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Original scientific paper

SPATIAL CLUSTERING OF PROTECTED FORESTS IN ITALY FOR STRATEGIC NATURE CONSERVATION

Polina LEMENKOVA ^{1*}

Abstract: *This research presented work on the actualisation of the existing landscape maps in the protected regions of Italy in northern, central and southern areas. The research aimed at evaluation of how land cover types change across Italy and what factors induce their changes: geology, climate change, natural hazards, anthropogenic activities (wood logging), and changes in forest dynamics (reforestation and deforestation). The methodology includes both the GIS-based analysis of the regional setting (climate and hydrology, topographic-geologic structure of the terrain) and fieldwork activities during the in-situ campaign (summer periods 2024 and 2025). Processing fieldwork data, aerial GEE images and maps, and integrating them into cartographic project through QGIS mapping enabled to extract valuable environmental information regarding land cover types in 3 different regions of Italy for analysis of landscape variability.*

Keywords: environmental monitoring, forest protection, nature, land planning.

PROSTORNO GRUPISANJE ZAŠTIĆENIH ŠUMA U ITALIJI U CILJU STRATEŠKOG PRISTUPA ZAŠTITI PRIRODE

Sažetak: *Ovo istraživanje je predstavilo rad na aktuelizaciji postojećih mapa pejzaža u zaštićenim regionima Italije u severnim, centralnim i južnim oblastima. Istraživanje je imalo za cilj da proceni kako se tipovi zemljišnog pokrivača menjaju širom Italije i koji faktori izazivaju njihove promene: geologija, klimatske promene, prirodne opasnosti, antropogene aktivnosti (seča drveta) i promene u dinamici šuma (pošumljavanje i krčenje šuma). Metodologija obuhvata i GIS-baziranu analizu regionalnog okruženja (klima i hidrologija, topografsko-geološka struktura terena) i terenske aktivnosti u okviru kampanje na licu mesta (letnji periodi 2024. i 2025. godine). Obrada podataka terenskog rada, GEE snimaka i mapa, i njihova integracija u kartografski projekat putem QGIS mapiranja, omogućila je izdvajanje vrednih informacija o okruženju u vezi sa tipovima zemljišnog pokrivača u 3 različita regiona Italije za analizu varijabilnosti pejzaža.)*

Ključne reči: praćenje životne sredine, zaštita šuma, priroda, planiranje zemljišta.

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1. INTRODUCTION

Forests are essential for the environment sustainability and human society. As important habitats for biodiversity, forests regulate climate by absorbing carbon dioxide, and provide essential resources as ecosystem services. At the same time, the health of forests inextricably depends on the complex of several factors: soil, geology, climate, and topography. The combination of these factors creates specific site conditions for resources and environmental gradients that determine the growth of species and functionality of forest ecosystems. Each factor plays a critical role for sustainability of forests: climate setting control temperature and precipitation, soil setting provides nutrients and water, geologic setting determines soil parent material and structure, and topography influences microclimate and water flow.

Forests are subject to climate change, since they are sensible to fluctuations in temperature and precipitation balance. Variability of annual and seasonal climate cycle trigger processes of reforestation or deforestation (Albert & Schmidt, 2010; Lexer et al., 2002). Understanding the resilience of forest to climate-related processes requires analysis of multiple factors that affect the sustainability of forest ecosystems. This is possible through advanced data analysis (Suárez-Córdoba et al., 2025) and multi-scale mapping (Feng et al., 2025; Pang et al., 2024; Li et al., 2025). To this end, the Geographic Information System (GIS) support advanced methods of spatial data analysis in forestry (Alizadeh et al., 2025; Kienast et al., 1996; Shivaprakash et al., 2022).

Smart solutions to tackle the issues of forest management by observations and environmental mapping aims at monitoring landscape dynamics (Jones & Vukomanovic, 2025). Cartographic data processing supports monitoring changes in forest stands across various regions (Kondratev et al., 2025). Traditional methods of forest monitoring are time-consuming field-based sampling and includes manual laborious work on data collection (Matović et al., 2018, 2021; Taura & Gudžinskas, 2025; Kint et al., 2004). In turn, GIS for data integration enables rapid and accurate forest mapping through processing of images and mapping (Crosby & McConnell, 2025; Gebru et al., 2025; Sparks et al., 2025; Abreu-Dias et al., 2025).

