UDC 631.17:004/007
007:528.9]:004
doi: 10.46793/AASer2661.011L

Acta Agriculturae Serbica, 31 (61), 11–20, 2026

Publisher: Faculty of Agronomy Čačak

www.afc.kg.ac.rs

Original scientific article

The implication of GIS mapping in agriculture and land monitoring for environmental policy development

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Received 4 June 2025; Accepted 18 September 2026

A B S T R A C T

This study proposes an interdisciplinary, data-driven approach to understanding historical and future trends in plant biodiversity in Italian rewilded mountain areas. We produced spatially explicit assessments of vegetation change between 1990 and 2020 in three mountain protected areas spanning the Italian Peninsula: 1) Eastern Alps (Lagorai mountain range); 2) Northern Apennines (Foreste Casentinesi Monte Falterona e Campigna NP), and 3) Central Apennines (Velino Massif). The methodology included generalized dissimilarity modeling (GDMs) to model the dissimilarity of plant assemblages as a function of their geographical distances, ecological dissimilarities, and differences in land cover derived by remote sensing. After calibrating the GDMs with historical and newly collected vegetation plot data, the maps of predicted species composition at different times were created, and their comparison allowed highlighting areas where change in land cover induced the largest changes in species composition and quantifying the consequences for regional plant diversity.

Keywords: Environmental monitoring, land planning, mapping, policy, nature conservation, Italy

И З В О Д

Ова студија предлаже интердисциплинаран, на подацима заснован приступ разумевању историјских и будућих трендова биљне разноликости у обновљеним планинским подручјима Италије. Израдили смо просторно експлицитне процене промена вегетације између 1990. и 2020. године у три заштићена планинска подручја која се простиру на италијанском полуострву: 1) Источне Алпе (планински ланац Лагораи); 2) Северни Апенини (Национални парк шума Касентинеси, планине Фалтерона и Кампиња) и 3) Централни Апенини (масив Велино). Методологија је укључивала генерализовано моделовање различитости (GDM) за моделовање различитости биљних заједница као функције њихових географских удаљености, еколошких различитости и разлика у покривачу земљишта изведених даљинским истраживањем. Након калибрације GDM-ова с историјским и новоприкупљеним подацима о вегетацији, креиране су карте предвиђеног састава врста у различитим временима, чије је поређење омогућило истицање подручја где је промена у покривачу земљишта изазвала највеће промене у саставу врста и квантификовање последица по регионалну биљну разноликост.

Кључне речи: Праћење стања животне средине, планирање земљишта, мапирање, политика, очување природе, Италија

1. Introduction

Climate change and biodiversity loss have an intertwined nature, and they threaten the resilience of the Earth and its inhabitants (Čavlović et al., 2012). Given Nature's essential role for planetary well-being, tackling these crises is the most urgent challenge of our time and is crucial for meeting UN Sustainable Development Goals (SDGs) (IPBES, 2019; Bongaarts, 2019; Belényesi & Sasvári, 2025). To foster transformative change of the economic, social, and political systems, however, we need to increase our capacity to understand and predict the consequences of global change for ecosystems and prepare for it (Faz et al., 2025; Kremenić et al., 2024; Zerbe, 2022; Brasanac Bosanac et al., 2011). Thirty years after the introduction of the Habitats Directive, the Natura 2000 network is a keystone of EU's response to global change and is at the core of the EU Biodiversity Strategy for 2030 (EU Commission, 2020; Balias, 2018; Stojanović, 2014).

Natura 2000 sites host large swaths of natural and semi-natural ecosystems, whose contribution to combat global change cannot be understated (Teofili & Battisti, 2011; Klaučo et al., 2013, 2017; Grigoriadis et al., 2009). Such ecosystems store huge amounts of carbon, are mostly net carbon sinks, and their positive contributions to climate change adaptation spill over to densely inhabited areas outside the protected areas themselves, for instance by dampening the effect of catastrophic hydrological events downstream. Despite the importance of the Habitats Directive, its focus is skewed on conserving species and habitats, rather than natural processes. This approach to conservation is currently being challenged by the promoters of rewilding (Thompson et al., 2018; Garrido et al., 2019; Fløjgaard et al., 2022), a solution aiming at restoring functioning, self-sustaining ecosystems complete with occupied trophic levels that are nature-led across the landscape (Ceaușu et al., 2015; Glentworth et al., 2024).

Since its conception, rewilding has acquired high policy relevance to the UN SDGs, the UN Decade on Ecosystem Restoration, and the post-2020 CBD Global Biodiversity Framework (Dunn-Capper et al., 2023; Amos, 2025; Zheliazkov & Zaimova, 2012; Milićević et al., 2024). While rewilding promises to enhance biodiversity, ecological resilience, and ecosystem service delivery, its long-term effects on biodiversity and climate benefits remain unquantified, especially in Natura 2000 sites (Haller & Bender, 2018; Ganatsas et al., 2013; Piana et al., 2018). The mountain ranges represent an ideal scenario for testing these effects. Once densely populated, these areas became economically marginal and underwent the cessation of traditional agro-forestry activities, widespread land abandonment, and profound habitat changes (Cai & Pettenella, 2012; Viciani et al., 2017; Trudić et al., 2015).

