"ALEXANDRU IOAN CUZA" UNIVERSITY OF IAȘI
FACULTY OF GEOGRAPHY-GEOLOGY
DOCTORAL SCHOOL OF GEOSCIENCES

Evaluation of ecosystem services in a peri-urban Natura 2000 site: Bârnova Forest

DOCTORAL THESIS ABSTRACT

Scientific advisor:
Prof.univ. dr. habil. Iuliana Gabriela BREABĂN

PhD Student:
Ioana ZAIȚ (căs. Lazăr)

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Alexandru Ioan Cuza University of Iași
Faculty of Geography and Geology
Doctoral School of Geosciences

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Scientific advisor:
Prof.univ. dr. habil. Iuliana Gabriela BREABĂN

Student-doctorand:
Ioana ZAIȚ (căs. Lazăr)

President of the Doctoral Committee:
Prof. univ. dr. Alexandra – Raluca IORDAN
Universitatea „Al.I.Cuza" din Iași, Facultatea de Chimie

Doctoral Supervisor:
Prof. univ. dr. habil. Iuliana-Gabriela BREABĂN
Universitatea „Al.I.Cuza" din Iași, Facultatea de Geografie și Geologie

Official Reviewers:

Prof. univ. dr. habil. Cristian Ioan IOJA - Universitatea din București, Facultatea de Geografie
Conf. univ. dr. Ștefan BILAȘCO - Universitatea Babeș - Bolyai din Cluj-Napoca, Facultatea de Geografie
Prof. univ. dr. habil. Mircea – Nicușor NICOARĂ - Universitatea „Al.I.Cuza" din Iași, Facultatea de Biologie

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Lect. univ. Dr.Vasile JITARIU - Universitatea „Al.I.Cuza" din Iași

Dr. Razvan Florian DEJU- Direcția Județeană de Mediu Iași

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Keywords

Ecosystem services, forest ecosystem services, CICES classification, ecosystem service assessment, multifunctionality, forest management, silvicultural arrangements, functional groups, GIS mapping, spatial analysis, remote sensing, NDVI, biophysical analysis, carbon stock, soil quality, water quality, biodiversity, forest habitats, protected natural areas, Natura 2000, Bârnova Forest, Bârnova–Repedea Forest, non-timber forest products, provisioning services, regulating services, cultural services, perception of ecosystem services, sustainable development, biodiversity conservation, forest ecosystem management.

Introduction

In the context of intensified anthropogenic pressures, climate change, and biodiversity loss, the assessment of ecosystem services has become essential for understanding the contribution of natural ecosystems to human well-being. Forests are not just sources of timber resources, but multifunctional ecosystems that contribute to climate regulation, soil and water resource protection, biodiversity conservation, and the provision of cultural and recreational benefits.

Although the concept of ecosystem services is well developed at the international level, the application of integrated approaches in the assessment of forest ecosystems in Romania remains relatively limited. In particular, the correlation of information from forestry management plans with biophysical indicators, spatial analyzes, CICES classification, and beneficiary perception represents a relevant research direction for underpinning sustainable forest management.

The present research focuses on the Bârnova Forest, defined by the area resulting from the overlap of the Natura 2000 sites ROSAC0135 Bârnova–Repedea and ROSPA0092 Bârnova Forest. The choice of the area is justified by the diversity of habitats and species of conservation interest, the continuity of forested areas, and the proximity to the municipality of Iași, which leads to an intensive use of the forest for recreational, sports, and educational activities.

The interest in this area is supported both by a long-term personal relationship with the Bârnova Forest and by the academic and professional experience accumulated in the field of environmental protection and the management of protected natural areas. These experiences have contributed to shaping an interdisciplinary perspective on the relationship between biodiversity conservation, the use of natural resources, and the needs of human communities.

The aim of the research is the integrated assessment of the ecosystem services provided by the Bârnova Forest, through the analysis of provisioning, regulating, and cultural services, as well as the interdependence relationships between them. The methodology combines information from forestry management plans and the CICES classification with biophysical analyzes, GIS and remote sensing techniques, field observations, and sociological investigations. Through this approach, the thesis aims to highlight the multifunctional character of the forest ecosystem and develop an evaluation framework that contributes to informed decision-making regarding biodiversity conservation, sustainable resource use, and the maintenance of benefits provided to society. The proposed methodology can serve as a starting point for similar assessments in other forest ecosystems in Romania.

Chapter I. Theoretical Framework in the Field of Study. The current state of research

I.1. The Global Context of Ecosystem Services

I.1.1. The Historical Premises of the Concept

The idea that human society fundamentally depends on nature for the sustenance of life and economic activities predates the establishment of the term "ecosystem services." In the 18th–19th centuries, economic thought recognized the role of natural resources, but the approach was predominantly utilitarian and focused on their extraction.

In the second half of the 20th century, scientific literature begins to highlight the limits of uncontrolled exploitation of natural resources. Hardin (1968) introduces the concept of the "tragedy of the commons," while Georgescu-Roegen (1971) highlights the limitations of the traditional economic model in relation to the degradation of natural capital.

Gradually, nature begins to be perceived not just as a reservoir of resources, but as a complex system of processes and functions essential for human life. Concepts such as "environmental services" (SCEP, 1970; Myers, 1996) and "natural capital" (Schumacher, 1973; Costanza & Daly, 1992), along with the typology of ecosystem functions proposed by de Groot (1992), have contributed to the development of the conceptual framework of ecosystem services.

Although the term began to be used in the early 1980s (Ehrlich & Ehrlich, 1981), its origins reflect the transition from an extractive perspective on nature to a systemic one, in which ecosystems are considered the foundation of economic development and human well-being (Gómez-Baggethun et al., 2010).

I.1.2. Consolidation and International Recognition of the Concept

The concept of ecosystem services became established in the 1990s through the contributions of Daily (1997) and Costanza et al. (1997), who highlighted the role of ecological processes and the value of the benefits ecosystems provide to society. Subsequently, de Groot et al. (2002) further examined the relationships between ecosystem structure, functions and resulting benefits.

A major milestone was the Millennium Ecosystem Assessment (MEA, 2005), which defines ecosystem services as the benefits people obtain from ecosystems and classifies them into four categories: provisioning, regulating, cultural and supporting services. It also highlights their contribution to health, security, material well-being and social relations.

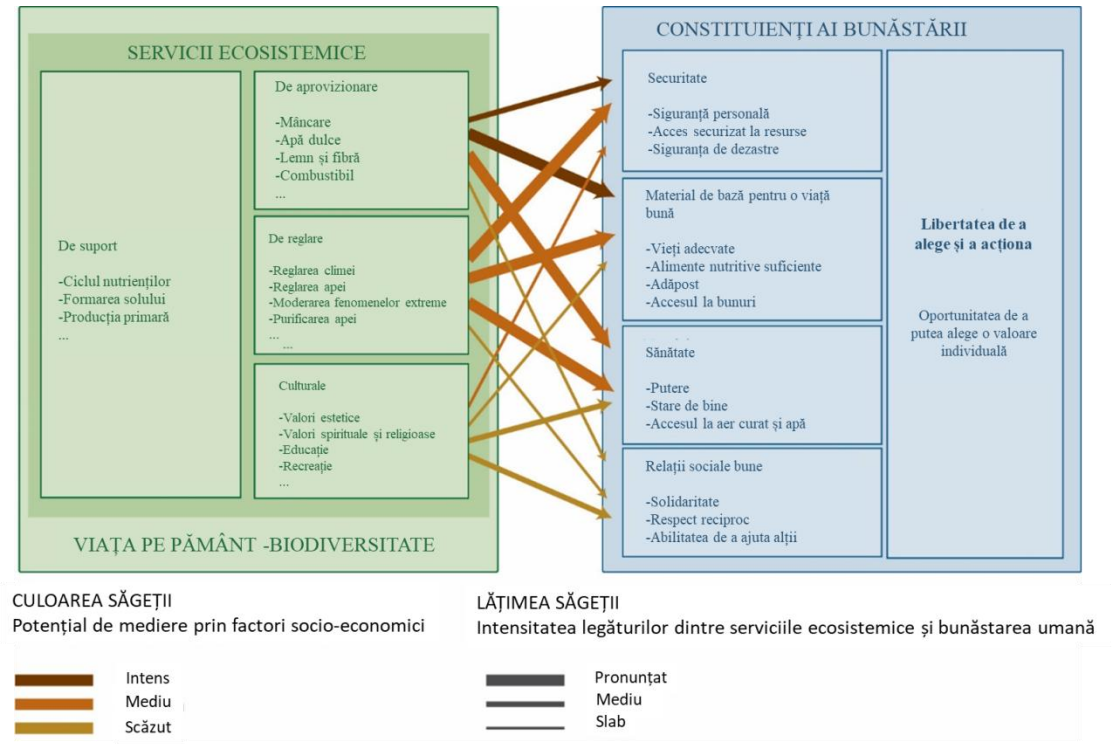

Figure 1 Assessment of the links between ecosystems and human well-being (after MEA, 2005)

Subsequently, the TEEB (2010) and MAES (Maes et al., 2016) initiatives promoted the economic and spatial assessment of ecosystem services, while IPBES broadened the perspective through the concept of "nature's contributions to people", also incorporating cultural and relational values (Díaz et al., 2018).

Thus, ecosystem services have become an important tool for biodiversity conservation, spatial planning and sustainable natural resource management.

I.2. The Role of Forests in Providing Ecosystem Services

Forests cover approximately one-third of the Earth's land area and contribute to climate regulation, biodiversity conservation and the maintenance of ecological balance (FAO, 2020). Through carbon storage, hydrological regulation and soil protection, they provide ecosystem services essential to human well-being (MEA, 2005; Pan et al., 2011).

Forests also provide timber and non-timber resources, recreational opportunities and economic benefits for local communities. Maintaining these functions depends on biodiversity conservation and the application of sustainable forest management principles (Balvanera et al., 2006; Forest Europe, 2020).

Integrated ecosystem service assessment makes it possible to highlight the multifunctional value of forests and to inform decisions regarding their sustainable use and conservation.

I.3. The Importance of the Natura 2000 Network in Providing Ecosystem Services

The Natura 2000 network is the European Union's principal instrument for biodiversity conservation, based on the Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC).

It comprises Sites of Community Importance (SCIs), subsequently designated as Special Areas of Conservation (SACs), and Special Protection Areas (SPAs), with the aim of maintaining habitats and species in a favourable conservation status (European Commission, 2013).

Natura 2000 allows human activities compatible with conservation objectives while also contributing to the provision of ecosystem services such as carbon storage, hydrological regulation, soil protection and recreation (Maes et al., 2013; EEA, 2020).

The integration of these services into site management is supported by the European MAES initiative (Mapping and Assessment of Ecosystems and their Services), which promotes ecosystem mapping and assessment to inform conservation and sustainable-use decisions (Maes et al., 2016).

I.4. Research Motivation

Interactions between nature and human society have undergone profound changes in recent decades amid intensifying economic activity and increasing pressure on natural resources. Habitat degradation, ecosystem fragmentation and biodiversity loss are widely documented worldwide. Their consequences directly affect ecosystems' capacity to provide services essential to human well-being. In this context, ecosystem service assessment has become a fundamental tool for understanding the relationship between conservation and development.

The choice of research topic is motivated both by previous academic interests in the benefits provided by protected natural areas and by an interest in analysing a peri-urban forest ecosystem near the city of Iași. Bârnova Forest is an area where biodiversity conservation, natural resource use and the recreational needs of urban residents intersect with traditional activities and the socioeconomic interests of local communities, forming a complex socio-ecological system characteristic of peri-urban forests. Accordingly, the research seeks to highlight the multiple values of a peri-urban protected natural area beyond its strictly conservation-related function.

I.5. Research Premises

The research is grounded in the need to understand the relationships between nature conservation, forest ecosystem functioning and societal development.

Peri-urban forests face growing pressures arising from the expansion of built-up areas, intensive recreational use and natural resource exploitation, which may affect their ecological balance and long-term capacity to provide ecosystem services.

Although Natura 2000 sites are designated primarily to conserve habitats and species of Community interest, they also contribute to socioeconomic well-being through the ecosystem services they provide. In Romania, existing assessments focus predominantly on biodiversity or sector-specific analyses, without coherently integrating ecological, economic and social dimensions.

In this context, understanding how a Natura 2000 site functions requires linking ecosystem characteristics to how its services are used and perceived by local communities and urban residents. Building on these premises, the research proposes an integrated assessment of the ecosystem services provided by Bârnova Forest as a case study representative of peri-urban forests in the Central Moldavian Plateau.

I.6. Research Problem

Natura 2000 sites aim to conserve habitats and species of Community interest; however, integrating ecosystem services into their assessment and management is becoming increasingly important (Maes et al., 2016; EEA, 2020). In Romania, integrated assessments of forest ecosystem services remain limited.

For the ROSAC0135 Bârnova–Repedea Forest and ROSPA0092 Bârnova Forest sites, although a management plan and biodiversity studies exist, a systematic assessment of ecosystem services is lacking (Sincron, 2015; Popescu & Gostin, 2025).

The central research problem is to assess the multifunctionality of this peri-urban forest ecosystem by identifying the services it provides, the environmental factors influencing them, and their contribution to biodiversity conservation and human well-being.

I.7. Research Aim and Objectives

The aim of the thesis is to provide an integrated assessment of the ecosystem services supplied by Bârnova Forest within the overlapping area of the Natura 2000 sites ROSAC0135 and ROSPA0092, by analysing the relationships between forest ecosystems, environmental factors, and socioeconomic and cultural benefits.

Seven specific objectives were established to achieve this aim:

1. To characterise the natural environment, habitats and specific features of forest ecosystems.
2. To identify and classify ecosystem services according to the CICES system.
3. To assess provisioning services through the analysis of timber and non-timber resources.
4. To assess regulating services through the analysis of climatic, soil-related, hydrological and ecological indicators.
5. To assess cultural services through the analysis of recreational use, heritage and public perceptions.
6. To analyse the spatial distribution and multifunctionality of ecosystem services by integrating forestry, biophysical, GIS, remote sensing and sociological data.
7. To highlight the contribution of ecosystem services to human well-being and to inform sustainable forest management.

I.8. Working Hypotheses

The research is based on the general hypothesis that Bârnova Forest is a multifunctional forest ecosystem whose value derives from the integrated provision of provisioning, regulating and cultural services, beyond its productive function.

Five working hypotheses were formulated to test this proposition:

Hypothesis 1. Bârnova Forest simultaneously provides diverse ecosystem services influenced by the structural and functional characteristics of forest stands.

Hypothesis 2. Integrating forestry, biophysical, GIS, remote sensing and sociological data enables a more comprehensive assessment of forest multifunctionality.

Hypothesis 3. Perceptions and uses of ecosystem services differ between local communities and urban residents.

Hypothesis 4. The biophysical characteristics of the forest influence the provision of regulating services, as reflected in climatic, soil-related and hydrological indicators.
Hypothesis 5. Integrated ecosystem service assessment helps inform sustainable forest management and highlight the forest's multiple values.

I.9. Thesis Structure

The doctoral thesis is organised into five chapters, followed by discussion and conclusions, covering the theoretical foundations, characterisation of the study area, methodology and integrated assessment of forest ecosystem services.

Chapter I – Theoretical Background in the Field of Study. Current State of Research presents the research context, motivation, research problem, aim, objectives and hypotheses.

Chapter II – Conceptual and Theoretical Framework addresses the concept of ecosystem services, classification systems, assessment methods and their relationship with sustainable forest management.

Chapter III – Study Area describes the physical-geographical, climatic, hydrological, soil and biological characteristics of Bârnova Forest.

Chapter IV – Research Methodology describes the data sources and methods used, including GIS and remote sensing analyses, field investigations, soil and water analyses, sociological questionnaires and multifunctionality assessment.

Chapter V – Ecosystem Service Assessment constitutes the applied component of the thesis, examining provisioning, cultural and regulating services by integrating forestry, biophysical, spatial and sociological data.

The discussion and conclusions synthesise the research findings, original contributions, study limitations and implications for sustainable forest ecosystem management.

CHAPTER II. CONCEPTUAL AND THEORETICAL FRAMEWORK

II.1. The Concept of Ecosystem Services

II.1.1. Fundamental Definitions of the Concept of Ecosystem Services

The concept of ecosystem services has been interpreted in various theoretical ways, all sharing a common element: the relationship between ecosystem functioning and human well-being.

From an ecological perspective, Daily (1997) defines ecosystem services in terms of the natural conditions and processes that sustain human life, emphasising the role of biophysical functions. Costanza et al. (1997) propose an economic approach in which ecosystem services represent the benefits obtained directly or indirectly from ecosystem functions and are regarded as flows generated by natural capital.

The Millennium Ecosystem Assessment (MEA, 2005) brings these perspectives together, defining ecosystem services as "the benefits people obtain from ecosystems". Subsequently, TEEB (2010, 2012) emphasises the economic value of natural capital and its integration into decision-making processes, while IPBES broadens the approach through the concept of "nature's contributions to people", including cultural and relational values (Díaz et al., 2018).

Thus, definitions of ecosystem services reflect three complementary perspectives: biophysical, economic and socio-ecological.

II.1.2. Theoretical Differences and Conceptual Clarifications

A fundamental distinction in the literature is that between ecosystem functions, ecosystem services and the benefits provided to society. Ecosystem functions refer to the biophysical processes and properties of ecosystems, such as photosynthesis, nutrient cycling and water infiltration (de Groot, 1992), whereas ecosystem services express their contribution to generating benefits for society (de Groot et al., 2002).

The "ecosystem services cascade" model (Haines-Young & Potschin, 2010) illustrates the sequence linking ecosystem structures and processes, functions, services and the benefits associated with human well-being.

The anthropocentric approach to ecosystem services has prompted debate about the risk of reducing the complexity of nature–society relationships to quantifiable benefits (Norgaard, 2010). In this context, IPBES promotes the integration of cultural and relational values (Díaz et al., 2018).

Another conceptual difference concerns supporting services, which are treated as a separate category in the MEA classification (2005) but incorporated into other categories in the TEEB and CICES systems to avoid overlaps and double counting.

Consequently, clarifying the relationships between functions, services and benefits is essential for the integrated assessment of ecosystem services provided by forests and protected natural areas.

II.2. Classification of Ecosystem Services

The classification of ecosystem services was systematised by the Millennium Ecosystem Assessment (MEA, 2005), which distinguishes four categories: provisioning services (material resources), regulating services (climate and water regulation and soil protection), cultural services (recreation, education and spiritual values) and supporting services (soil formation and biogeochemical cycles).

Subsequently, the TEEB system (2010), oriented towards economic valuation, and CICES (Haines-Young & Potschin, 2018) were developed. CICES proposes a hierarchical classification comprising three main sections: provisioning; regulation and maintenance; and cultural services, organised into divisions, groups and classes.

These systems enable the identification and assessment of ecosystem services and the analysis of synergies and trade-offs among them (Bennett et al., 2009).



Figure 2. Classification of ecosystem services and examples associated with the main categories (adapted from the Millennium Ecosystem Assessment, 2005).

II.3. Methods for Assessing Ecosystem Services

Ecosystem service assessment involves the integration of three main approaches: biophysical, economic and sociocultural (de Groot et al., 2010; Burkhard et al., 2012).

Biophysical assessment uses ecological, climatic, hydrological and soil indicators alongside GIS and remote sensing techniques. Economic valuation estimates the monetary value of benefits using methods such as market prices and avoided costs, while sociocultural assessment examines perceptions and uses of ecosystem services through questionnaires, interviews and participatory mapping (TEEB, 2010; Daniel et al., 2012).

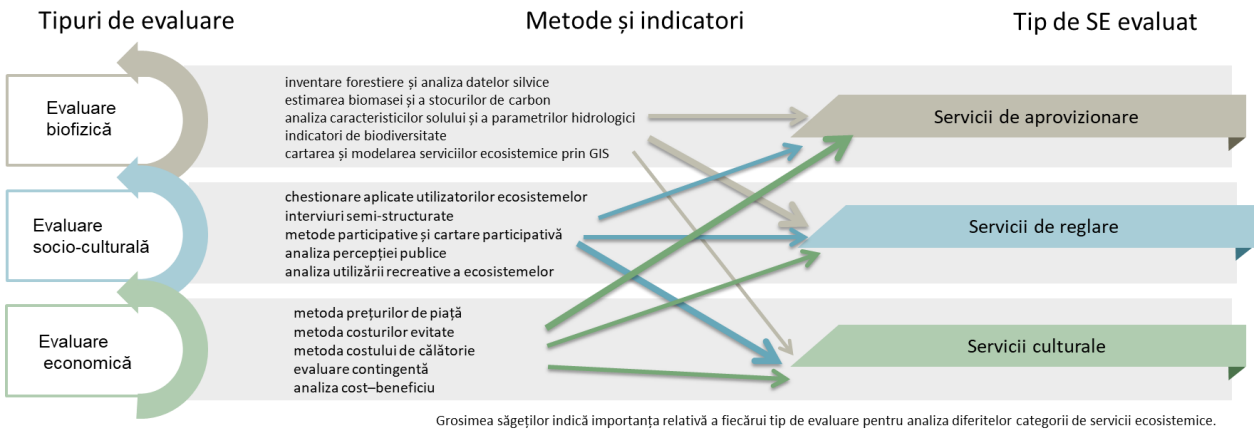

Figure 3. Main types of assessment used in ecosystem service analysis, methods applied and service categories analysed (adapted from de Groot et al., 2010; Burkhard et al., 2012; TEEB, 2010; Maes et al., 2013).

Integrating the three approaches enables a multidimensional assessment of ecosystem services, highlighting relationships among ecosystem functioning, natural resource use and human well-being.

II.4. Ecosystem Services in Forest Ecosystems and the Role of Sustainable Management

Forest ecosystems simultaneously provide provisioning, regulating and cultural services, influenced by stand structure and management practices. Structural diversity promotes forest multifunctionality, while synergies and trade-offs occur among ecosystem services (Gamfeldt et al., 2013; Nelson et al., 2009).

Sustainable forest management aims to balance economic, ecological and social functions. It is also supported by FSC and PEFC certification systems, which promote responsible management and the conservation of forest resources (Duncker et al., 2012; Auld et al., 2008).

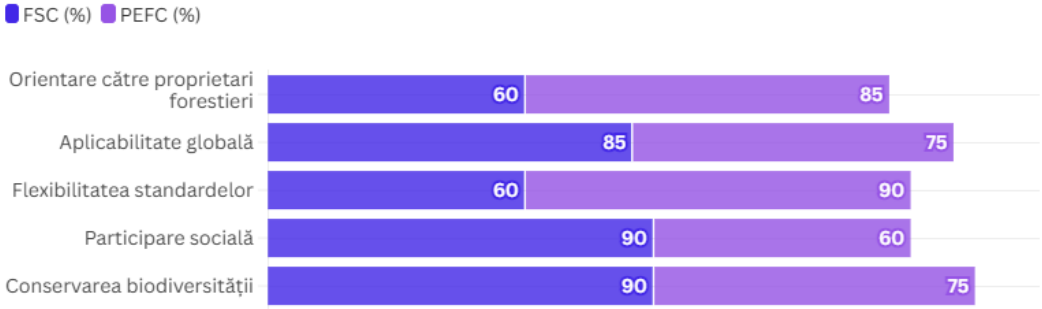

Figure 4. Comparison of the main characteristics of the FSC and PEFC forest certification systems.

