architects of Shared Life: Symbiont Fungi

The most vital role of fungi in the forest ecosystem is found in mycorrhizae, the mutualistic (mutually beneficial) symbiotic relationships they establish with plants (Smith and Read, 2008). This relationship refers to the joint structure formed where fungal hyphae merge with plant roots to exchange nutrients (van der Heijden et al., 2015). The main types of mycorrhizae vary depending on the ecosystem. Ectomycorrhiza (ECM) is associated with trees such as oak, pine, and beech in temperate and boreal forests. ECM forms a sheath (mantle) around the roots and establishes a network between cells known as the Hartig net. In contrast, Arbuscular Mycorrhiza (AMF) is the most common type worldwide; it penetrates the cell walls of plant roots to form tree-like structures called arbuscules.

Mycorrhizal fungi provide two critical ecological services to plants: enhanced nutrient and water uptake (Simard et al., 2002) and protection against abiotic stresses (Mohan et al., 2014). Fungal hyphae are much thinner than plant roots and possess a larger surface area, allowing them to collect nutrients—especially those with low mobility like Phosphorus (P) and Nitrogen (N)—much more effectively and transfer them to the host plant (Cairney, 2011). In return, the plant provides a significant portion of its photosynthesized carbon to the fungus as an energy source (Hobbie, 2006). This symbiotic partnership also significantly increases the plant's resilience to environmental challenges such as drought, high temperatures, and heavy metal stress in the soil (Kivlin vd., 2013). However, researchers like Hogberg et al. (2017) have drawn attention to the complex aspects of mycorrhizal roles, showing that ECM fungi can, in some cases, restrict soil organic matter accumulation by aiding in nitrogen fixation.

One of the most exciting findings of recent research is that mycorrhizal fungal hyphae create vast, interconnected networks beneath the soil—a phenomenon popularly referred to as the “Wood Wide Web” (Simard et al., 1997) (Figure 2). These networks connect not only individual plants with fungi but also different individuals and even different species across a forest (Simard et al., 1997). Through these networks, critical ecological processes occur:

Carbon and Nutrient Transfer: Shaded seedlings or small saplings can receive carbon from mature, sun-exposed trees (Klein et al., 2016). Essential nutrients can also be transferred through the network when a plant requires them (He et al., 2003).

Defense Signal Transmission: When a plant is attacked by a pathogen or herbivore, chemical signals can travel through the network to neighboring plants, enabling them to activate their defense mechanisms in advance (Song et al., 2010).

These networks transform a forest from a mere collection of individuals into an interconnected, interdependent whole—a superorganism (Gorzelak et al., 2015). Kyaschenko et al. (2017) confirmed the central role of ECM networks in ecosystem services by demonstrating how ECM fungi regulate nitrogen cycling and nitrogen retention in boreal forests.

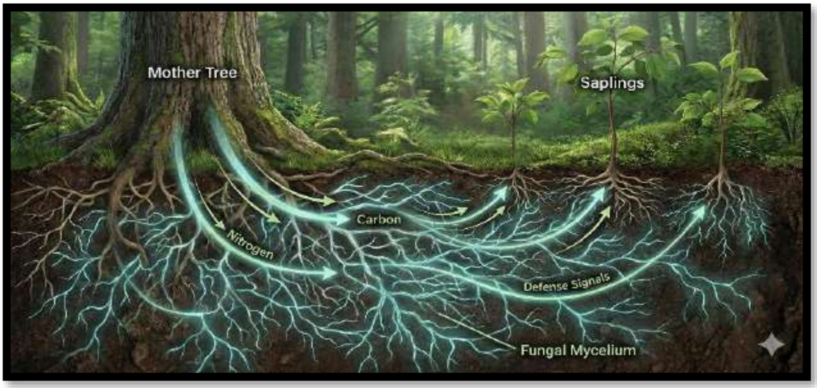


Figure 2. Wood Wide Web diagram showing underground connectivity and resource sharing between forest trees via mycorrhizal networks. (Google Gemini, 2025b)

Multifaceted Ecological Services of Fungal Diversity

The roles of fungi within the ecosystem are not limited to decomposition and symbiosis. Two other important groups, Pathogens and Endophytes, deeply influence the structure, biodiversity, and continuity of forests (Rodriguez et al., 2009). Fungal pathogens act as a significant force regulating ecosystem dynamics by attacking living trees and causing mortality (Gilbert, 2002). This situation has a vital ecological role; in tropical and temperate forests, pathogens drive the Janzen-Connell Effect, which reduces the survival success of a tree species in areas where its own species is dense (Janzen, 1970). By preventing a tree's seeds and seedlings from surviving near the parent tree or where conspecifics are dense, pathogens create a natural defense mechanism against the monopolization by dominant species, thereby preserving species diversity within the forest (Mangan et al., 2010) (Figure 3). Bagchi et al. (2010) presented empirical evidence of this mechanism on a tropical tree. Additionally, heartrot fungi (Basidiomycota) specifically degrade the heartwood of living trees, creating hollows and cavities (Stokland et al., 2012). These hollows become critical nesting and sheltering habitats for many bird, mammal, and insect species; thus, pathogens indirectly serve animal biodiversity (Cockle et al., 2011)

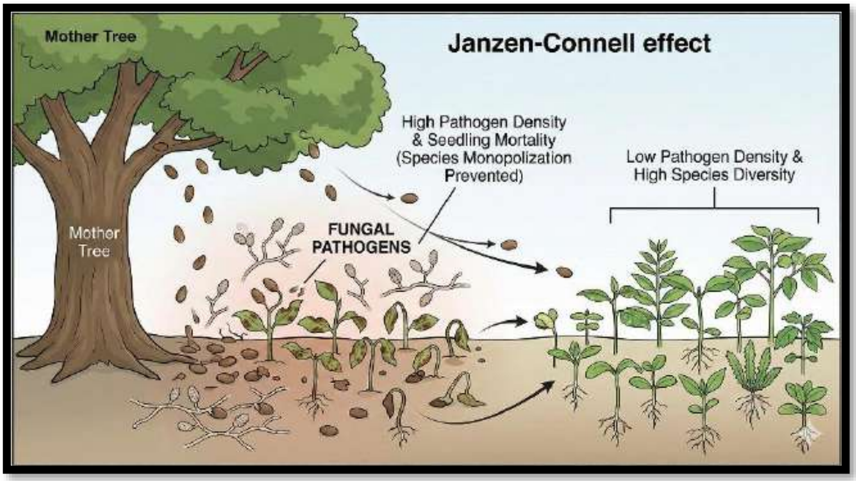


Figure 3. Schematic representation of the Janzen-Connell effect (Google Gemini, 2025c)

Another hidden force within forests is endophytic fungi species that live inside plant tissues (leaves, stems, or roots) without causing any visible symptoms of disease (Wilson, 1995). Endophytes provide important ecological benefits to their host plants (Porras-Alfaro & Bayman, 2011). Among these benefits is abiotic stress tolerance; endophytes can produce metabolites (antioxidants, osmolytes) that increase the plant's resistance to drought, heat, and salinity (Redman et al., 2011). For example, Sun et al. (2017) demonstrated the key role of endophytes in enhancing drought tolerance in desert plants. Endophytes also contribute to biological protection; some endophytes defend plants by producing secondary metabolites such as alkaloids that are toxic to insects and herbivores, or by directly competing against pathogens (Clay and Schardl, 2002). This forms a hidden layer of chemical defense within the forest ecosystem. Current studies (post-2020) are investigating how forest management practices (clearcutting, fire) alter the structure and function of fungal communities and the long-term consequences on ecosystem services (decomposition, disease resistance) (Tomao et al., 2020). Conserving fungal diversity is essential for the sustainability of these critical ecological services (Hawksworth, 2001). However, the biotic interactions of fungi are not limited to plants; they also engage in complex alliances and conflicts with insects, the most populous group in the forest ecosystem.

Cooperation and Conflict in Forest Ecosystems: Insect-Fungi Interactions

Forest ecosystems are dynamic systems where many biotic and abiotic factors interact. Among the biotic components, insects and fungi share multifaceted reciprocal relationships. These interactions manifest in various forms, including mutualism, parasitism/pathogenicity, vectoring, commensalism, and antagonism. Birkemoe et al. (2018) stated that the fundamental interactions between fungi and insects can be grouped under four functional relationships: nutrition (insects feeding on fungi and fungi feeding on insects), dispersal (insects transporting fungi), detoxification (fungi breaking down tree defenses that may be toxic to insects), and protection (insects protecting fungi and fungi protecting insects through various mechanisms).

Bark beetles (*Curculionidae: Scolytinae*) and ambrosia beetles (*Curculionidae: Scolytinae* and *Platypodinae*) cause significant damage and economic losses in forest and fruit trees worldwide (Hulcr and Dunn, 2011; Kushiyev et al, 2018). Symbiotic interactions exist between these beetle species and fungi, generally categorized under pathogenic relationships and nutritional mutualism/fungal cultivation. In the context of pathogenic relationships, insects act as vectors/spreaders of pathogens. For these fungi, there is no nutritional benefit derived from the insect. For example, *Ophiostoma* species fungi that cause Dutch Elm Disease (e.g., *Ophiostoma ulmi* and *O. novo-ulmi*) infect trees by being transported by Bark Beetles (*Scolytus spp.*). The fungi, proliferating in the xylem or water-conducting vessels of infected elms, cause the host tree to produce substances that, together with the fungus, clog the vascular system. This blockage prevents water uptake, eventually resulting in tree death (Rebek and Olson, 2014). This type of relationship between bark beetles and fungi falls under pathogenic vectoring or antagonistic/parasitic relationships (Figure 4a)

Blue stain fungi constitute a significant example of fungus-insect interaction. Bark beetles, while tunneling in the phloem, infect trees with the blue stain fungi they carry; these fungi weaken host defenses, provide food for larvae, and support beetle colonization and communication pheromones (Zhou et al., 2002; Masuya et al., 2003; Krokene, 2015; Six & Wingfield, 2011; Ayres et al., 2000; Zhao et al., 2015; Pan et al., 2018). Significant economic losses occur in logs and lumber damaged by blue stain fungi (Komut and Öztürk, 2018).

Many bark beetle larvae and adults derive their nutrition from plant tissues and fungi, with dependence on fungi varying (obligate, facultative, etc.) (Klepzig and Six, 2004). While some bark beetle species are not entirely fungivorous, they utilize fungi for nutrition. However, Ambrosia beetles engage in obligate feeding by consuming the fungal mycelium and spores they transport and cultivate on the walls of the galleries they bore into the wood (Figure 4b). Another example of insect-fungus interaction is Entomopathogenic fungi, which affect populations and biodiversity by infecting insects. "Entomopathogenic fungi (EPF) are widely distributed in almost all terrestrial ecosystems, with the highest species diversity found in tropical forests; some species can even be found in extreme habitats like the Arctic tundra (Hughes et al., 2004)". Examinations of insect bodies have isolated over 750 fungal species, classified into 100 different genera reflecting entomopathogenic fungal diversity (Shin et al., 2020; Sinha et al., 2016) (Figure 4c).