The goal of this research is to perform landscape analysis and updated vegetation mapping in the protected forests across three diverse and geographically distinct regions of the Italian Peninsula located in the north, centre and south: 1) Dolomite Mountains (Mts.) in special protection area Lagorai; 2) Apennines Mts., Foreste Casentinesi National Park, Monte Falterona and Campigna National Park; 3) Sirente Velino Regional Park (Figure 1).

The aim is to detect major driving forces that cause land cover changes and to analyse and compare landscape dynamics in different regions. To achieve this goal, the main technical approach is to extract environmental information from the geospatial data such as maps and geospatial data. This is possible using integrated methods of geographical analysis using GIS mapping for comparative analysis of remote sensing (RS) data (Čurlin et al., 2024; Lemenkova, 2025a; Kofidou & Ampas, 2025; Thien & Phuong, 2023). The technical approach to spatial data analysis includes diverse methods: image classification, analysis of landscape fragmentation, computing patch area size, to mention a few.

This study focused on the forest ecosystems in Italy through multi-source data analysis. The multi-disciplinary aspect of this research consists of two approaches: 1) QGIS software for cartographic data integration and mapping; 2) environmental analysis of impact factors affecting forest health: climate, geology, soil, topography and land use.

2. MATERIAL AND METHODS

The methodology includes the integration and analysis of the multi-source data for forest mapping, since regional complexity of the environmental processes in the forests of Italy requires integrated multi-disciplinary approaches. We employed mapping based on the open data for forest detection within the environmental context. The thematic cartographic data were from the open source repositories and verified on the aerial images from the Google Earth Engine (GEE). These data included information on topography, climate, geology and soil setting of Italy. New data were used for ecological analysis, vegetation and forest conservation. Such data are crucial for national strategic decision-making in forest management and protection. We updated vegetation maps using novel data verified in the GEE. The methods use data-driven approaches in different areas of Italy with the use of cartographic techniques of QGIS and GEE.

The open-source QGIS was selected as a major software, as it presents a powerful, versatile, and accessible tool for geospatial analysis with cross-platform compatibility, extensive functionality and built-in tools with vast library of Python-based plugins. Many examples of the use of QGIS are reported, which proves its effectiveness (Vujović & Nikolić, 2022; Bîscoveanu et al., 2025; Nikolić et al., 2023; Lemenkova, 2022, 2023; Vujović et al., 2023; Fawaz et al., 2025). We applied GIS for mapping and environmental analysis. The maps were prepared using Lambert Conic projection. The standard coordinate reference system is based on the WGS 84 datum and EPSG: 4326. The following tasks were performed:

1. Finding cartographic approaches for semi-automated image processing;
2. Developing the repetitive workflow for mapping spatial data using QGIS;
3. Soil mapping of Italy based on the Digital Soil Map of the World (DSMW), Food and Agriculture Organization of the United Nations (FAO UN).
4. Geologic mapping on bedrock age in Italy, from OneGeology portal.
5. Lithology mapping using Environmental Systems Research Institute (ESRI) dataset on rock age in Italy showing geologic setting that form soil.
6. Climate mapping of Italy according to the Köppen climate classification.

The methodological approaches included data collection using GPS, data import to GIS, data converting and formatting, image processing and classification, mapping and analysis. The image analysis primarily aimed at classification of land cover types compared to the old maps to detect landscape changes. Satellite images were visualised with thematic environmental maps across diverse regions. Additionally, vulnerable areas to climate change are analysed for hazard risk in mountainous regions, deforestation and soil.

Using QGIS software, the updated maps were used to create thematic environmental maps of Italy. Several mountainous regions were visited to check

location of diverse plant types and to monitoring vegetation growth. The topographic data were used for terrain analysis based on Digital Elevation Model (DEM) and visualisation of the relief. The environmental monitoring was based on the comparison of the topographic maps and aerials images and extracting information on land cover types which indicates landscape dynamics.

The opportunities of the advanced tools for environmental monitoring includes accurate and rapid data analysis. Satellite mage were classified to interpret the environmental information. In this study, we used QGIS to actualise landscape types across Italy. Applying cartographic techniques to processing aerial images brings new possibilities in environmental landscape analysis (Priyanka Biswas & Anup Prakash Upadhyay, 2025; Ukah et al., 2025). This software uses the principles of the semi-automated algorithms of geospatial data processing for technical mapping workflow. Using QGIS solutions and interface, we performed data modelling to analyse the complexity of spatial features in diverse forest regions of Italy by thematic mapping (geologic, soil, climate and topographic data).