CHAPTER III. STUDY AREA

III.1. Location and Delimitation of the Study Area

The study area comprises the Bârnova Forest massif, located in the southeastern part of Iași County, within the Central Moldavian Plateau, a subdivision of the Moldavian Plateau characterised by hilly terrain and extensive forest cover (Băcăuanu, 1980; Ungureanu, 1993).

In this research, the general name "Bârnova Forest" refers to the forest area included in the Natura 2000 sites ROSCI0135 Pădurea Bârnova–Repedea and ROSPA0092 Pădurea Bârnova, including the sections where they overlap. The total area analysed is 14,852.72 ha, representing one of the most important forest complexes in the central-eastern part of the Moldavian Plateau.

From a forestry administration perspective, the forest area is managed by the National Forest Administration – Romsilva, through the Iași Forestry Directorate and the Lunca Cetățuii, Dobrovăț and Pădureni forest districts (ICAS, 2018; ICAS, 2019). Territorially, the study area extends across seven communes: Bârnova, Ciurea, Comarna, Dobrovăț, Grajduri, Schitu Duca and Tomești.

Four nature reserves designated under Law No. 5/2000 are located within the study area: the Dealul Repedea Fossil Site (5.8 ha), a geological and palaeontological reserve; Poiana cu Schit (9.5 ha), a floristic reserve; and Pietrosu (83 ha) and Poieni–Cărbunăriei (9.2 ha), both forest reserves (Sincron, 2015).

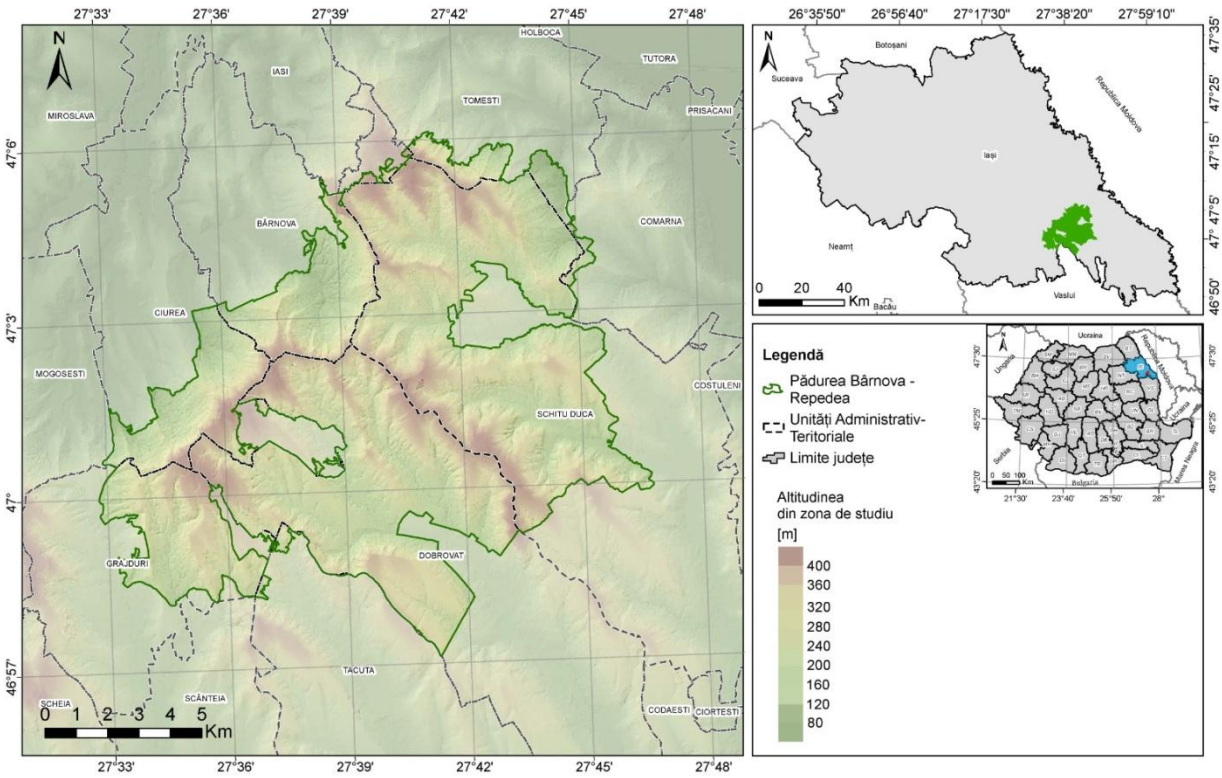

Figure 5. Location of the study area – Bârnova Forest, Iași County, Romania

III.2. Physical and Geographical Setting

III.2.1. Relief

Bârnova Forest is situated in the Central Moldavian Plateau, in a hilly landscape developed on Neogene sedimentary deposits, characterised by elongated interfluves, gently rounded ridges and incised valleys (Băcăuanu et al., 1980; Ungureanu, 1993).

The monoclinal geological structure and dissected terrain favour erosion and landslides, particularly on steep slopes (Șandru et al., 1972). Elevations range from approximately 105 to 415 m, with an average of 289 m (Sincron, 2015).

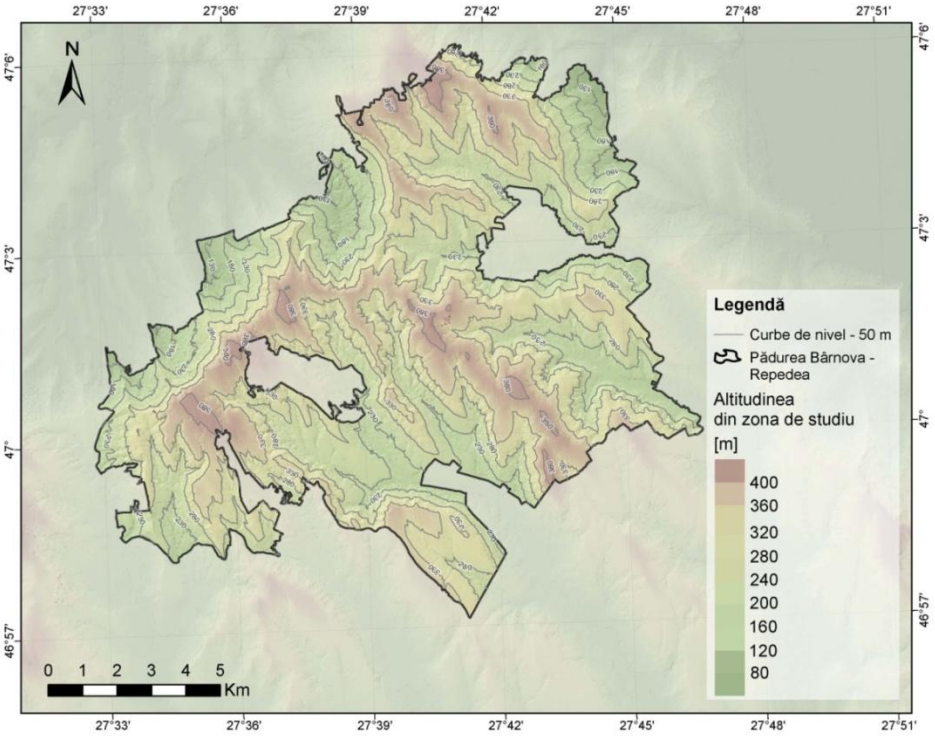

Figure 6. Hypsometric map of the study area – Bârnova Forest

III.2.2. Climate

Bârnova Forest has a temperate continental climate, with a mean annual temperature of approximately 9.6°C and mean annual precipitation of 650–700 mm, occurring predominantly during the warm season. The average annual duration of sunshine is 1,647.3 hours, and mean relative humidity is 75.6%. Analysis of climatic data indicates a warming trend over 2005–2023, with potential implications for vegetation, the hydrological regime and regulating ecosystem services.

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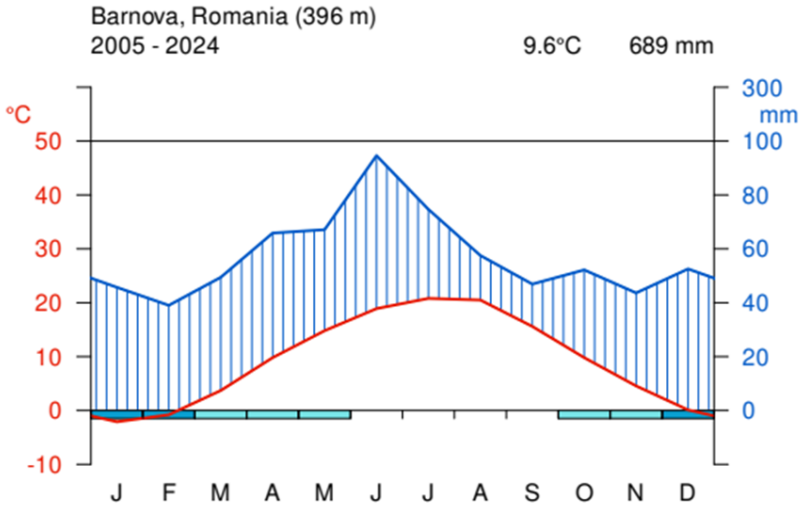

Figure 7. Climograph of the Bârnova meteorological station (396 m), showing mean monthly temperature and precipitation (2005–2024). Source: author's processing based on data from the National Meteorological Administration (ANM).

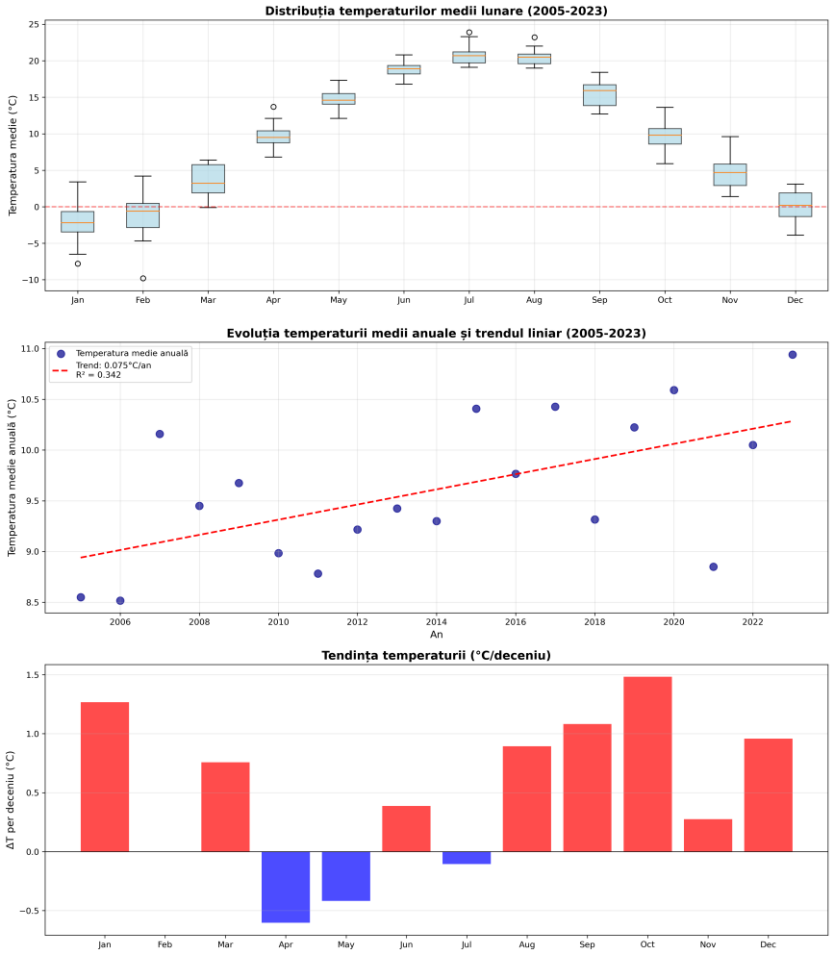

Figure 8. (A) Distribution of mean monthly temperatures; (B) Evolution of mean annual temperature and the linear trend; (C) Monthly temperature trends (°C/decade) in Bârnova Forest, 2005–2023. Source: author's processing based on ANM data.

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III.2.3. Hydrography

The hydrographic network of Bârnova Forest includes permanent, semi-permanent and temporary watercourses, fed predominantly by rainfall and snowmelt, with mean specific runoff of approximately 1–2 L/s/km² (Sincron, 2015).

The main watercourses are the Nicolina, Valea Tinoasă and Păunul in the northern part, and the Vasluieț, Cărbunăria, Poiana Lungă, Pietrosu, Cocoara and Dobrovăț in the southern part. Discharge varies seasonally under the influence of precipitation and snowmelt.

Forest vegetation contributes to the regulation of surface runoff and the hydrological regime, while moisture conditions near valleys influence habitat and vegetation distribution.

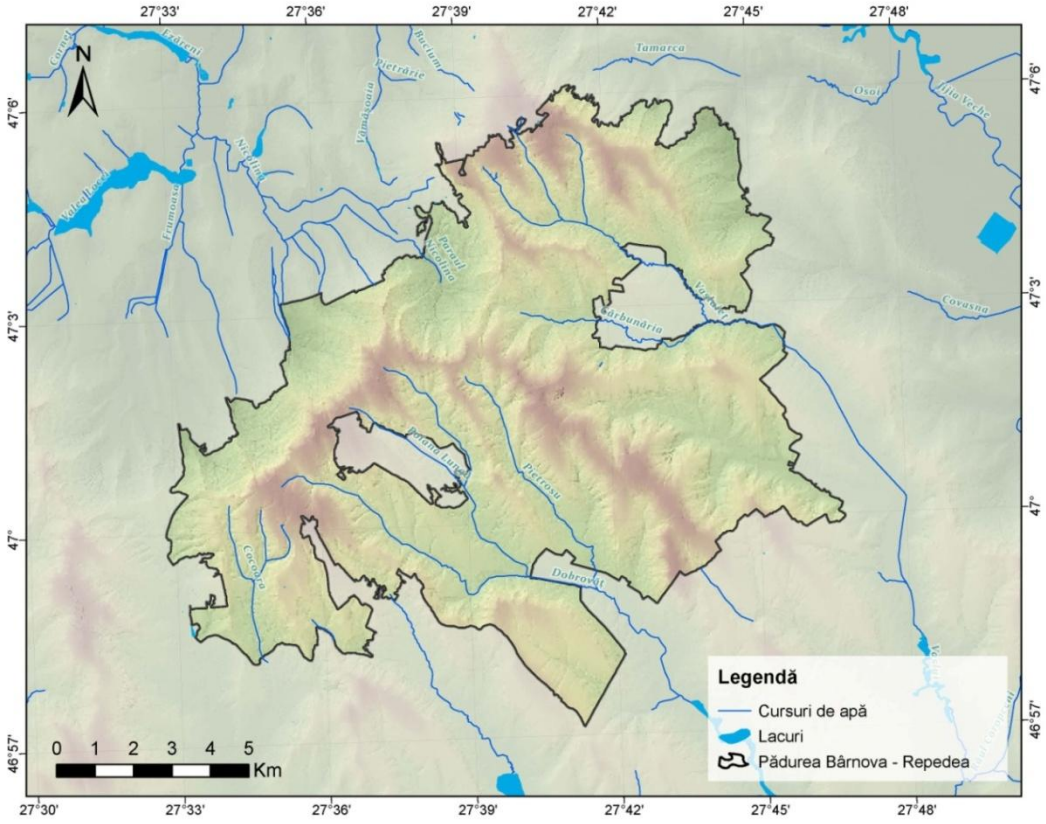

Figure 9. Hydrographic network and main watercourses in the Bârnova–Repedea Forest area.

III.2.4. Soil Cover

The soil cover of Bârnova Forest reflects the influence of climate, lithological substrate, relief and water regime. The main soil types are preluvosols, luvosols, eutric cambisols, alluvial soils and erodosols (Florea & Munteanu, 2012).

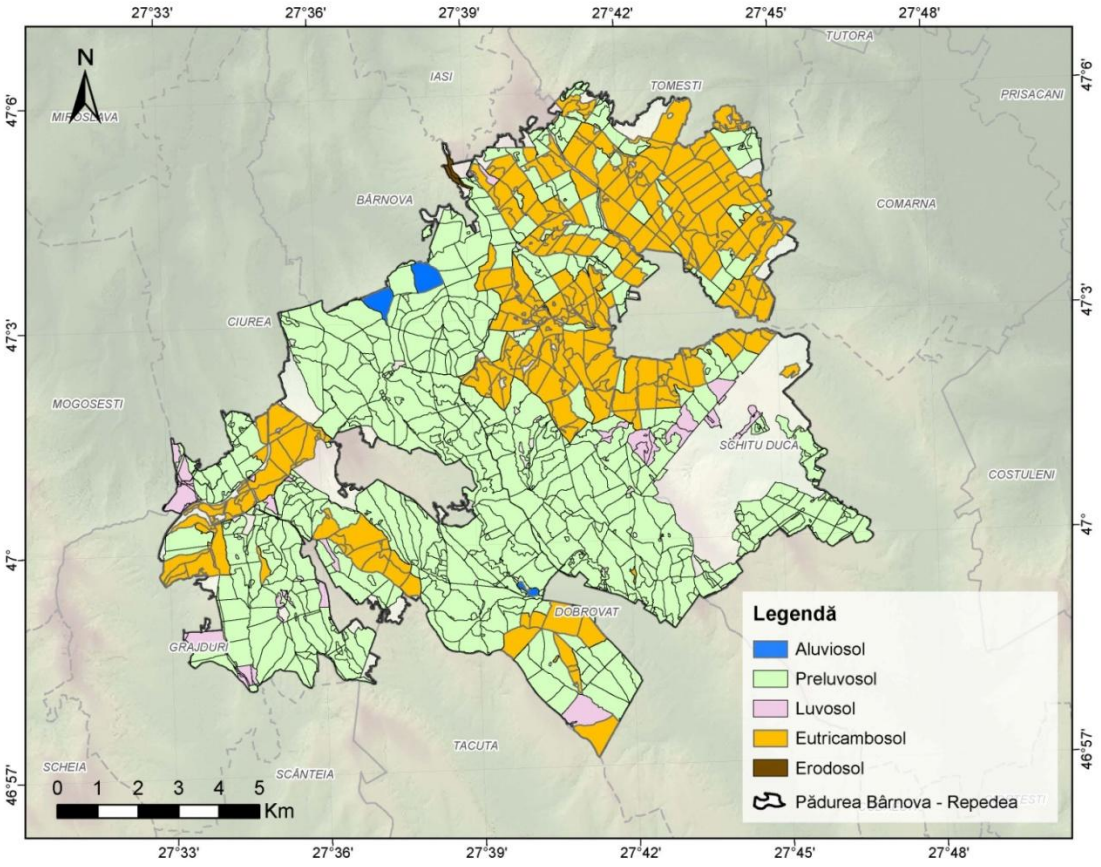

Figure 10. Distribution of the main soil types in the Bârnova Forest area.

Preluvosols and eutric cambisols provide favourable conditions for forest vegetation development, whereas luvosols are associated with poorly drained areas, alluvial soils with valleys, and erodosols with slopes affected by erosion (Sincron, 2016).

Soil diversity influences stand productivity and contributes to hydrological regulation, biogeochemical cycling and carbon storage, thereby supporting the provision of ecosystem services (Dominati et al., 2010; Adhikari & Hartemink, 2016).

III.2.5. Vegetation, Habitats and Fauna

The vegetation of Bârnova Forest is representative of deciduous forest ecosystems in the hilly region of the Central Moldavian Plateau. Its structure and distribution are influenced by climatic conditions, relief, soils, water regime and forest management practices (Donisă et al., 2006).

Forest stands consist predominantly of European beech (Fagus sylvatica), sessile oak (Quercus petraea), pedunculate oak (Quercus robur) and hornbeam (Carpinus betulus), together with associated species such as small-leaved lime (Tilia cordata), Norway maple (Acer platanoides), field maple (Acer campestre) and European ash (Fraxinus excelsior). The herbaceous layer includes species characteristic of mesophilous forests, such as Asarum europaeum, Carex pilosa, Circaea lutetiana, Galium odoratum and Pulmonaria officinalis.

Spatial analysis of the dominant forest species, based on forest management plans for the Dobrovăț, Lunca Cetățuii and Pădureni forest districts, reveals the predominance of beech forests,

sessile oak forests and mixed forests. Beech is more frequent at higher elevations and on north-facing slopes, while sessile and pedunculate oaks are more widespread on sun-exposed slopes and plateaus.

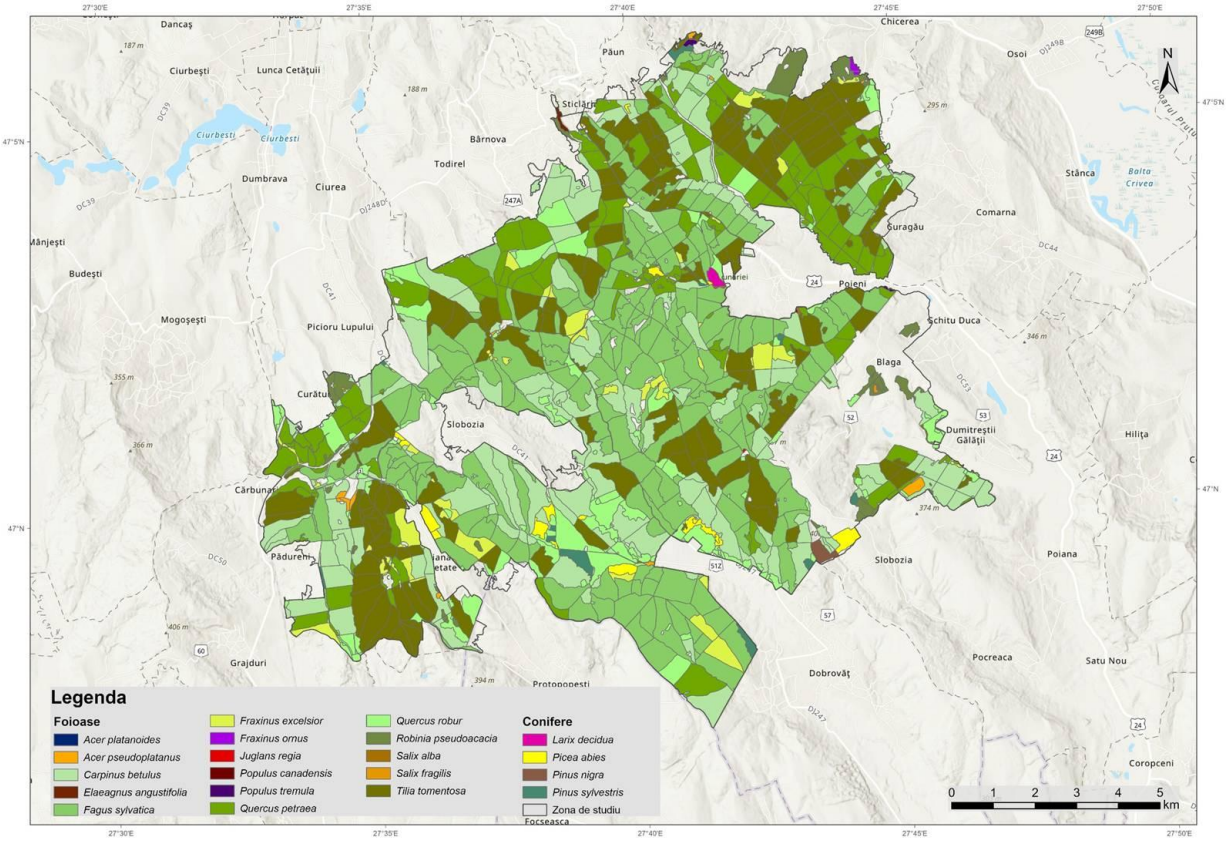

Figure 11. Distribution of dominant forest species (principal component) within the Bârnova–Repedea Forest site, according to the forest management plans of the Dobrovăț, Lunca Cetățuii and Pădureni forest districts.