2. Materials and methods

2.1. Objectives and goals

The motivation of this study is to perform environmental monitoring in order to reveal how temporal changes in land cover in Italy have affected the objects distribution on the satellite images: composition and spatial distribution of plant biodiversity, landscape dynamics, and quantification in percentage of areas that have undergone changes. The goal of this research is a GIS-based analysis of plant biodiversity and ecosystem change in protected areas of Italy using the developed multi-step workflow, Figure 1.

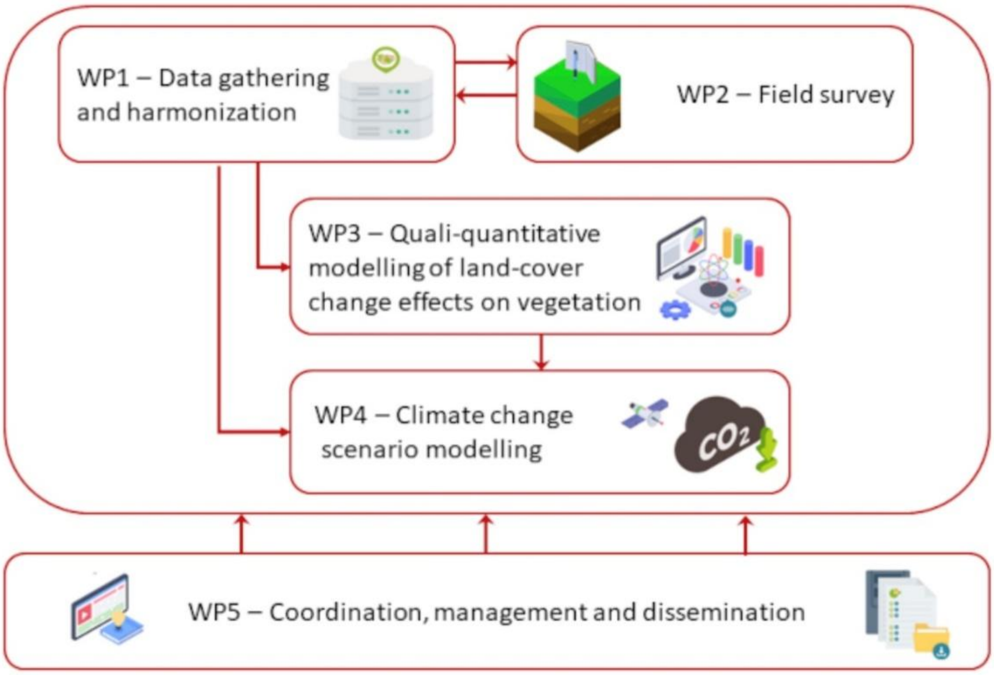

Figure 1. Workflow scheme

To this end, the goal is to conduct a land use impact and scenario evaluation using integrated methods of cartographic analysis and GIS-based data processing (Lemenkova, 2022). The overall objective of this study is to map historical trends and future outlooks of plant diversity and ecosystems in Natura 2000 mountain areas.

The specific objectives are the following ones:

1. to assess how temporal changes in land cover affected the composition and spatial distribution of plant biodiversity, highlight areas of maximum compositional change, and quantify the proportion of species for which rewilding substantially improved or worsened the conservation outlook;
2. to disentangle and characterize the multiple pressures driving habitats and biodiversity changes, and develop narratives for interpreting these changes;
3. to predict the impacts of different climate change scenarios on the future distribution of vegetation, combining vegetation vulnerability and exposure to future climate change to identify the areas with the higher risk of vegetation change.

To achieve these objectives, the data management and integrity included logical steps related to database preparation and implementation along with the ecological metadata infrastructure.

All data were aggregated into a workable electronic database. Using aggregated data, we identified multiple human-environmental pressures that triggered changes in habitats and biodiversity in selected landscapes, and developed narratives to interpret these changes based on both GIS-based data analysis and thematic literature review (Resch et al., 2014; Lemenkova, 2020; Kochanek et al., 2025). After defining the database and metadata structure, all data from previous tasks and vegetation plots were harmonized and aggregated into a workable electronic database according to the most recent techniques of GIS-based data storage and processing (Trudić et al., 2025; Lemenkova, 2021). Using satellite image analysis, we revealed the impact of different climate change processes on vegetation distribution, combining risk vulnerability and exposure to identify landscape areas with the most significant changes.