Entomopathogenic fungi represent an important environmentally friendly alternative in biological control, particularly against agricultural and forest pests. These fungi contribute significantly to biological control by killing pest insects, reducing their reproductive capability, weakening the pest's immune system, and supporting the spread of infection. While highly effective against pest insects, entomopathogenic fungi can also negatively impact beneficial insect species. Therefore, selecting species-specific entomopathogenic fungi and implementing ideal integrated pest management strategies is crucial to protecting beneficial species during pest control efforts (Figure 4d). Entomopathogenic fungi not only infect insects but also influence their behavior. This behavioral influence manifests in two distinct ways: insects avoiding fungal spores, or host insects acting as carriers to facilitate the spread of entomopathogens (Baverstock et al 2009).

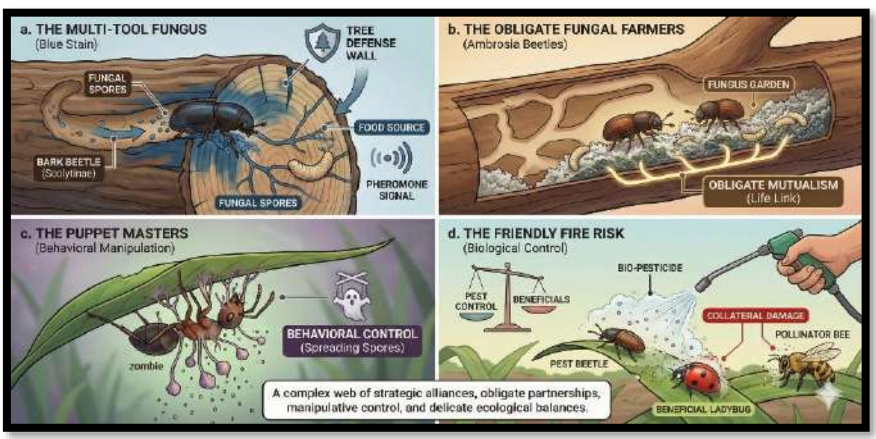
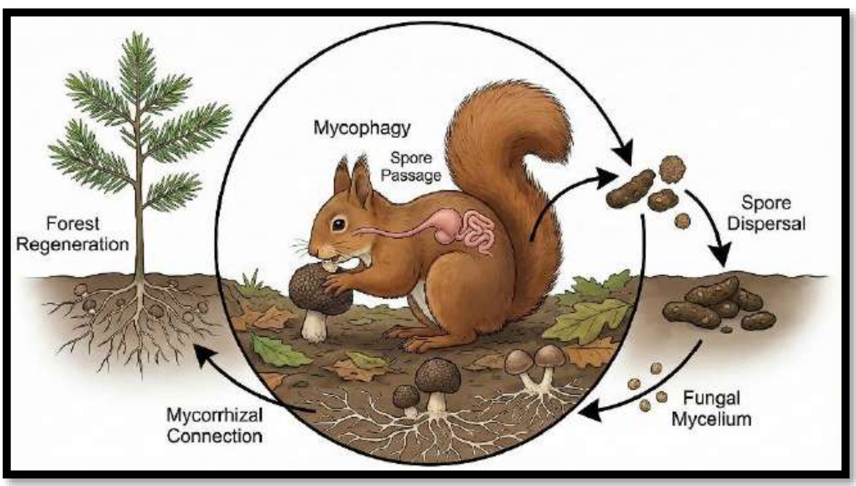


Figure 4. Examples of various insect-fungus interactions: (a) Multifaceted relationship between bark beetles and blue stain fungi, (b) Obligate fungus farming by Ambrosia beetles, (c) Fungal manipulation of insect behavior (zombie ant), (d) Risks of fungal use in biological control (Google Gemini, 2025d)

Fungi: Nutrient Source and Trophic Role in Forest Ecosystems

The roles of fungi in forest ecosystems extend beyond their characters as decomposers and symbionts to include serving directly as a food source (biomass) (Claridge and Trappe, 2005). The consumption of fungi as food is a vital phenomenon biologically and ecologically, beyond simple calorie intake. Unlike plants that rely on photosynthesis or animals that ingest food, fungi acquire nutrients by absorbing them from their environment, giving them a unique physiology (Webster and Weber, 2007). This physiology allows them to offer a rich nutritional composition combining features of both plant and animal foods, including high-quality proteins, micronutrients, and bioactive compounds (Kalač, 2013; Royse et al., 2017). At the ecosystem level, fungi introduce normally inaccessible nutrients into the biological cycle thanks to their ability to decompose lignocellulosic biomass (Boddy et al., 2008). The fruiting bodies (caps) they produce during this process form a vital link supporting diverse wildlife through a process known as "mycophagy" (fungus eating) in forest food webs. Many small mammals, including squirrels and voles, rely heavily on fungi, especially during periods when other food sources are limited (Maser et al., 2008) (Figure 5). For example, species like the Northern Flying Squirrel rely on truffles as a primary food source , while larger mammals like deer and elk consume fungi to meet mineral needs, particularly before winter (Claridge & Trappe, 2005; Kalač, 2013). In harsh tundra ecosystems, reindeer depend on lichens (symbiotic fungal associations) as a primary carbohydrate source (Storeheier et al., 2002).



Şekil 5. Example of Trophic Mutualism: Fungi providing calories to an animal, while the animal mediates the dispersal of fungal spores (Google Gemini, 2025e)

This trophic relationship often involves mutual benefit (mutualism) (Johnson, 1996). Many hypogeous (underground) fungi rely on animals for spore dispersal. Spores survive the digestive system and are transported to new areas via feces ; this supports the spread of mycorrhizal fungi essential for forest tree growth and forest regeneration (Vernes & Dunn, 2009; Trappe & Claridge, 2010).

From a human perspective, while fungi (especially Basidiomycota and Ascomycota) were historically opportunistic food sources, modern research has defined them as a fundamental biological resource (Chang & Miles, 2004). Commercial species (*Agaricus bisporus*, *Pleurotus spp.*) offer high-quality protein containing all essential amino acids at a rate of 19–35% on a dry weight basis (Mattila et al., 2002). Indeed, the protein digestibility of species like *Pleurotus ostreatus* rivals that of plant sources like soy (González et al., 2020). Furthermore, fungi act as strategic components of human nutrition as the only non-animal food source capable of synthesizing Vitamin D2 when exposed to UV light (Cardwell et al., 2018) and accumulating trace minerals like selenium and zinc (Falandysz, 2008).

In terms of sustainability, fungi offer alternatives with a much lower environmental footprint compared to livestock, with the potential to convert low-value biomass into high-quality protein by growing on agricultural waste (such as mycoprotein produced from *Fusarium venenatum*) (Grimm & Wösten, 2018; Finnigan et al., 2019) (Figure 6). Consequently, fungi serve as both an ecological fuel sustaining wildlife populations and a fundamental pillar of global food security.

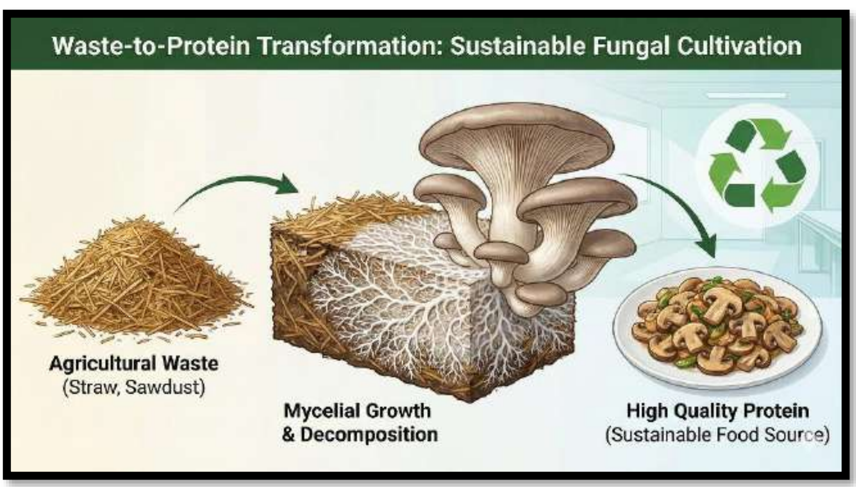


Figure 6. Sustainable mushroom production through the utilization of agricultural waste (Google Gemini, 2025f)

Fungi and Climate Change: Resilience and Vulnerability in Forest Ecosystems

Fungi emerge as both victims and resistance mechanisms in forest ecosystems under the pressure of global climate change. The fundamental components of climate change—rising temperatures, shifting precipitation regimes, and high atmospheric CO_2 concentrations—are fundamentally altering the structure and function of fungal communities (Treseder et al., 2016; Çiloğlu & Güneş Şen, 2025). This shift directly affects the ability of fungi to perform key ecosystem services. The impacts of climate change on fungal functions are particularly evident in the realm of Carbon Cycling and Temperature Interaction. Rising temperatures potentially increase the decomposition activity of saprotrophic fungi, and consequently, the amount of CO_2 released from the soil to the atmosphere (Crowther et al., 2016). This can lead to the rapid release of old carbon stored in the soil, creating a positive feedback loop that accelerates global warming (Figure 7). Clemmensen et al. (2013) demonstrated how delicate this balance is by highlighting the critical role of mycorrhizal roots in long-term carbon sequestration in boreal forests. Another area of impact is examined under the alteration and stress of mycorrhizal networks. High atmospheric CO_2 concentrations can increase plant photosynthesis, leading to greater carbon flow to mycorrhizal fungi (Terrer et al., 2016). However, under changing climate conditions (especially drought), the signaling and nutrient transfer between mycorrhizal networks (Wood Wide Web) may potentially be disrupted, diminishing the networks' ability to ensure ecosystem stability (Terrer et al., 2016). Karst et al. (2023) clearly stated that these networks are under threat due to the climate crisis. Furthermore, excessive nitrogen (N) deposition from industrial sources (Nitrogen deposition and weakening of symbiosis) can reduce the mutual dependence between mycorrhizal fungi and plants (Lilleskov et al., 2019). When plants can easily obtain N, the carbon flow to fungi decreases (resource limitation hypothesis), which can lead to the collapse of mycorrhizal communities and, consequently, less effective Phosphorus (P) and water uptake (Johnson, 2010).

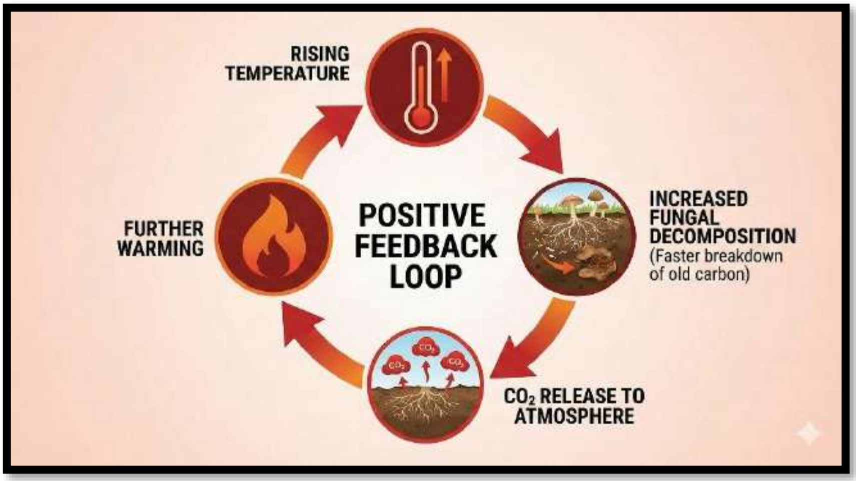


Figure 7. Positive feedback loop accelerating global warming (Google Gemini, 2025g)

Another serious consequence of global warming is the alteration of the geographic distribution and virulence of fungal pathogens (Pautasso et al., 2012). In temperate regions, trees under temperature stress may become more vulnerable to pathogens, creating a suitable environment for the spread of new, invasive pathogen species (Santini et al., 2013). This can result in devastating mortality across large forest areas and rapid changes in ecosystem structure (Boyd et al., 2013) (Figure 8). Despite all these environmental challenges, fungal communities possess high adaptive capacity to environmental changes (Romero-Olivares et al., 2017). Tedersoo et al. (2022) focused on the rapid adaptation mechanisms of fungal communities under global climate change. Understanding the role of fungi in processes such as carbon storage and resilience to forest fires is of vital importance for climate change mitigation strategies (Stein et al., 2014).