Analysis of the areas occupied by forest species shows the predominance of beech, covering approximately 8,104 ha (54.56%), followed by hornbeam at 4,704 ha (31.67%), lime at 4,145 ha (27.91%), sessile oak at 2,903 ha (19.55%), and pedunculate oak at 1,566 ha (10.54%). Other species, including ash, black locust, spruce and pine, occupy smaller areas. Non-forested areas total approximately 542 ha (3.65%).

These results confirm the predominance of deciduous forests and the importance of the forest habitats of Community interest 9130 – Asperulo-Fagetum beech forests and 91Y0 – Dacian oak-hornbeam forests. According to the Natura 2000 Standard Data Form, habitat 9130 covers approximately 33% of the site and is particularly associated with shaded slopes, fertile soils and relatively high moisture conditions (European Commission, 2013; Ministry of Environment, 2006).

Natural Habitats

Habitat diversity within the ROSAC0135 Pădurea Bârnova–Repedea site is influenced by topographic and soil-climatic conditions and forest management. The main habitats of Community interest are 9130 – Asperulo-Fagetum beech forests, found predominantly at higher elevations and on northern slopes, and 91Y0 – Dacian oak-hornbeam forests, which dominate the forest area. These are complemented by semi-natural habitats with restricted distributions: 6520 – Mountain hay meadows, 40C0 – Ponto-Sarmatic deciduous thickets, and 62C0 – Ponto-Sarmatic steppes** (Sincron, 2015).

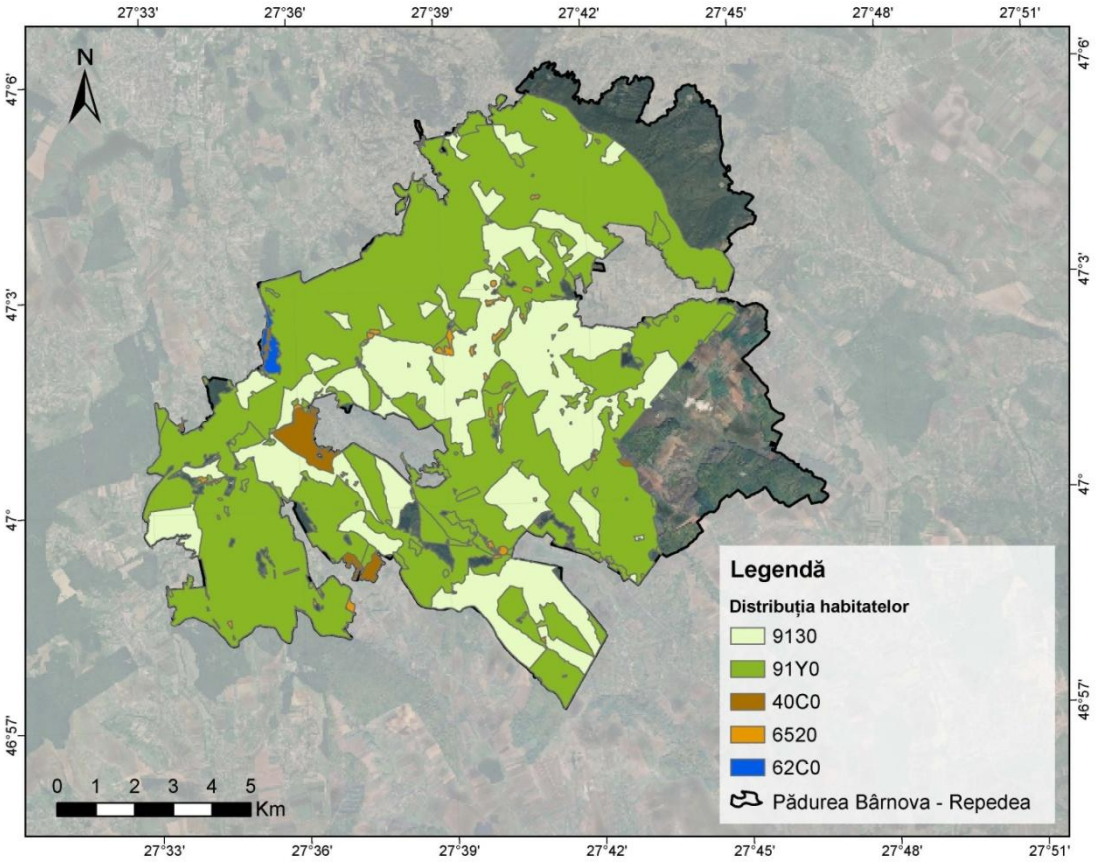

Figure 12. Distribution of habitats of Community interest and semi-natural habitats in the Natura 2000 site ROSAC0135 Pădurea Bârnova–Repedea

Fauna

Habitat diversity in Bârnova–Repedea Forest supports species of Community interest, including bats (Myotis myotis, Barbastella barbastellus), the European ground squirrel (Spermophilus citellus) and the European fire-bellied toad (Bombina bombina). Invertebrates are particularly important, with 18 species of Community interest, placing the site fourth nationally (Popescu & Gostin, 2025). The avifauna includes more than 100 bird species, highlighting the conservation value of forest and semi-natural habitats (Natura 2000 Standard Data Form ROSPA0092).

CHAPTER IV. RESEARCH METHODOLOGY

IV.1. Methodological Framework of the Research

The assessment of ecosystem services provided by Bârnova Forest was based on an integrated methodological approach combining the biophysical, economic, social and spatial dimensions of forest ecosystems. Given the multifunctional nature of forests, no single assessment method could have captured all the relationships between ecological processes and the benefits provided to society.

The research employed complementary methods from forestry, ecology, geography, remote sensing, geographic information systems and socioeconomic analysis. Its conceptual framework was based on the international CICES V5.1 classification and the recommendations of the European MAES initiative, adapted to the specific characteristics of forest ecosystems in the Natura 2000 sites overlapping Bârnova Forest.

The methodology integrated primary and secondary data obtained from forest management plans, administrative and economic records, climatic data, satellite imagery, laboratory analyses, field observations and sociological questionnaires. Specific indicators were selected for each ecosystem service category, enabling the characterisation of provisioning, cultural, and regulation and maintenance services.

The research stages included building the database, processing and integrating information, applying analytical methods specific to each service category, and conducting an integrated assessment of forest ecosystem multifunctionality.

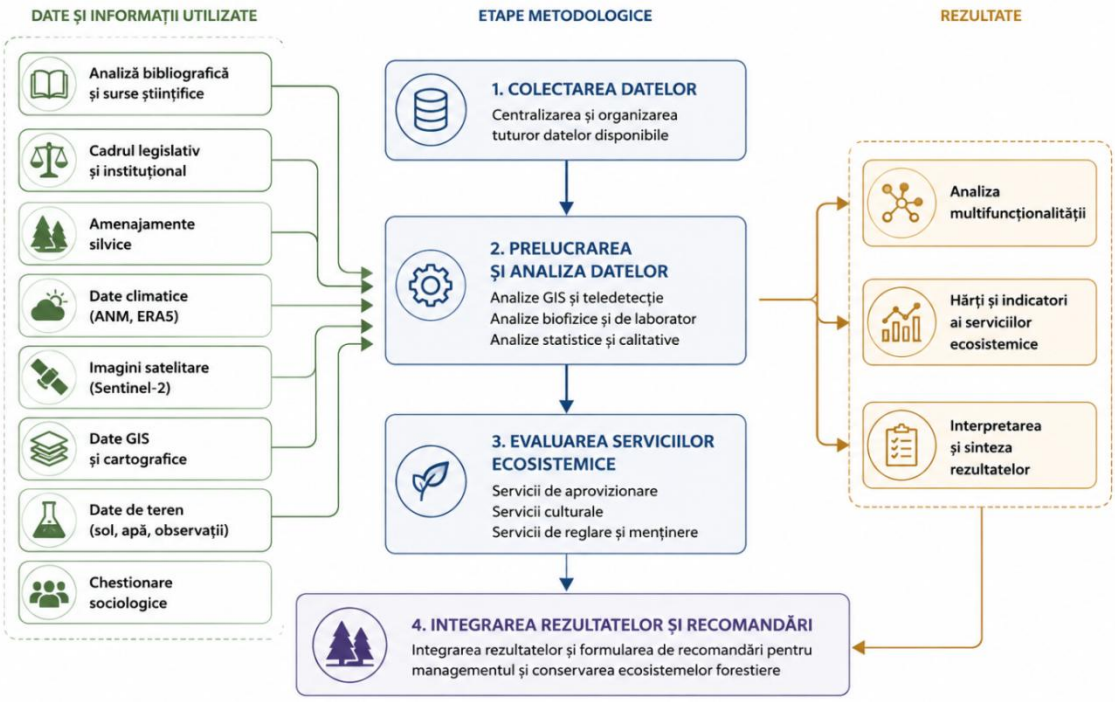

Figure 13. General methodological framework for assessing ecosystem services provided by Bârnova Forest

IV.2. Data Sources Used in the Research

The integrated assessment of ecosystem services required various data categories from documentary and institutional sources, geospatial databases, remote sensing products and original fieldwork. This information enabled the characterisation of forest ecosystems and the selection of indicators for biophysical, economic and sociocultural analyses.

IV.2.1. Documentary and Institutional Data

The literature review included scientific publications, technical reports, methodological guidelines and documents concerning ecosystem services, forestry and protected area management.

The main data source consisted of the forest management plans for the Dobrovăț, Lunca Cetățuii and Pădureni forest districts, obtained from Romsilva in 2019. Information was extracted on stand structure, site characteristics, forest functions, areas and timber volumes.

Administrative and economic data for 2017–2023 concerning the harvesting and commercial use of timber and non-timber products, game resources and beekeeping activities were used to assess provisioning services.

The documentary database was supplemented with data on protected habitats and species, Natura 2000 documentation, the site management plan, and climatic series spanning approximately 30 years, provided by the National Meteorological Administration for the Bârnova (Radar) station.

IV.2.2. Geospatial and Remote Sensing Data

Geospatial data were used to delineate the study area, represent the distribution of environmental factors, characterise forest stands and prepare thematic maps of ecosystem services.

Terrain analysis used a 5 m spatial-resolution digital terrain model (DTM) downloaded from geo-spatial.org. Information on the hydrographic network, road infrastructure and settlements was obtained from OpenStreetMap, while Natura 2000 site boundaries and the distribution of habitats of Community interest were obtained from the portal of the Ministry of Environment, Waters and Forests.

Vector data from forest management plans enabled the spatial representation of forest management units, functional groups, stand composition, age and canopy density. Sentinel-2 satellite imagery, available through the European Copernicus programme, was used to characterise forest vegetation and calculate remote-sensing-derived indicators.

For the spatial analysis of soil properties and water quality, sampling-point coordinates were linked to laboratory results and integrated into a geospatial database.

For cultural service assessment, tourist routes downloaded in KML format from the Codrii Iașilor platform were used alongside an original database of points of interest, including nature reserves, tourist attractions, accommodation establishments, restaurants and other recreational facilities.

All cartographic materials were produced in ArcGIS Pro using the Romanian national Stereo 1970 projection system.

IV.2.3. Data Collected through Fieldwork

Fieldwork was conducted periodically, on average at least once a month, to collect primary data and verify documentary and geospatial information.

To assess regulation and maintenance services, 103 soil samples (2020 and 2023) and 26 water samples from wells at forestry stations were collected; sampling locations were georeferenced and integrated into GIS.

The sociocultural component was investigated through questionnaires administered in person in local communities and online questionnaires distributed in 2023 to people interested in using the forest, regardless of their place of residence.

The research also included observations of habitats, species, natural and cultural heritage and tourist routes, supported by photographic documentation. Collected data were integrated with laboratory analyses and geospatial information for ecosystem service assessment.

IV.3. Analytical Methods Used

The data presented above were processed and analysed using methods appropriate to each information category, including spatial analysis techniques, biophysical methods and statistical tools. Method selection depended on data characteristics and the objectives pursued for each ecosystem service category.

V.3.1. Database Processing and Organisation

Data from forest management plans, administrative records, biophysical analyses, fieldwork and sociological questionnaires were compiled and processed using Microsoft Excel, ArcGIS Pro and Python, through standardisation, validation, and statistical and spatial analysis.

A key step involved linking the functional groups defined in forest management plans with the ecosystem services classified under CICES V5.1, to map their distribution and analyse forest multifunctionality.

Economic and climatic data and the results of soil and water analyses were processed statistically and integrated into databases. For cultural services, questionnaire responses and Strava Metro data were analysed to identify the main recreational and sporting routes.

Results were presented in tables, charts, thematic maps and Sankey diagrams, highlighting forest ecosystem characteristics and relationships between forest functions and ecosystem services.

IV.3.2. Spatial Analysis and Remote Sensing

Development of the Geospatial Database

The GIS database was developed in ArcGIS Pro using the Stereo 1970 projection system, integrating forest management information, the digital terrain model, Natura 2000 site boundaries, environmental data and soil and water sampling locations.

Spatial Analysis

Forest management data were used to prepare maps of stand structure, dominant species, age, canopy density and functional groups. The spatial distribution of soil and water parameters was estimated using inverse distance weighting (IDW), with a power parameter of 2, a raster resolution of 50 m, a variable search radius and 12 neighbouring points. Results were presented as thematic maps showing spatial variation in the analysed indicators. For cultural services, natural and human-made attractions were mapped together with recreational routes and related infrastructure.

Remote Sensing Analysis

Forest vegetation analysis used Sentinel-2 Level-2A satellite images from 2017–2024, selected for the growing season and low cloud cover. Processing in ArcGIS Pro and Python included calculation of the NDVI from spectral bands B4 (red) and B8 (near-infrared). NDVI values were correlated with forest management information, topographic characteristics and ERA5-Land climatic data to analyse spatial and temporal variation in forest vegetation.

Contribution of Spatial Analysis and Remote Sensing to Ecosystem Service Assessment

The integration of forest management, satellite, climatic and biophysical data enabled the spatial characterisation of forest ecosystems, production of thematic maps and analysis of relationships between vegetation, environmental factors and the ecosystem services provided by Bârnova Forest.

IV.3.3. Biophysical Analyses

Biophysical analyses aimed to characterise soil properties and water quality in order to assess regulation and maintenance ecosystem services. The methodology included sample collection, laboratory determinations and integration of results into GIS-based spatial analysis.

Soil Sample Analysis

To assess carbon storage capacity, 103 soil samples collected during the 2020 and 2023 campaigns were analysed. Sampling points were established using a regular grid and georeferenced. Samples were collected from the upper soil horizon, dried, homogenised and sieved to a particle size below 2 mm.

Total carbon (TC), total inorganic carbon (TIC), total organic carbon (TOC) and soil bulk density were determined. Carbon was measured by high-temperature combustion using an Analytik Jena multi N/C 2100 analyser equipped with the HT 1300 module and non-dispersive infrared (NDIR) detection. For TIC determination, samples were treated with 0.2 N HCl, in accordance with the principles of ISO 10693.

Total organic carbon was calculated as the difference between TC and TIC, while soil organic carbon stock (SOC Stock) was estimated from organic carbon content, bulk density and the thickness of the analysed soil layer.

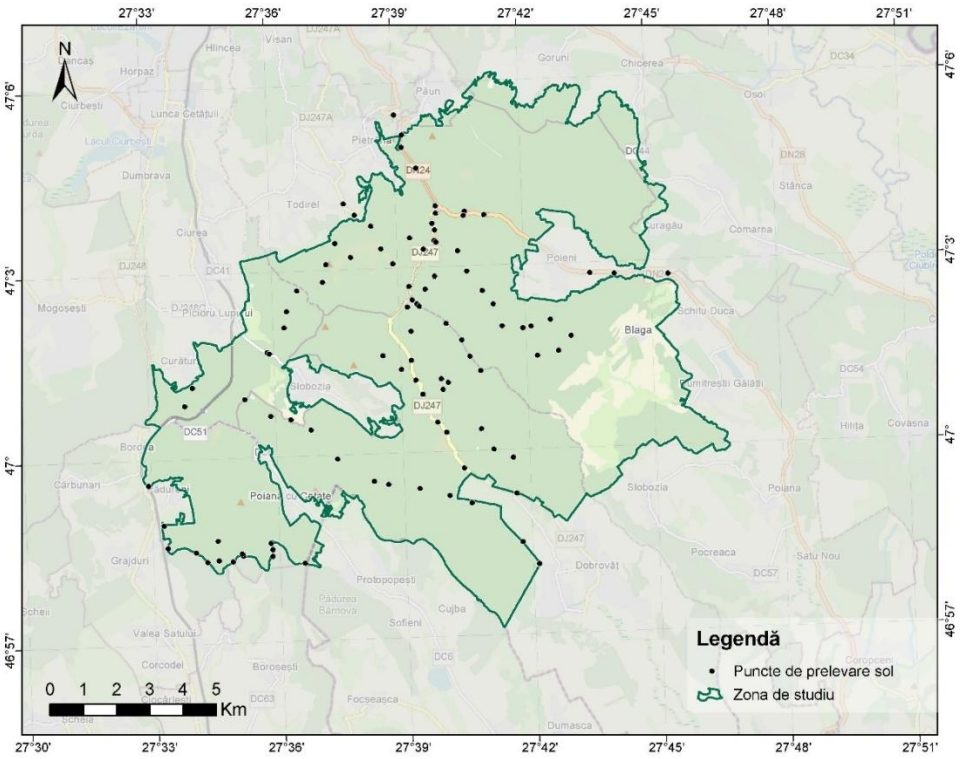

Figure 14. Location of soil sampling points in Bârnova Forest

Total carbon (TC) was determined by combustion at temperatures of 900–1000°C using the Analytik Jena multi N/C 2100 analyser equipped with the HT 1300 module and an NDIR detection system. Total inorganic carbon (TIC) was determined in samples treated with 0.2 N HCl, following the principles of ISO 10693.

Total organic carbon (TOC) was calculated indirectly as the difference between total and inorganic carbon:

$$\boldsymbol{TC = TIC + TOC}$$

yielding:

$$\boldsymbol{TOC = TC - TIC}$$

Based on TOC values, bulk density and the thickness of the analysed layer, soil organic carbon stock was estimated, expressed in tonnes of carbon per hectare:

$$SOC\ Stock\ (t\ C\ ha^{-1}) = TOC\ (\%) \times DA\ (g\ cm^{-3}) \times H\ (cm) \times 0{,}1$$

where TOC is the organic carbon content (%), BD is bulk density (g/cm³), H is soil layer thickness (cm), and 0.1 is the conversion factor.

Water Sample Analysis

To assess water quality, 26 samples were collected from wells at forestry stations in the Bârnova–Repedea Forest area; sampling points were georeferenced.

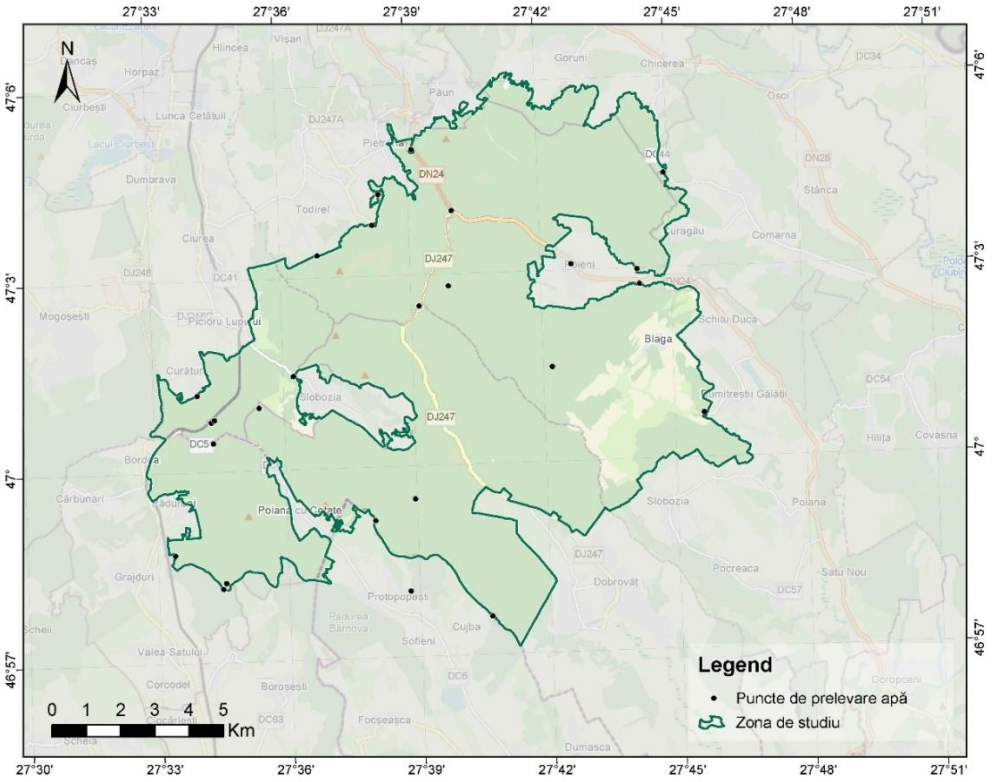

Figure 15. Spatial distribution of water sampling points

Water samples were analysed in the laboratory of the Faculty of Geography and Geology for the following physicochemical parameters: dissolved oxygen (DO), pH, electrical conductivity, ammonium (NH_4^+), nitrate (NO_3^-), total hardness, calcium and magnesium. Concentrations were calculated from laboratory determinations, including spectrophotometry and EDTA titration. Results were processed in Microsoft Excel and integrated into ArcGIS Pro for IDW interpolation-based spatial analysis.