Data collected from open repositories were processed for updating the existing vegetation maps. The spatial information was extracted from images and maps. During GIS analysis, the hydrological parameters of water balance included the collection of the parameters using Eddy covariance techniques: precipitation, moisture, evapotranspiration and temperature (Zhang et al., 2016; Liu et al., 2024; Diaz et al., 2025). This included tree transpiration sensors, images from the PhenoCam, throughfall and stemflow gauges, water discharge measurements, soil moisture sensors and epiphytes quantification. The methodology of the climate-hydrological measurement in forests was described in relevant studies (Wu et al., 2025; Lemenkova, 2025b, 2025c; Wang et al., 2025).

3. RESULTS

This study primarily focused on forest monitoring in Italy in the context of environmental impact factors: 1) topographic and geologic setting, 2) soil types, 3) distribution of climate types; and 4) land use (anthropogenic activities) across Italy. Additionally, the impact of hydrological balance on health of the subalpine forests and the presence of lichens on the tree trunks were analysed and reported with comparison to earlier relevant studies on forest hydrology (Buttle et al., 2005; Lemenkova, 2025d, 2025e; Zhang & Wei 2015).

Environmental data analysis of forest areas is based on the analysis of integrated data and mapping the distribution of forests over the area of the Apennines Peninsula (coloured green in Figure 1). Using data collected in different information sources (CORINE, FAO, MODIS remote sensing data), it becomes possible to evaluate distribution of forest stands in Italy, to identify cases of reforestation and deforestation. The cartographic analysis shows that forests in Italy are concentrated in the mountainous regions of the Alps and Apennines, as well as in some parts of Sicily and Sardinia, according to the Land Use Land Cover (LULC) map prepared using dataset on Coordination of information on the environment (CORINE), Figure 1.

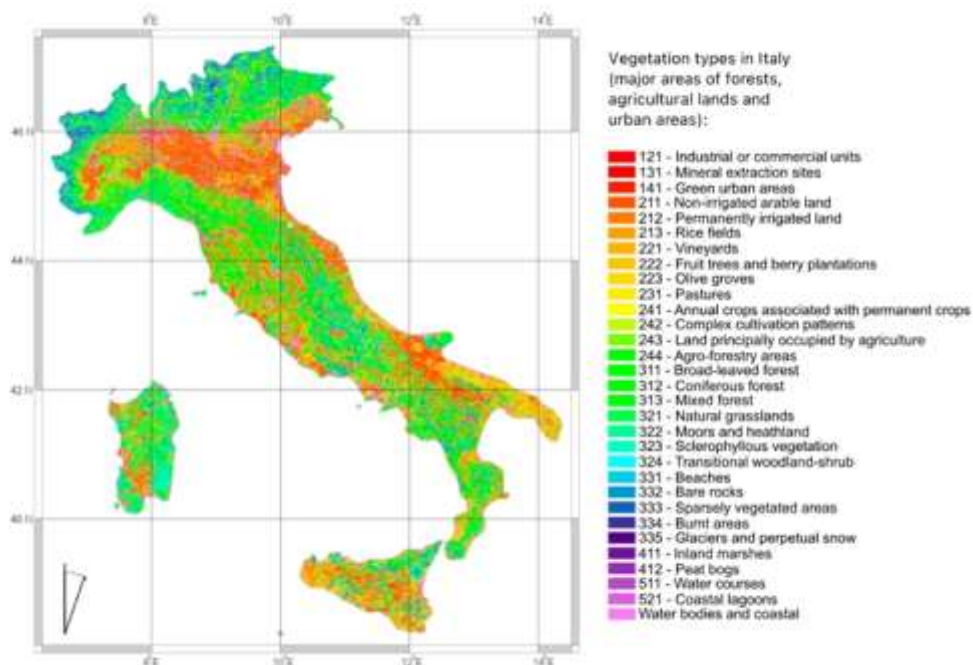


Figure 1. Forests in northern, central and southern Italy.

Data source: CORINE. Software: QGIS.

Map source: author.