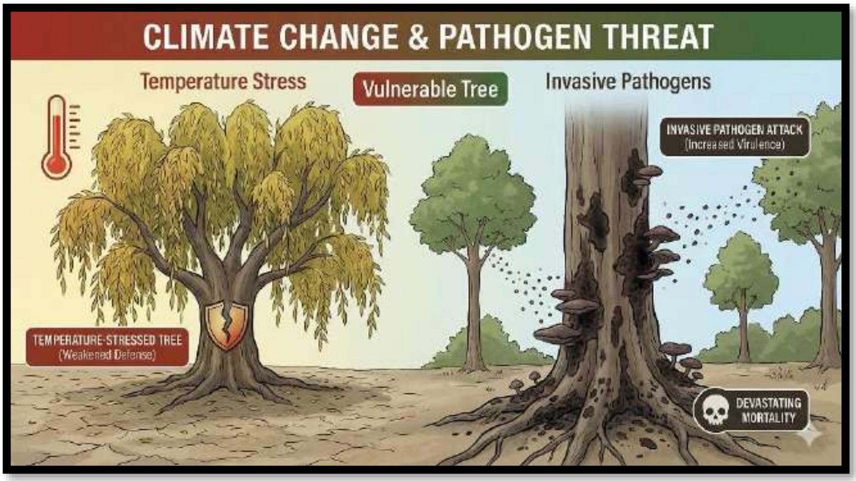


Figure 8. Increased tree vulnerability and invasive pathogen risk under climate change pressure (Google Gemini, 2025h)

Conclusion

In conclusion, forest ecosystems are not merely static communities of trees but dynamic and complex networks where fungi manage fundamental processes as "invisible architects". The molecular studies and ecological findings examined in this chapter prove that fungi go far beyond being simple organisms that decompose organic waste. Fungi are global operators controlling carbon and nutrient cycles (N, P), strategic partners ensuring communication and solidarity between plants via the "Wood Wide Web," and central actors regulating insect populations and biodiversity. This broad spectrum, ranging from the key role of saprotrophs in material cycling to the contribution of mycorrhizae to plant resistance and the stress tolerance provided by endophytes, reveals that forest health is directly dependent on the functional integrity of underground fungal networks.

In a time when the effects of global climate change are becoming increasingly severe, the ecosystem resilience-enhancing properties and carbon storage capacities of fungi place them at the center of future forest management strategies. However, changing climate conditions also threaten these delicate fungal communities, putting ecosystem services at risk. Therefore, in sustainable forestry activities, protecting not only above-ground biomass but also below-ground fungal biodiversity is a vital necessity. Preserving fungal diversity and functionality essentially means securing the adaptive capability of forests and the ecological balance of our planet.

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Chapter 10

NWFP from a climate finance perspective: carbon stock potential and economic valuation

Yağmur YEŞİLBAŞ[1]

When we talk about forest products, we mainly think of wood (the individual names of forest products and their aggregates include industrial roundwood, sawnwood, wood-based panels, fiber furnish, paper and paperboard, wood fuel, charcoal, and pellets (Bayram, 2020) and non-wood forest products (NWFPs) (honey, resin, mushrooms, medicinal and aromatic plants, etc.) that are used for consumption. In addition to the benefits derived from trees through timber production, NTFPs, also known as Minor Forest Products (MFPs), are an important source of income for all humanity, especially rural communities (Musa et al., 2023), not only through their production but also through their industry (Demir, 2015; Başar et al., 2021) and exports (Aydın et al., 2007; Kurt et al., 2016; Çakmaklı, 2019; Balcı and Köse, 2024) and are used as a tool for rural development in developing countries (Güngör and Çoban, 2024). NWFPs provide resources worldwide to meet needs such as food, medicine, fuel, and shelter (Kharalla et al., 2016). Honey, resin, mushrooms, medicinal and aromatic plants, pine cones, and forest fruits have become products of strategic value for both local communities and the global market. In recent years, increased market demand, preference for organic products, pharmaceutical interest in medicinal aromatic plants, and the shift towards environmentally friendly raw materials have changed the perspective on NWFPs, turning it into a growing economic sector in terms of both production volume and commercial value. Moreover, the 'resurgence of nature' observed during global crises such as the pandemic has reshaped societal perceptions of forest resources, further driving the demand for these natural products (Gençay & Çelik, 2025). Although it has been reported that approximately 1.6 billion people worldwide depend directly on forests for their livelihoods (FAO, 2017; Musa et al., 2023), a study based on conservative approaches found that the number of people benefiting from NWFPs globally is at least 3.5 billion and 5.76 billion, respectively, emphasizing that this is much

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higher than the generally reported 1.6 billion people (Shackleton and de Vos, 2022).

According to the Food and Agriculture Organization of the United Nations (FAO), NWFPs are defined as biologically derived goods that can be collected from forests, woodlands, or non-forest tree sources, or produced in forest plantations, agroforestry projects, and from non-forest trees (B.C. Government, 2009). This definition covers all kinds of products collected from nature, such as mushrooms, herbaceous species, resins, and medicinal plants, as well as modern plant-based raw materials produced in agroforestry systems (B.C. Government, 2009; FAO, 2022). In this respect, NWFPs are a category that encompasses both direct biological products and the economic and ecological outputs of ecosystem functions. Consequently, NWFPs lie at the intersection of policies related to sustainable forestry, rural development, and nature-based solutions (NbS); and they also interact indirectly with climate policies through dimensions such as the biomass cycle, soil health, and ecosystem resilience (Clemmensen et al., 2013; Seddon et al., 2019; Seddon et al., 2021; Huber, 2023).

Studies conducted specifically in Europe have emphasized that the contribution of NWFPs to household income is particularly pronounced in low-income communities and that they are also seen as a structural element in terms of cultural dimension and rural employment (Lovrić et al., 2020; Shackleton and de Vos, 2022). In this context, NWFPs are seen worldwide not as a secondary by-product but as one of the main elements of forestry (Ok et al., 2014; EFI, 2019; EFI & FAO, 2021). Lovrić et al. (2020) estimated the economic value of NWFPs across Europe at approximately €23 billion annually, including official records, informal local markets, and household consumption. Particularly in Eastern and Southern Europe, NWFPs constitute 10–60% of total household income for low-income communities and also have a direct impact on household welfare through their use for food, fuel, and health purposes (Lovrić et al., 2020). Studies show that households in Africa are highly dependent on NWFPs income; honey, gum/resin, wild food products, and medicinal plants play a vital role in both cash income and food security (Kharalla et al., 2016; Musa et al., 2023). It has been found that over 80% of the rural population in Africa, Latin America, and Asia regularly collects wild foods (Mbuvi and Boon, 2009; Meinhold et al., 2022).

The historical development of NWFPs in Türkiye began primarily with their traditional use, followed by public regulations. Subsequently, their economic impact came to the fore, and they evolved into a market-based structure focused on production and export. For many years, communities living in rural areas collected products such as mushrooms, medicinal and aromatic plants, resin, and laurel mainly for family consumption and local markets. However, since the

1990s, institutional regulations, inventory studies, and the expansion of export markets have gradually transformed NWFPs production into a planned economic activity. Work related to NWFPs was initially carried out under the 1995 Circular No. 283 on the Principles of Production and Sale of Secondary Forest Products and the 1996 Circular No. 289 on Permits to Be Granted to Those Who Wish to Benefit from Forest Products. gained a public structure with the establishment of the Non-Timber Products and Services Directorate in 2011. Subsequently, in 2013, the perspective on NWFPs changed completely with the publication of the Circular on the Inventory and Planning, Production, and Sales Principles of Non-Timber Forest Products No. 297 (Ok and Tengiz, 2018). Specifically, species such as laurel, thyme, sage, and carob have become important items in foreign trade over time (Kurt et al., 2016; Balcı and Köse, 2024).

Ecological Basis of NWFPs: Climate Change and Ecosystem Resilience

As explained in the previous section, NWFPs have become an important economic and socio-cultural sector both globally and in Türkiye. However, climate change, which is currently a global crisis, also threatens the economic and social contributions of NWFPs. Changing rainfall patterns and rising temperatures exert pressure on biological processes and ecosystem balances (IPCC, 2019; 2021; 2022); on the other hand, NWFP-focused forestry activities offer a strategic opportunity to combat climate change by preserving the integrity of forest ecosystems.

The emergence, continuity, and future production potential of these products are directly related to the structure and functioning of the forest ecosystems in which they are found. In other words, the presence of NWFPs in a region, their quantity and quality in that region, are closely linked to the climate conditions, topography, soil characteristics, and forest formation of that area. In this context, regional differences in NWFPs production depend not only on species distribution but also on the ecological conditions in which the products grow and how these conditions change over time. The European Forest Institute (EFI) report Non-wood forest products in Europe explains that spatial and temporal differences in NWFPs yields are largely explained by climatic variability (annual precipitation, temperature, extreme weather events), soil type, altitude, and forest conditions. Studies on the yield potential of blueberries and mushrooms in the Czech Republic explain that natural production capacity can vary significantly from year to year due to the combined effects of factors such as rainfall patterns, weather, soil, and altitude (EFI, 2019). Similarly, a study on species distribution modeling determined that changes in temperature and precipitation in climate scenarios projected for the future could narrow the potential distribution area of

Cornus mas (cornelian cherry), particularly reducing habitat suitability in low-altitude and aridifying areas (Akyol and Örücü, 2019). Another study examining the habitat characteristics of medicinal aromatic plants and species containing essential oils indicated that the percentage of fruit essential oils is significantly dependent on environmental factors such as the typical humid maritime climate, which provides the best conditions for these species (Ložienė et al., 2020).

Indeed, another study also mentions that the humidity and temperature conditions offered by areas dominated by broad-leaved trees have an effect on mushroom growth and development (Özkazanç and Yeşilbaş Keleş, 2019). These findings indicate that the spatial and interannual fluctuations observed in NWFPs production are closely related to climate parameters (EFI & FAO 2021; Huber, 2023).

NWFPs should also be seen as a natural reflection of the rich biodiversity and multi-layered vegetation cover of forest ecosystems. Indeed, studies examining the role of NWFPs in socio-economic development in Europe define these products as part of the multifunctional ecosystem services provided by forests. Tieminie et al. (2021) emphasize that food, medicinal products, cultural values, and recreational functions derived from forest ecosystems are produced together within the same forest structure. In this context, it is stated that the process should be addressed within the framework of multifunctional forest management (EFI & FAO, 2021). According to this perspective, NWFPs are not merely an additional source of income but rather an output of the entire forest ecosystem.