IV.3.4. Sociological Questionnaires

The sociological assessment examined public perceptions of the ecosystem services provided by Bârnova Forest, particularly cultural benefits and the use of forest resources (Daniel et al., 2012; Chan et al., 2016).

Two distinct questionnaires were used: one administered in person in local communities, addressing forest resource use, economic benefits and nature conservation, and one distributed online to people interested in Bârnova Forest regardless of residence, focusing on recreation, tourism and perceptions of ecological functions.

Responses were analysed using descriptive statistics and thematic analysis, enabling comparisons of perceptions of provisioning, cultural, and regulation and maintenance services (Braun & Clarke, 2006).

Sample Characteristics

Sociodemographic Structure of Respondents to the In-Person Questionnaire

Among respondents to the in-person questionnaire, 59% were women and 41% men. The age distribution showed a predominance of middle-aged and older individuals, with the most represented groups being 60–70 years (28.6%) and 70–80 years (22.9%). This distribution is relevant to interpreting local communities' direct relationship with forest resources.

Sociodemographic Structure of Respondents to the Online Questionnaire

The online questionnaire had a relatively balanced gender distribution, with 57.1% women and 42.9% men. Respondents were concentrated mainly in the 31–45 and 18–30 age groups, with a high proportion having completed higher education. This profile differs from that of local communities and is relevant to interpreting recreational, educational and aesthetic uses of the forest.

IV.4. Methodology for Assessing Ecosystem Services

The ecosystem services provided by Bârnova Forest were assessed by integrating biophysical, spatial and socioeconomic information, using indicators adapted to the three main service categories defined by CICES V5.1.

IV.4.1. Methodology for Mapping Dominant Ecosystem Services

Ecosystem services were mapped using the forest management unit (u.a.) as the analytical unit, based on functional groups and the 18 subgroups identified in forest management plans.

These were linked to the CICES V5.1 classification and assigned relative potential levels from 1 to 3 (low, medium and high). The service with the highest potential was considered dominant, allowing its spatial distribution to be represented.

IV.4.2. Assessment of Provisioning Services

Provisioning services were assessed using forest management plans, records of harvesting and commercial use of forest products, field observations and questionnaires administered to local communities. Timber and non-timber resources, their availability and use, and their economic and nutritional importance to the population were analysed.

IV.4.3. Assessment of Cultural Services

Cultural services were assessed by integrating GIS analyses, field observations and the results of sociological questionnaires. Natural and human-made attractions, tourist trails, recreational infrastructure and perceptions of the recreational, educational, spiritual and identity-related benefits associated with Bârnova Forest were analysed.

IV.4.4. Assessment of Regulation and Maintenance Services

The assessment of regulation and maintenance services integrated soil and water analyses, climatic data, forest management information and indicators derived from remote sensing, focusing on carbon storage, soil and water quality, stand characteristics and biodiversity.

Categoria serviciilor ecosistemice	Surse de date	Metode utilizate	Indicatori principali
Aprovizionare	Amenajamente silvice, baze de date ale ocoalelor silvice, chestionare, observații de teren	Analiză descriptivă, GIS, analiză statistică	Produse forestiere lemnoase și nelemnoase, producția cinegetică, apicultură, utilizarea resurselor
Culturale	Chestionare, observații de teren, analiză GIS, trasee și obiective de interes	Analiză spațială, analiză sociologică	Recreere, educație, patrimoniu cultural, valori spirituale și identitare
Reglare și menținere	Amenajamente silvice, analize de sol și apă, date climatice, NDVI	Analize biofizice, GIS, teledetecție, analiză statistică	Stoc de carbon, proprietățile solului, calitatea apei, habitate, biodiversitate, condiții climatice
Cartografierea serviciilor ecosistemice	Grupe și subgrupe funcționale din amenajamente, clasificarea CICES V5.1	Asocierea grupelor funcționale cu CICES, clasificarea potențialului, cartografiere GIS	Serviciul ecosistemic dominant, distribuția spațială a serviciilor ecosistemice

Table 1. Summary of data sources, methods and indicators used in ecosystem service assessment

IV.5. Analysis of Ecosystem Service Multifunctionality

The multifunctionality analysis sought to identify ecosystem services simultaneously associated with the same forest areas by linking the functional groups and subgroups in forest management plans to the CICES V5.1 classification. The relationships identified were represented using Sankey diagrams, highlighting connections between forest functions and provisioning, cultural, and regulation and maintenance services.

V. ASSESSMENT OF ECOSYSTEM SERVICES

V.1. Functional Structure of Forest Ecosystems – The Basis for Ecosystem Service Assessment

The assessment of the functional structure of Bârnova Forest revealed the predominance of forests classified in Group I – forests with special protection functions, while areas with production functions (Group II) show a fragmented, predominantly peripheral distribution. This characteristic is found across all three forest districts analysed – Dobrovăț, Lunca Cetățuii and Pădureni – with local differences in the distribution of production stands.

Distribution of the Main Functional Groups across the Entire Study Area

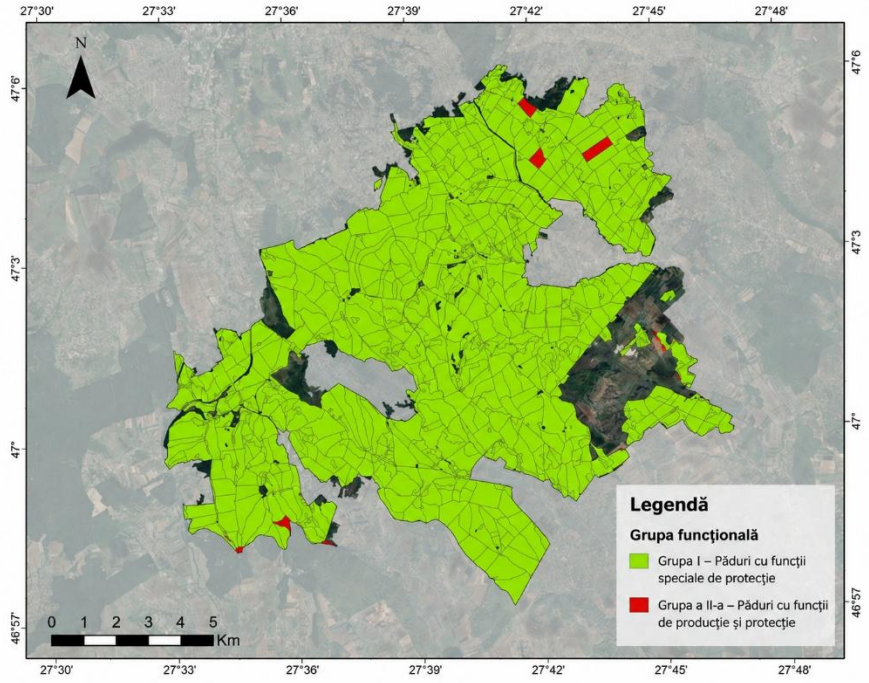

Figure 16. Distribution of the main functional groups within the Bârnova–Repedea Forest Natura 2000 site

The detailed analysis identified 18 main functional subgroups corresponding to different forest management objectives. Of these, subgroup 5M – forests included in protected areas of the Natura 2000 ecological network – occupies the largest area, namely 10,891.01 ha, accounting for more than 84% of the area analysed in terms of functional classification.

The other subgroups occupy considerably smaller areas, notably 4I – stands within hunting complexes (654.96 ha), 4B – stands surrounding settlements (385.06 ha), 5P – ancient natural forests (218.01 ha), 5L – forests designated for genetic resource conservation (217.28 ha) and 5H – seed reserves (164.96 ha). Subgroups with predominantly productive functions (1A, 1B and 1D) account for small proportions.

Distribution of the Main Functional Subgroups

The distribution of the main functional subgroups was analysed from both quantitative and spatial perspectives.

Cod subgrupă funcțională	Denumire	Suprafață totală (ha)
1A	Arboretele destinate să producă, în principal, arbori groși și foarte groși de calitate superioară, în vederea producerii de lemn de rezonanță și claviatură	15,56
1B	Arboretele destinate să producă, în principal, lemn pentru cherestea	86,89
1D	Arboretele destinate să producă, în principal, arbori mijlocii și subțiri pentru celuloză, construcții rurale și alte produse din lemn	0,01
2A	Arboretele situate pe stâncării, pe grohotișuri, pe terenuri cu eroziune în adâncime și pe terenuri cu înclinarea mai mare de 30 grade pe substrate de fliș (facies marnos, marno-argilos și argilos), nisipuri, pietrișuri și loess, precum și cele situate pe terenuri cu înclinare mai mare de 35 grade, pe alte substrate litologice	1,04
2B	Arboretele constituite din subparcele întregi, limitrofe drumurilor publice de interes deosebit și căilor ferate normale, din zonele cu relief accidentat, situate pe terenuri cu înclinare mai mare de 25 grade și cu pericol de alunecare	5,17
2E	Plantațiile forestiere de pe terenuri degradate	67,19
2H	Arboretele situate pe terenuri alunecătoare	1,37
2I	Arboretele situate pe terenuri cu înmlăștinare permanentă	3,76
2L	Arboretele situate pe terenuri cu substraturi litologice foarte vulnerabile la eroziuni și alunecări, cu pante cuprinse până la limitele indicate la categoria 1.2.a	17,59
4B	Arboretele din jurul localităților, precum și arboretele din intravilan	385,06
4E	Benzi de pădure constituite din subparcele întregi situate de-a lungul căilor de comunicații de importantă națională și internațională	118,94
4I	Arboretele din complexuri de vânătoare și crescătorii de vânat autorizate, destinate creșterii intensive a vânatului, în scopul recreerii prin vânătoare	654,96
5C	Arboretele cuprinse în rezervații naturale, cu regim strict de protecție	101,67
5H	Arboretele constituite ca rezervații seminologice	164,96
5K	Arboretele din parcuri dendrologice și arboretumuri	1,44
5L	Arboretele din păduri destinate conservării resurselor genetice	217,28
5M	Păduri incluse în ariile protejate cuprinse în rețeaua ecologică Natura 2000	10.891,01
5P	Arboretele incluse în păduri naturale seculare de valoare deosebită	218,01

Table 2. Areas occupied by the main functional subgroups

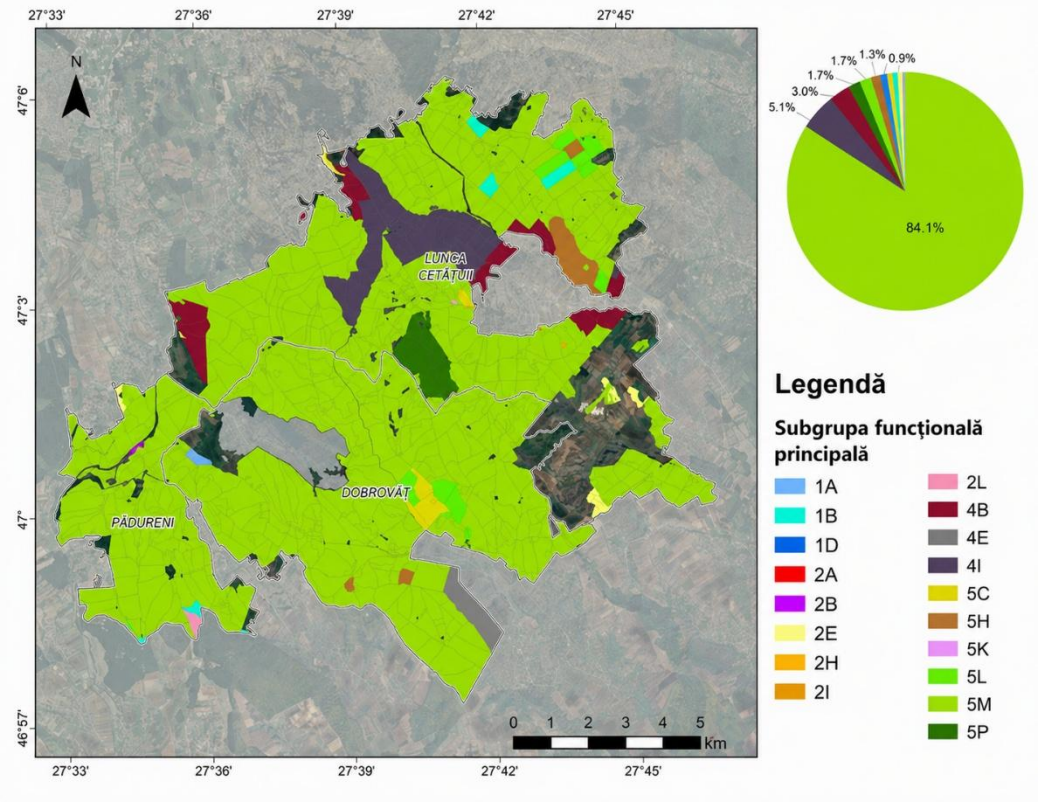

Figure 17. Map of the main functional subgroups in Bârnova Forest

Note. Polygons without a functional classification correspond, in most cases, to forest clearings and, to a lesser extent, forestry stations or other built features. These were retained in the cartographic representations to ensure spatial continuity and were treated separately in subsequent analyses.

The spatial distribution reveals the continuity of subgroup 5M throughout the forest massif, whereas the other subgroups occur in a fragmented pattern, associated with specific protection, conservation, recreation or production functions. Polygons without a functional classification correspond mainly to forest clearings and, to a lesser extent, forestry stations or other built areas; they were treated separately in subsequent analyses.

Overall, the functional structure confirms a predominant orientation towards conservation and protection, forming the basis for assessing the ecosystem services and multifunctionality of Bârnova Forest.

V.2. Provisioning Services

The assessment of provisioning ecosystem services sought to identify the main material resources supplied by Bârnova Forest and how they are used by local communities. The analysis integrated the results of sociological questionnaires, information from forest management plans and data provided by forest districts.

V.2.1. Non-Timber Forest Products

Non-timber forest products are an important component of provisioning services, contributing to the diversification of food resources, the maintenance of traditional practices and, to a lesser extent, the generation of additional income. Wild edible plants, medicinal plants, mushrooms and other forest resources used by the population were analysed.

V.2.1.1. Wild Plants

Use of Wild Plants in Local Communities

The results of questionnaires administered in local communities indicate that wild plants are used predominantly for personal consumption, while commercialisation is of secondary importance. Frequently mentioned resources include elder (Sambucus nigra), wild garlic (Allium ursinum), nettle (Urtica dioica), blackberries and other wild berries.

By food-use category, the most frequently reported were edible herbaceous plants (58.1%), fruits from wild shrubs and trees (38.7%) and wild berries (35.5%).

In the online questionnaire, wild berries were the dominant category (44.1%), followed by edible herbaceous plants and fruits from wild shrubs and trees (35.3% each). Nuts and seeds accounted for 5.9%, while 8.8% of respondents stated that they did not use such resources.

Perceptions of Wild Plant Use in the Online Questionnaire

Differences between the two respondent groups highlight distinct patterns of forest resource use, influenced by resource accessibility and the direct relationship with the forest ecosystem.

V.2.1.2. Medicinal Plants

Use of Medicinal Plants in Local Communities

The use of medicinal plants indicates the persistence of traditional practices in communities near Bârnova Forest. The most frequently mentioned species include lime (Tilia spp.), elder, St John's wort, chamomile and yarrow, used predominantly for personal consumption.

Classification by use shows a predominance of plants used for everyday herbal teas (77.4%), followed by trees and shrubs with medicinal uses (58.1%), plants with specific medicinal uses (38.7%), and depurative and tonic plants (35.5%). Among online respondents, plants used for everyday herbal teas also constitute the main category (64.7%), although the diversity of uses is lower. Moreover, 17.6% of respondents stated that they do not use medicinal plants.

Perceptions of medicinal plant use in the online questionnaire

Comparison of the results indicates a stronger connection between local communities and traditional practices of collecting and using medicinal plants, whereas their use among online respondents is more limited.

V.2.1.3. Mushrooms

Mushroom use in local communities

Edible mushrooms are an important food resource for communities in the Bârnova Forest area and are used predominantly for personal consumption. The local questionnaire results show high frequencies for porcini mushrooms (73%) and honey mushrooms (70%), followed by

chanterelles and pănișoare mushrooms (19% each). Regarding their use, 70% of respondents reported collecting mushrooms for personal consumption and 30% for supplementary income.

Perceptions of mushroom use in the online questionnaire

The online questionnaire results show the predominance of honey mushrooms (ghebe/opintici/bureți; 61.3%) and porcini mushrooms (51.6%) among the mushrooms mentioned by respondents, followed by chanterelles (9.7%), saffron milk caps and pănișoare mushrooms (6.5% each). These results reflect an interest in using mushrooms as non-timber forest resources.

V.2.1.4. Melliferous Resources

Melliferous resources provided by forest vegetation support beekeeping activities in the Bârnova Forest area. The questionnaire results reveal local communities' favourable perceptions of the forest's role in pollination and in providing resources necessary for apicultural production.

To assess the actual use of melliferous resources, data provided by the Dobrovăț, Lunca Cetățuii and Pădureni forest districts were analysed, concerning the number of beehives and permits for the temporary placement of apiaries in forest land during 2017–2023.

Analysis of annual trends shows that Lunca Cetățuii Forest District recorded the largest numbers of beehives throughout the period, followed by Pădureni and Dobrovăț. Peak values occurred in 2018, particularly in Lunca Cetățuii and Pădureni.

The number of permits for apiary placement fluctuated annually, without a pronounced downward trend, indicating sustained interest in using forest land for beekeeping. The combined analysis of beehive numbers and permits reveals differences among the three forest districts in the intensity of beekeeping activities and the use of melliferous resources.

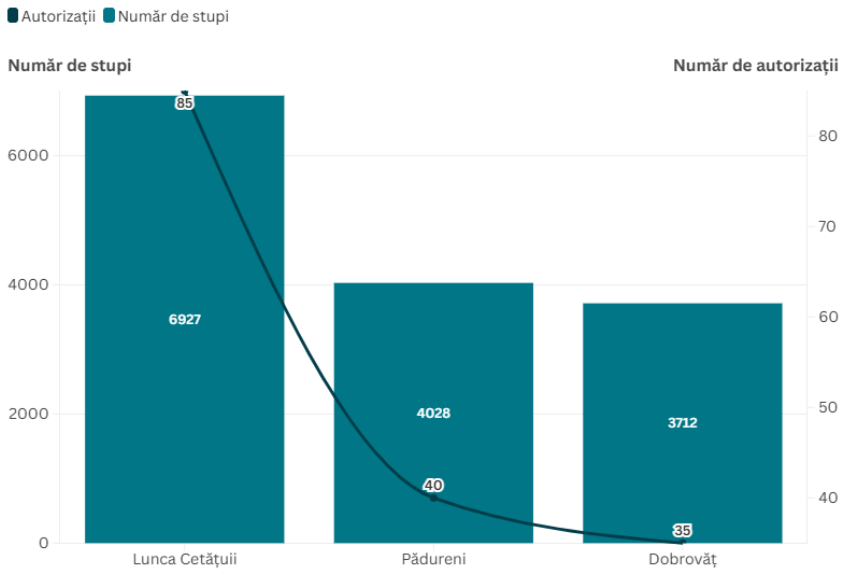

Figure 18. Cumulative number of permits and total beehives in the forest districts analysed

The results confirm the contribution of forest ecosystems to local beekeeping, both by providing melliferous resources and by allowing the temporary placement of apiaries. The

continuation of beekeeping activities during the period analysed highlights the importance of this provisioning service to the local economy.

V.2.1.5. Economic Use of Non-Timber Forest Products

The economic assessment of non-timber forest products was based on official data provided by the Iași Forestry Directorate and the three forest districts analysed for 2017–2023. Unlike questionnaire data, these records reflect quantities actually marketed and revenues recorded, enabling quantification of the economic contribution of the main resources: game meat, linden flowers and rose hips.

Game meat

Analysis of marketed quantities reveals differences among the three forest districts. Dobrovăț Forest District recorded the largest quantities, reaching approximately 6.2 tonnes in 2019 and 8.8 tonnes in 2023, as well as the highest revenues, exceeding RON 75,000 in 2023. In Lunca Cetățuii Forest District, quantities and revenues followed a downward trend after 2018, whereas Pădureni Forest District recorded moderate fluctuations, with a recovery after 2020.

Linden flowers

The marketing of linden flowers varied annually in terms of quantities collected and revenues generated. Lunca Cetățuii Forest District recorded the largest quantities in 2017–2018, exceeding 4 tonnes annually, followed by a decline until 2021 and a partial recovery in 2023. More pronounced fluctuations were observed in Dobrovăț Forest District, with high values in 2019 and 2023, while Pădureni showed a relatively more stable trend.

Revenues generally followed collection trends, while also being influenced by market conditions.

Rose hips

Analysis of rose hip marketing reveals differing trends among forest districts. Dobrovăț showed the largest fluctuations in collected quantities, with peaks in 2019 and 2023 and substantial decreases during 2020–2022. A general downward trend was observed in Lunca Cetățuii, particularly after 2019, whereas Pădureni showed a more stable pattern, with relatively small annual variations.

Overall, the results highlight the economic contribution of non-timber forest products, as well as spatial and temporal differences in their marketing. Variations in collected quantities and revenues underscore the influence of natural conditions, management characteristics and market dynamics on the economic benefits provided by forest ecosystems.

V.2.2. Timber Forest Products

Wood Biomass Provisioning

The assessment of ecosystem services related to timber forest products examined both the spatial distribution of wood biomass supply potential and trends in its economic use during 2017–2023. The analysis integrated information from forest management plans and official data provided by the Iași Forestry Directorate and the three forest districts analysed.