2.2. Study area

Mountain areas of Italy have experienced substantial socio-ecological changes over the last four decades. Partly due to outmigration, traditional agro-forestry activities and cultural landscapes have been progressively abandoned and forests have expanded substantially. Biodiversity trends observed during the last 30 years of restoration are unlikely to continue under climate change. Understanding the decadal impacts of rewilding remains challenging. Biodiversity monitoring data is scant, scarcely integrated, and scattered. Some vegetation plot time-series do exist, but they are essentially point observations in space. Achieving a complete picture of biodiversity change requires integrating different data, expertise, and, mostly, viewpoints. Integrating biodiversity surveys with data that is available with complete spatial coverage, such as remote sensing (RS), is a necessary first step. But interpreting biodiversity changes also requires considering people's perception and knowledge. Only a qualitative-quantitative approach allows understanding not only the patterns and trends of biodiversity change, but also the reasons why it changed. To this end, the qualitative-quantitative results were used in three areas to prepare the analysis of the impacts of rewilding-induced land cover change over the last thirty years on the study areas in the Foreste Casentinesi NP, Regional Park Sirente Velino, and the Lagorai range, Figure 2.

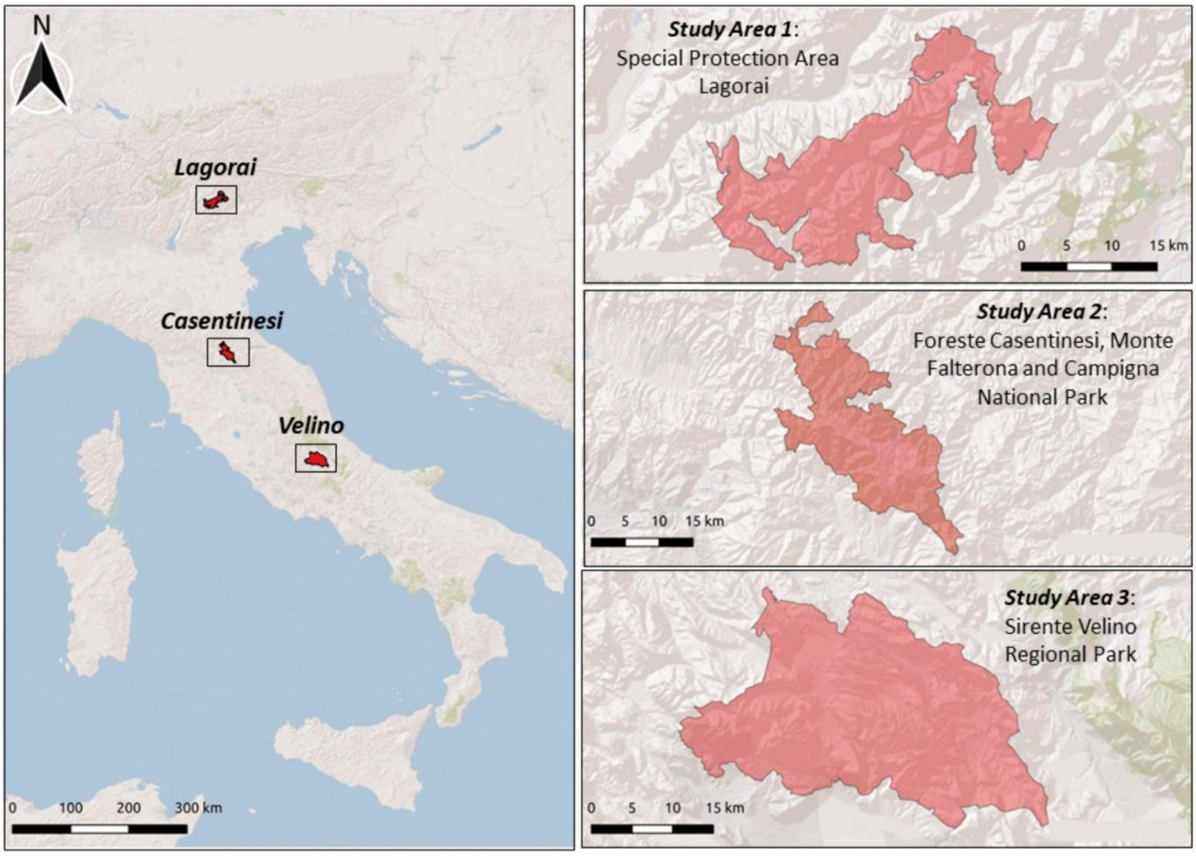

Figure 2. Location of the study areas in Italy

The location of the study areas is as follows:

1. The Lagorai mountain range is placed in eastern Trentino and represents the southwesternmost outpost of the Dolomites.
2. Foreste Casentinesi, Monte Falterona, and Campigna National Park (hereafter, for brevity, Foreste Casentinesi NP) is located in the Northern Apennines.
3. The Velino Massif is located within the Sirente Velino Regional Park, one of the largest regional parks in the Central Apennines.