NWFPs have a special significance in terms of the ecological basis of fungi's interactions with soil and plants. This is because a large portion of the organic carbon in the soil is formed by fine roots and fungi associated with roots (especially ectomycorrhizal fungi), which, together with the root system, are at the center of the soil carbon cycle (Clemmensen et al., 2013). Therefore, they contribute both as income-generating NWFPs and to the conservation of carbon stocks.

In this context, forests in Türkiye where laurel, pine, red pine resin, linden, and mushrooms are produced can be considered strategically important in terms of carbon storage and soil fertility. Indeed, the biological storage of carbon through natural processes such as plants, algae, and soil is an environmentally friendly approach (Berberler, 2025). Global climate change, a result of increasing greenhouse gases, affects ecological processes both directly and indirectly. Addressing forest ecosystems within the framework of nature-based solutions (NbS) has increasingly come to the fore as a solution to climate change. Seddon et al. (2021) emphasized that NbS is not an alternative to fossil fuel use, but encompasses not only forests but also a wide variety of ecosystems on land and at sea, and can be effective in mitigating and adapting to climate change when planned with community participation and in a way that protects and increases biodiversity. This approach also places NWFPs in a critical position in the context of climate resilience and the carbon economy.

Climate change-related temperature increases, changes in precipitation patterns, and extreme weather events are stress factors that directly affect NWFPs supply. Indeed, recent studies have shown that storms and biotic damage cause losses in forest carbon stocks and economic value. Global studies indicate that in western and central Africa, NWFPs is an important livelihood source for communities living in rural areas; however, changes in precipitation/temperature and droughts associated with climate change affect product quantity and species distribution (Tieminie et al., 2021; Musa et al., 2023). Similar climate sensitivity applies to medicinal and aromatic plants. Studies conducted in the Baltic region have shown that the volatile oil composition and yield of thyme and similar aromatic species can vary significantly depending on temperature, sunshine duration, soil moisture, and growing environment characteristics (Vaičiulytė et al., 2022).

Analyses of pine cone yield in the Mediterranean basin reveal that climatic stresses such as drought and high temperatures reduce both the number of cones and, indirectly, pine nut production (Mutke et al., 2005; Freire et al., 2019). Considering these findings and Türkiye's location in the Mediterranean region, it is thought that key NWFPs species with wide distribution in Türkiye, such as thyme, sage, laurel, and pine, may be at risk in terms of phenology, yield, and quality under adverse climate change scenarios.

The traditional form of forest management based on timber production generally involves cutting trees and removing biomass from the forest, and focusing on the sustainability of the wood and wood products (Bayram, 2021). This can lead to the partial release of carbon from the soil and a weakening of the carbon sink. However, studies have also reported that the biomass accumulated by trees, particularly in their root systems, plays a critical role in preserving carbon stocks and that this carbon remains stored in the forest as long as the plants are not cut down (Durkaya et al., 2019). The production and sustainability of NWFPs also depend on the continued existence of trees and forest cover (living biomass). NWFPs are, on the one hand, an indicator of the species diversity of forest ecosystems and, on the other hand, play an important role in maintaining basic ecosystem functions such as seed dispersal, pollination, soil formation, and microbial cycles (Shackleton et al., 2018).

For example, fungal species, as key decomposers that enable wood decay, perform a critical ecological function in returning carbon and nutrients to the soil cycle, while medicinal and aromatic plants contribute to the preservation of understory biomass and the regulation of soil moisture. The strong ecological value of NWFPs makes these products viable within the scope of NbS. This reinforces the fact that forests are not just a source of raw materials, but also dynamic and living systems that provide various Ecosystem Services such as carbon storage, regulating the water cycle, and preventing erosion (MEA, 2005). In the context of Türkiye, NWFPs ecology must also be considered in conjunction with the carbon sink functions of forests. Laurel, pine, red pine, beech, and fir forests, where NWFPs production is concentrated, are also part of these carbon stocks. Therefore, the climatic and edaphic sensitivities of these forests are critical not only in terms of NWFPs productivity but also in terms of national carbon balance and ecosystem resilience.

NWFPs Production in Türkiye (1988–2024)

An analysis of the time series for non-timber forest product production in Türkiye for the period 1988–2024 reveals a significant transformation in both product quantities and variety. According to the official statistics on which the study is based, total registered NWFPs production in 1988 was approximately 1,687 tons, while total production in 2024 rose to 71,189 tons (Figure 1). This increase indicates an approximately 42-fold growth in NWFPs production. In terms of product types, the production of approximately 30 species of NWFPs, including chestnuts, carob fruit, St. John's wort, lavender, resin, natural mushrooms, and pine cones, which were produced in 2024, had never been produced until 2000. NWFPs produced annually in excess of 10 tons in Türkiye between 1988 and 2024 are listed in Table 1.

Table 1. NWFP species with an annual production of more than 10 tons in Türkiye (OGM, 2024)

NWFP Species	Annual Average Tons (1988-2024)	NWFP Species	Annual Average Tons (1988-2024)
Bay laurel leaf, unprocessed	14,433	Snowflake bulb (wild grown)	79
Shrubs / Bushes	8,522	Cyclamen (wild grown)	56
Thyme, unprocessed	2,075	Rhododendron	44
Stone pine cone (wild grown)	1,864	Linden flower and leaf	40
Chestnut	1,546	Heath (root)	36
Myrtle leaf	620	Fern	35
Carob fruit (wild grown)	534	Boxwood (branch and shoot)	33
Sage, unprocessed	412	Snowdrop bulb (wild grown)	29
Rockrose (Cistus)	385	Ivy	28
Resin	290	Fir branch	26
Rosemary, unprocessed	242	Sternbergia bulb (wild grown)	17
Moss	190	Lavender	16
Natural mushroom	137	Lichen	11
Jerusalem sage (Phlomis)	124	**Total**	31,824

As can be seen from Table 1, bay leaves rank first among the NWFPs produced, accounting for approximately 45% of total annual production. Bay leaves also account for 10% of Türkiye's natural plant exports. In the global bay leaf trade, Türkiye controls 90% of the market volume and is the most important country in the market in terms of quality, price, and quantity (AKİB, 2009, cited in Demir, 2015). In addition, with its annual production of dried bay leaves for export, Türkiye controls 97% of the global bay leaf trade (Özhatay et al., 1997, cited in Demir, 2015). Recent studies show that NWFPs in Türkiye have become a fundamental element not only for additional income but also for rural development, local employment, and the regional economy (Kurt et al., 2016; Güngör and Çoban, 2024; Balcı and Köse, 2024).

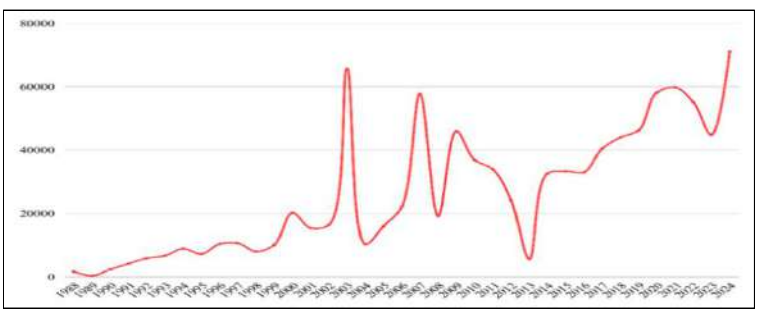

Figure 1. Total production of non-wood forest products in Türkiye, 1988–2024 period (tons).

The time series presented in Figure 1 shows that NWFPs production in Türkiye underwent a four-stage development process during the period 1988–2024. The first stage, covering the years 1988–1999, was an early period characterized by very low production levels. The average annual total production during this period was recorded as 6,362 tons. Considering the legal regulations, production during this period was mainly for local consumption and traditional use, and in the latter half, it was also characterized by partial marketing. The second phase is the 2000–2008 period. During this period, the average annual production amount increased significantly to 28,010 tons. This trend suggests that Türkiye's NWFPs production has come to the fore as a source of marketing and income rather than just consumption and traditional use. The 2008–2013 period, which can be considered the third phase, can be described as a period of stagnation in NWFPs production. While the annual average production for the period was 27,674 tons, production had a fluctuating structure. Although this period generally progressed in an upward direction, it did not show an average increase over the five-year period. In the fourth and final phase, 2013–2024, particularly high production values were recorded in 2020, 2021, and 2024. Despite declines in some years, the annual production average for the period was found to be 47,182 tons. When the time series for NWFPs production in Türkiye is examined overall, 1989 represents the lowest point in the series with 371 tons, while 2024 represents the highest point with 71,198 tons of production. This wide range of production quantities reveals how rapidly Türkiye has grown in terms of NWFPs.

The fact that NWFPs production in the time series experiences sudden increases and decreases in some years is thought to indicate its sensitivity to climatic conditions, market prices, and harvesting policies. Drought, late frosts, extreme temperature increases, and irregularities in rainfall patterns can cause significant fluctuations in the production of mushrooms, forest fruits, and some medicinal and aromatic species. In addition, collection restrictions, changes in permit procedures, or regulations on export permits implemented in some years are also reflected in production quantities. Therefore, the graph has been evaluated as having a structure that carries traces of the effects of other dynamics, not just production values.

In this context, when the graph is evaluated overall, NWFPs production in Türkiye has generally increased during the period 1988–2024. This situation indicates both the expansion of demand and trade opportunities and the fact that NWFPs have become increasingly visible in forest management. However, while the fluctuations seen in the graph over time point to the pressure of climate change and market conditions on the sector, the developing carbon markets in the global financial system offer a new strategy to manage this dynamic.

NWFP in Climate Finance: Carbon Stock Potential and Economic Valuation

As shown by the production statistics and historical development process examined, the NWFPs sector in Türkiye is growing in volume. However, this growth is still largely based on the model of collecting and selling raw materials; products are mostly offered to the market in an unprocessed form with limited added value. However, in the context of climate change mitigation policies developing on a global scale today, the economic role of forests has changed; forests are no longer just a source of biomass, but are defined as terrestrial infrastructure that cleans and stores carbon from the atmosphere. This definition, unlike traditional timber production, is based on the continuity of forest cover (living biomass), i.e., the conservation and use of living biomass. NWFPs such as resin, laurel, mushrooms, pine honey, or pine cones can be sustainably produced without disrupting the physical integrity of the tree and soil system. This ensures the continuity of carbon pools, which in turn allows areas where NWFPs are produced to be evaluated differently from traditional forestry.

In the forestry sector, carbon finance is mostly addressed in the context of afforestation and preventing deforestation (REDD+). REDD+ means reducing emissions from deforestation and forest degradation in developing countries, encompassing the sustainable management of forests and the conservation and enhancement of forest carbon stocks. Under REDD+, developing countries can receive results-based payments for emission reductions when they reduce deforestation. Chazdon and Brancalion (2019) emphasize that forest restoration is not just about planting trees, but that natural regeneration and biodiversity-conserving land uses create more resilient systems for carbon sequestration. Indeed, a study conducted on maquis communities in the Eastern Mediterranean also found that, due to the dominant role of the root system, a significant portion of the total biomass is stored underground and that these shrub formations constitute a much stronger carbon sink than expected (Durkaya et al., 2017).