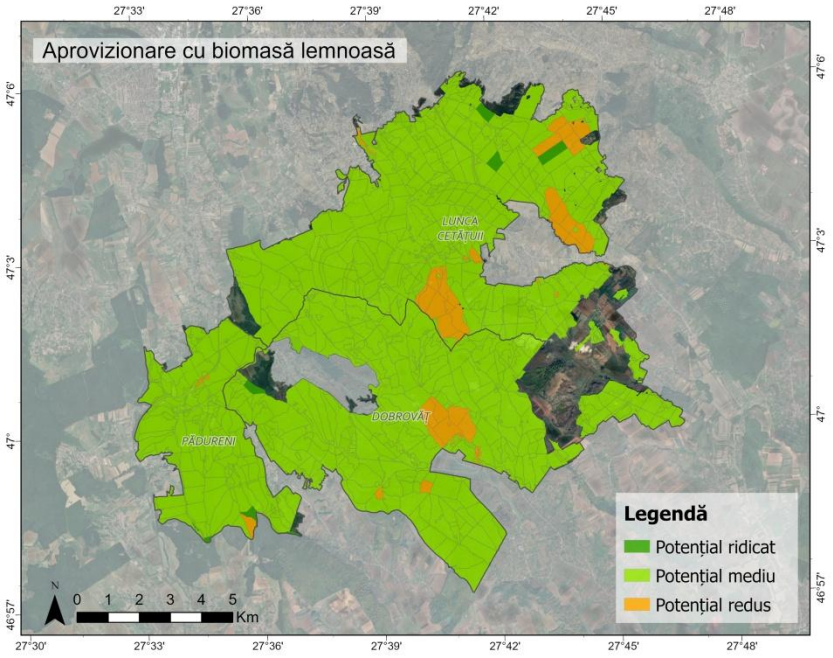

Figure 19. Spatial distribution of wood biomass provisioning potential in Bârnova Forest (forest management plan data)

The spatial distribution of wood biomass provisioning potential reveals differences determined by the functional classification of stands and restrictions associated with conservation objectives. High potential characterises areas with predominantly productive functions, corresponding to subgroups 1A, 1B and 1D, whereas medium potential predominates across the forest area analysed and is particularly associated with forests included in the Natura 2000 network (5M). Low potential corresponds to areas under strict protection, where timber harvesting is prohibited or severely restricted.

This distribution shows that wood biomass supply potential does not always coincide with the actual possibility of commercial use, which is conditioned by management and conservation objectives.

Trends in marketed timber volumes and total revenues

During 2017–2023, Lunca Cetățuii Forest District recorded the largest volumes of timber sold to businesses, Dobrovăț showed more pronounced fluctuations, and Pădureni displayed a relatively stable trend. Revenue trends were not always proportional to the volumes marketed, being influenced by prices, product assortments and forest market conditions.

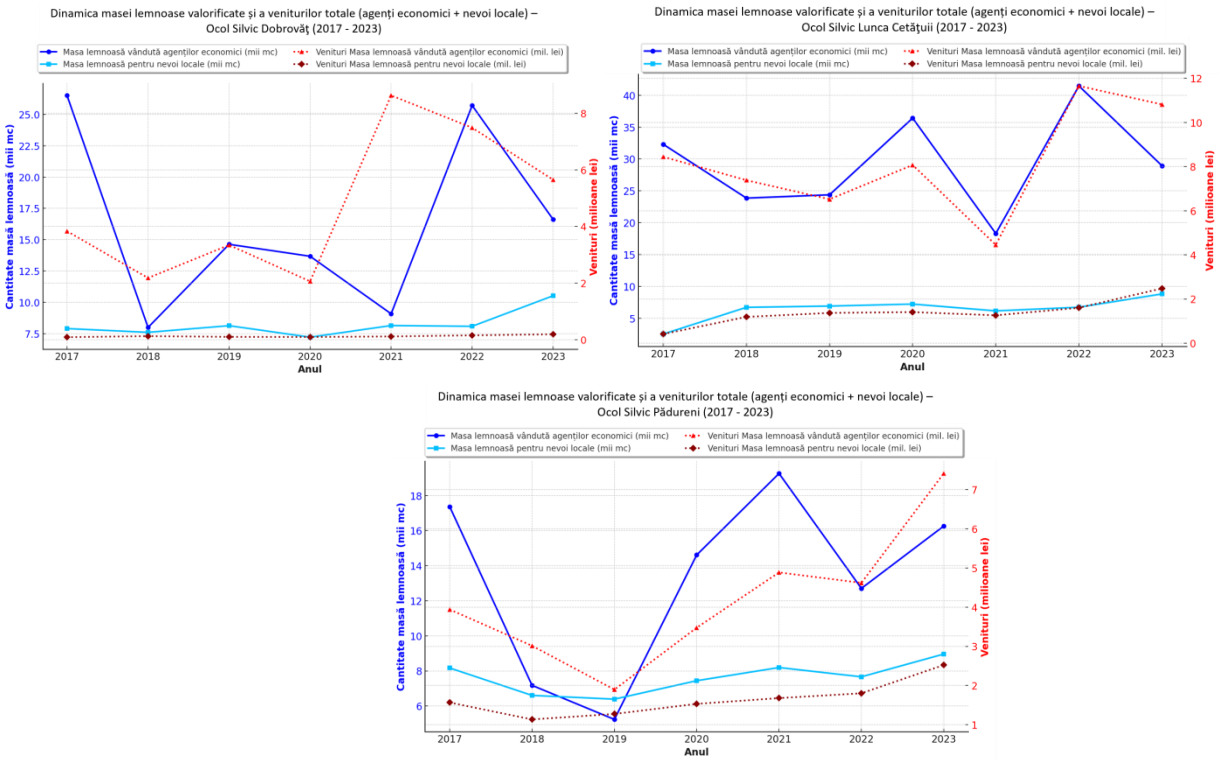

Figure 20. Trends in marketed timber volumes and total revenues – Dobrovăț, Lunca Cetățuii and Pădureni forest districts (2017–2023)

Timber sales for local consumption and to businesses

In all three forest districts, timber intended for local consumption was sold predominantly to residents, whereas sales to businesses were mainly of standing timber. Dobrovăț and Lunca Cetățuii recorded increases in quantities supplied to residents in 2023, while Pădureni exhibited more moderate variations.

Secondary products resulting from timber processing – wood products and sawdust waste

At Pădureni Forest District, the only district with its own processing workshop, wood products and sawdust waste were also marketed, contributing to more efficient use of timber resources.

Overall, the results highlight the economic and social importance of timber resources and the need to align their use with the conservation objectives of Bârnova Forest.

V.2.3. Multifunctionality of Provisioning Ecosystem Services

The multifunctionality of provisioning ecosystem services was assessed by linking the functional groups identified in forest management plans to the corresponding classes in the CICES V5.1 classification. The analysis highlights the capacity of forest ecosystems to provide several material resources simultaneously, according to their functional designation and management restrictions.

The results indicate a differentiated distribution of the services analysed. Wood biomass provisioning (CICES 1.2.1.1) is associated with a cumulative area of 11,579.6 ha and is subject to restrictions on forest resource harvesting.

The provision of wild animals and associated products (CICES 1.1.1.4) corresponds to a cumulative area of 11,545.9 ha, while plant genetic material (CICES 1.2.1.3) is associated with all functional groups, totalling 12,558.9 ha.

The Sankey diagram illustrates the overlap of provisioning services within the same functional categories, demonstrating that forest stands can simultaneously contribute wood biomass, non-timber forest products, game resources and plant genetic material.

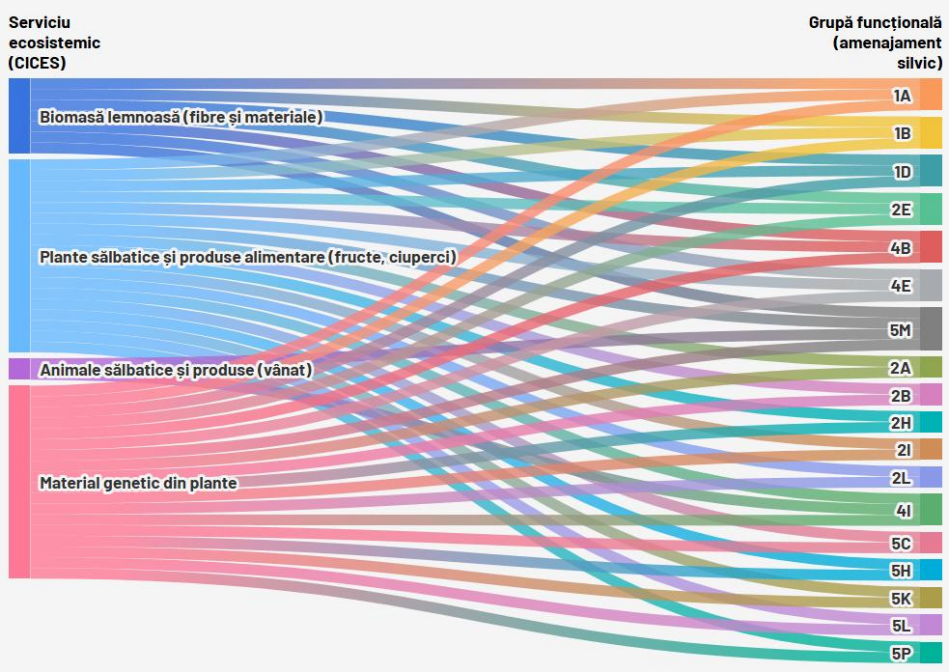

Figure 21. Sankey diagram showing relationships between provisioning ecosystem services and functional groups in Bârnova Forest

The results confirm the multifunctional character of Bârnova Forest and highlight the influence of functional classification on the diversity of provisioning services. In this context, forest management should pursue responsible resource use while maintaining the ecological functions of forest ecosystems.

V.3. Cultural Ecosystem Services

The assessment of cultural ecosystem services provided by Bârnova Forest integrated sociological questionnaire findings, information on natural and cultural heritage, forest management plan data, and analysis of recreational use of the forest. The research aimed to identify non-material benefits associated with recreation, sports activities, cultural and spiritual heritage, education, and the relationship between communities and the forest ecosystem.

V.3.1. Recreation and Social Use

The recreational function and social use of the forest

Bârnova Forest is an important recreational area for residents of Iași and neighbouring communities, owing to its proximity to settlements, accessibility, and diversity of forest landscapes.

The spatial distribution of recreational potential, analysed using functional groups from forest management plans, shows high values in areas near settlements and major access routes, particularly those associated with functional subgroups 4B and 4I. Medium potential characterises most of the forest, including stands in subgroup 5M, whereas low potential corresponds to areas where public access is restricted for conservation reasons.

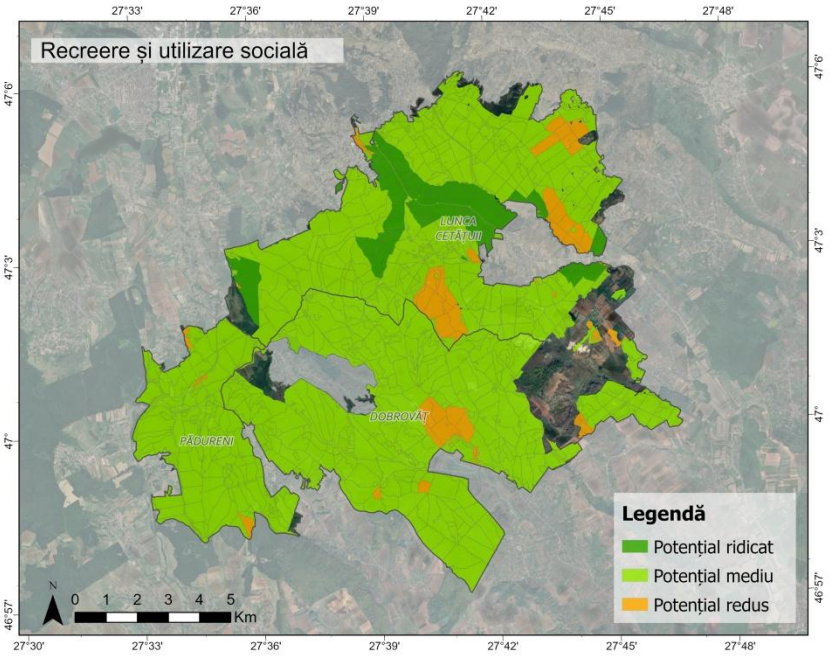

Figure 22. Spatial distribution of recreational and social-use potential in Bârnova Forest (forest management plan data)

Recreational use and accessibility of the forest

To identify the spatial distribution of recreational activities, data available through the Strava Global Heatmap platform were analysed, enabling the identification of routes used for walking, running, hiking, cycling, and mountain biking.

The results indicate a concentration of recreational activities in areas accessible from Bârnova, Pietrărie, Slobozia, and Dobrovăț, as well as corridors connecting natural, cultural, and spiritual attractions, including Poiana cu Schit and Poiana cu Cetate.

Walking routes are denser in accessible areas of high scenic value, while cycling and mountain-biking routes extend over larger areas, taking advantage of elevation differences and the connectivity of forest roads. Frequently used recreational segments highlight the importance of Bârnova Forest for outdoor sports and recreation.

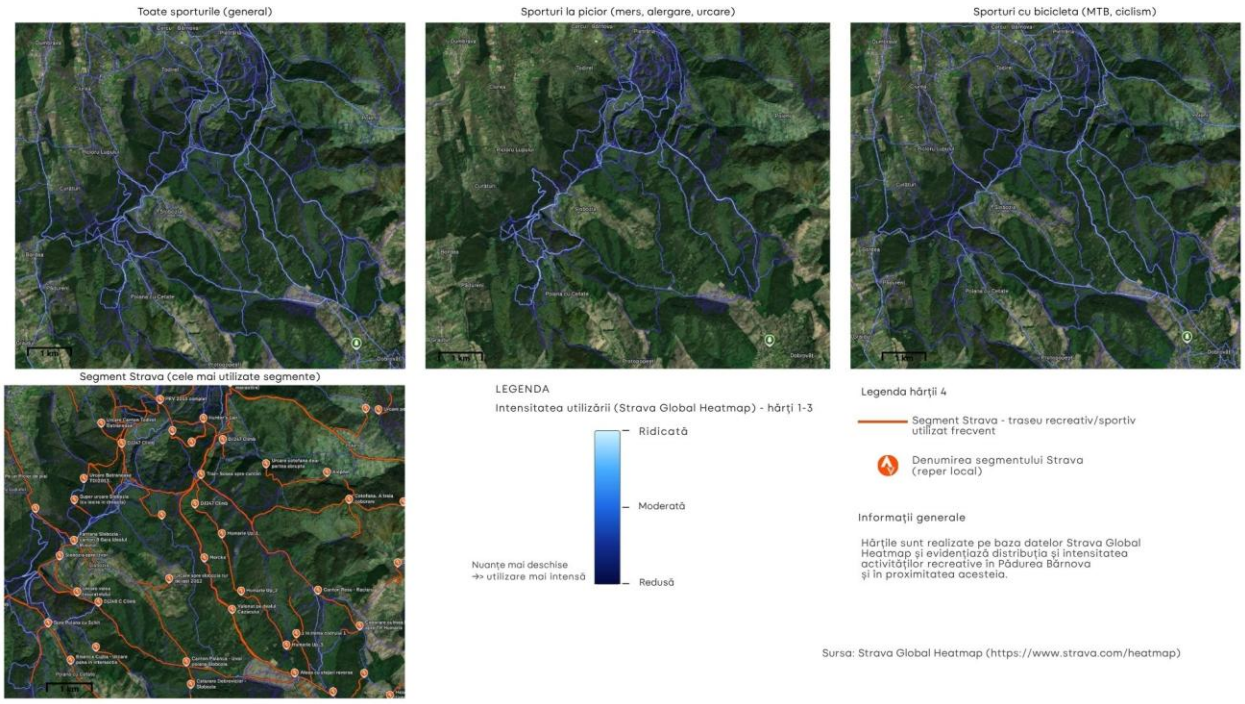

Figure 23. Overall distribution of recreational activities in Bârnova Forest based on Strava Global Heatmap data

The analysis highlights the role of Bârnova Forest as a peri-urban recreational space and the need to align accessibility and tourism use with forest habitat conservation objectives.

Network of recreational and thematic trails

Recreational use of Bârnova Forest is supported by more than 15 tourist and thematic trails for hiking, cycling, nature observation, and educational activities. Notable examples include “Nature, Culture, Spirituality – Poiana cu Schit” and “Bârnova Trail”, which showcase the area’s natural and cultural heritage. Strava Global Heatmap analysis shows more intensive use of accessible and well-connected areas, confirming the importance of the trail network for recreation.

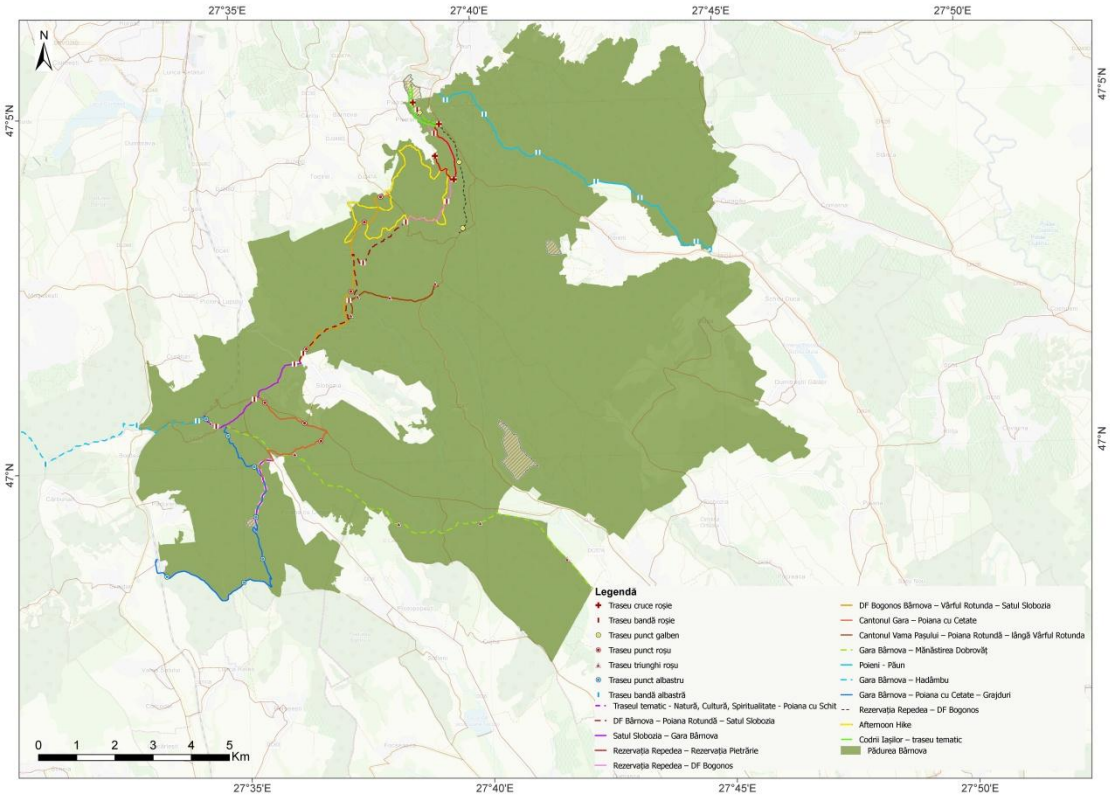

Figure 24. Network of the main recreational and thematic trails in Bârnova Forest

User perceptions and intensity of recreational use

The online questionnaire indicates a high level of familiarity with Bârnova Forest (95.9%). The main activities are hiking (28.6%), photography (14.3%), and mushroom picking (13.3%). More than 90% of respondents had visited the forest several times, predominantly travelling by private car (85.7%) and making day trips (87%). Tranquillity and the natural character of the area were the most appreciated features, whereas recreational infrastructure and trail markings were identified as aspects requiring improvement.

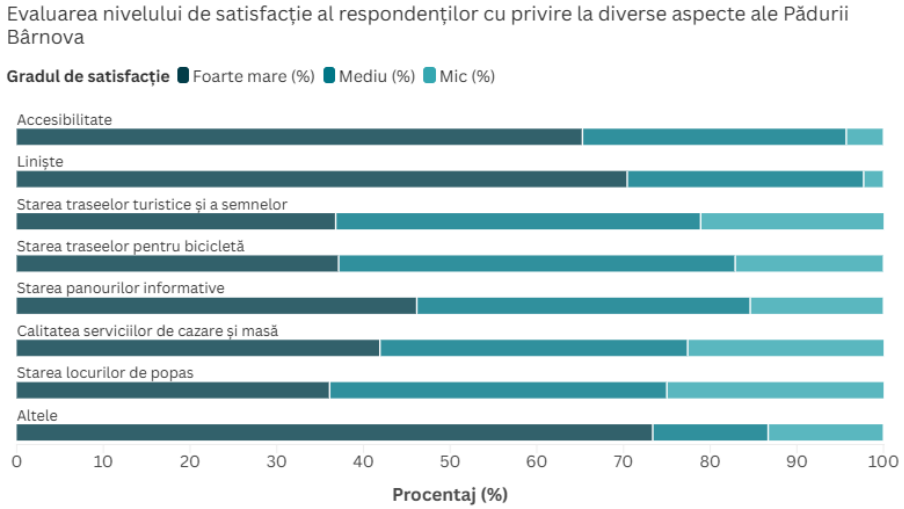

Figure 25. Respondents' satisfaction with recreational facilities and infrastructure in Bârnova Forest

V.3.2. Natural and Cultural Heritage Associated with Cultural Ecosystem Services

Protected natural areas and their contribution to cultural ecosystem services

Bârnova Forest has a complex protection status, being included in the Natura 2000 network through ROSAC0135 Pădurea Bârnova–Repedea and ROSPA0092 Pădurea Bârnova. These sites contain four nationally designated nature reserves: Dealul Repedea Fossil Site, Poiana cu Schit, Pietrosu, and Poieni–Cărbunăriei. These areas contribute both to natural heritage conservation and to cultural ecosystem services associated with recreation, education, and heritage appreciation.

Dealul Repedea Fossil Site is distinguished by its geological and palaeontological value, while Poiana cu Schit brings together natural, historical, spiritual, and artistic features. The Pietrosu and Poieni–Cărbunăriei reserves complement this heritage by conserving representative forest ecosystems.

The sociological questionnaire findings indicate high awareness and appreciation of the principal protected areas. Poiana cu Schit and ROSAC0135 Pădurea Bârnova–Repedea are the best known, recognised by approximately three-quarters of respondents. By contrast, Pietrosu and Poieni–Cărbunăriei are less well known and less frequently visited. For most sites analysed, more than half of respondents consider that they contribute "very much" to the attractiveness of the area.

These findings confirm the role of protected natural areas in diversifying recreational and educational experiences and strengthening the relationship between communities and natural heritage.