Future climatic predictors under scenarios were gathered from the integrated set of bioclimatic variables and calculated climate change velocity. To obtain alternative future predictions, two distinct socio-economic pathways were considered. For each, we used three different general circulation models, GCMs (the GFDL-ESM4, the IPSL-CM6A-LR, and the MRI-ESM2-0) to account for predictions' uncertainties across GCMs. These data were used to create thematic maps of climate change.

Spatial downscaling of current and projected bioclimatic variables was performed using bioclimatic variables that are available at spatial resolutions of 250–1000 m and vegetation plots (4–100 m). To avoid the scale mismatch, we downscaled all the spatial predictors to a 20 m of resolution using geographically weighted regression models.

Fitting statistical models to identify how climate contributes to the observed temporal trends was performed using tested climatic conditions of vegetation plots. To this end, the original samples were used for predicting observed variables by established statistical models (GLMs, GAM). The relative contribution of single climate predictors was assessed using variation partitioning and model accuracy quantified through root mean square error (RMSE). In this way, the areas with the highest vegetation change were highlighted.

Creating maps of climate change related risk for vegetation models was done using QGIS cartographic software. The maps were used to predict the near future using current bioclimatic variables as predictors and provide a spatially explicit estimation of vegetation change over time. By highlighting areas where vegetation is predicted to change the most under climate change, maps of vegetation vulnerability were created. These were combined with maps of exposure to climate change and maps of climate change velocity. The final task included mapping the risk of vegetation change under alternative climate change scenarios, as the combination of vulnerability and exposure.

3. Results and discussion

This study presented an internally coherent, complementary, and strongly interrelated project. Coherence stems from the common natural substrate of the three study areas located across different ecoregions of Italy. Complementarity arises from the different biogeographic expertise and datasets. Interrelation depends on the main expertise and applications of data analysis in forest, biodiversity modeling, and RS. Moreover, we applied knowledge on alpine ecology, protected areas, and vegetation change analysis, and used data on plant taxonomy and identification, habitat interpretation, vegetation classification, community ecology, and data management. This study contributed to improving the knowledge base on the advantages and disadvantages of passive rewilding, as a nature-based solution, to tackle problems related to biodiversity loss and climate change impacts (Wilkinson, & Clement, 2021; Lemenkova, 2024a, 2024b). We presented the following key exploitable results across three areas.

A) Multitemporal database of vegetation plot data in the three study areas across Italy. By gathering all available vegetation plot data on the study areas and by integrating them with the newly collected vegetation plot data in the field, the produced database has the potential to become a key instrument for monitoring plant biodiversity trends for protected area authorities. This database stimulates the protected area to digitize their procedures of biodiversity data storage and analysis.

B) Synthesis and analysis of the data on the long-term effects of passive rewilding in mountain areas. Rewilding is increasingly seen as a win-win solution to counter biodiversity loss, while simultaneously providing climate benefits. The results of this study tested this assumption using three real-world examples. The study areas were chosen among those that underwent a process of spontaneous rewilding in Italy. By integrating survey and RS data, quantitative modeling, and qualitative interviews with stakeholders, a multi-faceted understanding of the processes was created at play, not only by highlighting the most important determinants of vegetation change, but also by creating narratives to uncover the underlying socio-economic drivers. This knowledge is crucial to understanding the opportunities and challenges of rewilding and informing about the application of this solution to other mountain areas of Europe.

C) Ecosystem maps of vegetation risk from climate change. To understand the impacts of climate change on vegetation, the study borrowed a key framework from risk science, i.e., considering risk as the combination of exposure and vulnerability. The application of explicit risk analysis to modeling the impacts of climate change on vegetation is a concept with few applications (e.g., Lemenkova, 2024c; Liu et al., 2025; Nguyen et al., 2025). This approach is a new tool for creating predictions of vegetation response to climate change, which can be used by landscape managers to prioritize the conservation of those plant communities that are both vulnerable and experiencing higher-than-average rates of climate change.

D) Stand-alone studies on the history of land-cover change in 1) Lagorai, 2) Foreste Casentinesi NP, and 3) Velino Massif area. A few conceptual and methodological contributions are pinpointed. This study develops a deep understanding of the socio-ecological trajectories that these areas have followed in the last thirty years, therefore creating narratives that can be used to highlight the specificity and unique nature of the coevolution between the ecological and human systems. By creating possible scenarios of ecosystem evolution under climate change, this study embraced the uncertainties linked to climate change, and served as the inspiration for switching from a static to a dynamic approach to conservation, which supports protected area managers to improve the allocation of conservation resources.