In this context, it is important to view NWFP-focused managed forests not only as areas that can be reforested in terms of carbon sequestration capacity, but also as critical areas in terms of preserving existing carbon stocks. While timber production involves removing carbon from the stock and disturbing the soil (carbon release) by cutting trees, NWFPs production represents a management model where carbon is retained in situ. Therefore, NWFPs production areas have high potential for conservation-based carbon crediting. This indicates that

NWFPs production areas can be considered as areas capable of producing High-Quality Carbon Credits in voluntary carbon markets (VCM). In the VCM, factors such as biodiversity, local employment, and socioeconomic contributions directly affect credit value, in addition to reducing carbon emissions. Projects that combine these elements are traded at a higher unit price because they provide co-benefits (Ecosystem Marketplace, 2021). Areas such as pine nut or chestnut forests in Türkiye can create a double income (stacking revenues) model not only through NWFPs yields but also through the certification of the carbon they hold. In other words, economic returns can be obtained not only from product harvesting but also from preserving carbon stocks.

Another tool for ensuring the financial sustainability of NWFPs collection and integrating it with the climate economy is PES (Payment for Ecosystem Services) payments. According to the FAO (2022), pricing the services provided by forests, such as water retention, erosion prevention, and carbon storage, and paying their providers forms the basis of the green economy. Under the current system, NWFPs generates income directly from product sales. However, when preserving and maintaining the forest is considered a public ecosystem service, the economic value of this service can also create a strong incentive mechanism against deforestation. Particularly in areas at risk of fire in the Mediterranean region, the dependence of local communities on NWFPs income also serves as a strong social safeguard for forest conservation.

In this context, NWFPs contribute to combating climate change not only through carbon stored in the forest (in-situ) but also through carbon stocks in biomass harvested and added to the economy (ex-situ). Indeed, a study by Freire et al. (2019) has demonstrated the carbon sequestration capacity of the seedless biomass of stone pine (Pinus pinea) cones with concrete data. Using this approach as a reference, an analysis of NWFPs data in Türkiye has yielded important findings regarding the sector's carbon sink potential. Within the scope of the study, NWFPs species produced between 1988 and 2024 were classified into four groups (leafy/herbaceous, woody/hard-shelled, bulbous/fungal, and resinous) according to their biological and physical characteristics. The guidelines of Freire et al. (2019) and IPCC (2006) guidelines were used as references, and biomass conversion factors specified in the IPCC (2006) National Greenhouse Gas Inventories Guidebook (Volume 4) were determined for each group (Table 2).

Table 2. Grouping and conversion factors used in carbon stock calculations for NWFP species

Product Group	**Major Species Included**	**Physiological Characteristic**	**Dry Matter Coefficient (k_{dm})**	**Carbon Content Coefficient (k_c)**
Group I: Leafy and Herbaceous Species	Laurel, Thyme, Sage, Rosemary, Linden, Myrtle Leaf	High moisture content, mass loss upon drying after harvest.	0.35	0.45
Group II: Woody and Hard-Shelled Species	Chestnut, Stone Pine Cone, Bushes, Boxwood, Fir Branch	Low moisture, high lignin and cellulose content, dense biomass.	0.60	0.50
Group III: Bulbous and Mushroom Species	Natural Mushroom, Snowdrop, Snowflake, Cyclamen	Very high water content, low dry biomass yield.	0.15	0.40
Group IV: Resins and Extracts	Sweetgum Oil, Resin, Tragacanth	Water-free hydrocarbon structure, very high carbon density.	0.95	0.70

Using these conversion factors and cumulative production data (C_{fw}) for the period 1988-2024, calculations were performed using Equation 1. The estimated carbon amounts (C_{stock}) stored in the biomass of NWFPs species are presented in Table 3.

$$C_{stock} = C_{fw} \times k_{dm} \times k_c \quad (1)$$

Table 3. Top carbon-storing NWFP species in Türkiye and estimated carbon stocks (1988–2024 Cumulative)

NWFP Species	Phenological Group	Total Production (Tons)	Est. Dry Biomass (Tons)	Calculated Carbon Stock (Tons C)
Bay Laurel Leaf	Leafy	519,597	181.859	81.837
Bushes / Shrubs	Woody	204,537	122,722	61,361
Stone Pine Cone	Woody	65,252	39,151	19,575
Chestnut	Woody	38,651	23,19	11,595
Thyme	Leafy	70 563	24.697	11.114
Carob Fruit	Woody	13 341	8.005	4.002
Sage	Leafy	14 403	5,041	2,268
Other Species (Total)	Mixed	~60,000	~23,500	~11,700
Grand Total		~986,223	~428,000	~203,470

According to Table 3, in Türkiye, during the period 1988-2024, bay leaves alone accounted for the largest share of total recorded NWFPs production with approximately 81,837 tons of carbon stock; followed by shrubs with 61,361 tons and pine cones with 19,575 tons. The use of shells and husks left over after processing products such as pine nuts in biomass energy or long-lasting composite material production provides an additional service that allows this carbon to be sequestered from the atmosphere for a long time (Freire et al., 2019). Although calculations for all NWFPs species were made on a species basis, only some species are listed in Table 3. Species not listed are shown under other species (Total).

According to the analysis findings obtained as a result of the calculations, it was determined that approximately 203,470 tons of pure carbon was stored in the product biomass with the total NWFPs production recorded in Türkiye between 1988 and 2024. However, to determine its value in global carbon markets, it must be converted to carbon dioxide equivalent (tCO2e). This is because transactions in carbon markets are conducted based on tCO2e, not pure carbon. Therefore, the pure carbon stock obtained was converted to carbon dioxide equivalent (tCO2e) using the conversion factor of 3.667 (44/12) determined by the IPCC (2006), which is found by dividing the atomic mass of carbon by the molecular mass of carbon dioxide.

Accordingly, it was determined that NWFPs sequestered approximately 746,125 tCO2e from the atmosphere during the relevant period. In this context, the potential economic value of this carbon storage service provided by NWFPs production was determined based on current market data in the World Bank's State and Trends of Carbon Pricing 2025 report (World Bank, 2025). Three different pricing scenarios were developed based on the fact that NWFPs are a NbS and the different pricing of international carbon markets (Table 4).

Table 4. Economic valuation of the carbon stock in harvested NWFPs biomass (Based on World Bank 2025 Data)

Pricing Scenarios (2025 Real Values)	Reference Price (/tCO2e)	Total Economic Value ($)
Scenario 1: Nature-Based Removal (Market-Based) *(Average of Exchange-Traded Nature-Based Removals)*	15.50 $	11,564,937 $
Scenario 2: High-Integrity Compliance (Policy-Based) *(Paris Agreement Art. 6.2 and CORSIA Phase 1 Average)*	~30 $	22,383,750 $
Scenario 3: Paris Agreement Target Price (Social Value) *(Lower Bound Required for 2030 Climate Goals)*	100 $	74,612,500 $

**Note: Scenario 1 and 2 prices are based on exchange data (April 1, 2025) and country procurement tenders (e.g., Switzerland, Singapore) as reported in the World Bank "State and Trends of Carbon Pricing 2025" report.*

Table 4 shows that the carbon sink service provided by NWFPs production is valued at approximately US$11.5 million in 2025 prices under current carbon market conditions (Scenario 1). This value represents the potential revenue that could be generated if the products were traded as certifiable Nature-Based Carbon Credits. However, in Türkiye's bilateral carbon trade agreements with other countries under Article 6.2 of the Paris Agreement (Scenario 2), this value could reach US$ 22 million; based on the cost of carbon to society and the goal of limiting global warming to 2°C (Scenario 3), the social benefit value created by the sector could reach approximately US$75 million. This value in Scenario 3 is actually a calculation based on the target carbon price that should be set. When these data are evaluated, although NWFPs are seen as a by-product in traditional forestry operations, they play a significant role in combating climate change and, when their economic value is considered, can be evaluated as a source of Green Finance.

The integration of NWFPs into carbon markets is not limited to carbon credit production. In line with the European Union's Deforestation Regulation (EUDR), which came into force in 2023, not only the quality of the product but also whether the ecosystem in which it is produced is protected has become a factor determining its market value. In this context, NWFPs are inherently based on production methods that do not cause forest destruction. Accordingly, Türkiye's strong position in the European market, particularly with NWFPs such as laurel, thyme, and sage, has the potential to be transformed into an advantage compatible with climate policies. On the other hand, with the utilization of residues, waste, or by-products left over from NWFPs processing in areas such as organic fertilizer and biomaterials, NWFPs become part of an economic and climate-friendly industrial system.

Although the NWFPs sector is vulnerable to the effects of climate change, it has the potential to become an active tool for climate policies with the right financial and managerial mechanisms. When evaluated holistically, NWFPs are a strategic development tool at the intersection of climate change mitigation, natural capital, and rural prosperity.

General Assessment: A New Value Chain for NWFPs

Although NWFPs were initially seen as a traditional production area that provided a livelihood and contributed to household income for communities living in rural areas, today they are assessed within a much broader framework that encompasses ecological, economic, and social dimensions. As outlined in this chapter, NWFPs are not merely a product category; they also hold multidimensional strategic importance in combating climate change, rural development, protecting ecosystem services, and sustainable forest management. When evaluated in these dimensions, NWFPs are much more than a secondary product.

An evaluation of Türkiye's NWFPs production data for the period 1988–2024 shows that the sector has experienced remarkable growth of 42-fold over the last thirty years, gaining global competitiveness, particularly in medicinal and aromatic species such as laurel, thyme, sage, and pine cones; however, it also shows that the economic potential created by this growth has not yet been fully realized. Furthermore, this growth is mainly based on raw material exports, and value-added production remains limited.

When evaluated from an ecological perspective, NWFPs play an important role in preserving biological diversity and soil organic carbon and maintaining ecosystem functions. In this respect, NWFPs represent one of the forestry activities capable of producing concrete, measurable, and traceable outputs within the NbS approach.

Calculations based on the Freire et al. (2019) methodology and IPCC standards have revealed that NWFPs production offers an overlooked carbon sink area in the fight against climate change. It has been calculated that approximately 203,000 tons of pure carbon was stored in the NWFPs biomass harvested in Türkiye between 1988 and 2024, corresponding to approximately 746,000 tons of CO_2 equivalent. The monetary value of this ecosystem service ranges from US$11.5 to US$75 million, according to World Bank data for 2025. This value is concrete evidence of the critical role of NWFPs in combating climate change and clearly demonstrates that they should be considered as a climate finance instrument.

When evaluated in terms of carbon markets and payments for ecosystem services (PES/EHÖ), NWFPs hold potential that goes beyond mechanisms such as REDD+, which focus solely on preventing deforestation. This is because NWFPs production generates in-situ sequestration and adopts a management approach based on living biomass conservation. It also has the potential to create a significant competitive advantage for Türkiye in the EUDR.

This study highlights the need to rethink the NWFPs sector in terms of climate policies, carbon markets, and rural development. NWFPs can be considered strategically positioned in terms of reducing rural poverty, supporting local employment, promoting carbon financing instruments, and integrating green development policies into the field. However, achieving an optimal balance between the multiple benefits of forest ecosystems, such as timber production, carbon storage, and NWFPs provision, requires a complex planning process. Therefore, it is important to measure multiple benefits simultaneously using a multidimensional technique (Daşdemir, 2022). At this point, the use of multi-criteria decision-making methods in the most efficient allocation of forest areas to different functions is recommended as a powerful tool that will ground management decisions on a rational basis, as indicated by some studies conducted in Türkiye (Yılmaz, 2004, 2005; Ok and Deniz; 2007; Daşdemir and Güngör, 2010; Şen and Güngör, 2018; Güngör and Şen, 2018, 2024), is proposed as a powerful tool to ground management decisions on a rational basis. In this regard, the integration of carbon markets and the widespread adoption of certification processes stand out as key policy tools to ensure the sustainability of SFM production. It has been emphasized that forest management certification plays a supportive role in wood production, which evaluates social, economic, and ecological objectives (Şen and Güngör, 2019). The integration of green certification systems with the forestry sector plays a strategic role in increasing the economic value of products and achieving carbon management targets. In this context, the plans prepared by the General Directorate of Forestry (OGM) regarding NWFPs should include the carbon sequestration capacity (tonC/ha) of the product to be harvested. In this way, the possibility of recording, monitoring, and evaluating will be provided, and the groundwork will be laid for improving the national greenhouse gas inventory and financing efforts. If revenue can be generated from carbon financing in this area and shared with communities living in rural areas, the motivation of local communities to protect forests will be strengthened. NWFPs residues should not be considered waste; state incentives should be provided for R&D studies and facilities in this area.