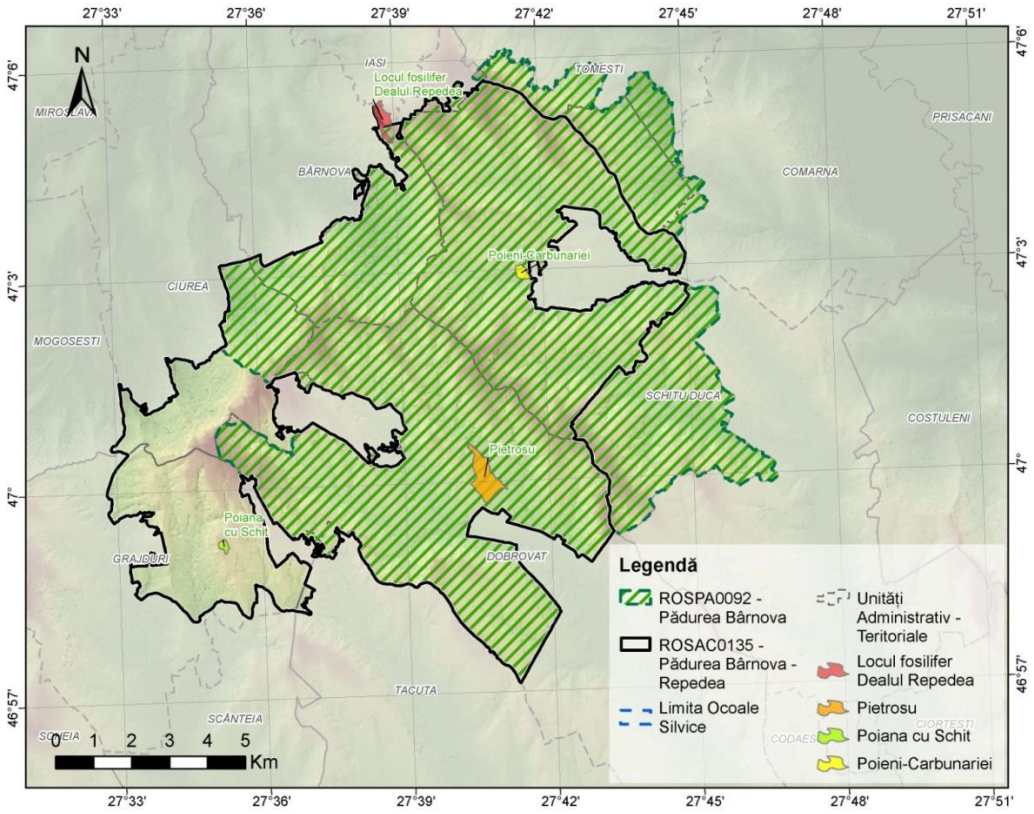

Figure 26. Distribution of protected natural areas within Bârnova Forest

Cultural and spiritual heritage of Bârnova Forest

The cultural and spiritual heritage of Bârnova Forest includes monasteries, hermitages, historical monuments, archaeological remains, and artistic features embedded in the forest landscape. Their distribution reveals the close relationship between local communities and the natural environment, contributing to cultural ecosystem services associated with spirituality, local identity, and collective memory.

The questionnaire administered to local communities indicates strong recognition of spiritual heritage. The most important landmarks are Bârnova and Dobrovăț Monasteries (92.4%), followed by the ruins at Poiana cu Schit (86.5%), Cujbă Church and other ancient sacred places (84.2%). Furthermore, 81.6% of respondents recognise the symbolic value of local place names, while 75.1% perceive the forest as a place of tranquillity and spiritual reflection.

Comparative analysis of the questionnaires reveals differences in perception: local communities attach greater importance to spiritual and identity-related dimensions, whereas online respondents particularly appreciate the tourism and recreational appeal of cultural attractions.

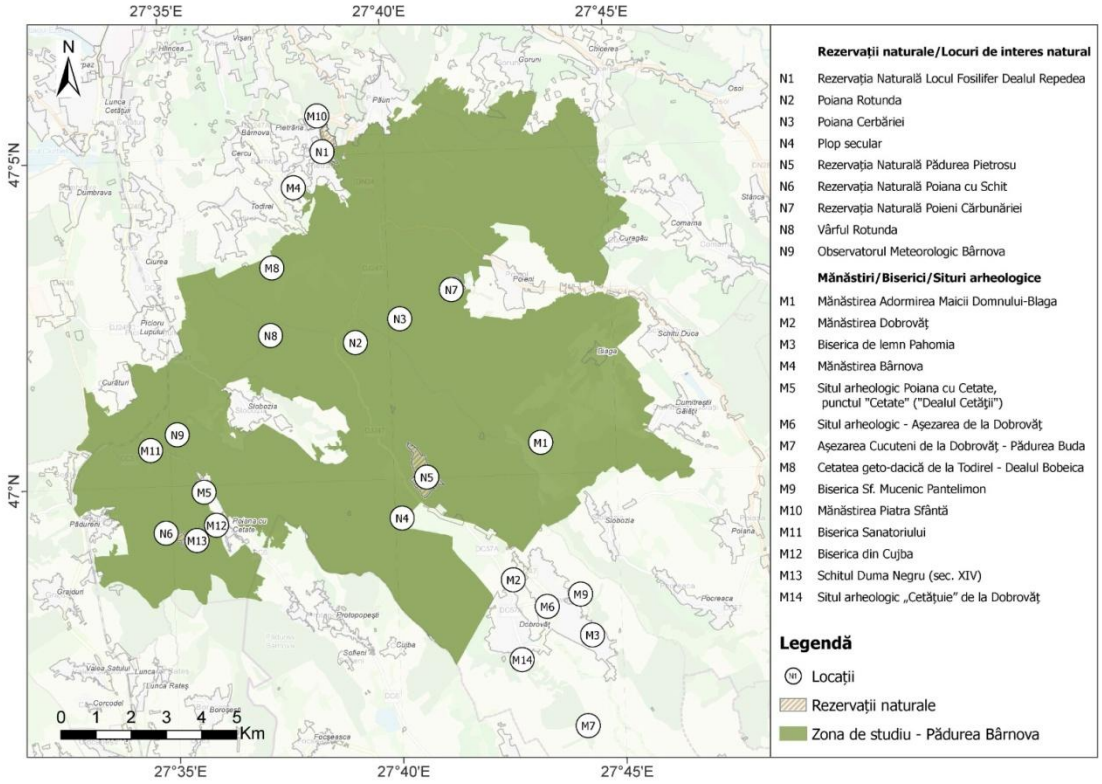

Figure 27. Map of cultural and spiritual heritage – distribution of the principal natural, cultural, and spiritual heritage features in Bârnova Forest

Main cultural and spiritual attractions in Bârnova Forest

Among the most representative sites are Dobrovăț Monastery, the last foundation of Stephen the Great, and Bârnova Monastery, founded by Miron Barnovschi, both important historical and spiritual landmarks for local communities.

Cujbă Church, built in 1609 in the village of Poiana cu Cetate, is a historical monument relevant to the area's cultural identity. Another important site is Poiana cu Schit, where the ruins of

an old hermitage attributed to Duma Negru and an ensemble of stone sculptures illustrate the overlap of natural, spiritual, and artistic values. Analysis of Strava Metro data confirms intensive recreational use of trails in this area.

The historical heritage also includes the "Cetățuie" archaeological site at Dobrovăț, associated with Getic remains dating from the fifth to third centuries BC, illustrating the continuity of relationships between human communities and the forest landscape.

Overall, the findings demonstrate that natural, cultural, and spiritual heritage is an essential component of the cultural ecosystem services provided by Bârnova Forest, contributing to tourism appeal, heritage education, and the strengthening of local identity.

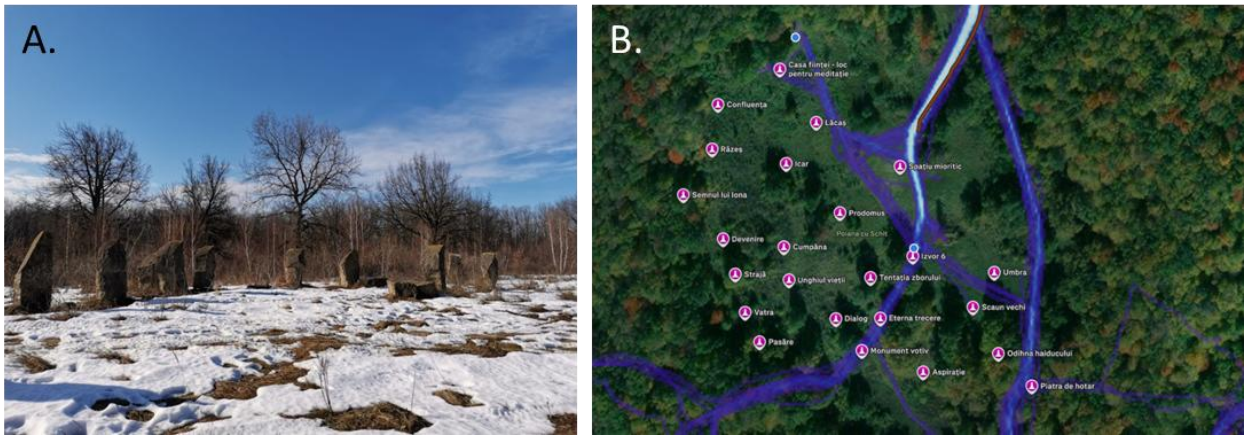

Figure 28. A. "Prodromos" sculpture by Romelo Pervolovici, 1988. Source: author's photograph, 2020. B. Distribution of sculptures and intensity of trail use in the Poiana cu Schit area (Strava Metro data)

V.3.3. Education, Cultural Identity, and Nature-Based Experiences

Nature observation, education, and experience of the natural environment

Bârnova Forest provides cultural ecosystem services with an important educational component by facilitating direct contact with biodiversity and offering thematic trails and information points. The "Nature, Culture, Spirituality" and "Bârnova Trail" routes include interpretive panels and interactive elements that promote knowledge of species, habitats, and ecological processes characteristic of forest ecosystems.

These facilities support non-formal education and awareness of the importance of biodiversity conservation, transforming recreational experiences into opportunities for learning and interpreting natural heritage.

Nature observation and artistic inspiration

Habitat diversity and the presence of species of conservation interest give Bârnova Forest considerable educational and aesthetic value. Species such as the lady's-slipper orchid

(Cypripedium calceolus), Alpine longhorn beetle (Rosalia alpina), and Ural owl (Strix uralensis) are representative subjects for nature observation, photography, and environmental education.

Furthermore, the diversity of forest landscapes, seasonal changes in vegetation, and characteristics of the hilly terrain contribute to cultural services associated with aesthetic experiences, contemplation, and artistic inspiration.



Figure 29. Representative species and landscapes contributing to the educational and aesthetic value and artistic inspiration associated with Bârnova Forest: A. lady's-slipper orchid (Cypripedium calceolus); B. Alpine longhorn beetle (Rosalia alpina); C. Ural owl (Strix uralensis); D. forest landscape in winter; E. forest landscape in the central part of Bârnova Forest. Source: author's photographs (A–C) and Tudor Mazilu (D, E).

The landscapes of Bârnova Forest, characterised by colour diversity, seasonal variation, and panoramic views, have significant aesthetic and artistic value, reflected in photography, tourism promotion, and environmental education. The relationship between local communities and the forest is also reflected in intangible cultural heritage and traditional objects, highlighting the contribution of the forest ecosystem to preserving local cultural identity.

Nature in local cultural identity

The relationship between local communities and the forest environment is also reflected in traditional cultural heritage through the incorporation of nature-inspired motifs into textiles and folk art.

The examples analysed—a traditional Romanian blouse from Pădureni and hand-embroidered towels from Poiana cu Cetate—show plant, floral, and geometric motifs with symbolic

meanings. These elements reflect the intergenerational transmission of cultural values and the link between the natural landscape and local community identity.

Overall, the findings show that cultural ecosystem services provided by Bârnova Forest extend beyond recreation, contributing to education, artistic inspiration, the conservation of intangible cultural heritage, and the strengthening of local identity.

V.3.4. Tourism Use of Cultural Ecosystem Services Provided by Bârnova Forest

Tourism use of the cultural ecosystem services provided by Bârnova Forest is supported by forest landscape diversity, natural and cultural heritage, and the development of leisure infrastructure. Spatial analysis of tourism facilities reveals their concentration near main access routes and areas of high scenic and recreational appeal.

Accommodation establishments, glamping facilities, picnic areas, and event venues were identified within the study area, including Valea Sânzienelor, Căsuța cu Maci, and Cabana Poieni. Events such as the Iași Rally, Trail la Cabană, and the WoodScape festival also help promote the forest as a destination for sporting, cultural, and recreational activities.

Initiatives such as Oaza Taină Vie demonstrate opportunities to integrate local products, educational activities, and nature-based recreational experiences, illustrating interactions between cultural and provisioning ecosystem services.

The findings demonstrate that Bârnova Forest provides an important foundation for nature-based tourism development and the diversification of local economic activities through the integrated use of recreational, educational, and cultural benefits.

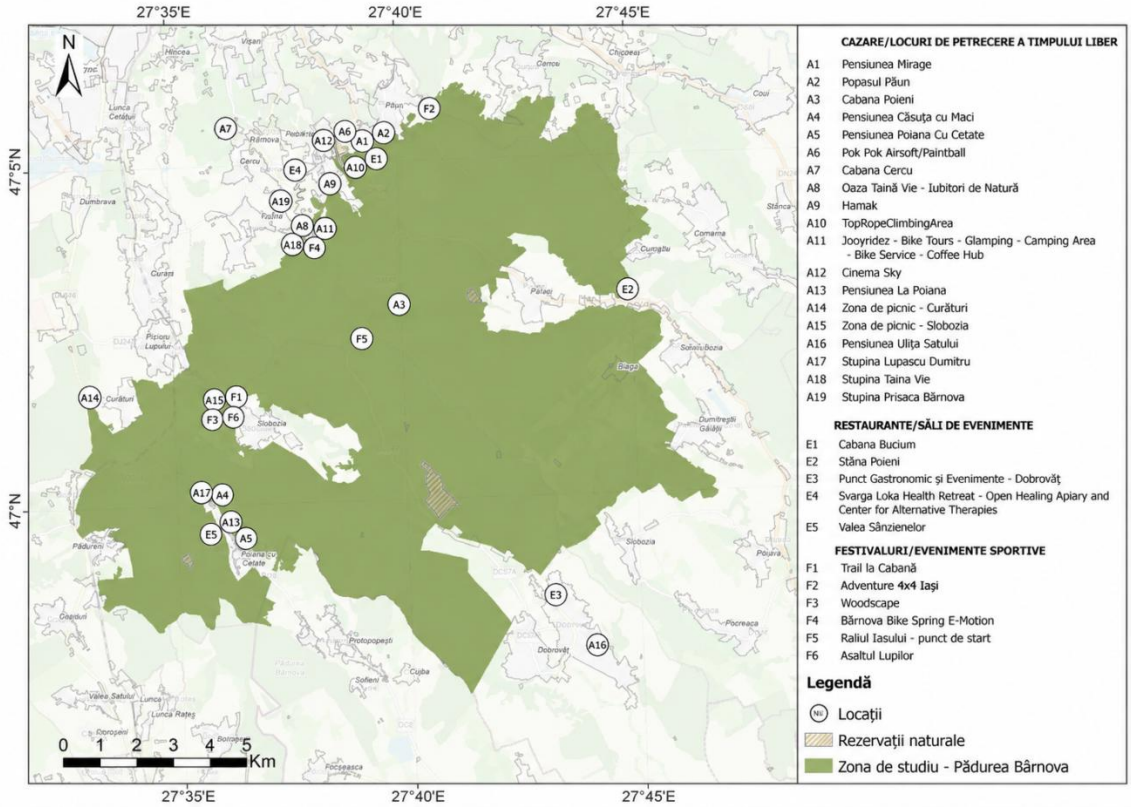

Figure 30. Map of tourism locations, local producers, and events

V.3.5. Community Involvement and Social Value

The social value of Bârnova Forest is expressed through community initiatives dedicated to environmental education, volunteering, and biodiversity conservation. Activities organised by civic groups and non-governmental organisations, including Codrii Iașilor, Greenpeace România, and ReSet Iași, help raise awareness of the importance of forest ecosystems.

Guided tours, nature observation activities, information campaigns, and volunteer initiatives facilitate community participation in promoting and protecting natural heritage.

These initiatives highlight the contribution of Bârnova Forest to strengthening social relationships, fostering a sense of belonging, and encouraging civic participation, demonstrating that the cultural benefits of forest ecosystems extend beyond individual recreation.

V.3.6. Multifunctionality of Cultural Ecosystem Services

The multifunctionality of cultural ecosystem services was analysed by linking functional groups from forest management plans to CICES V5.1 classes, highlighting the overlap of recreational, educational, aesthetic, and identity-related benefits provided by forest ecosystems.

The results indicate that experiential use of nature (CICES 3.1.1.1) is associated with a cumulative area of 11,088.3 ha, while recreational physical use (CICES 3.1.1.2) totals 12,003.9 ha. Scientific and educational interactions (CICES 3.1.2.1) cover 11,780.7 ha, confirming the forest's extensive potential for nature observation and interpretation.

The aesthetic value of the landscape (CICES 3.1.2.5) is associated with all functional groups, corresponding to an area of 12,558.9 ha. Existence values (CICES 3.2.4.1) and bequest values (CICES 3.2.4.2) are associated with cumulative areas of 11,992.6 ha and 11,246.6 ha, respectively, highlighting the importance of the forest as natural and cultural heritage for present and future generations.

The Sankey diagram illustrates the relationships between cultural services and the functional groups of forest stands, demonstrating that the same forest area can simultaneously provide multiple non-material benefits.

Overall, the findings confirm the multifunctional character of Bârnova Forest and highlight the need to integrate cultural, social, and educational values into forest ecosystem management.

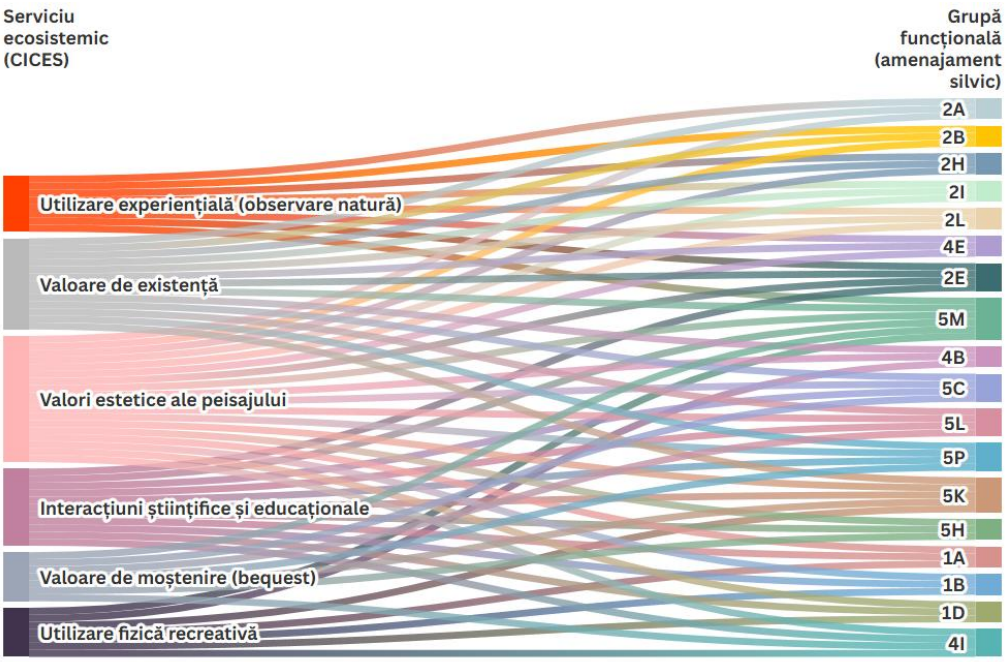

Figure 31. Functional relationships between cultural ecosystem services (CICES) and the functional groups of forest stands in Bârnova Forest

V.4. Regulating Ecosystem Services

The assessment of regulating ecosystem services provided by Bârnova Forest integrated information from forest management plans, climatic data, physicochemical analyses of soil and water samples, and information on habitats and biodiversity. The research focused on the main regulation and maintenance functions: climate regulation, regulation of the hydrological regime and water quality, soil protection, and biodiversity conservation.

V.4.1. Climate Regulation

The climate regulation ecosystem service was assessed by analysing the functional potential of forest stands, the dynamics of forest vegetation, and the capacity of soils to accumulate and store carbon.

Climate regulation potential according to forest management plans

The spatial distribution of climate regulation potential reveals a predominance of areas with high potential, primarily associated with forests included in the Natura 2000 network (5M), old-growth natural forests (5P), forests designated for the conservation of genetic resources (5L), and nature reserves (5C). Moderate potential characterises stands with mixed functions, including those surrounding settlements and along transport routes, whereas low potential occurs locally in areas where the climatic function is secondary to other management objectives.

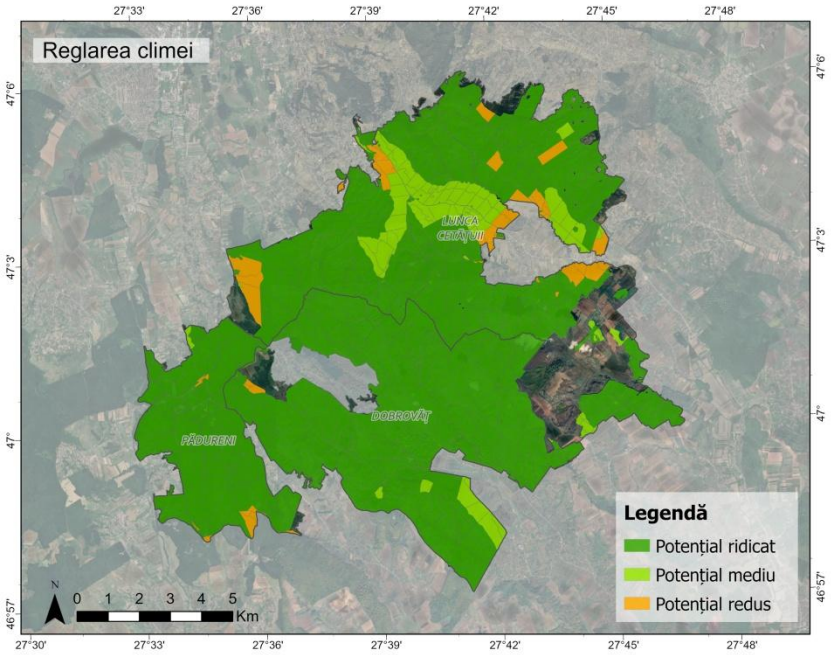

Figure 32. Spatial distribution of climate regulation potential in Bârnova Forest (forest management plan data)

Assessment of the climate regulation service based on biophysical and climatic indicators

The multitemporal analysis of the NDVI index, derived from Sentinel-2 imagery for 2017–2024, reveals a predominance of high values and the maintenance of generally favourable conditions of forest vegetation. Spatial changes were relatively limited, concentrated mainly at the edges of the forest massif and in sectors affected by forestry interventions or temporary changes in canopy cover.

Correlations calculated for August 2019 and June 2023 reveal the influence of climatic factors on vegetation dynamics. Precipitation and solar radiation show positive relationships with NDVI, whereas temperature shows a negative relationship, suggesting the influence of water stress during hot, dry periods. Topographic factors also contribute to the spatial differentiation of vegetation, with the highest NDVI values associated with gentle slopes of 0–10° and east- and west-facing slopes.