Calibration of the spatially explicit biodiversity models and creating maps of maximum compositional change. For each study area, we calibrated a spatially explicit, time-invariant generalized dissimilarity model linking plot-to-plot compositional dissimilarity to the dissimilarities in terms of environmental predictors and spectral response. The most important drivers of climate change for the study areas were pinpointed. Model outputs are used to predict the compositional dissimilarity over the entire study areas, based on pixel-to-pixel environmental and spectral dissimilarities from satellite images, and to infer plant species composition for each pixel from the year 1992 and 2022. By spatializing and comparing predictions, we map maximum compositional change and quantify the consequences for regional plant diversity, through assessing if rewilding substantially decreased the proportion of plant species committed to extinction.

3.1. Case study 1 – Foreste Casentines National Park

The selection of the areas where the data were collected for vegetation plot dataset in the field was based on the data retrieved in environmental monitoring and later consolidated in a database, Figure

3. It spans over 36,800 ha, 1,320 of which are under strict protection including 'Sasso Fratino', an old-growth forest recently included in the UNESCO world heritage list (Bernicchia, 1995). The area of the NP overlaps with 12 Natura 2000 sites. The NP encompasses an elevational range between ca. 500 m and 1,657 m a.s.l., and it is largely covered by *Fagus sylvatica* forests, with large areas locally dominated by *Abies alba* (Travaglini et al., 2012). On the northern side, the dominant land uses were croplands and pastures until the mid of the 20th century, when mountain settlements were gradually abandoned, forest harvesting decreased, and *Quercus* and *Ostrya carpinifolia* forests expanded substantially (Bussotti et al., 2021; Pesaresi et al., 2020).

The updated vegetation-plot database was built for the study area of Foreste Casentines National Park. The vegetation plot data from the relevant sources were retrieved, aggregated, and georeferenced. A workflow for taxonomic standardization was created to identify the spatial and temporal gaps in the data gathered in previous steps (Bartolucci & Conti, 2013). A survey scheme was defined for collecting additional data. The results included the collected data in the field to increase the spatial and temporal coverage of existing vegetation plot data and information on flora distribution (Viciani et al., 2010; Abbate et al., 2014; Aleffi et al., 1997). The spatio-temporal gaps were identified in the vegetation data to check whether the vegetation data aggregated in the dataset are representative of the three study areas, both in terms of geographic distribution and habitats sampled. Maps of land cover (CORINE Land Cover) or habitat distribution (EUNIS) were used as a benchmark, following the successful use of CORINE. The maps were created to illustrate sampled areas in each study region with applications of QGIS, as used in previous studies (Lemenkova, 2025d). The resampling of a representative subset of historical vegetation plots sampled in the 90s or earlier was prioritized among those having sufficient positional accuracy.

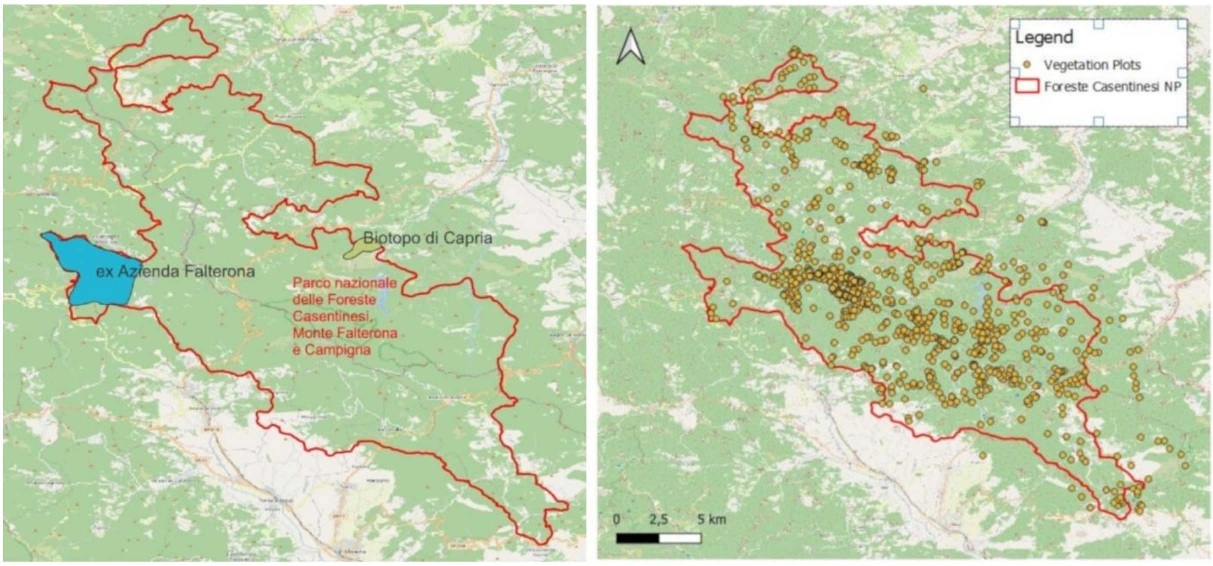

Figure 3. Case Study 1: Foreste Casentinesi NP

3.2. Regional Park Sirente Velino

The study area is located in the Abruzzo region (Central Italy) in Velino, Figure 4.