Using examples of different regions, we presented the interpretation of a variability of landscapes from northern to southern gradient, using systematic environmental monitoring. Mapping was performed in QGIS as a series of thematic maps, which identified forest areas and setting: geologic, topographic, soil, climate, land cover types and categories of protected areas.

High forest cover is typical for the Alps and Apennine mountains, as well as central Italian mountain range. Low forest cover, i.e. with less than 10% forest cover are primarily in the Po valley, along the Adriatic coast, and in the flat areas of southern Sicily and Sardinia. Forest areas in Italy are expanding most rapidly in less accessible rural municipalities, particularly in central and southern Italy, due to land abandonment and reduced human pressure. Scattered forests are found in central and southern Italy on less accessible rural land where agriculture has been abandoned. Overall, forest cover is increasing, which shows the process of reforestation, with forests now covering ca. 1/3 of the territory, or 10-11 M ha.

Geologic history shapes physical landscape where forests are distributed, affecting geomorphic factors (slope, aspect, and elevation) and soil formation, which controls nutrient availability, water drainage and fertility. These factors influence microclimates and water availability in forest stands. The geologic setting of the country were analysed to find links with forest distribution. The analysis of geologic map shows that the bedrock rocks age in Italy differs, from the Precambrian (pC) basement to Cenozoic (Ce) and Quaternary (Q) formations in selected areas. Such variability represents complex geological history of the region, Figure 2.

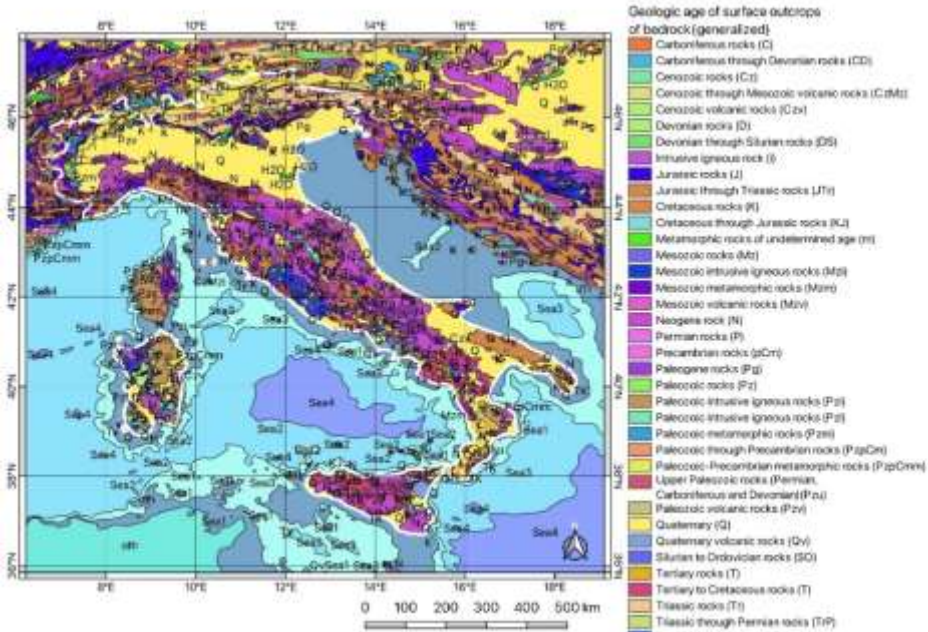


Figure 2. *Geologic map of Italy. Data: ESRI. Software: QGIS. Map source: author.*

The Alps, formed during the Mesozoic and Cenozoic eras, create a large, mountainous border in the north where coniferous forests are dominating. The Apennines, formed during the Oligocene, stretch along the peninsula, acting as a natural watershed for major types of broad-leaved forests and protected areas. The maps show that the oldest types include metamorphic basement rocks that are pC to Carboniferous (C), while younger sedimentary rocks in valleys can be aged 10 to 3 M years old, Figure 3.

The geologic setting has strong influence on soil types and formation. The comparison of maps in Figure 3 and Figure 4 shows links between the distribution of parent material and soil type across the peninsula. The diversified geology of Italy, including volcanic activity in the southern regions, sedimentary and metamorphic rocks in the Apennines, leads to a wide range of soil types that influence the distribution of specific vegetation types, e.g., coniferous or broad-leaved forests. The influence of geology consists in direct effects on the composition and properties of soil, and the geomorphology of the terrain, with processes including weathering and erosion.



Figure 3. Geologic map of Italy: bedrock coverage age.