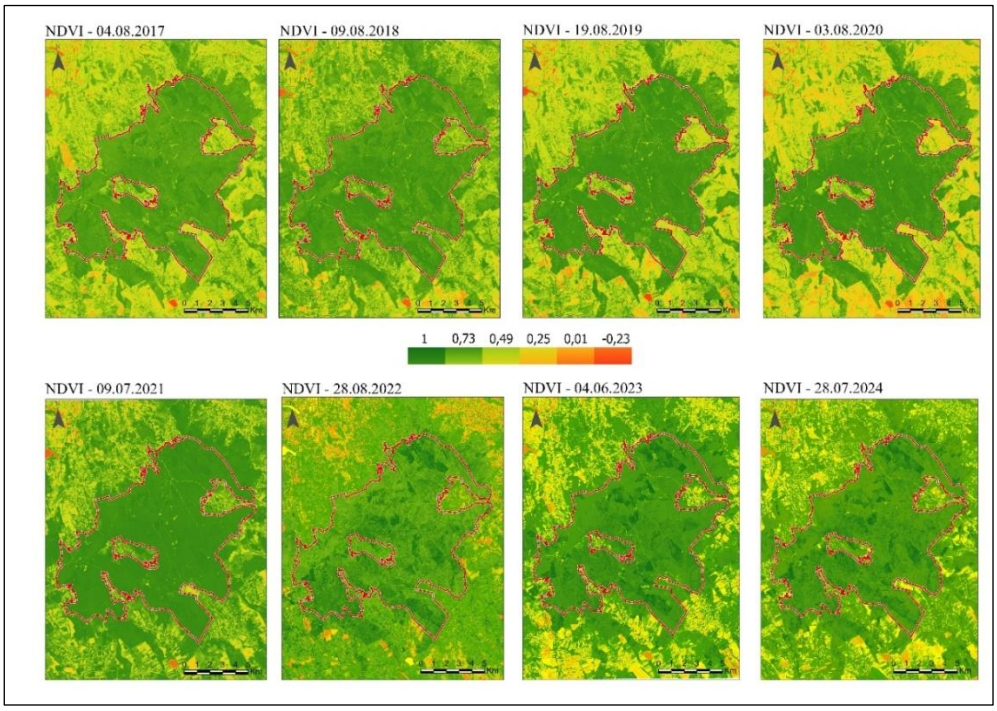

Figure 33. Spatial evolution of NDVI during 2017–2024

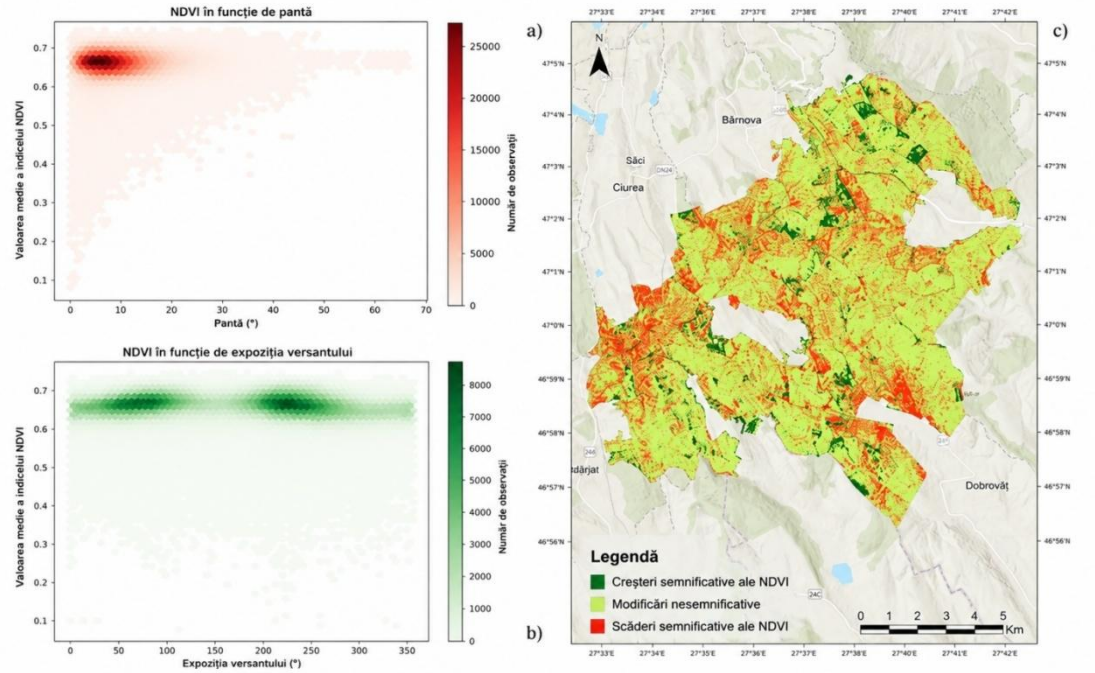

Figure 34. Relationship between NDVI, topographic factors, and spatial changes in vegetation

Validation of the climate regulation ecosystem service using indicators analysed in soil samples

The assessment was complemented by measurements of total carbon (TC), total inorganic carbon (TIC), and soil bulk density, from which total organic carbon (TOC) and soil organic carbon stock (SOC Stock) were calculated.

The results reveal substantial spatial differences between carbon fractions. Total carbon shows high values mainly in northern and northwestern sectors, locally exceeding 50.29 g/kg, whereas inorganic carbon concentrations are higher in the north and northeast, reaching over 30.31 g/kg. By contrast, total organic carbon shows high values in southern, southwestern, and some central sectors, locally exceeding 17.70 g/kg.

Bulk density is higher in the southern and southwestern parts and, together with organic carbon content, influences the amount of carbon stored in the soil. The spatial distribution of organic carbon stocks follows a pattern similar to TOC, with the highest values recorded in the south and southwest of the area and in some central sectors, locally exceeding 72.80 t C ha^{-1}.

The results demonstrate that the distribution of total carbon does not always reflect the actual capacity for organic carbon accumulation, highlighting the importance of distinguishing between carbon fractions. Integrating soil analyses with satellite data and forest management plan information confirms the substantial potential of Bârnova Forest to provide the climate regulation ecosystem service.

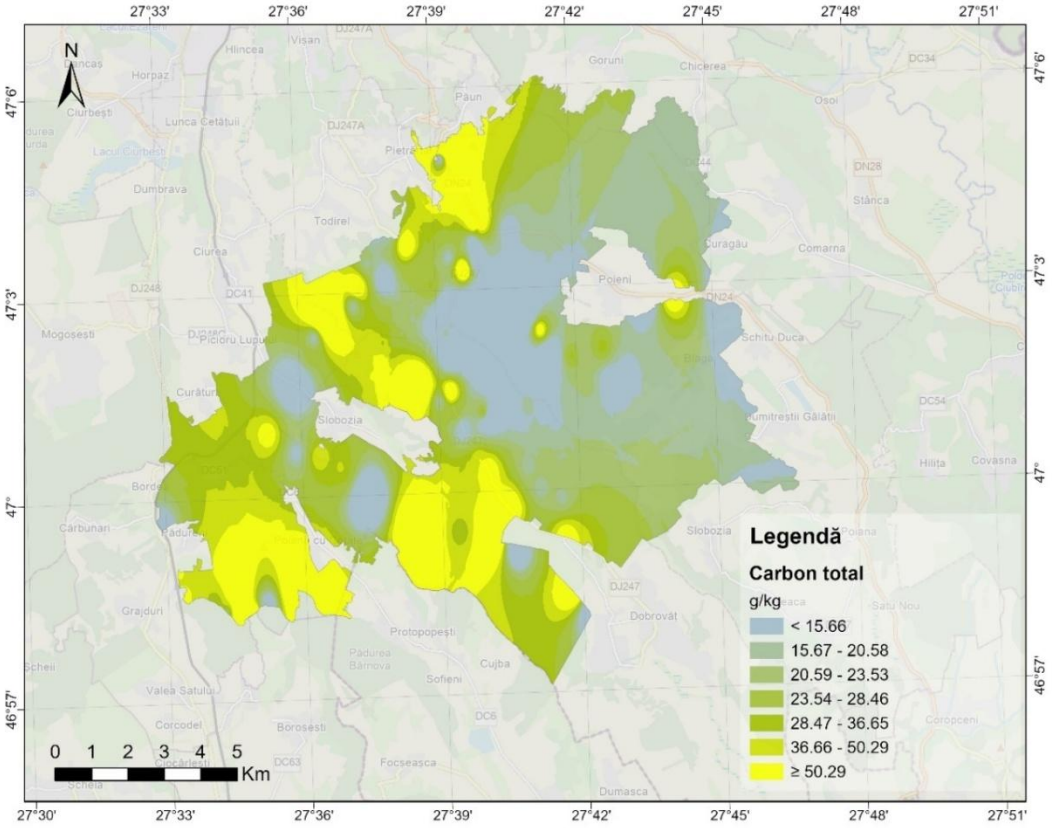

Figure 35. Spatial distribution of total carbon (TC) in the forest soils of Bârnova Forest

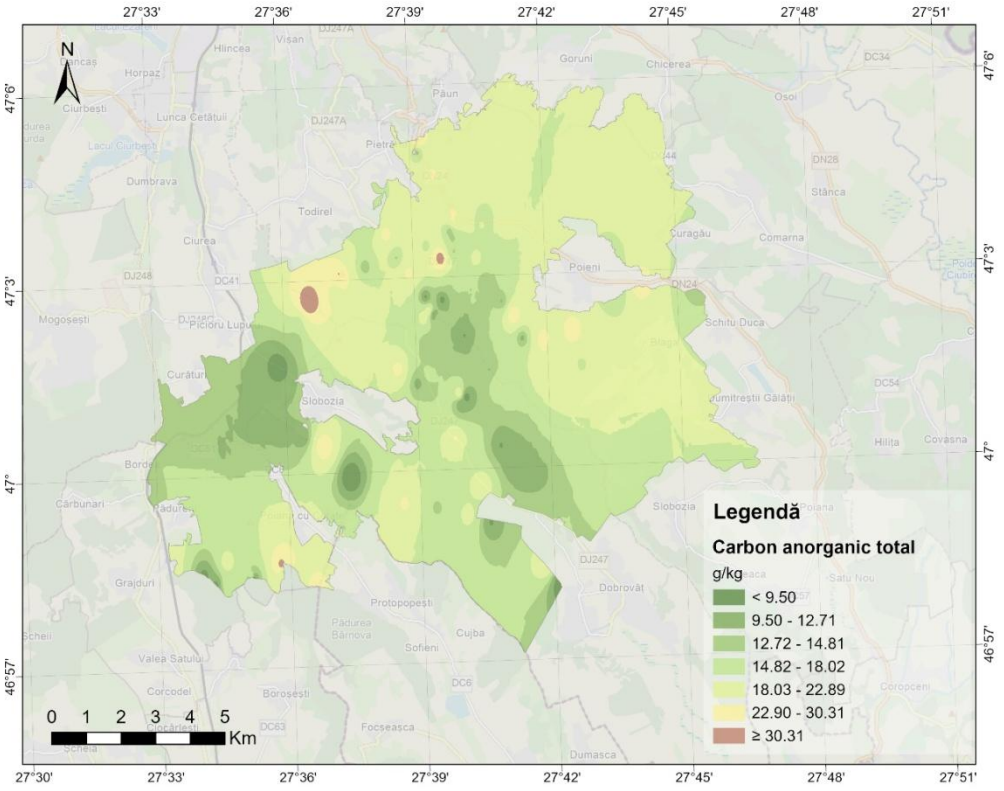

Figure 36. Spatial distribution of total inorganic carbon (TIC) in the forest soils of Bârnova Forest

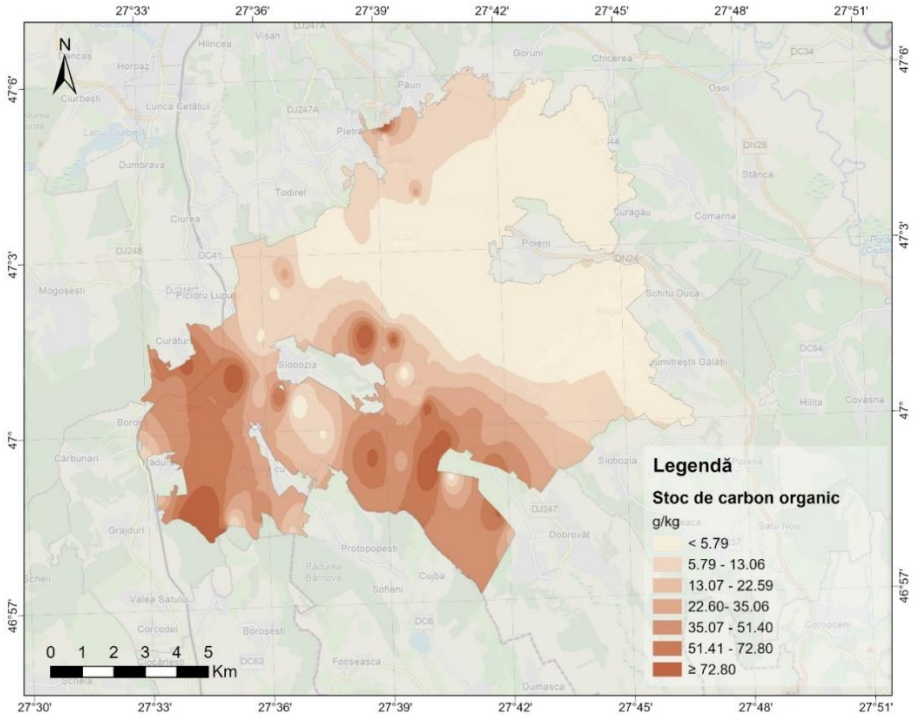

Figure 37. Spatial distribution of soil organic carbon stock (SOC Stock) in Bârnova Forest

V.4.2. Regulation of the Hydrological Regime and Water Quality

The ecosystem service of regulating the hydrological regime and water quality was assessed by integrating information from forest management plans with the results of physicochemical analyses of water samples collected from streams and springs in Bârnova Forest.

Water regulation potential according to forest management plans

The spatial distribution reveals a predominance of areas with moderate hydrological regulation potential, reflecting the general contribution of forest vegetation to precipitation interception, water infiltration, and the reduction of surface runoff. High potential mainly characterises stands with priority hydrological protection functions, located on slopes, in catchment areas, and on erosion-prone land. Areas with low potential are limited and predominantly correspond to stands with social or infrastructure protection functions, including functional subgroup 4E.

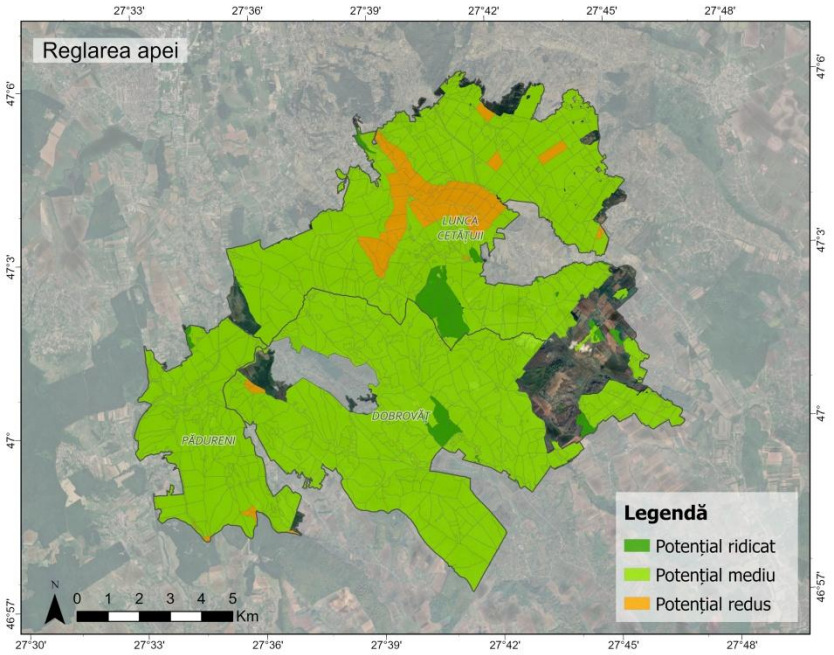

Figure 38. Spatial distribution of water regulation potential in Bârnova Forest (forest management plan data)

Assessment of the service based on water analyses

Physicochemical analyses characterised water quality by measuring pH, electrical conductivity, hardness, dissolved oxygen, calcium and magnesium concentrations, and nitrogen compounds.

The results indicate slightly alkaline waters, with pH values ranging from 7.3 to 7.8, reflecting limited spatial variability. Electrical conductivity ranges from approximately 618 to 1,179 µS/cm, while total hardness varies between 23 and 36 °dG, with higher values concentrated mainly in northern and northeastern sectors. These differences reflect the influence of geological and soil characteristics on water mineralisation.

Dissolved oxygen concentrations range from 1.2 to 2.3 mg/L, with higher values in northern and northeastern sectors and lower values in southern and southwestern sectors. The distribution of this indicator may be influenced by water temperature, flow velocity, and local oxygenation conditions.

Calcium and magnesium ion concentrations show spatial variations primarily associated with the characteristics of the geological substrate and natural mineral dissolution processes. Nitrate and ammonium ion concentrations are predominantly low to moderate, with higher values occurring locally rather than forming extensive areas.

Overall, the results highlight the influence of geological, soil, and hydrological conditions on the physicochemical characteristics of waters in Bârnova Forest. The predominance of forest areas with moderate and high hydrological regulation potential, together with the distribution of the indicators analysed, supports the importance of the forest ecosystem in maintaining the water cycle and protecting water resources.

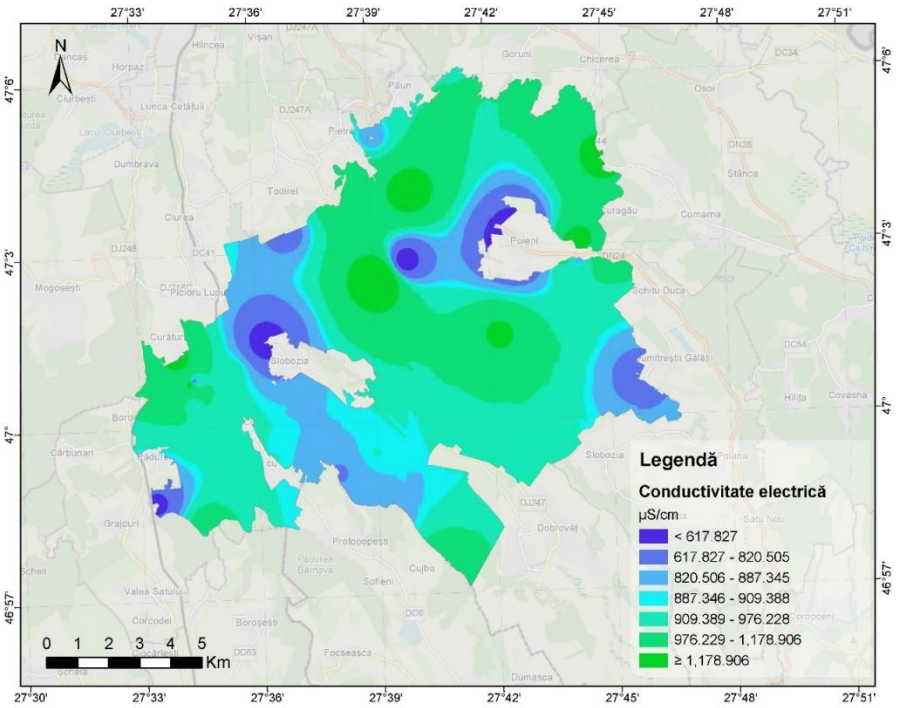

Figure 39. Spatial distribution of water electrical conductivity in Bârnova Forest

V.4.3. Soil Conservation and Protection

The ecosystem service of soil conservation and protection was assessed by integrating information from forest management plans with the results of physicochemical analyses of soil samples. The assessment sought to highlight the role of forest ecosystems in preventing erosion, maintaining slope stability, and conserving soil properties.

Soil protection potential according to forest management plans

Spatial distribution analysis reveals a predominance of areas with moderate soil protection potential, whereas high potential is particularly characteristic of stands on steep slopes, land with vulnerable lithological substrates, and areas affected by active geomorphological processes. These mainly correspond to functional subgroups in category 2 (2A–2L), whose priority role is to reduce

erosion and stabilise slopes. Areas with low potential are limited and associated with stands having predominantly social, infrastructure-related, or production functions.

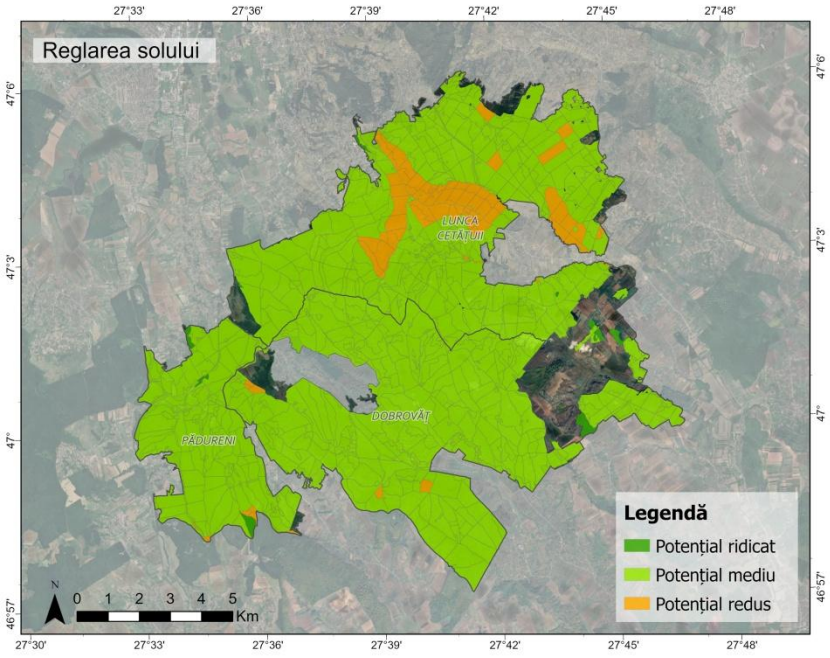

Figure 40. Spatial distribution of soil protection potential in Bârnova Forest (forest management plan data)

Assessment of the service based on soil analyses

The properties of forest soils were analysed in the context of the pedological and geomorphological characteristics of the area, which is dominated by preluvosols, luvosols, and eutric cambisols developed on clayey-marly deposits. The dissected hilly terrain, with elevations ranging from approximately 80 m to over 400 m, favours erosion processes, particularly on steep slopes.