The Velino Massif partially overlaps with a Natura 2000 site; it extends over around 450 ha, mainly inside the National Natural Reserve of Mount Velino, which is included in the Regional Natural Park of Sirente-Velino. More in detail, the area subject to resurvey activities is located on the south-western slope of Mount Velino, between Vallone di Sevice and Rave della Chiave, and covers an altitudinal range from 1,100 to 2,400 m a.s.l. (Anzalone & Veri, 1975). The massif encompasses an elevational range from ca. 1,000 m to 2,487 m a.s.l., and has a complex orographic structure partly determined by quaternary glaciations (Lemenkova, 2025b). This complexity offers a wide range of microclimatic conditions, resulting in very high plant and habitat diversity: the massif hosts more than 650 plant species and 20+ Natura 2000 Habitats. The area has been intensely grazed for centuries and is still almost totally treeless.

Temporal changes of plant communities through vegetation plot time series were analyzed. The Velino study area was used as a benchmark for studying the species that increased in occurrence or abundance over time, and the most vulnerable plant species were identified. For all vegetation plots where more than one temporal survey is available, the change in species richness was calculated, gained and lost species were identified, and temporal changes were estimated. We used the existing approaches of Shannon's index of diversity (Ercanli, 2018; Amara et al., 2019), Pielou's index of evenness (Jászayová et al., 2024; Blanco et al., 2016), and plot's rank abundance curves, defining a set of temporal trend indices at plot-level to quantify vegetation change over time.

Vegetation-plot data were retrieved and georeferenced from the published sources. Additional vegetation plot data were retrieved from the published sources, including literature, which were not yet digitized. For each vegetation plot, the localization and positional uncertainty were assigned using techniques of spatial dependence in predictive vegetation models (Miller, 2005), to allow a reliable matching of vegetation data with spatial predictors compared to the existing data (Moraldo, & La Valva, 1980; Dungan, 1998). For those vegetation plots without explicit geographic coordinates, we used the combined sources of toponym databases and existing vegetation maps to assign the most plausible geographic position. The created database was used for prioritizing areas for additional vegetation plots in the field. Afterwards, the newly collected data were integrated into the database and standardized by the taxonomic plant nomenclature.

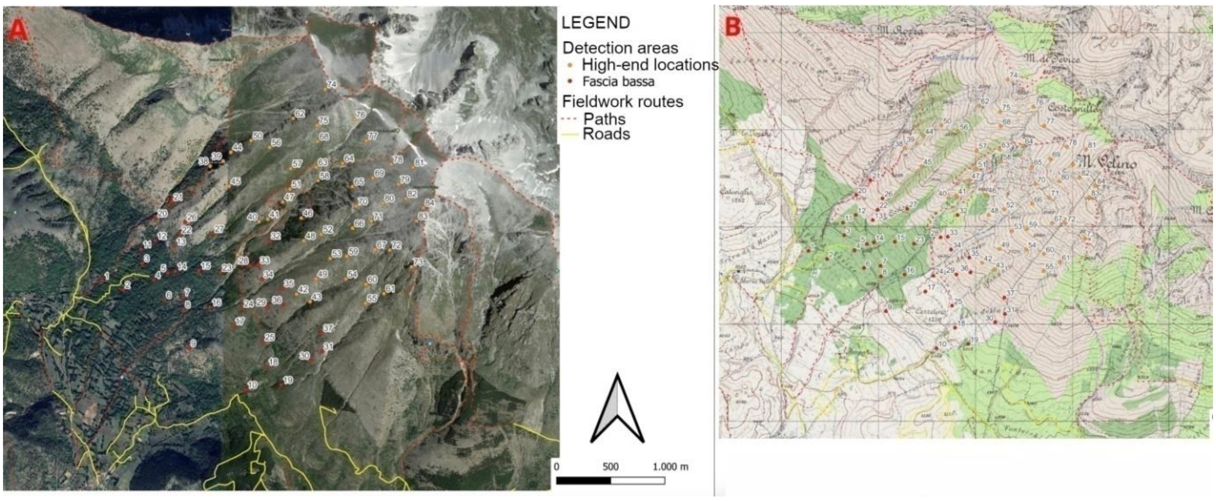

Figure 4. Case Study 3: Velino NP. The numbers next to the points indicate the serial indices of the observation points

3.3. Lagorai Mountain Range

The 3rd study area includes the Lagorai mountain range, which is located in the Eastern Alps, Trentino, northern Italy, Figure 5. It is located between Monte Panarotta (16 km from Trento) and Rolle Pass, and has a length of 70 km (Vergara et al., 2017; Gretter et al., 2018). Its boundaries include the Valsugana on the south, the Val di Fiemme on the north, the Val di Cembra on the west, and the Primiero and Vanoi eastwards. It extends for about 70 km and is considered the best wilderness area of the entire Alps. Though traditional agropastoral activities are still taking place, mainly in the submontane belt, these have decreased substantially in the last three decades (Lemenkova, 2025b). Most of Lagorai is a Special Area of Conservation containing 35 Annex I habitats.