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Chapter 11

Climate Change Strategy for Küre Mountains National Park: Strategic Recommendations Using the A'WOT-CJA Model

Ersin GÜNGÖR[1]

Climate change is one of the most complex and urgent global issues of the 21st century. Global warming, caused by rising concentrations of greenhouse gases in the atmosphere, is fundamentally altering the structure and function of ecosystems, accelerating biodiversity loss, and threatening the livelihoods of human communities (IPCC, 2022). The Intergovernmental Panel on Climate Change's (IPCC) latest Sixth Assessment Report (AR6) clearly states that land use change and deforestation are responsible for approximately 13% of net emissions and that the conservation and restoration of natural ecosystems is a critical and cost-effective "nature-based solution" (NbS) strategy in combating climate change (IPCC, 2022).

Turkey's diverse forest, steppe, and wetland ecosystems host extensive and valuable biodiversity resources that are significant on a global scale (Birben et al, 2016). Protected areas are at the forefront of these natural solutions, which are central to this fight. Defined by the IUCN as "geographical areas recognized and managed through legal or other effective means for the long-term conservation of nature, associated ecosystem services, and cultural values" (Dudley, 2008; Millennium Ecosystem Assessment, 2005), protected areas offer multifaceted benefits in both reducing the causes of climate change (mitigation) and adapting to its impacts (adaptation). Protected areas serve as an indispensable carbon sink, securing approximately 20% of the world's terrestrial carbon stock and a significant portion of the ocean carbon stock (Dinerstein et al., 2019; UNEP-WCMC, 2021). However, this carbon storage potential is under pressure from increasing stress factors. Indeed, recent studies conducted in the region, including the study area, have revealed that forest pests can cause carbon stock losses exceeding the annual increase (Yeşilbaş & Güngör, 2025). In this context, protected forest areas reduce atmospheric CO_2 concentrations by storing large amounts of carbon (Trumper et al., 2009), while also increasing communities'

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resilience to climate shocks by regulating water resources, preventing floods, and conserving agricultural biodiversity (Dudley et al., 2010).

However, fully realizing the potential of protected areas requires the development of multidisciplinary, participatory, and data-driven management strategies that go beyond traditional conservation approaches. Current protected area management plans are mostly designed for static climate conditions and do not adequately consider the dynamic and uncertain impacts of climate change. This indicates that biodiversity management proposals need to be reevaluated in light of climate change (Heller & Zavaleta, 2009). Furthermore, the traditional tensions between conservation and development become even more complex in the context of climate change. Therefore, the effective integration of climate strategies into protected areas requires integrated analysis tools that evaluate both ecological and socio-economic variables, systematize decision-making processes, and incorporate stakeholder preferences (Kukkala & Moilanen, 2013; Addison et al., 2020).

To address this need, this study proposes a hybrid model that combines the Analytical Hierarchy Process (AHP) and SWOT analysis into the A'WOT approach and integrates the preference analysis method Conjoint Analysis (CJA). This model is applied to the example of Küre Mountains National Park, one of Turkey's important protected areas, aiming to develop strategic priorities and policy recommendations to strengthen the role of protected areas in combating climate change. The main research questions and objectives of this study are presented in Table 1.

Table 1: Basic Research Questions and Objectives.

Research Question	Research Objective	Method Used
1. What are the internal strengths/weaknesses and external opportunities/threats of Küre Mountains National Park in the context of climate change?	Identification of SWOT Factors	SWOT Analysis, Expert Interviews
2. How are the relative importance levels of these factors ranked in terms of climate strategies?	Prioritization of Factors	Analytical Hierarchy Process (AHP)
3. Which features do stakeholders value more among climate-focused protected area management scenarios?	Analysis of Preference Structures	Conjoint Analysis (CJA)
4. In light of the findings obtained, what policies and management strategies can be proposed for effective and sustainable climate-conservation integration?	Development of Policy Recommendations	Integrated Analysis and Synthesis

The role of protected areas in combating climate change is based on the concept of ecosystem services (ES). The Millennium Ecosystem Assessment (2005) defines ecosystem services as "the benefits people receive from ecosystems" and divides these services into four main categories:

1. Category: Provisioning Services. Food, water, fiber, biochemicals, genetic resources.
2. Category: Regulating Services. Climate regulation, disease control, water purification, dust suppression.
3. Category: Cultural Services. Spiritual and religious values, recreation, aesthetic experiences.
4. Category: Supporting Services. Soil formation, photosynthesis, nutrient cycling.

Climate change exerts multifaceted pressures on the provision of these services. For example, rising temperatures and changes in precipitation patterns threaten provisioning services by affecting agricultural productivity; increased extreme weather events can overwhelm the capacity of regulating services; and ecosystem losses jeopardize the sustainability of cultural and supporting services.

The "Nature-Based Solutions" report systematically outlines how protected areas contribute to two key responses to climate change (Dudley et al., 2010):

1.Mitigation Role: The mitigation role of protected areas operates through three key mechanisms, primarily carbon storage and sequestration. Terrestrial ecosystems, particularly forests, peatlands, and mangroves, hold immense carbon stocks. For example, the Amazon forests and Congo Basin store 312 Gt of carbon, equivalent to approximately 15% of the world's terrestrial carbon stock. At the same time, protected areas reduce carbon emissions by limiting land conversion through preventing deforestation and increase the carbon sequestration capacity of degraded areas through habitat restoration.

2.Adaptation Role: Protected areas also help ecosystems and human communities adapt to climate impacts. This role can be grouped under four main headings: (1) reducing natural disaster risks (flood control, landslide prevention), (2) protecting water resources (watershed management), (3) conserving agricultural biodiversity, and (4) diversifying livelihoods. For example, in terms of water regulation, the cloud forests of the Andes and the Himalayan watersheds provide drinking water to 33 major cities; in terms of coastal protection, mangroves and coral reefs absorb 70-90% of storm waves; and in terms of disaster risk reduction, forested watersheds and peatlands reduce flood damage by 20-40%. Furthermore, it is emphasized that the conservation of agricultural biodiversity preserves more than 100 wild cereal species, which provide climate-resilient genetic material.

The concrete data presented here demonstrates that protected areas are not merely a "conservation tool" in the fight against climate change, but rather multifunctional solutions at the heart of mitigation and adaptation strategies. The role of protected areas in combating climate change is increasingly recognized in international policy processes.

Convention on Biological Diversity (CBD): Programme of Work on Protected Areas (PoWPA) Target 1.4.5 to "integrate climate change adaptation measures into protected area planning," Aichi Targets: Target 11: "effectively managed protected area systems" and the Post-2020 Global Biodiversity Framework: Expansion and effective management of protected areas.

United Nations Framework Convention on Climate Change (UNFCCC): REDD+ (Reducing Emissions from Deforestation and Forest Degradation): The role of forest conservation in climate mitigation, Ecosystem-Based Adaptation (EbA): Integration of natural ecosystems into adaptation strategies and National Adaptation Plans (NAPs): Inclusion of protected areas in national adaptation strategies.

Other International Agreements: Ramsar Convention: Conservation and wise use of wetlands, World Heritage Convention: Conservation of areas of outstanding universal value, and Convention to Combat Desertification (UNCCD): Reduction of land degradation.

Küre Mountains National Park A'WOT-CJA Framework

This study was designed in accordance with a mixed-methods research design. Qualitative and quantitative data were collected and analyzed in stages. The study area, Küre Mountains National Park (KMNP), is a 37,000-hectare protected area located in the Western Black Sea Region of Turkey (Table 2) and holds great potential not only for forest trees but also for macrofungal diversity (Yeşilbaş, 2015; Özkazanç et al., 2018; Özkazanç and Yeşilbaş Keleş, 2019). In this context, protecting the region's biodiversity from the pressures of climate change is critically important for ecosystem integrity.

Table 2: Basic Characteristics of Küre Mountains National Park.

Characteristic	Description	Importance in the Context of Climate Change
Location	Within the borders of Kastamonu and Bartın provinces	Sensitive to precipitation regime changes in the Black Sea climate region
Area	37,000 hectares	Potential to provide large-scale ecosystem services
Status	National Park (2000), UNESCO Tentative List (2012)	National and international conservation commitments
Ecosystems	Old-growth forests, canyons, rivers	High carbon storage, water regulation, biodiversity
Threats	Forest fires, climate change, mining	Concrete impacts of climate change

A'WOT is a hybrid decision-making tool formed by the integration of Analytic Hierarchy Process (AHP) and SWOT analysis. SWOT Analysis can be defined as the identification of internal (Strengths/Weaknesses) and external (Opportunities/Threats) factors. AHP Analysis can be defined as the prioritization of factors through pairwise comparisons.

Conjoint Analysis (CJA) is a marketing research technique developed to analyze consumer preferences. In CJA, attributes and their levels are defined, hypothetical scenarios are created, participant preferences are measured, and the relative importance of attributes is calculated.

Data Collection and Analysis Processes:

- Qualitative Data Collection and SWOT Analysis
  - Expert Interviews: Semi-structured interviews with 5 experts
  - Focus Group Discussions: 2 focus groups (8 participants each)
  - Document Analysis: Management plans, climate reports, policy documents
  - Content Analysis: Identification of SWOT factors
- AHP Survey and Analysis
  - Survey Design: Pairwise comparison matrices based on Saaty's 1-9 scale
  - Sample: 5 experts (2 managers, 2 academics, 1 NGO representative)
  - Analysis Software: Super Decisions 3.2
  - Analysis Steps:

1. Construction of the hierarchical structure
2. Creation of pairwise comparison matrices
3. Calculation of weights using the eigenvector method
4. Checking the consistency ratio (CR) ($CR < 0.10$)
5. Determination of global priorities

- CJA Survey and Analysis (Table 3)
  - Attribute and Level Definition: 5 attributes, with 2-3 levels for each attribute
  - Scenario Design: 16 profiles using the D-optimal design method
  - Sample: 20 participants (8 local residents, 6 visitors, 3 businesses, 3 public officials)
  - Analysis Software: IBM SPSS Statistics 25, Sawtooth Software Lighthouse Studio
  - Analysis Method: Hierarchical Bayes (HB) estimation method

Table 3: Attributes and Levels for the CJA Survey and Analysis.

Attribute	Level 1	Level 2	Level 3	Description
Carbon Management	Current Conservation	Restoration and Conservation	Restoration Only	Active/passive management approaches
Water Resource Protection	Watershed Monitoring	Structural Measures	Integrated Watershed Management	Integrated water management levels
Fire Risk Management	Traditional	Early Warning	Climate-Smart Plan	Technology and planning integration
Community Participation	Consultation	Co-Decision	Self-Governance	Levels of participation depth
Ecotourism Development	Limited Infrastructure	Sustainable Packages	Climate Education Center	Tourism development levels

The climate change strategy development process for Küre Mountains National Park was designed using a four-stage systematic approach within the A'WOT-CJA hybrid model framework (Figure 1).