Data source repository:

<https://portal.onegeology.org/OnegeologyGlobal/>

The distribution of soil types across Italy are highly diverse and depends on the geologic setting. Geologic strata act on the underlying bedrock and create unique soil profiles. For instance, the volcanic soil is rich in nutrients, while other soil types are derived from calcareous or siliclastic materials, Figure 4. In turn, soil affects forest stands through mineral composition, texture and structure. The international data from DSMW was used to map soil types in Italy, Figure 4. Cambisols are found in various forests, such as the silver fir (*Abies alba*) and beech forests (*Fagus sylvatica*) of the Vallombrosa Forest in Tuscany, the holm oak (*Quercus ilex*) forests of Sardinia, and the beech-fir (*Fagus sylvatica*) forests in the Eastern Prealps of Friuli Venezia Giulia.

These soils, also known as brown forest soils, form under a wide range of conditions and are a common soil type in mountain regions, associated with steep slopes and land use pressure, e.g., coppicing. Other significant soil types include Eutric Regosols, found on loose, unconsolidated sediments on Mount Etna (Sicily) and in parts of the Sardinian holm oak forests (*Quercus ilex*). This soil type supports diverse forest, but its shallow, weakly developed structure makes it prone to erosion. Vegetation succession can occur, leading to the development of stable soil horizons, e.g. Dystric Regosols and Podzols in recently deglaciated areas.

Dystric Cambisols, often associated with a broad range of forests: beech (*Fagus sylvatica*), oak (*Quercus ilex*), and fir (*Fagus sylvatica*). Dystric Cambisols are common in the mountainous or hilly regions which present acidic soil found in certain regions. The parent material of such soil is weathered, characterised by shallow cambic horizon, and associated with acid-resistant rocks, (phyllite).

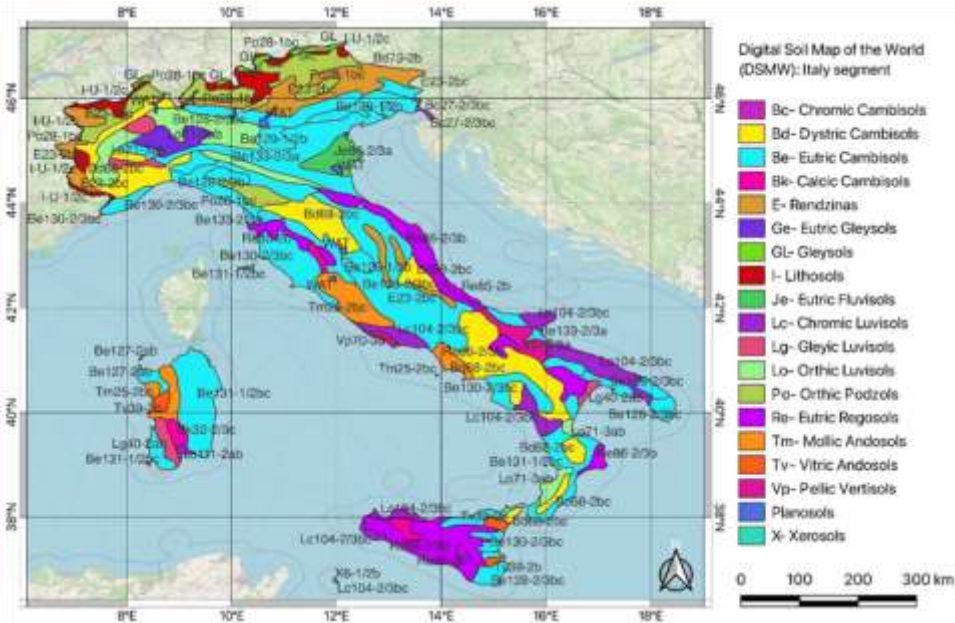


Figure 4. Soil map of Italy. Data: DSMW, FAO. Software: QGIS.

Source: author.