Laboratory results generally indicate bulk density values corresponding to a low degree of compaction, favourable to water infiltration and root development. In addition, the indicators previously analysed to assess climate regulation—total organic carbon and soil carbon stocks—provide relevant information on organic matter accumulation and the maintenance of soil fertility and structural stability.

The spatial variability of these indicators reflects the influence of pedological, geological, and geomorphological conditions, highlighting the contribution of forest vegetation to the conservation of soil properties and the reduction of susceptibility to erosion.

Overall, the results confirm the importance of Bârnova Forest for soil protection through the maintenance of forest cover, slope stabilisation, and support for natural processes that help conserve soil structure and fertility.

V.4.4. Biodiversity and Habitat Conservation

Bârnova Forest plays an important role in conserving regional biodiversity through its diversity of natural and semi-natural habitats, the structural complexity of forest stands, and the continuity of forest cover. This ecosystem service was assessed by analysing the functions assigned to stands in forest management plans and the characteristics of habitats and species of conservation interest.

Conservation potential according to forest management plans

Spatial distribution shows a predominance of areas with high potential for maintaining habitats and biodiversity, associated primarily with forests included in the Natura 2000 network (5M), ancient natural forests (5P), forests designated for the conservation of genetic resources (5L), nature reserves (5C), and seed reserves (5H). Moderate potential characterises stands with mixed functions, while areas with low potential are limited and mainly associated with production functions or other uses involving more frequent forestry interventions.

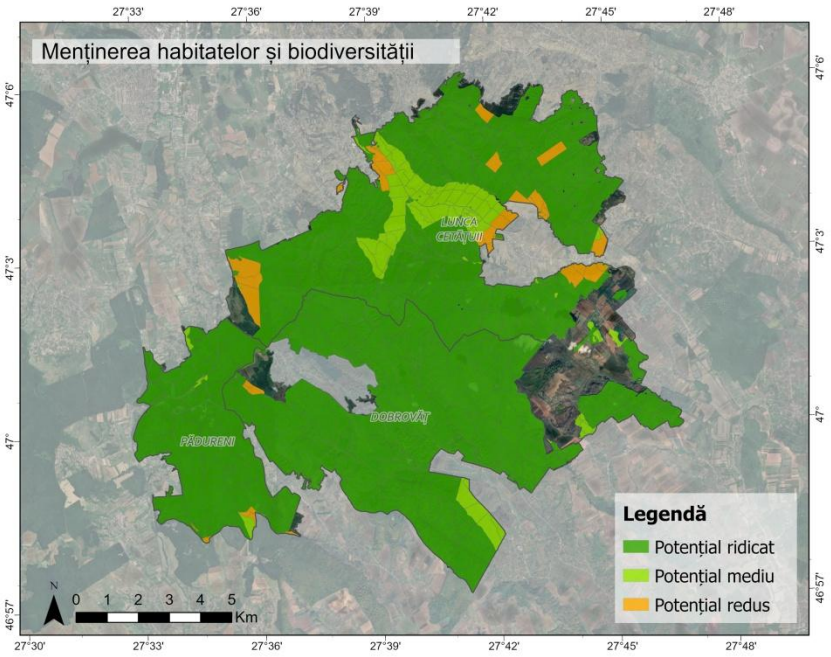

Figure 41. Spatial distribution of the potential for maintaining habitats and biodiversity in Bârnova Forest (forest management plan data)

Habitats and biodiversity

The biological diversity of Bârnova Forest is supported by a mosaic of habitats, mainly comprising forest habitats 91Y0 – Dacian oak-hornbeam forests and 9130 – Asperulo-Fagetum beech forests, complemented by semi-natural habitats such as 6520, 40C0*, and 62C0*. This diversity helps maintain favourable ecological conditions for numerous plant and animal species.

Mature and old trees, deadwood, forest microhabitats, and the layered structure of vegetation play an essential role by providing food resources, shelter, and breeding sites for numerous

organisms. The importance of these elements is demonstrated by the presence of 18 invertebrate species of Community interest identified within the site, including Lucanus cervus, Rosalia alpina, Cerambyx cerdo, Morimus funereus, and Osmoderma barnabita (Popescu & Gostin, 2025).

Faunal diversity is complemented by bat species such as Barbastella barbastellus and Myotis bechsteinii, as well as amphibians of Community interest. The Special Protection Area ROSPA0092 Pădurea Bârnova also supports more than 100 bird species, including Aquila pomarina, Circaetus gallicus, Pernis apivorus, and Dryocopus martius.

The presence of forest stands at different developmental stages, from regeneration to maturity and senescence, contributes to habitat diversification and the maintenance of ecological processes. Furthermore, the spatial continuity of the forest massif supports ecological connectivity, species movement, and genetic exchange between populations.

Overall, the results show that habitat and biodiversity maintenance is one of the dominant functions of Bârnova Forest, supported by habitat diversity, stand structural complexity, and the ecological continuity of the forest ecosystem.

V.4.5. Community Perceptions of Regulating Ecosystem Services

Perceptions of local communities

The results reveal strong appreciation of regulating services among local communities, particularly flood prevention and water quality protection (97.3% each), temperature regulation (85.1%), and maintenance of air quality (83.8%). Perceived microclimatic effects include the persistence of snow cover and the moderation of summer temperatures. Furthermore, 91.9% of respondents support nature conservation, recognising its importance for the environment, health, and future generations.

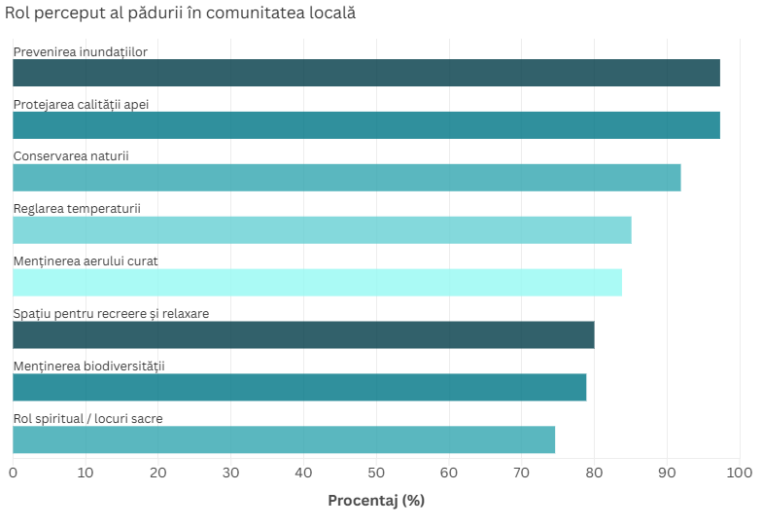

Figure 42. Perceived role of the forest in the local community

Perceptions of the urban population

Among urban respondents, climatic benefits are primarily associated with the moderation of temperatures during the warm season (33%), persistence of snow cover (28%), influence on precipitation (22%), and reduction in the frequency of extreme weather events (15%).

Nature conservation is considered important by 95.8% of respondents, who associate it particularly with maintaining air quality, improving health and quality of life, protecting biodiversity, and preserving natural heritage for future generations.

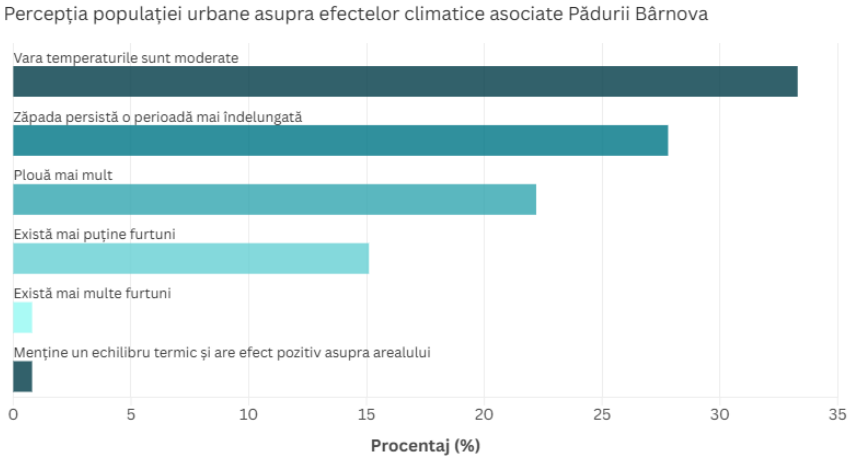

Figure 43. Urban respondents' perceptions of climatic effects associated with Bârnova Forest

Comparative analysis of local community and urban population perceptions

Comparing perceptions reveals differences between local communities, which predominantly value hydrological functions and the reduction of natural hazards, and urban respondents, who particularly appreciate thermal comfort, health, and environmental quality. Both groups demonstrate strong support for nature conservation (91.9% and 95.8%, respectively), emphasising the need to integrate the perspectives of different beneficiary groups into Bârnova Forest management.

V.4.6. Multifunctionality of Regulation and Maintenance Ecosystem Services

The multifunctionality of regulation and maintenance ecosystem services was assessed by linking the CICES classification to the functional groups assigned to forest stands in management plans, highlighting the overlap of ecological functions across Bârnova Forest.

The results indicate a high degree of multifunctionality. The services of maintaining populations and habitats (CICES 2.3.1.2), regulating micro- and regional climate (2.3.5.2), maintaining the hydrological cycle (2.2.2.1), and soil formation and maintenance (2.3.3.2) are associated with all functional groups and the entire analysed forest area of 12,558.9 ha.

Global climate regulation through carbon storage (CICES 2.3.5.1) is associated with an area of 11,738.8 ha, while mass stabilisation and erosion control (2.2.1.1), filtration and sequestration by biota (2.1.1.2), and maintenance of the chemical condition of freshwater (2.3.4.1) correspond to areas of 11,005.1 ha, 11,112.8 ha, and 10,894.8 ha, respectively.

By contrast, noise and pollution mediation (CICES 2.1.2.3) has the most restricted distribution, being associated with functional groups 2B, 4B, and 4E, over a cumulative area of 509.2 ha. This distribution reflects the localised character of the service, particularly near transport infrastructure and inhabited areas.

Overall, the results highlight the spatial overlap of regulation and maintenance services, demonstrating that the same forest areas simultaneously contribute to biodiversity conservation, climate and hydrological regulation, and soil protection. This multifunctionality underscores the importance of integrated forest management aimed at maintaining ecological functions and the benefits provided over the long term.

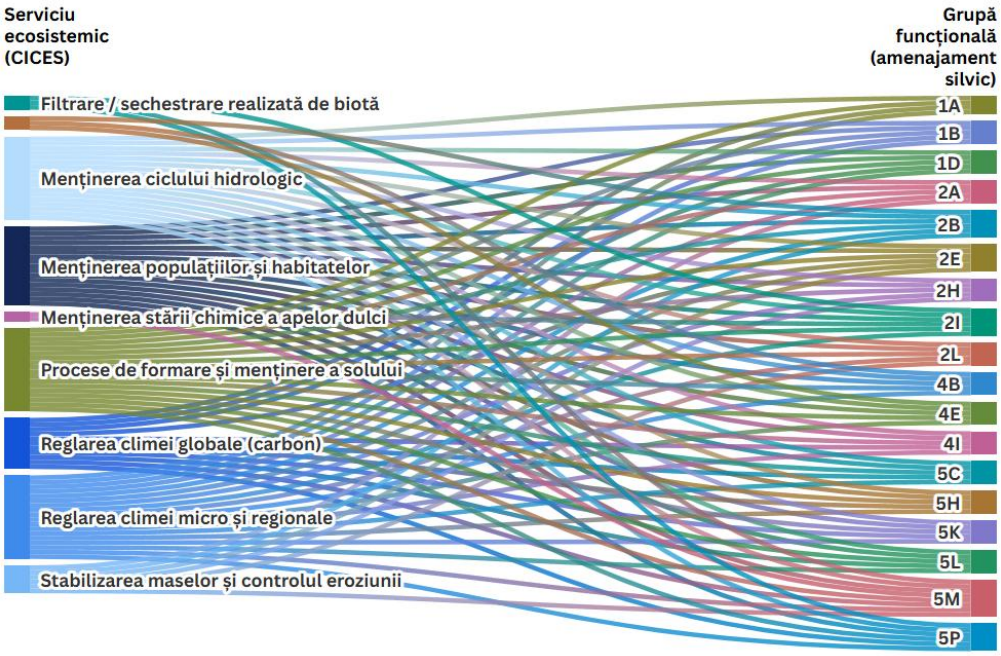

Figure 44. Relationships between regulation and maintenance ecosystem services (CICES) and functional groups in Bârnova Forest

VI. Discussion

VI.1. Integrated Assessment of Forest Ecosystem Services – From the Production Function to Ecosystem Multifunctionality

The research findings highlight the multifunctional character of Bârnova Forest, where provisioning, regulating, and cultural ecosystem services coexist and influence one another. This perspective goes beyond the traditional approach to forest management, which focuses predominantly on timber production, and highlights the importance of the ecological and social benefits provided by forest ecosystems.

Integrating forest management plans with the CICES classification, biophysical analyses, GIS and remote sensing techniques, and sociological investigations made it possible to identify relationships between forest structure, ecological functions, and benefits provided to society. The findings support the need for integrated ecosystem service assessment as a basis for sustainable forest management.

VI.2. Forest Management and Provisioning Ecosystem Services

The analysis of provisioning services shows that the economic and social value of Bârnova Forest is not limited to timber production but also includes non-timber forest products, medicinal plants, mushrooms, and melliferous resources, which diversify the benefits available to local communities.

The provision of these resources depends on maintaining biodiversity and the functioning of forest ecosystems. In this context, the FSC and PEFC certifications held by the forest districts analysed are instruments supporting responsible management practices by promoting habitat conservation, natural resource protection, and the sustainable use of forest products.

VI.3. Cultural Ecosystem Services and the Social Role of Bârnova Forest

The location of Bârnova Forest near the city of Iași gives particular importance to cultural ecosystem services associated with recreation, education, local identity, and spiritual values. Analysis of recreational trails and data from the Strava platform revealed actual forest use for sports and recreational activities, complementing information obtained through field observations and questionnaires.

Differences between respondents' perceptions highlight the context-dependent character of these services. Urban respondents predominantly value recreational opportunities and benefits for health and well-being, whereas local communities place greater importance on forest resources and identity-related values. These findings underscore the need to include the social dimension in planning forest ecosystem use and conservation.

VI.4. Regulating Ecosystem Services – The Foundation of Forest Ecosystem Functioning

Regulating ecosystem services provide the ecological foundation for the other categories of benefits supplied by Bârnova Forest. Integrated assessment of vegetation, soil, water, and climatic

characteristics highlighted the importance of the forest ecosystem for climate regulation, water resource protection, soil conservation, and biodiversity maintenance.

Multitemporal NDVI analysis, correlated with climatic indicators and the physicochemical properties of soils, revealed relationships between vegetation dynamics and environmental conditions, as well as differences in the spatial distribution of organic carbon and soil carbon stocks. These results support the importance of the forest for climate regulation and highlight the need to monitor forest ecosystems in the context of climate change.

Regarding hydrological regulation, analysis of stand functions and the physicochemical characteristics of water revealed spatial variability in the indicators examined and the influence of natural conditions on them. Soil properties and the distribution of stands with protective functions also underline the role of forest cover in limiting erosion and maintaining slope stability.

Biodiversity conservation is a fundamental component of forest ecosystem functioning, with habitat diversity and stand structural complexity supporting ecological processes. The results thus highlight the interdependence of regulating services and the need to maintain ecosystem integrity to ensure their long-term provision.

VI.5. Implications of the Findings for Sustainable Management of Bârnova Forest

The findings support the need for an integrated approach to forest management in which production objectives, biodiversity conservation, natural resource protection, and recreational use are considered together. Changes in stand structure or habitat degradation may simultaneously affect several categories of ecosystem services, making it important to avoid prioritising the production function exclusively.

Integrating forestry, biophysical, spatial, and sociological data provides a useful methodological framework for informing management decisions by highlighting both the ecological potential of the forest and the needs of different beneficiary groups.

In Bârnova Forest, protected area status and proximity to the city of Iași reinforce the need for adaptive, multifunctional management focused on habitat conservation, responsible resource use, and the long-term maintenance of ecological and social benefits.

VII. Conclusions

The research findings confirm the multifunctional character of Bârnova Forest, highlighting the interdependence of provisioning, regulating, and cultural ecosystem services. The value of this forest ecosystem extends beyond its traditional production function and is determined by the range of ecological, economic, and social benefits provided to human communities.

The research confirmed the hypothesis that ecosystem service provision results from interactions between the structure and functioning of forest ecosystems, natural environmental characteristics, and forest management practices. In this context, multifunctionality is a fundamental characteristic of the forest, enabling the simultaneous provision of natural resources, maintenance of ecological processes, and fulfilment of social and cultural needs.

The principal scientific contribution of the thesis is an integrated assessment of the ecosystem services provided by Bârnova Forest, linking forest management plans and the CICES classification with biophysical analyses, GIS and remote sensing techniques, and sociological investigations. This approach made it possible to identify relationships between the ecological functions of the forest, the spatial distribution of ecosystem services, and the benefits perceived by the population.

The results demonstrate the usefulness of forest management plans as a source of information for assessing forest multifunctionality, beyond their traditional role in planning forest management. Moreover, integrating the social dimension revealed differences between the perceptions of local communities and urban respondents, highlighting the need to adapt forest management to the characteristics and needs of different beneficiary groups.

From an applied perspective, the research supports integrating ecosystem services into forest planning and administration by linking biodiversity conservation objectives with sustainable resource use, climate change adaptation, and the maintenance of recreational and social functions. The interdisciplinary methodology employed can be adapted and applied to other forest ecosystems, contributing to the development of tools for assessing and monitoring natural capital.

In conclusion, Bârnova Forest is a relevant example of a multifunctional forest ecosystem whose ecological and social importance is amplified by its proximity to the city of Iași. The findings highlight the need for integrated and adaptive forest management capable of conserving ecosystem functions and maintaining the benefits provided to society over the long term.

References

1. Adhikari, K., & Hartemink, A. E. (2016). Linking soils to ecosystem services. Geoderma, 262, 101–111. https://doi.org/10.1016/j.geoderma.2015.08.009

2. Băcăuanu, V., Barbu, N., Pantazică, M., Ungureanu, Al., & Chiriac, D. (1980). Podișul Moldovei. Natură, om, economie. Editura Științifică și Enciclopedică, București.

3. Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. Ecology Letters, 12(12), 1394–1404. https://doi.org/10.1111/j.1461-0248.2009.01387.x

4. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

5. Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand and budgets. Ecological Indicators, 21, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019

6. Chan, K. M. A., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. Ecological Economics, 74, 8–18. https://doi.org/10.1016/j.ecolecon.2011.11.011

7. Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., ... & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387, 253–260. https://doi.org/10.1038/387253a0

8. Daily, G. C. (Ed.). (1997). Nature's services: Societal dependence on natural ecosystems. Island Press.

9. Daniel, T. C., Muhar, A., Arnberger, A., et al. (2012). Contributions of cultural services to the ecosystem services agenda. Proceedings of the National Academy of Sciences, 109(23), 8812–8819. https://doi.org/10.1073/pnas.1114773109

10. de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7(3), 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006

11. Díaz, S., Pascual, U., Stenseke, M., et al. (2018). Assessing nature's contributions to people. Science, 359(6373), 270–272. https://doi.org/10.1126/science.aap8826

12. Dominati, E., Patterson, M., & Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics, 69, 1858–1868. https://doi.org/10.1016/j.ecolecon.2010.05.002

13. Duncker, P. S., Raulund-Rasmussen, K., Gundersen, P., et al. (2012). How forest management affects ecosystem services, including timber production and economic return: Synergies and trade-offs. Ecology and Society, 17(4). https://doi.org/10.5751/ES-05066-170450

14. European Commission. (2014). Mapping and assessment of ecosystems and their services (MAES). Publications Office of the European Union.

15. Fish, R., Church, A., & Winter, M. (2016). Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. Ecosystem Services, 21, 208–217. https://doi.org/10.1016/j.ecoser.2016.09.002

16. Florea, N., & Munteanu, I. (2012). Sistemul Român de Taxonomie a Solurilor (SRTS). Editura Sitech.

17. Gamfeldt, L., Snäll, T., Bagchi, R., et al. (2013). Higher levels of multiple ecosystem services are found in forests with more tree species. Nature Communications, 4, 1340. https://doi.org/10.1038/ncomms2328

18. Haines-Young, R., & Potschin, M. B. (2010). The links between biodiversity, ecosystem services and human well-being. În D. G. Raffaelli & C. L. J. Frid (Eds.), Ecosystem Ecology: A New Synthesis (pp. 110–139). Cambridge University Press.
19. ICAS – Institutul Național de Cercetare-Dezvoltare în Silvicultură „Marin Drăcea". (2018). Amenajamentul fondului forestier proprietate publică a statului administrat de Ocolul Silvic Lunca Cetățuii. Direcția Silvică Iași.
20. ICAS – Institutul Național de Cercetare-Dezvoltare în Silvicultură „Marin Drăcea". (2018). Amenajamentul fondului forestier proprietate publică a statului administrat de Ocolul Silvic Dobrovăț. Direcția Silvică Iași.
21. ICAS – Institutul Național de Cercetare-Dezvoltare în Silvicultură „Marin Drăcea". (2019). Amenajamentul fondului forestier proprietate publică a statului administrat de Ocolul Silvic Pădureni. Direcția Silvică Iași.
22. IPBES. (2019). Global assessment report on biodiversity and ecosystem services. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
23. Millennium Ecosystem Assessment (MEA). (2005). Ecosystems and human well-being: Synthesis. Island Press.
24. Nedkov, S., Campagne, S., Borisova, B., et al. (2022). Modeling water regulation ecosystem services: A review in the context of ecosystem accounting. Ecosystem Services, 56, 101458. https://doi.org/10.1016/j.ecoser.2022.101458
25. Nelson, E., Mendoza, G., Regetz, J., et al. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment, 7. https://doi.org/10.1890/080023
26. Nicoară, M., & Bomher, E. (2014). Ghidul ariilor protejate din județul Iași. Editura Tipo Moldova.
27. Pan, Y., et al. (2011). A large and persistent carbon sink in the world's forests. Science, 333, 988–993. https://doi.org/10.1126/science.1201609
28. Sincron. (2015). Planul de management al sitului ROSCI0135 Pădurea Bârnova–Repedea. Iași.
29. TEEB. (2010). The economics of ecosystems and biodiversity: Ecological and economic foundations. Earthscan.
30. Vlami, V., Kokkoris, I. P., Zogaris, S., Kehayias, G., & Dimopoulos, P. (2021). Cultural Ecosystem Services in the Natura 2000 Network: Introducing Proxy Indicators and Conflict Risk in Greece. Land, 10(1), 4. https://doi.org/10.3390/land10010004