Stage 1: ntroduction. Begins with the definition of the study area and the core problem.

Stage 2: Qualitative Analysis. In the qualitative phase, park-specific SWOT factors (Strengths, Weaknesses, Opportunities, Threats) are identified through expert opinions and document analysis.

- Using the Analytic Hierarchy Process (AHP), survey data from 5 experts is analyzed with the Super Decisions software, and the SWOT factors are prioritized.
- Conjoint Analysis (CJA) is applied; preference data collected from 20 participants is evaluated using SPSS or Sawtooth software to reveal the importance stakeholders place on strategic attributes.

Stage 3: Integration. At this stage, the priorities obtained from AHP and the CJA results are synthesized using the A'WOT (SWOT-AHP) technique, creating a comprehensive strategic assessment supported by quantitative data.

Stage 4: Strategy Development and Policy Recommendations. Strategies are developed based on the synthesis. Concrete recommendations for policymakers and practitioners are provided for the implementation, monitoring, and sustainable management of the developed strategies.

The entire process provides a participatory and evidence-based strategic planning framework based on the integrated use of qualitative and quantitative data.

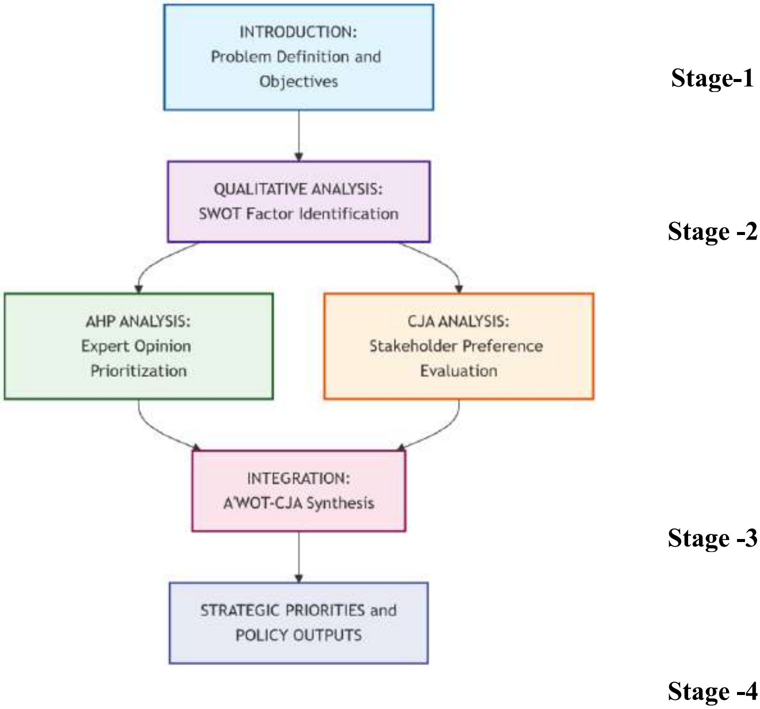

Figure 1: A'WOT-CJA Framework for KMNP

The A'WOT-CJA hybrid model involves determining SWOT factors, prioritizing relevant factors using AHP, scoring them using CJA, and finally creating a strategic priority matrix, i.e., A'WOT-CJA integration. First, SWOT factors were identified for Küre Mountains National Park, and the findings are presented in Table 4.

The AHP priority ranking of SWOT factors (Top 15) is given in Table 5, and the AHP weight distribution by category is given in Table 6.

Table 4: SWOT factors identified for Küre Mountains National Park.

Strengths	Weaknesses
S1: Old-growth forest ecosystems with high carbon storage capacity	W1: Inadequate management capacity (staff number, technical equipment)
S2: Rich and high-quality water resources (streams, springs, waterfalls)	W2: Limited funding sources and insufficient budget
S3: High biodiversity and presence of endemic species	W3: Lack of effective monitoring and data collection systems
S4: International recognition due to UNESCO World Heritage candidacy	W4: Weak communication and coordination between local communities and management
S5: Local knowledge base on traditional ecosystem management	W5: Infrastructure deficiencies (transportation network, communication infrastructure)
S6: Relatively low population pressure and limited human settlement	W6: Low number of research and scientific

S7: High ecotourism potential and infrastructure suitable for nature tourism S8: Strong and motivated local non-governmental organizations (NGOs)	studies W7: Lack of a management plan compatible with climate change scenarios W8: Mismatch between protected area boundaries and ecological boundaries
Opportunities	**Threats**
O1: Potential access to international climate finance (REDD+, GCF, GEF) O2: Strengthening of nature conservation legislation within the EU harmonization process O3: Increasing ecotourism demand and sustainable tourism market O4: Growing public awareness and interest in climate change O5: Opportunities for collaboration with universities and research institutions O6: Incentive programs for sustainable forestry and agricultural practices O7: Integration into regional ecological corridor projects (Black Sea Ecological Network) O8: Development of green economy and carbon markets	T1: Increased forest fire risk and severity due to climate change T2: Drought and water stress due to changes in precipitation patterns T3: Spread of invasive alien species and their impact on native species T4: Illegal logging and hunting activities T5: Pressure on ecosystems from planned energy and mining projects T6: Unsustainable practices in agriculture and livestock farming T7: Aging local population and rural-to-urban migration T8: Negative impact of political and economic instability on conservation efforts

Table 5: AHP Priority Ranking of SWOT Factors (Top 15).

Rank	Factor Code	Factor Description	Global Weight	Category	Priority Level
1	T1	Increasing Forest Fire Risk	0.142	Threat	Very High
2	S1	High Carbon Storage Capacity	0.138	Strength	Very High
3	W1	Inadequate Management Capacity	0.095	Weakness	High
4	S2	Rich Water Resources	0.088	Strength	High
5	O1	Access to Climate Finance	0.073	Opportunity	High
6	T2	Water Stress and Drought Risk	0.069	Threat	Medium High
7	W7	Lack of Climate-Adaptive Plan	0.054	Weakness	Medium
8	O3	Increasing Ecotourism Demand	0.048	Opportunity	Medium
9	T5	Pressure from Mining/Energy	0.045	Threat	Medium
10	S7	Ecotourism Potential	0.041	Strength	Medium
11	T3	Invasive Species	0.038	Threat	Medium
12	W2	Limited Funding	0.036	Weakness	Medium
13	S3	High Biodiversity	0.034	Strength	Low-Medium
14	O5	University Collaboration	0.032	Opportunity	Low-Medium
15	W4	Weak Communication	0.030	Weakness	Low

Consistency Analysis Results: The consistency ratio (CR) for all expert evaluations was found to be below 0.10. The average consistency ratio: 0.068.

The highest consistency ratio: 0.092. The lowest consistency ratio: 0.043 (Table 5).

Table 6: AHP Weight Distribution by Category.

Category	Total Weight	Average Factor Weight	Priority Rank
Threats	0.342	0.043	1
Strengths	0.301	0.038	2
Weaknesses	0.215	0.027	3
Opportunities	0.153	0.019	4

Findings from the Hierarchical Bayes analysis of preference data: Root Likelihood (RLH): 0.721 (acceptable above 0.5),

Hit Rate : 78.3%,
Pearson R^2 : 0.894,
Kendall Tau : 0.812.

The relative importance values of the attributes are shown in Table 7, while the part-worth utilities of the attribute levels are shown in Table 8. Furthermore, participants were segmented based on their preference structures through clustering analysis (K-means clustering). The segmentation analysis results are presented in Table 9.

Table 7: Relative Importance Values of Management Attributes.

Attribute	Relative Importance	Standard Error	Confidence Interval (95%)
Carbon Management	31.5%	±2.1	29.4% – 33.6%
Water Resource Protection	24.8%	±1.9	22.9% – 26.7%
Fire Risk Management	20.1%	±1.7	18.4% – 21.8%
Community Participation	13.2%	±1.4	11.8% – 14.6%
Ecotourism Development	10.4%	±1.2	9.2% – 11.6%
Total	100.0%		

Table 8: Detailed CJA of Attribute Levels.

Attribute and Levels	Utility Value	Standard Error	Relative Importance
Carbon Management			31.5%
Current Protection	0.00 (Ref)	-	-
Restoration & Protection	1.85	±0.12	-
Water Resource Protection			24.8%

Watershed Monitoring	0.00 (Ref)	-	-
Structural Measures	0.92	±0.09	-
Integrated Watershed Management	1.64	±0.11	-
Fire Risk Management			20.1%
Traditional Methods	0.00 (Ref)	-	-
Early Warning System	1.10	±0.08	-
Climate-Smart Fire Plan	1.98	±0.13	-
Community Participation			13.2%
Consultation	0.00 (Ref)	-	-
Co-Decision Making	1.45	±0.10	-
Self-Governance	0.87	±0.07	-
Ecotourism Development			10.4%
Limited Infrastructure	0.00 (Ref)	-	-
Sustainable Packages	1.12	±0.09	-
Climate Education Center	0.95	±0.08	-

Table 9: CJA Participant Segments and Characteristics.

Segment	Population (%)	Description	Priority Attributes
Environment-Focused	38%	High sensitivity to environmental issues	Carbon (38%), Water (28%), Fire (22%)
Community-Focused	32%	Emphasis on local participation and social justice	Participation (25%), Water (24%), Carbon (21%)
Development-Focused	22%	Priority on economic benefit and development	Tourism (28%), Carbon (23%), Water (20%)
Traditionalists	8%	In favor of maintaining the status quo	Fire (30%), Water (25%), Participation (20%)

The A'WOT-CJA strategic priority matrix is shown in Figure 2, and the results of the integrated analysis from A'WOT-CJA, presented as a strategic priority matrix, are shown in Table 10.

Table 10: Strategic Priority Matrix (A'WOT-CJA Integration).