Forest areas were analysed in climate context to identify regions affected by deforestation, aridification and periodical droughts, caused scarce precipitation and high temperature in summer periods. Such extremes are mainly caused by climatic processes related to the distribution of climate zones of Italy, Figure 5. Climate data were obtained from the analysis of Köppen climate types in Italy. Here, the legend of Köppen climate classification explains letter representing the following abbreviations: the first letter indicates a major climate group (A, B, C, D, or E), the second specifies precipitation patterns or dryness, and the third provides additional details, e.g., summer heat or winter severity. The dominating climate type according to Köppen classification scheme means “Csa” for Italy, i.e. “Hot-summer Mediterranean climate”, and “Csb”, - “Warm-summer Mediterranean climate”. Such climate types are characterised by mild, wet winters and hot, dry summers. This climate is typical for the southern regions and along the coasts, particularly in central and southern Italy, where it is defined by the coldest month above (0°C), with an average $T > 22^{\circ}\text{C}$, and at least four months with an average $T > 10^{\circ}\text{C}$. The diverse climate setting was analysed, including Mediterranean (Csa/Csb) in coastal and southern areas, humid subtropical (Cfa) in the Po Valley, and humid continental in north and center.

The performed research updated current GIS maps over protected areas of Italy, to more accurately represent the distribution and location of the actual vegetation types in various soil types, geological rocks and diverse climate setting. The research reported the environmental setting of the subalpine forests in the Dolomites, Apennines and Alps. The forests in these areas differ in regional settings (climate, topography, soil and geology), but present fragile ecosystems with high

importance for water resources and climate regulators. The collected data demonstrated land cover changes detected and visualised on the updated maps.

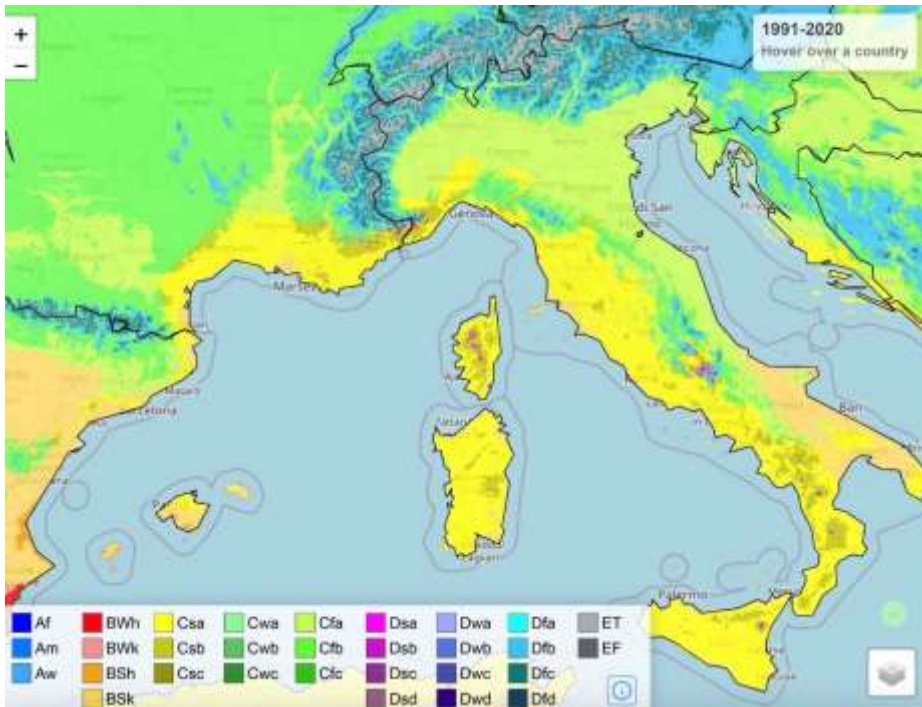


Figure 5. Climate Köppen classification. Data: <https://koppen.earth/>

The distribution of forests in the mountainous protected areas of Italy has undergone significant changes due to the advancement of forest management over the past three decades. Therefore, existing maps should be updated. As a response to these needs, the verification of the old maps (climate, topography, soil and geology) was done using multi-source data: OpenStreetMap (OSM) vector layers and thematic maps on geology, soil, forest distribution, protected areas and climate.

The integrated data analysis on soil, climate, forest distribution in land cover types, topography and geology enabled to classify the most important areas of the protected areas, and compare the updated map with the environmental map of Global National Parks, Figure 6. The integrated approach of data analysis enabled the identification of the forest areas in selected areas of Italy, and helped improving the conservation strategies of forest management related to major driving factors that affect forest health. Major driving factors that influence landscape dynamics in different forest regions of Italy were analysed with focus on the various factors: 1) geologic formation, 2) topography and geomorphology, 3) climate setting, 4) soil setting, 5) vegetation setting with specific focus on forests, 6) anthropogenic activities.