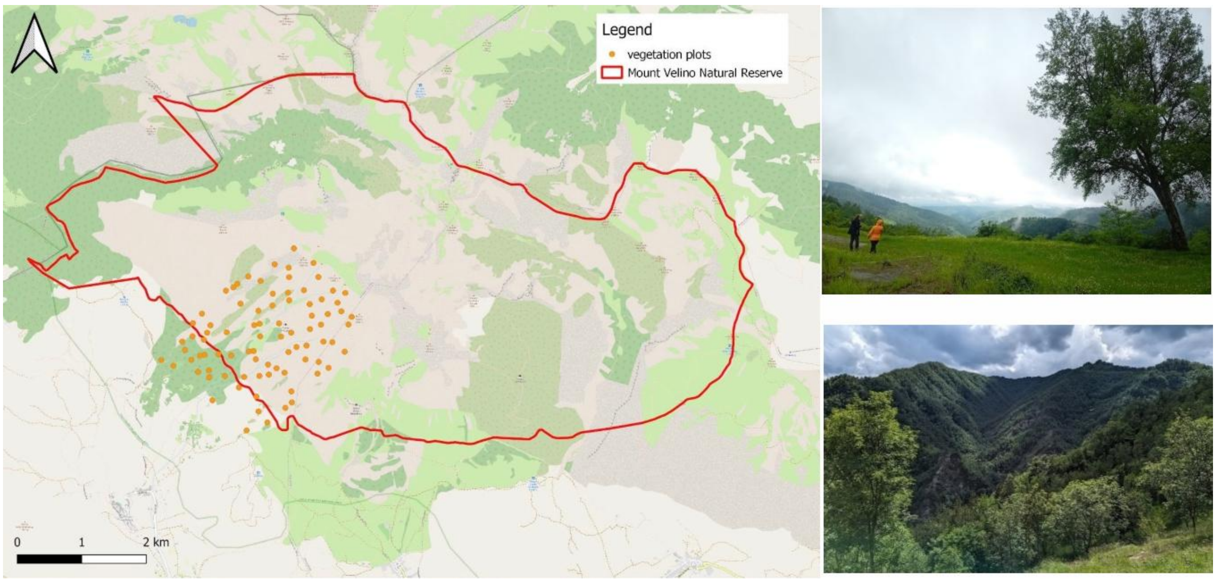

Figure 5. Case Study 2: Lagorai Protected Area

The highest peak, Cima di Cece, reaches 2,754 m a.s.l. (Ferrarini et al., 1986). Vegetation is characterized by sparse woodlands of *Pinus cembra* and *Larix decidua* at lower elevations, while *Carex curvula* grasslands, *Salix herbacea* snow beds and heaths of *Rhododendron ferrugineum* and *Vaccinium* spp. dominate at higher elevations, with their locations mapped on the plot in Figure 5. Quantifying land cover changes and landscape dynamics over a long time frame in a univocal, consistent and reproducible way is an unresolved topic in ecology and environmental mapping. Progress towards accurate explanatory modeling using a combination of computing techniques and RS data is limited in the coverage of similar GIS-based research for ecosystem modeling. In this study, we developed a framework to guide satellite image analysis for the detection and robust attribution of land cover changes using reported methods (Sohl et al., 2007; Lemenkova, 2025c; Chaudhary et al., 2017). Specifically, changes in land cover types were analyzed by comparing several datasets integrated in the workflow of RS data processing and maps.

We employed go-along walking methods with stakeholders to capture local knowledge in a structured way, allowing a more thorough characterization of the underlying drivers of vegetation change. Finally, we created predictions of vegetation change under different climate-change scenarios, in order to produce maps of vegetation vulnerability and vegetation exposure to climate change. By combining maps, we produced the assessment of vegetation risk from climate change to inform ecosystem-level conservation decisions and developed tailored resilience strategies in the study areas.

The relevance of this project beyond the study areas relates to two main aspects:

I. It benchmarks the ecosystem-level effectiveness of rewilding in a quasi-experimental fashion, therefore providing evidence of the challenges and opportunities of applying this NBS in other mountain areas of Europe.

II. It brings clear innovation potentials from the methodological point of view. By merging state-of-the-art statistical modeling, RS, qualitative data collection methods, and an approach borrowed from risk science, this study tackles complex environmental problems and creates a multi-faceted understanding of the drivers shaping diversity patterns and trends.

This study has achieved four main conceptual and methodological advances that are listed below, together with the corresponding task, the relevance, and the technological readiness level:

(a) multitemporal database of vegetation-plot data in the three study areas,

(b) statistical models integrating satellite and ground vegetation data,

(c) novel mixed-methods approach to qualitative-quantitative data interpretation,

(d) risk analysis of climate change impacts on biodiversity and ecosystem trends.