Strategic Area	AHP Priority	CJA Priority	Integrated Score	Strategic Actions
1. Carbon & Fire Management	Very High (0.280)	Very High (0.516)	0.798	Active carbon restoration Climate-smart fire plan Early warning systems
2. Water Resources Management	High (0.157)	High (0.248)	0.405	Integrated watershed management Water quality monitoring Flood control measures
3.	Medium High (0.125)	Medium (0.132)	0.257	Co-decision making mechanisms Staff training programs

Management Capacity & Participation				Establishment of monitoring systems
4. Financing & Ecotourism	Medium (0.089)	Low (0.104)	0.193	Access to climate funds Sustainable tourism packages Carbon credit projects

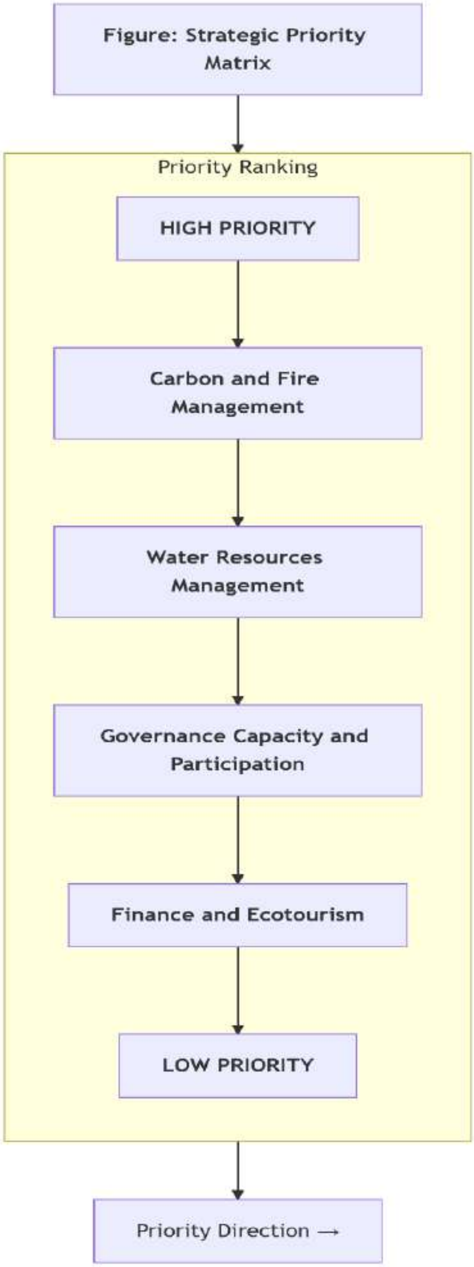

Figure 2: A'WOT-CJA Strategic Priority Matrix

The Conceptual Framework Relationship of A'WOT-CJA Outputs

Both the AHP and CJA results of our study indicate that carbon management and fire risk management are absolute strategic priorities. This finding is fully consistent with the role of protected areas as carbon sinks, as emphasized by Dudley et al. (2010). However, our study reveals that this role must go beyond passive storage. The high value stakeholders placed on the "restoration + conservation" option (utility value of 1.85) indicates that public acceptance extends not only to the conservation of existing stocks but also to the active restoration of degraded areas. This finding supports the "natural solutions" approach highlighted by Trumper et al. (2009), Şen & Güngör (2018), and Güngör & Şen (2024). Active restoration efforts in protected areas will both increase carbon sequestration capacity and strengthen ecosystem resilience. The perception of fire risk as the greatest threat (AHP weight: 0.142) is consistent with changes in fire regimes, one of the most tangible effects of climate change on protected areas in the Mediterranean basin (Schröter et al., 2005; Westerling et al., 2006). Additionally, longer fire seasons due to climate change negatively impact the workload and social welfare of technical personnel responsible for ecological balance, threatening the sustainability of management capacity (Güngör and Yeşilbaş, 2025). In this context, the fact that the "Climate-Smart Fire Plan" received the highest preference value (1.98) in the CJA indicates that stakeholders demand proactive strategies based on climate projections that go beyond traditional firefighting approaches.

The high importance given to protecting water resources (24.8% in CJA, 0.157 in AHP) confirms the critical role of protected areas in the water cycle. This finding aligns with the fact that many large cities worldwide source their drinking water from protected forest watersheds (Dudley et al., 2010). The fact that "Integrated Watershed Management" is the most preferred option in CJA (1.64 utility value) indicates that water management requires a holistic approach that transcends protected area boundaries. This finding is consistent with the literature emphasizing the importance of "connected protected area networks" in adapting to climate change (Heller & Zavaleta, 2009). It is known that climate change puts pressure on water resources by altering rainfall regimes (Bates et al., 2008). Therefore, protecting water resources in protected areas is no longer just a biodiversity issue, but also a fundamental climate adaptation and food security strategy, which requires integrated monitoring of water quality and quantity and the use of predictive, data-driven tools to support early warning and adaptive management under climate variability (Güneş Şen, 2025a; Güneş Şen, 2025b).

The lack of management capacity highlighted in the AHP (0.095) is a universal problem frequently mentioned in the protected area effectiveness literature (Leverington et al., 2008). In the CJA, stakeholders preferred the "joint decision-making" mechanism (1.45 utility value). When these two findings are considered together, it becomes clear that the solution is not merely a matter of demanding more budget and personnel, but also involves transforming the governance structure. Borrini-Feyerabend et al. (2004) argue that co-management models reduce resource conflicts, share management costs, and increase effectiveness by incorporating local knowledge into the process. Capacity building should include not only technical training but also the development of dialogue, negotiation, and joint planning skills among stakeholders. This is particularly important in dealing with complex and uncertain issues such as climate change.

The low priority given to ecotourism in the CJA (10.4%) reflects stakeholders' view that tourism revenue should not be the primary goal of conservation. However, the fact that access to finance is seen as an important opportunity in the AHP (0.073) suggests that ecotourism could be used as a strategic tool to finance other priorities. Sustainable financing models for protected areas should be developed. These include carbon credit projects, payments for ecosystem services (PES), (Wunder, 2005) channelling sustainable tourism revenues into conservation, and access to international climate funds (GCF, GEF). Ecotourism can not only provide funding for conservation efforts, but also increase social support for conservation by supporting the local economy and raising awareness about climate change.

The key methodological contributions of this study are as follows:

– Development of the A'WOT-CJA hybrid model: The integration of SWOT, AHP, and Conjoint Analysis (CJA) methodologies.

– Qualitative-quantitative data integration: The combined assessment of expert opinions and broad stakeholder preferences.

– Strategic prioritization framework: The systematization of multi-criteria decision-making processes.

Limitations of This Study

– Case study limitation: The generalizability of findings to other protected areas.

– Sample size: The CJA survey involved 200 participants; this could be supported by larger samples.

– Time constraint: Lack of long-term monitoring data.

– Climate uncertainty: The impact of uncertainties in climate projections on the formulated strategies.

Future Research Recommendations

– Conducting similar analyses in different ecosystem types (e.g., wetlands, arid lands, marine areas).

– Comparing the A'WOT-CJA model with other multi-criteria decision-making methods (e.g., TOPSIS, PROMETHEE).

– Integrating the analysis results with cost-benefit analyses.

– Simulating the long-term effects of strategies using dynamic system modeling.

Policy and Implementation Recommendations

This study analyzed the role of protected areas in combating climate change, specifically in the Küre Mountains National Park, using the A'WOT-CJA hybrid model. The main findings of the study reveal four key strategic priorities: (1) carbon management and fire risk are the highest priorities, (2) water resource management is the second priority, (3) management capacity and participatory mechanisms are critical for feasibility, and (4) financing and ecotourism should be considered strategic tools to support other priorities. In light of these findings, policy and implementation recommendations at different levels are presented below.

At the national level, a regulatory and institutional framework needs to be established to ensure the integration of climate and conservation policies. Although the current Turkish forestry legislation addresses climate change to a certain extent, it still needs improvement (Gençay and Birben, 2024). In this context, the Legal Infrastructure for Climate-Conservation Integration must first be strengthened. Climate change mitigation and adaptation targets should be added to the National Parks Law, a climate change section should be made mandatory in all protected area management plans, and the share allocated to protected area projects from national climate funds should be increased (Bosetti & Frankel, 2023). Including ecosystem-based adaptation (EbA) in planning processes as a legal requirement also stands out as an effective strategy (SCBD, 2021).

A Protected Area-Based Carbon Accounting System should be established. Including protected area carbon stocks, such as forests, peatlands, and blue carbon ecosystems, in the national carbon inventory will increase the reliability of national contributions (NDCs) (IPCC, 2019). Developing high-resolution and verifiable monitoring systems in these areas (WRI, 2022), combined with prioritizing protected areas, particularly for REDD+ projects, can strengthen both conservation and access to climate finance (World Bank, 2020). The representation of local communities on protected area management boards should be increased, co-management models should be scaled up through pilot applications, and local knowledge and traditional practices should be systematically integrated into conservation strategies. Sustainable Financing Mechanisms Should Be Developed. A dedicated fund such as a "Climate Resilient Nature Fund" could be established, pilot projects for payments for ecosystem services (PES) such as water quality or carbon sequestration could be launched, and project preparation and management capacity for accessing international climate funds such as the GCF and GEF should be strengthened.

At the local government level, a comprehensive management approach should be adopted to mitigate the effects of climate change on protected areas and increase their adaptation capacity. This approach should include concrete steps to reduce external pressures such as mining activities, illegal logging, and agricultural pollution by identifying the ecological vulnerabilities of protected areas (Karaca & Ayhan, 2025, p. 9; Tonyalıoğlu et al., 2020, p. 283). Furthermore, instead of relying on traditional conservation approaches based on isolated islands, it is necessary to transition to a holistic management approach that does not ignore the important functions within the landscape matrix (Tonyalıoğlu et al., 2020, p. 16). Subsequently, a Climate-Resilient Carbon and Fire Management Plan should be prepared. Detailed carbon stock mapping should be carried out, dynamic fire risk maps based on climate projections should be created, and active restoration efforts should be initiated using fire-resistant species. An Integrated Watershed Management Project should be launched. Management plans should be revised according to watershed boundaries rather than administrative boundaries, stations monitoring water quality and quantity should be established, and structural and non-structural measures such as flood control and erosion prevention should be implemented. Capacity Development Programs should be designed. Training should be organized for personnel and relevant stakeholders on climate change, fire management, and participatory planning. Technological infrastructure, such as remote sensing and early warning systems, should be strengthened, and the community should be involved in data collection and monitoring processes through citizen science programs. A Sustainable Ecotourism Strategy should be developed. "Climate-friendly tourism" standards should be established that minimize carbon footprint, ensure effective waste management, and promote high energy efficiency. Models should be designed where a significant portion of revenue is channeled into conservation efforts and the local economy, and effective awareness programs on climate change and ecosystem services should be implemented for visitors.

Global problems require global cooperation. First, Regional Climate-Protection Networks should be established. Active participation in existing initiatives such as the Black Sea Ecological Corridor Project should be ensured, transboundary protected area networks should be created to protect species' climate migration routes, and joint monitoring and research programs should be carried out (Hilty et al., 2020; IUCN, 2023). In this context, Bergerot et al. (2020) demonstrate that the success of similar cross-border collaborations in water management could serve as a model for ecosystem corridors.

Access to International Financial Resources should be increased. Competitive, high-quality project proposals should be prepared for sources such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF) (Atteridge & Canales, 2017), market-based financing mechanisms such as carbon credits and blue carbon should be evaluated (Seddon et al., 2021) and green investment partnerships with the private sector should be encouraged.

Active membership and participation in international conservation networks such as UCN and WWF should be ensured (Morrison, 2020), and good practice examples from our country (e.g., Ministry of Environment, Urbanization and Climate Change & UNDP Turkey, 2023) should be shared on international platforms, and joint publications and projects should be developed with researchers and practitioners from different countries.

This study contributes in four key areas. Methodologically, it demonstrates that the A'WOT-CJA hybrid model is a feasible and useful decision support tool for protected area planning. Its policy contribution lies in providing concrete and phased (local-national-international) policy recommendations for integrating protected areas into climate strategies. Its practical contribution is to propose priority action areas and feasible strategies for Küre Mountains National Park. Its theoretical contribution is to provide a new model that integrates quantitative and qualitative data and empirical findings derived from this model to the literature on protected area management and climate change.

In conclusion, in the era of climate change, protected areas are not just static museums preserving the biological treasures of the past, but dynamic, service-providing ecological infrastructures that are indispensable for building climate-resilient societies of the future. The hybrid model proposed in this study and the findings from Küre Mountains National Park provide a comprehensive roadmap for data-driven, participatory, multi-scale, and strategic planning processes necessary to strengthen these infrastructures.

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