Figure 6. Strategic areas of nature conservation as protected forests in Italy.
 Data source: Global National Parks cartographic survey (modified),
<https://www.globalnationalparks.com>

4. DISCUSSION

This study provides insights to environmental monitoring of the Italian forests through GIS-based analysis of the coniferous and broadleaved forest stands growing on various environmental setting: geologic conditions, soil types, climate setting and relief terrain. These factors present the essential factors that affect the dynamics of forest stands and contribute to the development of various types with high biodiversity, ecological significance and climate vulnerability. The ecological characteristics consists in mosaic of dense, old-growth forest sections, intertwined with young patches. Specific focus is on the geographic gradient (north-to-south) of forests from the subalpine to Mediterranean mountains. The effects of hydrological health of the coniferous forests were reported (Salcedo-Sanz et al., 2025; Sánchez-Falfan et al., 2023; Lemenkova, 2025f; Molina et al., 2025).

This study presented research project with the objective of detecting the links between forest sustainability and changes in land cover types of the ecosystems of Italy. This research involved the use of data obtained through GIS on forest in Italy, topographic, geologic, climate and soil maps. Advanced forest monitoring consists in data integration through GIS mapping. Environmental information on

forest can be obtained from the satellite image processing (Mallinis et al., 2008). Due to the variety of Earth Observation missions, the formats of the remote sensing differ and many images are suitable for forest monitoring using their technical characteristics (Kindu et al., 2020; Günlü et al., 2008; Lemenkova, 2024). Data-driven research in silviculture requires advanced GIS tools where data integration plays a crucial role (Aguirre et al., 2022; Klaučo et al., 2013, 2017).

5. CONCLUSION

This study integrated topographic, climatic and geologic data to provide an estimation of forest distribution and heterogeneity across Italy. This analysis prioritised nature conservation in the protected forests and reserves. Recent climate change changed nature conservation policy which has been increasing, e.g. as increase number of National Parks, areas, reserved for conservation and biodiversity protection. To support monitoring of such areas, spatial data offer possibilities due to the spatial and temporal scale of satellite and aerial images, maps and statistical data on forest monitoring (forest extent and health, wood production and trade, and forestry activities, afforestation and felling). Spatial data collections for forest conservation is a robust approach that is available openly.

Operative processing of environmental datasets enables to extract thematic information on forest stands using data integration in QGIS software. A wide variety of GIS may be used for effective data handling, including both commercial and open source programs. In this study, the methodology was developed on QGIS to support systematic operative environmental monitoring in the protected areas of Italy. The technical approach is based on cartographic tools and environmental monitoring for spatial data processing. Mapping and processing spatial data by QGIS enabled to extract valuable environmental information regarding forest distribution in different regions of Italy for analysis of environmental variability.

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SPATIAL CLUSTERING OF PROTECTED FORESTS IN ITALY FOR STRATEGIC NATURE CONSERVATION

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Summary

Within the framework of this study, protected areas of Italy were clustered for environmental forest monitoring. Different regions were compared and the project were designed under the cumulative project which summarised forest management in Italy and compared major geographic zones in Italy (protected forests). These areas were selected to focus on the comparative analysis of landscape variability in specific regions of Italy. The methodology included the in-depth regional analysis of variability of the land cover types using aerial images, maps and fieldwork measurements.

PROSTORNO GRUPISANJE ZAŠTIĆENIH ŠUMA U ITALIJI U CILJU STRATEŠKE ZAŠTITE PRIRODE

Polina LEMENKOVA

Rezime

U okviru ove studije, 3 različita zaštićena područja Italije su grupisana za praćenje šuma u životnoj sredini. Tri terenska rada su osmišljena u severnim, centralnim i južnim oblastima. Različiti regioni su upoređeni, a projekat je osmišljen u okviru kumulativnog projekta koji je sumirao upravljanje šumama u Italiji i uporedio glavne geografske zone u Italiji (zaštićene šume). Ova područja su odabrana da bi se fokusirala na uporednu analizu varijabilnosti predela u određenim regionima Italije. Metodologija je obuhvatala detaljnu regionalnu analizu varijabilnosti tipova pokrivača zemljišta korišćenjem aero snimaka, mapa i terenskih merenja.