Conclusion

The study contributed to the development of sustainable land management using advanced methods of GIS including RS data and algorithms of spatial analysis. It is an interdisciplinary, data-driven project aimed at understanding trends in landscape dynamics in target regions of Europe. The results of this project strengthen environmental policy synergies and contribute to the cross-disciplinarity of the GIS-based research cultures on forest ecosystems and climate change (Goodchild, 1994; Ostojić et al., 2020; Nikolić Jokanović et al., 2024; Soubry et al., 2021). While we focused primarily on the vegetation science, in daily practice, the research was performed across different scales, socio-ecological contexts, and research philosophies. The three reported cases of the protected areas contribute to the exchange of the environmental knowledge, maximizing synergies and improving collaboration. In this regard, this study represents an opportunity to strengthen the ties among multi-disciplinary sectors related to climate change and environmental protection. The methodology can be extended to other areas and applied in other regions worldwide by conservation practitioners and natural protection agencies.

The three case studies were enmeshed in a dense network of environmental research areas in Italy and beyond. In many cartographic cases, trends in biodiversity and land use change scenario evaluation are detected, but these trends are rarely evaluated using ML methods for automated image processing. In contrast, our framework presents an interdisciplinary study, since it strengthens the bridge between ecosystem studies and computer science through the application of ML algorithms and image processing as effective tools for land cover analysis and biodiversity mapping. This mix of the approaches – cartography, environment, RS – is central to the interdisciplinary research ethos (Hidalgo-Sánchez et al., 2025; Ostojić et al., 2020; Patel et al., 2021; Wang et al., 2025). Here, we strive to ensure the involvement of viewpoints of several disciplines: land management, nature conservation, geoinformatics, and physical geography. Therefore, this report is leveraged for feedbacks on specific aspects of the project and creates collaboration opportunities. When analyzing the conservation implications of our results and effectively modeling the effects of land cover on vegetation, we used expertise in land use science and RS. Problems related to vegetation monitoring aspects were discussed in order to effectively implement the qualitative aspects of the presented research. Moreover, the data were analyzed using multiple methods for creating and reinforcing links between different environmental disciplines: biodiversity, data analysis, climate change, and RS for nature conservation.

Climate change and biodiversity loss pose existential threats to human societies and are the most critical challenges. This urgency is well recognized in climate legislation, and it has been incorporated by the biodiversity strategy. This study strives to tackle conservation-relevant research questions, providing results that are relevant within and beyond the three study areas. At the study area level, this project improved the understanding of the effects of past and current drivers of biodiversity change and produced the explicit assessments of vegetation risk from climate change. Furthermore, this study employed the techniques outside of the sectors in multidisciplinary domains, such as computer science, geo-information, and data analysis, to ensure the regional monitoring of the three distinct areas of Italy. In this way, the development of cartographic algorithms for data visualization is essential for ecological mapping. Such interdisciplinary work ensured the productive working and efficient interdisciplinary approaches with the aim of nature conservation and environmental monitoring in Italy. This provides the protected area managers with a clearer understanding of the socio-ecological drivers at play and helps them improve the allocation of resources to protect habitat and/or species through a dynamic approach to conservation, which internalizes uncertainties linked to global change. To interpret past trends in vegetation dynamics, quantitative modeling was integrated with qualitative methods from social geographic approaches.

This study integrated the expertise in botany, taxonomy, eco-informatics, vegetation science, and landscape ecology. Specific tasks implemented in this study maximized the overall extension of the project through aspects faced towards land use science, RS, and biodiversity modeling. The field surveys aimed at investigating climate change, evaluating possible scenarios, and modeling vegetation impacts and risks. Using the data on basic and applied aspects of landscape conservation, restoration ecology, ecosystem management, and sustainable land, we performed a study on eco-informatics and habitat interpretation. We evaluated vegetation through classification, using available databases. This paper contributes to the development of applied vegetation science and biodiversity conservation in Italy.

With respect to the coherence as to the themes of the environmental plan for recovery and resilience, this study matches the need for the ecological protection of European mountains with regard to nature conservation. Specifically, it contributes to monitoring pressures and threats on species and habitats and climate change through geospatial analysis by strengthening monitoring actions through advanced tools of geographical mapping. This study also fits the needs of mapping ecological transition and protection of land and water resources. In line with the biodiversity strategy, this article contributes to enhancing the environmental measures of the European mountain ecosystems. It strengthens the capacity to predict climate change effects for the implementation of an advanced and integrated monitoring and forecasting system while safeguarding the environmental quality and biodiversity of the territory by protecting green areas in the Italian Alps and Apennines and soil and marine areas for the digitalization of national parks and marine protected areas.

Declaration of competing interests

Authors declare no competing interests.

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